# Prioritization Planning for Culvert Replacement

An Interactive Qualifying Project Proposal
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements for the degree of Bachelor of Science.


By:
Maryam Al Hakeem
Nathan Cloutier
Timothy Ryan

Water Resource Outreach Center
Massachusetts


Date:
May 2, 2023

Report Submitted to:


Key Words:
Culverts
Stormwater
Municipal Vulnerability Program (MVP)
Watershed
Blackstone River


Project Sponsor
Blackstone Watershed Collaborative

WPI Faculty Advisors
Professor Corey Dehner
Professor Paul Mathisen
Worcester Polytechnic Institute

Sustainability Development Goals:
SDG 3 – Good Health and Wellbeing
SDG 11 – Sustainable Cities and Communities

# Abstract

Culvert failure has been an increasing concern in Massachusetts municipalities due to increased rainfall and aging structures. The goal of our project was to develop a prioritization plan to help Massachusetts municipalities prioritize culvert repair and replacement. Using the town of Sutton, MA as a case study, we conducted background research, interviews, and field assessments and developed a prioritization plan, GIS map, and outreach material. The prioritization plan includes criteria to assist towns to prioritize culverts for repair or replacement.

# Acknowledgments

Our team would like to thank the Blackstone Watershed Collaborative for sponsoring this project. We also want to thank Clark University for providing us with a workspace for us to be more efficient. We also want to thank Stefanie Covino, our sponsor coordinator, for being our lead with the training and providing us with a lot of useful information for the project. In addition, we would like to thank all the people we interviewed from all the different organizations, including the Massachusetts Department of Public Works (MA DPW), PARE Corporation, GZA Environmental, Central Massachusetts Regional Planning Commission (CMRPC), Blackstone River Coalition, Fuss & O'Neill, and the volunteers from the Manchaug Pond Foundation, and the Blackstone River Watershed Association (BRWA). We would not have gathered all the useful and helpful information without your help. A list of our interviewees is presented in *Table 1*, located in *Appendix B*. Finally, we would like to thank Professor Dehner for giving us a head start on the project and our project advisor, Professor Mathisen, for helping us stay on track throughout our project.

# Executive Summary

Maintaining the health and quality of streams and allowing stormwater to flow effectively is crucial to the health and safety of our watersheds, but with climate change and storms becoming more intense, our systems that manage stormwater, such as culverts, are failing and are prone to catastrophic flooding. Our sponsor, the Blackstone Watershed Collaborative, a nonprofit organization, has identified stream crossings as a concern that has contributed to flooding in the past in the Blackstone River Watershed. The Blackstone River runs from Worcester, Massachusetts to Pawtucket, Rhode Island, and is credited as the birthplace of the American Industrial Revolution (NPS, 2021), home to the first water-powered cotton mill. This region played a critical role in developing our nation. But due to rapid industrialization, we must deal with the consequences of unregulated industrial development and alteration.

Culverts are structures that allow the flow of stream water to flow under roadways. The failure of culverts poses a number of safety, economic, environmental, and ecological impacts. Through literature review, we have found that many of the Commonwealth of Massachusetts' culverts were built in the early and mid-1900s. These culverts are aging, deteriorating, and causing issues such as floods and separation of aquatic habitats. We found through research that one of the goals of the North Atlantic Aquatic Connectivity Collaborative (NAACC) is to improve aquatic connectivity throughout the Eastern United States. NAACC supports restoration projects by providing information about where these projects are likely to bring the greatest improvements in aquatic connectivity. The NAACC developed common protocols for assessing culverts and stream crossings to aid in these efforts (Abbot and Jackson, 2015). Also, the NAACC developed considerations to prioritize which culverts needed to be listed as a priority for repair or replacement. However, these considerations did not come with a designated plan that communities could follow to prioritize replacing their own culverts. The goal of our project was to develop a prioritization plan to help Massachusetts municipalities prioritize culvert repair and replacement.

To achieve our goal, we followed five objectives. These included:

- Explore impacts and importance of culverts
- Develop understanding of variety of issues compromising integrity of culverts
- Identify other prioritization models and comparatively analyze
- Draft prioritization plan, seek feedback, and revise
- Create outreach material and develop recommendations

The first objective aims to explore the impacts and importance of culverts. In this objective, we did literature review by analyzing content of articles relevant to our project. We contacted experts in relevant professions to schedule interviews. Our team also studied environmental issues such as erosion and runoff from impervious surfaces and how these issues impacted the water quality of the Blackstone River. We conducted some online research on examples of failing culverts, culvert-related flooding and other effects of failing culverts, and ecological factors that relate to culverts.

The second objective developed an understanding of the variety of issues compromising the integrity of culverts throughout Central Massachusetts by considering the town of Sutton,

MA as a case study. In this objective, we reviewed the Sutton Municipal Vulnerability Preparedness (MVP) report and action plan, conducted interviews with ten experts, participated in culvert assessment training following NAACC standards, and used our culvert assessment training to create a GIS map of Sutton's culvert.

The third objective identified other prioritization models and comparatively analyzed them to find common themes to use in our prioritization plan. The three plans that were analyzed are 1) the NAACC Prioritization Considerations, 2) the Culvert and Storm Drain Management Case Study Vermont, Oregon, Ohio, and Los Angeles County, and 3) the CSCE Sustainability in Design, Construction and Rehabilitation of Culverts Plan in Ottawa and Ontario, Canada (*Prioritizing Projects*, 2018; Venner & Berger, 2014; Aghniaey & Rodgers, n.d.). Each prioritization plan had a different focus on specific criteria based on their needs, but overall some similarities that contributed to our prioritization plan.

For the fourth objective, we drafted a prioritization plan and reached out to the experts that were interviewed to seek feedback from them about our prioritization plan to revise it. This culvert repair and replacement prioritization plan considered a variety of factors for which we assigned ranks and developed a scoring system.

The fifth objective focused on finalizing our prioritization plan, creating outreach material, and developing recommendations. Using the feedback and suggestions from the experts we interviewed, the prioritization plan was refined and finalized. To create outreach material, we used our background research, data collected from our culvert assessments, and our interviews to create a brochure and a PowerPoint presentation to help raise awareness of the potential consequences of culvert failure and the importance of investing in repairs and replacement. This presentation was presented to residents of Sutton at a meeting regarding an ongoing Flooding Study. Finally, we developed a list of recommendations for the community of Sutton using the data collected from our culvert assessments and ranking. This list of recommendations was intended to be applied to both Sutton and surrounding communities.

Given the importance of proper culvert assessment in prioritizing culvert repair and replacement, our research focused on the process of assessing culverts using a set of criteria developed by the NAACC. In order to assess culverts using this criteria, our team was trained to be able to certify and assess culverts. We assessed twenty culverts. Our in-field assessments showed symptoms of aging metal pipe, as expected from the age of many of these culverts. Several of these culverts had their bottoms completely rusted out and showed signs of erosion in the soil below. However, other culverts were built recently and were in good condition. These culvert assessments gave ample data to develop additional considerations later in our project.

Meanwhile, we conducted interviews with ten local officials, volunteers, and engineers. One of the questions we asked pertained to issues related to being able to properly assess culverts. It was found that communities and organizations lacked the manpower and resources to assess culverts, given that town employees already have enough to focus on on a daily basis. As such, the length of the NAACC training would pose a significant barrier to communities getting trained and being able to assess culverts. Collectively, it was found that after a while the answers provided seemed to be somewhat repetitive. Based on one such repetitive answer, we would recommend that the NAACC lessen the length of training and focus on assessing a variety of culverts to make training easier and less of a barrier. In regard to resources, community buy-in is crucial to allow communities to reallocate funding or dedicate more manpower to assessing culverts, as will be discussed further below.

Initially, we were concerned that towns may not even be aware of the NAACC's criteria. While this was occasionally the case, we found that some of the communities whose officials we interviewed were aware of these criteria and even used them to assess and log assessments of their own culverts. One such community maintained a database similar to the NAACC database. On top of lessening training requirements, outreach to town employees to encourage them to get trained is also important. Holding more training sessions and advertising such sessions would likely draw in more trainees and bolster the relatively small population of individuals who are certified. Furthermore, we recommend that assessments done externally using the NAACC criteria should be considered as well. As long as the results are verified to be accurate, which can be done through analyzing photos of each culvert, resources could be saved by accepting these results rather than repeating the same assessments, which may number in the hundreds and would take several weeks of assessments to reassess.

The NAACC maintains an extensive and accurate map of culverts in Central Massachusetts, one that we took advantage of quite frequently for map related and assessment related tasks. Town officials in some communities pointed out that their own maps of culverts were outdated and incomplete. As mentioned previously, outreach would be key in resolving this issue. If the already-present map was more widely known, communities would not have to worry about updating their maps.

During our literature review and later through in-person observations done during the in-field culvert assessments, we found that culvert failure could have severe consequences and the potential to cause more destruction and interruption than a replacement project would cost. We looked at a few different instances of culvert failure that occurred in recent years and found in one example that failure completely washed out a large section of road and caused property damage in the town of Belchertown, MA. The visible impacts of this failure were much more severe than a temporary detour and culvert replacement would be.

We also compared several different culvert prioritization plans from different regions and compared them. In one case study, the importance of proactive culvert repairs and replacement was discussed, citing the impact of storm seasons and comparing the impact of proactive repairs and unexpected failure. Based on our findings, we would recommend that communities focus on inspecting culverts annually to identify structural defects before heightened water flow begins to come during storm seasons. Based on these inspections, we would recommend that communities proactively repair culverts found to be deficient, rather than waiting for them to fail.

Based on criteria used for culvert assessments, the three other prioritization plans we researched, and in the field observations, we developed our own prioritization plan that considered five different aspects of a culvert that were not explicitly described in the NAACC stream crossing form. Our criteria included the impacts a road closure would have on movement and safety, the structural integrity of a culvert, the ability of aquatic and terrestrial organisms to pass through a culvert, and the constriction of culvert in terms of stream width and probability of flooding. Through these criteria, we developed a scoring matrix to determine which culverts could be of highest priority.

Some information that was gathered from our interviews indicates that there is no type of outreach material regarding culvert awareness. To bring awareness, we created a brochure about culverts, assessments and training, information on disasters caused by culvert failures in Massachusetts, and details on how culvert repairs and replacements are funded. We focused on how culverts are an essential part of a town's infrastructure, as they allow for the proper drainage of waterways and prevent flooding. By educating residents about the potential risks associated with poorly maintained culverts, the towns can encourage them to report any issues observed. By increasing the quantity and quality of outreach materials, we can raise awareness of culvert issues and inspire more people to take action to ensure the proper maintenance and management of culverts.

# Table of Authorship

| | Primary Author(s) | Primary Editor(s) |
|---|---|---|
| **Abstract** | All | All |
| **Acknowledgements** | Maryam | All |
| **Executive Summary** | | |
| **1.0 – Introduction** | All | All |
| **2.0 – Background** | All | Maryam/Tim |
| 2.1 – Climate Change, Watersheds, and the Role of Culverts | Maryam | Maryam/Tim |
| 2.2 – Impacts of Culvert Failure | Maryam/Nate | Maryam/Tim |
| 2.3 – Culvert Inspection | Nate | Maryam/Tim |
| 2.4 – Condition of the Blackstone River | Tim | Maryam/Tim |
| 2.5 – Blackstone Watershed Collaborative | Tim | Maryam/Tim |
| **3.0 – Methodology** | All | Maryam/Tim |
| 3.1 – Objective 1: Explore Impacts and Importance of Culverts | Nate | Maryam/Tim |
| 3.2 – Objective 2: Develop Understanding of Variety of Issues Compromising Integrity of Culverts | Tim | Maryam/Tim |
| *3.2.1 – Priorities and Challenges* | Tim | Maryam/Tim |
| *3.2.2 – Culvert Assessment Training* | Tim | Maryam/Tim |
| *3.2.3 – Developing our GIS Model and Ranking System* | | Maryam/Tim |
| 3.3 – Objective 3: Identify Other Prioritization Models and Comparatively Analyze | Maryam | Maryam/Tim |
| 3.4 – Objective 4: Draft Prioritization Plan, Seek Feedback, and Revise | Maryam | Maryam/Tim |
| 3.5 – Create Outreach Material, Finalize Plan and Develop Recommendations | Nate | Maryam/Tim |
| **4.0 – Findings** | All | All |
| 4.1 – Background Research | Tim/Nate | All |
| *4.1.1 – Human Impacts on the Blackstone River* | Tim | All |
| *4.1.2 – Municipal Vulnerability Program (MVP) and Municipal Grants* | Nate | All |
| *4.2.3 – Hydraulic Modeling and Flood Plains* | Tim | All |
| 4.2 – Culvert Assessment and GIS Mapping | Tim/Nate | All |
| *4.2.1 – NAACC Assessment Protocols* | Nate | All |
| *4.2.2 – Culvert Assessments* | | |
| 4.3 – Prioritizing Replacement | Maryam | All |
| *4.3.1 – Comparative Analysis of Other Prioritization Plans* | Maryam | All |
| *4.3.1.1 – The NAACC Prioritization Considerations* | Maryam | All |
| *4.3.1.2 – The Culvert Management Case Studies in Vermont, Oregon, Ohio, and Los Angeles* | Maryam | All |

| | | |
|---|---|---|
| *4.3.1.3 – The CSCE Sustainability in Design, Construction, and Rehabilitation of Culverts Plan* | Maryam | All |
| *4.3.2 – Prioritization Criteria* | Maryam | All |
| 4.4 – Community Outreach | Nate | All |
| **5.0 – Conclusions and Recommendations** | All | All |
| 5.1 – Culvert Training | Maryam/Tim | All |
| *5.1.1 – Make Training More Accessible* | Tim | All |
| *5.1.2 – Encourage Town Employees to Get Trained* | Maryam | All |
| *5.1.3 – Consider External Assessments* | Tim | All |
| 5.2 – Regular Assessment and Proactive Repairs | Maryam | All |
| 5.3 – Prioritization Criteria | Tim | All |
| *5.3.1 – Take Advantage of Current Assessment Tools* | Tim | All |
| *5.3.2 – Prioritize Based on Broader Criteria* | Tim | All |
| *5.3.3 – Relying on the NAACC Database* | Tim | All |
| 5.4 – Applying for State and Federal Grants | Nate | All |
| 5.5 – Community Outreach | Nate | All |

# Table of Contents

# List of Tables and Figures

# 1.0 - Introduction

Maintaining the health and quality of streams and allowing stormwater to flow effectively is crucial to the health and safety of our communities. With storms becoming more intense, our aging stormwater management infrastructure is being put to the test. Failure of these systems, such culverts and other stormwater management infrastructure, could lead to catastrophic flooding. Stream continuity, or the ability of water to flow effectively without interruption, is a major part of keeping streams healthy and supporting a healthy ecosystem in a watershed. It also plays a crucial role in maintaining water quality. However, human needs have led to streams to be interrupted by stream crossings such as culverts that act as barriers to the fish and wildlife and have potential to flood or otherwise impact the surrounding communities (*Stream Crossings - Protecting and Restoring Stream Continuity*, n.d.).

The Blackstone Watershed Collaborative, a network of nonprofit organizations that focuses on the health of watersheds, has identified insufficient stream crossings as a significant problem in the Blackstone River Watershed, a vital watershed that runs from Worcester, Massachusetts to Pawtucket, Rhode Island. Many towns throughout Massachusetts have identified that their culverts, which are vital structures that channel stormwater under roadways and railroads, are in a concerning condition and may contribute to flooding during large rainfall events. For example, in the town of Sutton, Massachusetts, many culverts were built as early as the 1940s using steel pipes, which are prone to rusting and degrading over time (Sutton MVP Report, 2019). This problem, coupled with storms becoming more intense and less predictable, makes culvert assessment and prioritization of replacement of culverts much more important. Though small and often hidden from plain sight, failure of culverts poses a number of hazards; in late 2018, Southborough, MA, saw a major culvert that passed under Northboro Road collapse, closing the road to the public and requiring an American Rescue Plan Act (ARPA) grant of $70,000 to make repairs necessary to reopen the road (*Senator Eldridge Secures $70,000 in ARPA Funds for Collapsed Culvert in Southborough*, n.d.). If culverts are allowed to degrade and eventually fail, road collapses like this threaten public safety.

In an effort to get ahead of this issue and prepare for larger quantities of rainfall, communities have taken steps to assess and make prioritization plans to repair and replace aging culverts to avoid collapses that come with costly repairs and prevent worse disasters, to include catastrophic floods, from occurring. The North Atlantic Aquatic Connectivity Collaborative (NAACC) is a network of individual organizations from thirteen different states that work to improve aquatic connectivity throughout this area, spanning from Maine to West Virginia. This collaborative has created a culvert assessment program that includes a protocol to set standards for how culverts should be assessed and reported on. The NAACC has also developed a regional culvert GIS database where specific unassessed and assessed culvert locations in several towns of MA are spotted (*North Atlantic Aquatic Connectivity Collaborative*, 2018).

Unfortunately, many people are not familiar with or have not been trained on how to use the NAACC's culvert assessment tool and database. Only 295 out of approximately 5200 culverts in the Central Massachusetts region have been properly assessed and recorded into the database as of April 25, 2023. Few people in the whole state have been certified to do and record these culvert assessments. With this limited manpower, it is difficult to inspect culverts and locate culverts that need to be repaired or replaced. This makes it harder to prevent failure of culverts.

The goal of our project is to work in collaboration with the Blackstone Watershed Collaborative to assist Massachusetts municipalities in prioritizing culvert repair and replacement by developing a municipal prioritization plan that effectively integrates the prioritization tools available from the NAACC and other sources. Our project focused on Sutton, MA, using this community as a case study to apply our findings, eventually, to other communities. We initially conducted background research on the importance of culverts and unique problems related to them in local communities. In addition, we conducted interviews with experts that provided valuable information that helped us create our prioritization plan and helped us gain valuable insight into how professionals were working to solve similar problems. We then used the training we received to assess culvert structures in Sutton, MA, to identify what qualities were most important to look for when prioritizing culvert repair. With information gathered, we developed a prioritization plan and developed outreach materials to inform the public. Upon completion of the analysis, we provided our recommendations to the community of Sutton and presented our findings to members of the community at a Manchaug Village Flooding Study meeting on April 27, 2023.

# 2.0 - Background

In this chapter, we discuss relevant background research to aid in developing a prioritization plan for culvert replacement and repair. To create our prioritization plan, it was important to first understand the current condition of our area of focus, the Blackstone Rivershed. Then, we researched the consequences of culvert failure, an issue that we intend to help municipalities in the Commonwealth of Massachusetts avoid. In this chapter, we discuss climate change and the impact of stormwater runoff on watersheds. Culverts and their use in managing stormwater runoff are also discussed. In our second section, the public safety and economic impacts of culverts that do not have sufficient capacity for current rainfall amounts are discussed. Next, we explain the process of culvert inspection. Then, we discuss the state of the Blackstone River Watershed and previous efforts to clean the Blackstone. Finally, we introduce the Blackstone Watershed Collaboration and how it is providing relief to the Blackstone River.

## 2.1- Climate Change, Watersheds, and the Role of Culverts

Human behavior has played a significant role in accelerating the warming of our planet, speeding up the process of climate change. Climate change is the long-term natural shift that happens on earth, intensifying specific weather and temperature events such as extreme heat waves and heavy rainfall events (IPCC, 2021). While the impacts of climate change are vast, for the purposes of this project, we focus on its impacts in watersheds and in aging stormwater management infrastructure. A watershed is an area in which snowmelt and rainfall flow through the ground, over impervious surfaces, and into streams, all which flow to one common river (*What Is a Watershed?*, n.d.). For our project, this river is the Blackstone River. Stormwater runoff is water that flows over impervious surfaces such as roadways and other structures, as well as over permeable surfaces. Impervious surfaces obstruct water from soaking into the ground while permeable surfaces absorb a portion of the storm water that passes over it. Stormwater runoff flows directly into bodies of water and carries with its chemicals and pollutants from the surface of these impervious surfaces (US EPA, 2021). Culverts channel stormwater runoff and streams through and below roadways and railroads, thus allowing the water to bypass impervious surfaces and flow from place to place in a watershed (“Culvert”, 2021).

**Figure 1** - Culvert at Third Beach in Middletown, RI (US Fish and Wildlife Service, 2014)

Culverts are one way of managing stormwater and stream water, redirecting it under, around, or past manmade structures. They are tunnel structures that allow the flow of stream water to go from one place to another, bypassing obstructions, as shown in *Figure 1*. With increased precipitation due to climate change, culverts run the risk of not being able to channel the increased flows resulting from increased levels of rainfall. This can result in several consequences, such as erosion of soil, floods, property damage, and more. Roads flooded by rainfall that exceeds a culvert's capacity can also result in harmful substances being washed off roads and into streams, road closures that hinder travel and emergency services, and in some cases total road washout. Culvert flooding can have major effects on the environment and ecological habitats (Şen, 2020).

## 2.2- Impacts of Culvert Failure

Culvert failure has many consequences, some of which are safety, economic and aquatic impacts. Culvert failure can describe a few different things; a culvert may be undersized for a rainstorm, forcing water to redirect over roads. Culverts can also collapse, causing sinkholes and road closures. Culvert failure can also come in the form of culverts becoming clogged with debris, resulting in similar consequences to an overloaded culvert. The State of Massachusetts, as a part of Executive Order 569, created the Municipal Vulnerability Preparedness (MVP) Planning Grant Program in 2017. This program sought to provide funding to municipalities to allow them to assess ecological vulnerabilities to mitigate the effects of climate change in their communities (*Executive Order 569*, 2016). Each municipality seeking funding had to identify key areas of improvement to secure funding to address these issues. When completing these reports, many towns in Massachusetts highlighted culverts and flooding as areas of concern, including Sutton, Massachusetts, our community of focus in this project. The roads near some culverts are at a high risk of flooding, which could hinder residents' and emergency vehicles' ability to get to their destination (Northbridge MVP Workshop, 2018). Moreover, clogged culverts were found to be responsible for floods, torrents, landslides, and the loss of eight lives during a thunderstorm in Northeastern Turkey (Çelik et al., 2020). Culvert failure puts the safety of residents in jeopardy, but repairs are expensive, a factor which makes it difficult for towns to decide to replace culverts and to get public backing for such projects.

Despite the safety implications, culvert replacement is costly and requires years of applying for grants, winning over the public, and completing construction. However, repairs to roads and surrounding infrastructure damaged by failing culverts is even more costly than replacement before failure. The cost of repair for culverts is, on average, $845,500, but can cost over $4.2 million (Truhlar et al., 2020). As mentioned in our introduction, failure of culverts can limit or prevent travel altogether, which can be catastrophic should this occur on major roads. In the Southborough example, the repairs ended up costing a total of $192,000, with state funding only covering $70,000. Furthermore, the road was closed from late spring of 2021 until December 2022 while funding was secured, and repairs took place (Melo, 2022). Luckily, Northboro Road is not a major artery and detours around the site of the collapse would not have added too much time to residents traveling down the 0.6-mile-long road (Google, n.d.). Per our project sponsor, Stefanie Covino, had the imminent failure been detected before the collapse, it would have been both cheaper, quicker, and less impactful to apply for and receive grants than to have to request emergency funds following a collapse.

Another example of a major failure took place in Belchertown in July 2021. In this case, a 3-foot-wide culvert became clogged when debris from rainfall overtopped a beaver dam. This undersized culvert, once blocked, forced water around the culvert and completely washed out a portion of East Road, leaving behind a large trench where the road used to be and a split-in-half culvert pipe (*Washed Out Undersized Culvert,* 2022). Though an extreme case, undersized culverts are prone to severe consequences due to blockages such as the one described. The aftermath is shown below in *Figure 2*. Many other examples of culvert failure can be found through a quick Google search.

**Figure 2 -** Aftermath of East Road Culvert Failure, Belchertown, MA (*Washed Out Undersized Culvert*, 2022)

Furthermore, culvert failures can affect the environment by impacting fish movement. The alewife and blueback herring are two coldwater species that are migratory fish. They have been found extinct in the Blackstone River Watershed due to four dams found at the mouth of the Blackstone River in Pawtucket, Rhode Island (Staff Writer, 2006). According to a UMass Amherst study, in recent years coldwater fish migration has decreased drastically from more than 76% of fish migrating to less than 33% due to inadequate culverts and dams that hinder their movement. The inability of the alewife and blueback herring to move and migrate freely decreases fish diversity and disrupts aquatic connectivity (Alcott et al., 2021). However, fish that exist in the Blackstone River Watershed, especially fish that live in cold water fisheries, are also affected by culverts because the poor stream water flow through the culverts can increase the water's velocity and make it shallower at the outlet, causing the fisheries water to warm up (US EPA, 2016). This is bad for freshwater species living in coldwater fisheries since the cold-water temperature cannot exceed 68º F (20ºC) to be habitable (Cohen, 2017).

## 2.3- Culvert Inspection

Many of the Commonwealth of Massachusetts' thousands of culverts were built in the early and mid-1900s. These culverts were built to handle rainfall amounts at the time they were constructed when rainfall events were less severe. These culverts are aging, deteriorating, and causing many issues to the water and environment. According to the Massachusetts Department of Transportation, culverts that were built in the 1950's and 1960's have caused flooding and destruction of aquatic habitats (Dexter 2020). They are causing these issues because after they were built, the culverts were never occasionally checked for issues or faulty designs and were instead left to deteriorate. The continuous failure of these aging culverts is endangering the Blackstone River Watershed communities and quality of the water in the Blackstone River (US EPA, 2021).

The North Atlantic Aquatic Connectivity Collaborative (NAACC) is a network of individuals focused on improving aquatic connectivity from Maine to West Virginia. The NAACC has been aiding federal agencies in the New England region dedicated to improving stream connectivity for the health and resilience of our aquatic and terrestrial ecosystems. The NAACC has developed common protocols for assessing road-stream crossings such as culverts and bridges and a regional database for this field data. The NAACC has collected information that identified high priority bridges and culverts for upgrade and replacement. The NAACC will support planning and decision-making by providing information about where restoration projects are likely to bring the greatest improvements in aquatic connectivity (Abbot and Jackson, 2015). This will be done through assessment of culverts. Assessments will be conducted by individuals trained to use a set of criteria, as will be briefly discussed in the next section, to record information about each culvert based on the criteria to assess structural integrity, ability to channel water, and ability for organisms to move, to name a few.

## 2.4- Condition of the Blackstone River

The Blackstone River, flowing for 48 miles from Worcester, Massachusetts to Pawtucket, Rhode Island, is often credited as the birthplace of the American Industrial Revolution (NPS, 2021). Moreover, the river is culturally significant to the Nipmuc, Narragansett, and Wampanoag people. It was this river that fueled the rapid urbanization and industrialization that allowed Rhode Island and Central Massachusetts to prosper. This river was home to the first textile mill in the United States, built in Pawtucket in 1790. Being the site of this progress was not without a cost, though. In 1990, the United States Environmental Protection Agency stated that the Blackstone River was, in terms of toxic pollutants, the most polluted river in the country (US EPA, 2021). The Blackstone River Watershed, though cleaner than it was when that statement was made, now faces a new foe; climate change and increasing amounts of stormwater work to reverse the progress made over the last several decades in cleaning up this crucial body of water.

In 1972, the Clean Water Act was passed by the federal government, granting the government tools to regulate how industrial waste is managed. This prevented the dumping of untreated industrial and agricultural waste from being dumped into bodies of water. Furthermore, proper disposal that would not lead to run off polluting waterways was implemented. That same year, 10,000 volunteers took part in ZAP the Blackstone, credited as the largest one-day environmental cleanup in U.S. history. Over 10,000 tons of debris was removed from the river on that day (Lynch, 2022). And since this point in time, substantial progress has been made to clean up the Blackstone River. In 2021, the stretch of the Blackstone River in Rhode Island was no longer listed as being impaired for phosphorus and dissolved oxygen, a significant change from when the river was stated to be the most polluted river in the country. This cleanup event was certainly a step in the right direction and has had a large enough impact that the event has been revived on multiple occasions.

Despite efforts like ZAP the Blackstone, the Blackstone River is still polluted, being deemed unsafe for direct human contact by the State of Rhode Island due to the presence of various heavy metals, such as Copper, Lead, and Cadmium, and various pathogens (RI DEM-OWR, 2013). Much of the 21st century pollution originates from stormwater runoff, rather than industrial waste being dumped directly into the river. Further pollution has occurred from various accidents on and around the Blackstone River, such as one that occurred in early March 2023, when the Woonsocket Regional Wastewater Treatment Facility was overloaded and began spilling wastewater into the river. For a few weeks, the river was elevated to a no-contact advisory, though has since been returned to being safe for indirect contact (Bouras, 2023). Events like this are hard to predict and run the risk of undoing some of the progress made on the Blackstone. With continued urbanization and climate change, more and more water end up flowing over impervious surfaces and bypasses stormwater management systems. The stormwater quickly becomes contaminated runoff, picking up pollutants from impervious surfaces and dumping them into the Blackstone River (NBEP, 2017).

## 2.5- Blackstone Watershed Collaborative

From 2019 to 2021, the Narragansett Bay Estuary Program used funding from the EPA's Southeast New England Program to pursue the Blackstone River Watershed Needs Assessment report (NBEP, 2021). Over the course of these two years, eight meetings were held, and a report was developed outlining twenty action items to pursue between 2021 and 2025. This report is called the Blackstone River Watershed Needs Assessment Project Report. To meet the goals of this report, the Blackstone Watershed Collaborative, a partnership of 115 different private and public entities, was created. A Watershed Coordinator, Stefanie Covino, was hired to lead the Collaborative and the Collaborative would find its home at the George Perkins Marsh Institute at Clark University in Worcester, Massachusetts.

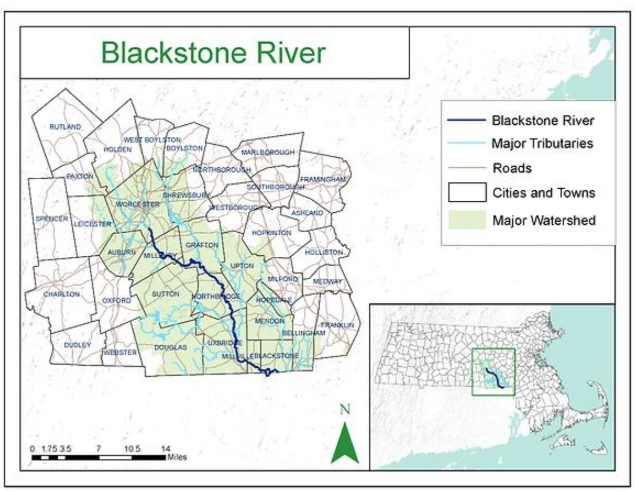



**Figure 3** - Map of Blackstone Watershed (Massachusetts River Alliance, 2021)

The community of Sutton falls within the Blackstone Watershed, as highlighted in *Figure 3*, and has experienced issues related to excessive rainfall and outdated stormwater management systems (MVP Workshop, 2018). Failing culverts were listed as priority items in Sutton's MVP Report. Findings such as this motivated communities to assess their own culverts to focus funding on repair projects and acquire grants from the state for repairs and replacements. To establish criteria to help standardize assessment amongst Massachusetts communities, the NAACC developed a protocol to assess structural integrity of culverts. A database was also created to store assessment data of the over 5,000 culverts in Central Massachusetts.

The goal of our project is to consider these culverts and develop a plan to help Massachusetts municipalities prioritize culvert repair and replacement as is discussed in the next chapter of this report. The NAACC protocol will be the basis for our criteria.

# 3.0 - Methodology

In collaboration with our project sponsor the Blackstone Watershed Collaborative and its Watershed Coordinator, Stefanie Covino, the goal of our project was to develop a prioritization plan to help Massachusetts municipalities prioritize culvert repair and replacement. To achieve this goal, we identified the following five objectives (See *Table 1*).

**Table 1 -** Project Objectives

| | |
|---|---|
| **Objective 1** | Explore impacts and importance of culverts |
| **Objective 2** | Develop understanding of variety of issues compromising integrity of culverts |
| **Objective 3** | Identify other prioritization models and comparatively analyze |
| **Objective 4** | Draft prioritization plan, seek feedback, and revise |
| **Objective 5** | Create outreach material and develop recommendations |

Below, we discussed in detail the methods that we used to achieve each objective and to meet our project goal. All participants in this research were asked for their informed consent prior to their participation (see *Appendix A*).

## 3.1- Objective 1: Explore impacts and importance of culverts

For this objective, we analyzed the content of articles relevant to our project goal found through online databases and reputable websites. Then, we contacted experts to schedule interviews which were completed in the next objective.

Our team studied environmental issues such as soil erosion and runoff from impervious surfaces and how these issues impact the water quality of the Blackstone River. These issues can be worsened by culverts in disrepair is one of the key factors that play a role in e culvert repair and replacement prioritization plan. We conducted online research on examples of failing culverts, culvert related flooding and other effects of failing culverts, and ecological factors that relate to culverts. It was identified in a Municipal Vulnerability Preparedness (MVP) report prepared by the towns of Grafton, Millbury and Northbridge, Massachusetts, that the streamflow and stormwater runoff in culverts was becoming a safety hazard in the communities (*Community Resilience Building MVP Workshop*, 2018). In this objective, we reached out to and interviewed ten environmental protection and stormwater experts, including MassDEP and town officials and individuals who worked with a variety of watershed-related non-profits. A complete list can be found in *Appendix B.* These individuals were suggested by our sponsor. A few of these experts referred us to other individuals in their respective organizations who were better qualified to answer our questions, so this portion of our project took longer than originally anticipated. Our list of interviewees and of interview questions can be found in *Appendix C*. These interviews were intended to help us understand the problem of aging and failing culverts in Massachusetts communities due to aging and failing culverts.

## 3.2- Objective 2: Develop understanding of variety of issues compromising integrity of culverts

This objective involved us gaining an understanding of issues that compromise the integrity of culverts throughout Central Massachusetts by considering the town of Sutton, MA as a case study. We participated in culvert assessment training following the North Atlantic Aquatic Connectivity (NAACC) standards, analyzed culvert-related information sources, conducted interviews with experts, and used our culvert assessment training to assess culverts and produce a GIS map of Sutton's culverts, in which we defined our own criteria for a ranking system for culverts using a code system to identify which culverts should be prioritized.

### *3.2.1 - Priorities and Challenges*

In Sutton's MVP report, culverts and flooding were identified as areas of concern (Sutton MVP Workshop, 2019). We analyzed this MVP report to identify why the town considered culverts, flooding, and other stormwater related issues to be a priority. Given our 8-week time frame, we were not able to focus on every culvert in Sutton, but used a list provided by Sutton to focus our assessments on culverts that were known to need assessment, a topic that will be discussed in the next section. This gave us a variety of different data to analyze.

Furthermore, we conducted interviews with ten experts that helped us identify the specific assessment challenges facing Sutton and other Massachusetts communities. These questions were modified based on each individuals' expertise, positions, and background, though general themes remained consistent.

### *3.2.2 - Culvert Assessment Training*

A large part of Objective 2 involved culvert assessment training. We learned to assess culverts based on the NAACC's criteria and assessment sheet, a sheet which can be found in *Appendix D*. Completion of this training, which involved assessing twenty culverts, would allow one to become certified in culvert assessment. This training consisted of two parts, with an online knowledge-based portion being completed with a quiz and several days spent conducting in-field culvert assessments with a certified professional. This training served two purposes. First, we were able to help communities assess their culverts, and second, we gained a better understanding of the assessment challenges and collected valuable data to create our prioritization plan. For our training we visited stream crossings, a term which encompasses culverts, bridges, and other structures through which streams flow through, that were identified by the Town of Sutton as potentially problematic to execute our field-based assessments, supervised by our sponsor Ms. Covino. Our field-based investigation method helped our team have better knowledge and visualizations of culverts in need of repair or replacement.

We used systematic observation to document culvert problems we identified during the assessment. Our team photographed each culvert and the surrounding area to provide better visuals of the problems and ranked each culvert's condition. Systematic observation is a method used to collect quantitative data by observing events as they occur and recording observations using charts, checklists, ranking scales, or inventories ("Systematic Observation", 2007). We chose to use the systematic observation method because the quantitative data that was recorded demonstrated evidence of the culvert issues to accurately define what condition each culvert is in. Quantitative data is data where researchers address the “what” or “how many” aspects of an issue or a research question (Hillemann, n.d.).

#### *3.2.3 - Developing our GIS Model and Ranking System*

After our culvert assessments, our team created a Google map to pinpoint each stream crossing in Sutton and following later objectives we color coded points we identified based on our prioritization codes that were developed. Furthermore, we included XY codes provided to us, and uploaded pictures taken during our assessment to each point. As a reference for our points, we used the regional culvert GIS database map provided by the Central Massachusetts Metropolitan Planning Organization (CMMPO). The CMMPO was created to oversee planning processes as required by the United States Department of Transportation in Central Massachusetts and administers an interactive map for this region using NAACC data. For the culvert GIS map that we created, we also developed a system that considers a variety of factors that the NAACC form does not consider, such as the significance of roadways and stream crossings to name a few, though this is detailed in *Appendix G*.

## 3.3- Objective 3: Identify other prioritization models and comparatively analyze

In our third objective, we analyzed data from our first two objectives and compared three prioritization models developed for different regions to find common themes to use in our prioritization plan.

To execute this objective, we first found and read through the culvert prioritization plans, taking notes on similar characteristics. Then, we comparatively analyzed those prioritization plans to see which aspects of each work for the needs of Sutton and Central Massachusetts. We identified the following three plans to analyze: 1) the NAACC Prioritization Plan, 2) the Culvert and Storm Drain Management Case Study Vermont, Oregon, Ohio, and Los Angeles County, and 3) the CSCE Sustainability in Design, Construction and Rehabilitation of Culverts Plan in Ottawa and Ontario, Canada (*Prioritizing Projects*, 2018; Venner & Berger, 2014; Aghniaey & Rodgers, n.d.). These plans are summarized in *Appendix F.* Later in the project, we used criteria found in these prioritization plans to develop our own.

## 3.4- Objective 4: Draft prioritization plan, seek feedback, and revise

In Objective 4, we drafted our prioritization plan and sought feedback on our plan from the experts we interviewed.

After comparing the different prioritization plans and considering both our assessment data and criteria mentioned by interviewees, we drafted a culvert repair and replacement prioritization plan that could be used by Sutton and surrounding communities to rank their own culverts. Our plan considered a variety of factors, factors which we assigned ranks to and developed a scoring system for. Once our draft plan was completed, we emailed it to our interviewees and asked for feedback, feedback which we intended to use to finalize our prioritization plan.

## 3.5- Objective 5: Create outreach material, finalize plan, and develop recommendations

In this objective, we finalized our plan and drafted a list of recommendations. To inform Massachusetts communities of what culverts are and why assessing them is important, we drafted and distributed outreach materials.

Using the feedback and suggestions from the experts we interviewed, we refined and finished our prioritization plan and created outreach material, including an in-person presentation. We used our background research, data collected during assessments, and interviews to develop our outreach materials and help raise awareness of the potential consequences of culvert failure and the importance of investing in repairs and replacement. We included information about culvert assessment and training, grants for culvert replacement and repair, information on what culverts are, how increasing rainfall and stormwater affect culverts, and examples of culvert failure. We developed a presentation discussing this material that was presented at Sutton's Manchaug Water Study Project meeting on April 27, 2023. Through this presentation, we were able to inform community members more specifically about culverts.

Finally, we developed our list of recommendations for the community of Sutton using the data we collected. These recommendations were based on our culvert assessments and included in our prioritization plan. We also included our rankings of the twenty culverts we assessed to serve as a basis for assessment work in Sutton. Our list was intended to be applied to both Sutton and surrounding communities.

# 4.0 – Findings

Through our in-person culvert assessments, interviews with experts, background research, and GIS mapping, we have identified several factors to consider when working with, assessing, and considering repairs to culverts in the Blackstone River Watershed. In this chapter, we discuss our findings from both our research and field work. As part of our first objective, we discuss the alterations made over time to the Blackstone River and how these alterations play into the presence of culverts, the consequences of culvert failure, and the Blackstone Watershed as a whole. In fulfilling our second object, we discuss assessment, training, and the difficulties of assessing culverts. Furthermore, we reference throughout this chapter interview results, with many interviews giving us information that spans the full scope of our project. Over several weeks, we conducted ten interviews. We discuss case studies researched in our third objective. To conclude our final two objectives, the importance of proper outreach in developing our list of recommendations and encouraging the communities to assess and proactively replace culverts. A set of criteria were developed to aid in our project goal of helping municipalities prioritize culvert replacement, as will be discussed further in our recommendations.

## 4.1- Blackstone River Watershed and Improvement Efforts

To understand the historical and technical parts of this project, we began our project by conducting research into the region where our project takes place, the Blackstone River Watershed, as well as the importance and history of culverts in this region. Our background research supported observations we made during the in-field portions of this project. Furthermore, we gained an understanding about hydrology by attending the Manchaug Flooding Study meeting in Sutton, MA. We worked to gain an understanding of the different programs available for towns to use following completion of our project, satisfying goals from our first two project objectives.

### *4.1.1 - Human Impacts on the Blackstone River*

As a river that was the birthplace of the American Industrial Revolution and a critical industrial/transportation hub along its banks, the Blackstone River has been modified vastly to harness the water through dams to power cotton spinning and other mills as well as the construction of a canal to facilitate transportation via the river and its footpaths. Man-made structures vastly redirected tributaries to the Blackstone River, creating ponds and providing few uninterrupted routes to the river.

From our starting point at Manchaug Mills, an old, converted mill structure in an historic section of Sutton known as Manchaug Village, we saw several dams in sequence on the Mumford River and man-made stone and concrete walls along the banks of portions of the river. These structures were all visible from the park across the street from the Mills. From researching and comparing the history of the Blackstone River to the area, this site alone demonstrates several ecological impacts of the area’s development. The mill structure is a relic from a time when dumping of industrial waste was unregulated and mills regularly deposited heavy metals and other pollutants into the Blackstone and other rivers (EPA, 2021).

**Figure 4** - Bridge Near Manchaug Mills, Sutton, MA

Sutton is home to several artificial ponds created by dams, many of which were built in the 19th century, as is reported in Sutton’s Municipal Vulnerability Preparedness (MVP) Report. To direct water to these artificial bodies and natural streams, the town is home to over 100 culverts, many of which were constructed in the 1940s. With the presence of dams, it was obvious through observation that many of the town's ponds and streams and the Mumford River did not consistently flow through the town in an uninterrupted manner. Beyond our visual observations, the map of dams in Sutton shown in *Figure 5* shows the majority of the town's streams being obstructed by dams, with some forming artificial ponds and others simply obstructing the steady flow of water. In one of our culvert assessments, we noted a causeway dividing Merrill Pond, a causeway that did not have any culverts connecting the two halves of the lake. As such, aquatic organisms would not be able to pass from one side of the pond to the other and may present water quality challenges due to lack of water mixing. While some species of fish are content with living in the same body of water their whole lives, ponds like this are a prime example of Sutton’s lack of ample avenues for aquatic organisms to move around.

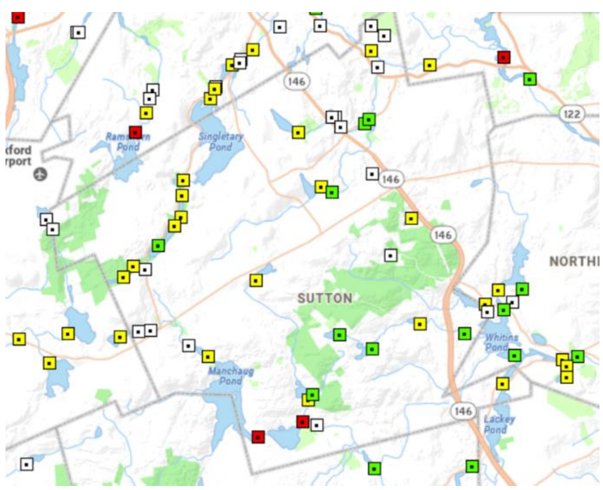



**Figure 5 -** Screenshot of Mass Mapper Dam Data, Sutton, MA

Though the Blackstone River itself does not pass through Sutton, several of our interviewees stated that the Blackstone River has been altered so much that it is impossible to know the natural path of the Blackstone River. Through interviews, it was noted that many of the migratory species of fish that were once present in the 19th century are not able to make their way into the Blackstone River, due to the dams down in Pawtucket, RI, let alone all the way up to Sutton. Coldwater fisheries do, however, remain in Sutton. Dams prevent their movement and several culverts we had the opportunity to assess also hindered fish passage. Programs do exist to help communities work to restore natural passage for fish and repair crossings, but communities do not always have capacity to plan ahead, apply for, and manage these grants, and there is greater demand than available funding.

### *4.1.2 - Municipal Vulnerability Program (MVP) and Municipal Grants*

While the majority of the municipal officials we interviewed were aware of the MVP program and associated grants, the process for getting grants can be somewhat time consuming. Furthermore, some municipalities are not necessarily aware of all of the funding and grant opportunities that the state has available to them. Beyond the MVP program, the Massachusetts Department of Ecological Restoration (DER) has grants available, too. For priority projects, DER has resources available to help municipalities with permitting and engineering work for projects. However, it was also noted in our interviews that grants rely on evidence to support grants, specifically grants outside of the MVP program. In terms of culvert assessment, it is beneficial to have multiple organizations do independent studies on culverts and return similar results. Completing assessments and applying them to multiple documents and grant applications can help secure funding and clarify where resources need to allocate, as stated by one interviewee. However, this is often not possible as municipalities may lack the funding to hire a consultant to do assessments, do not have the manpower or time available to dedicate resources to multiple rounds of assessments, and are often stretched thin focusing on all of the different things a town may need to repair or maintain.

### *4.1.3 - Hydraulic Modeling and Flood Plains*

While dam removal is not viable in many cases, many dams do not meet Massachusetts standards for dam capacity and are also in disrepair. We attended a meeting in Sutton, MA in which the Manchaug Flooding Study was discussed and hydrology data that was collected and analyzed by engineers from PARE Group, who was contracted by the Town of Sutton. Modeling of current and future rainfall amounts shows increases in rainfall amounts for different types of storms. For example, in the Manchaug Flood Study presentation it was predicted that in the future 5-year storms could see 5.2 inches of rain versus present day averages of 4.3 inches. To clarify, a 5-year storm event describes a storm that has a 20% chance of occurring each year, being more severe than 2-year storms and 1-year storms. When discussing 100-yr storms, which have a 1% chance of occurring each year, rainfall amounts could grow from 8.0 inches to 11.1 inches in the future. Analysis of dams in Sutton by their engineer PARE Group showed that several dams only have capacity for 10-year storms using present day figures, with many having even more limited capacity. This could be due to dams being in disrepair or being engineered for past conditions. While outside the scope of our project, dam failure and improvements do play a role in how stormwater is managed and how effective or ineffective upstream and downstream culverts may be. Just like culverts are in need of upgrades, dams need to be upgraded to handle future rainfall amounts.

## 4.2- Culvert Assessment and GIS Mapping for the Town of Sutton

To get a better understanding of the requirements of the culvert assessment process, we completed Culvert assessment training taught in accordance with the North Atlantic Aquatic Connectivity Collaborative. Using in-field work and review of online resources, our team mapped a majority of the culverts in the Town of Sutton and provided images to the database as well as assessing twenty culverts in the town.

### *4.2.1 - NAACC Assessment Protocols*

For our culvert assessments, we were trained in and used protocols developed by the North Atlantic Aquatic Connectivity Collaborative (NAACC), a standardized list of criteria for culvert assessments, as represented in *Appendix D*. The NAACC maintains a database with a linked GIS map that shows the assessment results for each culvert in Central Massachusetts. We used this data to map culverts located in Sutton MA, as shown in *Appendix E.* In our data collection, it was found that these criteria were known in some communities and were, in fact, used to assess each community's culverts. However, in other cases, officials didn't know how to access the database to see where all their local culverts were and most stated that they were not aware of training or how to become certified. In the Town of Holden, MA, our interviewee stated that the town maintained their own database of culvert assessments and assessed based on the NAACC protocols, but that they had developed their own set of protocols. And in interviews with other officials from different towns and members of non-profit organizations, it was stated that the training itself was a barrier. Training was time consuming (it took our group approximately three full days of field work and an online training to get certified), and with many organizations stating that they lacked the manpower to deal with culvert related issues they had already identified, it would not be logistically possible to send individuals to get trained. It was found that the biggest barrier to recording assessments of culverts was the certification itself and not necessarily a lack of awareness of the program.

**Figure 6** - Culvert on West Sutton Rd, Sutton

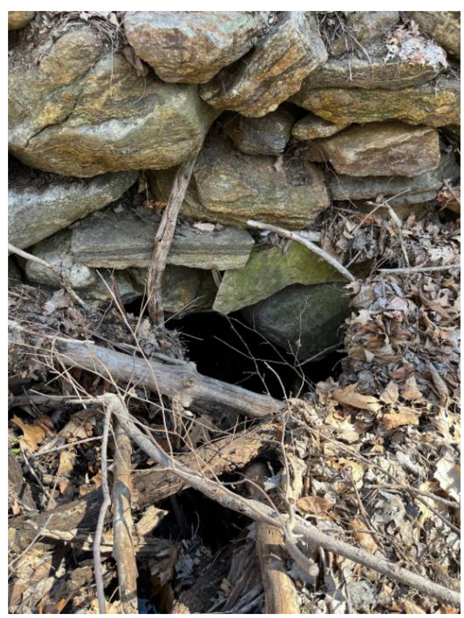


**Figure 7** - Culvert on Griggs Rd, Sutton

Before elaborating on issues related to mapping and culvert assessments, it is important to note some natural issues that may occur. Refer to *Figure 6* above on the left; older culverts may become buried over time or fill with debris. In the example above, it is likely that these stones, called riprap, were placed intentionally on the slope above the culvert when the road above the construction was repaired, but unintentionally fell down the slope to block the culvert's outlet. This issue was observed in several of our other assessments, as well. Accessibility was brought up in several of our interviews and is one of the criteria the NAACC protocols consider. Location is another barrier that poses an assessment challenge. Some culverts may be inaccessible due to the presence of plant growth, as demonstrated in *Figure 7*, where the inlet pipe was difficult to find due to natural debris, or other culverts that might be located somewhere that requires one to trek through poison ivy, thorns, and mud. Considering the time of year in which assessments are done is also important. Flow conditions and accessibility depend on the season, and as such periods of snowmelt or snow in general either increase flow substantially or prevent it altogether. Culvert assessments ideally take place during the summer during low-flow conditions.

Another challenging aspect is that culvert assessments are time-consuming in terms of receiving the training where that alone requires the assessment of 20 culverts, then finding the location of culverts that need to be assessed after getting certified and actually performing the assessment steps that include taking measurements, making observations to fill out the NAACC form and taking pictures. This is a challenge to especially smaller towns due to their limited capacity of workers. The smaller towns already have so much work and other projects to focus on that it will be time-consuming for them to have dedicated manpower for culvert assessments. Towns that are larger tend to not experience this challenge as they have enough manpower to perform several works, although they tend to not be consistent. Consistency helps with staying on top of the culvert assessments to know for sure which culverts need to be prioritized for repair or replacement in the future. But in order to properly assess culverts, it is important to keep track of locations.

Taking on a broader view of culvert assessments, we also considered mapping of culverts in general, and barriers that may exist to towns that follow the NAACC guidelines or their own set of protocols. In order to be able to assess culverts, it is important to first know where they are. Interviews with officials in several towns in the Blackstone River Watershed pointed to a similar problem; many maps they have of culverts are outdated and less prominent or significant culverts do not appear on maps. It is important to note that these culverts are just as critical to assess as a major crossing might be. Failure of a smaller culvert in a less traveled part of town can still cause property damage, close roads, and be a drain on resources. Recall the Belchertown example from the background chapter; East Street, the site of the failure, is a minor road that cuts through a forested area. And yet, the failure had a significant impact on nearby homeowners. In regards to culverts not being on maps, two of our municipal official interviewees attributed this to a lack of resources, namely manpower and funding, allocated to assessing culverts. Funding relies on residents being willing to allocate funding to a project, and the culvert issue is not a priority for many of them. The NAACC database maps many of these culverts that are unknown to communities. A key component of our project centers around developing a GIS map that aligns with our culvert assessments. The NAACC database was a crucial resource in mapping all of the culverts in Sutton. The database had precise coordinates for even the most unnoticeable culverts and allowed us to develop a Google Map to pinpoint each culvert in Sutton. This resource would be useful to municipalities.

#### *4.2.2 - Culvert Assessments*

We spent three days assessing the required twenty culverts with our sponsor as our certified trainer, both to collect data for our project and to receive a certification to assess culverts in the future. Upon completion of our assessments, we noticed the following trends:

- 12 of the 20 culverts assessed were made out of steel pipe
    - This was common practice in the 20th century
    - Because they were steel, this resulted in a lot of rusted out culverts
- Despite 8 out of the 20 culverts being in okay condition and 4 being new, there is still need for repair for most of the culverts
- A lot of aging/old culverts still in use, with only 4 out of the 20 culverts built within the last decade
    - Weakened material resulting in a smaller passage for passage
    - Leads to blockage
- There were not a lot of bank full width measurements because the inlets were being in wetlands or ponds being immediately upstream

There were many consistencies between assessed culverts, with many of the culverts having some less than ideal characteristics. *Appendix H* shows the culvert assessment process and the forms used.

## 4.3- Prioritizing Replacement

To understand how to create our own prioritization plan, in objective 3, we comparatively analyzed three prioritization plans to distinguish the similarities and differences between the aspects used within each prioritization plan. In objective 4, we proceeded to use this information with the information gathered from the in-field culvert assessments and interviews to create the prioritization plan for culvert repair and replacement. Finally, culvert failure can lead to consequences, therefore, being proactive about repairs and replacement is important.

#### *4.3.1 - Comparative Analysis of Other Prioritization Plans*

To consider the best approaches for prioritization of culvert repair, we comparatively analyzed the three different variations of prioritization models. The prioritization plans are: 1) The NAACC Prioritization Plan, 2) The Culvert Management Case Studies in Vermont, Oregon, Ohio, and Los Angeles County, and 3) The CSCE Sustainability in Design, Construction and Rehabilitation of Culverts Plan. Each prioritization plan focused on different priority aspects, which are summarized in *Appendix F.*

##### 4.3.1.1 – The NAACC Prioritization Considerations

The NAACC used a weighted ranking approach for their prioritization plan which is favored by us as well because it is flexible and does not require specific engineers and/or mathematicians to create a prioritization plan (Burch et al., 2022). The NAACC prioritization plan is based on ecological passage to identify those structures that create a barrier to aquatic and terrestrial passage. While it is run at a regional 14-state scale from Maine to Virginia, the data may also be used at a smaller scale to determine priority replacement. The NAACC website also has a page to assist municipalities and others determine how to prioritize their crossing replacement, which includes aspects such as structural conditions, vulnerability to flooding, historical and potential flooding, critical infrastructure presence, social impacts of flooding to roads, economic criteria, and water connectivity metrics regarding barriers to stream flow. The NAACC Prioritization recommendations also look at the ecological criteria such as quality of habitat, presence of rare species, water quality, local land use, condition of river shores, and stream importance for particular species (Prioritizing Projects, 2018).

#### 4.3.1.2 – The Culvert Management Case Studies in Vermont, Oregon, Ohio, and Los Angeles

The Culvert Management Case Studies in Vermont, Oregon, Ohio, and Los Angeles County had their prioritization plan focus on many things. This document is a compilation of studies done in all four communities, and thus represents one larger case study. The county of Los Angeles placed higher priority on culverts located on routes with no alternative routes where if a culvert failed, the road became impassable. They also focused on the economic criteria to compare the costs of culvert replacement and improvement project results to reduce ongoing maintenance cost repairs in the future. However, the state of Ohio directed their focus on culverts that have streamflow, and culverts that are in abrasive conditions which can lead to scour. The Culvert Management Case Study in Ohio also mentioned the economic criteria in the sense where they dedicated funding to repair or replace identified, deficient culverts using a cost benefit analysis. Furthermore, the state of Oregon centered their prioritization plan to look at a variety of aspects such as the culvert condition, culvert locations, addressing and improving fish passage barriers, and overall cost of selected repair and replacement. The state has also considered culverts that are in “critical” or “poor” conditions, the severity of the problem at the location, freight routes and routes supported by key bridges, and the safety of field crew working along the highways as top priority. They have conducted a ranking system to help them with their prioritization plan and a benefit and risk analysis to understand which culverts are prioritized. Finally, the state of Vermont mostly focused on the assessment and structural aspects of culverts. They assessed culverts for the inlet condition, outlet condition, barrel condition, pipe joint section separation, projecting culvert ends, stone pad, sediment, erosion, road surface conditions, shoulder sinkholes, piping, and culvert size. They also considered looking at the fish passage, road washout, and level of deterioration seen with eroded inverts or flooding that was due to a beaver dam building. The Culvert Management Case Study of Vermont also revised the hydraulic design manual and conducted an analysis of increasing storm frequencies and flood vulnerabilities (Venner & Berger, 2014).

#### 4.3.1.3 – The CSCE Sustainability in Design, Construction and Rehabilitation of Culverts Plan

Lastly, the CSCE Sustainability in Design, Construction and Rehabilitation of Culverts Plan focused on the physical characteristics of culverts, including dimensions and materials used. The plan looked at the type or shape of the culvert and whether it was a circular, box, arch, low profile arch, pipe arch, or elliptical culvert. The plan also looked at whether the culvert material was plastic, concrete, steel, etc., and the design of culverts in terms of allowable surcharging, and scour protection requirements. It was also mentioned that many of the culverts were manufactured to be in one common size and are not custom made depending on the region (Aghniaey & Rodgers, n.d.).

### *4.3.2 Prioritization Criteria*

From our interviews, we found that most individuals thought of similar considerations to include in a culvert assessment prioritization plan. One aspect that was commonly brought up by most of our interviewees was the structural condition of the culverts. Culvert structure plays a critical role in a culvert's condition, as poor structural condition can cause sudden failure and collapse. Good working conditions means that the culvert is in great condition, having no noticeable structural defects. Oftentimes, this was found solely in new culverts. Fair condition generally pertains to culverts that, though some wear and tear may be present, do not pose a significant risk of flooding. Poor conditions suggest that failure is imminent due to significant defects, such as if the bottom of the culvert was missing due to rust or other factors, as shown in *Figure 8*.

**Figure 8** - Poor Condition Culvert on Douglas Road in Sutton, MA

An additional aspect of the prioritization plan that was considered from our interviews was flooding, which can be due to undersized culverts or significant blockages that are caused by debris and or other things which cannot be easily moved. Interviewees suggested that we look at the hydraulic capacity and whether or not the location in question had flooded before. To determine if a culvert is undersized, constriction is the most obvious characteristic that we looked for in our field assessments. Constriction refers to whether or not a culvert is significantly narrower or shallower than upstream. Additionally, another criteria that was discussed during our interviews was potential property damage and safety hazards that may arise due to failure of a culvert. If culvert failure were to occur on a dead end road, for example, home owners may become stranded until repairs or relief can take place in the future. It would also be troubling if culvert failure were to occur on a major artery or highway as it will have a significant impact on traffic flow and emergency response times.

Another important consideration addressed for a prioritization plan from our interviews was aquatic and terrestrial passage and connectivity. Aquatic passage is important in terms of fish movement and if there are barriers along the way where the fishes are trying to go, then fish may not be able to migrate through a crossing. Stream connectivity refers to the flow and pathway of the stream water coupled with the aquatic and terrestrial passage. For example, if a culvert was perched such as in *Figure 9*, both terrestrial and aquatic organisms would not be able to pass through the culvert. Physical barriers such as fences, free falls, and deformation can also hinder aquatic and terrestrial organism movement as shown in *Figure 10* because if a fish or small terrestrial organism were to go through a culvert that has physical barriers, it is more likely to go back or get stuck and/or eventually die.

**Figure 9** - Perched Culvert on Mendon Road in Sutton, MA

**Figure 10** - Example of Free Fall from a Culvert on Douglas Road in Sutton, MA

Altogether, from our literature review and interviews, we have decided to compile the critical elements of prioritization into something easily accessible without significant training. This culvert prioritization plan or tool can be used to influence a community's decision on which culverts to replace first with limited funding. Those criteria are:

1. Culvert Structural Condition: This criteria focuses on the overall condition of culverts and stream crossings, and whether it is in good, fair or poor condition. It will also look at the age of the culverts and material, as well as surrounding structures, to determine whether it is in imminent risk of failure or not.

2. Road Closure and Detours: This criteria focuses on the impacts of transit and safety on the community. In the transit impacts, roads are being classified by several criteria; how substantial would detours be to people, is the road a major artery or minor road, do residents and businesses rely heavily on a road for their livelihood, and will a road closure strand residents. In the safety impacts, we are focusing on critical infrastructure by focusing on emergency response times and access to critical infrastructure.

3. River Flow and Water Levels: This criteria targets whether the culvert has capacity to convey water flow without creating a constriction or backup depending on many factors, including the culvert's shape, size, material, slope, inlet and outlet conditions. This criteria represents an initial indicator for hydraulic analysis. Factors that should be considered for this criteria include whether the structure is in a known flood plain, whether the structure has a history of flooding, and whether structures exist upstream or downstream that have the potential to cause the structure in question to flood in the future.

4. Aquatic and Terrestrial Organism Passability: This criteria focuses on whether aquatic organisms and terrestrial organisms have passage through stream crossings. Some of the questions to think about when considering this criteria; Can fish pass through the culvert, or is this crossing a barrier to fish migration? Would a terrestrial organism use this stream crossing as a route of travel or would it avoid this passage?

The culvert prioritization plan will include 1 to 3 priority codes where the lower number indicates a good/great condition and the higher number indicates a poor condition. This prioritization plan will help MA municipalities prioritize culvert repair and replacement before catastrophic problems occur.

## 4.4- Community Outreach

From our interviews, we made sure to question which type of outreach material will be suitable as well as the information being brought up in it. Outreach material is to inform the public on a certain matter to which the Blackstone Watershed Collaborative and our group are raising awareness to the Town of Sutton Massachusetts on the effects of culvert failures as well as the proper training and other significant factors to culvert assessment. The North Atlantic Aquatic Connectivity Collaborative has created Culvert Assessment Training however many communities aren't even aware that the training exists. Many people who we interviewed stated that they are interested in completing the training and made efforts to increase its popularity to the townspeople. Before the project started, members of our group had no idea what a culvert was, so informing the public more on what a culvert is and how it affects the community can change the actions taken before a culvert fails. Some of our interviews gave us some real examples of culvert failures that have happened in the close-by communities. One example is in the town that we are currently working in, Sutton Massachusetts. A dam blockage occurred and caused flooding of the culvert resulting in roadway closures, detours, and traffic of other roadways. By providing real life examples of what will happen resulting from culvert failure, will increase the awareness of culvert assessment. Funding of projects is a major factor when it comes to culvert replacement or training, so explaining the process of applying for private or government grants could increase the readiness of culvert repairs when needed.

To actually provide this information to the communities, we have been provided with several examples of material types by the people we have interviewed. The first idea is creating handouts such as brochures and fact sheets. Another idea could be creating some type of presentation whether it's a video or a slideshow that will be available to the public via the internet. Some other ideas are we create a website and upload our information there, creating a news article and sending it to new organizations. Outreach material is a key factor to help solve many reoccurring issues of culverts by raising awareness to the public.

# 5.0 – Conclusions and Recommendations

Based on our findings, we have compiled a list of recommendations for the Town of Sutton as well as surrounding communities and organizations. These recommendations are supported by our background research, interviews, and field observations. Our recommendations include deliverables such as our final outreach material and prioritization plan, as well as suggestions. The key areas include culvert training, assessment, proactive repairs, prioritization criteria, applying for grants, and community outreach.

## 5.1- Culvert Training

The recommendations regarding culvert training involve accessibility of training, encouragement for towns, and consideration of assessments that have been completed already.

### *5.1.1 - Make Training More Accessible*

Although the training of the NAACC is valuable, it is not very accessible to many people and towns. Our team, over the course of several days, completed this training and became certified to assess culverts on our own. However, given the time constraints of our projects, we were not sure if we would be able to complete the training before the end of our seven weeks of project work. All in all, it is apparent that the length of this training, which consists of two hours of online presentation and assessment of twenty culverts, poses a significant barrier to encouraging individuals to get certified. Our interviews, though oftentimes not explicitly about the training, pointed out that one of the major barriers to assessing culverts by their own criteria and using manpower and resources to perform culvert repairs was time and a lack of manpower. Town resources are already spread thin dealing with problems more important to the community and cannot be allocated to the culvert issue. Collectively, our assessments took 24 hours, over the course of 3 days, to complete. In towns where employees are already spread thin, it is not practical to send someone to get trained. Furthermore, similarities existed between a lot of the culverts we assessed, meaning a portion of our training culverts did not teach us more about the protocol. As such, we recommend that the training be shortened to make it more accessible. Training would be more desirable if it took less time.

### *5.1.2 - Encourage Town Employees to Get Trained*

From our interviews, we found that many people who are assessing culverts are not certified, making it impossible for them to enter the culvert assessments into the NAACC database. Many of those people are volunteers assessing culverts for prioritization. By making the training more shortened and accessible to communities, more people will be able to get certified to perform culvert assessments, including town employees, to be able to input the assessment into the NAACC database, minimizing the number of unassessed culverts. We encourage town employees to complete the training and get certified to inspire the idea of doing regular culvert assessments in the future in their towns, even if it requires the data to be inputted into their own database.

#### *5.1.3 - Consider External Assessments*

A common theme, it seemed, between interviewees from different towns was that they were aware of the need to assess culverts, and some were even familiar with and used the NAACC protocols. However, one such community, which used the very form we were trained on, maintained their own database of culverts and assessment results in a similar manner to how the NAACC does. It does not seem practical to make them reassess these culverts, especially given how sparse their resources and manpower are. As such, we recommend, given the number of unassessed culverts there are and the current barriers that exist to training, that communities that have already devoted time and resources to assessing their culverts be allowed to share this data and include it in the NAACC database.

### 5.2- Regular Assessment and Proactive Repairs

Our comparative analysis findings showed that the three prioritization plans had many recommendations that our team thought were helpful. One of the recommendations that we seek every MA municipality to do is to conduct regular annual culvert assessments and repairs before storm seasons or in between storm seasons. These inspections and repairs were found to be efficient to prevent having to deal with the consequences of culvert failures during the storm season. The Culvert Management Case Studies in Vermont, Oregon, Ohio, and Los Angeles suggested that routine annual inspections and maintenance for all culverts are worth being held to reduce the need for emergency repairs and prioritizations, and extend culvert life cycle (Venner & Berger, 2014).

### 5.3- Prioritization Criteria

#### *5.3.1 - Take Advantage of Current Assessment Tools*

While considering personal observation and the broader impacts of culvert failure is important and will be discussed in the next section, it is also important to take advantage of tools that already exist, namely the already-present NAACC database, once resources are available to commit to assessing culverts. Based on our field work assessing culverts using the NAACC's protocols, measurements taken did paint a picture of culvert limitations and could be used to assess and prioritize culverts. Our data from our field assessments provides measurements, descriptions, and other data that states specifically where a culvert is lacking. As such, we recommend that communities rely on this assessment tool to assess their culverts and log data following strict protocols before looking at the bigger picture.

#### *5.3.2 - Prioritize Based on Broader Criteria*

One area where the NAACC protocol could be improved, though, is providing an easier-to-follow, broader set of categories to base prioritization of culverts on. The NAACC assessment form logs only what the individual is looking at, relying on numbers and checkboxes to outline potential issues. What it does not consider but hopefully changes in the future are the impacts a culvert could have on the surrounding area and how the surrounding area may have negative impacts on the culvert. One of the major goals of our project was to develop a prioritization plan for communities to use to identify which culverts needed repairs or replacements the most. This plan considers criteria not defined in the NAACC culvert assessment protocol and criteria that are difficult to quantify. Criteria are based on the NAACC protocols as well as suggestions from interviews and observations made during field work. Ultimately, we chose to consider the list of criteria below:

- Potential for and Impact of Flooding
- Traffic Impacts of Road Closure and Detours
- Safety Impact of Road Closure and Detours
- Structural Condition
- Impacts on Aquatic and Terrestrial Organism Passage

These criteria were finalized based on feedback we received from several of our former interviewees. Each category could be rated using one of three scores: good, acceptable, or bad. As some categories had the potential for greater consequences, our priority code scores were weighted, and, as such, a score of bad in one category could be different in another category. Attached to our prioritization plan, found in *Appendix G*, is a grading matrix where the scores from each category could be added up to produce one final score for each stream crossing. To consider features not described on the NAACC assessment form, it is recommended that the list of criteria listed in our prioritization plan be used. Considering external factors is important, as repairs to a culvert that appear to be of the utmost priority based on the NAACC criteria could be overshadowed by one of slightly higher quality but with the potential of much greater consequences upon failure.

#### *5.3.3 - Relying on the NAACC Database*

The NAACC maintains an extensive and accurate database of culvert assessments and locations. In our field work in Sutton, Massachusetts, we found that some culverts mapped on the NAACC's map were not on the map maintained by the town. One interviewee from another community stated that the town he worked for had a map of culverts, but that it had not been updated in years. When left to maintain their own maps, evidence shows that these maps are often overlooked or forgotten about altogether. Towns would not have to worry about updating their maps if they were to rely more on the NAACC's map. As such, we encourage community officials to take advantage of this tool.

## 5.4- Applying for State and Federal Grants

The next recommendation is that communities should apply for grants to support culvert restoration, and should also develop culvert planning efforts that facilitate the grant preparation process. Grants are key factors for any type of project that requires any type of funding, as well as a culvert assessment. Assessment itself will need all kinds of equipment, thus requiring funding. There are multiple types of grants that could be given to anyone who applies for one. Public grants that come from the Commonwealth of Massachusetts and other organizations run by the state. There are also private grants, which can be obtained by applying for them through private organizations. Grants can play a crucial role in culvert assessment by providing the necessary funding for conducting surveys, investigations, and assessments of culverts' condition and capacity. Resulting from our interviews, we found that applying for private grants is a lot easier than obtaining the funding. To resolve this issue, we recommend that the municipalities provide information or links that were provided by the Commonwealth of Massachusetts

(Mass.gov). The process for applying for grants can be time-consuming and a hassle; in order to ease the process of applying for them, we recommend that Massachusetts municipalities provide reminders stating when the deadlines for grant applications are. Grants can provide the necessary financial resources to conduct regular inspections and assessments of culverts, identifying potential issues before they become major problems, and ensuring the safety of road users and the sustainability of infrastructure.

## 5.5- Community Outreach

The final recommendation is to develop outreach material because it is essential in creating awareness about the importance of culverts and their proper maintenance. Despite the importance of culvert awareness, there is still a need for more outreach materials to educate the public on the critical role that culverts play in infrastructure and the environment. One way to increase outreach materials is to leverage digital platforms such as social media, websites, and online newsletters. These platforms allow for the creation and distribution of educational videos, infographics, and other engaging content that can reach a wide audience. Additionally, partnerships with local community organizations and other relevant stakeholders can help distribute these materials and amplify their impact. By increasing the quantity and quality of outreach materials, we can raise awareness of culvert issues and inspire more people to take action to ensure the proper maintenance and management of culverts. These materials can include brochures, flyers, posters, videos, and social media campaigns, among others. They are designed to educate the public on the significance of culverts in managing water flow and protecting infrastructure and the environment. After finalizing our first four objectives, we made a brochure stating the facts and safety of culverts and other useful information. Outreach materials also provide information on how to identify signs of culvert failure and how to report issues to relevant authorities. By raising awareness and promoting public engagement, outreach materials can encourage individuals and communities to take an active role in protecting culverts, leading to improved maintenance and better management of water resources, thereby promoting sustainable development.

# References


Abbott, Alex, and Scott Jackson. *North Atlantic Aquatic Connectivity Collaborative Stream Crossing Survey Instruction Guide*. 2015, https://doi.org/10.13140/RG.2.1.4125.7125.

Aghniaey, N., & Rodgers, N. Sustainability in Design, Construction and Rehabilitation of Culverts. *GEN, 125, 1.*

Alcott, Derrick, et al. "Culverts Delay Upstream and Downstream Migrations of River Herring ( *Alosa* Spp.)." *River Research and Applications*, vol. 37, no. 10, 2021, pp. 1400–12, https://doi.org/10.1002/rra.3859.

Burch, C. A., Jardine, S. L., Lewis-Smith, C., & Deynze, B. V. (2022). *Western Washington culvert prioritization indexes: A cross jurisdictional comparative analysis of management strategies for salmon recovery.* bioRxiv. https://doi.org/10.1101/2022.11.07.515553

Çelik, Hüseyin E., et al. "Identifying Causes of the 2015 Hopa Flash Flood in NE Turkey and Mitigation Strategies." *Environmental Monitoring and Assessment*, vol. 192, no. 12, Nov. 2020, p. 769, https://doi.org/10.1007/s10661-020-08737-w.

*CMMPO Culvert Assessment Program*. https://culverts-cmrpc.hub.arcgis.com/apps/CMRPC::cmmpo-regional-culverts-dashboard/explore. Accessed 20 Feb. 2023.

Cohen, R. (2017, July 10). *10 Ways to Protect Cold Water Fishes and Streams.* Sea-Run Brook Trout Coalition. https://www.searunbrookie.org/conservation/10-ways-to-protect-cold-water-fishes-and-streams/

Community Resilience Building MVP Workshop. "Municipal Vulnerability Preparedness Program in Grafton, Milburry and Northbridge, Massachusetts." *Mass.Gov,* June 2018. https://www.mass.gov/doc/2017-2018-mvp-planning-grant-report-northbridge-grafton-millbury/download

Culvert. (2021). *In The Oxford Dictionary of Architecture.* Oxford University Press. https://www.oxfordreference.com/view/10.1093/acref/9780191918742.001.0001/acref-9780191918742-e-5489

Google. (n.d.). [Google Maps directions from east end to west end of Northboro Rd, Southborough]. Retrieved March 23, 2023, from https://www.google.com/maps/dir/42.3074122,-71.5553225/Northboro+Rd,+Southborough,+MA+01772/@42.3090268,-71.5651266,1371m/data=!3m1!1e3!4m9!4m8!1m0!1m5!1m1!1s0x89e38acd4c2a2f23:0x1d3ea568f9d55b04!2m2!1d-71.5659891!2d42.3115939!3e0

Google Maps. (n.d.). [Sutton Prioritization Plan Culvert Locations]. Retrieved April 25, 2023, from https://www.google.com/maps/d/u/5/edit?mid=1epBSdiVJzAL6uf6qC7M2yJ5qWR1QKRU&ll=42.14361456956223%2C-71.79118186292015&z=16

Hillemann, B. (n.d.). *All Guides: Data Module #1: What is Research Data?: Qualitative vs. Quantitative*. Retrieved February 15, 2023, from https://libguides.macalester.edu/c.php?g=527786&p=3608639

Intergovernmental Panel on Climate Change, *Climate Change Widespread, Rapid, and Intensifying – IPCC — IPCC*. https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/. Accessed 28 Jan. 2023.

Lynch, Melissa. "Blackstone Watershed Collaborative at Clark Highlights River's Needs through Expedition, Public Events." *Clark Now | Clark University*, 3 Aug. 2022, https://clarknow.clarku.edu/2022/08/03/blackstone-river-collaborative-at-clark-highlights-watershed-needs-through-expedition-public-events/.

MassMapper. (2023). *Screenshot of GIS Map of Sutton, MA with Dam's by Hazard Code* [map].

Melo, B. (2022, December 20). Northboro Road is reopened for use. My Southborough. https://www.mysouthborough.com/2022/12/20/northboro-road-is-reopened-for-use/

National Park Service, *Blackstone River Valley, Birthplace of the American Industrial Revolution (U.S. National Park Service)*. https://www.nps.gov/articles/000/brvnhc_winter_2021.htm. Accessed 3 Feb. 2023.

*No. 569: Establishing an Integrated Climate Change Strategy for the Commonwealth | Mass.Gov*. https://www.mass.gov/executive-orders/no-569-establishing-an-integrated-climate-change-strategy-for-the-commonwealth. Accessed 7 Feb. 2023.

*North Atlantic Aquatic Connectivity Collaborative.* (2018, November 6). Stream Continuity. https://streamcontinuity.org/naacc

*Northborough Road Culvert Replacement*. (n.d.). Retrieved April 7, 2023, from https://www.constructionjournal.com/projects/details/68732218b8754fd481fc1dae0596a8d2.html

*Prioritizing Projects.* (2018, November 29). North Atlantic Aquatic Connectivity Collaborative. https://streamcontinuity.org/naacc/toolkit/prioritizing-projects

RI DEM-OWR. *TOTAL MAXIMUM DAILY LOAD ANALYSIS FOR Blackstone River Watershed and Trace Metals Impairments*. Feb. 2013, https://dem.ri.gov/sites/g/files/xkgbur861/files/programs/benviron/water/quality/rest/pdfs/blackstn.pdf.

*Senator Eldridge Secures $70,000 in ARPA Funds for Collapsed Culvert in Southborough.* (n.d.). State Senator Jamie Eldridge. Retrieved March 21, 2023, from https://www.senatoreldridge.com/press-releases/senator-eldridge-secures-70000-in-arpa-funds-for-collapsed-culvert-in-southborough

Şen, Zekâi. "Water Structures and Climate Change Impact: A Review." *Water Resources Management*, vol. 34, no. 13, Oct. 2020, pp. 4197–216, https://doi.org/10.1007/s11269-020-02665-7.

Staff Writer. (2006). *Blackstone fish migration planned*. The Worcester Telegram & Gazette. Retrieved April 10, 2023, from https://www.telegram.com/story/news/local/east-valley/2006/03/21/blackstone-fish-migration-planned/53117646007/

*Stream Crossings - Protecting and Restoring Stream Continuity*. Department of Environmental Conservation. (n.d.). Retrieved March 19, 2023, from https://www.dec.ny.gov/docs/permits_ej_operations_pdf/streamcrossbroch.pdf

Sutton MVP Workshop. "MA Vulnerability Preparedness Workshop Findings, Town of Sutton, MA." *Mass.Gov*, 3 Sept. 2019, https://www.mass.gov/doc/sutton-report.

Systematic Observation. (2007). In E. M. Vonk, T. Tripodi, & I. Epstein, *Research Techniques for Clinical Social Workers* (pp. 51–69). Columbia University Press. https://doi.org/10.7312/vonk13388-003

Truhlar, A. M., Marjerison, R. D., Gold, D. F., Watkins, L., Archibald, J. A., Lung, M. E., Meyer, A., & Walter, M. T. (2020). Rapid Remote Assessment of Culvert Flooding Risk. Journal of Sustainable Water in the Built Environment, 6(2), 06020001. https://doi.org/10.1061/JSWBAY.0000900

US EPA. *Flow Duration Curves: A New Model to Envision Healthy Watersheds and Resilient Communities*. 8 Mar. 2021, https://www.epa.gov/snep/flow-duration-curves-new-model-envision-healthy-watersheds-and-resilient-communities.

---. (2016, April 15). *Pennsylvania Protects Coldwater Fisheries and Water Quality from Climate Change* [Overviews and Factsheets]. https://www.epa.gov/arc-x/pennsylvania-protects-coldwater-fisheries-and-water-quality-climate-change

---. *Re-Zapping the Blackstone: Keeping the River Recovery Going!* 5 May 2021, https://www.epa.gov/snep/re-zapping-blackstone-keeping-river-recovery-going.

U.S. Fish and Wildlife Service Northeast. *Culvert at Third Beach*. photo, 2 July 2014, https://www.flickr.com/photos/usfwsnortheast/14626360571/.

Venner, M., & Berger, L. (2014). *Culvert management case studies: Vermont, Oregon, Ohio, and Los Angeles county* (No. FHWA-HIF-14-008). United States. Federal Highway Administration.

*Washed out undersized culvert*. (2022, January 5). River Smart Communities. https://extension.umass.edu/riversmart/washed-out-undersized-culvert-0

*What Is a Watershed?* https://oceanservice.noaa.gov/facts/watershed.html. Accessed 29 Jan. 2023.

# Appendix A - Informed Consent

This appendix displays the informed consent that was sent prior to conducting the interviews.

**Interviews Informed Consent:**
We are a group of students from Worcester Polytechnic Institute in Massachusetts and we are working with the Blackstone Watershed Collaborative.

We are conducting this interview to learn more about the impacts of failing and/or aging culverts on stormwater management to help watersheds prioritize culvert replacement in Sutton, Massachusetts, and protect infrastructures.

The interview should take about an hour.
Your participation in this interview is completely voluntary and you may withdraw at any time.

If you prefer, we will keep your identity confidential. No names will appear on the questionnaires or in any of the project reports or publications.

If you have questions, you may reach out to our faculty advisor (mathisen@wpi.edu). If you would like, we are happy to share a copy of our results at the conclusion of the study.
Thank you for your participation!

# Appendix B - List of Interviewees

**Table 2 -** List of Interviewees for Objectives 1 and 2

| Name | Position | Organization | Date of Interview |
|---|---|---|---|
| David Pickart | Conservation Agent | Town Hall of Northbridge | March 31, 2023 |
| Heather Parry | Environmental Scientist | Blackstone River Coalition | March 22, 2023 |
| Isabel McCauley | Water and Sewer Superintendent | Holden, MA DPW | March 21, 2023 |
| Julianne Busa | Sr. Project Manager | Fuss & O'Neil | March 24, 2023 |
| Matthew Dunn | Sr. Project Engineer | PARE Corporation | April 4, 2023 |
| Matthew Stencel | Highway Superintendent | Sutton, MA DPW | March 29, 2023 |
| Phyllis Charpentier | Foundation President | Manchaug Pond Foundation, Sutton MA | April 4, 2023 |
| Rosalie Starvish | Sr. Project Manager | GZA Environmental | March 22, 2023 |
| Ted Beauvais | President and Policy Director | Blackstone River Watershed Association | March 24, 2023 |
| Zach Blais | Transportation Planner | CMRPC | March 29, 2023 |

Abbreviations:
CMRPC - Central Massachusetts Regional Planning Commission
DPW - Department of Public Works

## Appendix C - Interview Questions

This appendix lists the interview questions we generally asked our interviewees. The questions were modified based on the organizations our interviewee worked at.

**General Interview Questions:**

1. What makes you passionate about this topic? (warm up question)
   a. We know that you work with the …(mention the collaborative or organization they work in) but can you tell us a bit about what caught your attention about working here.
2. (Ask a question about the collaborative or organization they work at) Ex: We know that the … was created in … with the goal of … Could you tell us a bit more about how it started? … Something like that not entirely sure!
3. What do you see as the biggest challenges when it comes to assessing culverts?
   a. What considerations do you think are important when developing a prioritization list?
4. What outreach material do you know that could potentially be helpful to raise awareness about this culvert issue?
5. Do you have any recommendations for resources that might be helpful to us and our project?
6. This is totally up to you, but would you consider meeting with us again to have a look at our findings and provide us with feedback? You can answer no to this question and we totally understand!
7. Thank you so much for taking the time to talk with us! We really appreciate it. It has been a pleasure. If we have any more questions, would it be okay to reach out? [If so] what would be the best way to contact you?

# Appendix D - NAACC Aquatic Connectivity Stream Crossing Survey

This appendix displays the NAACC Stream Crossing Assessment Sheet used during our training and assessments.

NAACC

**AQUATIC CONNECTIVITY**

**Stream Crossing Survey**

**DATA FORM**

DATABASE ENTRY BY ______ ENTRY DATE ______

DATA ENTRY REVIEWED BY ______ REVIEW DATE ______

**CROSSING DATA**

Crossing Code______ Local ID (Optional)______

Date Observed (00/00/0000)______ Lead Observer______

Town/County______ Stream______

Road______ Type: MULTILANE, PAVED, UNPAVED, DRIVEWAY, TRAIL, RAILROAD

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

Location Description

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

Number of Culverts/ Bridge Cells ______

Photo IDs: INLET______ OUTLET______ UPSTREAM______ DOWNSTREAM______ OTHER______

Flow Condition: NO FLOW, TYPICAL-LOW, MODERATE, HIGH

Crossing Condition: OK, POOR, NEW, UNKNOWN

Tidal Site: YES, NO, UNKNOWN

Alignment: FLOW-ALIGNED, SKEWED (>45°)

Road Fill Height (Top of culvert to road surface; bridge = 0)______

Bankfull Width (Optional)______

Confidence: HIGH, LOW/ESTIMATED

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

Tailwater Scour Pool: NONE, SMALL, LARGE

Crossing Comments

**STRUCTURE 1**

Structure Material: METAL, CONCRETE, PLASTIC, WOOD, ROCK/STONE, FIBERGLASS, COMBINATION

**OUTLET**

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, CLOGGED/COLLAPSED/SUBMERGED, 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

Inlet Type: PROJECTING, HEADWALL, WINGWALLS, HEADWALL & 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 % (Optional)______ 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______

Comments

5/26/16

1 AQUATIC CONNECTIVITY STREAM CROSSING SURVEY DATA FORM

## STRUCTURE 4

**Structure Material** METAL | CONCRETE | PLASTIC | WOOD | ROCK/STONE | FIBERGLASS | COMBINATION

### OUTLET

**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 | CLOGGED/COLLAPSED/SUBMERGED | 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

**Inlet Type** PROJECTING | HEADWALL | WINGWALLS | HEADWALL & 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 %** (Optional)________ **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**________

**Comments**

## STRUCTURE 5

**Structure Material** METAL | CONCRETE | PLASTIC | WOOD | ROCK/STONE | FIBERGLASS | COMBINATION

### OUTLET

**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 | CLOGGED/COLLAPSED/SUBMERGED | 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

**Inlet Type** PROJECTING | HEADWALL | WINGWALLS | HEADWALL & 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 %** (Optional)________ **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**________

**Comments**

## STRUCTURE 6

**OUTLET**

**Structure Material** METAL CONCRETE PLASTIC 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 CLOGGED/COLLAPSED/SUBMERGED 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

**Inlet Type** PROJECTING HEADWALL WINGWALLS HEADWALL & 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 %** (Optional)_______ **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**_______

**Comments**

## STRUCTURE 7

**OUTLET**

**Structure Material** METAL CONCRETE PLASTIC 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 CLOGGED/COLLAPSED/SUBMERGED 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

**Inlet Type** PROJECTING HEADWALL WINGWALLS HEADWALL & 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 %** (Optional)_______ **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**_______

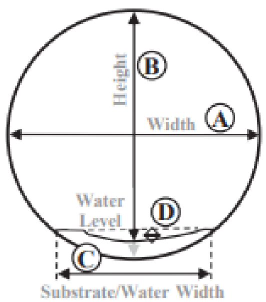
**Comments**

## 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 approriate 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.

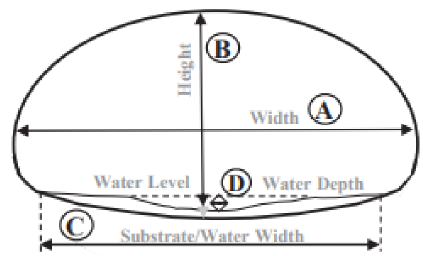
**NOTE:** Culverts 1, 2 & 4 may or may not have substrate in them, so height measurements (B) are taken from the level of the "stream bed", whether that bed is composed of substrate or just the inside bottom surface of a culvert (grey arrows below show measuring to bottom, black arrows show measuring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

**1**



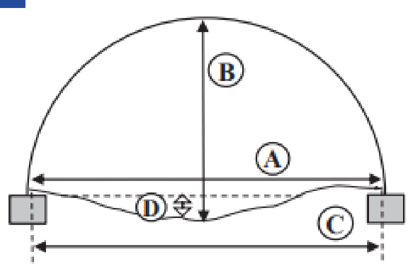

Round Culvert

**2**



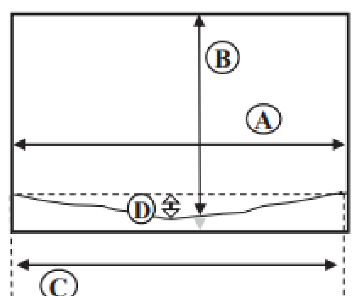

Pipe Arch/Elliptical Culvert

**3**



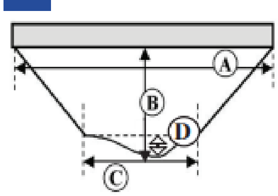

Open Bottom Arch Bridge/Culvert

**4**



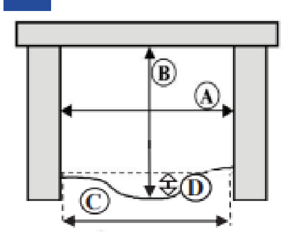

Box Culvert

**5**



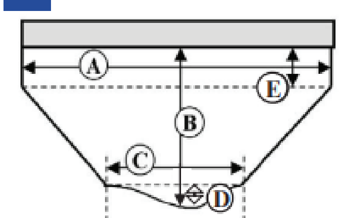

Bridge with Side Slopes

**6**




Box/Bridge with Abutments

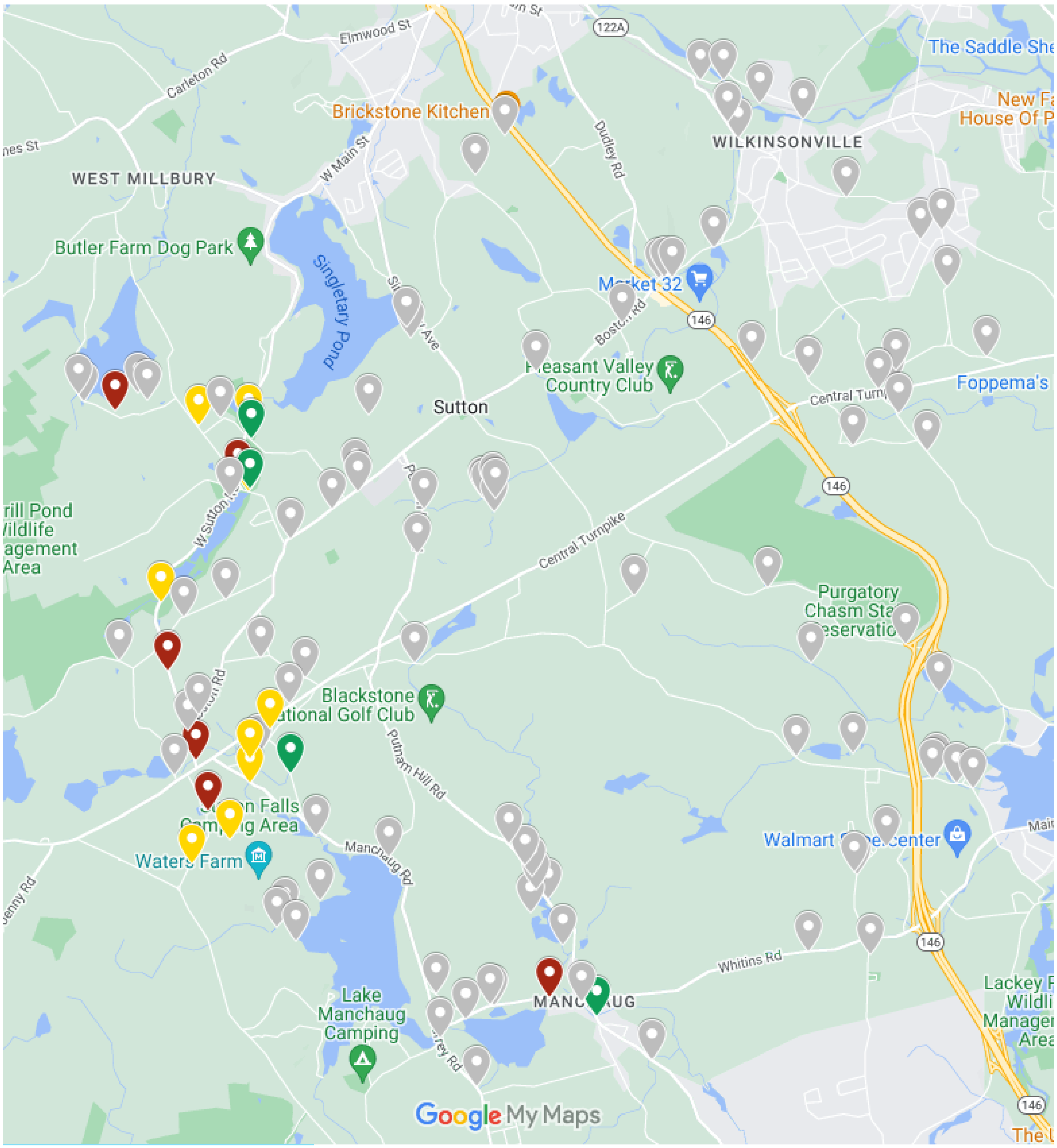
**7**




Bridge with Abutments and Side Slopes

# Appendix E - Map of Culverts in Sutton, MA

This appendix shows a picture of the GIS Map that we created using google maps to locate culvert locations (Google Maps, n.d.). The culverts that were assessed are color coded by their priority codes from *Appendix I*.




Unassessed Culverts

Priority 3 Culverts

Priority 2 Culverts

Priority 1 Culverts

# Appendix F - Summary of Other Prioritization Plans

This appendix summarizes the three prioritization plans that we comparatively analyzed. For each prioritization plan, there is a list of criteria the prioritization plan focused on.

## The NAACC Prioritization Considerations

Common considerations:

- Aquatic organism passage field assessment results
- Water connectivity metrics regarding barriers to stream flow
- Ecological criteria including quality of particular species habitat, presence of particular species, water quality, local land use, condition of river shores (riparian zone), stream importance for particular species

Other considerations:

- Structural condition of culverts/crossings
- Vulnerability of region to flooding
- Criticalness and impact of flooding to roads
- Historical and potential flooding

## The Culvert Management Case Studies in Vermont, Oregon, Ohio, and Los Angeles

- **Los Angeles County**
    - Higher priority on culverts located on routes with no alternative route; if the culvert failed and the road became impassible.
    - Cost: compares the cost of a culvert replacement/improvement project and its resultant reduced maintenance cost with minor concrete repair and ongoing additional maintenance costs.

- **Ohio**
    - Culverts that have constant stream flow
    - Culverts in abrasive conditions which can lead to scour
    - Cost: Dedicated funding to repair or replace identified, deficient culverts
        - Cost benefit analysis

- **Oregon**
    - Culverts that are in "critical" or "poor" conditions
    - Addressing and improving fish passage barriers
    - Culvert location
    - Culvert condition
    - Whether the culverts are new, ok, or poor in the ranking system
    - Severity of problem at each culvert location
    - Overall cost of a selected culvert repair or replacement
    - Top priority for freight routes and those supported by key bridges
    - Focus on safety of field crews working along Interstate Highways
    - Benefit and risk analysis

- **Vermont**
    - Assessment of structural aspects of culverts
        - Inlet treatment condition
        - Outlet treatment condition
        - Barrel condition
        - Pipe joint section separation
        - Projecting culvert ends
        - Stone pad
        - Sediment
        - Erosion
        - Road surface conditions
        - Shoulder sink holes
        - Piping
    - Revised hydraulic design manual that requires a 1.2 bankfull-width standard
    - Analysis of increasing storm frequencies and flood vulnerabilities
    - Level of deterioration seen with eroded inverts or flooding due to beaver dam building
    - Fish passage
    - Road washout
    - Culvert size

## The CSCE Sustainability in Design, Construction and Rehabilitation of Culverts Plan

- Provides info on culvert's characteristics such as the different sizes and materials.
- Explains the many types of culverts: Circular, Box, Arch, Low Profile Arch, Pipe Arch, and Elliptical.
- Many culverts are manufactured in one common size and usually aren't custom made, depending on the region. The culvert will usually get a list of its dimensions.
- Common culverts are made of concrete, plastic, and steel. With other culverts being made of timber and masonry (Older models).
- Concrete Culverts: If designed properly, they can last 75 years but can experience chemical attack, corrosion of reinforcement, cracking & spalling.
- Metal Culverts: Higher ductility and tensile strength making them suitable for wider projects. Prone to a series of defects such as corrosion, permanent deformation, cracking, and loose connections. Can purchase coating to protect against the defects.
- Also looks at the common culvert defects such as scaling, disintegration, erosion, corrosion, delamination, spalling, cracking, deformations, etc.

# Appendix G - Prioritization Plan

## Culvert Assessment Prioritization Plan

For Culverts in the Commonwealth of Massachusetts, with a focus on Sutton, MA

This prioritization plan is intended for use by municipalities to help prioritize the repair and replacement of their culverts and stream crossings, with the intent of applying for grants and completing preemptive repairs and replacements of deficient stream crossings.

This plan was created based on culvert assessment protocols developed by the North Atlantic Aquatic Connectivity Collaborative (NAACC). The plan was developed by students from Worcester Polytechnic Institute as a part of their Interactive Qualifying Project (IQP). This project was sponsored by the Blackstone Watershed Collaborative. For the project, a set of culvert assessments conducted in Sutton, MA, were used as a case study to gain insight into the considerations regarding culvert failure and practical aspects of culvert assessment when developing this plan.

This plan builds from the foundation of the NAACC culvert assessment criteria, the Massachusetts Stream Crossing Handbook, and references the American Association of State Highway and Transportation Officials (AASHTO) roadway categories.[1] These resources were considered in our criteria below and help define certain terms that are used in our criteria.

The following criteria are assigned values based on in-person assessment. Values should be added up and crossings with the highest total point values typically are most in need of repair and replacement. This plan is designed to complement the NAACC assessment training, not to replace it, and offers a faster and more simplified approach to culvert assessment for those communities or individuals wanting to identify culverts to replace.

[1] **American Association of State Highway and Transportation Officials (AASHTO) Definitions**
Interstate - highest classification of roadways in the United States. These arterial roads provide the highest level of mobility and the highest speeds over the longest uninterrupted distance.
Other Arterial - provide limited mobility and are the primary access to residential areas, businesses, farms, and other local areas.
Collector - major and minor roads that connect local roads and streets with arterials. Collectors provide less mobility than arterials at lower speeds and for shorter distances. They balance mobility with land access.
Local Road - include freeways, multilane highways, and other important roadways that supplement the Interstate System. They connect, as directly as practicable, the Nation's principal urbanized areas, cities, and industrial centers. Land access is limited.

## Impacts of Road Closure and Detours

### *Transit Impacts*

Road significance describes the traffic impacts that a road closure would have on the community. Roads are classified by several criteria; how substantial would detours be, is the road a major artery or minor road, do residents and businesses rely heavily on a road for their livelihood, and will a road closure strand residents. The level of overall traffic flow impacts is the basis for this category. For descriptions of road types, refer to AASHTO definitions on the previous page.


| Priority Code | Description | Example |
|---|---|---|
| 1 | Road is either insignificant to overall traffic flow or is short enough where failure would not lead to substantial detours. (AASHTO Local Roads) | In the above map, the unnamed side streets branching off Boston Rd would fit this category as local roads. The only exception to this rule in this guide would be dead end roads |
| 2 | Road is a main road, meaning that closure would harm overall traffic flow and lead to detours, but not in a catastrophic manner. Detours are not substantial/roads are not the only way in and out of an area. In the case of dead-ends, failure would prevent access to or egress from their residences. (Dead End Roads, AASHTO Collector Roads) | Boston Rd, an important road through Sutton, MA, would fit this category as a collector road |
| 3 | Road is a major artery or highway. Failure of this crossing would severely impact traffic flow and create costly and impactful detours and road closures. (AASHTO Intestates and Arterial Roadways) | Multiple types of roadways would fit this category, but the most significant and noticeable in the map above would be Route 146, an important state highway and arterial road by AASHTO standards |

### *Safety Impacts*

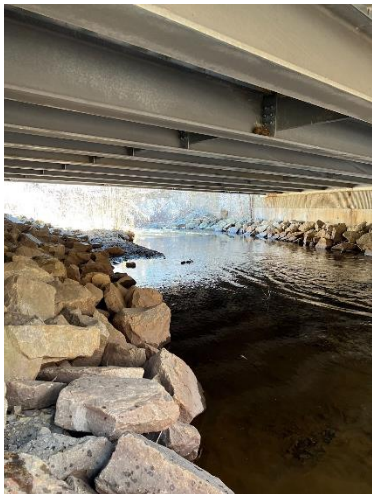
Critical infrastructure is defined similarly to road significance but focuses on emergency response times and access to critical infrastructure. However, this category considers emergency services and their response times, schools, government buildings, and other locations of significance. While the first category focuses on economic impacts, this category focuses on safety implications.

| **Priority Code** | **Description** | **Example** |
|---|---|---|
| 1 | Failure of this stream crossing would have minimal impact on public health, emergency response times, and safety. | This category is broad and applies to stream crossing for which failure would not threaten public health or safety. |
| 2 | Failure of this stream crossing would have some safety implications. Failure would lead to a marginal impact on public health and safety and emergency response times. However, failure of a crossing would impact the lives of residents and delay emergency response times. | This could apply to major roads that have readily available detours, side streets in the event of more severe flooding, and important but not vital infrastructure. |
| 3 | Failure of this crossing would have a high impact on public health and safety and emergency response times. | This code could apply to major arteries or streets that house police and fire stations, hospitals, dead-end roads, and other vital infrastructure |

Note: Additional considerations for these first two categories would be to consider the impacts and potential for impact to homes, community assets, and buildings. Though not explicitly outlined in these first two categories, flooding of these kinds of structures and assets should be considered in ranking safety impacts, as even on a smaller local road, there may be more safety implications in densely populated areas.

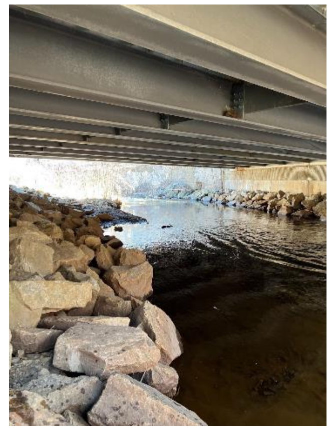
## Structural Condition

This criteria focuses on the overall structural condition of the stream crossing. Age of culvert and material of culvert, as well as surrounding structures should be considered.

| Priority Code | Description | Example |
|---|---|---|
| 1 | Stream crossing and roadway have little to no structural defects or deterioration. The deficiencies that do exist are minor and could be addressed with isolated repair approaches; full crossing replacement is not warranted |  |
| 2 | Stream crossing and roadway have some minor and/or developing deficiencies that will likely need to be addressed soon. Full crossing and roadway replacement is likely the most appropriate way to address the deficiencies when the time comes to do so. |  |
| 3 | Stream crossing and roadway have significant deficiencies that will likely need to be addressed soon as soon as funding is available. Full crossing and roadway replacement is needed to address the deficiencies. This could also include crossings for which the inlet or outlet are not able to be located/accessible. |  |

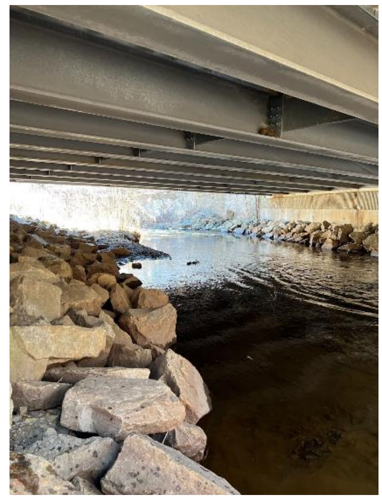
## Impacts on Aquatic and Terrestrial Organism Passability

Aquatic and Terrestrial Organism Passability focuses on the ability of aquatic and terrestrial organisms to pass through stream crossings. Can fish pass through the culvert, or is this crossing a barrier to fish migration? Would a terrestrial organism use this stream crossing as a route of travel, or would it avoid this passage?

| **Priority Code** | **Description** | **Example** |
|---|---|---|
| 1 | Crossing has open bottom culverts/bridges with a large enough span to support full passage. Water flows uninterrupted smoothly where aquatic and terrestrial organisms have sufficient room to pass. |  |
| 2 | Crossing has open bottom culverts and/or spans the full stream but is not large enough to support full dry passage for terrestrial organisms. |  |
| 3 | Crossing is perched, blocked, or is significantly constrictive, making it not appropriately passable to aquatic or terrestrial organisms. |  |

## Impacts on River Flow and Water Levels

This category provides an indication of whether the culvert has capacity to convey flow. The ability of a culvert to convey a required flow without creating a constriction or backup depends on many factors, including the culvert's size, shape, material, slope, and inlet and outlet conditions. A full analysis of the ability the impacts on river flow and water levels requires knowledge of a design flow and a hydraulic analysis of the flow through the culvert. As such, this category represents an initial indicator. Factors that should be considered for this category include whether the structure is in a known flood plain, whether the structure has a history of flooding, and whether structures exist upstream or downstream that have the potential to cause the structure in question to flood in the future.

| Priority Code | Description | Example |
|---|---|---|
| 1 | Crossing span is equal or greater than the river's bankfull width. Crossing height and overall geometry appears adequate to accommodate high/severe rain events without notably impacting water levels within the river. There is no history of impacted water (high head differentials, upstream flooding, roadway overtopping) during most storm events. |  |
| 2 | Crossing span is 50-90% of the river's bankfull width. Crossing height and overall geometry appear adequate to accommodate low to moderate rain events without notably impacting water levels within the river; however, water levels within the river will likely be impacted by the crossing during moderate to high rain events. There is likely a history of impacted water levels during moderate to high rain events. Constriction is uncertain due to presence of pond and/or no bankfull width. |  |
| 3 | Crossing span is less than 50% of the river's bankfull. Crossing height and overall geometry do not appear adequate and will likely impact water levels within the river during most rain events. There is a history of impacted water levels during most rain events. |  |

## Other Important Considerations

Accessibility is an important consideration when assessing culverts. Culverts should be easily accessible for inspection and maintenance, but this does not warrant repair or replacement. In our assessment, there were several culverts for which one side of the culvert was unreachable due to being buried or otherwise and warranted additional study.

Whether or not a stream crossing falls within a Federal Emergency Management Agency (FEMA) Flood Zones is another consideration as it states the probability of flooding for different levels of rainfall and should be considered in the capacity of stream crossings.

Hydraulic capacity should also be considered but is not included in the flooding section because it is outside of the scope of this project and involves hydraulic analysis and modeling, and other engineering work.

Finally, federal, state, and local regulations should be considered during replacement considerations. For instance, the Massachusetts Stream Crossing Standards Handbook has regulatory requirements for MA, and the Army Corp of Engineers has federal requirements for culvert replacement, such as a required openness factor and bankfull width requirements and prohibiting the act of sliplining a culvert or otherwise reducing its capacity without appropriate permitting.

**Culvert Scoring Matrix**

To calculate score, rate each culvert for each category on a scale of 1 to 3 and add values from the same culver ID to determine its final score. Culverts with higher scores should be of higher priority. By default, these categories are weighted equally but can be adjusted based on condition and broader picture. Total scores will range from 5-15.

| **ID** | Safety Impacts of Closure (20%) | Transit Impacts of Closure (20%) | Structural Condition (20%) | Organism Passage (20%) | Flooding and River Flow (20%) | **Score** |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

# Appendix H - Culvert Assessment Forms and Photos

This appendix displays a sample of the NAACC assessment sheets that were filled out during our in-field culvert assessments with the upstream, downstream, outlet, and inlet pictures of each location.

For digital viewers, all twenty assessments can be found here: https://docs.google.com/document/d/1uLF0nDlHb91hz-73YwLmNCsYo1D1Z6I_mPPnyzIOt-c/edit?usp=sharing

---

**1**

NAACC

AQUATIC CONNECTIVITY
**Stream Crossing Survey**
DATA FORM

DATABASE ENTRY BY ____ ENTRY DATE ____
DATA ENTRY REVIEWED BY ____ REVIEW DATE ____

**CROSSING DATA**

Crossing Code ____ Local ID (Optional) ____

Date Observed (00/00/0000) 03/20/2023 Lead Observer Stefanie Cavino

Town/County Sutton Stream Mumford River

Road Main St. Type ☐ MULTILANE ☒ PAVED ☐ UNPAVED ☐ DRIVEWAY ☐ TRAIL ☐ RAILROAD

GPS Coordinates (Decimal degrees) 42.09224 °N Latitude −71.74612 °W Longitude

Location Description

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

Number of Culverts/ Bridge Cells 1

Photo IDs INLET ____ OUTLET ____ UPSTREAM ____ DOWNSTREAM ____ OTHER 10:00 - 11:49am

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

Crossing Condition ☐ OK ☐ POOR ☒ NEW ☐ UNKNOWN

Tidal Site ☐ YES ☒ NO ☐ UNKNOWN

Alignment ☒ FLOW-ALIGNED ☐ SKEWED (>45°)

Road Fill Height (Top of culvert to road surface; bridge = 0) 0

Bankfull Width (Optional) 31 Confidence ☐ HIGH ☒ LOW/ESTIMATED

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

Tailwater Scour Pool ☒ NONE ☐ SMALL ☐ LARGE

Crossing Comments

**STRUCTURE 1**

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

**OUTLET**

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 ☐ CLOGGED/COLLAPSED/SUBMERGED ☐ UNKNOWN

Outlet Dimensions A. Width 42.5 B. Height 27.8 C. Substrate/Water Width 25.0 D. Water Depth 2.0

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) 49.3

**INLET**

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

Inlet Type ☐ PROJECTING ☐ HEADWALL ☐ WINGWALLS ☒ HEADWALL & WINGWALLS ☐ MITERED TO SLOPE ☐ OTHER ☐ NONE

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

Inlet Dimensions A. Width 41.4 B. Height 7.5 C. Substrate/Water Width 24 D. Water Depth 1.5

**ADDITIONAL CONDITIONS**

Slope % (Optional) ____ 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 5'

Comments

1 16' Bankful 35.8 Bankful up stream 40.0' Average

AQUATIC CONNECTIVITY STREAM CROSSING SURVEY DATA FORM

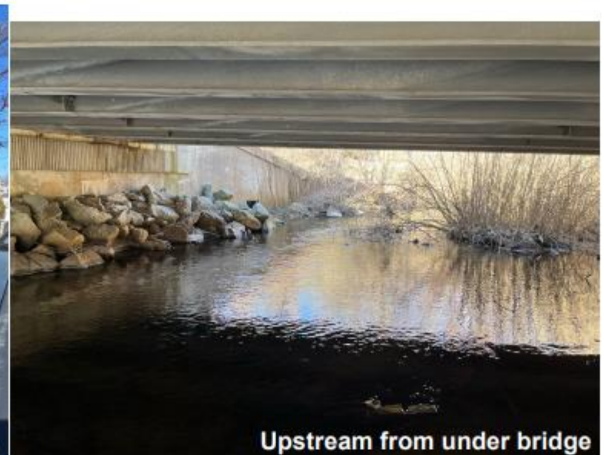
Bridge Outlet

Close-up Bridge Outlet

Downstream

Downstream from udner bridge

Upstream



Upstream from under bridge

2

1/2

AQUATIC CONNECTIVITY
# Stream Crossing Survey
DATA FORM

DATABASE ENTRY BY ______ ENTRY DATE ______

DATA ENTRY REVIEWED BY ______ REVIEW DATE ______

## CROSSING DATA

Crossing Code XY4211168167179024 Local ID (Optional) ______

Date Observed (00/00/0000) 03/20/2023 Lead Observer Nathan Cloutier

Town/County Sutton Stream ______

Road Mendon Type ☐ MULTILANE ☒ PAVED ☐ UNPAVED ☐ DRIVEWAY ☐ TRAIL ☐ RAILROAD

GPS Coordinates (Decimal degrees) 42.11683 °N Latitude −71.79026 °W Longitude

Location Description

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

Number of Culverts/ Bridge Cells 3

Photo IDs INLET______ OUTLET______ UPSTREAM______ DOWNSTREAM______ OTHER______

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

Crossing Condition ☒ OK ☐ POOR ☐ NEW ☐ UNKNOWN

Tidal Site ☐ YES ☒ NO ☐ UNKNOWN

Alignment ☒ FLOW-ALIGNED ☐ SKEWED (>45°)

Road Fill Height (Top of culvert to road surface; bridge = 0) 2.2

Bankfull Width (Optional) 13 Confidence ☐ HIGH ☒ LOW/ESTIMATED

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

Tailwater Scour Pool ☐ NONE ☐ SMALL ☒ LARGE

Crossing Comments 2:30 image

## STRUCTURE 1

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

### OUTLET

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 ☐ CLOGGED/COLLAPSED/SUBMERGED ☐ UNKNOWN

Outlet Dimensions A. Width 1.3 B. Height 1.3 C. Substrate/Water Width 0 D. Water Depth 0

Outlet Drop to Water Surface 0.7 Outlet Drop to Stream Bottom 1.2 E. Abutment Height (Type 7 bridges only) ______

L. Structure Length (Overall length from inlet to outlet) 32.5

### INLET

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

Inlet Type ☒ PROJECTING ☐ HEADWALL ☐ WINGWALLS ☐ HEADWALL & WINGWALLS ☐ MITERED TO SLOPE ☐ OTHER ☐ NONE

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

Inlet Dimensions A. Width 1.3 B. Height 1.3 C. Substrate/Water Width 0.0 D. Water Depth 0.0

### ADDITIONAL CONDITIONS

Slope % (Optional) ______ 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 1.3

Comments

V.3/2/16

## STRUCTURE 2

**Structure Material** [X] METAL ☐ CONCRETE ☐ PLASTIC ☐ WOOD ☐ ROCK/STONE ☐ FIBERGLASS ☐ COMBINATION

### OUTLET

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

**Outlet Grade** (Pick one) [X] AT STREAM GRADE ☐ FREE FALL ☐ CASCADE ☐ FREE FALL ONTO CASCADE ☐ CLOGGED/COLLAPSED/SUBMERGED ☐ UNKNOWN

**Outlet Dimensions** **A. Width** 3.7 **B. Height** 2.1 **C. Substrate/Water Width** 3.0 **D. Water Depth** 0.3

**Outlet Drop to Water Surface** 0.0 **Outlet Drop to Stream Bottom** 0.6 **E. Abutment Height** (Type 7 bridges only) ____.__

**L. Structure Length** (Overall length from inlet to outlet) 30.5

### INLET

**Inlet Shape** ☐ 1 [X] 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ FORD ☐ UNKNOWN ☐ REMOVED

**Inlet Type** ☐ PROJECTING [X] HEADWALL ☐ WINGWALLS ☐ HEADWALL & WINGWALLS ☐ MITERED TO SLOPE ☐ OTHER ☐ NONE

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

**Inlet Dimensions** **A. Width** 3.7 **B. Height** 2.1 **C. Substrate/Water Width** 3.7 **D. Water Depth** 0.6

### ADDITIONAL CONDITIONS

**Slope %** (Optional) ____ **Slope Confidence** ☐ HIGH ☐ LOW **Internal Structures** [X] NONE ☐ BAFFLES/WEIRS ☐ SUPPORTS ☐ OTHER____

**Structure Substrate Matches Stream** [X] NONE ☐ COMPARABLE ☐ CONTRASTING ☐ NOT APPROPRIATE ☐ UNKNOWN

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

**Structure Substrate Coverage** [X] NONE ☐ 25% ☐ 50% ☐ 75% ☐ 100% ☐ UNKNOWN

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

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

**Water Depth Matches Stream** ☐ YES [X] NO-SHALLOWER ☐ NO-DEEPER ☐ UNKNOWN ☐ DRY

**Water Velocity Matches Stream** ☐ YES [X] NO-FASTER ☐ NO-SLOWER ☐ UNKNOWN ☐ DRY

**Dry Passage through Structure?** ☐ YES [X] NO ☐ UNKNOWN **Height above Dry Passage** ____

**Comments**

## STRUCTURE 3

**Structure Material** [X] METAL ☐ CONCRETE ☐ PLASTIC ☐ WOOD ☐ ROCK/STONE ☐ FIBERGLASS ☐ COMBINATION

### OUTLET

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

**Outlet Grade** (Pick one) ☐ AT STREAM GRADE [X] FREE FALL ☐ CASCADE ☐ FREE FALL ONTO CASCADE ☐ CLOGGED/COLLAPSED/SUBMERGED ☐ UNKNOWN

**Outlet Dimensions** **A. Width** 1.3 **B. Height** 1.3 **C. Substrate/Water Width** 0.0 **D. Water Depth** 0.0

**Outlet Drop to Water Surface** 0.3 **Outlet Drop to Stream Bottom** 1.0 **E. Abutment Height** (Type 7 bridges only) ____.__

**L. Structure Length** (Overall length from inlet to outlet) 33.2

### INLET

**Inlet Shape** [X] 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ FORD ☐ UNKNOWN ☐ REMOVED

**Inlet Type** ☐ PROJECTING [X] HEADWALL ☐ WINGWALLS ☐ HEADWALL & WINGWALLS ☐ MITERED TO SLOPE ☐ OTHER ☐ NONE

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

**Inlet Dimensions** **A. Width** 1.3 **B. Height** 1.3 **C. Substrate/Water Width** 0.0 **D. Water Depth** 0.0

### ADDITIONAL CONDITIONS

**Slope %** (Optional) ____ **Slope Confidence** ☐ HIGH ☐ LOW **Internal Structures** [X] NONE ☐ BAFFLES/WEIRS ☐ SUPPORTS ☐ OTHER____

**Structure Substrate Matches Stream** [X] NONE ☐ COMPARABLE ☐ CONTRASTING ☐ NOT APPROPRIATE ☐ UNKNOWN

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

**Structure Substrate Coverage** [X] NONE ☐ 25% ☐ 50% ☐ 75% ☐ 100% ☐ UNKNOWN

**Physical Barriers** (Pick all that apply) ☐ NONE ☐ DEBRIS/SEDIMENT/ROCK ☐ DEFORMATION ☐ FREE FALL ☐ FENCING [X] 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 [X] DRY

**Water Velocity Matches Stream** ☐ YES ☐ NO-FASTER ☐ NO-SLOWER ☐ UNKNOWN [X] DRY

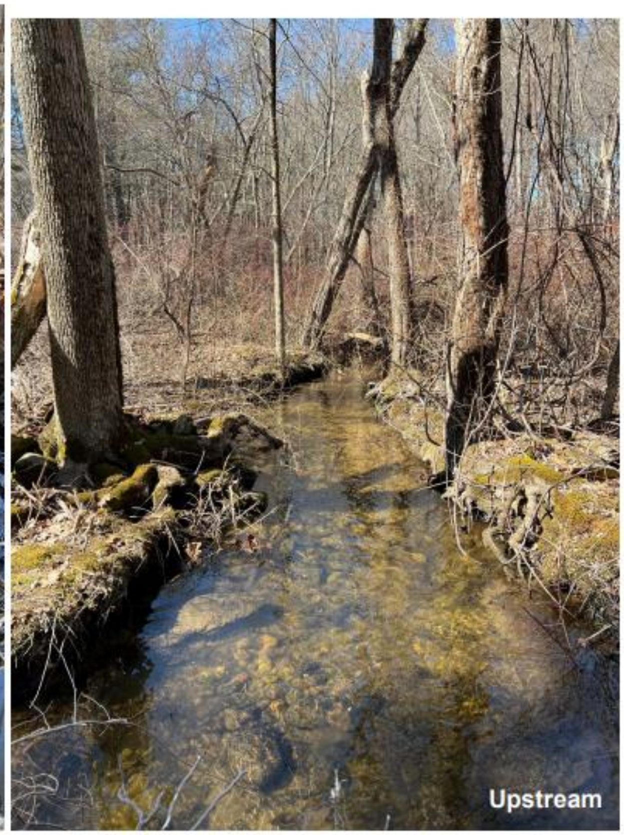
**Dry Passage through Structure?** [X] YES ☐ NO ☐ UNKNOWN **Height above Dry Passage** 1.3

**Comments**


Multiple Culvert Outlet


Multiple Culvert Inlet


Downstream


Upstream

3

NAACC

AQUATIC CONNECTIVITY
# Stream Crossing Survey
DATA FORM

DATABASE ENTRY BY ______ ENTRY DATE ______
DATA ENTRY REVIEWED BY ______ REVIEW DATE ______

## CROSSING DATA

Crossing Code ______ Local ID (Optional) ______

Date Observed (00/00/0000) 03/20/2023 Lead Observer Stefanie Cavino

Town/County Sutton Stream Unnamed Trib - Mumford

Road West Sutton Road Type ○ MULTILANE X PAVED ○ UNPAVED ○ DRIVEWAY ○ TRAIL ○ RAILROAD

GPS Coordinates (Decimal degrees) 42.11666 °N Latitude −71.79718 °W Longitude

Location Description Dam upstream

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

Number of Culverts/ Bridge Cells 1

Photo IDs INLET ______ OUTLET do not have UPSTREAM ______ DOWNSTREAM ______ OTHER 3:00 pm

Flow Condition ○ NO FLOW ○ TYPICAL-LOW X MODERATE ○ HIGH

Crossing Condition ○ OK X POOR ○ NEW ○ UNKNOWN

Tidal Site ○ YES X NO ○ UNKNOWN

Alignment X FLOW-ALIGNED ○ SKEWED (>45°)

Road Fill Height (Top of culvert to road surface; bridge = 0) 1.4

Bankfull Width (Optional) ______ Confidence ○ HIGH ○ LOW/ESTIMATED

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

Tailwater Scour Pool ○ NONE ○ SMALL X LARGE

Crossing Comments Dam upstream of Culvert

## STRUCTURE 1

Structure Material X METAL ○ CONCRETE ○ PLASTIC ○ WOOD ○ ROCK/STONE ○ FIBERGLASS ○ COMBINATION

### OUTLET

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

Outlet Armoring ○ NONE X NOT EXTENSIVE ○ EXTENSIVE

Outlet Grade (Pick one) ○ AT STREAM GRADE X FREE FALL ○ CASCADE ○ FREE FALL ONTO CASCADE ○ CLOGGED/COLLAPSED/SUBMERGED ○ UNKNOWN

Outlet Dimensions A. Width 4 . B. Height 4 . C. Substrate/Water Width 0 . D. Water Depth 0 .

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) 49 . 6

### INLET

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

Inlet Type ○ PROJECTING ○ HEADWALL ○ WINGWALLS ○ HEADWALL & WINGWALLS ○ MITERED TO SLOPE X OTHER ○ NONE

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

Inlet Dimensions A. Width 4 . 0 B. Height 4 . 0 C. Substrate/Water Width 3 . 3 D. Water Depth . 8

### ADDITIONAL CONDITIONS

Slope % (Optional) ______ Slope Confidence ○ HIGH ○ LOW

Internal Structures X NONE ○ BAFFLES/WEIRS ○ SUPPORTS ○ OTHER ______

Structure Substrate Matches Stream X NONE ○ COMPARABLE ○ CONTRASTING ○ NOT APPROPRIATE ○ UNKNOWN

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

Structure Substrate Coverage X NONE ○ 25% ○ 50% ○ 75% ○ 100% ○ UNKNOWN

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

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

Water Depth Matches Stream ○ YES ○ NO-SHALLOWER ○ NO-DEEPER X UNKNOWN ○ DRY

Water Velocity Matches Stream ○ YES ○ NO-FASTER ○ NO-SLOWER X UNKNOWN ○ DRY

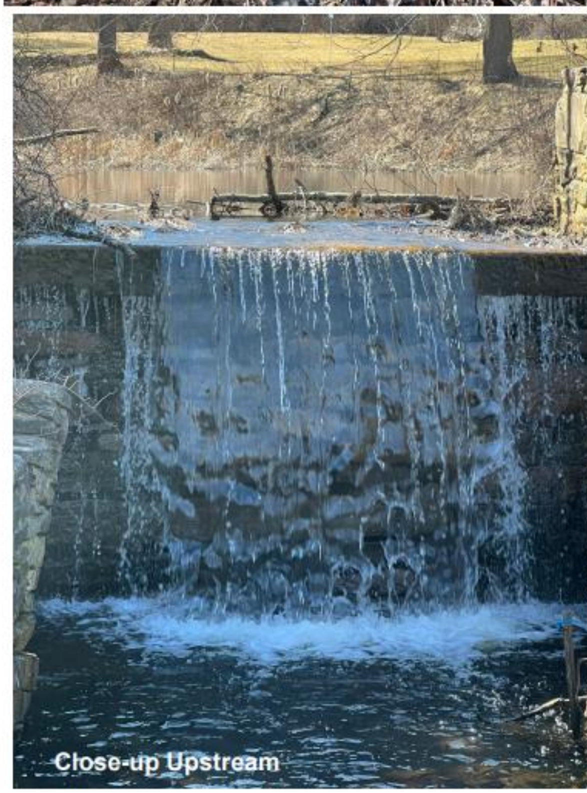
Dry Passage through Structure? ○ YES X NO ○ UNKNOWN Height above Dry Passage ______

Comments

5/20/16


Inlet

Downstream

Upstream

Close-up Upstream

# 4

NAACC

AQUATIC CONNECTIVITY
# Stream Crossing Survey
DATA FORM

DATABASE ENTRY BY ____ ENTRY DATE ____
DATA ENTRY REVIEWED BY ____ REVIEW DATE ____

## CROSSING DATA

Crossing Code ____ Local ID (Optional) ____

Date Observed (00/00/0000) ____ Lead Observer Stefanie Cowie

Town/County Sutton Stream Unknown

Road West Sutton Type MULTILANE ✓PAVED UNPAVED DRIVEWAY TRAIL RAILROAD

GPS Coordinates (Decimal degrees) 42.12497 °N Latitude -71.80046 °W Longitude

Location Description

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

Number of Culverts/ Bridge Cells 1

Photo IDs INLET____ OUTLET____ UPSTREAM____ DOWNSTREAM____ OTHER____

Flow Condition NO FLOW ✓TYPICAL-LOW MODERATE HIGH

Crossing Condition OK ✓POOR NEW UNKNOWN

Tidal Site YES ✓NO UNKNOWN

Alignment ✓FLOW-ALIGNED SKEWED (>45°)

Road Fill Height (Top of culvert to road surface; bridge = 0) 2.6

Bankfull Width (Optional) 2 Confidence HIGH ✓LOW/ESTIMATED

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

Tailwater Scour Pool ✓NONE SMALL LARGE

Crossing Comments

## STRUCTURE 1

Structure Material METAL CONCRETE PLASTIC WOOD ROCK/STONE FIBERGLASS COMBINATION

### OUTLET

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 CLOGGED/COLLAPSED/SUBMERGED UNKNOWN

Outlet Dimensions A. Width 3.9 B. Height 2.5 C. Substrate/Water Width 4.5 D. Water Depth 0.2

Outlet Drop to Water Surface 1.3 Outlet Drop to Stream Bottom 1.5 E. Abutment Height (Type 7 bridges only) —

L. Structure Length (Overall length from inlet to outlet) 37.0

### INLET

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

Inlet Type PROJECTING HEADWALL ✓WINGWALLS HEADWALL & WINGWALLS MITERED TO SLOPE OTHER NONE

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

Inlet Dimensions A. Width 5.5 B. Height 5.5 C. Substrate/Water Width 4.9 D. Water Depth 0.1

### ADDITIONAL CONDITIONS

Slope % (Optional) — 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 —

Comments

5/26/16


Outlet

Inlet

Upstream

5

AQUATIC CONNECTIVITY
# Stream Crossing Survey
DATA FORM

NAACC

Malyam Al Hakeem — DATABASE ENTRY BY
3/20/2023 — ENTRY DATE
DATA ENTRY REVIEWED BY ____ REVIEW DATE ____

Culvert #3 @ 12:30

## CROSSING DATA

Crossing Code: XY42115448717853165 — Local ID (Optional): ____

Date Observed (00/00/0000): 03/20/2023 — Lead Observer: Stefanie Covino

Town/County: Sutton — Stream: unnamed trib to Mumford river

Road: Old Mill Road — Type: MULTILANE / ✓ PAVED / UNPAVED / DRIVEWAY / TRAIL / RAILROAD

GPS Coordinates (Decimal degrees): 42.11560 °N Latitude — -71.78534 °W Longitude

Location Description

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

Number of Culverts/ Bridge Cells: 1

Photo IDs: INLET____ OUTLET____ UPSTREAM____ DOWNSTREAM____ OTHER____

Flow Condition: NO FLOW / TYPICAL-LOW / ✓ MODERATE / HIGH

Crossing Condition: ✓ OK / POOR / NEW / UNKNOWN

Tidal Site: YES / ✓ NO / UNKNOWN

Alignment: ✓ FLOW-ALIGNED / SKEWED (>45°)

Road Fill Height (Top of culvert to road surface; bridge = 0): 1.6

Bankfull Width (Optional): ____ — Confidence: HIGH / LOW/ESTIMATED

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

Tailwater Scour Pool: NONE / ✓ SMALL / LARGE

Crossing Comments: Wetland up and down stream

## STRUCTURE 1

Structure Material: ✓ METAL / CONCRETE / PLASTIC / WOOD / ROCK/STONE / FIBERGLASS / COMBINATION

### OUTLET

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 / CLOGGED/COLLAPSED/SUBMERGED / UNKNOWN

Outlet Dimensions: A. Width 2.0 — B. Height 2.0 — C. Substrate/Water Width 1.6 — D. Water Depth 0.6

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): 39.1

### INLET

Inlet Shape: ✓ 1 / 2 / 3 / 4 / 5 / 6 / 7 / FORD / UNKNOWN / REMOVED

Inlet Type: PROJECTING / HEADWALL / WINGWALLS / ✓ HEADWALL & WINGWALLS / MITERED TO SLOPE / OTHER / NONE

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

Inlet Dimensions: A. Width 2.0 — B. Height 2.0 — C. Substrate/Water Width 1.7 — D. Water Depth 0.4

### ADDITIONAL CONDITIONS

Slope % (Optional) ____ — 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 ____

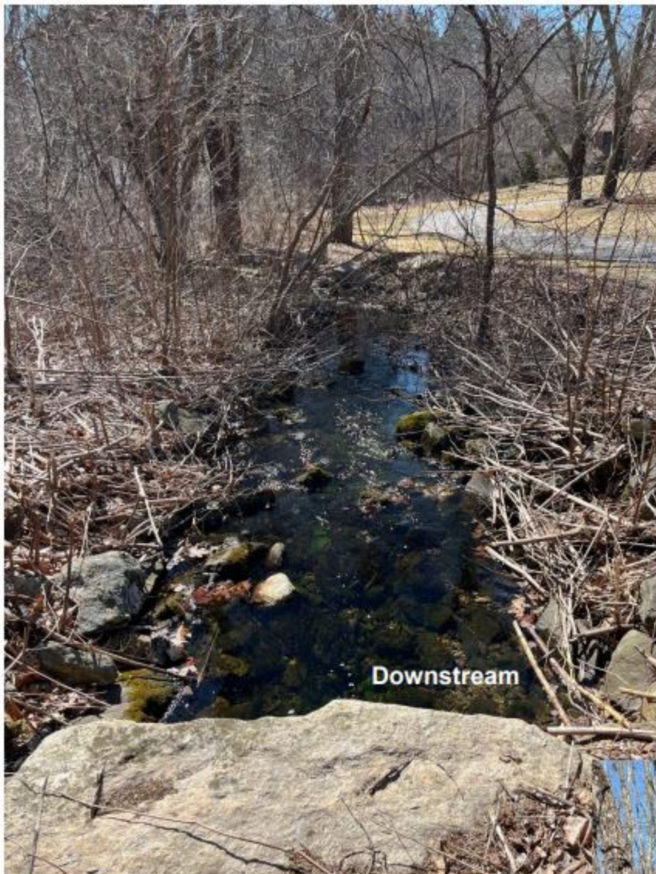
Comments

5/26/16


Outlet

Inlet

Inside of Culvert


Downstream


Upstream

## Appendix I - Culvert Assessment Scores Based on Prioritization Plan

This appendix shows the culvert scores table following the ranking system based in the prioritization plan criteria. These scores were used to make the priority code colors for the map displayed in *Appendix E*.

**Table 3:** Assessed Culvert Scores for Sutton, MA Based on the Prioritization Plan Criteria

| **Culvert Scoring Matrix** | | | | | | |
|---|---|---|---|---|---|---|
| Each category below is weighted differently. To calculate score, rate on a scale of 1 to 3 and multiply by weight percent when adding final score. | | | | | | |
| **ID** | Safety Impacts of Closure (20%) | Movement Impacts of Closure (20%) | Structural Condition (20%) | Organism Passage (20%) | Flooding and River Flow (20%) | **Score** |
| 1 | 2 | 2 | 1 | 1 | 1 | 7 |
| 2 | 1 | 1 | 2 | 3 | 3 | 10 |
| 3 | 2 | 2 | 2 | 3 | 3 | 12 |
| 4 | 2 | 2 | 3 | 3 | 1 | 11 |
| 5 | 1 | 1 | 2 | 2 | 1 | 7 |
| 6 | 2 | 2 | 2 | 3 | 3 | 12 |
| 7 | 1 | 1 | 3 | 3 | 3 | 11 |
| 8 | 2 | 2 | 3 | 3 | 2 | 12 |
| 9 | 1 | 1 | 2 | 2 | 1 | 7 |
| 10 | 1 | 1 | 2 | 2 | 2 | 8 |
| 11 | 1 | 1 | 3 | 3 | 2 | 10 |
| 12 | 1 | 1 | 3 | 3 | 2 | 10 |
| 13 | 2 | 2 | 2 | 2 | 2 | 10 |
| 14 | 1 | 1 | 2 | 2 | 2 | 8 |
| 15 | 1 | 1 | 3 | 3 | 3 | 11 |
| 16 | 2 | 2 | 1 | 2 | 2 | 9 |
| 17 | 2 | 2 | 2 | 2 | 1 | 9 |
| 18 | 2 | 2 | 1 | 2 | 1 | 8 |
| 19 | 1 | 1 | 1 | 2 | 1 | 6 |
| 20 | | | | | | 0 |

# Appendix J - Massachusetts Stream Crossing Standards

## STREAM CROSSING STANDARDS

Stream crossing standards are based on six important variables. While the specifics of the regulations listed below may change over time, the crossing guidelines presented in the Massachusetts Stream Crossings Handbook remain effective for fish and wildlife.

### 1. TYPE OF CROSSING

- General: Spans (bridges, 3-sided box culverts, open-bottom culverts or arches) are strongly preferred.
- Optimum: Use a bridge.

### 2. EMBEDMENT

- All culverts should be embedded (sunk into stream) a minimum of 2 feet, and round pipe culverts at least 25%.
- If pipe culverts cannot be embedded this deep, then they should not be used.
- When embedment material includes elements >15 inches in diameter, embedment depths should be at least twice the $D_{84}$ (particle width larger than 84% of particles) of the embedment material.

### 3. CROSSING SPAN

- General: Spans channel width (a minimum of 1.2 times the bankfull width of the stream).
- Optimum: Spans the streambed and banks (at least 1.2 times bankfull width) with suf.cient headroom to provide dry passage for wildlife.

### 4. OPENNESS

- General: Openness ratio (cross-sectional area/crossing length) of at least 0.82 feet (0.25 meters). The crossing should be wide and high relative to its length.
- Optimum: Openness ratio of at least 1.64 feet (0.5 meters) and minimum height of 6 feet. If conditions significantly reduce wildlife passage near a crossing (e.g., steep embankments, high traf.c volumes, and physical barriers), maintain a minimum height of 8 feet (2.4 meters) and openness ratio of 2.46 feet (0.75 meters).

### 5. SUBSTRATE

- Natural bottom substrate should be used within the crossing and it should match the upstream and downstream substrates. The substrate and design should resist displacement during floods and maintain an appropriate bottom during normal flows.

### 6. WATER DEPTH AND VELOCITY

- Water depths and velocities are comparable to those found in the natural channel at a variety of flows.

A Well Designed Crossing


Large size suitable for handling high flows

Open-arch design preserves natural stream channel

Openness ratio greater than 0.5m, suitable for most settings

Crossing span helps maintain dry passage for wildlife

Water depth and velocity are comparable to conditions upstream and downstream

Natural substrates create good conditions for stream-dwelling animals

# Appendix K - Brochure for Community Outreach

This appendix presents one of the methods, a brochure, we used for community outreach to raise awareness about culverts.

**Outside Page**


**Inside Page**

# Appendix L – Team Assessment

### Team Learned Strategies

One team strategy that we found is that when we have some sort of conflict is that we always listen to everyone that has some sort of opinion before we end up having some sort of yelling competition. One example is that while we were working on our Findings and Conclusion, there were some disagreements about where certain parts go. We first listened to what everyone had to say and in less than five minutes, we resolved the issue.

Another strategy that we learned through the IQP that led to effective team outcomes was splitting the workload among team members. The equality of work lets team members feel relaxed and not feel too overwhelmed with the assignments given. One example of how we specifically did this for assignments was by having action items in our agendas, and each team member would be assigned a specific action item to work on until the next meeting. This way, each team member was given an equal number of sections to write.

Though we often gave basic feedback on each other's portions of assignments, it was not until we worked on our first formative assessment that we started to give more constructive feedback and made a plan to have a weekly meeting where we discuss areas of improvement for each of us. It helped each of us hold each other accountable and pointed out areas where we all struggled, allowing us to work together to ensure we all succeeded.

### Team Areas of Improvement

One area where we struggled was being willing to reach out to and schedule meetings with our advisor and sponsor when we had questions about stuff, instead waiting until we had the opportunity to see them during a regularly scheduled meeting or sending an email, a method of communication that has its limits. In the future, we could all be more willing to ask for help and communicate more freely and regularly with supervisors and advisors.

An area that team members need to improve on in future teamwork experience is sticking to internal deadlines. Internal deadlines are set up so that team members can finish their homework, consolidate it and revise it together before the actual assignment deadline. For example, our team has been setting up internal deadlines for assignments but not everyone is sticking to finishing up their homework before we meet to pass in the assignment. This causes the need to rush to work on the assignment, impacting the quality of work. Also, it usually causes a delay in terms of passing in the assignment. To improve this issue, we remind or ask each other to do our parts of the assignment. This has been effective, however, there is always room for improvement.  Another area where we struggled is that many times each group member got carried away and lost concentration while we worked on many assignments. Due to this, we missed some internal deadlines but fortunately the assignments were completed however, they were slightly later than intended. To improve this issue, whether we are working together in person, we can hide all phones in one member’s backpack and shut them down for the time being. We could also set deadlines and if they weren’t accomplished, that specific person had to pay for coffee for the next in person meeting.