

Boylston Culvert Assessment Report



Prepared by CMRPC Transportation staff



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1. Background

The Central Massachusetts Regional Planning Commission (CMRPC) began its Culvert Assessment Program in FFY 2021 as part of its Unified Planning Work Program (UPWP). As part of CMRPC's other data collection efforts, culvert assessments focus primarily on federal-aid eligible roads in the planning region. The purpose of this program is to help communities build resiliency through flood risk protection and mitigation by identifying culvert locations and prioritizing undersized culverts for replacement or restoration. This is especially important as the impacts from climate change and severe weather become increasingly frequent and many culverts are undersized relative to current stream flows. The [CMRPC Water Module](#) provides more detail regarding the threats of climate change and the impacts of vulnerable culverts on transportation infrastructure, emergency services, inland buildings, economic loss, and more.

To assess culverts staff have received training and guidance from the North Atlantic Aquatic Connectivity Collaborative (NAACC) – a network focused on the aquatic passability at road-stream crossings.

The goal of the CMRPC culvert assessments and inventory for the Town of Boylston is to provide a detailed list, report, and interactive mapping platform to help town officials identify and plan for culvert replacement or repairs.

North Atlantic Aquatic Connectivity Collaborative (NAACC)

The NAACC began in 2015 with startup funding from the North Atlantic Landscape Conservation Cooperative (NALCC) and US Department of the Interior (DOI) Hurricane Sandy Mitigation funds. The funds were used by the University of Massachusetts Amherst to convene a group of partners to develop a unified protocol for assessing aquatic passability at road-stream crossings and develop a programmatic infrastructure to support crossing assessments. As part of its efforts, the NAACC has:

- Developed a unified protocol, data form, scoring system, and database for road-stream crossing assessments to identify bridges and culverts that are problematic from an aquatic connectivity perspective.
- Launched in-person and online training and certification program to ensure data quality.
- Created online database for crossing assessment data.
- Developed web-based tools.
- Encouraged and supported efforts to conduct crossing assessments throughout the region.

The NAACC has separate protocols for both non-tidal and tidal streams, and they partner with the Massachusetts Division of Ecological Restoration (DER) to provide training and advise the group.

To ensure data quality the NAACC has set up a hierarchy of roles to maintain training, assessments, and data. It has separated these roles into three main categories, as summarized in **Table 1** on the following page.

Table 1: NAACC Roles, Responsibilities, and Training Requirements

Roles	Responsibilities	Training Requirements
L3 (Level 3) Coordinator	<ul style="list-style-type: none"> • Update field protocols • Create/update scoring systems • Develop QA/QC procedures • Maintain the online database • Spread news/updates to NAACC community 	<p>Must be referred to by other Central Coordinators</p>
L2 (Level 2) Coordinator	<ul style="list-style-type: none"> • Oversee surveys in their geographic area • Recruit/supervise L1 Coordinators • Coordinate training • Ensure implementation of QA/QC procedures • Add/edit data and add/edit Lead Observers 	<ul style="list-style-type: none"> • Certification as a Lead Observer • Online Coordinator training unit • Pass online Coordinator training unit test
L1 (Level 1) Coordinator	<ul style="list-style-type: none"> • Recruit/supervise Lead Observers • Create maps and determine survey locations • Establish standards and expectations for safety • Ensure adherence to protocols and QA/QC procedures • Field audit 10% of a Lead Observer's first 50 records • Review and approve data entered into database • Add/edit data, and add/edit Lead Observers 	<ul style="list-style-type: none"> • Certification as a Lead Observer • Online Coordinator training unit • Must pass online Coordinator training unit test
Lead Observer	<ul style="list-style-type: none"> • Lead survey teams • Coordinate survey materials and schedules • Collect field data • Match survey locations to xy codes • Ensure assessments are done safely • Enter data into online database 	<ul style="list-style-type: none"> • Non-tidal protocol training (in-person/online) and pass quiz • Non-tidal field training • Shadow a certified Lead Observer/Coordinator (20 crossings)

Currently, CMRPC staff have one L1 Coordinator and two Lead Observers to assess and enter data into the NAACC online database. CMRPC also partners with the NAACC and other properly trained entities to host trainings within the region when available. Training others in the region to assess culverts is essential as there is an overwhelming number of culverts to assess. According to the GIS data provided by the NAACC there are over 5,000 culverts in the CMRPC region. The majority of these culverts have not been assessed. By training others in the region, especially municipal staff, everyone can work together to assess all culverts in the region sooner rather than later.

Assessments

Culvert assessments in the Town of Boylston were conducted in 2024. There are about 66 culverts and small bridge structures in the Town of Boylston and 19 structures along federal-aid eligible roadways. CMRPC staff visited all known structures along federal-aid eligible roads that were located in the NAACC GIS inventory to conduct an assessment. There was one other culvert that was not along a federal-aid eligible roadway that was also assessed by staff. This culvert was very close to another culvert that was being assessed and part of the same stream. Therefore, a total of 20 assessments were completed by staff. In total, a total of 23 culverts have been completed in the Town of Boylston (others have been completed by individuals other than CMRPC staff).

Assessments included the verification of the structure location, NAACC non-tidal field assessment, and associated photos of the inlet, outlet, upstream, and downstream (if possible). The data collected during these assessments can be found both in this report as well as in an ArcGIS Online Dashboard.

Not included in the CMRPC culvert assessment efforts are:

- Inspection of bridges (these are regularly inspected by MassDOT)
- Inspection of the interior of the culverts
- Hydraulic analysis or structural analysis
- Inspection of culverts along Interstates or dangerous areas along state routes
- Inspection of culverts along non-federal aid eligible roadways

ArcGIS Online Dashboard

In addition to this report, which includes a table and a map, CMRPC has developed an interactive ArcGIS Online Dashboard to display the data. The Dashboard includes a map, interactive filters to view barrier types or zoom to individual culvert locations; a search bar for streets/addresses or crossing codes; and interactive data charts.

The Dashboard is available to share for public use and is a great resource for the town to map and identify assessed and non-assessed culverts.

[Click here to view the Town of Boylston Culvert Dashboard.](#)

Grants and Future Repairs

The NAACC scoring system can be used to help identify culverts that may be in need of repairs or replacement. The barrier types can be used to determine which culverts should be prioritized relative to

the others. Section 4 will review some recommendations for priority culverts based on these scores. In addition, culvert projects can be very costly and difficult for a town to afford. Section 4 will also review grant opportunities to help fund culvert repair and replacement projects. And finally, Section 4 will also outline resources that help provide technical assistance for culvert repair or replacement projects.

2. Definitions

Culvert

According to MassDOT, a culvert is a structure with a span of less than 10 feet in length that supports a roadway or other access way over a stream or waterbody. According to the MassDOT Roadway Culverts GIS Layer, MassDOT have a total of 5,863 culverts in their statewide online database, which includes 12 culverts in the Town of Boylston.¹

[See the Town of Boylston Culvert Dashboard for more information.](#)

Small Bridge

According to MassDOT, a small bridge is a structure with a span between 10 feet and 20 feet that supports a roadway or other access way over a water body or stream. These are categorized as “BRI” structures. According to the MassDOT Bridges GIS Layer, there are two small bridges in the Town of Boylston. Both of these structures are owned by the Town of Boylston.²

[See the Town of Boylston Culvert Dashboard for more information.](#)

Bridge

According to MassDOT, a bridge is a structure with a span of 20 feet or greater. These are categorized as National Bridge Inventory (NBI) structures. MassDOT inspects NBI bridges on a bi-annual basis. According to the MassDOT Bridges GIS Layer, there are two bridges in the Town of Boylston. Both of these structures are owned by MassDOT.²

[See the Town of Boylston Culvert Dashboard for more information.](#)

CMRPC Culvert Assessments

CMRPC used the **NAACC Non-Tidal Aquatic Connectivity Stream Crossing Survey Data Form** (see **Appendix 1** for a copy of the form) to assess culvert structures in the Town of Boylston. CMRPC digitized the paper form into an ArcGIS Survey123 to improve field data collection and overall efficiency. In addition to images of the inlet, outlet, upstream, and downstream, data that is collected for an assessment includes:

- Crossing type
- Alignment
- Structure material
- Flow conditions
- Scour pool
- Outlet dimensions

¹ https://geodot-massdot.hub.arcgis.com/datasets/fe0b508f917242a39dbe5c43c757f21e_0/explore?location=42.050162%2C-71.672058%2C8.73

² <https://geodot-massdot.hub.arcgis.com/datasets/MassDOT::bridges/explore>

- Inlet dimensions
- Length
- Internal Structures
- Substrate
- Physical barriers
- Water depth/velocity
- Dry passage/height above dry passage

The completed assessment data for a culvert is then uploaded to the [NAACC Data Center](#) where it receives scoring for Aquatic Passability and Barrier Type (see **Appendix 2** to review the scoring system). CMRPC uses the numeric scoring system defined by the NAACC to record and map the Barrier Type of culverts. For mapping purposes, NAACC bases the following narrative descriptors for different ranges of aquatic passability and barriers on **Table 2** below.

Table 2: NAACC Culvert Aquatic Passability Scoring Categories*

Aquatic Passability Score	Barrier Type
1.00	No Barrier
0.80 - 0.99	Insignificant Barrier
0.60 - 0.79	Minor Barrier
0.40 - 0.59	Moderate Barrier
0.20 - 0.39	Significant Barrier
0.00 - 0.19	Severe Barrier

**Please Note: The relationship between these categories and the actual passability for fish and other aquatic organisms is relatively unknown and is still a fruitful area for future research. The concept of aquatic passability is complicated and includes many variables that make it difficult to create a definitive scoring system. The best way to approach these aquatic passability scores and barrier types is that they represent the degree to which a crossing deviates from an ideal. It is assumed that crossings that are very close to the ideal (scores over 0.6) will present only minor or insignificant barriers to aquatic organisms. Structures that are farthest from the ideal (scores below 0.4) are likely to be either significant or severe barriers.*

The NAACC Data Center includes an individual assessment report for each culvert, which has its images, data, and scoring results.

3. Culvert Inventory and Results

Overview

As was previously mentioned, there are about 66 structures in the Town of Boylston and 19 culverts and small bridges along federal-aid eligible roads. A few other structures have been assessed in the past using NAACC protocols, making a total of 23 assessments in the Town of Boylston to date.

Staff completed culvert assessments along federal-aid eligible roads in the Town of Boylston. These included:

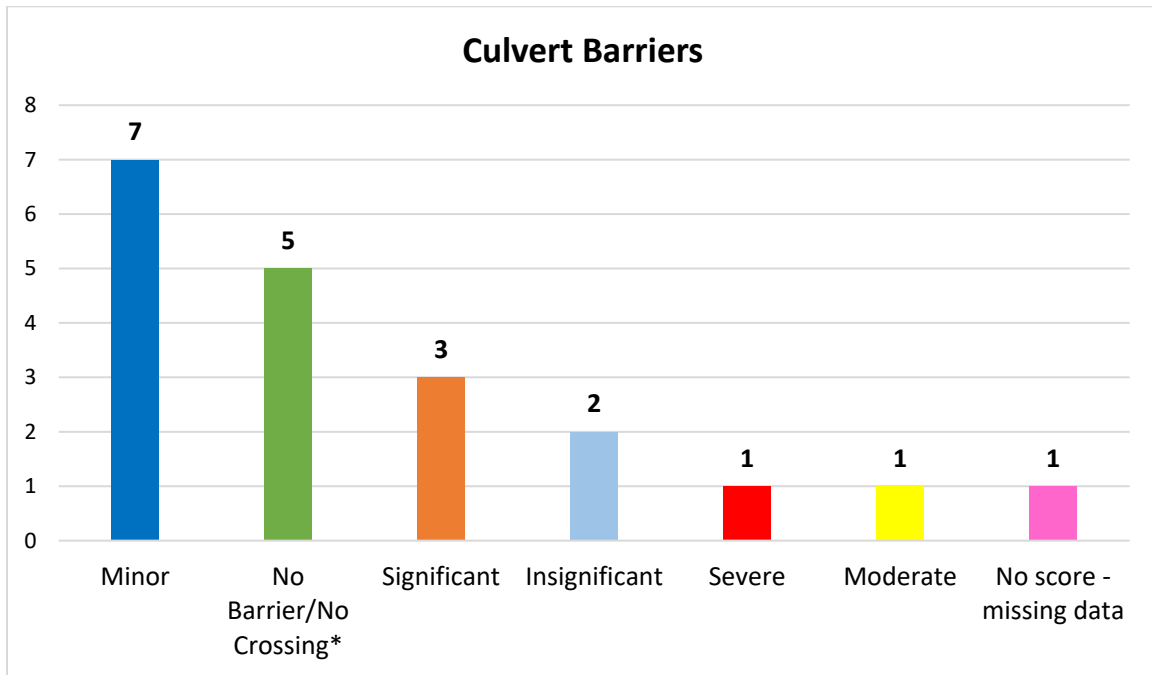
- Main Street (Route 70)
- French Drive
- Central Street
- School Street
- West Boylston Street (Route 140)
- Shrewsbury Street (Route 140)

As a reminder, staff do not consider Interstates as part of data collection efforts.

Culvert Results

In total, CMRPC staff assessed 19 locations along the federal-aid eligible roads and 1 culvert not along a federal-aid eligible road, as mentioned previously. Below, **Figure 1** displays the 2024 CMRPC assessment results grouped by Barrier Type, as previously defined in Section 2.

Figure 1: 2024 Town of Boylston CMRPC Assessment Results by Barrier



**Culverts that are labeled as “No Crossing” receive a score of “No Barrier” in the NAACC Scoring System. In this case, all five of the culverts with the score of “No Barrier” are a “No Crossing”, meaning staff did not find a culvert at this location.*

On the following page, **Table 3** summarizes the results for each assessment. The table includes the NAACC Crossing Code, Road Name, Aquatic Passability (AP) Score, Barrier Type, if the culvert is within a flood zone, and relevant notes. There were several locations on the NAACC GIS layer that did not have any culverts when visited in the field. Those locations are also noted in the table. The crossing code can be clicked to view the structure on the NAACC Data Center for a full report of the structure, including its images and assessment data.

Table 3: 2024 Town of Boylston CMRPC Assessment Results

Crossing Code <i>click to view record on NAACC Data Center</i>	Road	Score	Barrier Type	Flood Zone	MassDOT Culvert	Notes
xy4234410571761204	West Boylston Street	0.00	Severe Barrier	Yes - 100 year flood zone		Downstream is reservoir, cascading outlet
xy4233353371727858	Shrewsbury Street	0.22	Significant Barrier	Yes - 500 year flood zone	Yes	Large scour pool, outlet free fall
xy4232370571756555	Main Street	0.27	Significant Barrier	No	Yes	Almost dry, concrete beginning to deteriorate
xy4237965371704594	Main Street	0.37	Significant Barrier	No		Inlet drop, physical barrier (debris, sediment, rock)
xy4236912671723754	Main Street	0.58	Moderate Barrier	Yes - 500 year flood zone	Yes	Beaver dam at outlet, physical barrier (debris, sediment, rock)
xy4238918271689506	Main Street	0.62	Minor Barrier	Yes - 100 year flood zone	Yes	Old metal pipe rusted out, culvert half full of sediment
xy4234574771734256	School Street	0.63	Minor Barrier	Yes - 500 year flood zone		Drainage pipe at outlet
xy4233389571726442	School Street	0.66	Minor Barrier	Yes - 500 year flood zone		

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xy4232736271749388	Main Street	0.67	Minor Barrier	No	Yes	Dry
xy4233974071744316	Main Street	0.71	Minor Barrier	No	Yes	
xy4234795771706550	Central Street	0.72	Minor Barrier	No		
xy4235761471732526	Main Street	0.74	Minor Barrier	No	Yes	Poison ivy, inlet headwall deterioration and falling apart
xy4237878171707648	Main Street	0.83	Insignificant Barrier	No	Yes	
xy4233852871692681	Central Street	0.93	Insignificant Barrier	Yes - 500 year flood zone		Large open bottom culvert
xy4237961571704470	Main Street	1.00	No Barrier	No		No Crossing
xy4237117671719662	Main Street	1.00	No Barrier	No		No Crossing
xy4233152271746584	Main Street	1.00	No Barrier	No		No Crossing
xy4235732771731404	French Drive	1.00	No Barrier	No		No Crossing
xy4235714671730109	French Drive/Fuller Drive	1.00	No Barrier	No		No Crossing
xy4238261471702555	Main Street		No score-missing data	No	Yes	Partially inaccessible - could not locate inlet, could be buried

Figure 2 on the following page shows a map of the assessment results in the Town of Boylston. The map shows culverts by barrier type, federal-aid eligible roads, and Interstates.

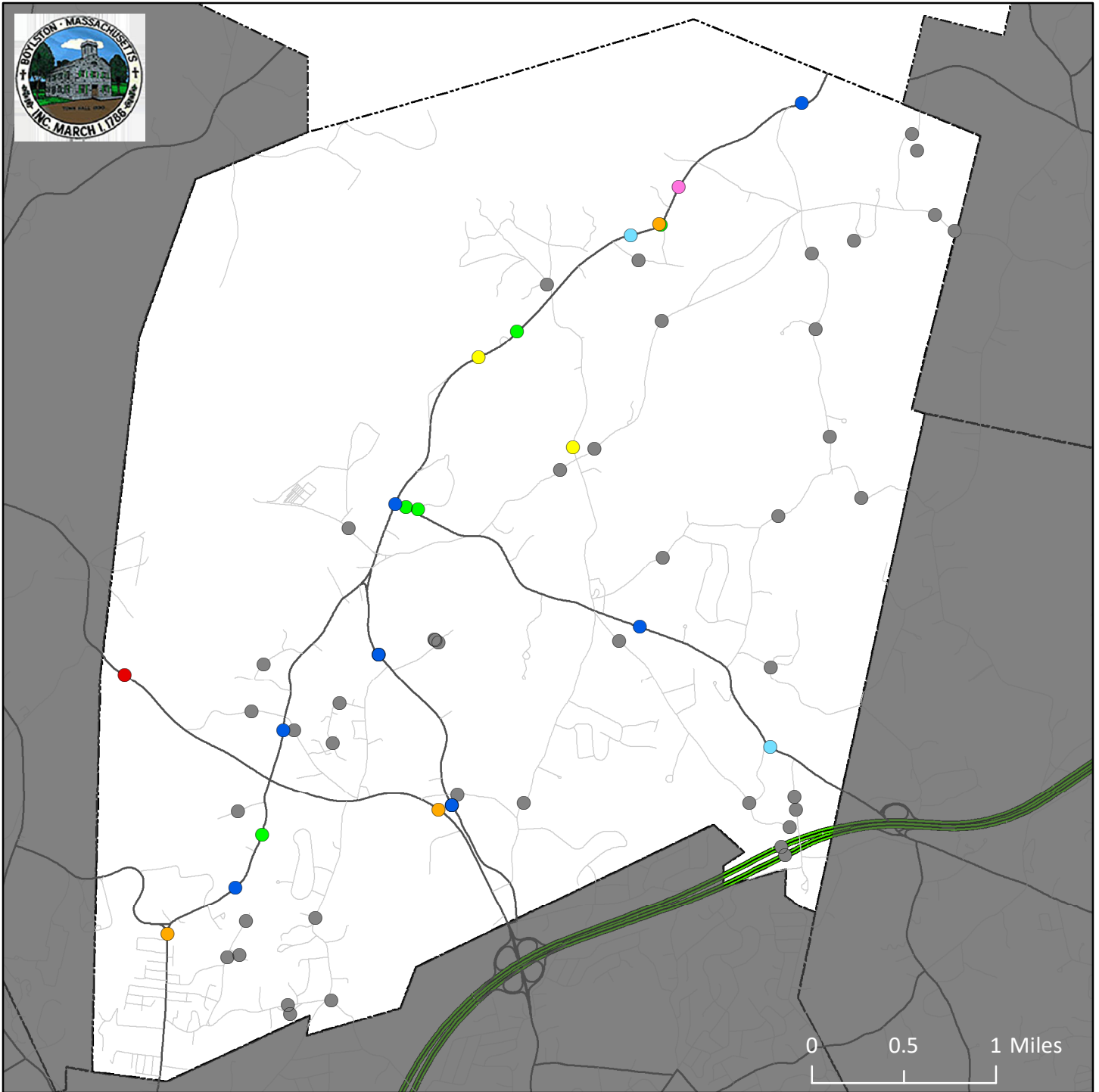


Figure 2: 2024 Town of Boylston Culvert Assessments

Culvert Barriers

- | | | |
|-----------------------|---------------------------|------------------------|
| ● Severe barrier | ● Insignificant barrier | — Federal Aid Eligible |
| ● Significant barrier | ● No barrier | — Not Eligible |
| ● Moderate barrier | ● no score - missing data | — Interstate - NHS |
| ● Minor barrier | ● Not assessed | ▭ CMRPC Towns |



4. Moving Forward

Recommendations

After assessing the culvert structures, prioritizing which culverts to replace or repair is an important next step. While it is important to begin reviewing the culverts that received scores between severe and moderate barriers, it is equally as important to review every culvert as the NAACC scoring structure does not focus on aspects of structural conditions (i.e., rusting, crushing, or structural integrity) and the scoring system relies on many variables. **Table 4** below lists several culverts that staff recommend prioritizing for potential repair, replacement, and related flood prevention improvements (i.e., debris removal).

Table 4: Town of Boylston Culvert Prioritization List

Crossing Code <i>click to view record on NAACC Data Center</i>	Road	Barrier	Notes
xy4234410571761204	West Boylston Street	Severe Barrier	Downstream is reservoir, cascading outlet
xy4233353371727858	Shrewsbury Street	Significant Barrier	Large scour pool, outlet free fall
xy4237965371704594	Main Street	Significant Barrier	Inlet drop, physical barrier (debris, sediment, rock)
xy4236912671723754	Main Street	Moderate Barrier	Beaver dam at outlet, physical barrier (debris, sediment, rock)
xy4235761471732526	Main Street	Minor Barrier	Poison ivy, inlet headwall deterioration and falling apart
xy4237878171707648	Main Street	Insignificant Barrier	

Funding

Funding for the repair and replacement of culvert and small bridge structures can be a substantial challenge for many municipalities. However, there are many federal and state funding programs that help support culvert repair or replacement projects. A popular program in Massachusetts that is included in the table below is the Massachusetts Culvert Replacement Municipal Assistance (CRMA) Grant Program. After reviewing these results, staff highly suggest that the Town of Boylston consider this grant program when thinking of applying for culvert repair or replacement funding. The CRMA Grant Program is administered by the Massachusetts Division of Ecological Restoration (DER) and awards

projects that aim to repair or replace undersized, perched, and/or degraded culverts located in areas of high ecological value and improve flood resiliency. Below, **Table 5** summarizes relevant federal and state sources to fund culvert repair or replacement projects.

Table 5: Culvert Funding Opportunities

Funding Opportunity	About	Link
Culvert Replacement Municipal Assistance (CRMA) Grant	For communities in Massachusetts interested in replacing an undersized, perched, and/or degraded culvert located in an area of high ecological value. Funding encourages applicants to replace aging culverts with better designed crossings that meet improved structural and environmental design standards and flood resiliency criteria. Projects are required to meet the goals of the Massachusetts Stream Crossing Standards.	https://www.mass.gov/how-to/culvert-replacement-municipal-assistance-grant-program
Municipal Vulnerability Preparedness (MVP) Grant Program	The MVP grant program provides support for communities in Massachusetts to identify climate hazards, assess vulnerabilities, and develop action plans to improve resilience to climate change. Communities that complete the MVP process are eligible for MVP Action Grant funding to implement priority actions identified through the MVP planning process.	https://resilientma.mass.gov/mvp/
Municipal Small Bridge Program	For communities in Massachusetts for the replacement, preservation, and rehabilitation of eligible bridges. Bridges must be on local public ways and must be on the State Bridge Inventory with a span between 10-20 feet.	https://www.mass.gov/municipal-small-bridge-program
National Culvert Aquatic Organism Passage (AOP) Grant Program	Awards grants for projects for the replacement, removal, and repair of culverts or weirs that meaningfully improve or restore fish passage for anadromous fish.	https://www.fhwa.dot.gov/engineering/hydraulics/culverthyd/aquatic/culvertaop_grants.cfm
CMMPO Transportation Improvement Program (TIP)	The TIP is a planning document that lists all highway, bridge, transit, and intermodal projects in Central Massachusetts that are programmed to receive federal-aid funding. Projects that improve air quality and safety, projects of regional and statewide significance, and non-federal aid projects fully funded by the state are included in the TIP. Use MassDOT MaPIT to initiate new projects to be considered for the TIP.	https://www.mass.gov/info-details/massdot-highway-initiating-a-project

<p>Building Resilient Infrastructure and Communities (BRIC)</p>	<p>FEMA/MEMA annual grant program to implement hazard mitigation projects that reduce risks from disasters and natural hazards. There is an added focus on infrastructure projects benefiting disadvantaged communities, nature based solutions, and climate resilience and adaptation. The funds are administered through MEMA. Culverts are eligible for this grant.</p>	<p>https://www.mass.gov/service-details/building-resilient-infrastructure-and-communities-bric-flood-mitigation-assistance-fma-grant-programs</p>
<p>Flood Mitigation Assistance (FMA) Program</p>	<p>FEMA/MEMA annual grant program to reduce or eliminate long-term risk of flood damage to buildings, manufactured homes, and other structures insured under the National Flood Insurance Program (NFIP).</p>	<p>https://www.mass.gov/service-details/building-resilient-infrastructure-and-communities-bric-flood-mitigation-assistance-fma-grant-programs</p>
<p>Hazard Mitigation Grant Program (HMGP)</p>	<p>Massachusetts provides funding to projects that reduce loss of life, protect natural resources, property, infrastructure, public health, and the economy from natural hazards and climate change impacts through hazard mitigation and climate adaptation projects. Provides funding after a disaster to help reduce or eliminate risk to lives and property from natural hazards. Among the eligible projects includes drainage and culvert improvements. Funding is available to all communities.</p>	<p>https://www.mass.gov/info-details/hazard-mitigation-grant-program-hmGP#:~:text=The%20HMGP%20provides%20funds%20to,and%20property%20from%20natural%20hazards.</p>

Training Opportunities

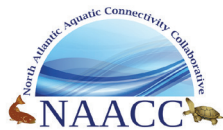
There are about 43 culvert locations throughout the Town of Boylston that are not along federal-aid eligible roads and were not assessed by staff. There is still a lot of work to be done and there are opportunities for town officials to complete NAACC Lead Observer training to assess local culverts throughout town, as well as keep up with the culverts that have already been assessed.

If you are interested and would like to complete NAACC Lead Observer training please contact Zack Blais, Transportation Principal Planner, at zblais@cmrpc.org.

Appendices

Appendix 1

This appendix includes the NAACC Non-Tidal Aquatic Connectivity Stream Crossing Survey Field Form that is used by CMRPC staff to conduct the culvert assessments. An individual must be certified as a NAACC Lead Observer in order to fill out this form, plug the information into the NAACC Data Center, and receive a score for the crossing (i.e., barrier type).



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

Tailwater Scour Pool NONE SMALL LARGE SPANS FULL CHANNEL & BANKS

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 _____

STRUCTURE 2

Structure Material METAL CONCRETE PLASTIC WOOD ROCK/STONE FIBERGLASS COMBINATION

OUTLET

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

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

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

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

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

INLET

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

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

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

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

ADDITIONAL CONDITIONS

Slope % (Optional) _____ Slope Confidence HIGH LOW Internal Structures NONE BAFFLES/WEIRS SUPPORTS OTHER _____

Structure Substrate Matches Stream NONE COMPARABLE CONTRASTING NOT APPROPRIATE UNKNOWN

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

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

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

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

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

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

Dry Passage through Structure? YES NO UNKNOWN Height above Dry Passage _____

Comments

STRUCTURE 3

Structure Material METAL CONCRETE PLASTIC WOOD ROCK/STONE FIBERGLASS COMBINATION

OUTLET

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

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

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

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

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

INLET

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

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

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

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

ADDITIONAL CONDITIONS

Slope % (Optional) _____ Slope Confidence HIGH LOW Internal Structures NONE BAFFLES/WEIRS SUPPORTS OTHER _____

Structure Substrate Matches Stream NONE COMPARABLE CONTRASTING NOT APPROPRIATE UNKNOWN

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

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

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

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

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

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

Dry Passage through Structure? YES NO UNKNOWN Height above Dry Passage _____

Comments

STRUCTURE 4

Structure Material METAL CONCRETE PLASTIC WOOD ROCK/STONE FIBERGLASS COMBINATION

OUTLET

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

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

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

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

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

INLET

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

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

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

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

ADDITIONAL CONDITIONS

Slope % (Optional) _____ Slope Confidence HIGH LOW Internal Structures NONE BAFFLES/WEIRS SUPPORTS OTHER _____

Structure Substrate Matches Stream NONE COMPARABLE CONTRASTING NOT APPROPRIATE UNKNOWN

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

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

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

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

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

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

Dry Passage through Structure? YES NO UNKNOWN Height above Dry Passage _____

Comments

STRUCTURE 5

Structure Material METAL CONCRETE PLASTIC WOOD ROCK/STONE FIBERGLASS COMBINATION

OUTLET

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

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

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

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

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

INLET

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

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

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

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

ADDITIONAL CONDITIONS

Slope % (Optional) _____ Slope Confidence HIGH LOW Internal Structures NONE BAFFLES/WEIRS SUPPORTS OTHER _____

Structure Substrate Matches Stream NONE COMPARABLE CONTRASTING NOT APPROPRIATE UNKNOWN

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

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

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

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

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

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

Dry Passage through Structure? YES NO UNKNOWN Height above Dry Passage _____

Comments

STRUCTURE 6

Structure Material METAL CONCRETE PLASTIC WOOD ROCK/STONE FIBERGLASS COMBINATION

OUTLET

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

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

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

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

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

INLET

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

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

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

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

ADDITIONAL CONDITIONS

Slope % (Optional) _____ Slope Confidence HIGH LOW Internal Structures NONE BAFFLES/WEIRS SUPPORTS OTHER _____

Structure Substrate Matches Stream NONE COMPARABLE CONTRASTING NOT APPROPRIATE UNKNOWN

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

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

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

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

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

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

Dry Passage through Structure? YES NO UNKNOWN Height above Dry Passage _____

Comments

STRUCTURE 7

Structure Material METAL CONCRETE PLASTIC WOOD ROCK/STONE FIBERGLASS COMBINATION

OUTLET

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

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

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

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

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

INLET

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

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

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

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

ADDITIONAL CONDITIONS

Slope % (Optional) _____ Slope Confidence HIGH LOW Internal Structures NONE BAFFLES/WEIRS SUPPORTS OTHER _____

Structure Substrate Matches Stream NONE COMPARABLE CONTRASTING NOT APPROPRIATE UNKNOWN

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

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

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

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

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

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

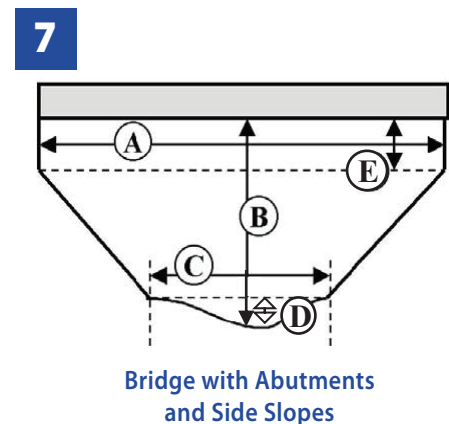
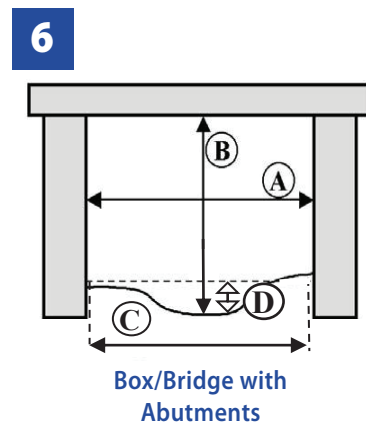
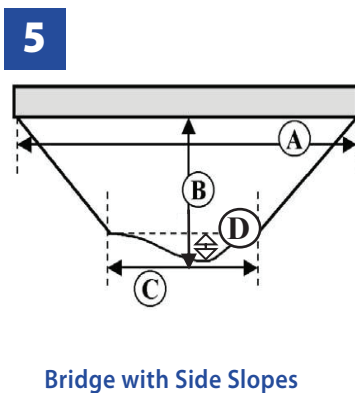
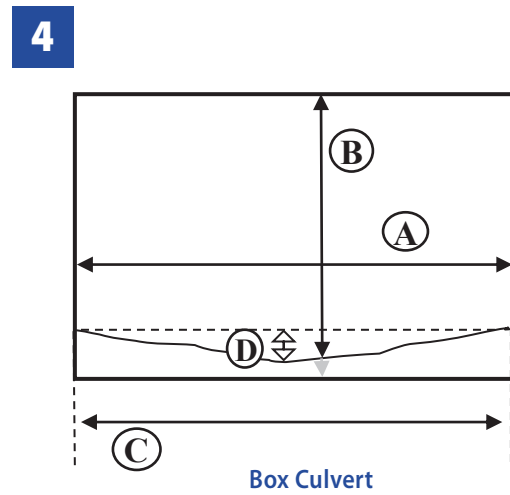
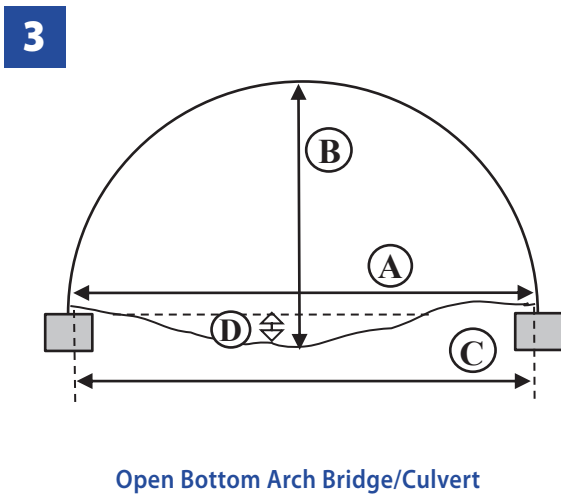
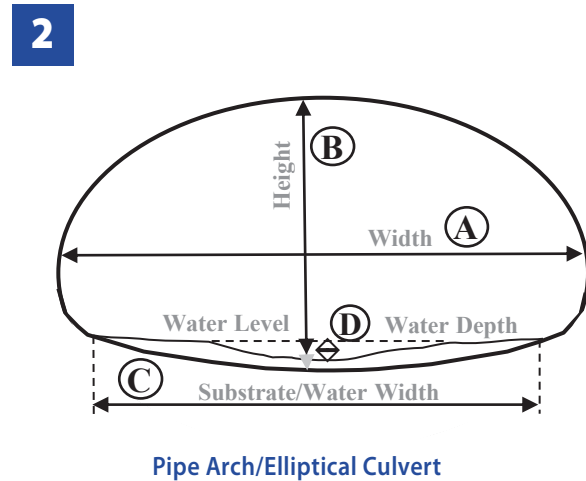
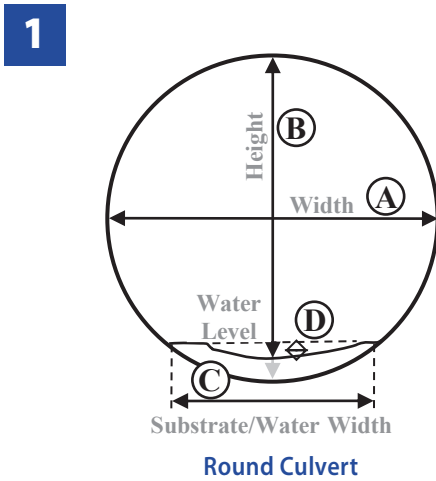
Dry Passage through Structure? YES NO UNKNOWN Height above Dry Passage _____

Comments

Structure Shape & Dimensions

- 1) Select the Structure Shape number from the diagrams below and record it on the form for Inlet and Outlet Shape.
- 2) Record on the form in the appropriate blanks dimensions **A**, **B**, **C** and **D** as shown in the diagrams;
C captures the width of water or substrate, whichever is wider; for dry culverts without substrate, C = 0.
D is the depth of water -- be sure to measure inside the structure; for dry culverts, D = 0.
- 3) Record Structure Length (**L**). (Record abutment height (**E**) only for Type 7 Structures.)
- 4) For multiple culverts, also record the Inlet and Outlet shape and dimensions for each additional culvert.

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



Appendix 2

This appendix includes the NAACC document that explains the scoring system involved in evaluating aquatic passability at road-stream crossings. This scoring system was adopted by the NAACC Steering Committee in November 2015.

Scoring Road-Stream Crossings as Part of the North Atlantic Aquatic Connectivity Collaborative (NAACC)

Adopted by the NAACC Steering Committee
November 10, 2015

INTRODUCTION

The North Atlantic Aquatic Connectivity Collaborative (NAACC) was launched in 2015 with a rapid assessment protocol for evaluating aquatic passability at road-stream crossings and an online database (<https://www.streamcontinuity.org/cdb2>) for storing and scoring data collected using this protocol. Two scoring systems are proposed to evaluate aquatic passability at road-stream crossings. The first is a coarse screen for use in classifying crossings into one of three categories: “Full AOP” (Aquatic Organism Passage), “Partial AOP,” and “No AOP.” The second system is an algorithm for computing an aquatic passability score, ranging from 0 (low) to 1 (high), for each road-stream crossing. These two scoring systems are not particular to any taxonomic or functional group but instead seek to evaluate passability for the full range of aquatic organisms likely to be found in rivers and streams.

NAACC COARSE SCREEN

Table 1 below identifies characteristics and conditions that allow crossings to be classified as providing “Full AOP,” “Reduced AOP,” or “No AOP.”

Table 1. NAACC Coarse Screen

Metric	Flow Condition	Crossing Classification		
		Full AOP	Reduced AOP	No AOP
		<i>If all are true</i>	<i>If any are true</i>	<i>If any are true</i>
Inlet Grade		At Stream Grade	Inlet Drop or Perched	
Outlet Grade		At Stream Grade		Cascade, Free Fall onto Cascade
Outlet Drop to Water Surface		= 0		≥ 1 ft
Outlet Drop to Water Surface/ Outlet Drop to Stream Bottom				> 0.5
Inlet or Outlet Water Depth	Typical-Low	> 0.3 ft		< 0.3 ft w/Outlet Drop to Water Surface > 0
	Moderate	> 0.4 ft		< 0.4 ft w/Outlet Drop to Water Surface > 0
Structure Substrate Matches Stream		Comparable or Contrasting		
Structure Substrate Coverage		100%	< 100%	
Physical Barrier Severity		None	Minor or Moderate	Severe

The primary objective of the coarse screen is to identify those crossings that are likely to be a barrier to most or all species and those that are likely to provide something close to full aquatic organism passage. If it is necessary to get a better feel for how bad those crossing are that are labeled as “reduced AOP” one can use the numeric scoring system.

NAACC NUMERIC SCORING SYSTEM

The numeric scoring algorithm is based on the opinions of experts who decided both the relative importance of all the available predictors of passability as well as a way to score each predictor. Scoring involves three steps: (1) generating a component score for each predictor variable, (2) combining these predictions with a weighted average to generate a composite score for the crossing, and (3) assigning a final score based on the minimum of the composite score or the component score for the *outlet drop* variable.

Variables Used

Crossing assessments are generally done during “typical low-flow conditions.” Some variables are important for assessing conditions at the time of the survey; others provide indirect evidence of likely conditions at higher flows.

Inlet Grade: The position of the structure invert relative to the stream bottom at the inlet.

Outlet Drop: Outlet drop is based on the variable *Outlet Drop to Water Surface* unless the value for *Water Depth Matches Stream* = “Dry” in which case outlet drop is based on the variable *Outlet Drop to Stream Bottom*.

Physical Barriers: This variable covers a wide variety of circumstances ranging from obstructions to dewatered culverts or bridge cells that represent physical barriers to aquatic organism passage.

Constriction: The relative width of the crossing compared to the width of the stream. “Severe” = <50%, “Moderate” = 50-100%; other options include “Spans Only Bankfull/Active Channel” and “Spans Full Channel & Banks.” *Constriction* is an indirect indicator of potential velocity issues at higher flows.

Water Depth: Water depth in the structure relative to water depths found in the natural channel at the time of survey.

Water Velocity: Water velocity in the structure relative to water velocities found in the natural channel at the time of survey.

Scour Pool: Presence/absence of a scour pool at the crossing outlet and size relative to the natural stream channel. *Scour Pool* is an indirect indicator of potential velocity issues at higher flows. *Scour pool* is included solely as an indicator of velocities at higher flows. It is not based on the effects of the pool itself which can actually be positive for fish passage.

Substrate Matches Stream: An assessment of whether the substrate in the structure matches the substrate in the natural stream channel. *Substrate Matches Stream* is used to evaluate how a discontinuity in substrate might inhibit passage for species that either use substrate as the medium for travel (e.g., mussels) or require certain types of substrate for cover during movements (e.g., crayfish, salamanders, juvenile fish).

Substrate Coverage: Degree to which a crossing structure is covered by substrate. *Substrate Coverage* is directly related to passability for some aquatic species that require substrate or that tend to avoid areas that lack cover. It is also an important element of roughness that can create areas of low-velocity water (boundary layers) utilized by weak-swimming organisms. *Substrate Coverage* is also an indirect indicator of potential velocity issues at higher flows.

Openness: Cross-sectional area of the structure opening divided by the structure length (distance between inlet and outlet) measured in feet. *Openness* is calculated for both the inlet and outlet and the lower value is assigned to the structure. If there are multiple structures at a crossing the value for the structure with the highest *Openness* is assigned to the crossing as a whole. Turtles are believed to be affected by the *Openness* of a crossing structure; other species may be affected as well.

Height: Maximum height of the crossing structure. This variable is parameterized so that it only comes into play for very small structures.

Outlet Armoring: Presence/absence of streambed armoring (e.g., riprap, asphalt, concrete) at the outlet and the relative amount of armoring. Armoring is considered “extensive” if the length (upstream to downstream) of the streambed that is armored is greater or equal to half the bankfull width of the natural stream channel. *Outlet Armoring* is an indirect indicator of potential velocity issues at higher flows.

Internal Structures: Presence/absence of structures inside a culvert or bridge (e.g. weirs, baffles, supports). The *Internal Structures* variable is used in the scoring algorithm as it relates to the potential for creating turbulence within a crossing structure. To the extent that *Internal Structures* physically block the movement of aquatic organisms it is covered by the *Physical Barriers* variable.

Step 1: Component Scores

The component scores are not meant to equate to passability. In each case the component score is intended to cover the full range of problems (assessable by our protocol) associated with that variable: from 0 (worst case) to 1 (best case). For *inlet grade*, having an inlet drop or perched inlet is the worst case among the options, thus they score "0." This is not meant to say that all structures with inlet drops are impassible. The effect of *inlet grade* on passability scores is controlled by the weight it is given in computing the composite score (see Step 2 below).

Scoring categorical predictors is simply a matter of assigning a score for each possible category. Table 2 lists all of the categorical predictors and the scores associated with each category.

Scoring continuous predictors requires a function to convert the predictor to a score. There are three continuous predictors and three associated functions. The functional forms used were chosen because they have shapes desired by the expert team or because they fit the series of points specified by the expert team. Appendix A includes the r code defining each of these functions (“x” is the measured value for each variable).

The scoring equation for *Openness* is:

$$(1) s_o = a(1 - e^{-kx(1-d)})^{1/(1-d)}$$

Where S_o is the score for openness, $a=1$, $k=15$, and $d = 0.62$ when openness is recorded in feet.

The equation for Height is:

$$(2) s_h = \min\left(\frac{ax^2}{b^2 + x^2}, 1\right)$$

Where S_h is the component score for height, $a = 1.1$, and $b=2.2$ when height is recorded in feet.

The equation for Outlet Drop is:

$$(3) s_{od} = 1 - \frac{ax^2}{b^2 + x^2}$$

Where S_{od} is the Outlet Drop component score, $a=1.029412$, and $b=0.51449575$ when outlet drop is recorded in feet.

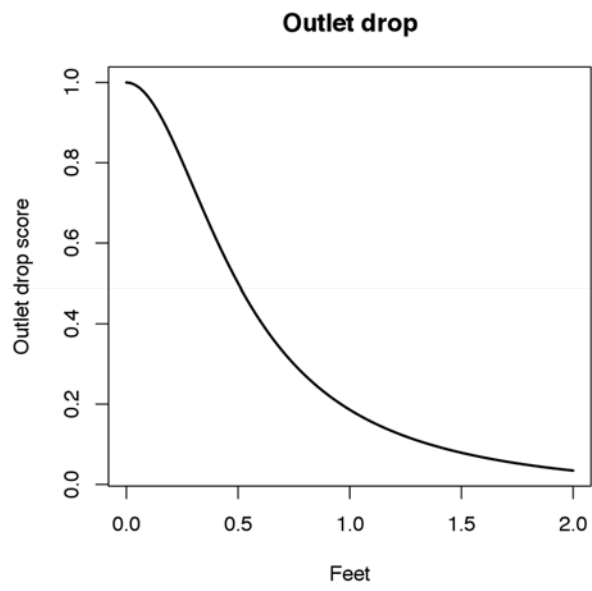
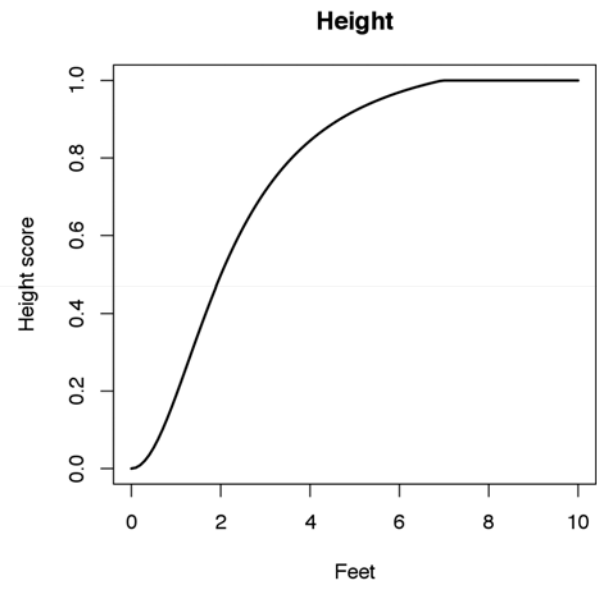
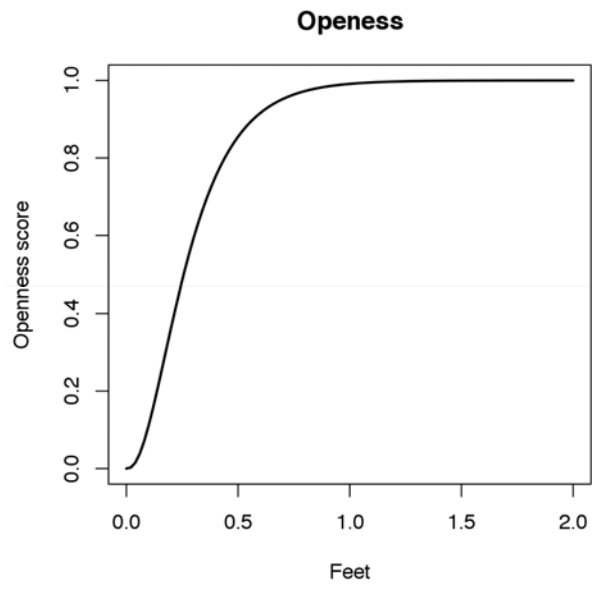


Figure 1. Continuous predictor variables

Table 2. Component scores for categorical variables used in calculating the crossing score

parameter	level	score
Constriction	severe	0
Constriction	moderate	0.5
Constriction	spans only bankfull/active channel	0.9
Constriction	spans full channel and banks	1
Inlet grade	at stream grade	1
Inlet grade	inlet drop	0
Inlet grade	perched	0
Inlet grade	clogged/collapsed/submerged	1
Inlet grade	unknown	1
Internal structures	none	1
Internal structures	baffles/weirs	0
Internal structures	supports	0.8
Internal structures	other	1
Outlet armoring	extensive	0
Outlet armoring	not extensive	0.5
Outlet armoring	none	1
Physical barriers	none	1
Physical barriers	minor	0.8
Physical barriers	moderate	0.5
Physical barriers	severe	0
Scour pool	large	0
Scour pool	small	0.8
Scour pool	none	1
Substrate coverage	none	0
Substrate coverage	25%	0.3
Substrate coverage	50%	0.5
Substrate coverage	75%	0.7
Substrate coverage	100%	1
Substrate matches stream	none	0
Substrate matches stream	not appropriate	0.25
Substrate matches stream	contrasting	0.75
Substrate matches stream	comparable	1
Water depth	no (significantly deeper)	0.5
Water depth	no (significantly shallower)	0
Water depth	yes (comparable)	1
Water depth	dry (stream also dry)	1
Water velocity	no (significantly faster)	0
Water velocity	no (significantly slower)	0.5
Water velocity	yes (comparable)	1
Water velocity	dry (stream also dry)	1

Some notes about the component scores

1. The option "clogged/collapsed/submerged" for *inlet grade* is an option surveyors use to indicate that it was not possible to measure the structure's dimensions. If the inlet is clogged or collapsed enough to affect passability it will be covered under *physical barriers*. This is why it receives a "1" instead of a "0", because problems associated with this option are covered by the *physical barriers* variable.
2. The rationale for giving a component score of "1" to "unknown" for *inlet grade* is similar to that for "clogged/collapsed/submerged." It is hard to know how to interpret "unknown." However, if conditions at the inlet are creating a physical barrier to passage it will be covered under *physical barriers*.
3. We included *inlet grade* as a variable in addition to *physical barriers* because inlet drops create both velocity and physical barrier (jump barrier) issues. The physical barrier issues are covered by the *physical barriers* variable. The *inlet grade* variable captures the velocity issues at the inlet. Perched inlets can create depth issues at low flows (if water can't get into the structure inlet). These may not be apparent at the time of the survey. Thus, the presence of a perched inlet is a concern even if it doesn't represent a physical barrier ("dry") at the time when the survey is conducted.
4. The variable *internal structures* is included to account for turbulence issues. There is likely to be turbulence associated with weirs and baffles when these are included inside crossing structures. If they also create physical barriers they will be covered by the *physical barriers* variable. They are often included in structures to help aquatic organism passage but they sometimes do more harm than good and may be good for some species while creating problems for others. The inclusion of well-designed weirs or baffles is likely to improve the component scores for water depth and water velocity. They get docked a little in our scoring system for introducing turbulence.
5. It is difficult to know how to score the "other" option under *internal structures* because it is difficult to know what, if any, impact these other structures will have on turbulence. If, however, they represent a physical barrier they will be covered under the *physical barriers* variable.

Step 2: Weighted Composite Scores

An expert team of nine people provided input on how the variables should be weighted based on best professional judgement. The weights used with the component scores are listed in table 3. The weights are simply the means of the nine weights for each variable provided by the experts. We display the weights out to three decimal places not to suggest that we know the weights to this level of precision but to reduce overall error in the model by not introducing an additional source of error (rounding error). The composite score is the sum of the products of each component score and its weight.

Table 3. Weights associated with each parameter in the scoring algorithm.

<u>parameter</u>	<u>weight</u>
Outlet drop	0.161
Physical barriers	0.135
Constriction	0.090
Inlet grade	0.088
Water depth	0.082
Water velocity	0.080
Scour pool	0.071
Substrate matches stream	0.070
Substrate coverage	0.057
Openness	0.052
Height	0.045
Outlet armoring	0.037
Internal structures	0.032

Step 3: Final Aquatic Passability Score

The final Aquatic Passability Score is the lower of either the composite score or the *Outlet Drop* component score. The rationale for this is that although many factors can affect aquatic organism passage, when an outlet drop is above a certain size it becomes the predominant factor that determines passability.

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

Mapping Aquatic Passability Scores

For mapping purposes, we assigned narrative descriptors for different ranges of aquatic passability as follows.

Descriptor	Aquatic Passability Score(s)
No barrier	1.0
Insignificant barrier	0.80 – 0.99
Minor barrier	0.60 – 0.79
Moderate barrier	0.40 – 0.59
Significant barrier	0.20 – 0.39
Severe barrier	0.00 – 0.19

People often ask about the relationship between these categories and actual passability for fish and other aquatic organisms. At this point the relationship is unknown and we regard it as a fruitful area for future research. The concept of aquatic passability is complicated and includes: variation in the swimming and leaping abilities of individuals within a species (what proportion of the population can pass), variability in passage requirements for a broad diversity of species that inhabit rivers and streams (what proportion of species can pass), and the timing of passability (for what proportion of the year is the structure passable).

For now, the best way to consider the aquatic passability scores is that they represent the degree to which crossings deviate from an ideal. We assume that those crossings that are very close to the ideal (scores > 0.6) will present only a minor or insignificant barrier to aquatic organisms. Those structures that are farthest from the ideal (scores < 0.4) are likely to be either significant or severe barriers. These are, however, arbitrary distinctions imposed on a continuous scoring system and should be used with that in mind.

APPENDIX A - R code for continuous scoring functions.

```
#-----#
# define function for Openness score calculation
#-----#
calc.openness.score <- function(x){
  # Using von Bertalanffy functional form (Bolker pg 97)
  a = 1
  k = 15
  d=0.62
  return(a * (1-exp(-k*(1-d)*x))^(1/(1-d)))
  # note exp is based on e not 10.
}

#-----#
# Define Function for Calculating Height Scores
#-----#
calc.height.score <- function(x){
  a <- 1.1
  b <- 2.2
  # Use Holling Type II function (Bolker pg 92):
  result <- a*x^2/(b^2 + x^2)
  result[result > 1] <- 1 # Truncate results to 1
  return(result)
}

#-----#
# Define Function for Calculating Outlet Drop Scores
#-----#
calc.outlet.drop.score <- function(x){
  a <- 1.029412
  b <- 0.51449575
  score <- 1 - a*x^2/(b^2 + x^2)
  score[x > 36] <- 0
  return(score)
}
```