MQP-PPM-1674

Restoration of the Walker Street Culverts in Norton, Massachusetts

A Major Qualifying Project

Submitted to the Faculty of Worcester Polytechnic Institute

In partial fulfillment of the requirements

for the Degree of Bachelor of Science

Submitted by

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Approved:

Professor Paul Mathisen, Advisor

Abstract

This project worked with the Town of Norton to investigate the Walker Street crossing of the Wading River. A stream constriction causes flooding in periods of heavy rainfall and has created a large downstream scour pool inhibiting fish passage. After analyzing channel flowrates and depths at varying flood levels, the team evaluated and compared culvert replacement options to develop the final recommendation that best eases fish passage and mitigates flooding. The recommended design is an open-bottom, precast concrete arch culvert.

Capstone Design Criteria

This Major Qualifying Project (MQP) satisfies the requirements for a capstone design as specified by the Civil and Environmental Engineering Department at Worcester Polytechnic Institute.

The Accreditation Board for Engineering and Technology (ABET) requires capstone design projects to address a multiple of the following realistic constraints: economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability. The goal of this project was to develop a stream crossing design that improves the habitats of local wildlife, mitigates flooding, and meets as many regulatory standards as possible. This section provides a summary of the relevant constraints considered in the final recommendations of this project.

Economic: Cost is a crucial restraint in all engineering decisions. The scope of this project included considering the initial and maintenance costs of each design option. Cost is also often a limiting factor in the progression of projects. The recommended design aims to be cost-effective for the Town of Norton while providing improvements needed to meet updated regulations.

Environmental: The environment is a large concern for engineering projects. This project specifically focused on improving the wetlands area surrounding the stream crossing site. State-listed endangered species were also a driving factor behind the recommended design. The new design creates a more accessible environment for the species concerned while minimizing impact to the natural wetlands and normalizing past disruptions.

Political: This project works closely with the Town of Norton Conservation Commission. Continuation of the project based on the recommendations will include town and state approval and permitting, in addition to correspondence with multiple agencies including the Southeastern Regional Planning and Economic Development District, the Natural Heritage and Endangered Species Program, the Massachusetts Division of Fisheries and Wildlife, and the Narragansett Bay Estuary Program.

Health and Safety: At its current state, the existing stream crossing often causes flooding over the roadway during periods of heavy rainfall, potentially restricting local traffic and damaging abutting properties. The goal of this project was to minimize flooding in order to prevent property damage and mitigate safety concerns. The recommended design greatly reduces the likelihood of flooding at the project site.

Manufacturability: The research involved in this project supports the manufacturability of the final recommendation. Ease and duration of installation were considered in the design, in addition to access of required materials and labor. Research included a variety of manufacturers, specific types of structures, and recommended construction practices.

Sustainability: Sustainability is becoming a more prevalent concern for engineering decisions. The recommended design is a low-maintenance structure with a relatively long lifespan. This project also considered environmental sustainability. After construction, the recommended design will have a limited impact on the surrounding environment and will help to promote the restoration of a normal stream system.

Professional Licensure

An engineer must be licensed by the state they perform engineering services in in order to ethically and legally sign, seal, and submit engineering plans to a client. To become licensed, an engineering student must first pass the Fundamentals of Engineering Exam after or near the end of successful completion of an ABET-accredited engineering or related science program. Once the Fundamentals of Engineering Exam is passed, the engineer in training must gain a minimum of four years of engineering experience to be able to take the Professional Engineering Exam in their state of choice. Both exams are offered periodically at NCEES-approved testing centers.

The Professional Engineering License is the main factor that differentiates a professional engineer from an engineer in training. Professionally licensed engineers have proven they have sufficient knowledge of the fundamentals of engineering and are capable of approaching ethical dilemmas in regards to the liability that comes with planning and construction through the appropriate channels. Engineers in training on the other hand, are not professionally licensed and therefore too liable. They cannot legally provide engineering services or advertise themselves as engineers because they have yet to demonstrate to the state that they are able to approach ethical dilemmas with the same knowledge and mindset as a professional.

Acknowledgements

We would like to thank our project advisor, Professor Paul Mathisen for his help and guidance throughout the year. We would also like to thank our sponsor liaisons, Ms. Jennifer Carlino of the Town of Norton Conservation Commission and Mr. Bill Napolitano of the Southeastern Regional Planning and Economic Development District for providing us with their expertise, support, and enthusiasm for this project.

Executive Summary

Introduction

Culverts are common structures used to divert the flow of a stream or river beneath roadways or stretches of land. More often than not, culverts disrupt the natural movement of water by creating bank erosion, inlet and outlet scour, restricted wildlife passage, and flooding. Engineers and planners can design larger, more open structures, or add reinforcements to banks and streambeds to abate these issues, but the most effective—though not always realistic—way to restore natural flow is to remove culverts altogether. This project investigated various options of renovating or replacing the existing culverts at a stream crossing in southeastern Massachusetts.

Walker Street is located in a residential area of Norton, Massachusetts. The Wading River flows beneath it through two large metal culverts. The constriction caused by these culverts has created a large scour pool downstream of the crossing which inhibits fish passage, more specifically the passage of bridle shiners, a state-listed endangered species. Also, during periods of heavy rainfall the channel backs up and may even flood over the roadway. The goal of this project was to provide the Town of Norton with a cost-efficient stream crossing design that would improve the habitats of local wildlife and mitigate flooding.

Methodology

The overall approach to this project was to determine and compare the flow capacities of several types of hydraulic structures to find one that improved the existing conditions while remaining a practical option for the Town of Norton. To do this, we visited the project site with the goal of visually inspecting the stream crossing site and gathering the necessary measurements for flow data analysis and design development. We utilized flow data provided by the United States Geological Survey (USGS) in parallel with our measurements to calculate various flood depths and velocities at the existing culverts. We then created three new designs: two larger culverts, a short-span bridge and an open-bottom arch culvert, and followed the same calculation process to determine if the new designs would better accommodate the flows and velocities of the predicted flood levels.

Results & Discussion

The results of our calculations based on Manning's and the head loss equations showed that currently, any flood greater than the 5-year flood will overtop Walker Street. All three of our design options improved on the current flow capacity of 500 cubic feet per second, but each option had its advantages and disadvantages. We weighed each design option in regards to cost, constructability, environmental impact, and adherence to standards set forth by the Wetlands Protection Act and decided that the open-bottom arch culvert was the most practical option for the Town of Norton.

Conclusions & Recommendations

Our team concluded that an open-bottom arch culvert is the best option for the Town of Norton. A properly-sized arch structure has the capacity to handle flows up to 1500 cubic feet per second, the equivalent of the 500-year flood, while maintaining minimal contact with the natural streambed. The arch also spans the entire width of the existing channel which minimizes stream constriction and promotes safe wildlife passage. We recommend choosing a precast concrete arch for ease and quickness of installation.

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Tables and Figures

1 Introduction

1.1 Overview

Culverts are pipes that are typically used to allow small streams to cross under roads or other small obstructions. In general they are fully closed and embedded in the ground underneath the obstruction they are bypassing. Though they are very useful, many problems are created by culverts. These issues include stream throttling, restriction of wildlife passage and the creation of harmful environmental structures such as scour pools and bank erosion.

Walker Street is located in a residential area of Norton, Massachusetts. The Wading River flows beneath the street through two large metal culverts. As with many culverts, the natural flow of the stream is constricted at Walker Street which leads to several negative impacts on the wildlife, the surrounding wetlands area and nearby residents, including but not limited to:

- Bank erosion,
- Inlet/outlet scouring,
- Restricted wildlife passage, and
- Flooding.

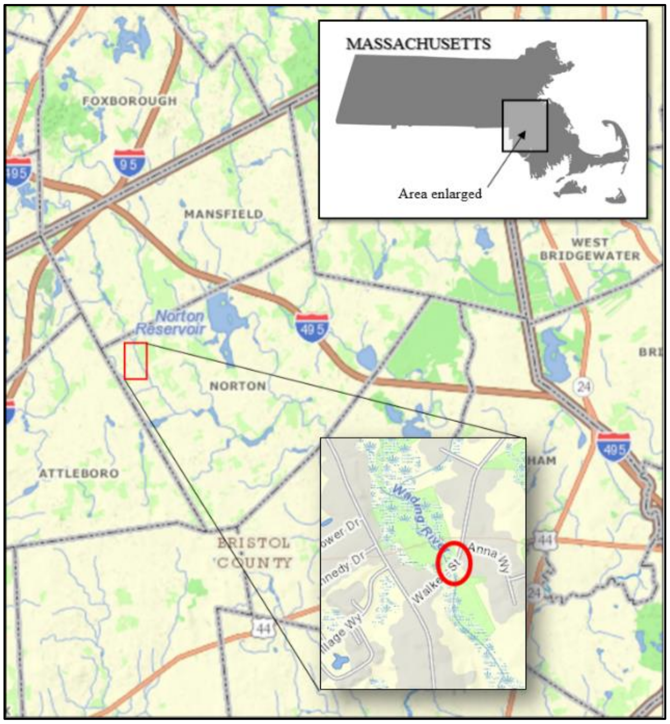

Figure 1.1: Location of Walker Street stream crossing site

1.2 Problem Statement

The constriction caused by the two culverts beneath Walker Street leads to flooding over the roadway during periods of heavy rainfall. Sometimes the depth of the water exceeds two feet above the pavement and reaches a nearby home.

The flow through the culverts also has caused a large scour pool downstream of the structure. This pool prevents local fish species including the bridle shiner, a species that is on the endangered species list, from swimming upstream during periods of low flow.

1.3 Goal Statement

The goal of this project was to provide a design recommendation to the Town of Norton for a cost-effective stream crossing that a) minimizes the flooding of Walker Street and b) improves the bridle shiner habitat and the surrounding wetlands area. The scope of the project included:

- Background research,
- Field reconnaissance,
- Flow data analysis,
- Conceptual design development,
- Design evaluation, and
- Final recommendations.

1.4 Overall Approach

This project involved background research on the local geography of the Walker Street site, the development of several design options, hydraulic calculations to determine flow capacities of various design options, and the evaluation of each option in order to recommend the most beneficial design. Our team assessed the existing conditions of the stream crossing through visual inspection and site surveying. Our team utilized United States Geological Survey (USGS) flow data for the Wading River from a stream gauge within the vicinity of the Walker Street site. We adjusted this data based on drainage basin size (Section 3.3). Through analyzing background research on culvert design, conducting site visits and collecting field data, and performing extensive calculations our project team was able to develop a final design recommendation that will mitigate flooding and improve the habitats of bridle shiners and other local wildlife.

2 Background

The following chapter summarizes the project team's background research and sponsor correspondence. Section 2.1 discusses the location, environment, and current conditions of the project site. Section 2.2 recognizes the key stakeholders involved with or impacted by the implementation of this project. Section 2.3 examines the Massachusetts Stream Crossing Standards for Fish and Wildlife Passage and its application to the project site. Section 2.4 presents general information about culverts, and Section 2.5 concludes our background research by discussing the impact the existing culverts have at Walker Street.

2.1 Site Description

The stream crossing at Walker Street consists of two large culverts running under a residential road. The stream upstream of the culvert runs parallel with the roadway until it nears the culverts and turns perpendicular to proceed under the road. Once through the culverts the stream turns into a 40-foot long scour pool and then constricts back into a low-flow stream.

Figure 2.1: The inlet of the Walker Street stream crossing

2.1.1 Local Geography

Our project is focused on the stream crossing of the Wading River, located at the southern end of Walker Street in the western portion of Norton, Massachusetts. The Town of Norton is located in Bristol County in southeastern Massachusetts, and has an area of approximately 30 square miles (Norton, 2016). The Wading River originates in the Town of Foxborough and is located almost entirely within the Taunton River watershed, which is a part of the larger Narragansett Bay Watershed, it travels 13.1 miles through mostly low, swampy areas and through Norton where it joins the Three Mile River just northwest of the Taunton border.

The Taunton River watershed spans an area of 562 square miles of southeastern Massachusetts which includes the Town of Norton. Within this area there are hundreds of lakes, ponds and miles of rivers and streams. It is also home to multiple plant and animal species, along with 27 different types of habitats. Several of the plant, vertebrate and invertebrate species that dwell in the watershed are protected by the Massachusetts Natural Heritage and Endangered Species Program (Section 2.2.4) (TRWA, 2016).

2.1.2 Existing Conditions

The following sections describe the existing conditions of the Walker Street site. Section 2.1.2.1 discusses the location of the river in respect to the roadway, Section 2.1.2.2 presents the physical condition of the stream crossing structure, and Section 2.1.2.3 analyzes the status of the surrounding wetlands area.

2.1.2.1 Flow Patterns

In its current state, the Wading River runs parallel to Walker Street and turns from the north side of the road at a 90 degree angle and runs under the road through two adjacent 72" diameter culverts (see Figure 2.2). Below the culverts there is a large scour pool with maximum dimensions of approximately 70 feet long by 40 feet wide and 6-8 feet deep. Downstream from the scour pool the stream constricts back to a normal bankfull width of 23 feet.

Figure 2.2: Aerial view of the Wading River at Walker Street. The blue arrow indicates the location and direction of flow (Google Maps, 2017).

2.1.2.2 Condition of Structure

The Walker Street stream crossing consists of two 72" corrugated metal pipes. The structure itself is made of cement and medium-sized (1-2' diameter) reinforcing boulders with cement fill surrounding them (see Figure 2.1). The culverts are in moderate to poor condition with corrosion around the sections of the pipe which contact water around the inlet and outlet. The rust is extensive enough to create holes all the way through the pipes in some areas. The roadway itself is in decent condition with recent patching used to cover any holes present.

2.1.2.3 Status of Surrounding Wetlands

There are wetland areas both upstream and downstream of the Walker Street crossing. Upstream from the crossing the wetlands extend to the southwest where there is a 200-foot buffer zone. Downstream from the crossing there are residential buildings about 200-300 feet away from either side of the stream. There are no buildings or man-made structures in the classified wetlands area. The wetlands themselves are in good condition with a myriad of new vegetation growing, and there is minimal erosion and little to no human disturbance present in the wetlands.

2.2 Key Stakeholders

The following sections introduce the main stakeholders involved with or impacted by the implementation of the Walker Street culvert renovation. Section 2.2.1 discusses the Town of Norton, Massachusetts. Sections 2.2.2-2.2.4 include the Southeastern Regional Planning and Economic Development District, the Narragansett Bay Estuary Program, and the Natural Heritage and Endangered Species Program, respectively. Lastly, Section 2.2.5 recognizes neighbors and abutting property owners of the project site.

2.2.1 Town of Norton, MA

The Town of Norton was established in 1710 in Bristol County, Massachusetts. Since its founding, the town has grown to a population of approximately 19,000 residents. The town is governed by a town manager and a board of selectmen. The management of the town includes several boards, departments and committees (Norton, 2016).

One board of particular interest is the Conservation Commission. The main responsibility of the conservation commission is to enforce the Wetlands Protection Act and its associated regulations. The Town itself does not have any wetlands protection bylaws (Commission, 2016).

2.2.2 The Southeastern Regional Planning and Economic Development District

The Southeastern Regional Planning and Economic Development District (SRPEDD) is an agency governed by local officials to plan and program for the future of the region. The region is composed of 27 communities over 808 square miles, including the Town of Norton. The SRPEDD provides technical assistance its member cities and towns in the preparation of bylaws and ordinances for the region, zoning and housing regulation, and funding for various economic, environmental, and transportation programs and projects.

The environment program of the SRPEDD accounts for a wide range of projects, including open space planning and preservation, dam removals, and storm water runoff mitigation. The SRPEDD is also very involved in the conservation of the Taunton River Watershed. The organization is currently in the second phase of the Taunton River Watershed Study, which aims to restore the fragile natural resources of the 560 square mile area and to enhance the quality of life for the residents of the watershed (SRPEDD, 2016).

2.2.3 Management Committee of the Narragansett Bay Estuary Program

The main goal of the Narragansett Bay Estuary Program (NBEP) is to conserve and restore the natural resources of the Narragansett Bay and its watershed. The Narragansett Bay Watershed spans a large portion of the coastline of Rhode Island and extends through southeastern Massachusetts and to the northwest as far as Worcester. The NBEP operates under the National Estuary Program, which was established in 1987 by the United States Clean Water Act.

The NBEP is overseen by a Management Committee which provides approval and guidance for the implementation of the Comprehensive Conservation and Management Plan for

Narragansett Bay (CCMP). The Management Committee is made up of 26 individuals representing various organizations including the U.S. Department of Agriculture, the U.S. Environmental Protection Agency, the Southeastern Regional Planning & Economic Development District, the Massachusetts Department of Environmental Protection, and the Massachusetts Audubon Society, amongst others. The Management Committee is responsible for fostering communication and collaboration from all involved organizations in order to best implement the CCMP, for encouraging community involvement in planning for the Narragansett watershed, and providing input to help improve the CCMP and overall ecological restoration of the region (NBEP, 2016).

2.2.4 The Natural Heritage and Endangered Species Program

The Natural Heritage and Endangered Species Program (NHESP) is part of the Massachusetts Division of Fisheries and Wildlife. The main goal of the program is to preserve and protect hundreds of animal and plant species and their respective habitats throughout the state. The priority of the program is to protect those species listed by the state of Massachusetts as endangered or threatened (NHESP, 2016).

2.2.4.1 Bridle Shiners

One of the fish species recognized by the Natural Heritage and Endangered Species Program is the bridle shiner. Bridle shiners (*Notropis bifrenatus*) are small, silver fish native to northeastern America that generally do not grow to be more than two inches long. They have a basic physical appearance with a black line running from the front of the head to the start of the tail fin. The stomach is fully scaled and is silver in color with light speckles on the peritoneum.

The bridle shiner habitat generally resembles that of the Wading River. The species tends to dwell in shallow water (two feet) or in water that has moderate vegetation as stream bed cover. Bridle shiners lay their eggs on this vegetation between May and July. When the young shiners hatch they stay in the small vegetation until August. Once they have matured they leave the weeds and join the adult schools where they live out the rest of their one to two year lives.

Bridle shiners are greatly threatened in rivers such as the Wading River. Due to their small size they are not easily able to navigate turbulent water or large changes in elevations. Structures such as culverts, dams and pipes that cause these flow disruptions pose a large threat to the shiner population. Shiners also have poor vision which makes them extremely susceptible to prey when the stream turbidity increases. This reduces their range of vision and makes it much easier for predators such as pickerel, perch and bass to quickly sneak up on and eat them. These variables have all lead to bridle shiners being on the endangered species list.

2.2.5 Neighbors & Abutting Property Owners

As mentioned previously, there are several properties neighboring the Walker Street stream crossing and three homes within a 250-foot radius of the crossing. A neighbor has spoken of backed-up water flooding approximately two feet over Walker Street and reaching the southerly house on the upstream side of the road. The other two neighboring houses are at higher elevations and have not been flooded by the Wading River.

2.3 Massachusetts Stream Crossing Standards for Fish and Wildlife Passage

New stream crossing structures in Massachusetts are governed by the Massachusetts Stream Crossing Standards for Fish and Wildlife Passage. This document (Standards, 2011) outlines specific structural and environmental requirements new designs have to meet. The following sections summarize the standards. Section 2.3.1 discusses the general standard requirements and Section 2.3.1 discusses the optimum standard requirements. The application of these standards is discussed in Section 2.3.3.

2.3.1 General Standards

The Wetlands Protection Act mandates general stream crossing standards when there is new construction or renovations planned for a structure that serves as both a stream crossing and a wildlife habitat. Generally, the suggested structure in these situations is an open-bottom box culvert. According to the standards, the culvert must not increase the flow rate so that it is higher than the natural flow rate of the river. It must also meet the proper openness specifications (Section 2.3.1.3) (RSCP, 2006).

2.3.1.1 Spans

Spans are highly rated when considering structures to replace or use as stream crossings. Spans are built over the stream and have no interaction with the stream bed. This reduces stress on the creek and makes the specifications much easier to build. The suggested spans include 3-sided box culverts, bridges and arches. The main requirement for spans is that the structure and its components do not interact or disturb the stream bottom. When designing spans it is important to also consider bankfull conditions of the stream. In order to accurately calculate bankfull, one must measure the width of the river at normal flow (not drought or flood) at a minimum of three places that are outside of the influence of structures such as dams and culverts. These measurements may be averaged to determine bankfull. The minimum width of the span needed to meet general standards is then calculated by multiplying bankfull width by 1.2 (RSCP, 2006).

2.3.1.2 Culverts

Culverts are defined as structures that have water flowing over one part of the structure. If a structure meets this requirement it is also required to meet a number of other specifications. Primarily all culverts must be embedded in the ground a minimum of two feet. However, if the culvert utilizes a round pipe then the structure must be embedded the initial two feet plus 25 percent of the diameter of the culvert. The aim of this specification is to maintain the natural flow patterns of the stream during normal flow and special conditions such as the 100-year flood (RSCP, 2006).

2.3.1.3 Stream Bottom Design

The design of the stream bottom is vital when determining how to integrate a culvert into its surroundings. The substrate characteristics of the culvert often have more of an effect on passibility than turbidity and water velocity do. If it is too rugged or textured, creatures such as crayfish and salamanders will often have trouble navigating through the culvert. Therefore substrate should be sized appropriately for the local fauna. The substrate should also have a variety of sizes in order to help maintain stream characteristics during large floods and other changes in stream flow rate (RSCP, 2006).

2.3.1.4 Openness

In order to meet Massachusetts standards, all culverts are required to have an openness larger than 0.82 feet. Openness is defined as the cross sectional area of the pipe divided by the crossing length. The openness lets enough light in the culvert to allow animals to see and safely navigate the culvert or stream crossing (RSCP, 2006).

2.3.2 Optimal Standards

The optimal stream crossing standards are to be applied to places where permanent stream crossings are planned. These areas are planned to have some kind of regional or statewide significance for their "landscape level connectedness." This means an area where the crossing will connect two or more areas of significant animal habitat (50 acres). However, there is currently no defined specification or rule specifying when to use the optimal stream crossing (RSCP, 2006).

2.3.2.1 Standards

The USACE lays out standards for how to design culverts and bridges in their "River and Stream Crossing Standards." The first suggestion that is made is that when considering what type of structure to use for a stream crossing to first consider using a bridge. Bridges are advantageous for many reasons. One being they do not disturb the stream bed over which they are built because there is no contact with the stream bed. This allows wild animals to cross under the bridge without the risk of getting lost or injured (RSCP, 2006).

2.3.2.2 Span

The standards for span in the optimal standards are the exact same for those of the general standards. The span also has the same requirement as the general requirements with the crossing having a required span of at least 1.2 times bankfull width (RSCP, 2006).

2.3.2.3 Natural Bottoms

In order to meet the requirements for the optimal standards stream crossings must meet strict requirements for bottom standards. The first requirement is that culvert bed substrate matches that of the stream bed. This is aimed at alleviating the stress put on fish by the implementation of unnatural streambed substrates. Secondly the substrate must be designed to resist large floods. If the substrate is removed during large floods the habitat of the animals is also removed (RSCP, 2006).

2.3.2.4 Dimensions

The dimensions of the stream crossings vary depending on whether or not there is a structure that will impair the travel of animals. This may include a road, a fence or another type of structural development. If there is such a structure then a minimum height of 8.2 feet and a minimum openness of 2.46 feet must be achieved. This will allow the animals sufficient light as well as ample room to get around whatever is obstructing their path. If there are no obstructions then the height can be as low as 6 feet and the openness can be as small as 1.64 feet (RSCP, 2006).

2.3.3 How to Apply Standards

A large amount of planning must be done in order to accurately apply the standards described as "optimal." Culverts and streambeds must be analyzed to determine the effect of different sized culverts. If the culvert is simply placed without any prior planning the streambed can become unstable and there can be head cutting, an extreme type of scouring (RSCP, 2006). Alongside the planning it is necessary to decide which standard will be the best logistically to meet in the location. This can change based on geography, funding and local wildlife. However there are set conditions that dictate a specific level of standard.

2.3.3.1 Evaluation

Prior to building, a long-use profile should be established for the selected area. This means the river or stream needs to be assessed for downstream flooding during floods such as the one year, ten year and 100-year flood. If potential culvert sites are not properly assessed and designed there is a large potential for erosion from flooding and the stream stability could fail. The habitats present in the surrounding area should also be assessed for physical features such as wetlands, endangered species areas and residential spaces. If not properly identified prior to construction, the habitats and lives of many animals and people could be destroyed (RSCP, 2006).

2.3.3.2 Construction of Crossing

After physical and geographical evaluations of the surrounding area is completed, the culvert or crossing must be designed accordingly. In order to help reduce washout and erosion from flooding, factors such as inlet/outlet drops, stream constriction, scour pools and wildlife barriers need to be avoided. Avoiding negative culvert characteristics such as these will help to improve the stream quality and the passability for animals (RSCP, 2006).

2.3.3.3 Timing

When building, it is necessary to make sure construction is done in accordance with fish spawning patterns and seasonal water flows. Ideally, culvert restoration is done between July 1 and September 30. During this time period the local fish are spawning and the water flow is significantly lower than during other months. This will help to maintain the characteristics of the stream and protect its inhabitants (RSCP, 2006).

2.3.3.4 Stormwater/Pollution Management

The stream crossing standards suggest using a “downstream retention pond” for all construction projects that will involve interaction with the streambed. This suggestion is intended to minimize contact with the streambed, which will help to minimize the impact on nearby vegetation and prevent harmful runoff. A silt fence or a barrier can be made of straw bales, mats, Coir logs, mulch or compost filter tubes. A important constraint on the silt barrier is that it barrier does not come in contact with the streambed. Any equipment that is used in construction should be washed prior to use in order to not bring outside pollutants into the construction zone. Overall the goal is to mimic the habitat of the surrounding area and reduce the environmental impact of culvert construction (RSCP, 2006).

2.4 Culverts

Materials used in culvert construction most commonly include corrugated steel, high density polyethylene (HDPE), polyvinyl chloride (PVC) and concrete. Installation of small-diameter corrugated metal pipes (CMPs) is decreasing in the United States, rather they are being replaced by HDPE culverts. Compared to CMP, HDPE culverts have a longer lifespan, are more adaptable to changing conditions, more resistant to corrosion and fatigue, and have smoother joints, ultimately preventing leaks. A structure may be constructed of a combination of materials, for example it may be advantageous for an open-bottom steel culvert to have a concrete footing.

2.4.1 Problems with Culverts

The most common problems caused by culverts are scour and erosion. These issues are often caused by improper installation or sizing. Culverts alter the natural flow of a stream and the new constricted passage may negatively affect fish and other wildlife species. Sediment may also build up in culverts and this clogging can cause flooding over a roadway or even structure washout. Sometimes, designers choose to include armored embankments to prevent erosion and scour to improve streambeds. It is recommended to follow best management practices to restore streambeds to their natural state in order to improve fish and wildlife passage.

2.5 Culvert Impact at Walker Street

In the case of the Walker Street stream crossing, the two large CMP culverts constrict the natural flow of the Wading River and this results in a large scour pool downstream of the structure. Sponsor correspondence tells us that the scour pool in turn prohibits a certain endangered species of fish, the bridle shiner, from swimming upstream. In periods of heavy rainfall, the constriction also results in channel back up and even flooding, sometimes reaching the neighboring properties. Thus, removing the existing culverts and installing an improved stream crossing structure is recommended for the Town of Norton.

3 Methodology

The following chapter describes the processes used by our team to produce results that ultimately lead to the development of our final design. Section 3.1 lists the scope of the project and Sections 3.2-3.5 discuss our field work, flow analysis, evaluation of existing conditions, and the conceptualization of our design options, respectively.

3.1 Project Scope

The Town of Norton, Massachusetts has plans in the works to renovate stream crossings throughout the town. However, there has been little movement due to lack of engineering services for reconstruction of these stream crossings. This project focuses specifically on one crossing over the Wading River, near Walker Street (see Figure 2.2). The goal of this project is to redesign the Walker Street stream crossing in order to minimize flooding and to improve the habitats of bridle shiners and other local wildlife species. Our project team accomplished this goal by:

- Conducting background research through literature review and sponsor correspondence (Chapter 2),
- Field work—Investigating the project site through visual inspection and surveying (Section 3.2),
- Flow analysis—Analyzing the flow patterns of the Wading River (Section 3.3),
- Evaluating existing conditions—Evaluating the current site, structure, and flow conditions (Section 3.4),

- Conceptualizing design options—Developing new designs based on our learned information (Section 3.5), and
- Final design development--Recommending the most beneficial stream crossing design to the Town of Norton (Section 3.6).

3.2 Field Work

We investigated the project site through field work and site reconnaissance in order to see for ourselves what about the current structure is and is not effective. This research was vital to our project as it allowed us to properly understand the current situation and develop designs that best fit the needs of the Town, stream, and surrounding ecological system.

We obtained initial information for our project by contacting the project's sponsors, Jennifer Carlino, a conservation agent for the Town of Norton, and Bill Napolitano, the Environmental Planning Director for the Southeastern Regional Planning and Development District. Our introductory meeting with our sponsors was very useful as both Ms. Carlino and Mr. Napolitano are highly knowledgeable about the area and gave us a tour of the Walker Street stream crossing.

We visited the site of the Walker Street stream crossing several times after this meeting. Prior to each site visit the team created a checklist of goals to be accomplished. These included taking specific measurements, making observations and taking pictures of areas of interest to help us analyze the crossing at a later date. We followed the example of the North Atlantic Aquatic Connectivity Collaborative (NAACC) Stream Crossing Survey C (Appendix 7.2) and the NAACC Stream Crossing Survey Data Form Instruction Guide (NAACC, 2015). These were given to us by representatives of the NAACC at an educational workshop in October 2016.

These instructional guides provided insight into what to look for in the stream crossing and helped us to present accurate stream crossing designs to the Town of Norton.

Once we established dates for our surveying visits, we obtained professional surveying gear from the Civil and Environmental Engineering Department at Worcester Polytechnic Institute for use onsite. Our site visits started with simple observations about the culverts and streambed and then proceeded to taking measurements that included lengths, heights, and mapping the elevations of the roadway, streambed, and surrounding areas. Our team recorded these measurements in a field notebook and later transferred them online for ease of access for all team members, advisor and sponsors included. The following sections describe our four site visits in the fall of 2016.

3.2.1 Site Visit 1: September 7, 2016

The team's first site visit was a brief trip to Norton to meet with the project sponsors, Jennifer Carlino and Bill Napolitano. We introduced ourselves and discussed the scope of the Major Qualifying Project (MQP). The sponsors explained their goals for our project and how the Walker Street stream crossing has been a priority project for “the last 9 years." They explained to us that they would be using the designs and ideas from our MQP to directly apply for a MassDOT restoration grant.

Ms. Carlino and Mr. Napolitano also provided links to information about where to find regulations and standards that would need to be met in order to continue with restoration, and invited our group to join in on an official Massachusetts Society of Municipal Conservation Professionals (MSMCP) presentation (Appendix 7.3) and field trip coming up in November. At the end of the meeting the team prepped to visit Walker Street.

At the stream crossing the team was able to ascertain basic information such as the material of the culverts as well as the natural streambed characteristics, such as the stream substrate. We also observed instances of scour pools and bank erosion, which we would be aiming to eradicate with the new stream crossing design options.

We took pictures (Appendix 7.4) that captured the stream crossing structure as a whole and the effect that it was having on the river upstream and downstream of Walker Street. Ms. Carlino and Mr. Napolitano then described in detail the recent extreme flood conditions and what the crossing had looked like in those situations. They also told us about bridle shiners, an endangered species of minnow residing in the stream, explaining that they would like the site to be a better environment and provide easier upstream passage for these fish.

3.2.2 Site Visit 2: October 4, 2016

After our team's first visit on September 7 we discussed with our project sponsors the possibility of setting up a visit during which we could take more detailed measurements of the culvert. Prior to the visit the team got together and determined which measurements and observations were vital to moving forward on the project. We created a list with all the observations we needed to make about the culverts (Appendix 7.5). We also drew a basic schematic of the culverts where we could write down measurements to use as a reference for flow capacity and culvert design further down the line.

We met in the morning on the day of the visit and packed up the necessary surveying equipment which included a tripod, a level, a surveying rod, temporary benchmarks, flagging, and measuring tape then drove to Norton. Ms. Carlino met us at the site and provided us with safety equipment for use during surveying. We spent the next hour measuring elevations on and around the roadway, taking pictures and making observations on the physical characteristics of culvert structure. This site visit proved to be instrumental in the jump-starting of the initial designs for the new stream crossing options as it provided us with the general dimensions for the stream, existing culverts and the surrounding area.

3.2.3 Site Visit 3: September 28, 2016

At the first meeting on September 7, 2016 Ms. Carlino mentioned that our team was invited to sit in on a MSMCP meeting and field trip. The goal of attending this meeting was to learn more about the methods of analyzing a stream so that we would be able to better apply existing and learned knowledge to our stream.

On September 28 we arrived at the Palmer, Massachusetts police station at 10:30am for the start of the Culvert Assessment presentation lead by Carrie Banks, an employee of the Massachusetts Division of Ecological Restoration. Ms. Banks walked us, and the other 30 people at the presentation, through the parts of culvert restoration that are most important to the wellbeing of a stream and local wildlife. She discussed the impact that a poorly designed culvert will have on a stream by creating excessive water speeds, inlet drops and scour pools, and acting as unmovable man-made dams. She then proceeded to run through the field assessment form that is used by the MSMCP (Appendix 2) that we would be using on our short field trip.

Once the presentation was complete the group packed up and headed out to a site located at Burleigh Park on Old Warren Road in Palmer. While at the site Ms. Banks walked the group through the culvert assessment form (Appendix 7.2). She answered many questions from the group and our project team. One of the main concerns was exactly how to measure the "bankfull" width of stream. She explained, in detail, that the spot you are meant to measure from is the location of the average daily stream flow bank location.

Overall this site visit and presentations proved to be extremely useful for our team as we got more insight into how to approach a culvert assessment as well as valuable information on the specifics of appropriate culvert design.

3.2.4 Site Visit 4: November 2, 2016

On November 2 our group prepared for the last of our field visits before the winter months. The goal of this site visit was to obtain the dimensions of the downstream scour pool, the bankfull width of the stream both above and below the culvert as well as other dimensions of the culvert such as the pipe length, pipe opening and outlet drop height. We completed these measurements using a measuring tape and a surveying rod.

Our team measured the depths of the scour pool using a surveying rod. Jackson simply gaged the depth of the pool by where the water level fell on the rod. The depths were taken at 10 points around the edge of the scour pool. When the pool became too deep to step in, Jackson kept one end of the surveying rod at a consistent height and angled the other end to the deep center of the pool. Our team used basic trigonometry to determine these inner depths, as shown in Table 4.1 in the Results chapter of this report. This process was used for eight locations in the middle of the pool.

In order to get accurate bankfull measurements we first had to find the edge of the bank. During our visit the water level was abnormally low so determining the correct edges to use was slightly more difficult than anticipated. Once we located both edges where normal flow should reach we ran a measuring tape from one edge of the bank to the other and noted the distance. We used this process for three measurements both upstream and downstream of the culvert structure and averaged the distances together in order to obtain the most accurate bankfull width.

This visit was key in the design of the culvert as the many of the measurements the team took that day were key in calculating the performance of the new culvert designs and the dimensions that would be needed to handle the maximum flow rates of the stream.

3.3 Flow Analysis

In order to determine the specific flow rates associated with the current culvert and the new proposed designs we needed to determine the exact flow rates for the stream at flood levels ranging from the 5-year flood to the 500-year flood. The United States Geological Survey (USGS) provides stream data for thousands of streams across the United States. The Wading River stream gauge numbered 01090004 is located only four miles downstream from the Walker Street crossing. This is the gauge that our team used when assuming the flow rate averages. The USGS website provides discharge data ranging all the way back to 1925. In order to find the daily average flows we went though and averaged the data by month. The six largest data points were averaged to find the daily maximum flow and the smaller six points were used to find the daily minimum flow. This method was rudimentary but an accurate enough for the scope of the project.

We then used a program called HEC-SSP to perform a Bulletin 17B analysis on the 01090004 stream gauge to determine the yearly flood flow rates. According to the HEC-SSP user manual the Bulletin 17B is the best test to use for this as it allows the user to best focus on the outlying flood data (Army Corps, 2010). Through HEC-SSP we were able to produce exact numbers for the 20%, 10%, 5%, 2%, 1% and 0.2% exceedance probabilities corresponding with the 5, 10, 50, 100, 200 and 500-year floods, respectively.

The only problem with the data that was pulled from the USGS website was the fact that the stream gauge was four miles further downstream than the Walker Street crossing. This means that the drainage basin for the gauge would be much larger in square miles than that of the Walker Street crossing. However, we were also able to find a study done by the USGS in Norton on Richardson Avenue (Zarriello and Barbaro, 2014). Richardson Avenue is only one river mile away from the Walker Street crossing and, according to the USGS Report drainage basin area of 21.5 square miles. In order to determine the drainage basin at Walker Street we used two sets of USGS flow data, one from Richardson Avenue and one from the USGS stream gauge four river miles downstream from Walker Street. These sites were compared and a ratio of flow rate to drain basin size was determined. The drainage basin size at Walker Street was calculated based on the difference in river miles between the USGS project site located at Richardson Avenue and the USGS stream gauge. Walker Street is located approximately one-fifth of the river distance between Richardson Ave and Stream Gauge 01090004. In order to account for this, one-fifth of the drainage basin area at Richardson Avenue was added to its original area of 21.5 square miles. This gave us an estimate of 25.2 square miles for the drainage basin area at Walker Street. The flow rates from the USGS report were then cross multiplied with the new drainage basin size to allow us to have more accurate flow data for future culvert calculations.

3.4 Evaluating Existing Conditions

It was crucial for our team to understand what is currently happening at the existing structure so that we could determine the necessary areas of improvement. Naturally, any improvement to the existing culverts would be a step in the right direction. However the goal of the project was to develop a design that would provide the greatest improvements possible.

Section 3.4.1 discusses the analysis of the onsite measurements and observations, and Section 3.4.2 discusses the process used to calculate the flow capacity of the existing structure.

3.4.1 Analysis of Background & Field Work Data

Our team conducted background research in order to understand the structural and flow conditions of the project site. In addition to the available documentation, the team also conducted on-site surveys and visual observations. Through the combination of our background research and field work data, we determined the dimensions of the current stream crossing structure, the characteristics of the streambed and scour pools, the bankfull width of the Wading River upstream and downstream of the crossing, and the impact of flooding on the surrounding areas and properties (measurements may be seen in Appendix 7.7). These measurements and observations helped us to accurately portray the current structure and landscape in order to create new designs that will have minimal impact on the existing habitat.

The analysis of the field work data started with synthesizing all of the measurements from our team's site visits and using them to create Revit and AutoCAD models of the downstream scour pool and the inlet and outlet profiles of the current culvert structure (Section 4.1). These models presented all of our elevation, depth, and distance measurements in a simple form that is easy to understand. We later used these drawings as a basis for our three proposed design options (Section 4.2) and water surface profiles (Section 4.4).

3.4.2 Analysis of Depth & Flow Data

Using the flow data from Section 3.3, we were able to calculate the flow capacities of the existing and proposed design options and calculate the resulting depths of each flood condition. For the scope of our calculations, our team utilized the following flow conditions to determine the resulting depths of water at the crossing:

- Average minimum flow,
- Average maximum flow,
- 20% Annual Exceedance Probability (5-year flood),
- 10% Annual Exceedance Probability (10-year flood),
- 5% Annual Exceedance Probability (20-year flood),
- 2% Annual Exceedance Probability (50-year flood),
- 1% Annual Exceedance Probability (100-year flood), and
- 0.2% Annual Exceedance Probability (500-year flood).

We assigned different case titles to each type of flooding scenario (Table 3.1). Case I represents normal open channel flow through the culvert. Case II represents surcharged flow conditions, in which flow submerges the pipe but does not overtop the roadway. Case III an extremely high flow condition, in which the water is flooding over the roadway. Each case requires a different equation to accurately calculate flow depth at the inlet of the structure, as shown in Table 3.1.

Table 3.1: Different flooding scenarios

CASE	Applicable Equation	Flow Description
CASE I	Manning's	Inlet/outlet submerged or lower
CASE II	Head Loss	CASE I < CASE II < Top of Roadway
CASE III	Head Loss, Broad-Crested Weir	CASE II < CASE III < Roadway Overtopping

The applicable equations are as follows:

- Manning's Equation

$$V = \frac{K_n}{n} R^{2/3} S^{1/2},$$

- Head Loss Equation

$$HW = TW - S_0 L + (1 + K_e + f\frac{L}{4R})\frac{Q^2}{2gA^2}$$

- Broad-Crested Weir Equation

$$Q = C_w L (HW_r)^{3/2}$$

All of our calculations are organized in a spreadsheet which may be found in Appendix 7.6.

3.4.2.1 Manning's Equation

Manning's equation represents uniform flow in an open channel or unsubmerged pipe. The commonly used formula,

$$V = \frac{K_n}{n} R^{2/3} S^{1/2},$$

can be rearranged as

$$AR^{2/3} = \frac{A^{5/3}}{P^{2/3}} = \frac{nQ}{K_n S^{1/2}},$$

where:

- V is the cross-sectional average velocity (feet per second).
- K_n is a conversion factor from SI to English units. Since our calculations are in English units, we used a K_n-value of 1.49.
- n is the Manning coefficient, which is dependent on the roughness of the channel.

- R is the hydraulic radius in feet, equal to the cross-sectional area of flow divided by the wetted perimeter of the channel.
- S is the slope of the channel bed, assuming water depth is constant.
- A is the cross-sectional area of flow in square feet.
- P is the wetted perimeter of the channel in feet, and
- Q is the flow rate in cubic feet per second.

This arrangement of the Manning equation allows us to simply solve for $AR^{2/3}$, as our flow rates and channel slope are known. A Manning's coefficient value of 0.024 was chosen (Sturm, 2010). Manning's coefficient is dependent on the pipe material and roughness of the corrugation. $AR^{2/3}$ is used to find the normal depth, y_0 , using Figure 4.9 from Sturm's text as a guide (Sturm, 2010). For each Case I scenario, our team solved for the collective $AR^{2/3}$ values according to the different flow rates. We divided the $AR^{2/3}$ value by the pipe diameter raised to the $\frac{8}{3}$ power. We used this $\frac{AR^{2/3}}{d^{8/3}}$ value to find the corresponding $\frac{y_0}{d}$ value with the chart, which we multiplied by the pipe diameter to solve for the headwater depth, y_0.

Once the headwater depth exceeded the pipe diameter, the team progressed to use the head loss equation for full submerged pipe flow to solve for headwater depths. This equation is discussed in more detail in Section 3.4.2.2.

3.4.2.2 Head Loss Equation

Case II represents flow that is higher than the crown of the pipe but not yet overtopping the roadway. For this scenario, our team utilized the energy equation arranged from headwater to tailwater, or head loss equation, which is written as

$$HW = TW - S_0 L + \left(1 + K_e + f\frac{L}{4R}\right)\frac{Q^2}{2gA^2}\,,$$

where:

- HW is the headwater depth relative to the inlet invert in feet;
- TW is the tailwater depth relative to the outlet invert in feet;
- S_0 is the slope of the culvert;
- L is the length of the culvert in feet;
- K_e is the entrance loss coefficient which is dependent on the type of structure and entrance design (Sturm, 2010);
- f is the Darcy-Weisbach friction factor;
- R is the full-flow hydraulic radius in feet;
- Q is the flow rate in cubic feet per second;
- g is the gravitational force in feet per second per second; and
- A is the cross-sectional area of the pipe in square feet.

While it is recognized that a variety of conditions exist for culvert flow, the equations above represent flooded conditions in culvert sections, and are considered to be sufficient for this analysis.

The Darcy-Weisbach equation can be rewritten in terms of the Manning equation, so that

$$f\frac{L}{4R} = \frac{2gn^2L}{K_n^2 R^{4/3}}$$

(Sturm, 2010)

and we have a known value for $f\frac{L}{4R}$.

Since there were two pipes, we assumed the flow in each pipe represented one-half of the flowrate. Assuming a tailwater depth equal to the outlet pipe diameter, we were able to use the head loss equation to calculate each headwater depth until the depth exceeded 8.9 feet, which is the distance from the culvert invert to the top of the roadway. Once the depth exceeded 8.9 feet, the head loss equation was no longer applicable and the team had to include the broad-crested weir equation to account for flow above the roadway. This equation is discussed in more detail in Section 3.4.2.3.

3.4.2.3 Broad-Crested Weir Equation

Case III represents the condition in which flow is overtopping the roadway. The equation to account for the flow over the roadway in this scenario is the broad-crested weir equation, represented as

$$Q = C_w L (HW_r)^{3/2},$$

where:

- Q is the flow rate in cubic feet per second;
- C_w is the weir discharge coefficient;
- L is the length of the roadway crest in feet; and
- HW_r is the head on the roadway in feet.

For the flow rate value, our team found the difference between the flood level rate and the flow rate that produced an 8-foot headwater depth using the head loss equation (Section 3.4.2.2). Using the resulting flow rate value, the team was able to calculate the depth of flow over the roadway.

3.5 Conceptualizing Design Options

After considering the potential options, we decided on three designs for the Walker Street stream crossing:

- a short-span bridge,
- new larger culverts, and
- an open-bottom box culvert.

We had to analyze the Massachusetts Stream Crossing Standards (Section 2.3) in order to develop designs that met the different qualification levels. A bridge would be the optimal option, while simply replacing the culverts would not have much effect in terms of meeting new regulations. Our two main concerns for the new designs were meeting the stream crossing requirements and maximizing the flow capacities of the new structures.

3.5.1 Application of the Optimum/General Standards

The optimal and general stream crossing standards are laid out in Section 2.4 of this report. This section discusses the guidelines for building and redesigning culverts to fit the needs of the surrounding environment.

When designing the new culverts we had to consider the level of standards that would make the most sense on a cost, time and land space perspective. In order to meet the optimum standards the Town of Norton would have to build a bridge across the Wading River. We compared the cost of constructing a bridge to the cost of an option that would meet the general standards—an open-bottom box culvert.

3.5.2 Analysis of Design Flow Capacities

Flow capacity is the volume of flow a stream crossing structure allows before flooding occurs. The new design options for the Walker Street stream crossing must have higher flow capacities than the existing culverts in order to minimize or even eradicate flooding or the roadway and neighboring homes. Therefore, we must know the inlet and outlet depths that each flood level produces on each structure to determine their flow capacities.

We organized our calculations for flow depth (Section 3.4.2) into a spreadsheet (Appendix 7.6) that allowed us to quickly alter the dimensions of each design option. These calculations gave the team insight into the flow capacities of each type of stream crossing structure. Our ultimate goal was to create a design that met all of the stream crossing standards (Section 2.3) and had the greatest flow capacity possible, while minimizing impact to the surrounding wetlands. The team developed what we believe to be the optimal design possibilities through simple trial and error of different combinations of pipe sizes, bridge and arch spans and heights.

The team calculated the design flow capacities for each design option in a manner similar to that of the existing culverts as discussed in Section 3.4.2. The existing culverts were the only structure that required the head loss equation for the Case II scenario. The three design options all required Manning's equation for Case I scenarios. The larger culverts followed the same process as the existing culverts, but we assumed a trapezoidal channel for the short-span bridge and the open-bottom arch culvert. We substituted all of the necessary pipe diameter, or *d* values, with the widths of the trapezoidal channel bottoms, *b*. To solve for $\frac{AR^{2/3}}{b^{8/3}}$, we used another derivation of Manning's equation:

$$\frac{AR^{2/3}}{b^{8/3}} = \frac{nQ}{K_n S^{1/2} b^{8/3}}.$$

Our team chose Manning coefficient values of 0.024, 0.03, and 0.03 for the larger culverts, short-span bridge, and open-bottom arch culvert, respectively. These values were conservatively based off of the material of the culverts and the streambed. All of the design options followed the same process as the existing culverts for the Case III scenario.

4 Results & Discussion

The following chapter summarizes the results produced by the measurements, observations, and calculations discussed in Chapter 3 of this report. Section 4.1 describes the existing conditions at the project site, Section 4.2 identifies the proposed design options, Section 4.3 develops these design options further, and Section 4.4 evaluates the advantages and disadvantages of each option.

4.1 Existing Conditions

The following two sections consolidate the results of our site visit observations and measurements (Section 4.1.1) and depth and flow data analysis (Section 4.1.2). Using these results, our team was able to identify areas of improvement to address with our designs.

4.1.1 Field Measurements & Observations

We made several visits to the site of the Walker Street stream crossing (Figure 4.1). These visits gave us insight into the current status of the structure itself and helped to validate flood claims made by our project sponsors, abutting property owners, and our own literature review. Overall, the culverts were in a suitable structural condition, but the outdated structure did not meet the requirements set forth by the Massachusetts Stream Crossing Standards.

Figure 4.1: A downstream view of the existing culverts

We observed very low flow at the time of our visits. This was due to a prolonged drought during the 2016 summer season, and was inconsistent with the United States Geological Survey (USGS) flow data. The stream appeared to have a very low velocity, and was not more than a foot deep through the culverts. We observed and measured the upstream and downstream scour pools, which were much deeper than the rest of the surrounding stream. The majority of the smaller upstream pool was approximately 2 feet deep and the larger downstream pool (Figures 4.2, 4.3) was up to 8 feet deep in some places. The results of our downstream scour pool depth calculations may be seen in Table 4.1.

Table 4.1: Calculations for the inner depths of the downstream scour pool

CALCULATING INNER DEPTHS									
Location	Outer Depth (ft)	Submerged Length of Rod (ft)	Unsubmerged Length of Rod (ft)	Water Level to End of Rod (ft)	Angle (rad)	Hor. Distance from End of Rod to Rod Entry (ft)	Hor. Distance from Rod Entry to Location (ft)	Distance from Outer Depth to Location (ft)	Depth at Location (ft)
A	2.5	10.2	5.8	2.5	0.4456	5.2	9.2	14.4	**4.4**
B	1.3	10.0	6.0	3.7	0.6645	4.7	7.9	12.6	**6.2**
C	0.9	8.5	7.5	4.1	0.5784	6.3	7.1	13.4	**4.6**
D	0.7	5.5	10.5	4.3	0.4219	9.6	5.0	14.6	**2.3**
E	0.6	5.8	10.2	4.4	0.4460	9.2	5.2	14.4	**2.5**
F	0.8	7.7	8.3	4.3	0.5446	7.1	6.6	13.7	**4.0**
G	1.4	10.6	5.4	3.6	0.7297	4.0	7.9	11.9	**7.1**
H	1.6	11.1	4.9	3.5	0.7956	3.4	7.8	11.2	**7.9**

Figure 4.2: The downstream scour pool

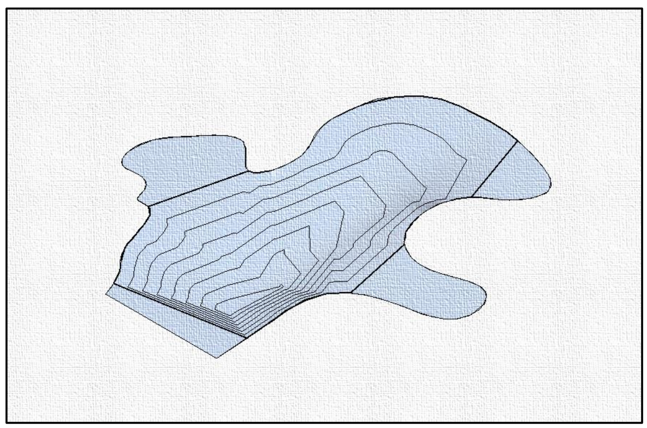

Figure 4.3: Revit model of the downstream scour pool

We measured the dimensions and elevations of the existing structure in order to accurately determine flow depths for given flow rates. Simply put, if a flow depth exceeded the height of culvert openings, we would know the stream would back up. If a flow depth exceeded the height of the structure, we would conclude that the stream would flood over the roadway. Our inlet (Figure 4.4) and outlet (Figure 4.5) profile drawings helped our team to visualize what was happening with the current structure.

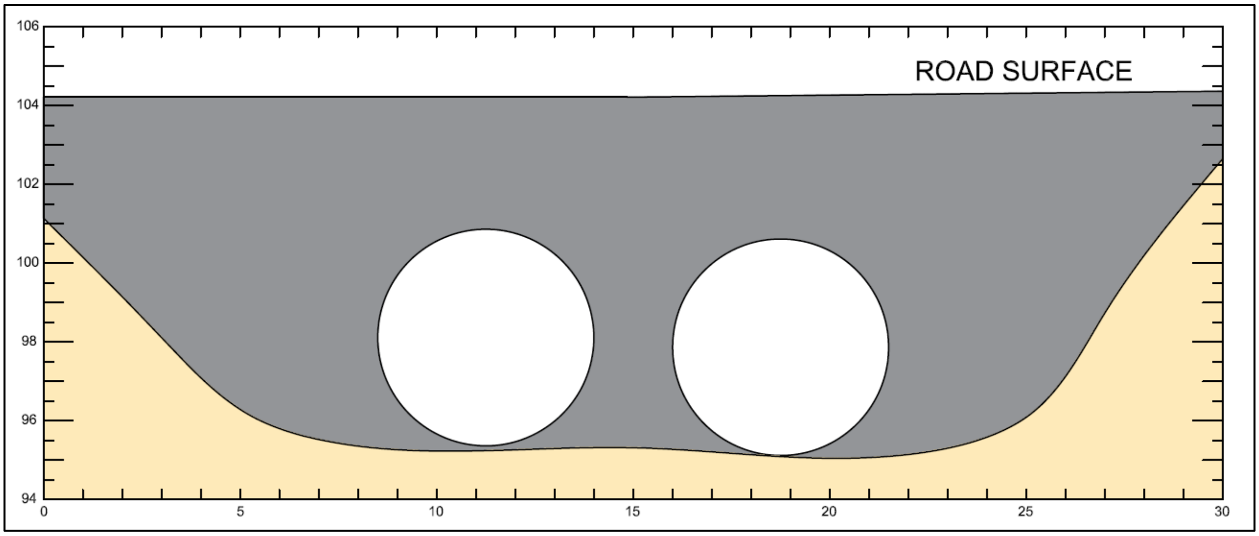

Figure 4.4: AutoCAD model of the existing inlet profile. Measurements are in feet.

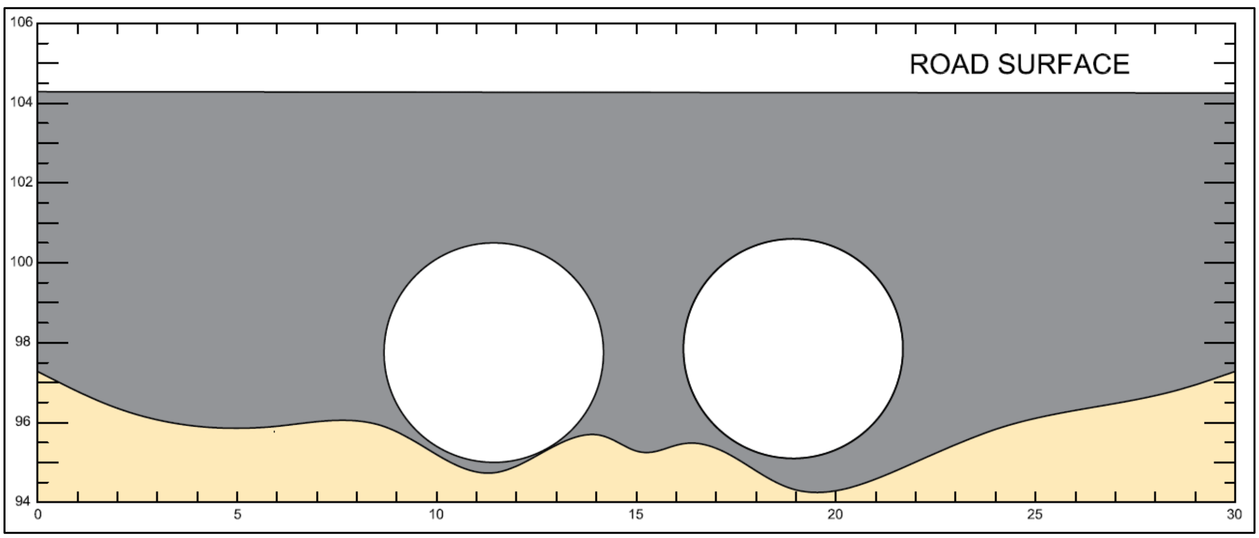

Figure 4.5: AutoCAD model of the existing outlet profile. Measurements are in feet.

4.1.2 Depth & Flow Data

The complete results of our depth and flow data may be found in the spreadsheet in Appendix 7.6. In summary, our team discovered that the existing culverts can only handle the average minimum and maximum flows. Based on our calculations, a 5-year flood will cause the water level to rise above the crowns of the culverts, and any flood greater than the 5-year flood will overtop the roadway. For the scope of our calculations, we assumed steady flow through the culverts which resulted in equal respective headwater and tailwater depths.

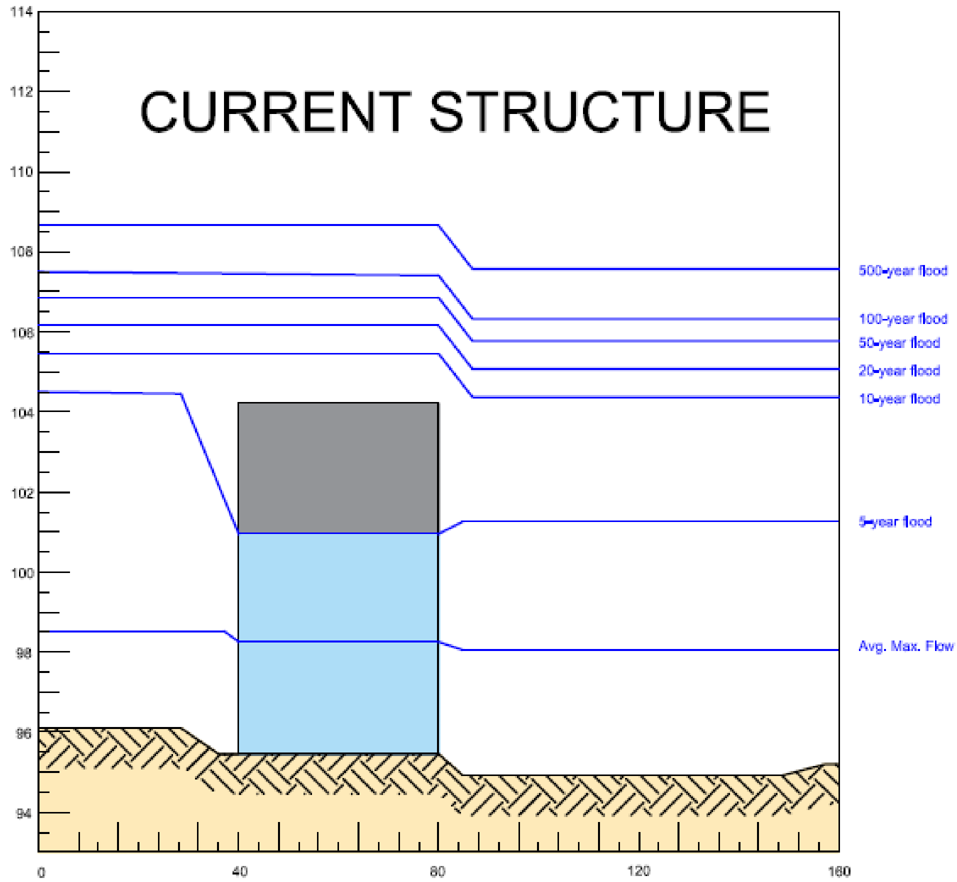

Figure 4.6: Water surface profile for the existing culvert structure with approximate upstream and downstream head losses. Measurements are in feet.

4.2 Identifying Design Options

As discussed previously, there are several design options that may ease the flooding of Walker Street, minimize streambed erosion, or create a more suitable environment for the state-listed bridle shiner. The goal of this project was to determine the design that best remedies these needs, in addition to being cost-efficient and having the least impact on the surrounding wetlands. The three proposed design options are:

- Two new, larger culverts,

- A short-span bridge, and
- An open-bottom arch culvert.

Each of these design options will be discussed further in this section and evaluated in Section 4.4. Our team determined the most beneficial option by considering cost, constructability, environmental impact, flow capacity, and regulatory compliance. The consideration of the Massachusetts Stream Crossing Standards is discussed in Section 4.2.1. The final design recommendation and specifications are presented in Chapter 5 of this report.

4.2.1 Standards Consideration

The team looked at the general Massachusetts Stream Crossing Standards in both Section 2.3 of the Background and Section 3.5.1 in the Methodology. After much consideration, our project team decided that a design that met the optimal standards would be too costly for the Town of Norton and would reduce the likelihood of the Town receiving a construction grant. For these reasons we decided that the goal for our final recommendation was to meet the general standards with a type of culvert structure, but we also chose to include in this report a design option, a bridge, that would meet the optimal standards for comparison.

4.2.2 Renovated Culverts

The installation of new, larger culverts would be relatively quick and cost-efficient. However, the main concern of the existing culverts is that they do not meet the Massachusetts Stream Crossing Standards and could not be permitted under the Massachusetts Wetlands Protection Act. Larger culverts may have a greater flow capacity, but they still will not meet the regulatory requirements.

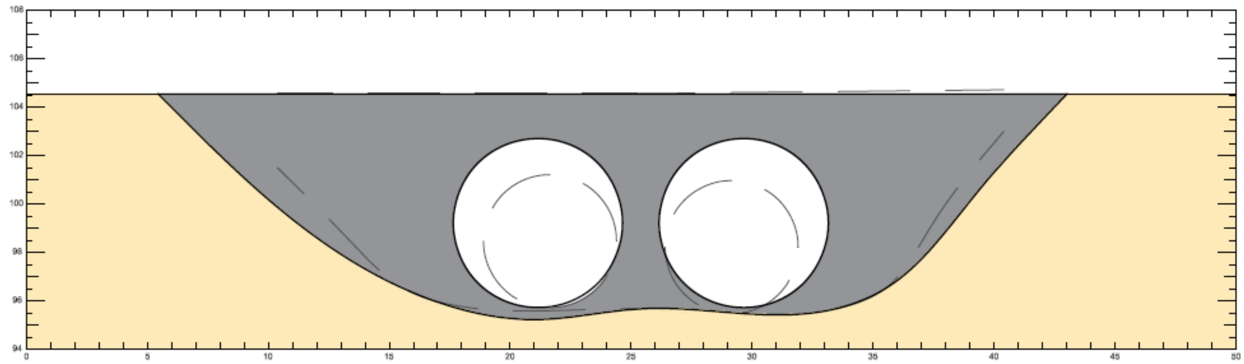

Figure 4.7: Design schematic of the renovated culverts with the existing culverts superimposed with the dashed line. Measurements are in feet.

4.2.3 Short-Span Bridge

Installing a short-span bridge is a very favorable option in terms of regulatory requirements, flow capacity, fish passage, and minimal streambed erosion. A bridge would meet the optimal requirements set forth by the Massachusetts Stream Crossing Standards. The downside of the short-span bridge is the cost and constructability.

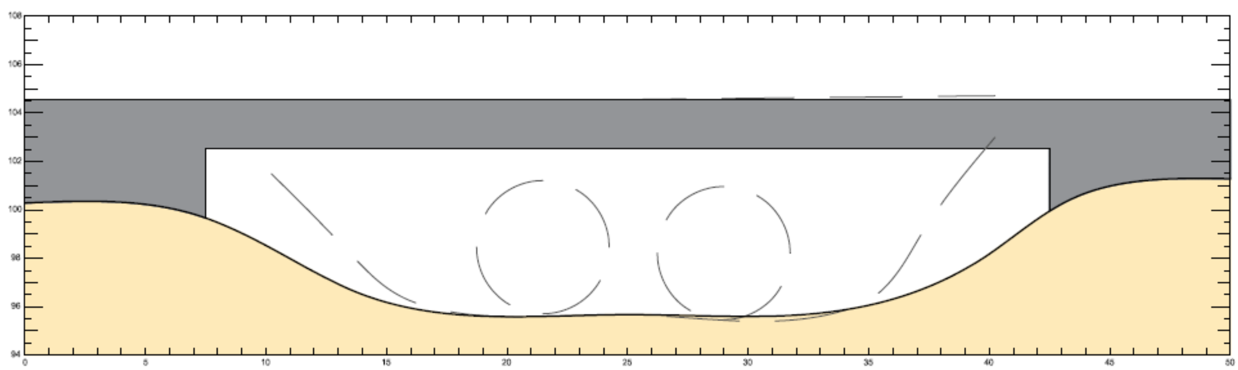

Figure 4.8: Design schematic of the short-span bridge with the existing culverts superimposed with the dashed line. Measurements are in feet.

4.2.4 Open-Bottom Arch Culvert

An open-bottom arch culvert is an effective option. It would meet the general requirements set forth by the Massachusetts Stream Crossing Standards. It has a high flow capacity, and the open-bottom design of the culvert allows for sufficient fish passage and minimal streambed erosion.

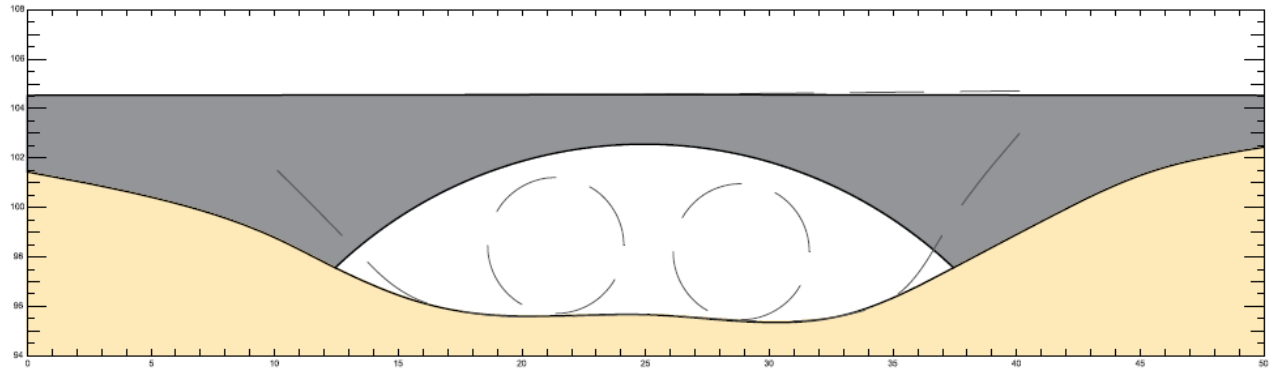

Figure 4.9: Design schematic of the open-bottom arch culvert with the existing culverts superimposed with the dashed line. Measurements are in feet.

4.3 Final Design Development

The team continued utilizing the design options of larger culverts, a short-span bridge, and an open-bottom arch culvert. The next steps were to determine the optimal dimensions of each option in order to maximize each of the respective flow capacities, and to determine which of the proposed options would be the most beneficial to the Town of Norton.

4.3.1 Design Assumptions

Our team made several assumptions for the analyses of the existing culvert structure and for the proposed design options. One overarching assumption made in this project was that the elimination of pipe culverts will minimize streambed erosion and the depth of the scour pool will normalize, easing upstream fish passage. The following sections list the specific assumptions made in order to clarify our work for those who may use it or build upon it in the future.

4.3.1.1 Field Measurements

We are confident that the measurements taken during our site visits are sufficient for the scope of this project, however our methods were rudimentary and the measurements should not be used for official design plans. A professional survey may be required for additional work with this project.

4.3.1.2 Flow Analysis

When determining flow rates for the Walker Street crossing the team had to make assumptions based on two separate sources. One source was the USGS stream gauge located four miles downstream of the Walker Street crossing. This gauge has data going back to 1925 and it uses a drainage basin size of 43.3 square miles. The other source is a USGS stream crossing report using the same data that is provided by the USGS stream gauge, however, the drainage basin is less than half the size of drainage basin where the stream gauge is located. In order to account for this, USGS uses a calculation called the expected moment analysis which converts the flow rates based on drainage basin size. This calculation is very complex and is outside the scope of our project. Instead, we conservatively estimated the drainage basin size at our site by comparing the distance in river miles between the USGS Richardson Avenue site and Walker Street, then multiplied this ratio of 0.17 to the size of the drainage basin at Richardson Avenue (21.5 square miles). We then added this result to the Richardson Avenue area to yield a final result of a 25.2 square mile drainage basin at Walker Street.

4.3.1.3 Calculating Flow Capacities

Our team made several assumptions during the process of calculating the flow capacities of each stream crossing structure. It was assumed that:

- The inverts of the existing and proposed culverts are at the same elevation.
- The inverts of the existing and proposed culverts are level with the streambed surface.
- Uniform depth is maintained throughout each structure.
- Tailwater depth is equal to the diameter of the culvert in Case II scenarios.
- The slope of the existing culverts is equal to the channel bottom slope for each design option.
- A trapezoidal channel best represents the shape of the short-span bridge and arch culvert options.
- The weir discharge coefficient C_w is equal to 3.1.

4.3.2 Determining Dimensions

The simplest design was the larger culverts. Our team wanted to make the two culverts as large as possible while still maintaining the structural integrity of the crossing and minimizing change to the existing road elevation and grade. The existing culverts have diameters of 5.5 feet (66 inches). The current distance from the culvert inverts to the top of the roadway is 8.9 feet, leaving 3.4 feet of backfill between the top of the culvert and the road surface. Contech® Engineered Solutions presents various minimum coverages as shown in Table 4.2.

Table 4.2: Minimum coverages for various structures (Contech, 2012)

Type of Culvert	Minimum Coverage
84" corrugated aluminum pipe	21"
84" corrugated steel pipe	12"

Aluminum box culvert (full invert)	17"
Precast buried bridge (arch culvert)	24"

The required coverages for either an aluminum or steel corrugated pipe are both less than two feet, so the new design is able to span up to a 7.5-foot diameter if we decided to choose steel as the pipe material. Using the design spreadsheet (Appendix 7.6), the team was able to test different pipe diameters that were able to handle higher flows than the existing culverts and also meet coverage requirements. Ultimately, we decided on a 7-foot pipe diameter for the two culverts so that we could improve the hydraulic capacity while maintaining a conservative coverage depth of 2-feet.

Next, we calculated the crossing length of the short-span bridge. The Massachusetts Stream Crossing Standards recommend bridges span the length of 1.2 multiplied by the measured bankfull width of the river or stream. During our second site visit (Section 3.2.2), we calculated the upstream and downstream bankfull widths guided by the North Atlantic Aquatic Connectivity Collaborative (NAACC) method of averaging three width measurements on either side of the crossing. We multiplied the average value of 29.3 feet to yield a bridge span of 35.1 feet. This design would also aim to preserve the existing road elevation and grade.

The team researched different options for open-bottom and embedded culverts, ultimately deciding on an open-bottom box culvert as the third design choice for the Town of Norton. More specifically, the team based design calculations on a CON/SPAN® O-Series® precast concrete "buried bridge" manufactured by Contech® Engineered Solutions. We chose Contech® due to its large variety of bridge, pipe, and culvert systems to match the needs of this project and the availability of sufficient technical documentation. The structures come in prefabricated sizes, so the team chose the arch that best suited the width of the streambed and the existing height of the roadway with an acceptable coverage depth. This arch has a 24-foot span and a 5-foot rise, which allows for almost 4 feet of top coverage.

4.3.3 Recommending the Most Beneficial Option

Several series of trial and error using the team's design spreadsheet (Appendix 7.6) led to the optimal dimensions of each of the three design options based on flow capacity, channel velocity, and coverage depth. Section 3.4.2 discusses the calculation of each resulting flow depth through the stream crossing structure for every flood level. We sorted these flow depths based on their level on the structure, and assigned cases for each scenario, as seen in Table 3.1. Case I represents normal flow through the culvert, Case II represents a flow submerging the pipe but not yet overtopping the roadway, and Case III represents flooding over the roadway.

The best design options were the ones with minimal instances of Cases II and III. Both the short-span bridge and arch culvert options only had instances of Case I, meaning none of the flood levels will overtop the structures. The third option, the larger culverts, had four out of six flood levels overtopping the roadway. The lower two flood levels were of the Case I scenario.

In addition to flooding concerns, the project team also had to consider flow depths and velocities in regards to the bridle shiners that inhabit the area. The Massachusetts Natural Heritage and Endangered Species Program states that the optimal habitat for bridle shiners requires 1.5-4.0 feet of water moving at 0-0.5 feet per second (MDOFW, 2015). Our team evaluated which design option would best suit these needs, and how we might be able to alter this option to accommodate the bridle shiner and other minnow species.

4.4 Evaluating Design Options

In addition to the existing culvert structure, our team also analyzed the flood data for each of our three proposed design options: the larger culverts, the short-span bridge, and the open-bottom arch culvert. Once the design options were solidified, the team evaluated the cost, constructability, environmental impact, and regulatory compliance of each of the three stream crossing structures. The results of these evaluations are presented in Sections 4.4.1-4.4.3.

4.4.1 Renovated Culverts

The larger pipe culverts have a greater flow capacity than the existing culverts. They would be able to handle flows up to the 10-year flood level, as shown in Figure 4.10. Any flow rate above this flood level would cause roadway overtopping. Flow through larger culverts would continue to erode the streambed and would not alleviate the existing downstream scour pool, meaning upstream fish passage may still be difficult. Streambed armoring could be an option to remedy this, however it may lead to more habitat and wildlife concerns.

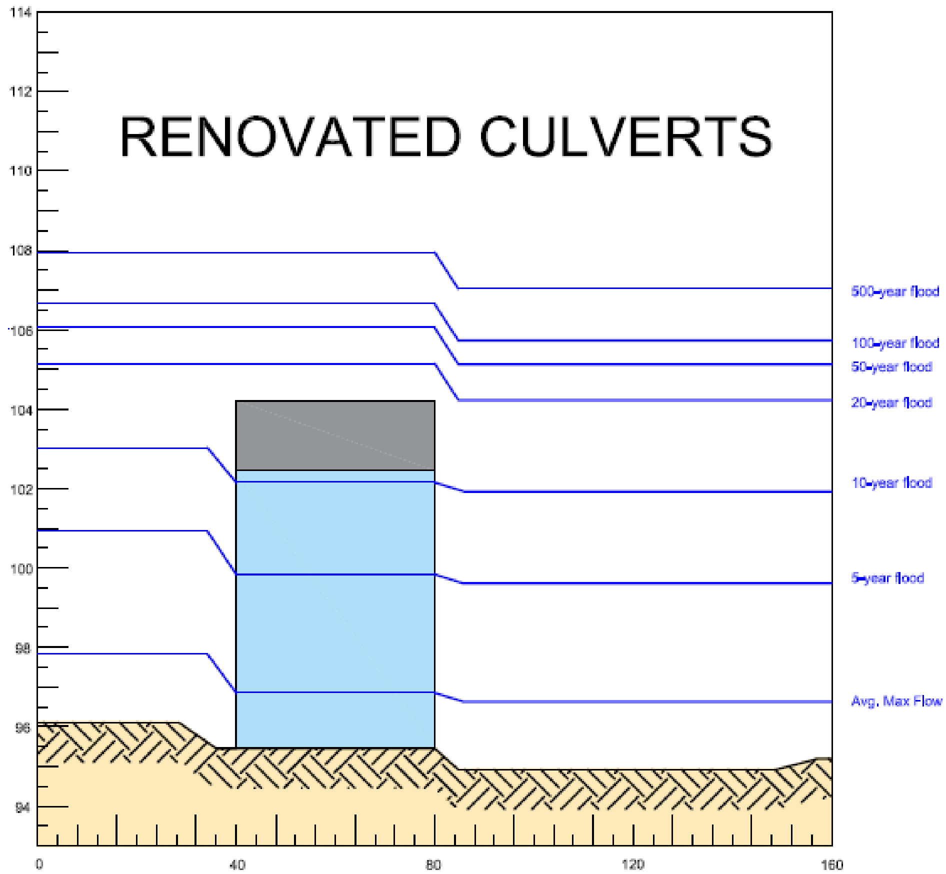

Figure 4.10: Water surface profile for the larger pipe culverts with approximate upstream and downstream head losses. Measurements are in feet.

The installation of new culverts would have a relatively low cost and simple constructability. A simple culvert renovation would not meet the Massachusetts Stream Crossing Standards and would not be able to acquire the proper permitting under the Massachusetts Wetlands Protection Act, due to its flow constriction and contact with the natural streambed.

4.4.2 Short-Span Bridge

Constructing a short-span bridge is the best option in terms of regulatory requirements. A bridge would meet the optimal standards set forth by the Massachusetts Stream Crossing Standards and would encourage the most natural stream flow out of all of the proposed options, due to its lack of contact with the natural streambed. The lack of streambed contact would also help to promote the normalization of the downstream scour pool. A bridge would be able to handle up to at least 500-year flood levels, as shown in Figure 4.11.

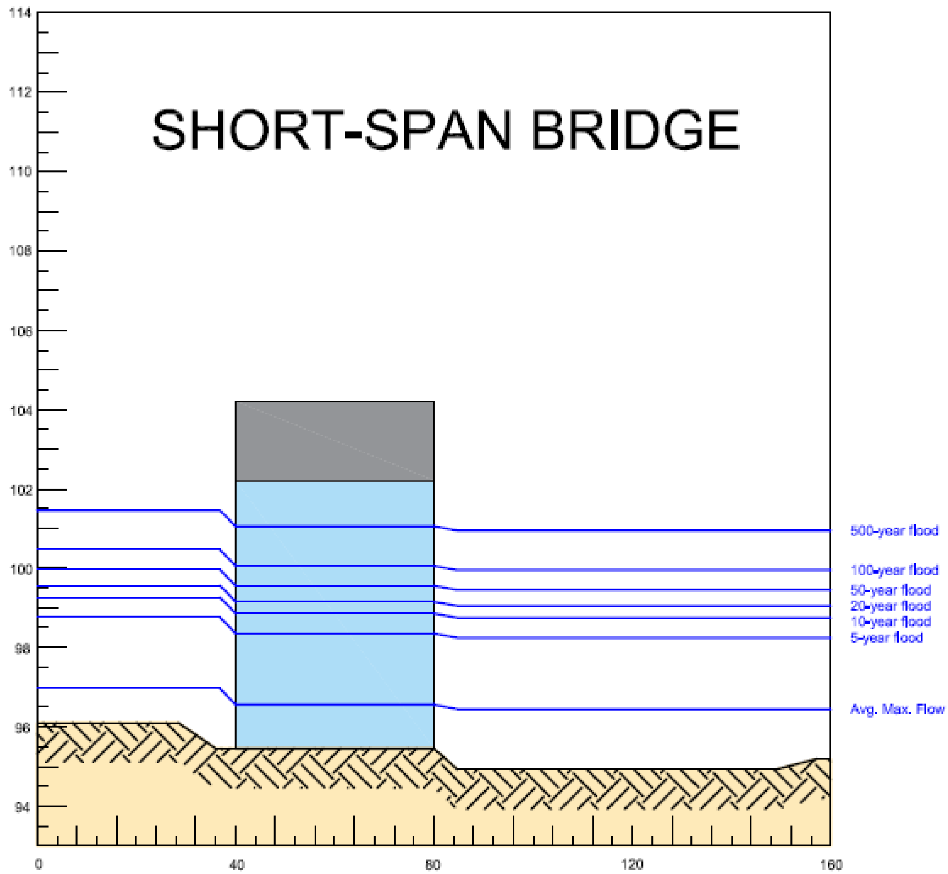

Figure 4.11: Water surface profile for short-span bridge with approximate upstream and downstream head losses. Measurements are in feet.

The downside of the short-span bridge option is its cost and constructability. The installation of a bridge is relatively expensive and complex. Construction would be time-consuming and would require a complete destruction of the existing stream crossing structure. It would be crucial for careful precautions to be taken in order to minimize impact to the surrounding wetlands area during construction.

4.4.3 Open-Bottom Arch Culvert

Like the short-span bridge option, an open-bottom arch culvert sized to the dimensions specified in Section 4.3.2 would be able to handle flows up to the 500-year flood level, as shown in Figure 4.12. The arch culvert option would meet the general standards set forth by the Massachusetts Stream Crossing Standards and would have a favorable environmental impact. The arch structure would have minimal contact with the natural streambed, easing upstream fish passage. The promotion of natural flow will normalize the downstream scour pool over time.

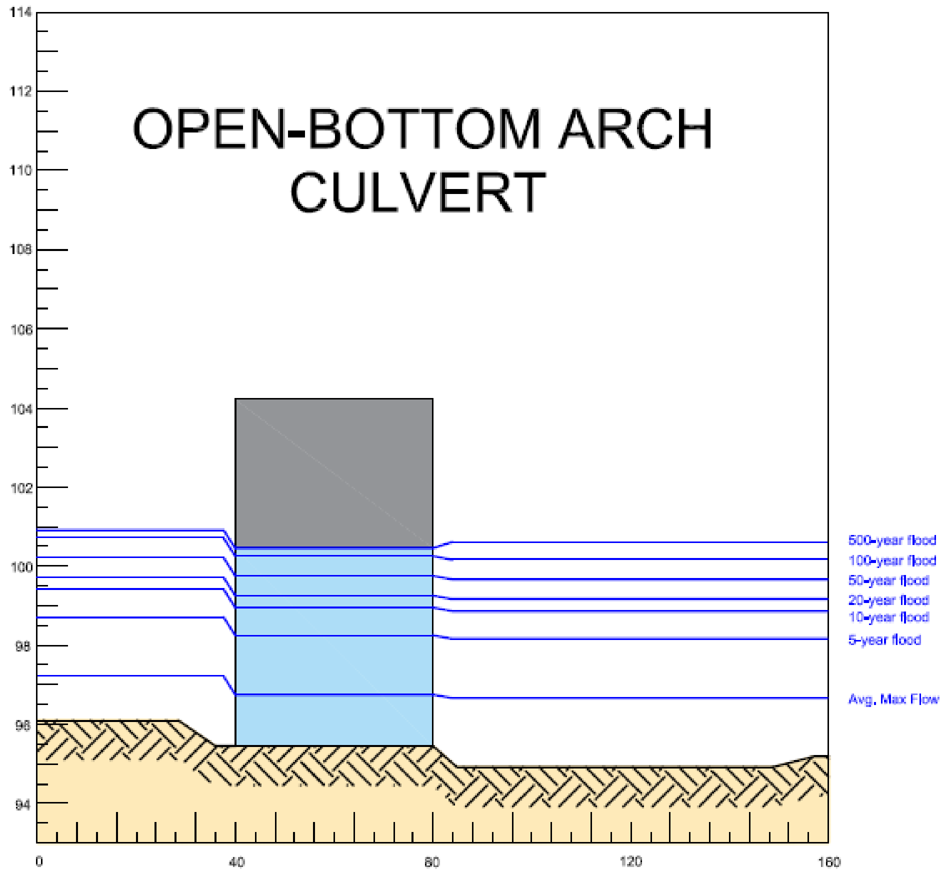

Figure 4.12: Water surface profile for the open-bottom arch culvert with approximate upstream and downstream head losses. Measurements are in feet.

The relative cost and constructability of a prefabricated concrete arch structure are both moderate. Construction duration is quick compared to the short-span bridge option. Necessary precautions during construction would have to be taken in order to minimize disruption of the existing streambed.

4.4.4 Summary

This section presents summary tables of the hydraulic capacities (Table 4.3) and the advantages and disadvantages of each design option compared to the existing culverts (Table 4.4). The capacities table shows the water elevations caused by each flooding event. In the comparison table, plus signs represent an advantage, and minus signs represent disadvantages. The open-bottom arch culvert offers the most hydraulic and environmental improvements while being relatively affordable and easily constructible.

Table 4.3: Hydraulic capacities of each structure

Flood Level (Elevation at Invert-95.5ft)	Flow Rate (Cfs)	Elevation @ Inlet (Exisiting)	Elevation @inlet (Larger Culverts)	Elevation @inlet (Short-Span Bridge)	Elevation @inlet (Open Bottom Arch)
Average Minimum Flow	162.9	97.7	97.6	96.5	96.3
Average Maximum Flow	216.6	98.3	97.8	96.6	96.8
20% Annual Exceedance Probability (5-year flood)	714.9	104.5	100.4	98.4	98.3
10% Annual Exceedance Probability (10-year flood)	884.0	105.5	102.5	98.9	99
5% Annual Exceedance Probability (20-year flood)	1059.2	106.2	105.5	99.2	99.3
2% Annual Exceedance Probability (50-year flood)	1306.2	106.9	106.4	99.6	99.8
1% Annual Exceedance Probability (100-year flood)	1507.4	107.5	107	100.1	100.3
0.2% Annual Exceedance Probability (500-year flood)	2032.7	108.7	108.4	101.1	100.5

Table 4.4: Advantages and disadvantages of design options

	Existing Culverts	Renovated Culverts	Short-Span Bridge	Open-Bottom Arch Culvert
Total Cost	n/a	+	-	+
Constructability	n/a	+	-	+
Flow Capacity	-	-	+	+
Meets Optimum Standards	-	-	+	-
Meets General Standards	-	-	+	+
Environmental Impact	-	-	+	+

5 Conclusions & Recommendations

This project provided culvert re-design to ease address wildlife passage and flooding concerns at Walker Street in Norton, Massachusetts. We analyzed and compared three different types of hydraulic structures: two larger pipe culverts, a short-span bridge, and an open-bottom arch culvert. We ultimately concluded that an open-bottom arch culvert would best fit the needs of the Town of Norton. Section 5.1 of this chapter discusses the specifications of an open-bottom arch culvert design and Section 5.2 considers the design's compliance with the Massachusetts Stream Crossing Standards. Section 5.3 recommends steps for the Town of Norton to take to support the continuation of this project.

5.1 Open-Bottom Arch Culvert Design

Through the evaluation of the proposed larger pipe culverts, short-span bridge, and open-bottom arch culvert (Section 4.4), our project team recommends the open-bottom arch culvert as the most beneficial choice for the Town of Norton. Sections 5.1.1-5.1.3 discuss the recommended material and dimensional specifications and the consideration of cost for the arch culvert option (Figure 5.1).

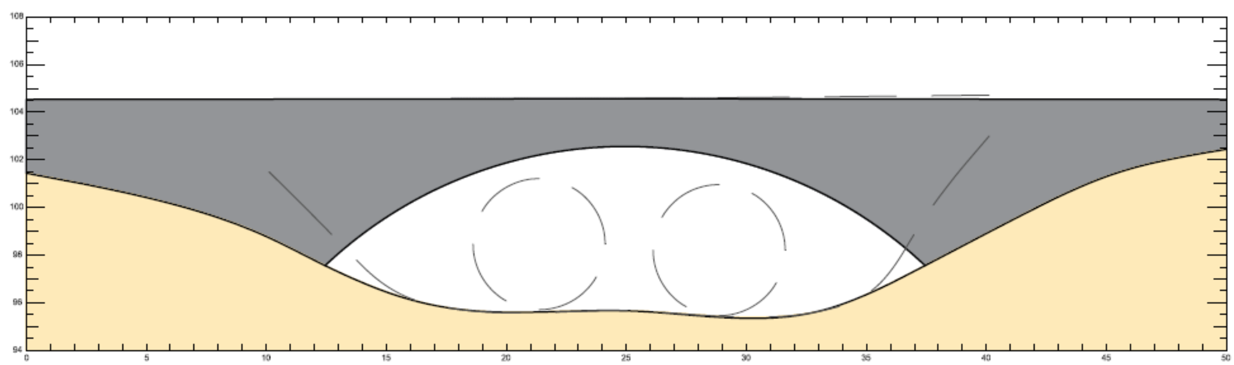

Figure 5.1: Design schematic of the open-bottom arch culvert with the existing culverts superimposed with the dashed line. Measurements are in feet.

5.1.1 Materials

Our team recommends a prefabricated concrete open-bottom arch culvert for Walker Street. Contech® Engineering Solutions manufactures and provides technical specifications for these structures, so we used their product (Figure 5.2) as an example for our calculations. Our team based the flow capacity calculations on an O-Series® structure. These precast concrete hydraulic structures come in a standard range of spans and rises, which are discussed in Section 5.1.2. The buried bridge structures are comprised of 8-foot wide concrete arch segments connected together onsite. The Walker Street stream crossing would require at least four of these segments. The O-Series® product brochure may be found in Appendix 7.8 and the details specification sheet may be found in Appendix 7.9.

Figure 5.2: Example of a finished B-Series® buried bridge, a similar Contech® structure with different span and rise options (ArchiExpo, 2017)

5.1.2 Hydraulic Design

Our team based calculations off of an arch with a 24-foot span and a 5-foot rise for maximum hydraulic capacity in our given site constraints. A 5-foot rise allows for a coverage depth of 4 feet. If desired or necessary, the Town of Norton may adjust these dimensions, however a decrease in span and waterway area directly impacts the hydraulic capacity of the structure. Contech® lists standard dimensions for their precast bridge units, as shown in Table 5.1. Our project team has provided the Town of Norton with a digital copy of the spreadsheet that contains all of our hydraulic capacity calculations for ease of dimensional adjustment. A print version of this spreadsheet may be found in Appendix 7.6.

Table 5.1: Standard Contech® unit dimensions and waterway areas (Contech, 2012)

STANDARD CON/SPAN® BRIDGE UNITS

RISE (FT.)	WATERWAY AREA ($FT.^2$) SPAN (FEET)											
	12	14	16	20	24	28	32	36	42	48	54	60
3	30	*	*	*	*	*	*	*	*	*	*	*
4	42	50	55	65	*	*	*	*	*	*	*	*
5	54	64	71	85	95	*	*	*	*	*	*	*
6	66	78	87	105	119	139	*	*	*	*	*	*
7	78	92	103	125	143	167	184	*	*	*	*	*
8	90	106	119	145	167	195	216	232	*	*	*	*
9	102	120	135	165	191	223	248	268	*	*	*	*
10	114	134	151	185	215	251	280	304	334	387	435	*
11	*	*	*	*	239	279	312	340	376	435	489	*
12	*	*	*	*	*	*	344	376	418	483	543	578
13	*	*	*	*	*	*	*	412	460	531	599	638
14	*	*	*	*	*	*	*	448	501	579	652	698

RISE (FT.)	WEIGHT (TONS/FT.) SPAN (FEET)											
	12	14	16	20	24	28	32	36	42	48	54	60
3	.94	*	*	*	*	*	*	*	*	*	*	*
4	1.04	1.14	1.59	1.73	*	*	*	*	*	*	*	*
5	1.14	1.24	1.71	1.86	2.05	*	*	*	*	*	*	*
6	1.24	1.34	1.83	1.99	2.18	2.84	*	*	*	*	*	*
7	1.34	1.44	1.96	2.12	2.31	2.99	3.56	*	*	*	*	*
8	1.44	1.54	2.09	2.24	2.44	3.14	3.71	4.06	*	*	*	*
9	1.54	1.64	2.21	2.36	2.57	3.29	3.86	4.23	*	*	*	*
10	1.64	1.74	2.33	2.49	2.69	3.44	4.01	4.40	4.87	5.27	6.52	*
11	*	*	*	*	2.81	3.59	4.16	4.58	5.04	5.48	6.72	*
12	*	*	*	*	*	*	4.31	4.76	5.21	5.67	6.92	7.76
13	*	*	*	*	*	*	*	4.93	5.38	5.88	7.12	7.98
14	*	*	*	*	*	*	*	5.11	5.58	6.08	7.32	8.21

5.1.3 Cost Consideration

There are many costs that would be associated with the renovation of the Walker Street culverts. These costs include professional engineering services, construction, and general maintenance. First, it would be necessary to contract professional engineering services to review our team's proposal and produce professional documentation for an arch culvert design. These engineering services may include a professional survey of the site and the application for the required permitting to move the project forward.

After the design is finalized and permitted, the next costs would be the construction of the culvert. The scope of construction would include the removal of the existing culverts, temporarily diverting the stream's flow, assembling the precast arch structure and installing the proper foundations, and re-grading and repaving the roadway. The Town may also consider the restoration of the downstream scour pool to match the natural streambed.

During construction the road leading to and from the culvert would have to be temporarily shut down. Due to the fact that Walker Street is a connector street a detour would have to be established for the duration of the construction. Then, the precast concrete arch culvert would need to be professionally installed. After the construction phase of the project is completed the only cost would be regular maintenance of the structure and surrounding area in order to prolong the structure's lifespan.

5.2 Meeting Standards

The precast arch structure meets many of the optimum standards set forth by the Massachusetts Stream Crossing Standards (Section 2.3), in addition to all of the general standards. The arch would have minimal contact with the natural streambed and the existing banks, which promotes natural stream flow with little impact to the current landscape. Optimum standards require culverts to have an openness ratio larger than 1.64 feet (RSCP, 2006). Our recommended structure has an openness ratio of 2.4 feet, which greatly exceeds this standard. The only optimum standard the arch fails to meet is the type of structure itself. In order to qualify as an optimal design, the structure must be a bridge.

Meeting the general standard requirements will ideally allow the Town of Norton to receive the permitting and funding necessary to move the project forward.

5.2.1 Environmental Impact

The Contech® buried bridge structure or similar will offer significant improvements to the Walker Street stream crossing. The structure's minimal contact with the streambed will allow for natural, uninterrupted flow beneath the roadway at normal flow levels. The Town of Norton may choose to restore the area downstream of the crossing to recreate the natural streambed. If this is not an option, we anticipate the scour pool will normalize over time due to the absence of the pre-existing constriction.

The arch culvert has the hydraulic capacity to handle up to the 500-year flood without overtopping the roadway. In addition to its flood management improvements, the new structure will also benefit the local wildlife by lowering stream velocities at the site. More specifically, the structure will help improve the habitats of bridle shiners and other minnow species.

Bridle shiners require a specific environment to thrive in streams and creeks. They require a very low flow velocity in order to pass through culverts or other structures. They also require water to be less than four feet deep. Instances of flooding in the Wading River will always create velocities that are too fast for the bridle shiners, however under normal flow conditions our recommended design may be paired with a modified streambed to create the perfect environment for the species. We suggest adding moderate sized stones to the natural streambed beneath the arch structure. These stones will create small eddies for the bridle shiners and other minnow species to rest in as they travel upstream.

5.3 Next Steps

Our project team met with a representative of the Natural Heritage and Endangered Species Program on February 24, 2017 (Appendix 7.10). This meeting was very useful in that it gave us insight into where our work stands in the scope of the entire Walker Street culvert restoration project headed by the Town of Norton. We learned that now is the opportune time to get in touch with endangered species programs to ensure that proposed designs will adhere to Massachusetts Endangered Species Act (MESA) regulations.

If the Town of Norton agrees with our final recommendations and decides to continue our work, the next step would be to compile a request for proposal (RFP) and evaluate bids. The Town will choose the best bidder that provides engineering services to obtain the proper local and state permitting and professional design work. Once the Town has professional engineering plans, another RFP will need to be circulated to contract construction services to install the new structure. Overall, this may be a lengthy process, as it will depend on project funding and various approvals.

5.4 Summary

Through our team's thorough research and calculations we found that our recommended open-bottom arch culvert design is the best choice for improving the conditions of the Walker Street stream crossing in a cost-efficient and practical manner. We hope that the work compiled in this report is sufficient in helping the Town of Norton move forward in the permitting process and the eventual construction of a culvert that will meet the needs of the Town and the surrounding environment.

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7 Appendices

7.1 Walker Street Culvert Restoration Proposal

1. Introduction

Norton is a town located in the southeast region of Massachusetts. The Town of Norton is partnering with Worcester Polytechnic Institute (WPI) to sponsor a Major Qualifying Project (MQP) aimed to redesign the Walker Street crossing of the Wading River in Norton. The goal of the MQP is to recommend to the Town new stream crossing designs that minimize flood risks and improve the habitats of local fish species including the endangered bridle shiner. This goal will be accomplished using environmental and structural engineering knowledge and skills.

1.1 Problem Statement

The Town of Norton has a long standing need to replace many of its existing culverts because they are considered to be substandard stream crossings by the Massachusetts Department of Ecological Restoration. Substandard stream crossings have the potential to cause flooding, interfere with fish movement, and negatively impact wetland habitats by disrupting a stream's natural flow.

The goal of this project is to redesign the substandard Walker Street stream crossing in order to minimize flooding and to improve the habitats of bridle shiners and other wildlife. Our project team will accomplish this goal by conducting background research, investigating the project site, and analyzing the flow patterns of the Wading River.

1.2 Project Goals and Objectives

The overarching goal of this project is to provide sound design recommendations to the Town of Norton. The team will research and investigate the project site and surrounding areas in order to better understand the existing structure and the behavior of the Wading River (i.e. flow patterns, flooding history, etc.). The team will develop a series of designs and evaluate each one based on stream crossing standards specifications, cost analyses, and overall effectiveness.

1.3 Project Deliverables

The project deliverables will include a final report detailing the design options and a cost analysis of each. The team will also perform a hydraulic study of the highest-rated design.

1.4 Project Timeline

The time frame for completing this MQP is from the beginning of WPI's A Term (August 25, 2016) to the end of C Term (March 3, 2017). The deadlines for specific tasks may be seen outlined in the Methodology chapter of this report (Table 1). The tasks themselves are also described in detail in the Methodology chapter.

2. Background

2.1 Local Geography

2.1.1 Norton, Massachusetts and the Wading River

The Town of Norton is located in Bristol County in southeastern Massachusetts. It has an area of approximately 30 square miles. The Wading River runs through the town until it joins the Three Mile River just northwest of the Taunton border. The Wading River originates in the Town of Foxborough and its 13.1 miles travel mostly through low, swampy areas. It is located entirely within the Taunton River Watershed which is also part of the larger Narragansett Bay Watershed. Our project is focused on the Walker Street crossing of the Wading River, located at the southern end of Walker Street in the western portion of Norton (Norton, 2016).

2.1.2 Taunton River Watershed

The Taunton River Watershed encompasses 562 square miles of southeastern Massachusetts including the Town of Norton and the Wading River. It hosts hundreds of lakes and ponds and hundreds of miles of rivers and streams. It is also home to multiple plant and animal species, along with 27 different types of habitats. Several of the plant, vertebrate and invertebrate species that dwell in the watershed are protected by the Massachusetts Natural Heritage and Endangered Species Program (see Section 2.3.4) (TRWA, 2016).

2.2 Existing Conditions of Site

2.2.1 Flow Patterns

In its current state, the Wading River runs parallel to Walker Street and crosses from the north at a near to 90 degree angle. It runs under the road and into a large scour pool. The pool's maximum dimensions are approximately 70 feet long by 40 feet wide and 6 feet deep. Downstream of the scour pool the turbidity increases and the stream constricts back to regular size.

2.2.2 Condition of Structure

The Walker Street structure that crosses the Wading River is made up of two 72" CMP culverts. The structure itself is made of cement and medium-sized (12"-24" diameter) reinforcing boulders with cement fill surrounding them (see Figure 2). The pipes are in moderate to poor condition with corrosion around the sections of the pipe which contact water around the inlet and outlet. The rust is extensive enough to create holes all the way through the pipes rendering them substandard. The roadway itself is in decent condition with recent patching used to cover any holes present. Overall the road conditions do not have an effect on the usability of the road.

2.2.3 Status of Surrounding Wetlands

There are wetland areas both upstream and downstream of the Walker Street crossing. Upstream from the crossing the wetlands extend to the left where there is a 200 foot buffer zone. There are no buildings or man-made structures in the area that is classified as wetlands. Downstream from the crossing there are residential buildings to both the left and right of the stream. They are relatively close (200-300 feet) but do not have any impact on the stream or stream bed. The wetlands themselves are in good condition with a myriad of new vegetation growing. There is limited erosion and little to no human disturbance present in these wetlands.

2.3 Key Stakeholders

2.3.1 Town of Norton, Massachusetts

The Town of Norton was established in 1710 in Bristol County, Massachusetts. Since its founding, the town has grown to a population of approximately 19,000 residents. The town is governed by a town manager and a board of selectmen. The management of the town includes several boards, departments and committees.

One board of particular interest is the Conservation Commission. The main responsibility of the conservation commission is to enforce the Wetlands Protection Act and its associated regulations. The Town itself does not have any wetlands protection bylaws (Commission, 2016).

2.3.2 Southeastern Regional Planning & Economic Development District

The Southeastern Regional Planning and Economic Development District (SRPEDD) is an agency governed by local officials to plan and program for the future of the region. The region is composed of 27 communities over 808 square miles, including the Town of

Norton. The SRPEDD is responsible for the preparation of bylaws and ordinances for the region, zoning and housing regulation, and funding for various economic, environmental, and transportation programs and projects.

The environment program of the SRPEDD accounts for a wide range of projects, including open space planning and preservation, dam removals, and stormwater runoff mitigation. The SRPEDD is also very involved in the conservation of the Taunton River Watershed. The organization is currently in the second phase of the Taunton River Watershed Study, which aims to restore the fragile natural resources of the 560 square mile area and to enhance the quality of life for the residents of the watershed (SRPEDD, 2016).

2.3.3 Management Committee of the Narragansett Bay Estuary Program

The main goal of the Narragansett Bay Estuary Program (NBEP) is to conserve and restore the natural resources of the Narragansett Bay and its watershed. The Narragansett Bay Watershed spans a large portion of the coastline of Rhode Island and extends through southeastern Massachusetts and to the northwest as far as Worcester. The NBEP operates under the National Estuary Program, which was established in 1987 by the United States Clean Water Act.

The NBEP is overseen by a Management Committee which provides approval and guidance for the implementation of the Comprehensive Conservation and Management Plan for Narragansett Bay (CCMP). The Management Committee is made up of 26 individuals representing various organizations including the U.S. Department of Agriculture, the U.S. Environmental Protection Agency, the Southeastern Regional Planning & Economic Development District, the Massachusetts Department of Environmental Protection, and the Massachusetts Audubon Society, amongst others. The Management Committee is responsible for fostering communication and collaboration from all involved organizations in order to best implement the CCMP, for encouraging community involvement in planning for the Narragansett watershed, and providing input to help improve the CCMP and overall ecological restoration of the region (NBEP, 2016).

2.3.4 Natural Heritage and Endangered Species Program

The Natural Heritage and Endangered Species Program (NHESP) is part of the Massachusetts Division of Fisheries and Wildlife. The main goal of the program is to preserve and protect hundreds of animal and plant species and their respective habitats throughout the state. The priority of the program is to protect those species listed by the state of Massachusetts as endangered or threatened (NHESP, 2016).

2.3.4.1 Bridle Shiners

One of the fish species recognized by the Natural Heritage and Endangered Species Program is the bridle shiner. Bridle shiners (*Notropis bifrenatus*) are small, silver fish that are native to northeastern America. They are inherently small fish and generally do not grow to be more than 2 inches long. They have a basic physical appearance with a black line running from the front of the head to the start of the tail fin. The stomach is fully scaled and is silver in color with light speckles on the peritoneum.

The bridle shiner habitat generally resembles that of the Wading River. The species tends to dwell in shallow water (2 feet) or in water that has moderate vegetation as stream bed cover. Bridle shiners lay their eggs on this vegetation between May and July. When the young shiners hatch they stay in the small vegetation until August. Once they have matured they leave the weeds and join the adult schools where they live out the rest of their one to two year lives.

Bridle shiners are greatly threatened in rivers such as the Wading River. Due to their small size they are not easily able to navigate turbulent water or large changes in elevations. Structures such as culverts, dams and pipes that cause these flow disruptions pose a large threat to the shiner population. Shiners also have poor vision which makes them extremely susceptible to prey when the turbidity increases. This reduces their range of vision and makes it much easier for predators such as pickerel, perch and bass to quickly sneak up on and eat them. These variables have all lead to bridle shiners being on the endangered species list (MDOFW, 2015).

2.4 Massachusetts Stream Crossing Standards

2.4.1 General Standards

The general stream crossing standards are meant to be used when there is new construction or renovations planned for a structure that serves as both a stream crossing and a wildlife habitat. Generally, the suggested structure in these situations is an open-bottom box culvert. According to the standards, the culvert must not increase the flow rate so that it is higher than the natural flow rate of the river. It must also meet the proper openness specification (see Section 2.4.5) (RSCP, 2006).

2.4.2 Spans

Spans are highly rated when considering structures to replace or use as stream crossings. Spans are built over the stream and have no interaction with the stream bed. This reduces stress on the creek and makes the specifications much easier to build. The suggested spans include 3-sided box culverts, bridges and arches. The main requirement for spans is that the structure and its components do not interact or disturb the stream bottom. When designing spans it is important to also consider bankfull of the stream. In order to accurately calculate bankfull, one must measure the width of the river at normal flow (not drought or flood) at a minimum of three places that are outside of the influence of structures such as dams and culverts. These measurements may be averaged to determine bankfull. The minimum width of the span needed to meet general standards is then calculated by multiplying bankfull width by 1.2 (RSCP, 2006).

2.4.3 Culverts

Culverts are defined as structures that have water flowing over one part of the structure. If a structure meets this requirement it is also required to meet a number of other specifications. Primarily all culverts must be embedded in the ground a minimum of 2 feet. However, if the culvert utilizes a round pipe then the structure must be embedded the initial 2 feet plus 25 percent of the diameter of the culvert. The aim of this specification is to maintain the natural flow patterns of the stream during normal flow and special conditions such as the 100 year flood (RSCP, 2006).

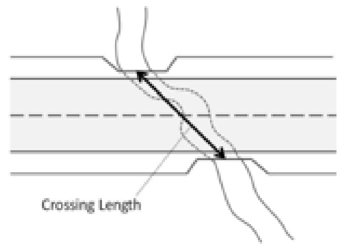
2.4.4 Stream Bottom Design

The design of the stream bottom is a vital when determining how to integrate a culvert into its surroundings. The substrate characteristics of the culvert often have more of an effect on passibility than turbidity and water velocity do. If it is too rugged or textured, creatures such as crayfish and salamanders will often have trouble navigating through the culvert. Therefore substrate should be sized appropriately for the local fauna. The substrate should also have a variety of sizes in order to help maintain stream characteristics during large floods and other changes in stream flow rate (RSCP, 2006).

2.4.5 Openness

In order to meet Massachusetts standards, all culverts are required to have a openness larger than 0.82 feet. Openness is defined as the cross sectional area of the pipe divided by the crossing length. The openness lets enough light in the culvert to allow animals to see and safely navigate the culvert or stream crossing (RSCP, 2006).

$$Openness = \frac{Area}{Crossing\ Length}$$



2.5 Optimal Standards

2.5.1 Application

The optimal stream crossing standards are to be applied to places where permanent stream bed crossings are planned. These areas are planned to have some kind of regional or statewide significance for their “landscape level connectedness.” This means an area where the crossing will connect two or more areas of significant animal habitat (50 acres). However, there is currently no defined specification or rule specifying when to use the optimal stream crossing (RSCP, 2006).

2.5.2 Standards

The USACE lays out standards for how to design culverts and bridges in their “River and Stream Crossing Standards.” The first suggestion that is made is that when considering what type of structure to use for a stream crossing to first consider using a bridge. Bridges are advantageous for many reasons. One being they do not disturb the stream bed over which they are built because there is no contact with the stream bed. This allows wild animals to cross under the bridge without the risk of getting lost or injured (RSCP, 2006).

2.5.3 Span

The standards for span in the optimal standards are the exact same for those of the general standards. The span also has the same requirement as the general requirements with the crossing having a required span of at least 1.2 times bankfull width (RSCP, 2006).

2.5.4 Natural Bottoms

In order to meet the requirements for the optimal standards stream crossings must meet strict requirements for bottom standards. The first requirement is that culvert bed substrate matches that of the stream bed. This is aimed at alleviating the stress put on fish by the implementation of unnatural streambed substrates. Secondly the substrate must be designed to resist large floods. If the substrate is removed during large floods the habitat of the animals is also removed (RSCP, 2006).

2.5.5 Dimensions

The dimensions of the stream crossings vary depending on whether or not there is a structure that will impair the travel of animals. This may include a road, a fence or another type of structural development. If there is such a structure then a minimum height of 8.2 feet and a minimum openness of 2.46 feet must be achieved. This will allow the animals sufficient light as well as ample room to get around whatever is obstructing their path. If there are no obstructions then the height can be as low as 6 feet and the openness can be as small as 1.64 feet (RSCP, 2006).

2.5.6 How to Apply the Standards

A large amount of planning must be done in order to accurately apply the standards laid out as “optimal.” Culverts and stream beds must be analyzed to determine the effect that a larger culvert will have. If the culvert is simply placed without any prior planning the stream can become unstable and there can be head cutting (RSCP, 2006).

2.5.6.1 Evaluation

Prior to building, a long-use profile should be established for the selected area. This means the river or stream needs to be assessed for downstream flooding during floods such as the one year, ten year and 100 year flood. If potential culvert sites are not properly assessed and designed there is a large potential for erosion from flooding and the stream stability could fail. The habitats present in the surrounding area should also be assessed for physical features such as wetlands, endangered species areas and residential spaces. If not properly identified prior to construction, the habitats and lives of many animals and people could be destroyed (RSCP, 2006).

2.5.6.2 Building

After physical and geographical evaluations of the surrounding area is completed, the culvert or crossing must be designed accordingly. In order to help reduce washout and erosion from flooding, factors such as inlet/outlet drops, stream constriction, scour pools and wildlife barriers need to be avoided. Avoiding negative culvert characteristics such as these will help to improve the stream quality and the passability for animals (RSCP, 2006).

2.5.6.3 Timing

When building, it is necessary to make sure construction is done in accordance with fish spawning patterns and seasonal water flows. Ideally, culvert restoration should be done between the 1st of July and the 30th of September. During this time period the local fish are spawning and the water flow is significantly lower than during other months. This will help to maintain the characteristics of the stream and protect its inhabitants (RSCP, 2006).

2.5.6.4 Storm Water/Pollution Management

The stream crossing standards suggest using a “downstream retention pond” for all projects that will involve interaction with the stream bed. This is intended to minimize contact with the stream bed, which will help to minimize the impact on nearby vegetation and prevent harmful runoff. The barrier should be a silt fence or be made of hay bales, mats, Coir logs, mulch or compost filter tubes. Any equipment that is used in construction should be washed prior to use in order to not bring outside pollutants into the construction zone. Overall the goal is to mimic the habitat of the surrounding area and reduce the environmental impact of culvert construction (RSCP, 2006).

3. Methodology

The Town of Norton, Massachusetts has plans in the works to renovate stream crossings throughout the town, yet there has been little movement due to lack of engineered designs for reconstruction. This project focuses specifically on the Wading River near Walker Street. The goal of this project is to redesign the Walker Street stream crossing in order to minimize flooding and to improve the habitats of bridle shiners and other wildlife. Our project team will accomplish this goal by conducting background research, investigating the project site through observation and surveying, analyzing the flow patterns of the Wading River, evaluating the current site conditions, developing new designs based off of our learned information, and recommending the most beneficial stream crossing design to the Town of Norton. These tasks are described in more detail below.

3.1 Field Work

Our team will visit the site of the Walker Street stream crossing several times throughout the duration of this project. The aim of these site visits is to gather as much data as possible in order to present a sufficient and accurate stream crossing design to the Town of Norton. We will gather data through correspondence with our sponsors and literature review, visual inspection, and by surveying the site. Information that is recorded in the field will be neatly organized and transferred to an online document for permanent storage and easy access.

3.1.1 Sponsor Correspondence and Literature Review

Our sponsors have a lot of collective knowledge and experience in the Taunton River Watershed. This information will give our team a better understanding of the problems at hand, similar past projects and their results, and regulations to adhere to. Communication with our sponsors will also help the team to best comprehend the needs of the Town and to determine the optimal design that meets these needs. Constant communication with our sponsors is one of our main goals in the early stages of the project. Our sponsors' knowledge and experience in the Taunton River Watershed will give out team a better understanding of the problems that need to be addressed over the course of the project. As the project progresses further the sponsors will be integral in the project as advisors by explaining their perception of the direction of the project and ensuring both parties understand the final objectives.

Our team will also perform background research in the initial stages of the project. This research includes collecting information about the local geography of the site, the existing conditions of the site, the key stakeholders in the project, and the current regulations in place, specifically the Massachusetts Stream Crossing Standards. The Background chapter of this report presents the results of our literature review at this point in the project.

3.1.2 Visual Inspection

Visual inspection of the site will help to determine the condition of the existing culvert, the roadway, and the bridge structure. Our team will also be able to assess the traffic flow in the area to see what effect construction will have. During our visual inspection, we will also take detailed photographs of the site to visually explain the conditions of the site. These on-site inspections will help us assess the severity of the existing conditions and give us insight into the designs for a new stream crossing.

3.1.3 Surveying the Site

Following correspondence with our project's sponsors and the initial site visit, our team will take several trips to the site to survey the stream crossing and take appropriate measurements. The goal of these trips is to gather data on the existing structure and the wetlands surrounding the crossing. Data such as stream bed elevations, inlet and outlet drops, upstream and downstream profiles and other measurements will help us to better understand the flood patterns and fish passage concerns when designing a new crossing aimed to minimize these issues.

3.2 Flow Analysis

In addition to our gathered field information, our team will utilize flow data for the Wading River provided by a United States Geological Survey (USGS) flow gauge roughly half a mile downstream from the Walker Street crossing. In this data we will be looking for patterns in the monthly, seasonal and annual flow data. This data will help our team to better understand the characteristics of the river's flow and base our new designs on real data and ensure the design meets all of the Massachusetts stream crossing standards.

3.3 Evaluation of Current Conditions

After the initial site visit our team will use subsequent site visits to evaluate the current conditions of the existing structure in order to determine the most suitable design for the culvert that matches the ideas of the Town of Norton. We will visually assess the structural condition of the culvert, the roadway and the surrounding landscapes. Based on the current condition of the culvert, our team will propose a variety of culvert renovation options. Each proposal will meet different levels of stream crossing stream crossing standards and require more work and funding to complete.

3.4 Design Alternatives

Our team plans on proposing three stream crossing design options for the Town of Norton to consider. The first design will meet the optimal design standards per Massachusetts Stream Crossing Standards (MSCS) meaning it will be ideally designed for avoiding interaction with the stream bed and allowing free passage for animals. The second design will be a step down from the first, but still meeting all of the general design requirements set by the MSCS meaning if in contact with the stream bed it will mimic substrate characteristics and provide easy access for animals. The third design will be a simple culvert renovation with upgrades to the piping and a renovation of the supporting structures. Our team will lay out costs as well as the pros and cons of each of these options to help the town determine the design that best meets their abilities.

3.5 Recommended/Final Designs

The goal of the final design is to provide the Town of Norton with a cost-efficient, low-maintenance stream crossing structure that also improves the surrounding ecosystem and minimizes flooding. After our team has developed our designs, we will analyze the options to determine the most feasible alternative to the existing structure. All of our designs must meet the Massachusetts Stream Crossing Standards in order to obtain the proper wetland permitting per the Wetlands Protection Act.

3.6 Project Timeline

The timeline for this project is presented below in Table 1. At this stage of the project, the bulk of our background research, visual inspection, and project proposal are completed. The focus of B Term will be to collect all of our survey data and to create an accurate plan of the current structure. Once we conduct our flow analyses and determine the specific needs of the new design, we will be able to create three or four design plan options. C Term will be focused on solidifying these designs and performing a cost analysis on each one. Through our cost analyses, we will be able to determine our highest-rated option and present our final recommendations to the Town of Norton in the form of a written report. The project will be finished by the end of C Term, March 3, 2017.

Table 1: MQP Timeline

TASK	**A TERM** (8/25-10/13/16)	**B TERM** (10/25-12/15/16)	**C TERM** (1/12-3/3/17)
Background Research			
Visual Inspection			
Project Proposal			
Site Survey			
Drawing of Current Structure			
Flow Analysis			
Evaluation of Need			
Design Options			
Cost Analysis			
Final Recommendations			

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7.2 Massachusetts Stream Crossing Survey (MSMCP Form)

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

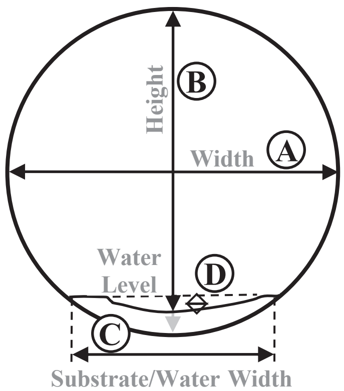
5/26/16

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.

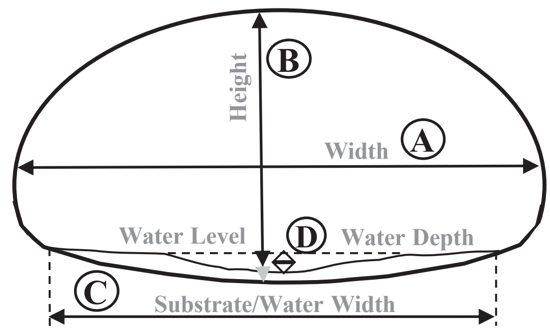
NOTE: Culverts 1, 2 & 4 may or may not have substrate in them, so height measurements (B) are taken from the level of the "stream bed", whether that bed is composed of substrate or just the inside bottom surface of a culvert (grey arrows below show measuring to bottom, black arrows show measuring to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

1



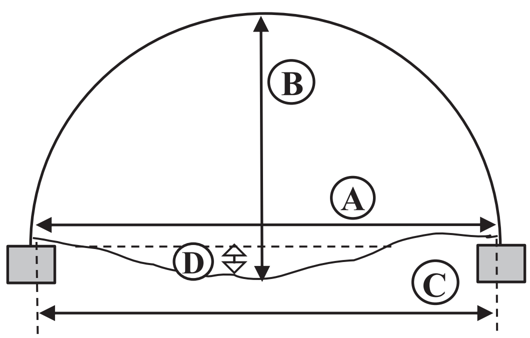
Round Culvert

2



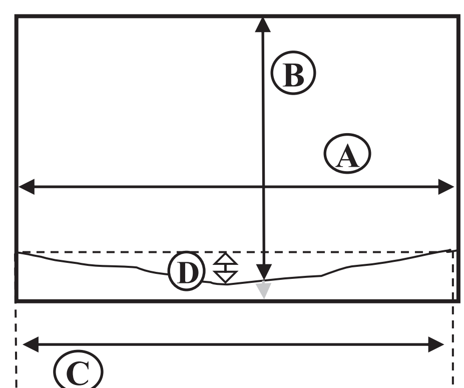
Pipe Arch/Elliptical Culvert

3



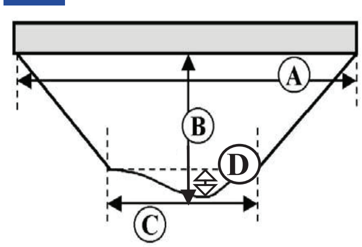
Open Bottom Arch Bridge/Culvert

4



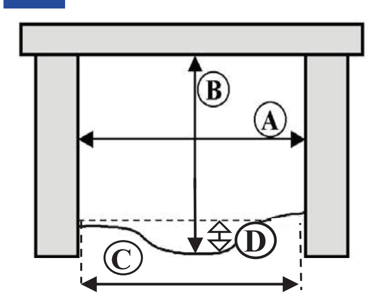
Box Culvert

5



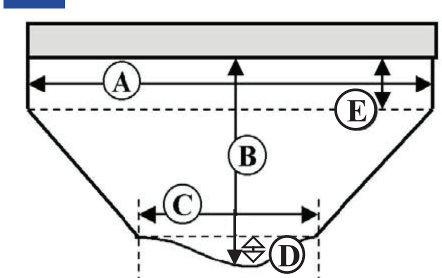
Bridge with Side Slopes

6



Box/Bridge with Abutments

7



Bridge with Abutments and Side Slopes

7.3 Massachusetts Society of Municipal Conservation Professionals (MSMCP) Presentation (pdf)

Road-Stream Crossing Assessments

Carrie Banks

MA DER State Survey Coordinator

North Atlantic Aquatic Connectivity Collaborative
NAACC

DEPARTMENT OF FISH AND GAME
Division *of* Ecological Restoration

Road-Stream Crossing Assessments

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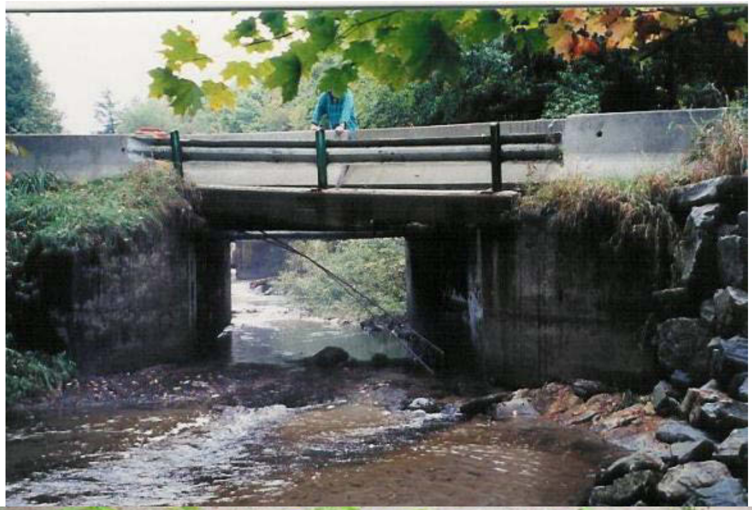
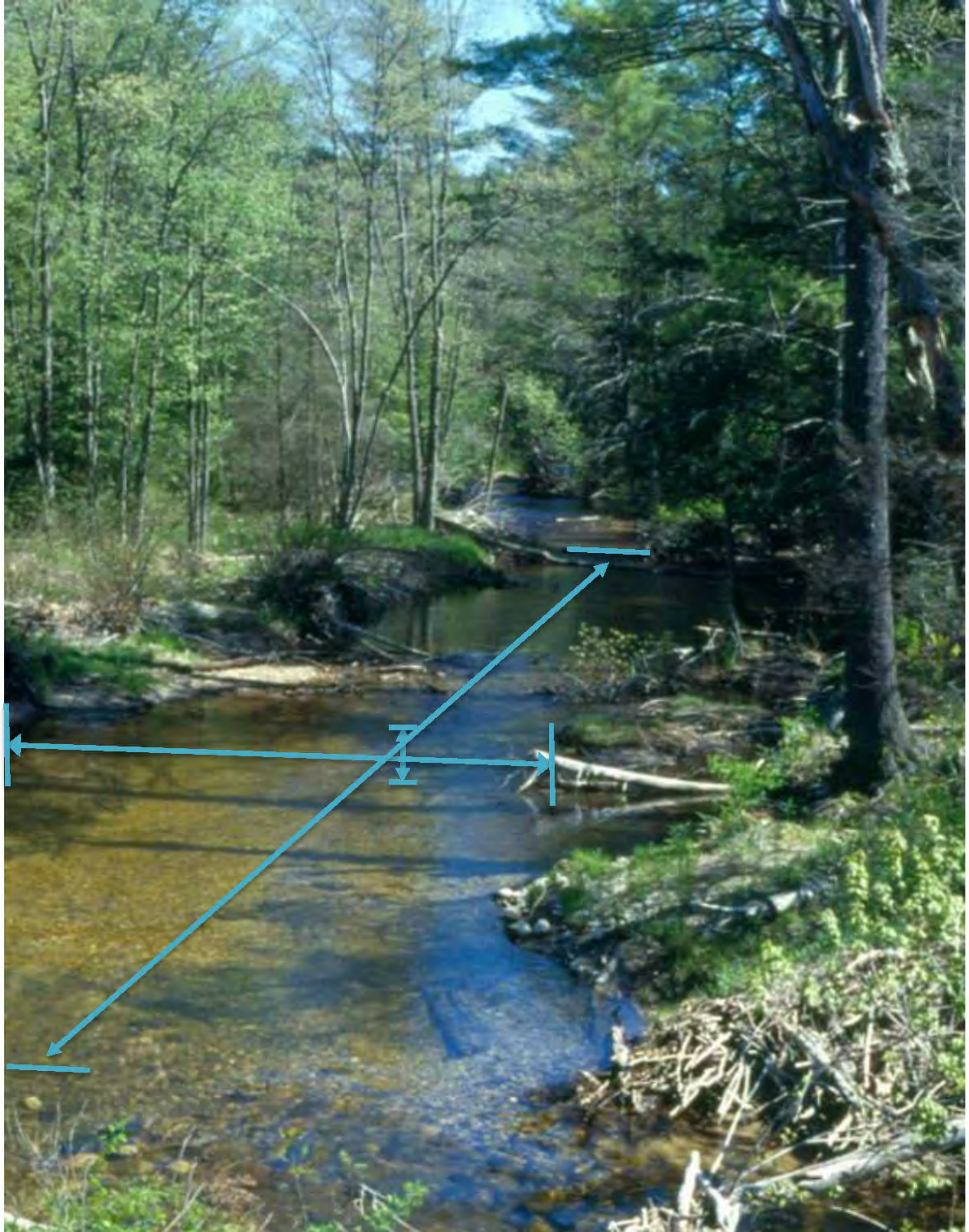
Overview

1. Importance of Aquatic Connectivity
2. Project Organization, Roles & Training
3. Field Forms
4. Field Visits

Stream Crossings

- Where roads and railways cross rivers and streams






Micrographia


Alan Richmond


Micrographia


© 1999 Joyce Gross


Robert Jenkins & Noel Burkhead


Barry Wicklow

Species on the *Move!*

- Need access for different lifetime needs:
  - Spawning habitat
  - Nusery habitat
  - Adult habitat

- Need to move due to threats:
  - Predation
  - Stressors – extreme high or low flows
  - Pollution

- Need access for different seasonal needs:
  - Refuge from thermal events (hot or cold)
  - Different food sources

Dams

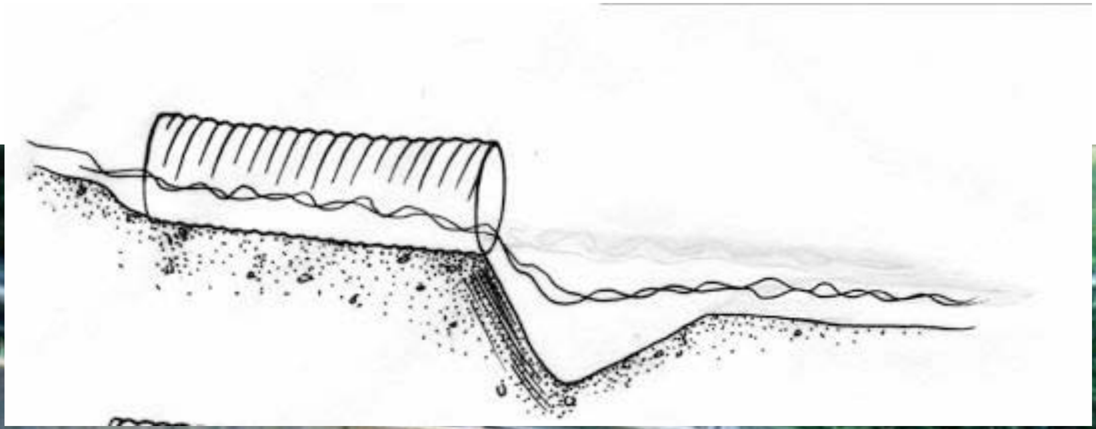
Sub-Standard Culverts

Excessive Velocities

Flow Contraction

Inlet Drop

Scour Hole



Outlet Drop (Perching)

Tail Water Armoring

Insufficient Water Depth


Wood Turtle
Scott Jackson


Beaver


Muskrat
© 2003 John White


Scott Jackson
Snapping turtle


Star-nosed mole
Kenneth Catania


Otter


Spring Salamander


Scott Jackson
Dusky salamander


Mink

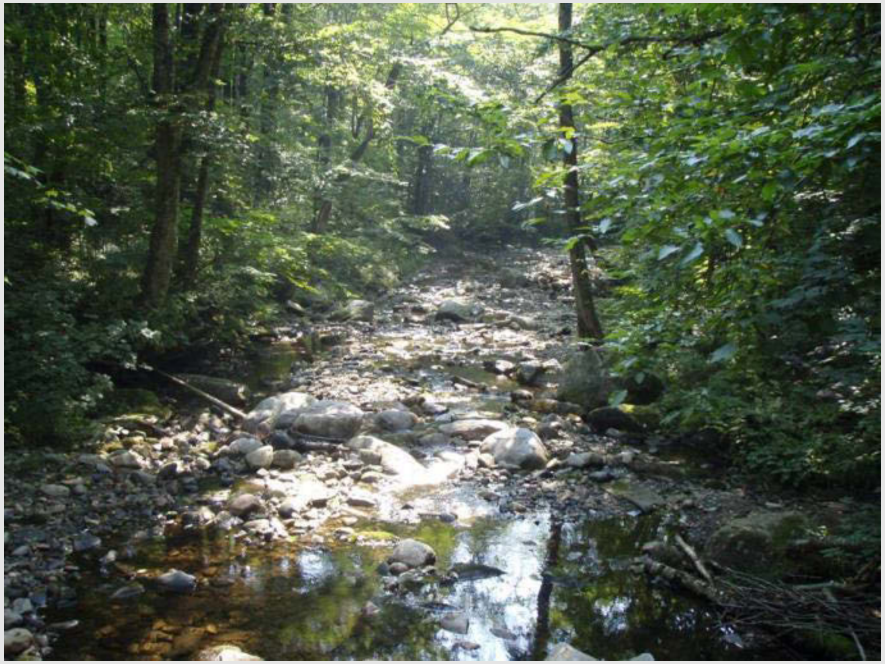
Openness

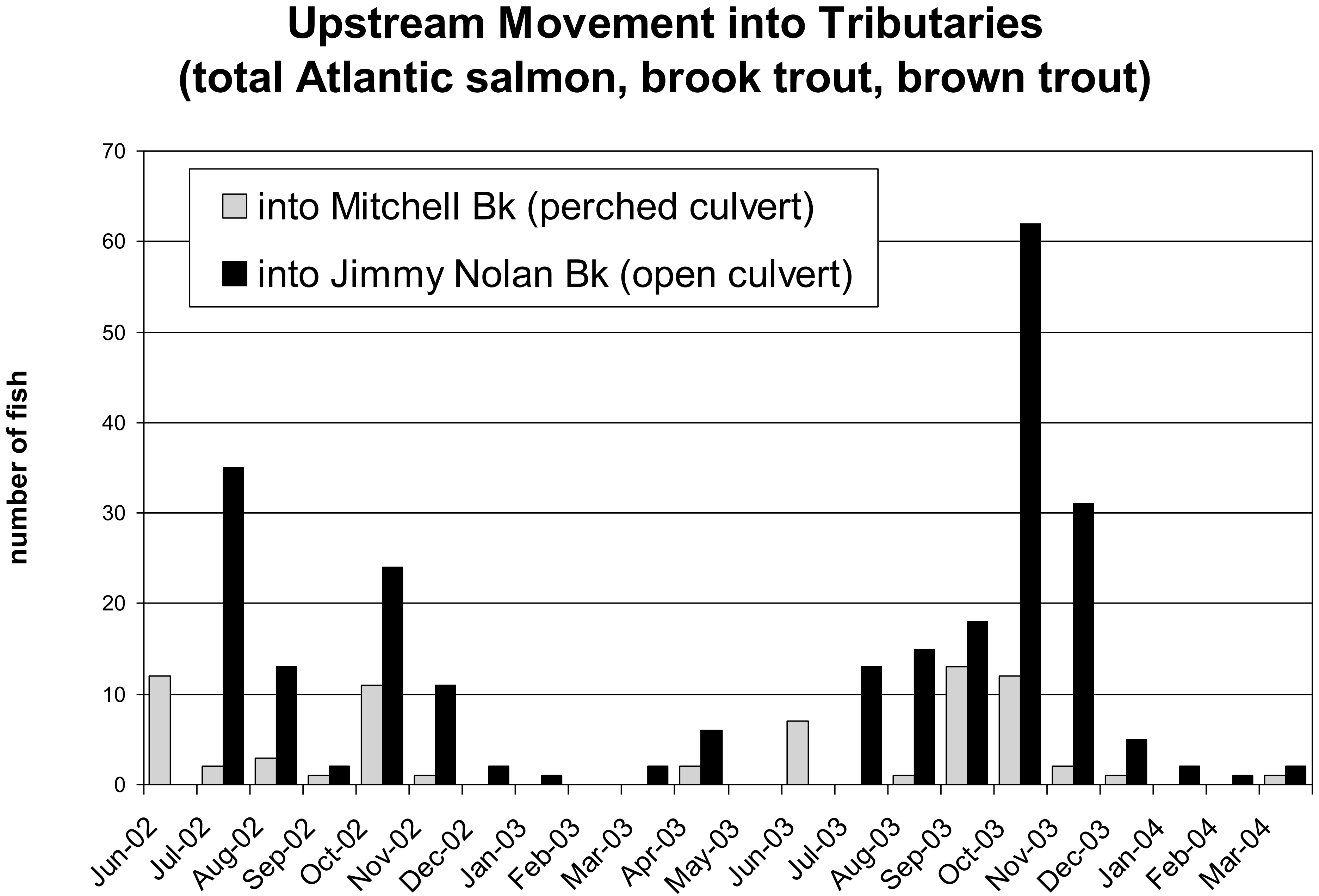
Impacts of Sub-Standard Crossings

- Loss or degrade habitat
- Alter ecological processes
- Lead to road kill and population losses
- Isolate and fragment populations – loss of genetic diversity
- Reduce access to vital habitats
- Disrupt processes that maintain regional populations

Importance of Small Streams

- Make up a large percentage of stream miles
- Cumulatively provide more habitat than large rivers
- Support species not found in larger streams and rivers
- High productivity
- Provide important spawning & nursery habitat for fish




Upstream Movement into Tributaries
(total Atlantic salmon, brook trout, brown trout)
into Mitchell Bk (perched culvert)
into Jimmy Nolan Bk (open culvert)
number of fish
0
10
20
30
40
50
60
70
Jun-02
Jul-02
Aug-02
Sep-02
Oct-02
Nov-02
Dec-02
Jan-03
Feb-03
Mar-03
Apr-03
May-03
Jun-03
Jul-03
Aug-03
Sep-03
Oct-03
Nov-03
Dec-03
Jan-04
Feb-04
Mar-04

Glimpse of Existing Situation

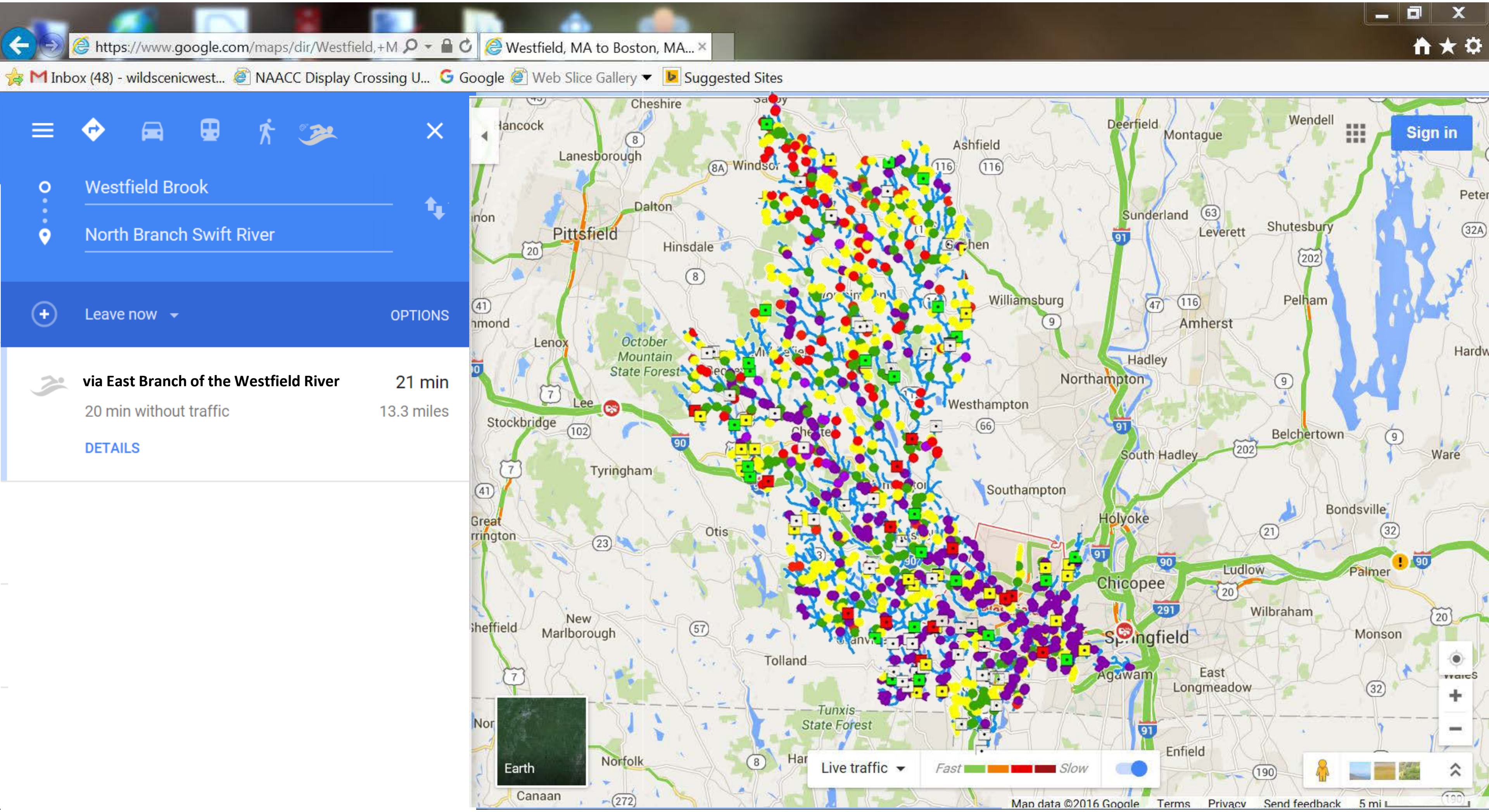
A survey of 6,030 single and multiple culverts in five New England states:

	Number	Percent
Severe barrier	93	1.5
Significant barrier	782	13.0
Moderate barrier	2,347	38.9
Minor barrier	2,539	42.1
Insignificant barrier	269	4.5
Full passage	0	0

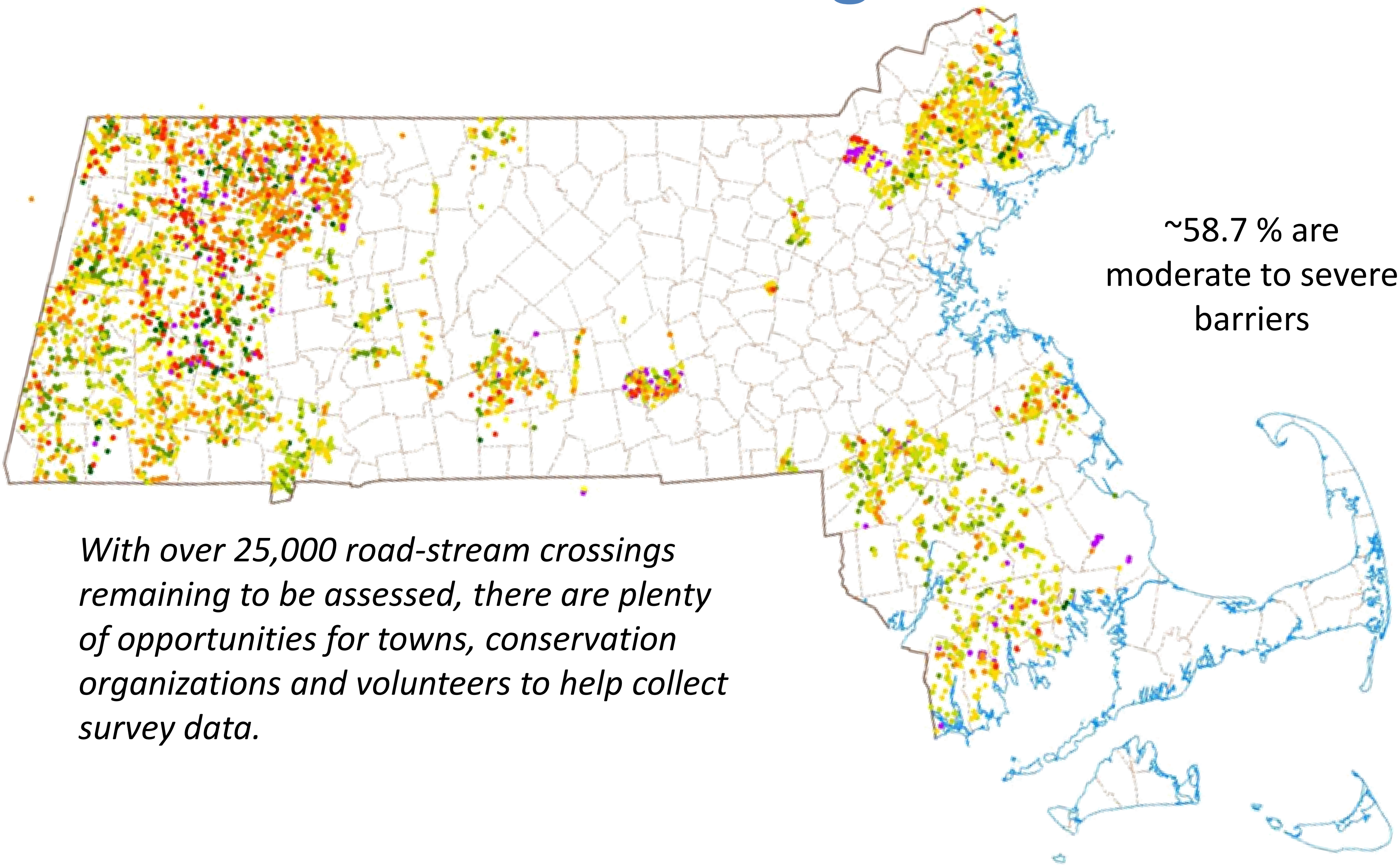
53.4 % are moderate to severe barriers

None provided full aquatic organism passage

Westfield River Watershed – Live Stream Traffic App



Road-Stream Crossing Assessments



~58.7 % are moderate to severe barriers

With over 25,000 road-stream crossings remaining to be assessed, there are plenty of opportunities for towns, conservation organizations and volunteers to help collect survey data.

Culvert Failure

Culverts and Changes in Precipitation Events:

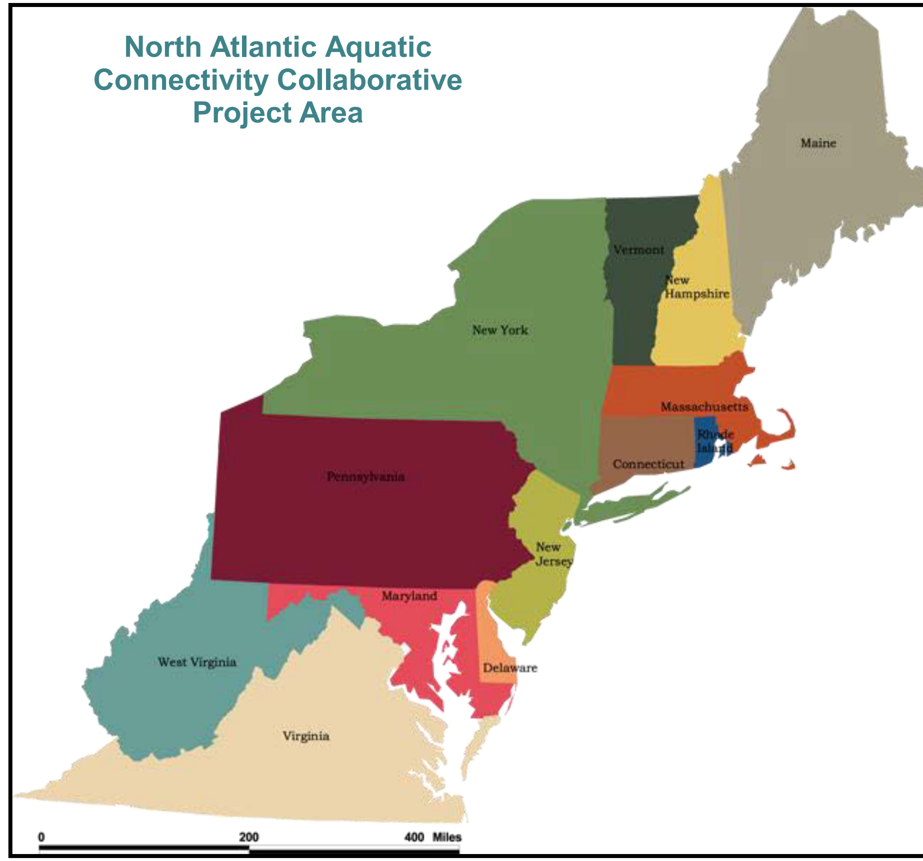
Changes in the precipitation events make culverts a critical issue for natural resource conservation and protection of infrastructure and public safety

North Atlantic Aquatic Connectivity Collaborative

NAACC

www.streamcontinuity.org

- ✓ ***Create a network in the North Atlantic region***
- ✓ ***Develop a Unified Stream Crossing Assessment Protocol***
- ✓ ***Create an infrastructure to support collection of road-stream crossing data***



UMASS AMHERST

The Nature Conservancy
Protecting nature. Preserving life.

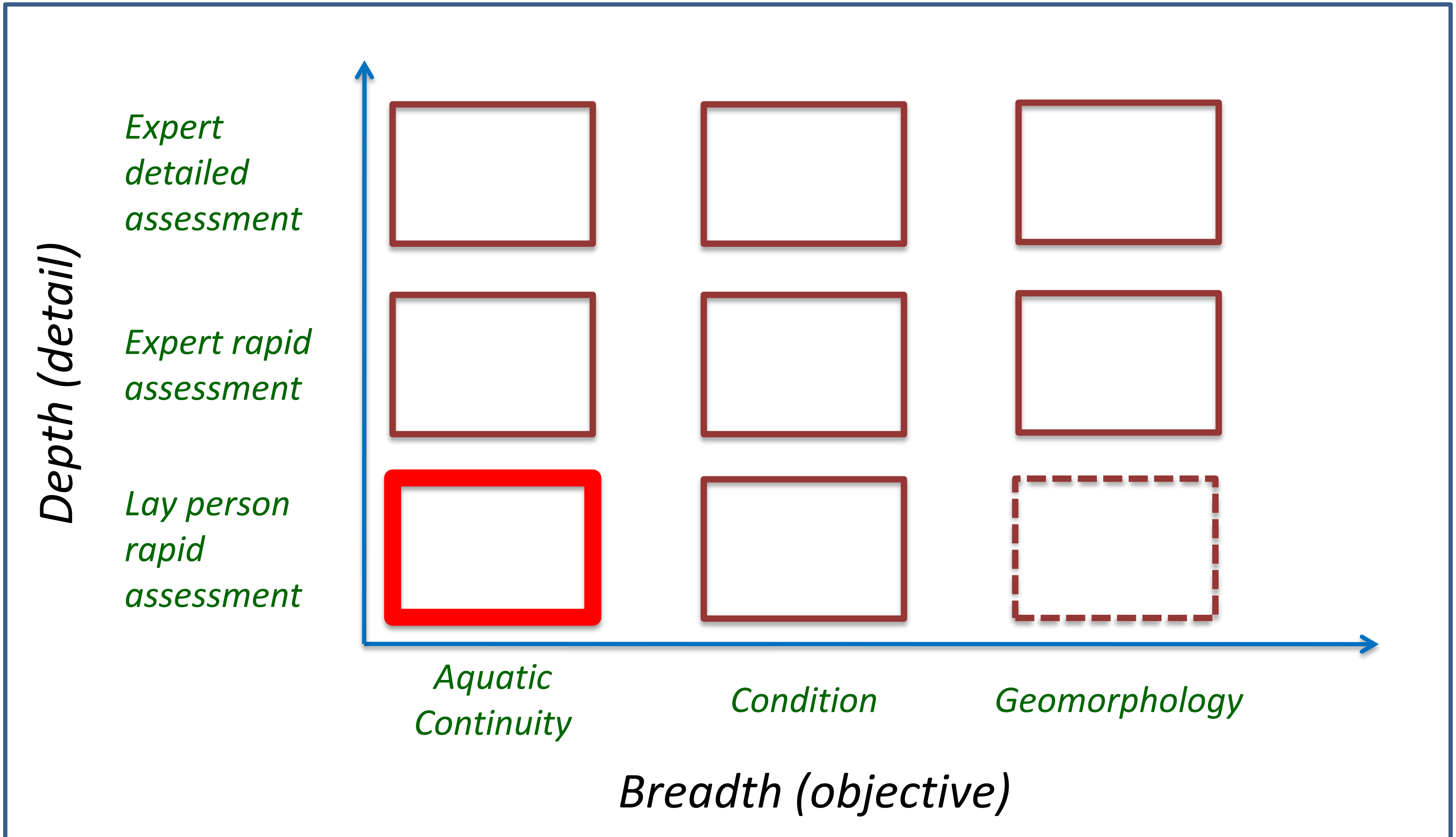
U.S. Fish & Wildlife Service
Department of the Interior

North Atlantic LCC
North Atlantic Landscape Conservation Cooperative

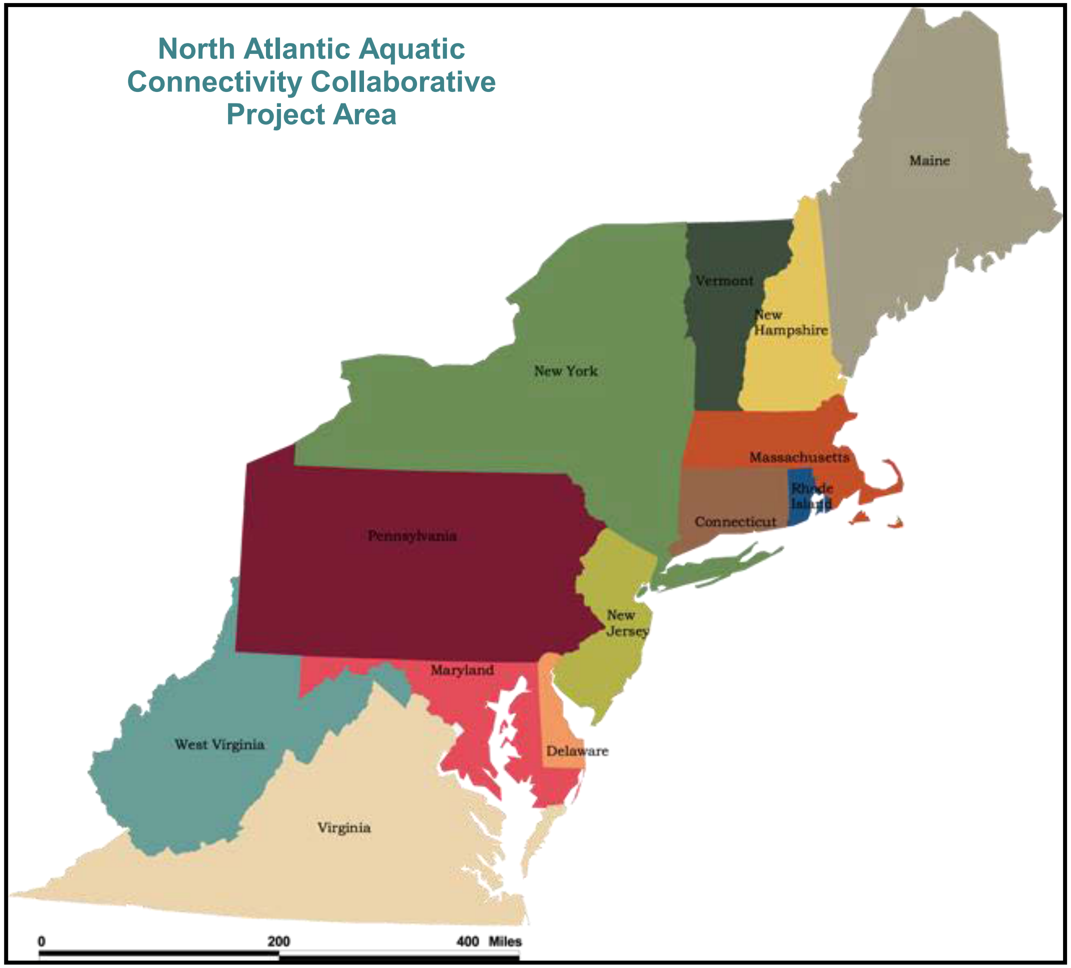
North Atlantic Aquatic Connectivity Collaborative (NAACC): Objectives

- Reconnect streams & rivers to support healthier populations of fish & wildlife
- Proactively identify and prioritize sites for stream crossing upgrades/replacements
- Facilitate communication and information sharing among partners

Modular approach to crossing assessment



Distributed Coordination



Lead Observers
(data collectors)

- Technicians
- Volunteers

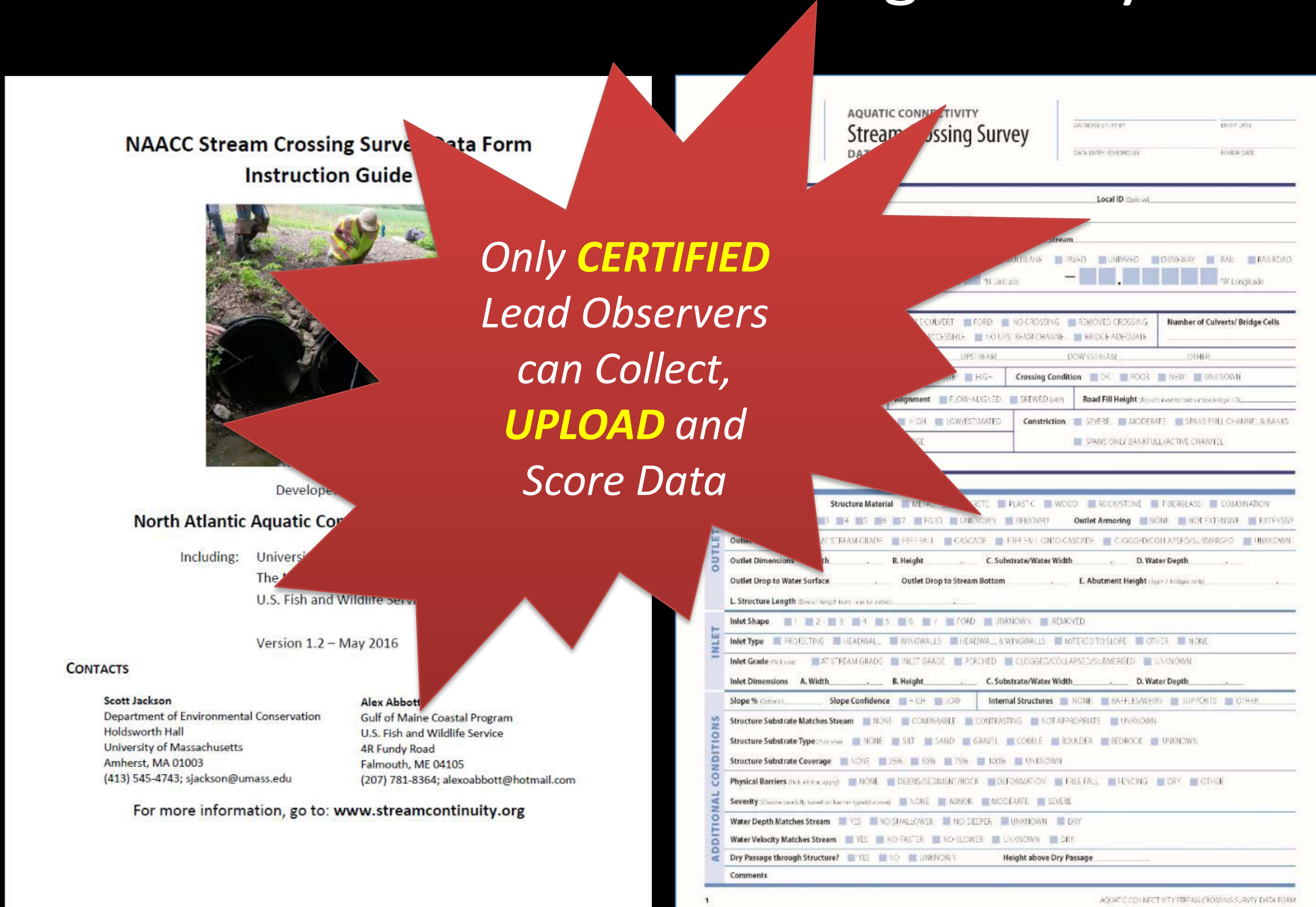
L1: Local Coordinators

L2: Regional Coordinators

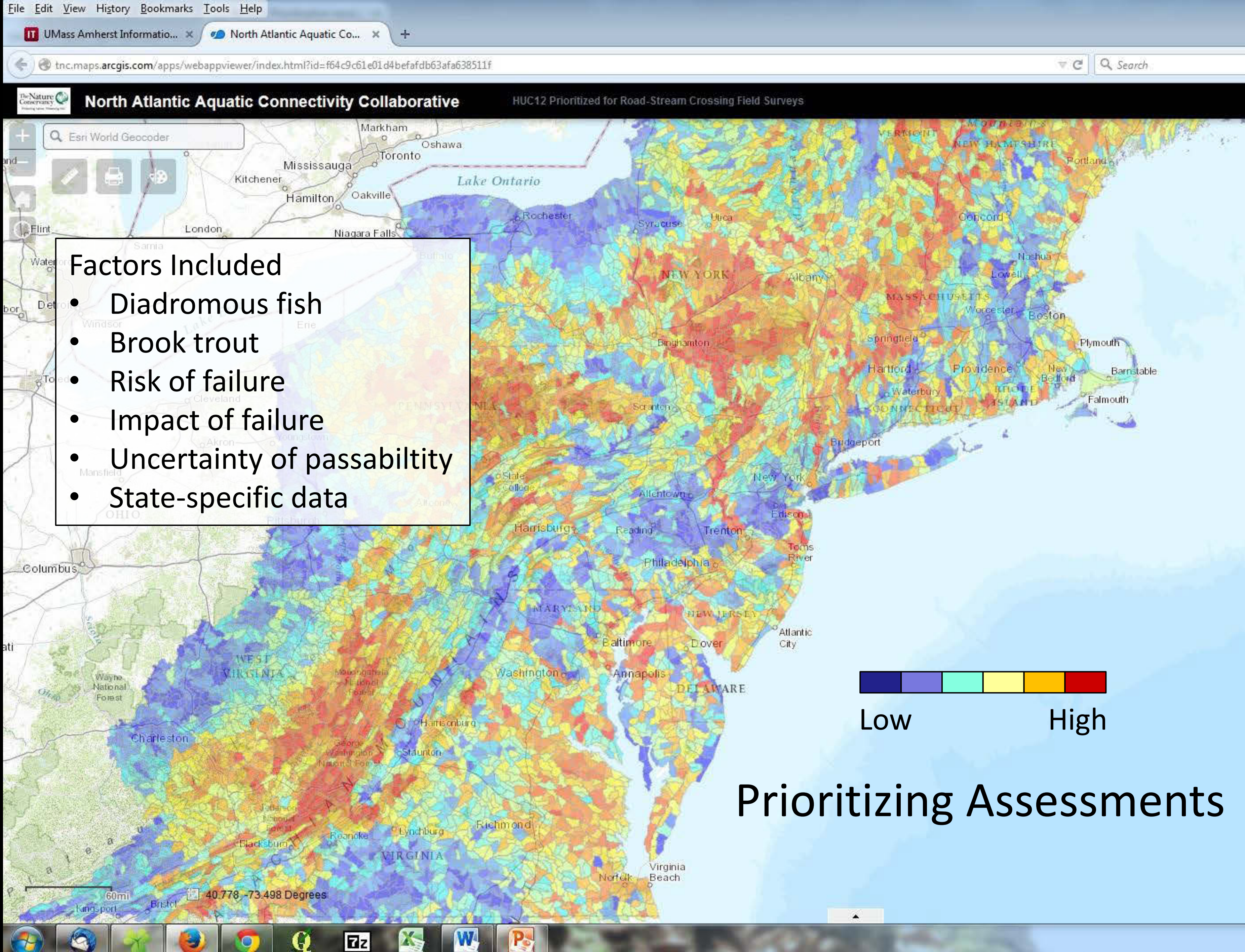
L3: Central Coordinators

Trainers

NAACC Stream Crossing Survey




xy4249167172555187
xy4249008272557769
xy4249026072557049
xy4248912072560564



Factors Included

- Diadromous fish
- Brook trout
- Risk of failure
- Impact of failure
- Uncertainty of passabiltity
- State-specific data

Low High

Prioritizing Assessments

Conservation Assessment & Prioritization System (CAPS)

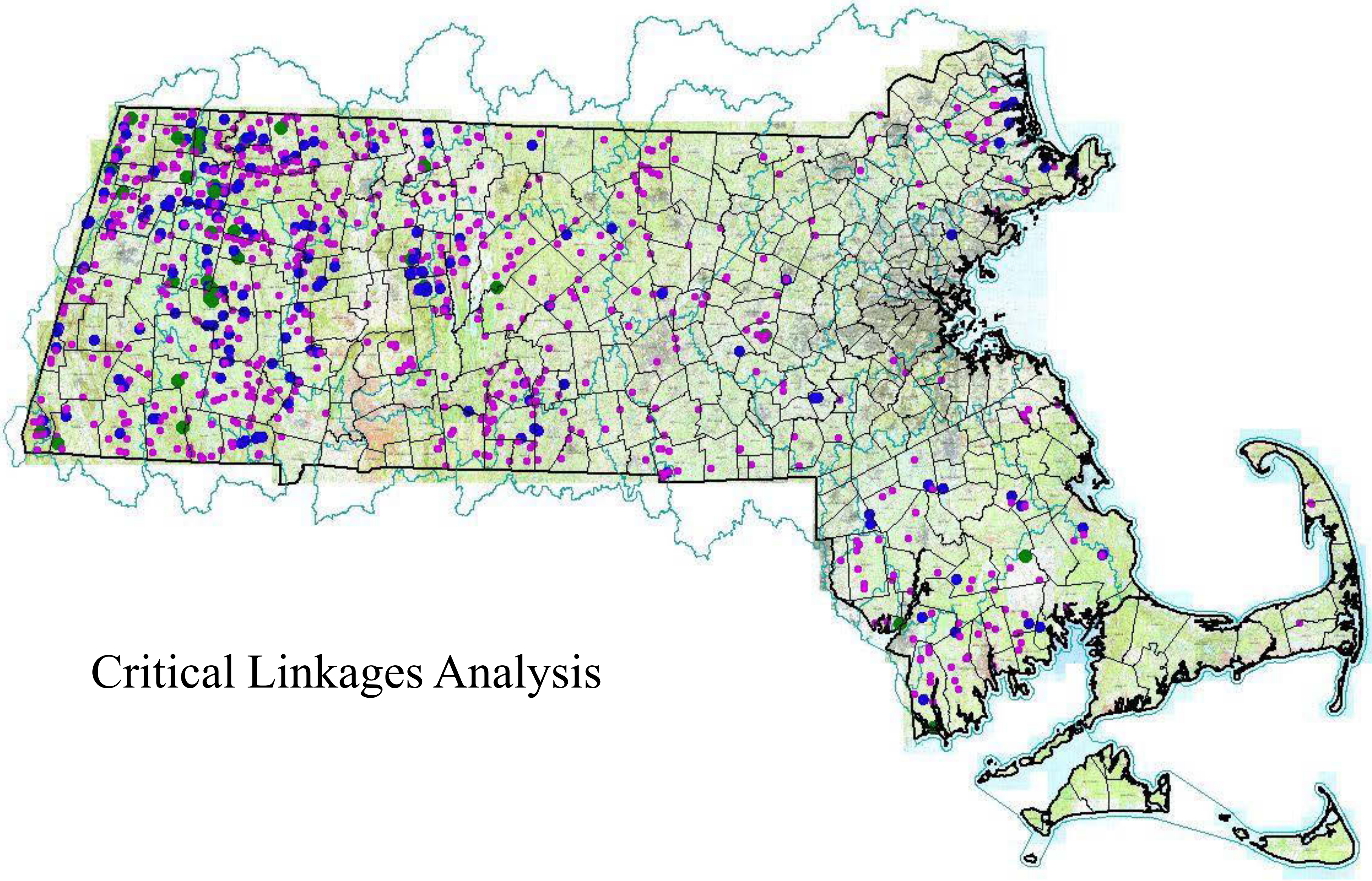
Assessing ecological integrity and supporting decision-making for land conservation, habitat management, project review & permitting to protect biodiversity

Landscape Ecology Lab

UNIVERSITY OF Massachusetts Amherst

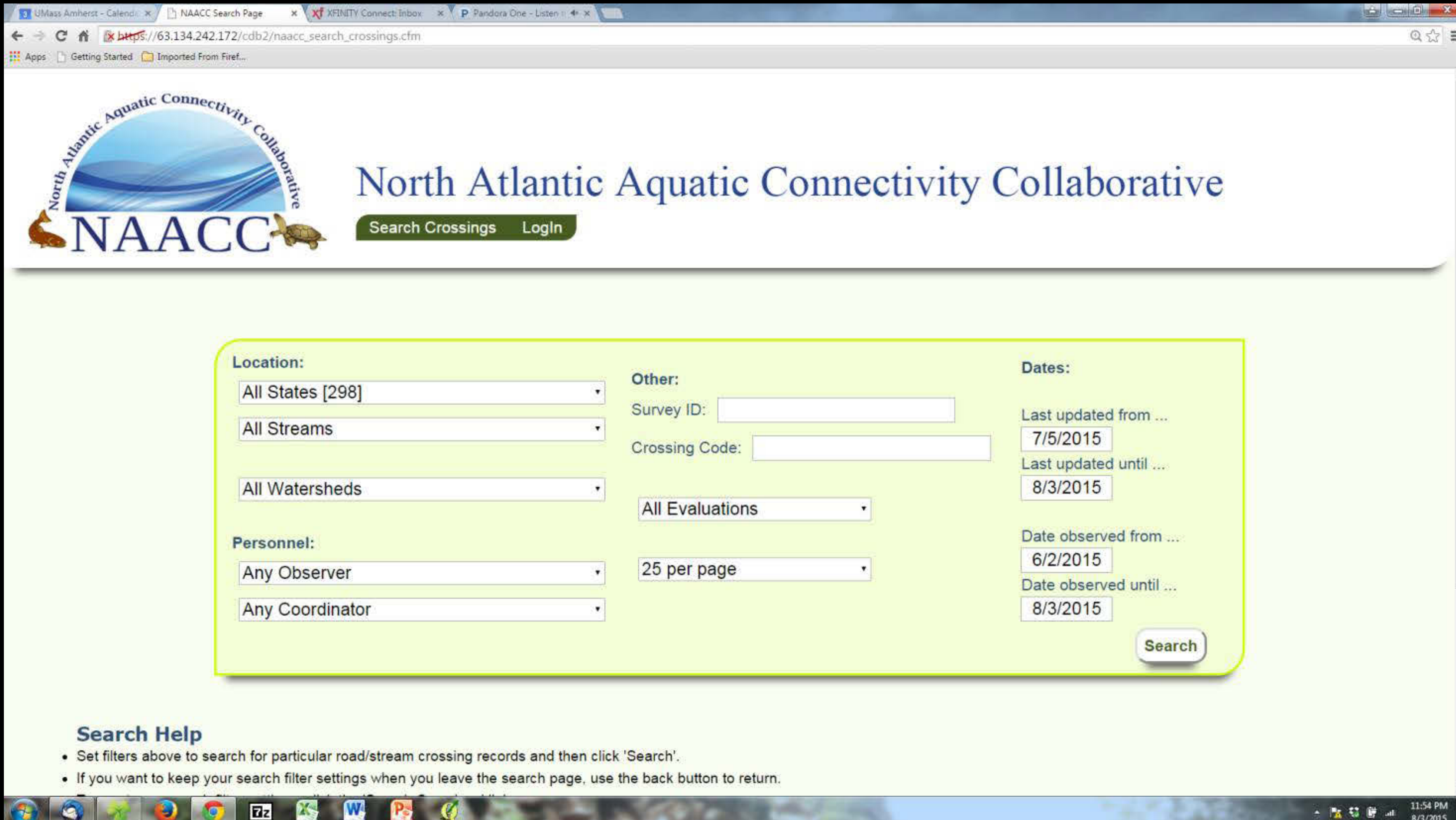
UMassAmherst Outreach UMass Extension

http://www.masscaps.org



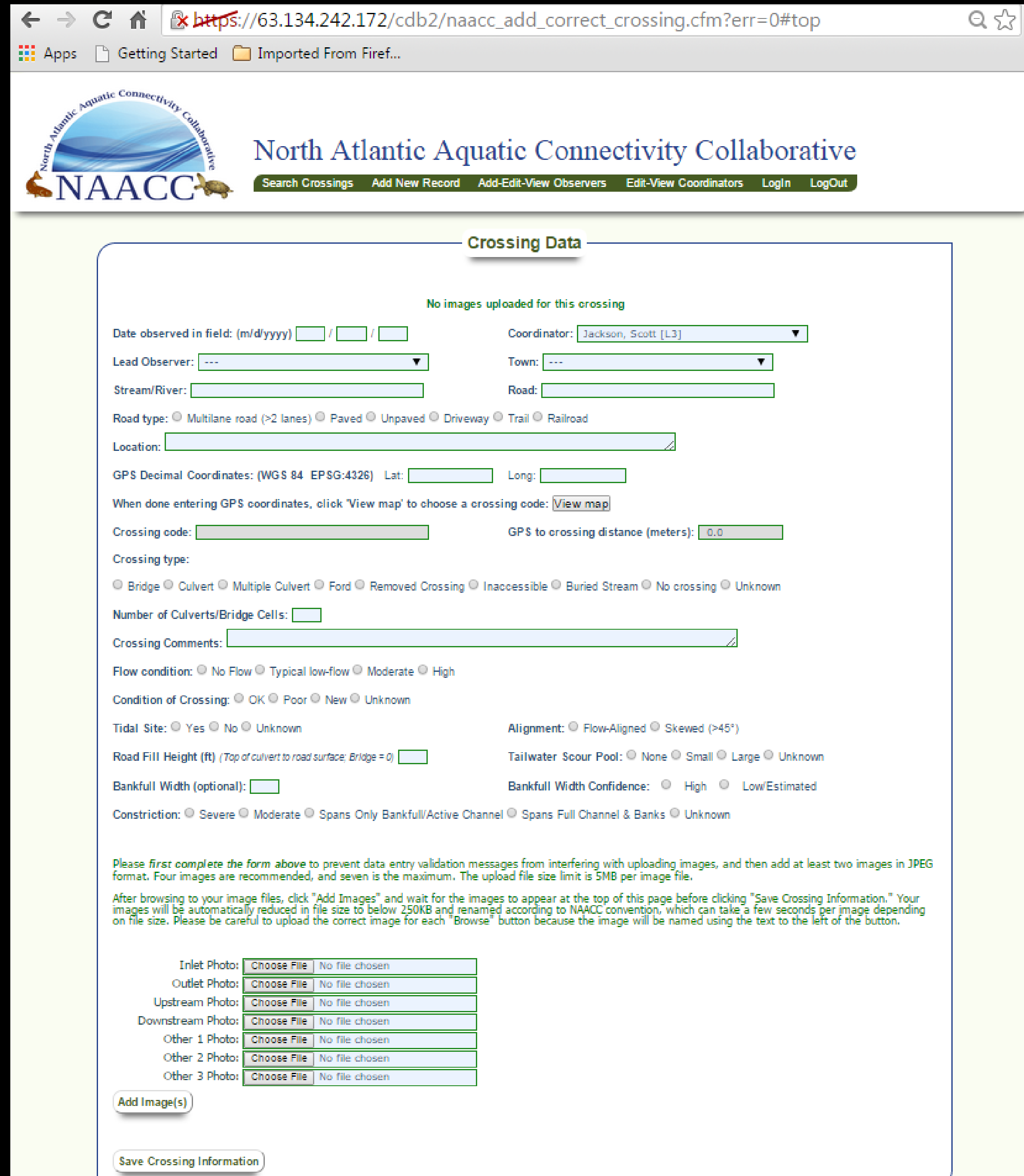
Critical Linkages Analysis

Online Crossings Database

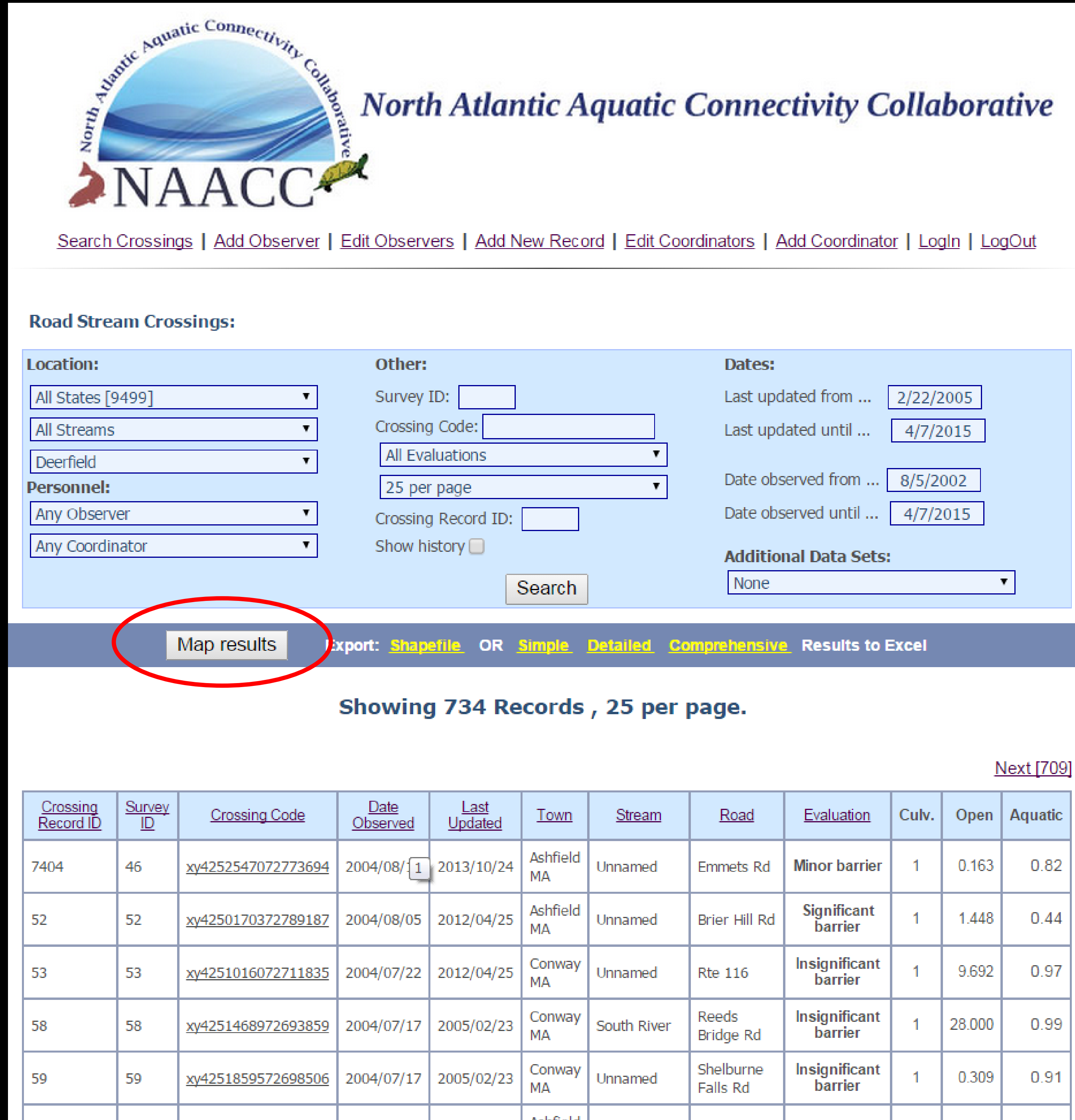


Data Input

- *Paper forms*
- *Electronic data collection*
- *Bulk uploads*



Mapping Support



North Atlantic Aquatic Connectivity Collaborative

NAACC

Search Crossings | Add Observer | Edit Observers | Add New Record | Edit Coordinators | Add Coordinator | LogIn | LogOut

Road Stream Crossings:

Location:
All States [9499]
All Streams
Deerfield

Personnel:
Any Observer
Any Coordinator

Other:
Survey ID:
Crossing Code:
All Evaluations
25 per page
Crossing Record ID:
Show history

Search

Dates:
Last updated from ... 2/22/2005
Last updated until ... 4/7/2015
Date observed from ... 8/5/2002
Date observed until ... 4/7/2015

Additional Data Sets:
None

Map results

Export: Shapefile OR Simple Detailed Comprehensive Results to Excel

Showing 734 Records , 25 per page.

Next [709]

Crossing Record ID	Survey ID	Crossing Code	Date Observed	Last Updated	Town	Stream	Road	Evaluation	Culv.	Open	Aquatic
7404	46	xy4252547072773694	2004/08/1	2013/10/24	Ashfield MA	Unnamed	Emmets Rd	**Minor barrier**	1	0.163	0.82
52	52	xy4250170372789187	2004/08/05	2012/04/25	Ashfield MA	Unnamed	Brier Hill Rd	**Significant barrier**	1	1.448	0.44
53	53	xy4251016072711835	2004/07/22	2012/04/25	Conway MA	Unnamed	Rte 116	**Insignificant barrier**	1	9.692	0.97
58	58	xy4251468972693859	2004/07/17	2005/02/23	Conway MA	South River	Reeds Bridge Rd	**Insignificant barrier**	1	28.000	0.99
59	59	xy4251859572698506	2004/07/17	2005/02/23	Conway MA	Unnamed	Shelburne Falls Rd	**Insignificant barrier**	1	0.309	0.91

https://www.streamcontinuity.org/cdb2/naacc_search_map.cfm - Google Chrome

https://www.streamcontinuity.org/cdb2/naacc_search_map.cfm

Welcome to

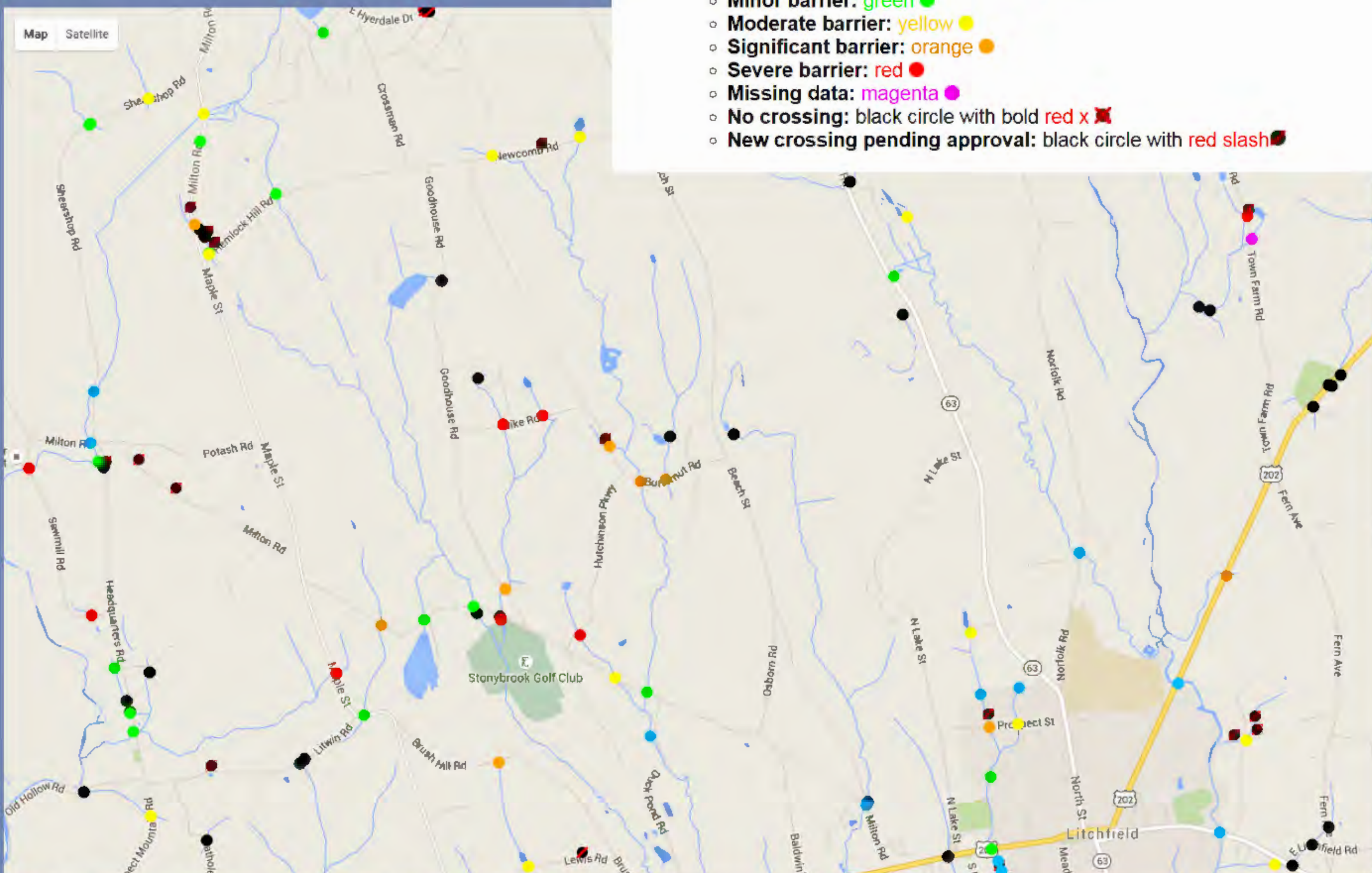
(Note that 1105 of 1116 surveyed records in your search results have been mapped. O

records with du

Map information Click to show/hide map information

Map information Click to show/hide map information

1. The colored circles on the map represent surveyed crossings color coded as follows:
   - **No barrier:** blue
   - **Insignificant barrier:** blue green
   - **Minor barrier:** green
   - **Moderate barrier:** yellow
   - **Significant barrier:** orange
   - **Severe barrier:** red
   - **Missing data:** magenta
   - **No crossing:** black circle with bold red x
   - **New crossing pending approval:** black circle with red slash



Data Reports

- *Excel files*
- *Shapefiles*
- *Mapping interface*

NAACC

North Atlantic Aquatic Connectivity Collaborative

Search Crossings | Add Observer | Edit Observers | Add New Record | Edit Coordinators | Add Coordinator | LogIn | LogOut

Road Stream Crossings:

Location:
All States [9499]
All Streams
Deerfield

Personnel:
Any Observer
Any Coordinator

Other:
Survey ID:
Crossing Code:
All Evaluations
25 per page
Crossing Record ID:
Show history

Search

Dates:
Last updated from ... 2/22/2005
Last updated until ... 4/7/2015
Date observed from ... 8/5/2002
Date observed until ... 4/7/2015

Additional Data Sets:
None

Map results

Export: Shapefile OR Simple Detailed Comprehensive Results to Excel

Showing 734 Records , 25 per page.

Next [709]

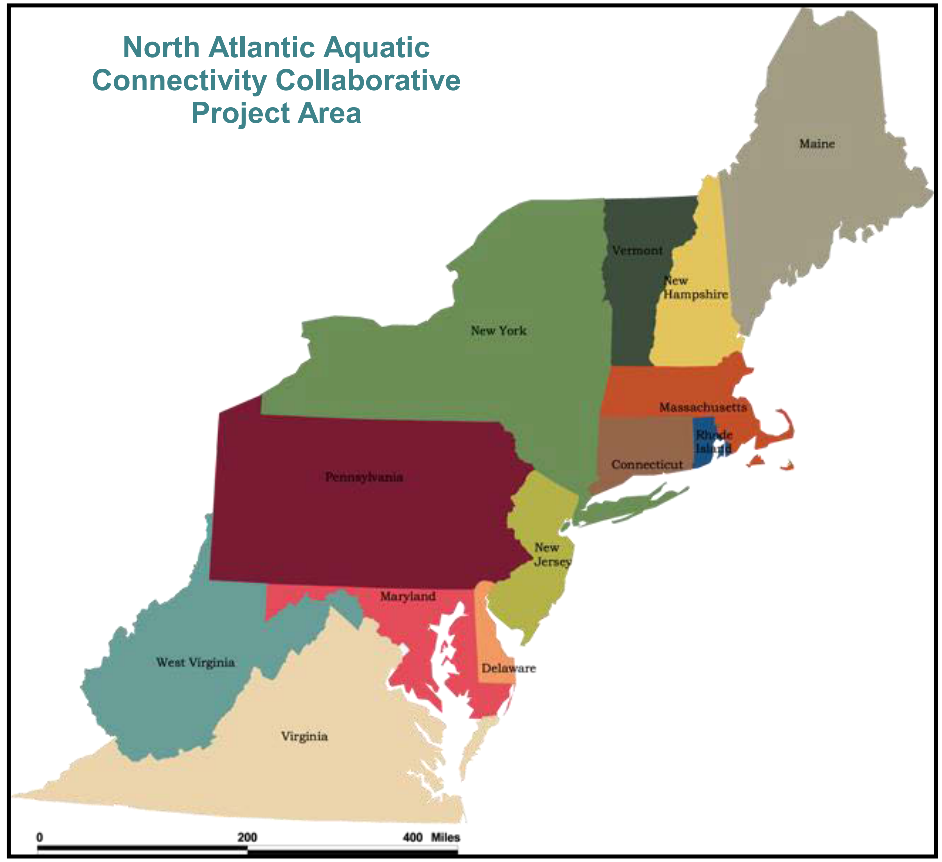
Crossing Record ID	Survey ID	Crossing Code	Date Observed	Last Updated	Town	Stream	Road	Evaluation	Culv.	Open	Aquatic
7404	46	xy4252547072773694	2004/08/[illegible]	2013/10/24	Ashfield MA	Unnamed	Emmets Rd	**Minor barrier**	1	0.163	0.82
52	52	xy4250170372789187	2004/08/05	2012/04/25	Ashfield MA	Unnamed	Brier Hill Rd	**Significant barrier**	1	1.448	0.44
53	53	xy4251016072711835	2004/07/22	2012/04/25	Conway MA	Unnamed	Rte 116	**Insignificant barrier**	1	9.692	0.97
58	58	xy4251468972693859	2004/07/17	2005/02/23	Conway MA	South River	Reeds Bridge Rd	**Insignificant barrier**	1	28.000	0.99
59	59	xy4251859572698506	2004/07/17	2005/02/23	Conway MA	Unnamed	Shelburne Falls Rd	**Insignificant barrier**	1	0.309	0.91
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Ashfield	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Benefits of Citizen-Generated Data

- Prioritizes projects
- Builds partnerships
- Secures funds and technical resources
- Generates Case Studies
- Documents crossing and stream function
- Assesses vulnerability
- Provides comprehensive picture of the problem

Photo: Erika Bailey, TNC

Photo: Bridget MacDonald, LLC



Contacts

Carrie Banks
MA State Coordinator
Carrie.Banks@state.ma.us

Scott Jackson
sjackson@umass.edu

www.streamcontinuity.org

7.4 Pictures of Walker Street Stream Crossing

7.5 Site Visit Preparation

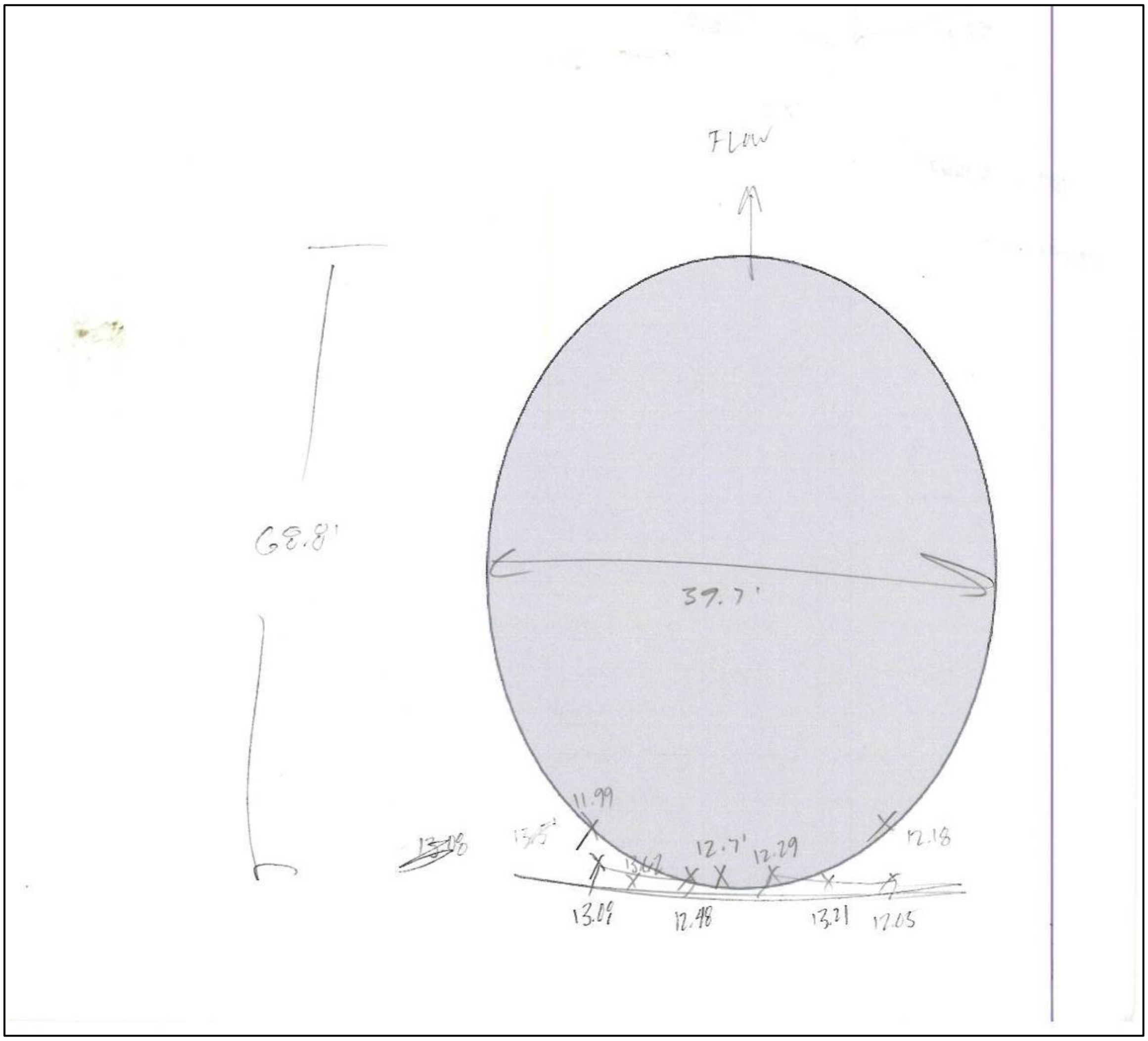
Points of Interest

Elevations:

- Top of bridge
- Top of culverts (72” dia.)
- End of bridge
- Profile of outlet scour pool (0’, 5’, 10’, 20’, get sense of pool size)

- Size of pipe
- Slope of upstream/downstream banks around the crossing
- Angle of approach from upstream
- Angle of pipes across the road
- Distance between culverts
- Width & length of crossing (road)
- Distance From stream bed to bottom of road (for hight of possible culvert)__________
- Variation downstream
- Bankfull measurements
- Stream bed
    - Substrate composition
    - Size and shape
- Substrate in culvert
- Cross sectional area of the pipe_____
- Condition of CMP
- Stream crossing
    - Condition

- Materials
- Repairs
- Structures that impair animal crossing? (steep banks___, high traffic volume___, fencing___, jersey barriers ____, or other)



On-site measurements

7.6 Flow Data Calculation Sheet

Bridle Shiner Requirements

0-0.5 fps
1.5-4 ft depth

CASE	Governing Equation	Flow Description
CASE I	Manning's	Inlet/outlet submerged or lower
CASE II	Head loss	Top of roadway > CASE I
CASE III	Broad-Crested Weir	Road overtopping > CASE II

GOAL: Minimize red in new designs

Description	Gage Flowrate (cfs)	Adjusted Flowrate (cfs)	Velocity (fps)	AR^(2/3)/d^(8/3)	y0/d (from chart)	Hin (ft) (depth @ upstream culvert invert)	Hout (ft)	
EXISTING CULVERT STRUCTURE								
Average Minimum Flow	162.9	122	5	0.11	0.40	2.2	1.9	
Average Maximum Flow	216.6	162	7	0.15	0.50	2.8	2.4	
20% Annual Exceedance Probability (5-year flood)	714.9	536	23	0.49		9.0	5.5	*TW assume*
10% Annual Exceedance Probability (10-year flood)	884.0	663	28	0.61		10.0	9.7	
5% Annual Exceedance Probability (20-year flood)	1059.2	794	33	0.73		10.7	10.3	
2% Annual Exceedance Probability (50-year flood)	1306.2	980	41	0.90		11.4	11.1	
1% Annual Exceedance Probability (100-year flood)	1507.4	1131	48	1.04		12.0	11.6	
0.2% Annual Exceedance Probability (500-year flood)	2032.7	1525	64	1.40		13.2	12.9	
SHORT-SPAN BRIDGE								
Average Minimum Flow	162.9	122	0.5	0.005	0.043	1.0	0.7	
Average Maximum Flow	216.6	162	0.7	0.007	0.045	1.1	0.7	
20% Annual Exceedance Probability (5-year flood)	714.9	536	2.3	0.023	0.12	2.9	2.6	
10% Annual Exceedance Probability (10-year flood)	884.0	663	2.9	0.029	0.14	3.4	3.1	
5% Annual Exceedance Probability (20-year flood)	1059.2	794	3.4	0.035	0.15	3.7	3.3	
2% Annual Exceedance Probability (50-year flood)	1306.2	980	4.2	0.043	0.17	4.1	3.8	
1% Annual Exceedance Probability (100-year flood)	1507.4	1131	4.9	0.049	0.19	4.6	4.3	
0.2% Annual Exceedance Probability (500-year flood)	2032.7	1525	6.6	0.066	0.23	5.6	5.2	
OPEN-BOTTOM ARCH CULVERT								
Average Minimum Flow	162.9	122	1.3	0.005	0.03	0.8	0.4	
Average Maximum Flow	216.6	162	1.7	0.007	0.05	1.3	0.9	
20% Annual Exceedance Probability (5-year flood)	714.9	536	5.6	0.022	0.11	2.8	2.4	
10% Annual Exceedance Probability (10-year flood)	884.0	663	7.0	0.027	0.14	3.5	3.2	
5% Annual Exceedance Probability (20-year flood)	1059.2	794	8.4	0.032	0.15	3.8	3.4	
2% Annual Exceedance Probability (50-year flood)	1306.2	980	10.3	0.040	0.17	4.3	3.9	
1% Annual Exceedance Probability (100-year flood)	1507.4	1131	11.9	0.046	0.19	4.8	4.4	
0.2% Annual Exceedance Probability (500-year flood)	2032.7	1525	16.0	0.062	0.2	5.0	4.7	
REPLACEMENT CULVERT STRUCTURE								
Average Minimum Flow	162.9	122	3	0.06	0.30	2.1	1.8	
Average Maximum Flow	216.6	162	4	0.08	0.25	1.8	1.4	
20% Annual Exceedance Probability (5-year flood)	714.9	536	14	0.26	0.70	4.9	4.6	
10% Annual Exceedance Probability (10-year flood)	884.0	663	17	0.32	1.00	7.0	6.7	
5% Annual Exceedance Probability (20-year flood)	1059.2	794	21	0.38		10.0	9.7	
2% Annual Exceedance Probability (50-year flood)	1306.2	980	25	0.47		10.9	10.6	
1% Annual Exceedance Probability (100-year flood)	1507.4	1131	29	0.55		11.5	11.2	
0.2% Annual Exceedance Probability (500-year flood)	2032.7	1525	40	0.74		12.9	12.5	

Existing Culverts Data

Slope Calcs	
Hin (ft)	95.5
Hout (ft)	95.15
Difference	0.35
Length of pipe (ft)	40.6
Slope of pipe (ft/ft)	0.00862

Headwater Calcs	
Diameter of pipe (ft)	5.5
Area of the pipe (ft^2)	23.76
Pi	3.14159
Mannings Coefficient	0.015
Elevation at top of road (ft)	104.4
Invert--->Top of Road (ft)	8.9
Full Flow Hydraulic Radius	1.375
Roughness coefficient (n)	0.024
CASE I (cfs)	339
Kn	1.49
Roughness coefficient (n)	0.024
Entrance loss coefficient (Ke)	0.5
fL/4R	0.4437
	530
Cd	0.44
CASE II (cfs)	868
Cw	3.1
Bankfull width	29.3
L (1.2*bankull)	35.16

Larger Culverts Data

Slope Calcs			
Hin (ft)	95.5		
Hout (ft)	95.15		
Difference	0.35		
Length of pipe (ft)	40.6		
Slope of pipe (ft/ft)	0.00862		

Diameter of pipe (ft)	7		
Area of the pipe (ft^2)	38.48		
Pi	3.14159		
Mannings Coefficient	0.015		
Elevation at top of road (ft)	104.4		
Invert--->Top of Road (ft)	8.9		
Full Flow Hydraulic Radius	1.75		
Roughness coefficient (n)	0.024		
CASE I (cfs)	644		full flow
Kn	1.49		
Roughness coefficient (n)	0.024		
Entrance loss coefficient (Ke)	0.5		
fL/4R	0.3217		
	686		
CASE II (cfs)	1331		663
Cw		3.1	
Bankfull width		29.3	
L (1.2*bankull)		35.16	

Open-Bottom Arch Culvert Data

Slope Calcs	
Hin (ft)	95.5
Hout (ft)	95.15
Difference	0.35
Length of pipe (ft)	40.6
Slope of pipe (ft/ft)	0.00862

Headwater Calcs	
bottom width (ft)	25
Area (ft^2)	95.00
Pi	3.14159
Mannings Coefficient	0.03
Elevation at top of road (ft)	104.4
Invert--->Top of Road (ft)	6.9
Full Flow Hydraulic Radius	6.25
Roughness coefficient (n)	0.03
CASE I (cfs)	2973
Kn	1.49
Roughness coefficient (n)	0.03
Entrance loss coefficient (Ke)	0.5
fL/4R	0.0921
	#NUM!
Cd	
CASE II (cfs)	#NUM!
Cw	3.1
Bankfull width	29.3
L (1.2*bankull)	35.16

Short-Span Bridge Data

Slope Calcs	
Hin (ft)	95.5
Hout (ft)	95.15
Difference	0.35
Length of pipe (ft)	40.6
Slope of pipe (ft/ft)	0.00862

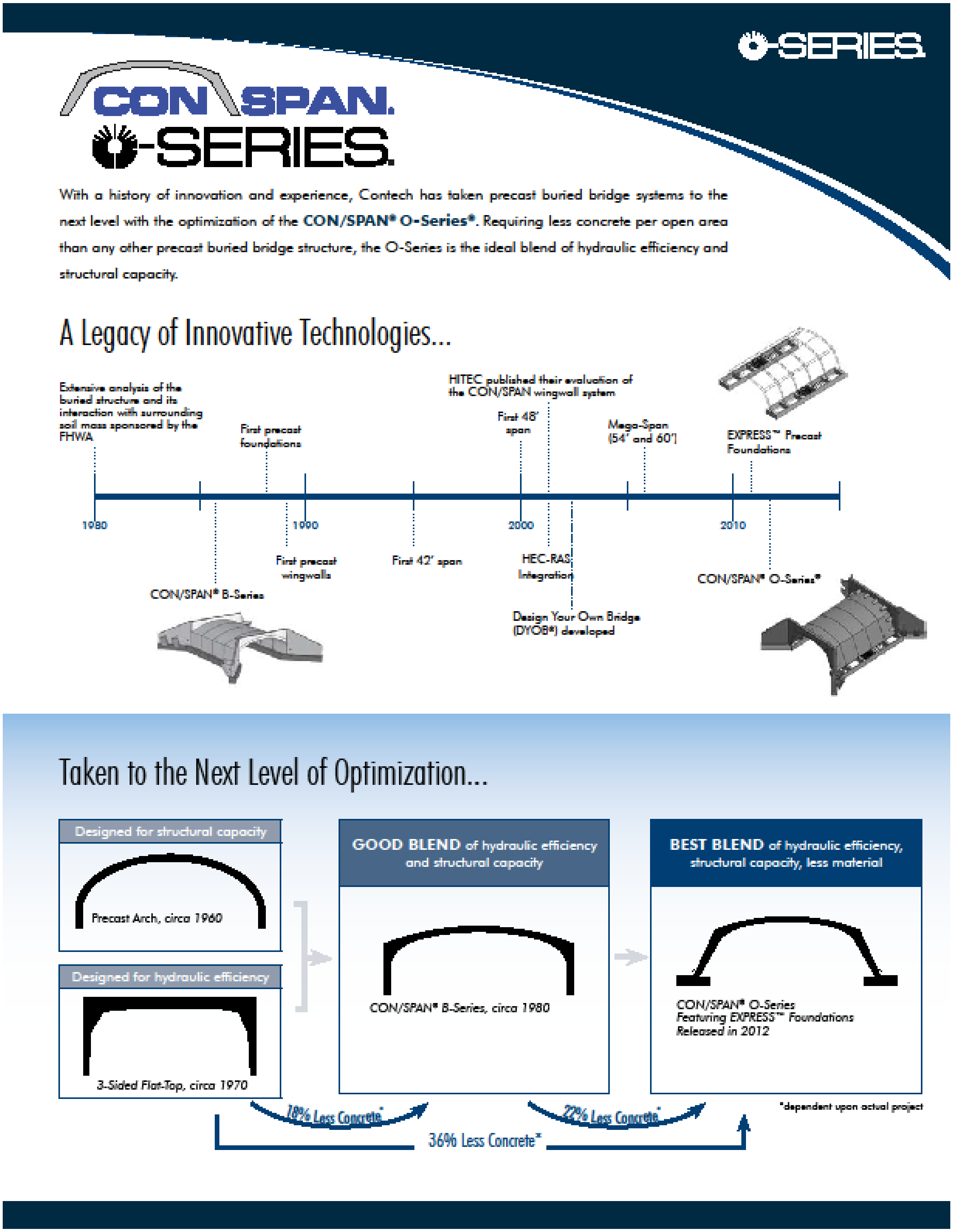
Headwater Calcs					
bottom width (ft)	24.34		measured from autocad	top width	41.6
Area (ft^2)	231.30		assume trapezoidal area	side slope	0.635
Pi	3.14159			height	7
Mannings Coefficient	0.03				
Elevation at top of road (ft)	104.4				
Invert--->Top of Road (ft)	6.9				
Full Flow Hydraulic Radius	6.085				
Roughness coefficient (n)	0.03				
CASE I (cfs)	7110				
Kn	1.49				
Roughness coefficient (n)	0.03				
Entrance loss coefficient (Ke)	0.5				
fL/4R	0.0954				
	#NUM!				
Cd					
CASE II (cfs)	#NUM!				
Cw		3.1			
Bankfull width		29.3			
L (1.2*bankull)		35.16			

7.7 Bankfull & Depth Measurements

	BANKFULL WIDTH			
	Inlet (ft)	Outlet (ft)		
	49.7	22.0		
	33.4	23.0		
	31.3	22.8		
	29.3			Bridge Span
Average:	**35.9**	**22.6**	29.3	35.1

CALCULATING INNER DEPTHS									
Location	Outer Depth (ft)	Submerged Length of Rod (ft)	Unsubmerged Length of Rod (ft)	Water Level to End of Rod (ft)	Angle (rad)	Hor. Distance from End of Rod to Rod Entry (ft)	Hor. Distance from Rod Entry to Location (ft)	Distance from Outer Depth to Location (ft)	Depth at Location (ft)
A	2.5	10.2	5.8	2.5	0.4456	5.2	9.2	14.4	**4.4**
B	1.3	10.0	6.0	3.7	0.6645	4.7	7.9	12.6	**6.2**
C	0.9	8.5	7.5	4.1	0.5784	6.3	7.1	13.4	**4.6**
D	0.7	5.5	10.5	4.3	0.4219	9.6	5.0	14.6	**2.3**
E	0.6	5.8	10.2	4.4	0.4460	9.2	5.2	14.4	**2.5**
F	0.8	7.7	8.3	4.3	0.5446	7.1	6.6	13.7	**4.0**
G	1.4	10.6	5.4	3.6	0.7297	4.0	7.9	11.9	**7.1**
H	1.6	11.1	4.9	3.5	0.7956	3.4	7.8	11.2	**7.9**

7.8 Contech® CON/SPAN® O-Series® Brochure (pdf)



O-SERIES

CON/SPAN. O-SERIES.

With a history of innovation and experience, Contech has taken precast buried bridge systems to the next level with the optimization of the **CON/SPAN® O-Series®**. Requiring less concrete per open area than any other precast buried bridge structure, the O-Series is the ideal blend of hydraulic efficiency and structural capacity.

A Legacy of Innovative Technologies...

Extensive analysis of the buried structure and its interaction with surrounding soil mass sponsored by the FHWA

First precast foundations

HITEC published their evaluation of the CON/SPAN wingwall system

First 48' span

Mega-Span (54' and 60')

EXPRESS™ Precast Foundations

1980

1990

2000

2010

CON/SPAN® B-Series

First precast wingwalls

First 42' span

HEC-RAS Integration

Design Your Own Bridge (DYOB®) developed

CON/SPAN® O-Series®

Taken to the Next Level of Optimization...

Designed for structural capacity

Precast Arch, circa 1960

Designed for hydraulic efficiency

3-Sided Flat-Top, circa 1970

GOOD BLEND of hydraulic efficiency and structural capacity

CON/SPAN® B-Series, circa 1980

BEST BLEND of hydraulic efficiency, structural capacity, less material

CON/SPAN® O-Series
Featuring EXPRESS™ Foundations
Released in 2012

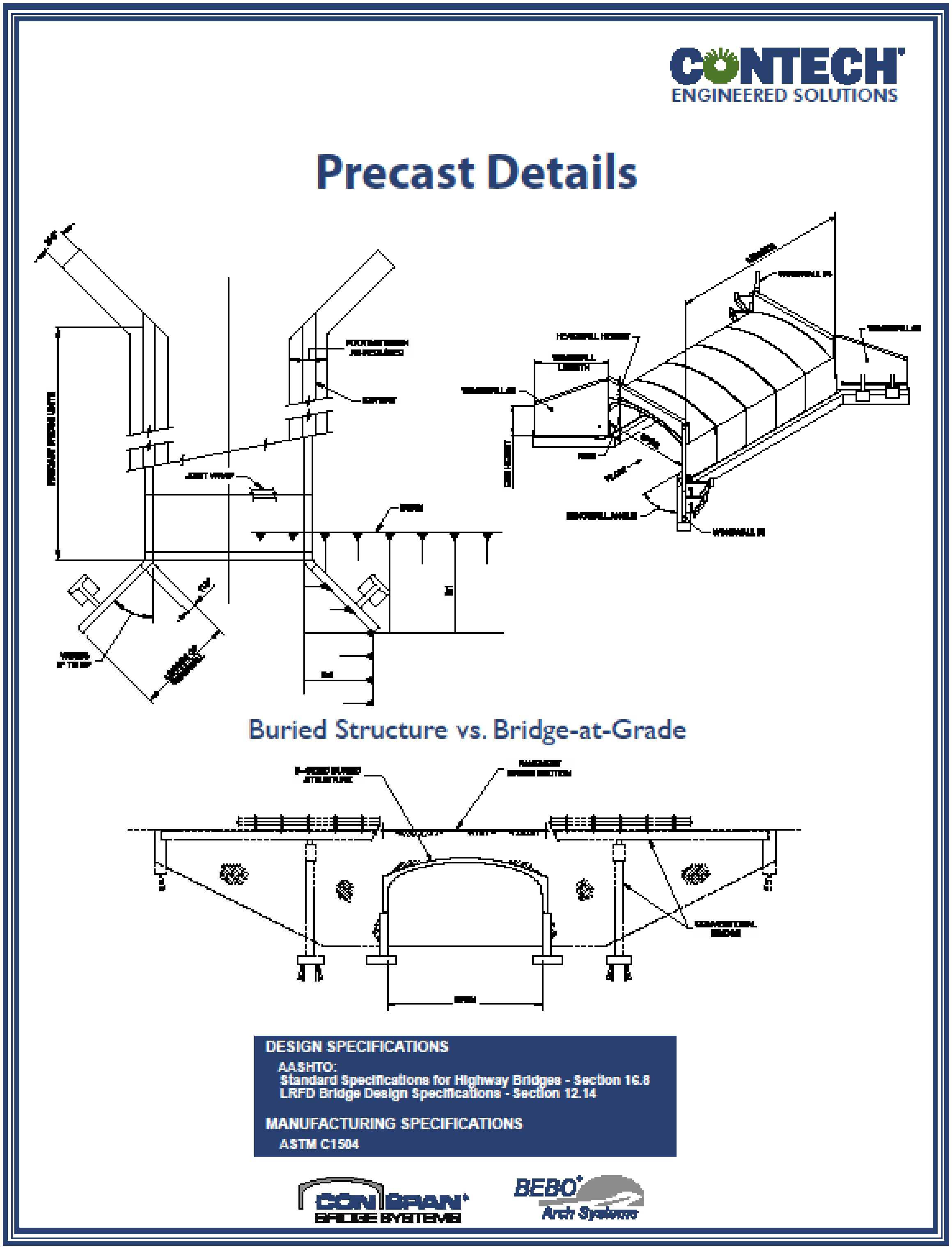
18% Less Concrete*

22% Less Concrete*

36% Less Concrete*

*dependent upon actual project

7.9 Contech® Precast Details (pdf)


CONTECH
ENGINEERED SOLUTIONS

Precast Details

Buried Structure vs. Bridge-at-Grade

DESIGN SPECIFICATIONS

AASHTO:
Standard Specifications for Highway Bridges - Section 16.8
LRFD Bridge Design Specifications - Section 12.14

MANUFACTURING SPECIFICATIONS

ASTM C1504

CON/SPAN BRIDGE SYSTEMS

BEBO Arch Systems

7.10 NHESP Meeting Summary

On February 24 at 9:00am the project team of Jackson Krupnick, Julia Pershken, Professor Mathisen and Ms. Carlino arrived at the Massachusetts Natural Heritage and Endangered Species Program (NHESP) office in Westborough, Massachusetts. We met with David Paulson, a senior endangered species review biologist, to discuss the implications of our culvert design on the state-listed endangered species inhabiting Eastern Massachusetts, specifically in the Taunton River watershed.

We first discussed the scope of our project and our proposed culvert designs detailing the criteria we were aiming to meet and the advantages and disadvantages of each. We explained that we had looked into the stream requirements for Bridle Shiners, an endangered minnow species found in the Wading River. We noticed that the velocities and depths associated with every flood level are too extreme for the bridle shiners, but a new culvert design might be able to accommodate them at normal flow conditions.

Mr. Paulson expressed that our recommended arch culvert design was satisfactory and even exceeded his expectations. He then addressed the issue we had brought up in regards to flood velocities and depths. He stated that this issue was going to be unavoidable regardless of the hydraulic structure and that as long as we worked to improve the conditions as much as possible the NHESP would approve the design. He then suggested a number of improvements to our design that would improve the habitat and upstream passage for the bridle shiners. These suggestions included rip-rapped banks, streambed armoring, and artificial eddies beneath the structure.

At the end of the meeting, Mr. Paulson gave us more material on Massachusetts endangered species and the official approval process. Some useful resources are provided below:

- Massachusetts Department of Transportation Design Requirements and Submittals for New Bridge and Full Bridge Replacement Projects https://www.massdot.state.ma.us/Portals/8/docs/smallBridge/DesignRequirements.pdf
- Masschusetts Department of Transportation Municipal Small Bridge Program http://www.massdot.state.ma.us/highway/DoingBusinessWithUs/LocalAidPrograms/MunicipalSmallBridgeProgram/ProgramDescription/ReviewandApprovalProcess.aspx
- Massachusetts Emergency Management Agency Pre-Disaster Mitigation (PDM) Grant Program http://www.mass.gov/eopss/agencies/mema/resources/grants/pdm/
- Massachusetts Endangered Species Act Project Review Checklist http://www.mass.gov/eea/docs/dfg/nhesp/regulatory-review/mesa-proj-review-check-elect.pdf
- Natural Heritage and Endangered Species Program Regulatory Review
- http://www.mass.gov/eea/agencies/dfg/dfw/natural-heritage/regulatory-review/