

Road-Stream Crossing Assessment Technical Memorandum

Town-Wide Road Stream Crossing Assessment and Climate Change Adaptation Plan

TOWN OF BELCHERTOWN, MASSACHUSETTS

prepared by

FUSS & O'NEILL

JUNE 2019



MEMORANDUM

TO: Steven Williams, Director
Department of Public Works
Town of Belchertown

FROM: Erik Mas, P.E., Julianne Busa, Ph.D.
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1550 Main Street, Suite 400
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DATE: June 24, 2019

RE: Town-Wide Road-Stream Crossing Assessment and Climate Change Adaptation Plan – MVP Action Grant
Road-Stream Crossing Assessment Technical Memorandum

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1 Introduction

Inadequate or undersized road-stream crossings can be flooding and washout hazards and can serve as barriers to the passage of fish and other aquatic organisms. As precipitation events become more intense and less predictable as a result of climate change, inadequate or undersized road-stream crossings throughout the Town of Belchertown are expected to pose a greater threat of failure; flooding damage to homes and businesses, transportation infrastructure, and utilities; and stream channel erosion. The Swift River is the most likely to generate major flooding conditions, but culverts and bridges in Belchertown are recognized as a potential concern Town-wide.

Fuss & O'Neill assessed road-stream crossings throughout the Town in support of Belchertown's Town-wide Road-Stream Crossing Assessment and Climate Adaptation Plan, a project which was funded through the inaugural round of the Commonwealth's Municipal Vulnerability Preparedness (MVP) Action Grant funding. The goal of the project is to increase resilience to flooding and flood-related impacts

Financial assistance was provided by the Executive Office of Energy & Environmental Affairs (EEA) under the FY18 Municipal Vulnerability Preparedness (MVP) Grant Program. The MVP Action Grant offers financial resources to municipalities that are seeking to advance priority climate adaptation actions to address climate change impacts resulting from extreme weather, sea level rise, inland and coastal flooding, severe heat, and other climate impacts.

throughout the Town. To that end, the project systematically assessed road-stream crossings Town-wide to identify existing and future vulnerabilities and high-priority culvert/bridge replacement projects that would reduce flood vulnerability, increase the climate resilience of the Town's transportation infrastructure, and increase stream continuity for aquatic organism passage.

The assessments consisted of field surveys of individual stream crossings using established road-stream crossing assessment protocols, followed by analysis of the field data to assign vulnerability ratings to each crossing based on multiple factors including hydraulic capacity, structural condition, geomorphic risk, aquatic organism passage, transportation and emergency services, other flooding impacts, and climate change considerations. The vulnerability ratings were used to prioritize structures for upgrade or replacement. Conceptual designs for replacement of high-priority crossings were developed based upon the field data and vulnerability ratings.

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

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2 Stream Crossing Field Surveys

2.1 Selection of Crossings

Road-stream crossings to be included in the assessment were initially identified based on review of aerial imagery, flood mapping, and other local, county, or state-wide data layers. The Belchertown Department of Public Works provided additional information on locations of known culvert/bridge infrastructure occurring on smaller, unmapped streams. The project sought to assess all road-stream crossings Town-wide, including local and state roads, which could reasonably and safely be assessed.

172 road-stream crossings throughout Belchertown were ultimately assessed via field surveys and desktop vulnerability assessments. As shown in Figure 1, the crossings span six watersheds. The locations of the selected crossings are shown on the watershed map in Figure 1. Summary information on each crossing is provided in Appendix B—Table 1. These crossings all occur at naturally flowing streams, which typically pose the greatest potential for fooding impacts. Additional drainage culverts were geolocated for use by the Town, but were not formally assessed.

2.2 Field Data Collection

Field surveys of the selected crossings were conducted between September 14th and October 15th, 2018 using road-stream crossing assessment procedures and field data collection forms adapted from the North Atlantic Aquatic Connectivity Collaborative (NAACC) and similar standardized assessment protocols used in the northeastern U.S. In addition to the 2016 NAACC stream crossing survey protocol for assessing aquatic connectivity, the road-stream crossing survey methods used for this project also incorporated structural condition assessment protocols from the 2017 NAACC Culvert Condition Assessment Manual and collection of other field data for evaluating geomorphic vulnerability, hydraulic capacity, and potential flooding impacts to infrastructure and public services. Digital photographs were also taken at each crossing. A blank copy of the field data collection form is provided in Appendix A.

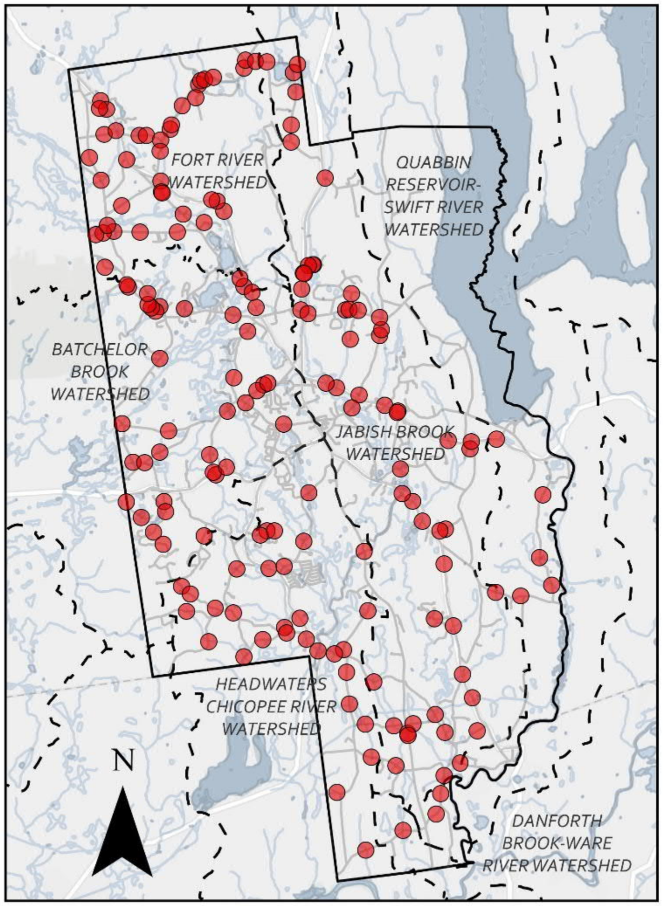

Figure 1. Road-stream crossings selected for assessment in the Town of Belchertown. Watershed boundaries are indicated by dotted lines.

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

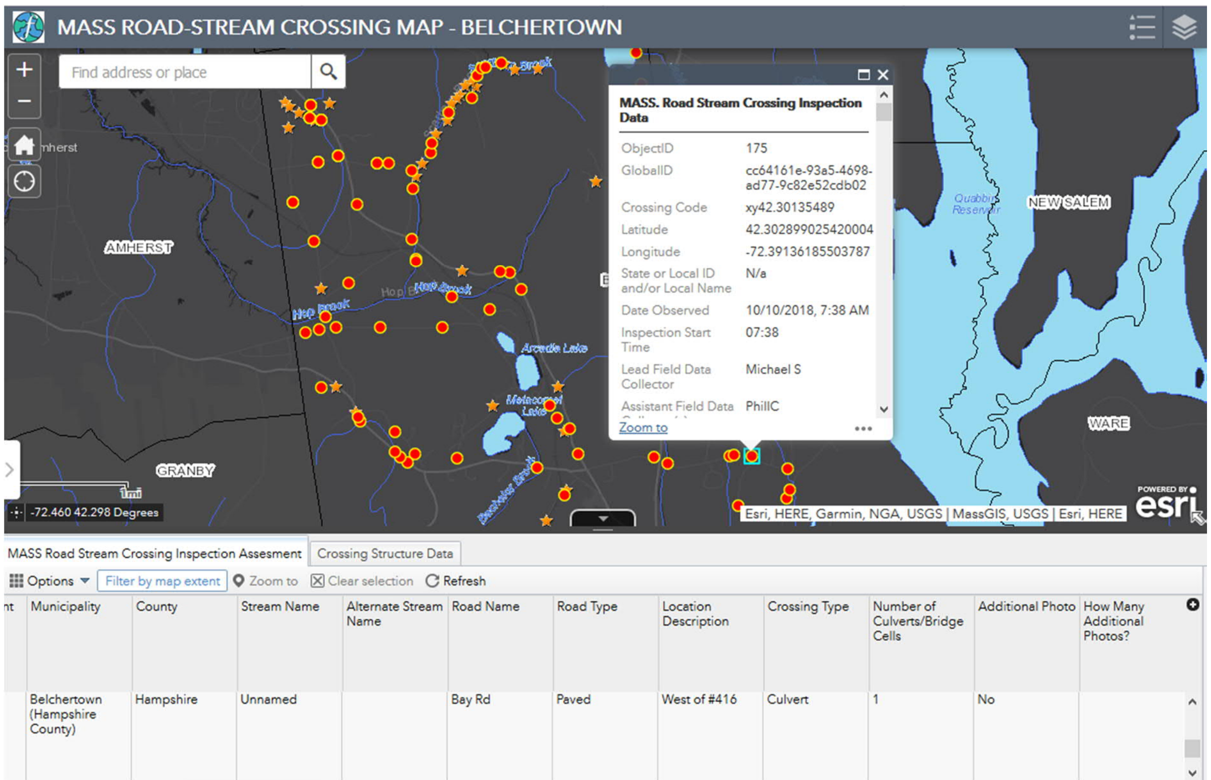

Figure 2. ArcGIS web application for Belchertown stream crossing survey data

2.3 Crossing Survey Findings Summary

Appendix B summarizes key field data and findings of the road-stream crossing surveys for the Town of Belchertown.

The following issues were observed at the surveyed stream crossings:

- Poor Structural Condition: Many of the crossings were observed to be in poor condition and in need of significant repairs or replacement. Significant erosion of the crossing embankment and unstable or deteriorating headwalls or wingwalls were common at many of these crossings. Corrugated metal pipes with rusted out bottoms were also relatively common throughout the Town.
- Flow Constriction: All but five of the assessed crossings, including the assessed culverts and bridges, are significantly narrower than the bankfull width of the stream channel and therefore appear to constrict flood flows. 114 of the crossings were rated as severely constricted, indicating that the bankfull width of the stream channel was at least twice as wide as the structure opening(s). The hydraulic capacities of many of the crossings in the watershed are limited due to undersized crossing structures and/or significant accumulation of sediment at some locations.
- Physical Barriers: 41% of the crossings serve as moderate to severe barriers to aquatic organism passage. Several structures have cascading or freefalling outlets with drops of up to two to four feet. Most structures do not have

Figure 3. Examples of crossing structures in poor structural condition observed at various locations during field assessments.

substrates that match the streambed, creating a discontinuity for organisms trying to pass through the crossing.

- Channel Erosion: Varying degrees of stream channel erosion were observed in the reaches immediately upstream and/or downstream of the assessed crossings. Efforts to repair recent channel erosion through bank stabilization were evident at several of the surveyed locations, including along Gulf Road.
- Sediment Deposition: Substantial sediment deposition was observed at two dozen crossings throughout the Town. At these locations, sediment deposits were noted to have depths at least half the height of the stream banks. Such sediment deposition can reduce flow conveyance capacity, increase the potential for blockage or clogging during higher flows, and potentially restrict aquatic passage during low-flow conditions or affect the quality of in-stream habitat.

3 Vulnerability Assessment and Prioritization

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

3.1 Assessment Method

The following individual assessments were performed for each stream crossing (equations and tables associated with each assessment method can be found in Appendix C):

- Existing and Projected Future Streamflow: Existing and future (climate change scenario) peak discharge were estimated for common recurrence intervals[1] (10-year, 25-year, 50-year, and 100-year) using regional regression equations developed by USGS for estimating peak flows at ungaged locations (i.e., StreamStats) or drainage area ratios for crossing locations where regional regression equations are unreliable. Flood flows under future climate change were estimated using a design flow multiplier of 1.2, representing a 20% increase in rainfall intensity above current conditions to account for anticipated increases in design rainfall intensities associated with future climate change projections. The recommended 20% increase in design rainfall intensity is consistent with climate change projections for extreme precipitation under a medium to high emissions scenario and a 50- to 100-year planning horizon[2], based on the typical

[1] The recurrence interval is based on the probability that a given streamflow will be equaled or exceeded in any given year. For example, a 100-year recurrence interval means that there is a 1 in 100 or 1 percent chance that a streamflow will occur in any given year (i.e., the 1 percent annual chance flow).

[2] Projected increases for the northeast generally range from around 5% to 25% for the 2-year to 100-year storm events based on several sources of climate change projections: Boston Water and Sewer Commission climate adaptation planning; U.S. EPA Climate Resilience Evaluation and Awareness Tool; U.S. EPA Storm Water Management Model Climate Adjustment Tool; Downscaled Projections of Extreme Rainfall in New York State developed by the Northeast Regional Climate Center (NRCC) and the New York State Energy Research and Development Authority (NYSERDA); New York City Preliminary Climate Resiliency Design Guidelines

design life (50 years) of most storm drainage infrastructure, and the useful life, which is typically 50-100 years for stormwater infrastructure. It should be noted that design life is different from useful life, which is typically longer than the design life and more accurately represents the extended service life of infrastructure, assuming regular maintenance.

- Hydraulic Capacity: The hydraulic capacity of each road-stream crossing was estimated using standard Federal Highway Administration culvert/bridge hydraulic calculation methods following FHWA Hydraulic Design Series Number 5 (HDS-5). Bentley CulvertMaster, which employs HDS-5 methods, was used for the analysis. Hydraulic capacity was determined for a selected headwater depth, which represents that depth at which the crossing is at risk of structural failure or the roadway is at risk of overtopping, depending on crossing type and material. Manning's Equation for uniform open channel flow was used to estimate the crossing hydraulic capacity for larger structures (bridges) or where the cross-sectional area could not be approximated with CulvertMaster. A capacity ratio (defined as the ratio of estimated hydraulic capacity to the estimated peak discharge for a specified return interval) was calculated for each crossing for existing and projected future peak streamflow. Each crossing was then assigned a Hydraulic Capacity Rating based on the largest return interval for which the crossing structure has sufficient capacity (capacity ratio greater than or equal to 1) to pass the peak discharge associated with that return interval.

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

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

- Aquatic Organism Passage: The ability of a crossing structure to allow the passage of fish and other aquatic organisms (referred to as aquatic organism passage or "AOP") was assessed using the latest NAACC protocols and rating system for assessing stream continuity. The method was adapted from the NAACC Numeric Scoring System for AOP, which was developed with input from multiple experts in aquatic passability. The NAACC Numeric Scoring System methodology is designed as a quantitative but rapid assessment tool for use by trained observers. The assessment is not species-specific, but rather seeks to evaluate passability for the full range of aquatic organisms likely to be found in rivers and streams.

- Impacts to Transportation Services: The potential disruption of transportation services resulting from single crossing failures was evaluated by considering the functional classification of the roadway (i.e., level of travel mobility and access to property that it provides) as a surrogate for transportation services and overall impacts to the transportation system. Disruption of transportation services is assumed to occur if the crossing is either overtopped or washed away by flooding, as either failure mode would prohibit the use of the road-stream crossing by traffic.
- Other Potential Flooding Impacts: The potential impacts to existing development, infrastructure, and land use upstream and downstream of each stream crossing were assessed in the event of failure of the crossing. A potential impact area was approximated for each crossing, having a width defined by buffering the stream centerline by a distance equal to two times the bankfull width, and a length defined as 0.5 miles upstream and downstream of the crossing. Flooding vulnerability was quantified based on the percentage of developed land cover, using 0.5 meter resolution land cover data from the Massachusetts statewide Land Use (2005) datalayer, and the presence of upstream or downstream crossings within the impact area, as well as any infrastructure (gas, sewer, water, etc.) observed to be attached to or located within the crossing structure.

3.2 Prioritization Method

The crossing structures were assigned a relative priority for upgrade or replacement based on the results of the individual assessments and consideration of failure risk. Failure risk is defined as the product of the probability of failure of a crossing (i.e., vulnerability) and the potential consequences of failure (i.e., impacts). A crossing may be at risk if the probability of failure is high, if the consequences of failure are high, or both. An overall priority score was calculated based on the combined hydraulic risk (existing and future climate change), geomorphic risk, structural risk, and aquatic organism passability of each crossing. See details of the prioritization method in Appendix C.

The overall failure risk for a crossing (represented by the Crossing Risk Score) is dictated by the highest (i.e., worst-case) level of risk, which is calculated as the maximum of the hydraulic risk and future hydraulic risk scores, geomorphic risk score, and structural risk score. The potential ecological benefit of removing an existing barrier to aquatic passage is also an important consideration in the crossing prioritization process. The additional habitat value accessed after a crossing replacement depends on both the quality and the extent of aquatic habitat that is reconnected as a result of replacing the existing crossing with a structure that provides for improved aquatic passage. Aquatic passage benefit scores were assigned to each crossing based on the concept of Index of Ecological Integrity (IEI). IEI scores were derived using the Critical Linkages methodology developed by the Landscape Ecology Lab at UMass Amherst as part of the Conservation Assessment and Prioritization System (CAPS) program.

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

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

Road Name	Stream Name	HUC 12 Watershed Name	Impact Score	Hydraulic Risk Score	Future Hydraulic Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Scaled Crossing Priority	Relative Priority Rating
Ludlow St	Roaring Brook	Headwaters Chicopee R.	5	20	25	15	10	12	25	0.87	High
Granby Road	Roaring Brook	Headwaters Chicopee R.	5	25	25	15	10	6	25	0.81	High
Gulf Rd	Scarboro Brook	Fort River	4	20	20	16	8	15	20	0.75	High
Rural St	Weston Brook	Batchelor Brook	4	16	20	12	20	12	20	0.72	High
George Hannum	unnamed	Batchelor Brook	4	16	20	16	8	9	20	0.69	High
North St	Montague Brook	Fort River	4	20	20	16	20	9	20	0.69	High
North Gulf Rd	Scarboro Brook	Fort River	4	16	20	16	8	6	20	0.66	High
Gulf Rd	Scarboro Brook	Fort River	4	20	20	16	4	6	20	0.66	High
Ledgewood Dr	unnamed	Headwaters Chicopee R.	4	0	0	16	20	6	20	0.66	High
Ledgewood Circle	unnamed	Headwaters Chicopee R.	4	20	20	12	20	6	20	0.66	High
Boardman St	Weston Brook	Batchelor Brook	4	4	4	16	20	4	20	0.64	High
Federal St	Scarboro brook	Fort River	4	20	20	12	20	3	20	0.63	High
Gulf Rd	Scarboro Brook	Fort River	4	16	20	8	4	3	20	0.63	High
Forest Rd	Unnamed	Headwaters Chicopee R.	4	20	20	8	20	3	20	0.63	High
North St	Scarboro Brook	Fort River	3	15	15	15	6	15	15	0.6	High
Warren Wright Rd	Hop Brook	Fort River	5	unassessed	unassessed	10	5	unassessed	10	0.3	Low*

*Attempts were made to assess the Warren Wright Road/Hop Brook crossing on three separate occasions. On each occasion, the crossing was submerged due to beaver activity downstream. All available information suggests that the crossing should be among the top priorities, despite limited assessment information which skews the prioritization score.

3.3 Assessment and Prioritization Results

Table 1 summarizes the hydraulic risk (existing and future), geomorphic risk, structural risk, and aquatic organism passability scores, as well as the relative priority score (normalized on a scale of 0 to 1) for each of the highest priority crossings

3.4 Assessment and Prioritization Results

Table 1 summarizes the hydraulic risk (existing and future), geomorphic risk, structural risk, and aquatic organism passability scores, as well as the relative priority score (normalized on a scale of 0 to 1) for each of the highest priority crossings located on Town-owned roads. Note that identification of the highest priority crossings focused exclusively on Town-owned crossings, as replacement projects at these sites can be initiated by the Town, whereas projects on state-owned roads are subject to financing and construction timelines dictated by MassDOT. Detailed road-stream

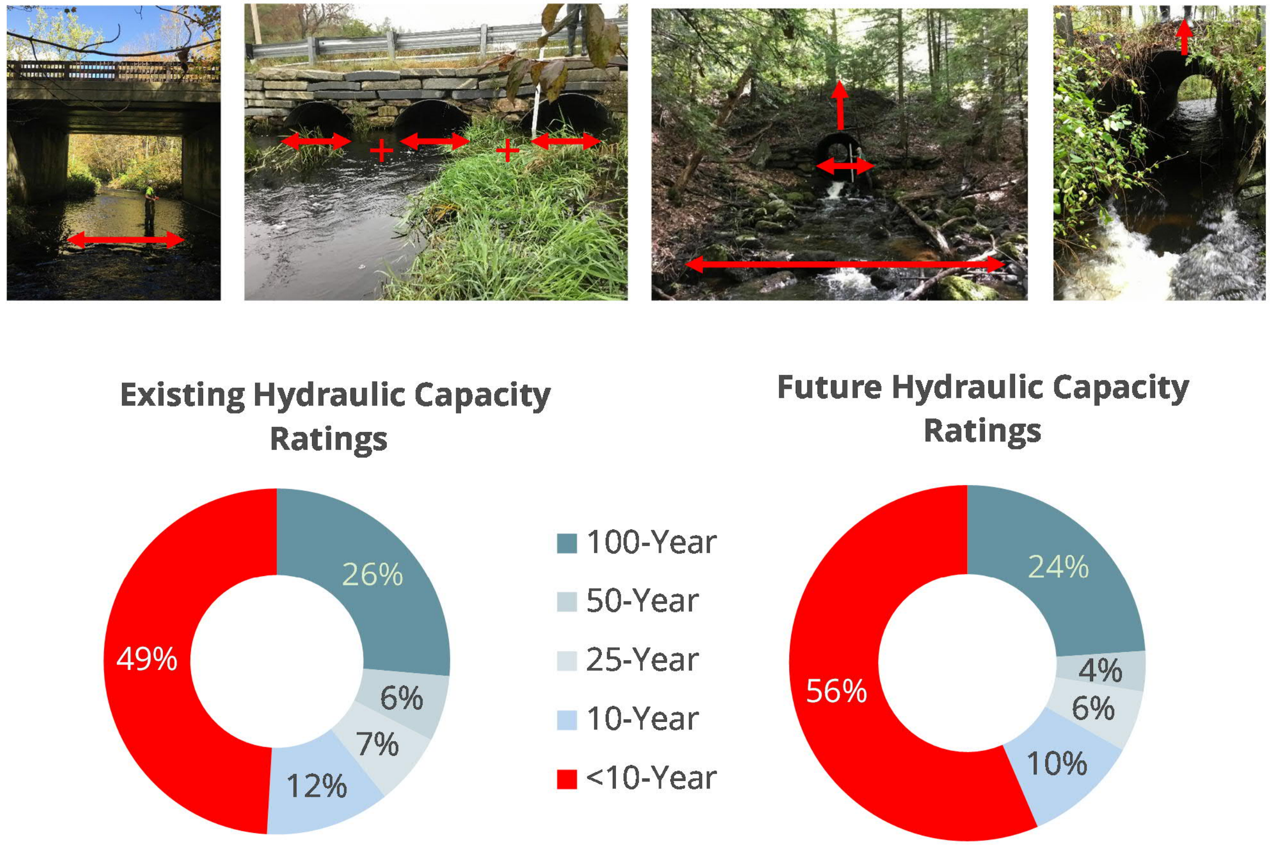

Figure 4. Top: Illustration of various factors that determine hydraulic capacity ratings. Left and far left: structure width or combined width of multiple structures; Center right: Structure width relative to expected peak stream flows; Far right: height of road fill over structure determines when water will overtop road.
Bottom: Distribution of hydraulic capacity ratings across all assessed crossings, for both existing conditions and expected future precipitation conditions under a climate change scenario.

crossing assessment and prioritization worksheets and scores are provided in Appendix B.

Hydraulic Risk

49% of the crossings assessed are hydraulically undersized under existing precipitation conditions, having insufficient capacity to convey the 10-year peak flow (Figure 4). Another 12% of crossings are hydraulically undersized relative to the 25-year return interval peak flow (Figure 4). 26% of crossings were found to be sized such that they could pass the 100-year return interval peak flow under existing conditions (these include larger bridges, as well as some smaller structures where peak flows are also low as a result of a smaller watershed area feeding into the crossing). Under future climate conditions, assuming an increase in peak flows of 20% for all return intervals evaluated, 56% of crossings are expected to be undersized for the 10-year peak flow, 10% are expected to be undersized for the 25-year return interval flow, and only 24% are expected to be able to pass the 100-year return interval peak flow.

These percentages are for all crossings taken together, but hydraulic capacity ratings differ by structure type (Figure 5). Bridges, due to their larger openings, are generally sized to accommodate larger flows. In Belchertown, all assessed bridges had sufficient capacity to pass the existing 100-year peak flow. Round and elliptical culverts tend to have the most variation in size, with many of the undersized structures throughout Town falling into one of these categories. Geographically, hydraulic risks are spread throughout the Town, with clusters of high-risk crossings on Gulf Road and the state-owned roadways (Figure 6).

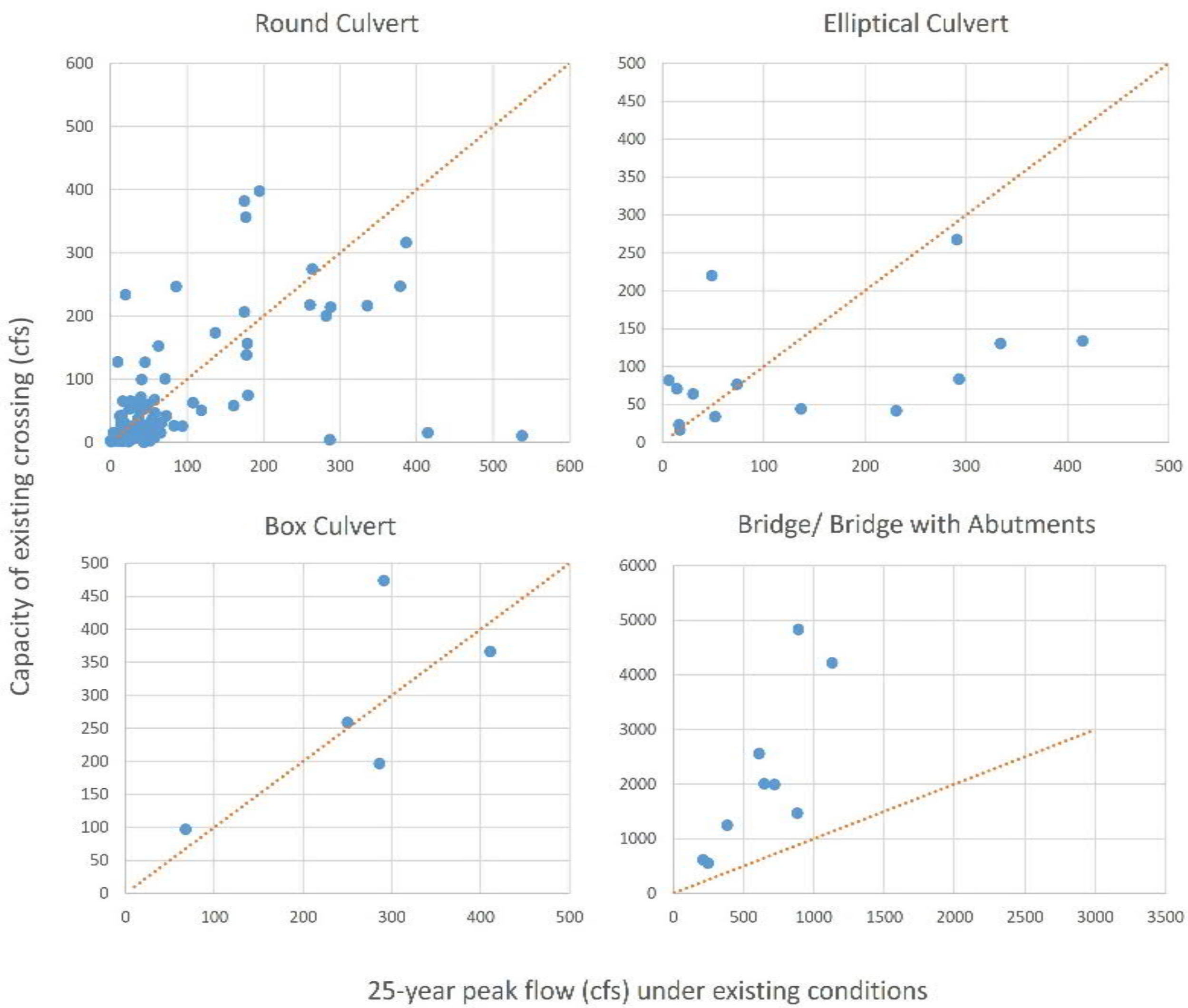

Figure 5. Capacity of existing crossings relative to the existing 25-year return interval, broken down by structure type. The dotted line in each panel represents the point at which capacity is matched to peak flows at a 1:1 ratio. Points above the line are sized with excess capacity for the 25-year return interval peak flow; points below the line have insufficient capacity to pass the 25-year return interval peak flow.

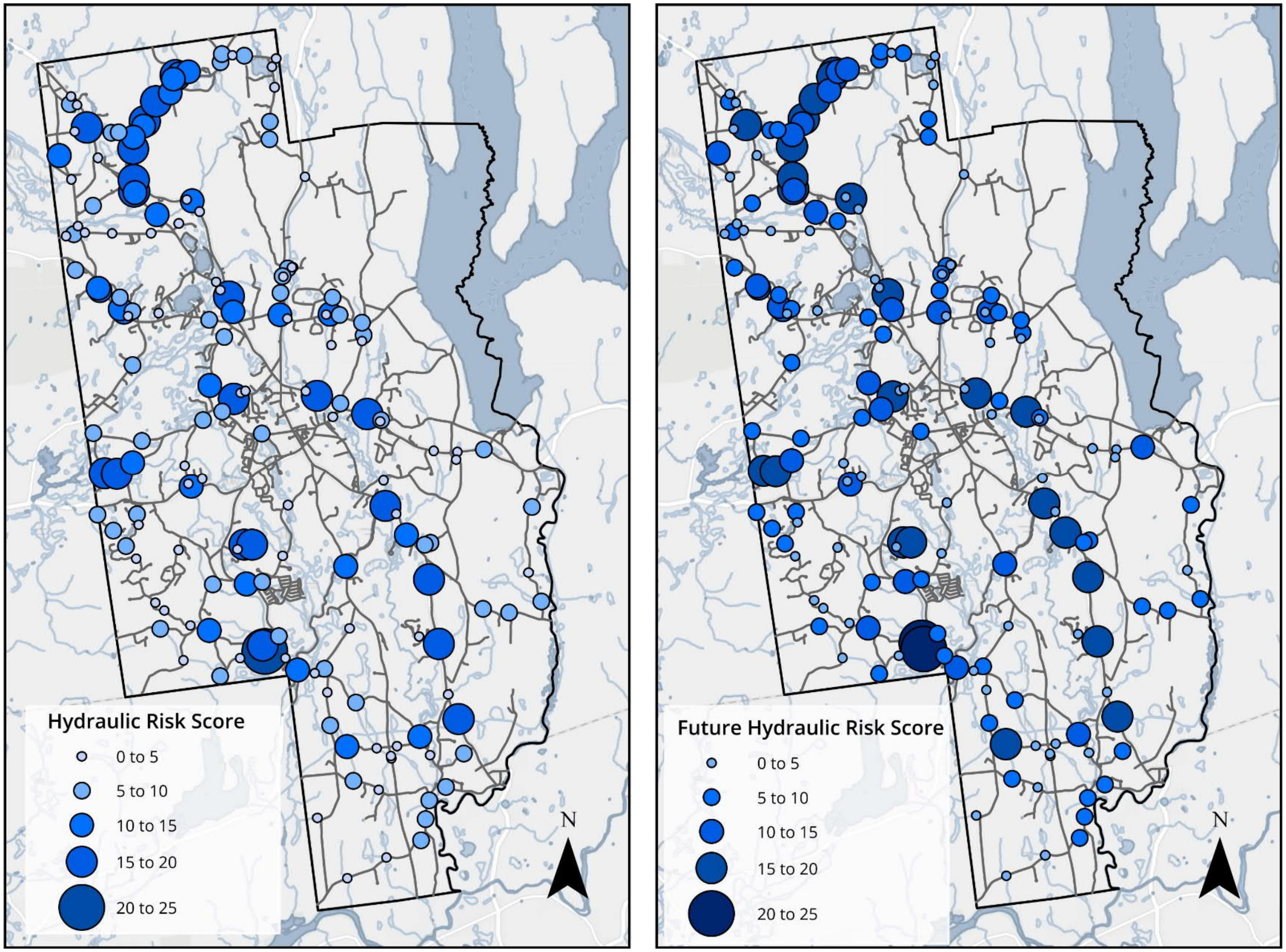

Figure 6. Spatial distribution of hydraulic risk scores for all assessed crossings under existing (left) and projected future (right) climate (precipitation and peak flow) conditions.

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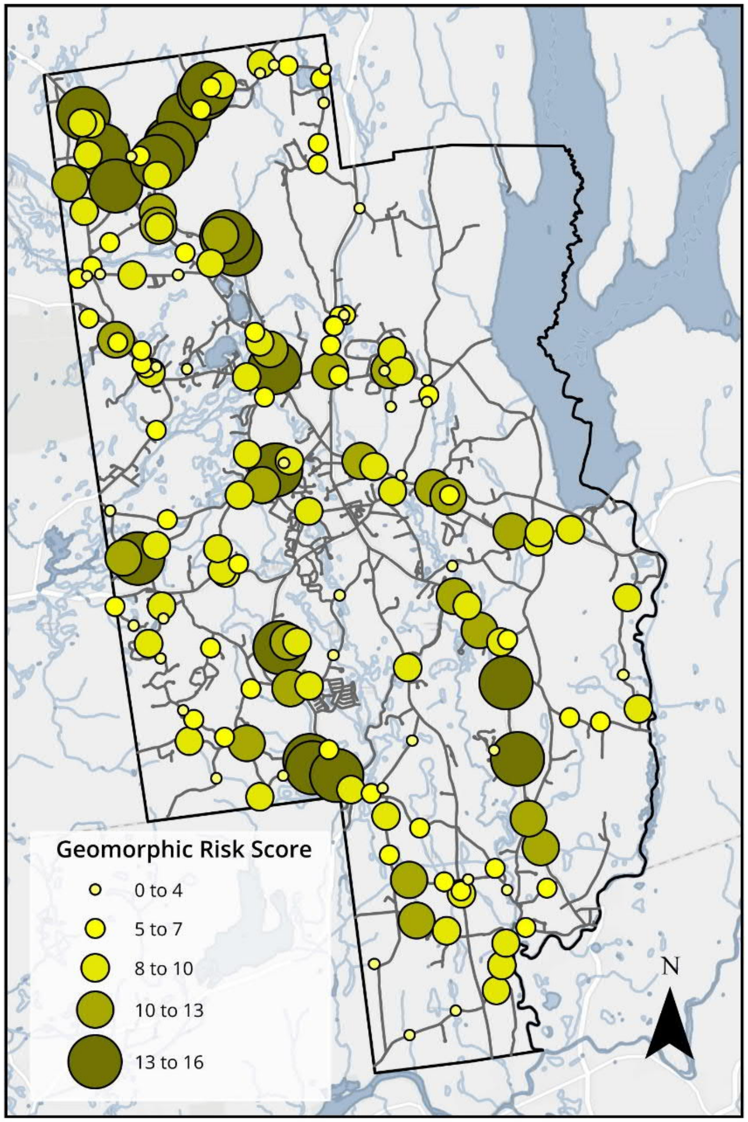


Geomorphic Risk

Approximately half of all assessed crossings were rated as having moderate/intermediate geomorphic risk (Figure 9), taking into account both observed geomorphic impacts and potential geomorphic impacts. The remainder of crossings were split evenly between low risk/unlikely impacts and significant/likely impacts (see examples of each end of the spectrum in Figure 8). Crossings with the highest geomorphic risk include crossings on East Street, Orchard Street, Gulf Road, and North Street; most of these structures of highest concern are clustered in the Fort River Watershed (Figure 7).

Figure 8. Geomorphic Vulnerability Ratings consider factors such as outlet drops which contribute to scour, the bankfull width of the stream, and alignment of the stream with the structure. The North Street/Scarboro Brook crossing (top) scored a 5 due to the freefall and scour pool conditions. The Hickory Hills crossing (bottom) has good alignment and no constriction and scored a 1.

Figure 7. Spatial distribution of geomorphic risk scores for all assessed crossings.

Structural Risk

37% of assessed crossings were rated as critical relative to structural condition, and 52% were rated as either good or satisfactory (Figure 9). Many of the highest ranking crossings for structural risk occur on state roads, a result that is partially driven by the fact that state roads have higher potential impact for transportation disruptions, which raises their overall risk score (Figure 10). Among Town-owned structures, the seven structures that rated highest for structural risk based on structural condition and potential for flooding impacts (with a score of 20 out of 25) are all among the top priority crossings overall (Table 1).

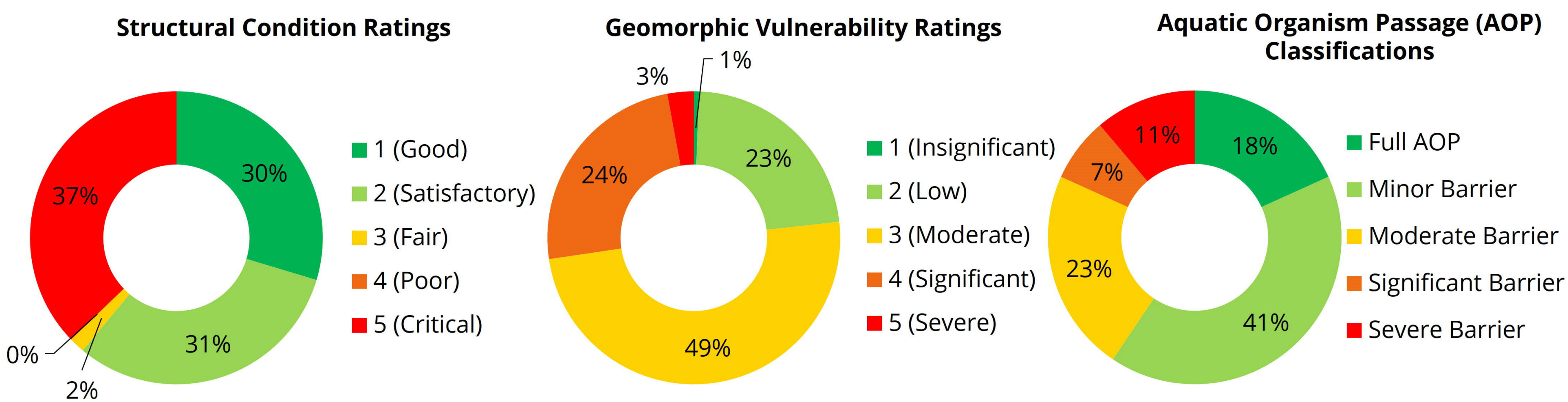
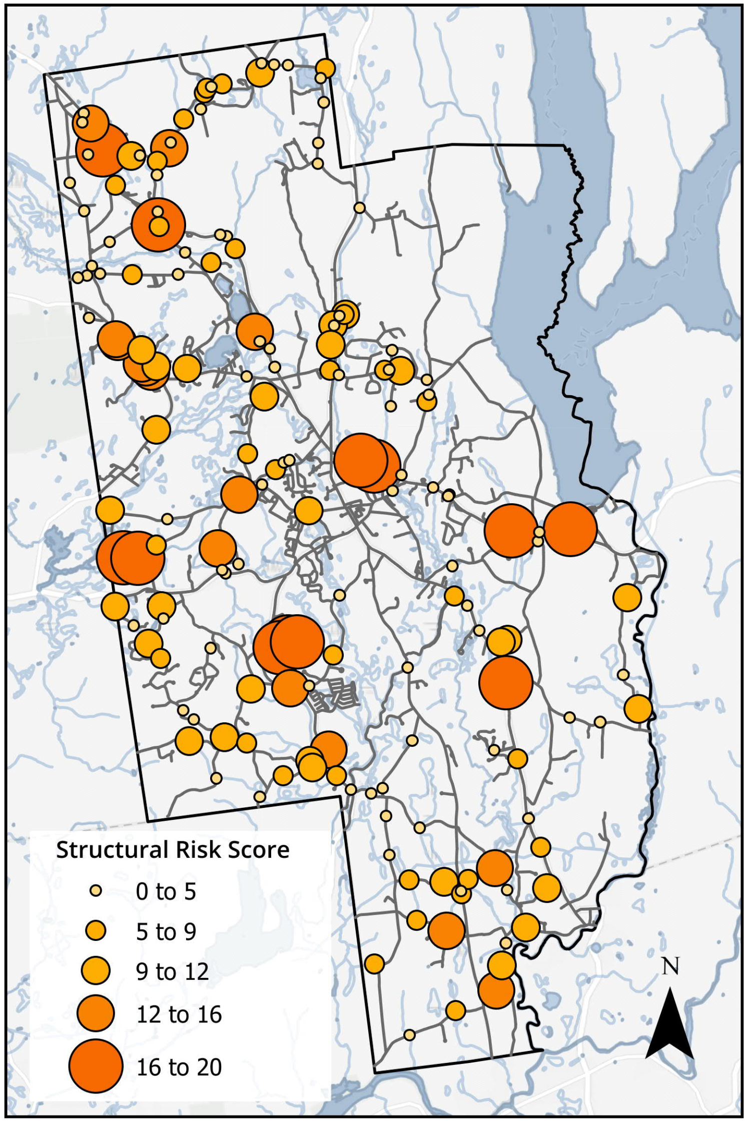


Figure 9. Left to Right: Distribution of structural condition, geomorphic vulnerability, and aquatic organism passage ratings across all assessed crossings.



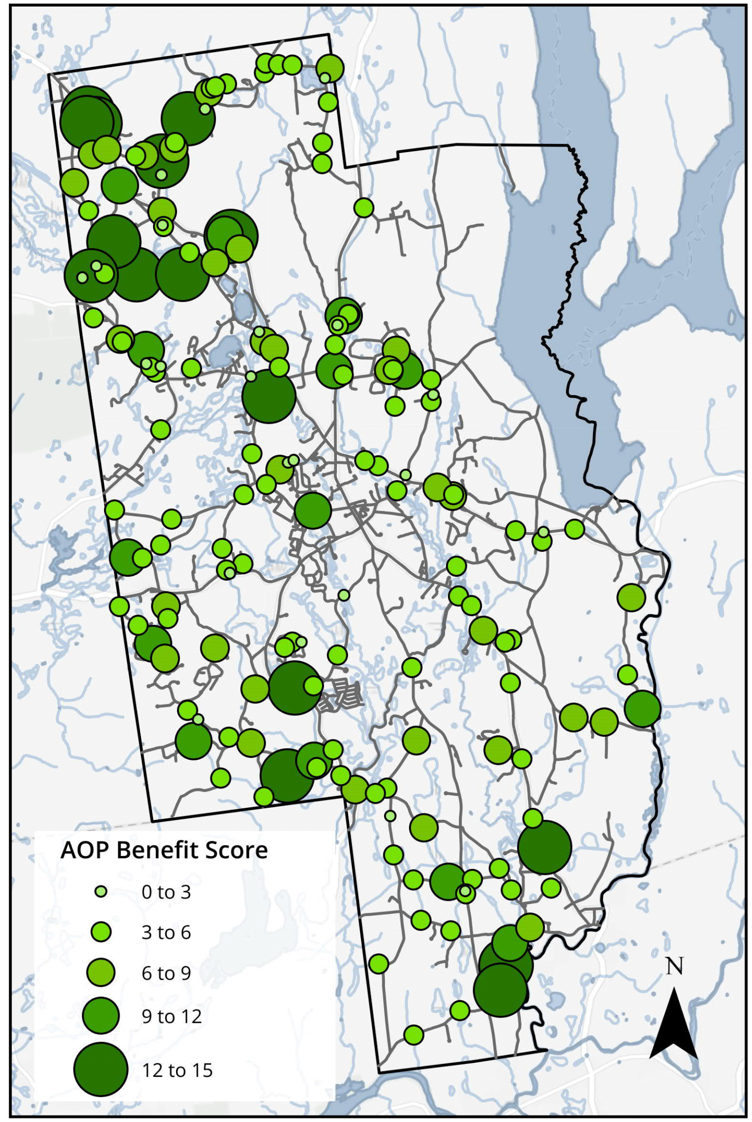


Figure 10. Spatial distribution of structural risk scores (left) and aquatic organism passage benefit (right) for all assessed crossings.

Aquatic Organism Passage

Approximately 40% of structures are considered moderate or worse barriers to aquatic organism passage (Figure 9), but only 11% of structures were considered to act as significant barriers. 18% are considered to provide full aquatic passage. Among the crossings with the highest potential AOP benefit scores—that is, crossings which are barriers to aquatic organism passage but which are also at locations where improved passage would have the greatest benefit—ten were also scored as high priority overall. Approximately two-thirds of crossings with the highest AOP benefit scores are located in the Fort River watershed (Figure 10).

Potential Impacts

Because impacts to transportation services were calculated as a function of road classification, the crossings with the highest potential for transportation disruption were found to occur on state roadways, rather than Town-owned roads. Some of the sites with high potential for flooding impacts were also located on state roads (e.g., Route 21 at Roaring Brook, Route 9 at Scarboro Brook). However, high impact scores related to potential flooding were also seen on municipal roads throughout Town, particularly in the Chicopee River, Batchelor Brook, and Fort River watersheds. Crossings of Roaring Brook at Ludlow Street and Granby Road were the highest ranked for potential flooding impacts (Figure 11).

Prioritization

The Ludlow Street and Granby Road crossings of Roaring Brook were the highest priority crossings overall, with the highest potential for impacts due to flooding or service disruptions and high risks associated with both current and future hydraulic capacity. Several crossings along Scarboro Brook (at crossings with Gulf Road, North Gulf Road, North Street, and Federal Street) are included among the top priorities. The Ledgewood Drive neighborhood, off of Route 21, also has three crossings among the top priorities, which may be partly attributable to the age of development relative to other neighborhoods in Belchertown (Table 1, Figures 12 and 13).

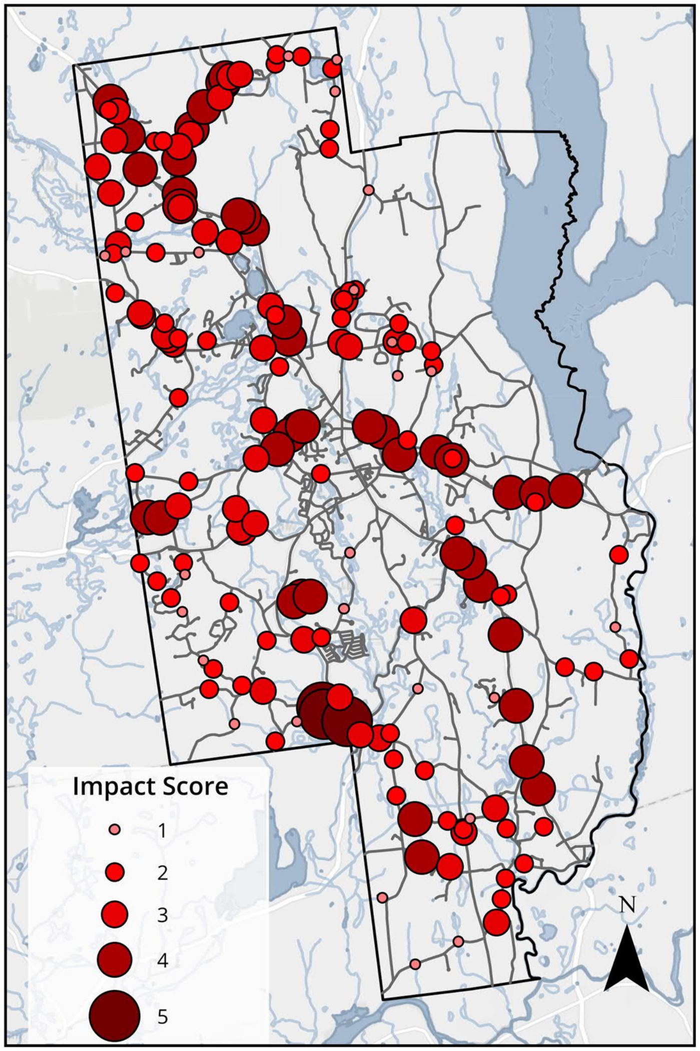


Figure 11. Spatial distribution of impact scores for all assessed crossings.

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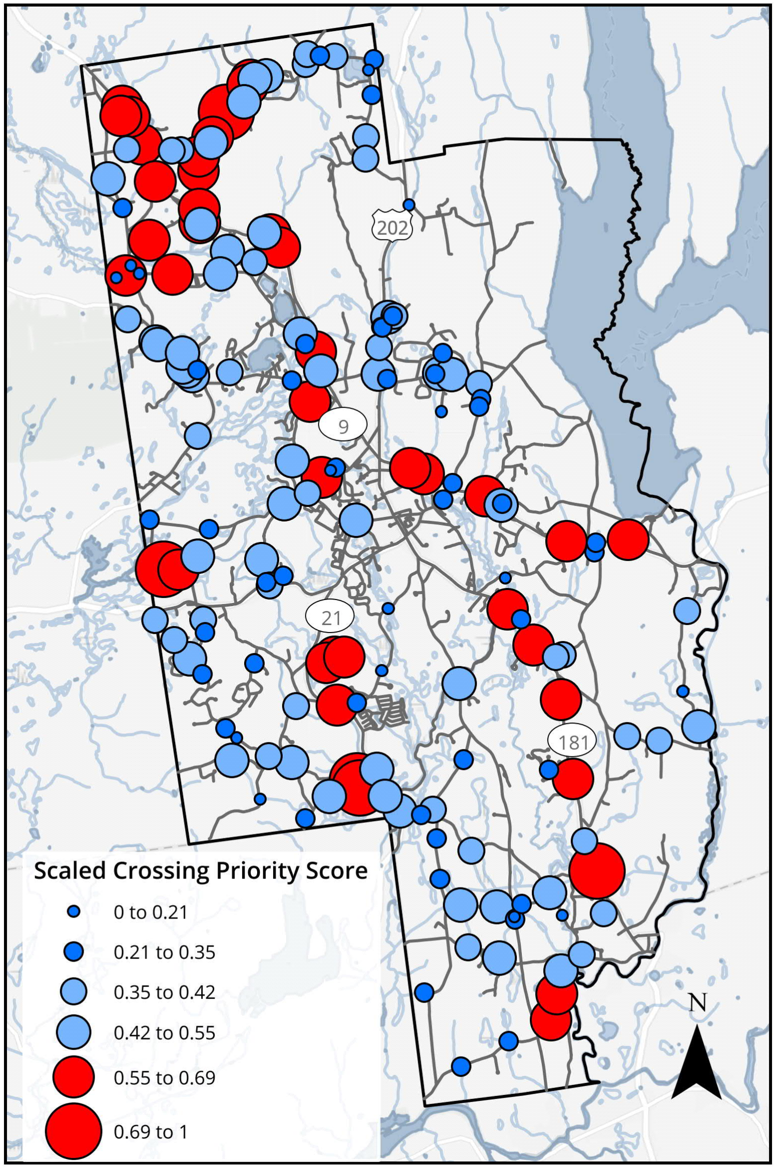


Figure 12. Spatial distribution of scaled crossing priority scores for all assessed crossings, Town-wide. Red dots indicate high priority crossings; light blue dots indicate medium priority crossings, and dark blue dots indicate low priority crossings.

4 Concept Designs

Specific recommendations for crossing upgrades or replacements (i.e., upsizing the existing crossings with larger structures) were developed for the top priority stream crossings on Town-roads that were evaluated as part of this assessment (Table 1). Two additional concepts were developed for Town-maintained crossings on state routes at high priority locations where the Town has experienced past flooding. These planning-level recommendations and design concepts are intended to enhance the resilience of the stream crossings and river system by withstanding extreme flood events, providing for the passage of debris during floods, and providing for passage of aquatic organisms under normal flow conditions. At several of the crossings, we also recommend channel or floodplain restoration in upstream or downstream areas along with the proposed crossing upgrades to enhance flood resilience, water quality, and aquatic habitat using a combination of natural and infrastructure-based approaches.

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

The following concept designs provide a summary of the existing issues, recommendations, and screening-level cost ranges for Belchertown's top priority stream crossings where upgrades or replacement are recommended. Each two-page concept includes a description and photographs of existing conditions, key data and findings from the field assessment, a description of the proposed design concept, and a plan view drawing of the site conditions and proposed replacement crossing.

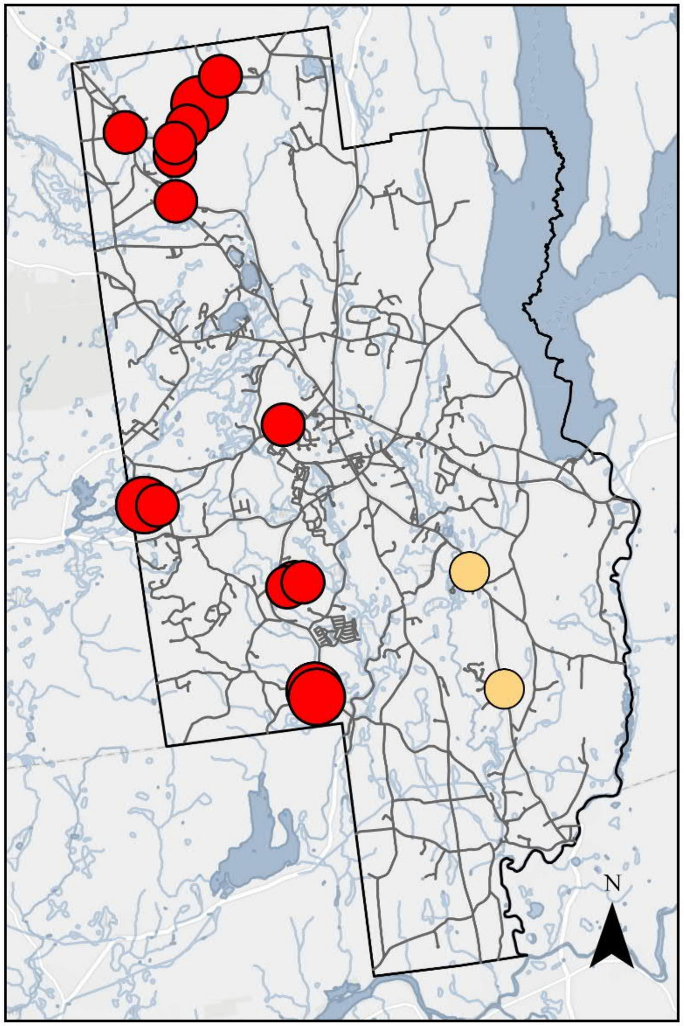


Figure 13. Locations of high priority Town-owned or Town-maintained crossings for which concept designs were developed. Larger dots indicate higher priority scores. Red dots indicate locations on Town roads; orange dots indicate locations on numbered state routes.

Ludlow Street at Roaring Brook
Culvert Replacement Concept
Belchertown, MA

Site Description

Ludlow Street crosses Roaring Brook several hundred feet north of Granby Road. The crossing consists of a single 5-foot diameter corrugated metal pipe, making the crossing width less than one third of Roaring Brook's bankfull width. Due to the severe constriction at the crossing, flow velocities in the culvert are significantly faster than the surrounding stream. These conditions pose a barrier to aquatic passage and have also resulted in creation of a large scour pool at the outlet and downstream deposition of displaced sediment. The outlet has been extensively armored in an attempt to prevent erosion, but the severity of the stream's constriction and high-velocity flows will continue to cause scour. The crossing can pass the existing 10-year peak flow, but is undersized for larger recurrence interval peak flows that were analyzed (25-year, 50-year, and 100-year) and estimated peak flows given future climate change projections.

Proposed Concept

- Replace the existing undersized culvert with a bridge of approximately 22 foot span to accommodate the 1.2 times bankfull width design standard of the Massachusetts River and Stream Crossing Standards.
- Restore the stream banks and streambed to repair the existing scour pool and erosion, and match the substrate characteristics of the natural stream channel.
- The proposed culvert replacement design concept will:
  - ➢ Improve the alignment of the stream to the crossing structure
  - ➢ Provide increased hydraulic capacity to reduce flooding risk
  - ➢ Reduce erosion and scour by decreasing flow velocity through the crossing

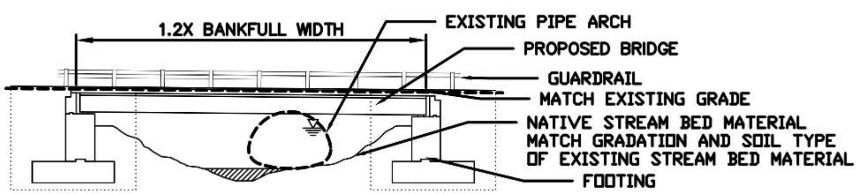


Image 4: Typical detail of a replacement bridge designed to meet the MA River and Stream Crossing Standards

Image 1: View of current crossing inlet taken during field assessment on October 3, 2018.

Image 2: Stream alignment relative to culvert inlet. Arrow indicates flow path entering culvert.

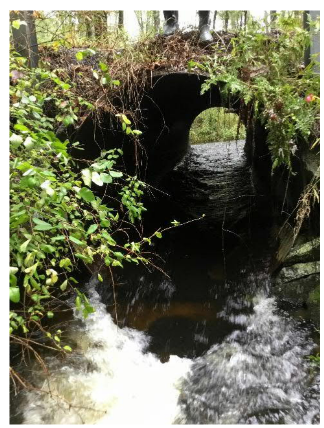


Image 3: View of current crossing outlet, October 3, 2018.

Site Prioritization Summary

Scaled Crossing Priority Score (0-1): 0.87
Impact Score (1-5): 5
Hydraulic Risk Score (1-25) (Existing/Future): 20/25
Geomorphic Risk Score (1-25): 15
Structural Risk Score (1-25): 10
AOP Benefit Score (1-25): 12

Existing Crossing Characteristics

Material: Corrugated Metal Pipe
Structure Width: 5 feet
Structure Height: 5 feet
Structure Length: 27 feet
Bankfull Width: 18 feet

Hydraulic Capacity Summary

Total Drainage Area: 1.47 miles^2
Existing Structure Capacity: 138 cfs
Estimated Peak Flows:

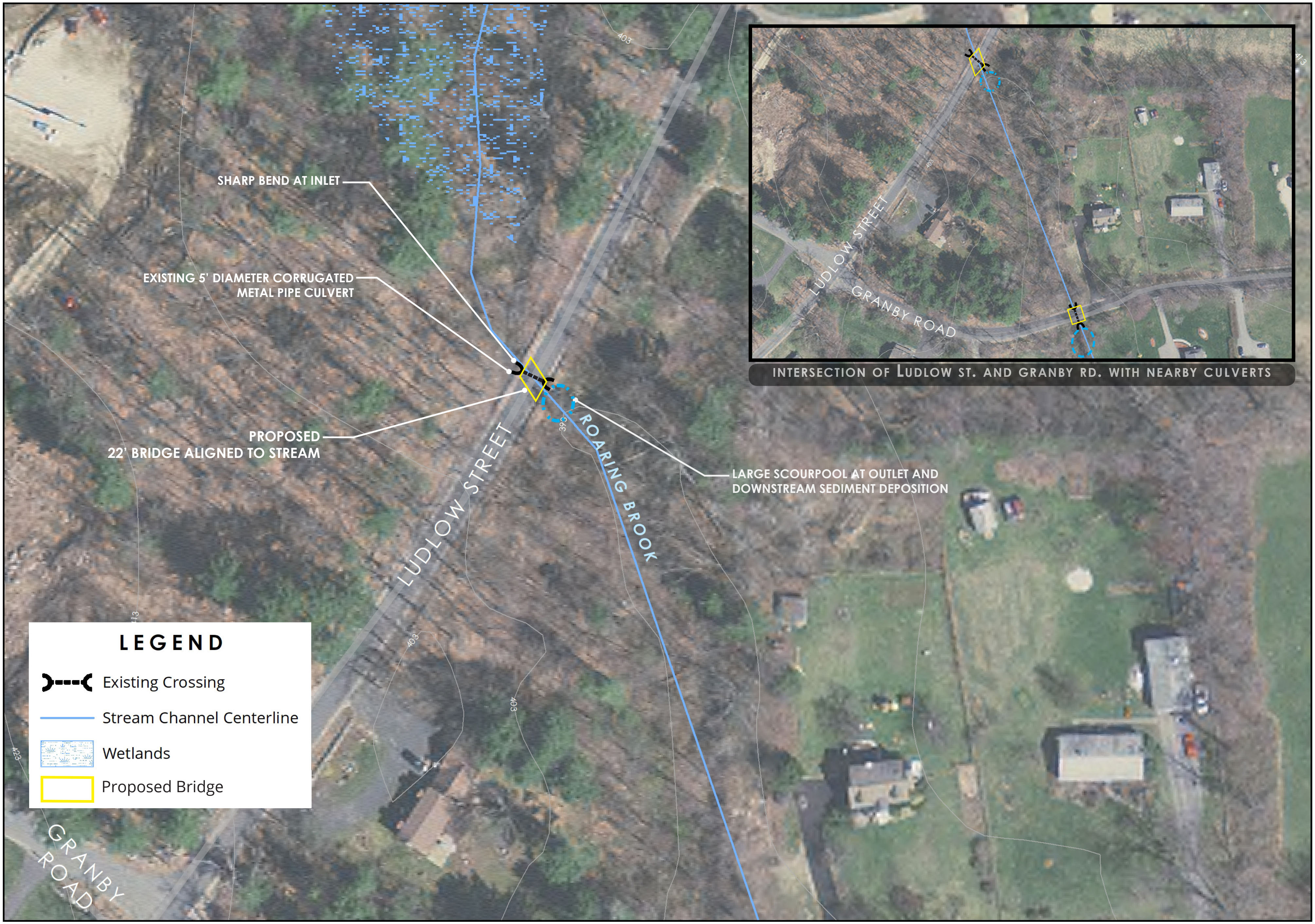
Recurrence Interval	Existing	Future
10-year	130 cfs	156 cfs
25-year	178 cfs	214 cfs
50-year	218 cfs	262 cfs
100-year	261 cfs	313 cfs

Notable Assessment Findings

Severe constriction
Large downstream scour pool
Downstream sediment deposition

Estimated Replacement Cost Range

Total project cost: $750K to $1 million



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Ludlow Road at Roaring Brook

Culvert Replacement Concepts, Belchertown, MA

0 50 100 Feet

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Granby Road at Roaring Brook
Culvert Replacement Concept
Belchertown, MA

Site Description

Granby Road crosses Roaring Brook a few hundred feet east of Ludlow Street. The crossing consists of a single corrugated metal pipe of approximately 6 feet in diameter, making the crossing width less than one third of Roaring Brook's bankfull width. Due to the severe constriction at the crossing, flow velocities in the culvert are significantly faster than the surrounding stream. These conditions pose a barrier to aquatic passage and have also resulted in creation of a large scour pool at the outlet and downstream deposition of displaced sediment. The crossing is significantly undersized for all of the recurrence interval peak flows that were analyzed (10-year, 25-year, 50-year, and 100-year), as well as the estimated peak flows given future climate change projections. Several crayfish were noted at the crossing during the field assessment, indicating that the stream provides important wildlife habitat and underscoring the relevance of aquatic organism passage at this site. The crossing is also scored as among the top 15% of culverts identified for replacement in the Massachusetts Wildlife Climate Action Tool.

Proposed Concept

- Replace the existing undersized culvert with a bridge of approximately 22 foot span to accommodate the 1.2 times bankfull width design standard of the Massachusetts River and Stream Crossing Standards.
- Reconstruct stream banks at the crossing to match the existing stream channel up and downstream of the crossing, and match the substrate characteristics of the natural stream channel.
- The proposed culvert replacement design concept will:
    - Provide increased hydraulic capacity to reduce flooding risk
    - Reduce erosion and scour by decreasing flow velocity through the crossing

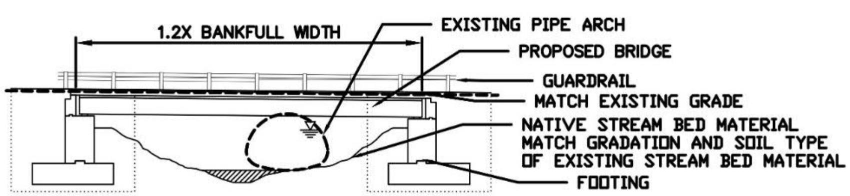

Image 4: Typical detail of a bridge designed to meet the MA River and Stream Crossing Standards

Image 1: View of current crossing inlet taken during field assessment on October 3, 2018.

Image 2: View of current crossing outlet taken during field assessment on October 3, 2018.

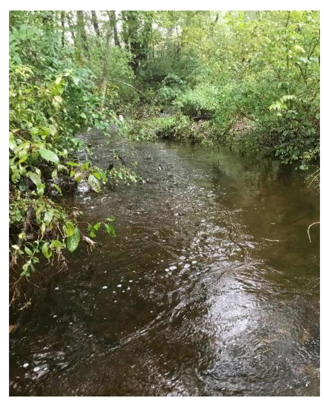

Image 3: View of upstream channel, October 3, 2018.

Site Prioritization Summary

Scaled Crossing Priority Score (0-1): 0.81
Impact Score (1-5): 5
Hydraulic Risk Score (1-25) (Existing/Future): 25/25
Geomorphic Risk Score (1-25): 15
Structural Risk Score (1-25): 10
AOP Benefit Score (1-25): 6

Existing Crossing Characteristics

Material: Corrugated Metal Pipe
Structure Width: 5.7 feet
Structure Height: 4 feet
Structure Length: 29 feet
Bankfull Width: 18 feet

Hydraulic Capacity Summary

Total Drainage Area: 1.49 miles^2
Existing Structure Capacity: 74 cfs
Estimated Peak Flows:

Recurrence Interval	Existing	Future
10-year	132 cfs	158 cfs
25-year	180 cfs	216 cfs
50-year	220 cfs	264 cfs
100-year	264 cfs	317 cfs

Notable Assessment Findings

Severe constriction
Large downstream scour pool
Downstream sediment deposition

Estimated Replacement Cost Range

Total project cost: $750K to $1 million

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Granby Road at Roaring Brook

Culvert Replacement Concepts, Belchertown, MA

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Gulf Road at Scarboro Brook (multiple crossings)
Culvert Replacement Concept
Belchertown, MA

Site Description

Gulf Road and Scarboro Brook cross several times as the road and stream wind down a steep slope at the northern end of Belchertown. Three of these crossings were identified as among the top priorities for replacement. Each of the crossings consists of two corrugated metal pipes of approximately 4-5 feet in diameter, resulting in repeated constrictions of the stream's approximately 17-foot bankfull width. Road fill over the structures ranges from 1.5 feet to 3.7 feet. Downstream sediment deposition and high erosion are typical of the system as a whole and were present at each of the priority structures. The surrounding area is lightly developed, but the potential for flooding impacts is increased by the large number of undersized crossings in sequence. Only the most downstream of the three crossings is sized to pass the existing 10-year peak flow; when climate change projections are considered, none of the crossings is adequately sized to pass the estimated future 10-year peak flow. Scarboro Brook is a high-velocity, high-gradient stream in a heavily wooded area. The ability of structures to pass woody debris and sediment is of high concern to prevent blockages and related culvert failures.

Proposed Concept

- Replace the upstream and middle crossings with bridges, and install an open-bottom arch at the downstream crossing, reconstructing the streambed and banks at each crossing to match the natural channel and spanning 1.2 x bankfull width at each crossing to meet the Massachusetts River and Stream Crossing standards (approximately 21-feet).
- Restore the stream banks and streambed to repair existing scour pool and erosion and realign the middle crossing to eliminate the potential for sediment and debris to accumulate at the inlet.
- The proposed culvert replacement design concept will:
  - ➢ Provide increased hydraulic capacity
  - ➢ Increase aquatic passage in a high-quality, coldwater stream system
  - ➢ Good potential for funding through DER Culvert Grant (rated highly on the Massachusetts Wildlife Climate Action Tool and potential flood risk)

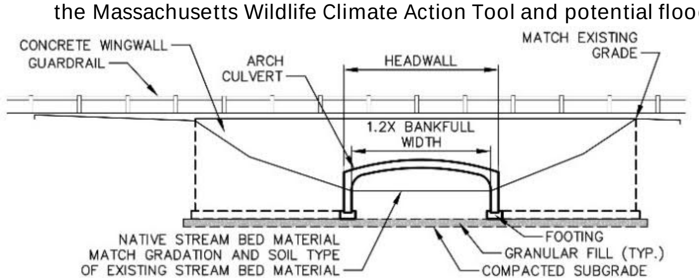

Image 4: Typical detail of an open arch culvert designed to meet MA Stream Crossing Standards


Image 1: View of current structure inlet at the most downstream of the three crossings; September 21, 2018


Image 2: View of inlet to middle crossing, September 17, 2018. As indicated by flow arrows, Scarboro takes a near-90-degree turn into the culvert.


Image 3: Outlet of the most upstream of the three crossings, September 17, 2018.

Site Prioritization Summary

Scaled Crossing Priority Score (0-1): 0.63 to 0.75
Impact Score (1-5): 4 to 5
Existing Hydraulic Risk Score (1-25): 16 to 20
Future Hydraulic Risk Score (1-25): 20
Geomorphic Risk Score (1-25): 8 to 16
Structural Risk Score (1-25): 4 to 8
AOP Benefit Score (1-25): 3 to 15

Existing Crossing Characteristics

Material: Corrugated Metal Pipe
Combined Width: 8 to 10 feet (4-5 feet per pipe)
Structure Height: 4 to 5 feet
Structure Lengths: 24 to 32 feet
Typical Bankfull Width: 17 feet

Hydraulic Capacity Summary

Total Drainage Area: 1.68 to 2.65 miles^2
Existing Structure Capacity: 130 to 316 cfs
Estimated Peak Flows:

Recurrence Interval	Existing	Future
10-year	204 to 281 cfs	245 to 337 cfs
25-year	282 to 387 cfs	338 to 464 cfs
50-year	348 to 476 cfs	417 to 571 cfs
100-year	420 to 572 cfs	504 to 686 cfs

Notable Assessment Findings

High erosion of embankment and banks
Severe constriction
Small scour pool
Evidence of piping

Estimated Replacement Cost Range

Individual crossing replacements:
$500K to $750K each

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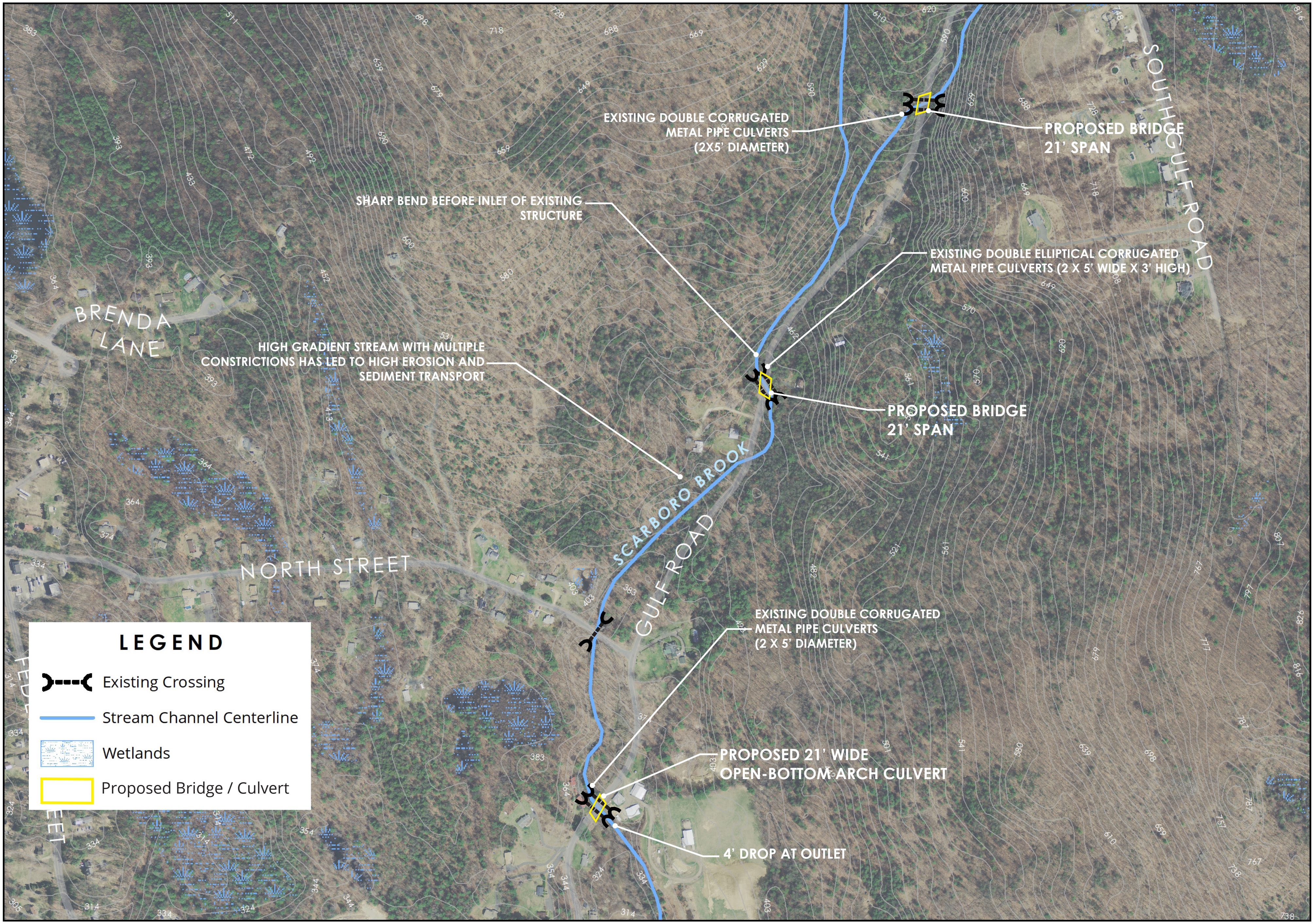

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Gulf Road at Scarboro Brook

Culvert Replacement Concepts, Belchertown, MA

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Rural Street at Weston Brook
Culvert Replacement Concept
Belchertown, MA

Site Description

Rural Street crosses Weston Brook a few hundred feet north of Boardman Street. The crossing consists of a single 6-foot diameter corrugated metal pipe culvert, which severely constricts Weston Brook's 16-foot bankfull width. This constriction has resulted in a large downstream scour pool. At the time of the field assessment on October 5, 2018, DPW had recently cleared away beaver dam debris from the crossing and placed new rip rap on the slope to the right of the inlet (looking downstream). Beaver Solutions was on site the same day to install a beaver deceiver at the crossing inlet. This site was assessed for beaver activity on December 18, 2018. At that time, a partially intact beaver dam was located upstream of the crossing. Hydraulically, the crossing is sized for the 10-year peak flow, but does not have sufficient capacity for larger recurrence interval peak flows that were analyzed (25-year, 50-year, and 100-year) and estimated peak flows given future climate change projections.

Proposed Concept

- Replace the existing corrugated metal pipe culvert with a bridge, reconstructing the crossing to meet the Massachusetts River and Stream Crossing standards, including a design span of at least 19.2 feet to span 1.2 times the stream's bankfull width.
- Restore the downstream banks and streambed to repair existing scour pool and erosion, and match the substrate characteristics of the natural stream channel.
- The proposed culvert replacement design concept will:
  - Provide increased hydraulic capacity to reduce flooding risk and allow water and debris associated with larger storms to pass.
  - Reduce geomorphic risk associated with erosion and scour
  - Decrease attractiveness to beaver by reducing sounds of flowing water associated with the current constriction condition
  - Decrease potential for backwatering above the crossing inlet

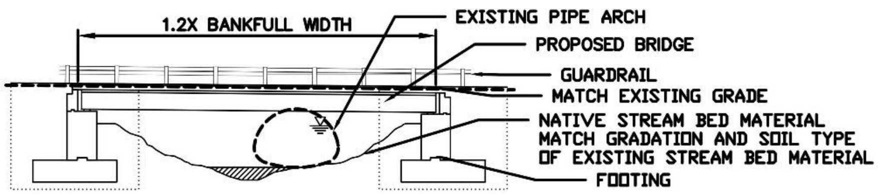


Image 4: Typical detail of a replacement bridge designed to meet the MA River and Stream Crossing Standards

Image 1: View of current structure inlet taken during field assessment on October 5, 2018

Image 2: Looking downstream from the crossing. Note the width of the scour pool immediately downstream of the crossing relative to the bankfull width of the channel further downstream.

Site Prioritization Summary

Scaled Crossing Priority Score (0-1): 0.72
Impact Score (1-5): 4
Hydraulic Risk Score (1-25) (Existing/Future): 16/20
Geomorphic Risk Score (1-25): 12
Structural Risk Score (1-25): 20
AOP Benefit Score (1-25): 12

Existing Crossing Characteristics

Material: Corrugated Metal Pipe
Structure Width: 6 feet
Structure Height: 6 feet
Structure Length: 24 feet
Bankfull Width: 16 feet

Hydraulic Capacity Summary

Total Drainage Area: 3.78 miles^2
Existing Structure Capacity: 214 cfs
Estimated Peak Flows:

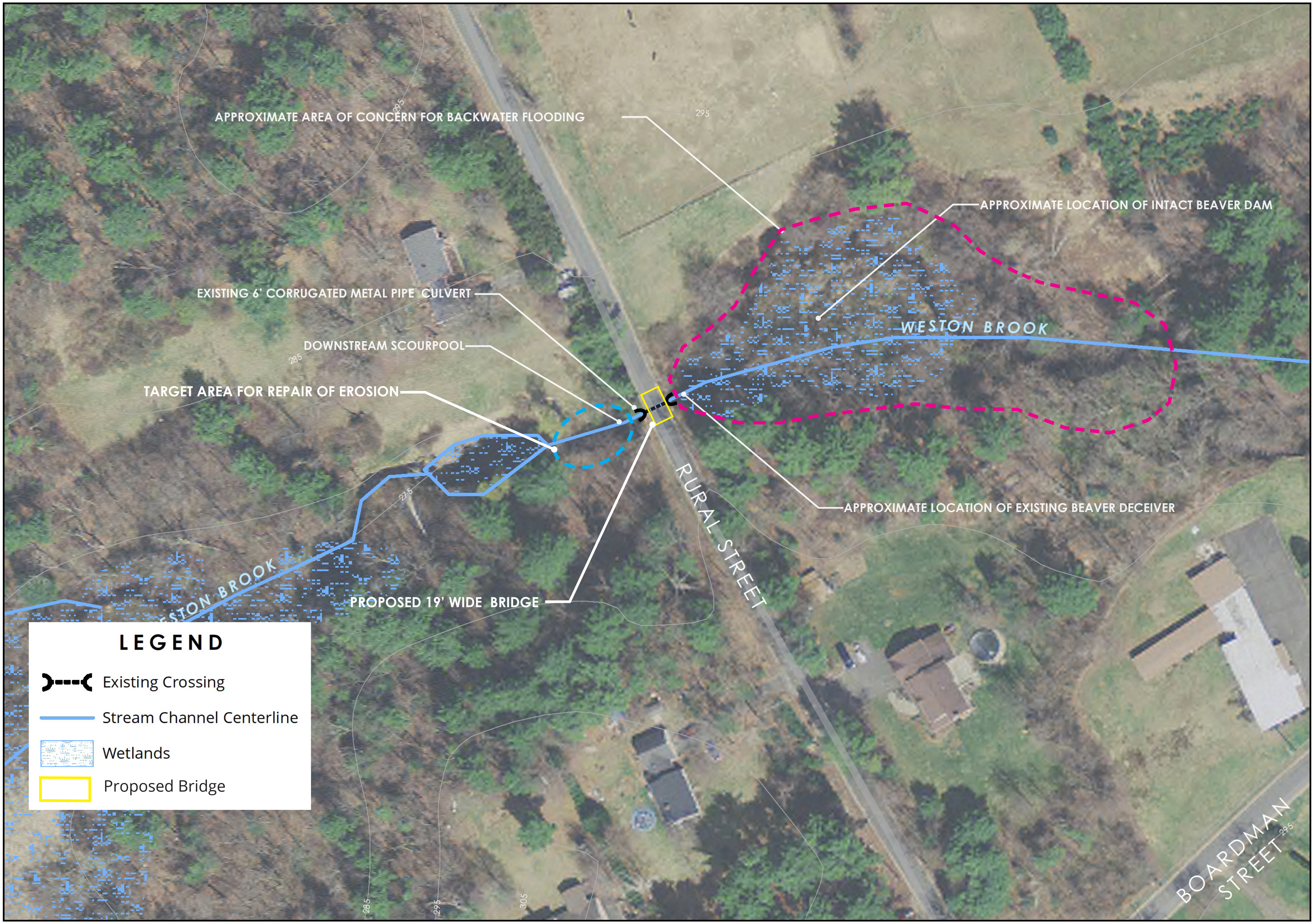
Recurrence Interval	Existing	Future
10-year	213 cfs	256 cfs
25-year	288 cfs	346 cfs
50-year	350 cfs	420 cfs
100-year	416 cfs	499 cfs

Notable Assessment Findings

Armoring in critical condition
Severe constriction
Large scour pool

Estimated Replacement Cost Range

Total project cost: $400K to $500K



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Rural Street at Weston Brook

Culvert Replacement Concepts, Belchertown, MA

0 50 100 200 Feet

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George Hannum Street at Unnamed Tributary to Lampson Brook
Culvert Replacement Concept
Belchertown, MA

Site Description

George Hannum Street crosses an unnamed tributary to Lampson Brook immediately east of the driveway of Austin-Gaughn Memorial Field. The crossing consists of a single corrugated metal pipe of approximately 2.5 feet in diameter, severely constricting the stream relative to its bankfull width. Due to the constriction, water velocity through the pipe is considerably faster than the upstream and downstream flow velocities. The inlet is dropped below the grade of the streambed, and debris is accumulating at the inlet because the stream and culvert are poorly aligned. At the outlet, there is a freefall onto cascade condition that has resulted in a large scour pool. The existing structure is sized to pass the 10-year peak flow but is undersized for larger recurrence interval peak flows that were analyzed (25-year, 50-year, and 100-year) and estimated peak flows given future climate change projections.

Proposed Concept

- Replace the existing corrugated metal pipe culvert with an embedded box culvert, reconstructing the crossing to meet the Massachusetts River and Stream Crossing Standards, including a design span of at least 10 feet to span 1.2 times the stream's bankfull width.
- Realign the crossing to better match the natural path of the stream and reduce potential for accumulated debris to block flows, and match the substrate characteristics of the natural stream channel.
- The proposed culvert replacement design concept will:
  - ➢ Provide increased hydraulic capacity to reduce flooding risk and allow water and debris associated with larger storms to pass
  - ➢ Reduce geomorphic risk associated with erosion and scour by eliminating freefall condition
  - ➢ Improve alignment of crossing with stream path to improve passage of woody material through structure and prevent accumulation of debris

Image 3: Example of embedded box culvert (Maine Audubon).

Image 1: View of current structure outlet taken during field assessment on September 27, 2018. Note that outlet has a freefall onto cascade condition which contributes to scour and geomorphic risk.

Image 2: View of inlet to current structure. The existing inlet is below the grade of the streambed, creating an inlet drop condition.

Site Prioritization Summary

Scaled Crossing Priority Score (0-1): 0.69
Impact Score (1-5): 4
Hydraulic Risk Score (1-25) (Existing/Future): 16/20
Geomorphic Risk Score (1-25): 16
Structural Risk Score (1-25): 8
AOP Benefit Score (1-25): 9

Existing Crossing Characteristics

Material: Corrugated Metal Pipe
Structure Width: 2.5 feet
Structure Height: 2.5 feet
Structure Length: 45 feet
Bankfull Width: 8 feet

Hydraulic Capacity Summary

Total Drainage Area: 0.26 miles^2
Existing Structure Capacity: 25 cfs
Estimated Peak Flows:

Recurrence Interval	Existing	Future
10-year	22 cfs	28 cfs
25-year	31 cfs	37 cfs
50-year	38 cfs	45 cfs
100-year	46 cfs	55 cfs

Notable Assessment Findings

Freefall onto cascade at outlet
Inlet drop
Severe constriction
Large scour pool
Poor alignment of pipe with stream

Estimated Replacement Cost Range

Total project cost: $200K to $300K

George Hannum Street - Tributary to Lampson Brook

Culvert Replacement Concepts, Belchertown, MA

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North Street at Montague Brook
Culvert Replacement Concept
Belchertown, MA

Site Description

Montague Brook crosses North Street at a bend in the road approximately 400 feet west of Route 9. The crossing consists of two corrugated metal elliptical pipes, each approximately 3.5 feet wide, severely constricting Montague Brook's 14-foot bankfull width. The headwall at the outlet is in critical condition; several of the large headwall stones have fallen into the stream and partially block the outlet of one of the two structures. The crossing is hydraulically undersized, with total capacity only about a quarter of the estimated 10-year peak flow. A large outlet scour pool indicates that water is forced through the culverts at high velocity during storm events. This has led to significant bank erosion and is likely responsible for the failure of the outlet headwall.

Proposed Concept

- Replace the existing undersized culvert with an open-bottom arch with an approximately 17-foot span to accommodate the 1.2 times bankfull width design standard of the Massachusetts River and Stream Crossing Standards.
- The proposed culvert replacement design concept will:
  - Provide increased hydraulic capacity to reduce flooding risk
  - Reduce erosion and scour by decreasing flow velocity through the crossing
  - Protect North Street from undermining and failure risk

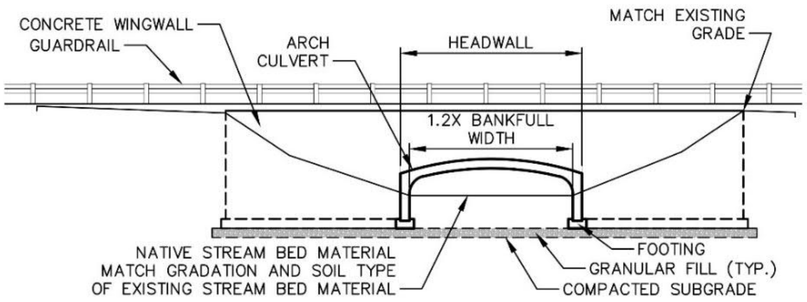

Image 4: Typical detail of an open arch culvert designed to meet the MA River and Stream Crossing Standards

Image 1: View of current crossing inlet taken during field assessment on September 21, 2018.

Image 2: View of critical headwall condition at outlet, September 21, 2018.

Image 3: Location of the crossing at a bend in the road on North Street.

Site Prioritization Summary

Scaled Crossing Priority Score (0-1): 0.69
Impact Score (1-5): 4
Hydraulic Risk Score (1-25) (Existing/Future): 20/20
Geomorphic Risk Score (1-25): 16
Structural Risk Score (1-25): 20
AOP Benefit Score (1-25): 9

Existing Crossing Characteristics

Material: Corrugated Metal Pipe
Combined Structure Width: 7 feet (3.5 feet each)
Structure Height: 2.4 feet
Structure Length: 50 feet
Bankfull Width: 14 feet

Hydraulic Capacity Summary

Total Drainage Area: 1.84 miles^2
Existing Structure Capacity: 42 cfs
Estimated Peak Flows:

Recurrence Interval	Existing	Future
10-year	169 cfs	203 cfs
25-year	231 cfs	277 cfs
50-year	283 cfs	340 cfs
100-year	339 cfs	407 cfs

Notable Assessment Findings

Outlet headwall in critical condition
High bank erosion
Severe constriction
Large scour pool
Inlet drop at one structure

Estimated Replacement Cost Range

Total project cost: $400K to $500K

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North Street at Montague Brook

Culvert Replacement Concepts, Belchertown, MA

0 50 100 200 300 Feet

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North Gulf Road at Scarboro Brook
Culvert Replacement/Stream Restoration Concept
Belchertown, MA

Site Description

Scarboro Brook crosses North Gulf Road just south of the Scarborough Brook Conservation Area, at the intersection of North Gulf, Gulf, and South Gulf Roads. Scarboro Brook then crosses Gulf Road several more times as the road and stream wind down a steep slope. The crossing at North Gulf Road is located in a deep gully below the intersection and is covered by 11 feet of fill. The crossing consists of a single 6-foot diameter corrugated metal pipe, severely constricting Scarboro Brook's 26-foot bankfull width. Two dams impound water upstream of the crossing, the nearest of which is approximately 150 feet upstream of the culvert inlet. The dam spillway is not aligned with the culvert; Scarboro Brook makes a sharp s-bend immediately before entering the inlet. This in turn causes severe slope erosion along Gulf Road. Silt fence and heavy armoring of the Gulf Road embankment were noted during the field assessment. This erosion can be attributed to high-velocity flows in combination with the poor alignment of the culvert with the stream. The 90-degree bend at the inlet is also a risk factor for blockages due to accumulation of woody debris. The crossing's cascading outlet is well-aligned with the stream and naturally armored from streambed scour. Hydraulically, the crossing is sized to pass the existing 10-year peak flow but is undersized for all other recurrence interval flows that we evaluated and for future climate projections.

Proposed Concept

- Shift the dam's spillway north to realign the upstream channel, eliminate the s-bend and reduce geomorphic risk, and reduce erosion of Gulf Road.
- Replace the existing undersized culvert with an open-bottom arch that spans 1.2 times bankfull width in compliance with the Massachusetts River and Stream Crossing Standards.
- The proposed culvert replacement design concept will:
  - ➢ Provide increased hydraulic capacity to reduce flooding risk
  - ➢ Increase aquatic passage in a high-quality, coldwater stream system
  - ➢ Protect Gulf Road from undermining and erosion

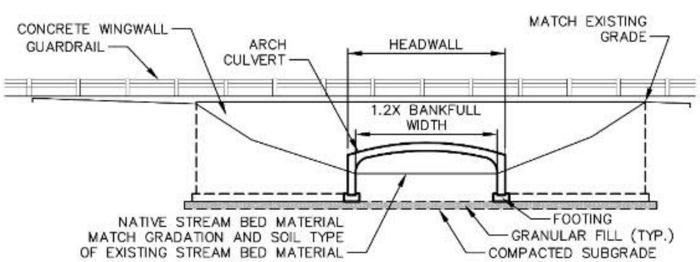

Image 4: Typical detail of an open arch culvert designed to meet the MA Stream Crossing Standards

Image 1: View of current structure inlet taken during field assessment on September 17, 2018. Arrow indicates approximate flow path of Scarboro Brook.

Image 2: View of outlet to middle crossing, September 17, 2018. Note that Scarboro Brook enters from the left of image and takes a near-90 degree turn into the culvert.

Image 3: View upstream from the crossing; September 17, 2018. Red arrow indicates location of the upstream dam.

Site Prioritization Summary
Scaled Crossing Priority Score (0-1): 0.66
Impact Score (1-5): 4
Hydraulic Risk Score (1-25) (Existing/Future): 16/20
Geomorphic Risk Score (1-25): 16
Structural Risk Score (1-25): 8
AOP Benefit Score (1-25): 6

Existing Crossing Characteristics
Material: Corrugated Metal Pipe
Structure Width: 6 feet
Structure Height: 6 feet
Structure Length: 60 feet
Bankfull Width: 26 feet

Hydraulic Capacity Summary
Total Drainage Area: 1.52 miles^2
Existing Structure Capacity: 218 cfs
Estimated Peak Flows:

Recurrence Interval	Existing	Future
10-year	189 cfs	227 cfs
25-year	261 cfs	313 cfs
50-year	323 cfs	388 cfs
100-year	390 cfs	468 cfs

Notable Assessment Findings
High bank erosion
Severe constriction
Sharp s-bend immediately upstream of inlet
Evidence of piping

Estimated Replacement Cost Range
Estimated $1 million for crossing replacement
Estimated $300K to $800K for restoration spillway replacement

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North Gulf Road at Scarboro Brook

Culvert Replacement Concepts, Belchertown, MA

0 50 100 200 Feet

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Ledgewood Drive Neighborhood
Culvert Replacement Concepts
Belchertown, MA

Site Description

The Ledgewood Drive neighborhood, located off of Route 21, consists primarily of homes built in the mid to late 1970s. Several small wetlands and an unnamed stream are located within the neighborhood. The stream is crossed by all three roads in the neighborhood: Forest Road (near #13), Ledgewood Circle (near #22), and Ledgewood Drive (near #19). The Forest Road crossing consists of two 1-foot diameter corrugated metal pipes, both of which are severely deteriorated, with rusted out inverts and critical scores for structural integrity. One of the two structures is also partially filled in with muck, decreasing its hydraulic capacity. The inlet to the Ledgewood Circle crossing is in similarly critical condition, and the outlet is blocked by fallen rock. The inlet of the Ledgewood Drive culvert is crushed and blocked and the pipe also appears to be collapsed approximately three feet inside the outlet. The exact path of the Ledgewood Drive crossing was not clear, but the inlet and outlet appear to be aligned perpendicular to one another, suggesting a 90 degree turn somewhere in the structure, or possibly a connection with the drainage system across the street from the outlet. Though the watershed of the unnamed stream is small and does not carry large flows, the three crossings are all undersized to pass the 10-year peak flow and are severely constricted relative to the channel's bankfull width.

Proposed Concept

- Replace the existing undersized and deteriorated crossings at Forest Road and Ledgewood Circle with embedded box culverts approximately 6 feet wide by 4 feet high, designed to meet the Massachusetts River and Stream Crossing Standards.
- Refine bankfull width measurement and realign and enlarge the Ledgewood Drive crossing with an approximately 12-foot wide open bottom arch to provide direct connection between the stream inlet and outlet and improve flow conveyance and wildlife passage.
- The proposed culvert replacement design concept will:
  - ➢ Provide increased hydraulic capacity to reduce flooding risk
  - ➢ Remedy the current potential for structural failure at all crossings
  - ➢ Reduce sediment deposition and associated blockages
  - ➢ Improve terrestrial and aquatic passage conditions to connect forested wetlands throughout the neighborhood

Image 1: View of current Forest Road crossing inlet taken during field assessment on October 4, 2018.

Image 2: View of the blocked outlet at Ledgewood Circle taken during field assessment on October 4, 2018.

Image 3: View of deteriorated invert condition.

Site Prioritization Summary

Scaled Crossing Priority Score (0-1): 0.63 to 0.66
Impact Score (1-5): 4
Hydraulic Risk Score (1-25) (Existing/Future): 20/20
Geomorphic Risk Score (1-25): 8 to 16
Structural Risk Score (1-25): 20
AOP Benefit Score (1-25): 3 to 6

Existing Crossing Characteristics

Material: Corrugated Metal Pipe
Structure Widths: 1 foot
Structure Heights: 1 foot
Structure Length: 40 feet to 101 feet (estimated)
Bankfull Width: 5 feet (upstream) to approximately 16 to 20 feet (downstream)

Hydraulic Capacity Summary

Total Drainage Area: 0.02 miles^2
Existing Structure Capacity: 1 to 3 cfs
Estimated Peak Flows:

Recurrence Interval	Existing	Future
10-year	4 to 17 cfs	5 to 20 cfs
25-year	6 to 24 cfs	7 to 29 cfs
50-year	7 to 30 cfs	9 to 36 cfs
100-year	9 to 37 cfs	11 to 44 cfs

Notable Assessment Findings

Severe constriction
Critical invert deterioration
Critical structural integrity at two crossings
Clogged/blocked inlets at two crossings
Outlet blocked by boulders at one crossing
Upstream/downstream sediment deposition
Frogs and mammal tracks noted at crossings

Estimated Replacement Cost Range

Total project cost: $500K to $750K

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Ledgewood Drive Neighborhood

Culvert Replacement Concepts, Belchertown, MA

0 50 100 200 300 Feet

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Boardman Street at Weston Brook
Culvert Replacement Concept
Belchertown, MA

Site Description

The Boardman Street/Weston Brook crossing is located immediately east of the intersection with Eskett Road and consists of two round corrugated metal pipes of approximately 5 feet in diameter (both are slightly deformed). The combined width of the structures is slightly greater than half of the stream's bankfull width, representing a severe constriction. One of the two structures is well-aligned with the stream and receives more of the existing flow at low-flow conditions, while the other is poorly aligned and therefore receives less flow. The crossing is sized to pass the existing 10-year peak flow, but is undersized for the other recurrence interval peak flows that were analyzed (25-year, 50-year, and 100-year). Furthermore, the crossing is expected to be undersized for the 10-year peak flow given future climate change projections.

Proposed Concept

- Replace the existing corrugated metal pipe culvert with a bridge, reconstructing the crossing to meet the Massachusetts River and Stream Crossing Standards, including a design span of at least 21.6 feet to span 1.2 times the stream's bankfull width.
- Restore the stream banks and streambed to repair the existing scour pool and erosion, and match the substrate characteristics of the natural stream channel.
- The proposed culvert replacement design concept will:
  - ➢ Provide increased hydraulic capacity to reduce flooding risk and allow water and debris associated with larger storms to pass.
  - ➢ Decrease potential of road overtopping during heavy precipitation
  - ➢ Reduce geomorphic risk associated with erosion and scour
  - ➢ Create a single span to eliminate risks of road undermining due to erosion and piping between the two existing structures

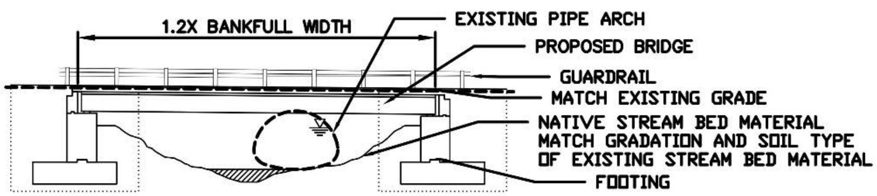

Image 4: Typical detail of an open arch culvert designed to meet the MA River and Stream Crossing Standards

Image 1: View of current structure outlet taken during field assessment on October 15, 2018

Image 2: Erosion of fill and protective armoring between the two structures at the crossing inlet.

Image 3: Location of the crossing adjacent to the intersection of Boardman Street and Eskett Road.

Site Prioritization Summary

Scaled Crossing Priority Score (0-1): 0.64
Impact Score (1-5): 4
Hydraulic Risk Score (1-25) (Existing/Future): 16/20
Geomorphic Risk Score (1-25): 16
Structural Risk Score (1-25): 20
AOP Benefit Score (1-25): 4

Existing Crossing Characteristics

Material: corrugated metal pipe
Combined Structure Width: 10 feet (5 feet x 2)
Structure Height: 5 feet
Structure Length: 25 feet
Bankfull Width: 18 feet

Hydraulic Capacity Summary

Total Drainage Area: 3.74 $miles^2$
Existing Structure Capacity: 234 cfs
Estimated Peak Flows:

Recurrence Interval	Existing	Future
10-year	212 cfs	254 cfs
25-year	287 cfs	344 cfs
50-year	349 cfs	419 cfs
100-year	415 cfs	498 cfs

Notable Assessment Findings

High erosion of embankment and stream banks
Severe constriction
Small scour pool
Evidence of piping

Estimated Replacement Cost Range

Total project cost: $750K to $1 million

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Boardman Street at Weston Brook

Culvert Replacement Concepts, Belchertown, MA

0 50 100 200 Feet

N W E S

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

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Federal Street at Scarboro Brook
Culvert Replacement Concept
Belchertown, MA

Site Description

The crossing at Federal Street and Scarboro Brook consists of two elliptical corrugated metal pipes of approximately 6.4 feet in diameter, making the crossing moderately constricted relative to the Brook's bankfull width. Both structures have large rocks at their outlets and sediment is accumulating downstream of the structures. An eddy at the inlet to one of the structures appears to be directing most of the flow toward the second structure, which is set further back, closer to the road. After passing through the Federal Street crossing, Scarboro Brook takes a 90 degree turn to pass through a second stone culvert with a single, narrower opening that is located approximately 40 feet downstream of the first crossing on private property. The latter crossing was not assessed, but may contribute to backwater during high flows. The Federal Street crossing is significantly undersized for the 10-year peak flow, as well as all other recurrence interval peak flows that were analyzed (25-year, 50-year, and 100-year) and estimated peak flows given future climate change projections.

Proposed Concept

- Work with the private landowner at 803 Federal Street to replace both the existing undersized crossings with 18-foot wide embedded box culverts.
- Alternatively, abandon the private crossing and realign the stream to cut diagonally under Federal Street through an 18-foot wide box culvert, eliminating the sharp bend in the stream channel. Reconstruct the streambed to match the existing channel upstream and downstream.
- The proposed culvert replacement design concept will:
  - Provide increased hydraulic capacity to reduce flooding risk.
  - Reduce scour by eliminating the sharp bend in the stream and constriction points at both crossings.
  - Good potential for funding under the DER Culvert replacement program; both crossings listed as Top 10% coldwater stream crossings for replacement in the Massachusetts Wildlife Climate Action Tool.

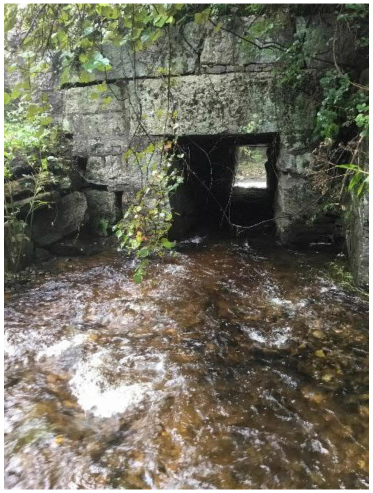

Image 3: Secondary, privately-owned crossing downstream of assessed crossing.

Image 1: View of current crossing inlet taken during field assessment on September 26, 2018. Note deteriorating headwall condition.

Image 2: View of crossing outlet on September 26, 2018. Note the different flow velocities between the structures.

Image 4: View of structure deformation/crushing and poor headwall condition.

Site Prioritization Summary

Scaled Crossing Priority Score (0-1): 0.63
Impact Score (1-5): 4
Hydraulic Risk Score (1-25): (Existing/Future): 20/20
Geomorphic Risk Score (1-25): 12
Structural Risk Score (1-25): 20
AOP Benefit Score (1-25): 3

Existing Crossing Characteristics

Material: Corrugated Metal Pipe
Combined Structure Width: 12.8 feet (6.4 feet each)
Structure Height: 3.4 feet
Structure Length: 31 feet
Bankfull Width: 15 feet

Hydraulic Capacity Summary

Total Drainage Area: 2.98 miles^2
Existing Structure Capacity: 134 cfs
Estimated Peak Flows:

Recurrence Interval	Existing	Future
10-year	303 cfs	364 cfs
25-year	415 cfs	498 cfs
50-year	510 cfs	612 cfs
100-year	613 cfs	736 cfs

Notable Assessment Findings

Moderate constriction
Large downstream scour pool
Downstream sediment deposition
Deteriorating headwall and crushing of pipe.
Second constriction and sharp bend downstream

Estimated Replacement Cost Range

Total project cost: \$400K to \$500K per crossing
Alternative concept: \$1 to \$1.5 million

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Federal Street at Scarboro Brook

Culvert Replacement Concepts, Belchertown, MA

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North Street at Scarboro Brook
Culvert Replacement/Stream Restoration Concept
Belchertown, MA

Site Description

North Street crosses Scarboro Brook just west of the intersection with Gulf Road. The North Street crossing is located between two high-priority crossings on Gulf Road, but differs from those crossings in several important ways. The North Street crossing consists of a single 6-foot diameter corrugated metal pipe, severely constricting Scarboro Brook's 25-foot bankfull width. The outlet has a freefall condition, with a drop of 5.8 feet from the bottom of the pipe to the stream bottom. This has in turn caused the creation of a scour pool approximately 50 feet wide and over 3 feet deep at the time of the field assessment. Displaced sediment from the scour pool has accumulated to form a downstream island approximately 15 feet long by 5 feet wide. Hydraulically, the crossing is undersized for the existing 10-year peak flow, as well as other recurrence interval peak flows that were analyzed (25-year, 50-year, and 100-year) and estimated peak flows given future climate change projections.

Proposed Concept

- Replace the existing undersized culvert with an approximately 30-foot span bridge span to accommodate the 1.2 times bankfull width design standard of the Massachusetts River and Stream Crossing Standards.
- Construct a new streambed to match the slope, width, and substrate of the existing natural channel.
- The proposed culvert replacement design concept will:
  - ➢ Provide increased hydraulic capacity to reduce flooding risk and impacts to upstream crossings
  - ➢ Decrease geomorphic risk by reducing scour and sediment deposition
  - ➢ Increase aquatic passage in a high-quality, coldwater stream system
  - ➢ Good potential for funding through DER due to listing as a coldwater stream and top 10% culvert for replacement in the Massachusetts Wildlife Climate Action Tool

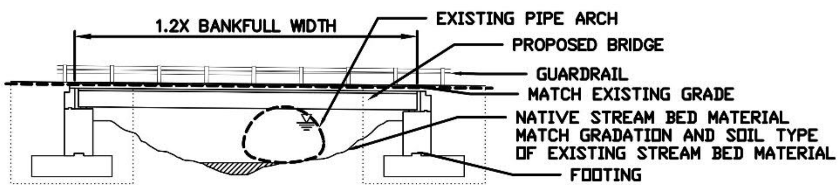

Image 4: Typical detail of a replacement bridge designed to meet the MA River and Stream Crossing Standards

Image 1: View of current structure inlet taken during field assessment on September 21, 2018. Arrows indicate flow paths of Scarboro Brook during low and high flows.

Image 2: View of crossing outlet, September 21, 2018.

Image 3: Poor headwall condition at inlet.

Site Prioritization Summary
Scaled Crossing Priority Score (0-1): 0.6
Impact Score (1-5): 3
Hydraulic Risk Score (1-25) (Existing/Future): 15/15
Geomorphic Score (1-25): 15
Structural Risk Score (1-25): 6
AOP Benefit Score (1-25): 15

Existing Crossing Characteristics
Material: Corrugated Metal Pipe
Structure Width: 6 feet
Structure Height: 6 feet
Structure Length: approximately 58 feet
Bankfull Width: 25 feet
Outlet Drop to Stream Bottom: 5.8 feet

Hydraulic Capacity Summary
Total Drainage Area: 2.57 miles^2
Existing Structure Capacity: 247 cfs
Estimated Peak Flows:

Recurrence Interval	Existing	Future
10-year	275 cfs	330 cfs
25-year	379 cfs	455 cfs
50-year	467 cfs	560 cfs
100-year	572 cfs	673 cfs

Notable Assessment Findings
High bank erosion
Severe constriction
Large scour pool
Downstream sediment accumulation
Poor headwall condition at inlet

Estimated Replacement Cost Range
Total project cost: $750K to $1 million

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North Street at Scarboro Brook

Culvert Replacement Concepts, Belchertown, MA

0 50 100 200 Feet

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Mill Valley Road/Route 181 at Unnamed Stream
Culvert Replacement Concept
Belchertown, MA

Site Description

Franklin Street/Route 181 crosses an unnamed stream on the north edge of the Mill Valley Golf Links property. The existing structure is a 6-foot diameter corrugated metal pipe, resulting in a severe constriction of the stream's approximately 20-foot bankfull width. The culvert inlet is protected by a beaver deceiver built out of fencing with 6-inch gaps, as shown at right. The beaver deceiver essentially sits on top of an existing beaver dam and accumulated debris; this material forms a semi-circle around the inlet and results in a significant inlet drop before water enters the culvert. The crossing is sized to pass the 10-year and 25-year peak flows, but is undersized for all longer recurrence interval peak flows under existing conditions; it is expected to become undersized for the 25-year peak flow under future climate conditions.

Proposed Concept

- Replace the existing metal pipe culvert with a bridge or open-bottom arch of approximately 24 feet in width, reconstructing the crossing to meet the Massachusetts River and Stream Crossing Standards and span 1.2 times the stream's bankfull width.
- Remove existing beaver dam and beaver deceiver.
- The proposed culvert replacement design concept will:
  - ➢ Provide increased hydraulic capacity to reduce flooding risk and allow water and debris associated with larger storms to pass.
  - ➢ Decrease potential of road overtopping during heavy precipitation.
  - ➢ Decrease attractiveness of the site to beavers by eliminating constriction of the stream and decreasing the sound of flowing water.

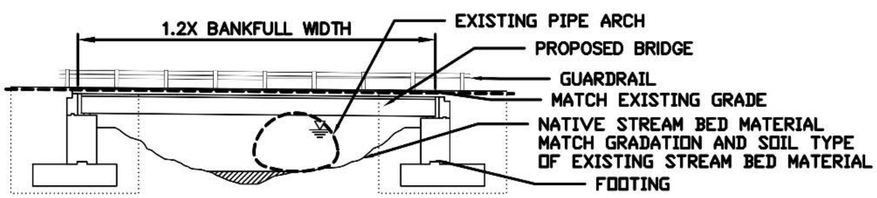

Image 4: Typical detail of a bridge designed to meet the MA River and Stream Crossing Standards.

Image 1: View of current structure inlet taken from within the beaver deceiver fencing during field assessment on October 10, 2018.

Image 2: View from above looking down on the structure inlet, beaver deceiver, and existing beaver dam/accumulated debris.

Image 3: View of current structure outlet taken during field assessment on October 10, 2018.

Site Prioritization Summary

Scaled Crossing Priority Score (0-1): 0.57
Impact Score (1-5): 4
Hydraulic Risk Score (1-25) (Existing/Future): 12/16
Geomorphic Risk Score (1-25): 12
Structural Risk Score (1-25): 4
AOP Benefit Score (1-25): 9

Existing Crossing Characteristics

Material: corrugated metal pipe
Structure Width: 6 feet
Structure Height: 6 feet
Structure Length: 57 feet
Bankfull Width: approximately 20 feet

Hydraulic Capacity Summary

Total Drainage Area: 1.76 miles^2
Existing Structure Capacity: 207 cfs
Estimated Peak Flows:

Recurrence Interval	Existing	Future
10-year	128 cfs	154 cfs
25-year	175 cfs	210 cfs
50-year	214 cfs	257 cfs
100-year	256 cfs	307 cfs

Notable Assessment Findings

High potential for transportation disruption
Severe constriction
Existing beaver impacts

Estimated Replacement Cost Range

Total project cost: $600K to $800K

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Mill Valley Road / Route 181 at Unnamed Stream

Culvert Replacement Concepts, Belchertown, MA

0 50 100 200 Feet

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Franklin Street/Route 181 at Unnamed Stream
Culvert Replacement Concept
Belchertown, MA

Site Description

Franklin Street/Route 181 crosses an unnamed stream approximately 300 feet north of Pease Street. The existing structure is a 2.5-foot diameter plastic pipe, resulting in a severe constriction of the stream's 6-foot bankfull width. This condition has contributed to the development of a large downstream scour pool, and sediment deposition was noted both upstream and downstream of the crossing. Both the inlet and outlet are surrounded by headwalls built of concrete blocks. As shown at right, the blocks do not fit tightly against the existing pipe. The crossing is undersized for all recurrence interval peak flows that were analyzed, including the 10-year peak flow.

Proposed Concept

- Replace the existing plastic pipe culvert with an embedded box culvert or open-bottom arch of approximately 7.5 feet in width, reconstructing the crossing to meet the Massachusetts River and Stream Crossing Standards and span 1.2 times the stream's bankfull width.
- The proposed culvert replacement design concept will:
  - ➢ Provide increased hydraulic capacity to reduce flooding risk and allow water and debris associated with larger storms to pass.
  - ➢ Decrease potential of road overtopping during heavy precipitation.

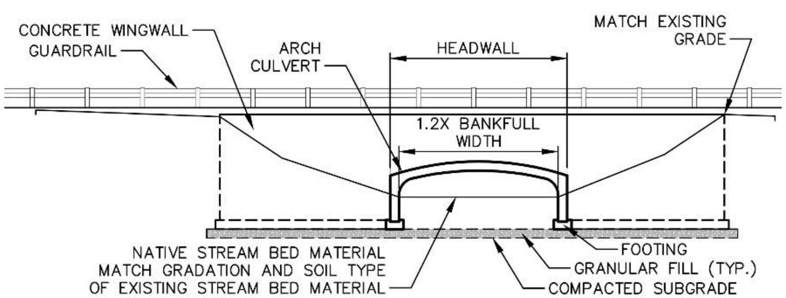

Image 4: Typical detail of an open arch culvert designed to meet the MA River and Stream Crossing Standards.

Image 1: View of current structure inlet taken during field assessment on October 1, 2018.

Image 2: View of current structure outlet taken during field assessment on October 1, 2018.

Image 3: View looking upstream from the structure inlet.

Site Prioritization Summary

Scaled Crossing Priority Score (0-1): 0.64
Impact Score (1-5): 4
Hydraulic Risk Score (1-25) (Existing/Future): 20/20
Geomorphic Risk Score (1-25): 16
Structural Risk Score (1-25): 8
AOP Benefit Score (1-25): 4

Existing Crossing Characteristics

Material: plastic pipe
Structure Width: 2.5 feet
Structure Height: 2.5 feet
Structure Length: 55 feet
Bankfull Width: 6 feet

Hydraulic Capacity Summary

Total Drainage Area: 0.28 miles^2
Existing Structure Capacity: 28 cfs
Estimated Peak Flows:

Recurrence Interval	Existing	Future
10-year	40 cfs	48 cfs
25-year	55 cfs	66 cfs
50-year	68 cfs	82 cfs
100-year	82 cfs	99 cfs

Notable Assessment Findings

High potential for transportation disruption
Severe constriction
Large downstream scour pool

Estimated Replacement Cost Range

Total project cost: $200K to $300K

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Franklin Street / Route 181 at Unnamed Stream

Culvert Replacement Concepts, Belchertown, MA

0 50 100 200 Feet

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Appendix A

Stream Crossing Survey Field Data Form (blank)

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Road-Stream Crossing Assessment Field Data Form

QA/QC INITIALS: ________ DATE: ________
Status ___ FINAL ___ FOLLOW-UP

CROSSING DATA

Crossing Code ________ State or Local ID/Name ________ Date ________ Start Time ________ AM / PM
pp. 4-5

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

Municipality ________ County ________ Stream ________

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

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

Location Description ________

Crossing Type ☐ BRIDGE ☐ CULVERT ☐ MULTIPLE CULVERT ☐ FORD ☐ NO CROSSING ☐ REMOVED CROSSING ☐ BURIED STREAM ☐ INACCESSIBLE ☐ PARTIALLY INACCESSIBLE ☐ NO UPSTREAM CHANNEL ☐ BRIDGE ADEQUATE
Number of Culverts / Cells
pp. 5-7

Photo #____ INLET Photo #____ OUTLET Photo #____ ________ Photo #____ ________
Photo #____ UPSTREAM Photo #____ DOWNSTREAM Photo #____ ________ Photo #____ ________
Photo #____ ROADWAY Photo #____ ________ Photo #____ ________ Photo #____ ________

Flow Condition ☐ NO FLOW ☐ TYPICAL-LOW ☐ MODERATE ☐ HIGH
Road-Killed Wildlife ________ or None

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

Alignment ☐ SHARP BEND ☐ MILD BEND ☐ NATURALLY STRAIGHT ☐ CHANNELIZED STRAIGHT
Road Fill Height ________ Road Crest Height ________
pp. 9-12

Bankfull Width ____ Confidence ☐ HIGH ☐ LOW/ESTIMATED
Constriction ☐ SEVERE ☐ MODERATE ☐ SPANS ONLY BANKFULL/ACTIVE CHANNEL ☐ SPANS FULL CHANNEL & BANKS

Tailwater Scour Pool ☐ NONE ☐ SMALL ☐ LARGE

HY-8

Using HY-8? ☐ YES ☐ NO
Estimated Overtopping Length ________ Crest Width ________
Road Surface Type ☐ PAVED ☐ GRAVEL ☐ GRASS
pp. 8, 13-15

Channel Slope ________
Side Slope ☐ 5:1 ☐ 4:1 ☐ 3:1 ☐ 2:1 ☐ 1:1 ☐ 0.5:1 ☐ steeper than 0.5:1
Stream Substrate ☐ MUCK/SILT ☐ SAND ☐ GRAVEL ☐ COBBLE ☐ BOULDER ☐ BEDROCK ☐ UNKNOWN

GEO.

Bank Erosion ☐ HIGH ☐ LOW ☐ ESTIMATED ☐ NONE
Significant Break in Valley Slope ☐ YES ☐ NO ☐ UNKNOWN
pp. 13

Sediment Deposition ☐ UPSTREAM ☐ DOWNSTREAM ☐ WITHIN STRUCTURE ☐ NONE

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

TIDAL

Tidal? ☐ YES ☐ NO ☐ UNKNOWN
Tide Chart Location ________
Tide Prediction ____:____ AM / PM
pp. 16-18

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

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

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

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

CROSSING COMMENTS

pp. 5

____

FORM PUBLISHED: OCTOBER 18, 2018

STRUCTURE 1

pp. 19-35

OUTLET

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

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

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

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

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

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

INLET

pp. 35-43

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

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

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

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

ADDITIONAL CONDITIONS

pp. 43-56

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

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

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

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

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

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

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

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

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

STRUCTURAL CONDITION ASSESSMENT

pp. 57-70

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

STRUCTURE COMMENTS

pp. 44

FORM PUBLISHED: OCTOBER 18, 2018

STRUCTURE 2

OUTLET

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

pp. 19-35

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

Outlet Armoring ☐ NONE ☐ NOT EXTENSIVE ☐ EXTENSIVE

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

Outlet Dimensions A. Width__________.____ B. Height__________.____ C. Substrate/Water Width__________.____ D. Water Depth__________.____

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

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

INLET

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

pp. 35-43

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

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

Inlet Dimensions A. Width__________.____ B. Height__________.____ C. Substrate/Water Width__________.____ D. Water Depth__________.____

ADDITIONAL CONDITIONS

Slope % __________ Slope Confidence ☐ HIGH ☐ LOW

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

pp. 43-56

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

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

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

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

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

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

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

Dry Passage through Structure? ☐ YES ☐ NO ☐ UNKNOWN

Height above Dry Passage__________

STRUCTURAL CONDITION ASSESSMENT

pp. 57-70

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

STRUCTURE COMMENTS

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STRUCTURE 3

OUTLET

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

pp. 19-35

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

Outlet Armoring ☐ NONE ☐ NOT EXTENSIVE ☐ EXTENSIVE

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

Outlet Dimensions A. Width__________.____ B. Height__________.____ C. Substrate/Water Width__________.____ D. Water Depth__________.____

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

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

INLET

pp. 35-43

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

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

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

Inlet Dimensions A. Width__________.____ B. Height__________.____ C. Substrate/Water Width__________.____ D. Water Depth__________.____

ADDITIONAL CONDITIONS

pp. 43-56

Slope % __________ Slope Confidence ☐ HIGH ☐ LOW

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

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

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

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

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

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

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

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

Dry Passage through Structure? ☐ YES ☐ NO ☐ UNKNOWN

Height above Dry Passage__________

STRUCTURAL CONDITION ASSESSMENT

pp. 57-70

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

STRUCTURE COMMENTS

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STRUCTURE 4

OUTLET pp. 19-35

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

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

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

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

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

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

INLET pp. 35-43

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

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

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

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

ADDITIONAL CONDITIONS pp. 43-56

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

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

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

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

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

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

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

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

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

STRUCTURAL CONDITION ASSESSMENT pp. 57-70

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

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STRUCTURE 5

OUTLET pp. 19-35

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

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

Outlet Armoring ☐ NONE ☐ NOT EXTENSIVE ☐ EXTENSIVE

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

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

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

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

INLET pp. 35-43

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

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

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

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

ADDITIONAL CONDITIONS pp. 43-56

Slope % ________ Slope Confidence ☐ HIGH ☐ LOW

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

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

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

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

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

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

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

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

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

STRUCTURAL CONDITION ASSESSMENT pp. 57-70

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

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STRUCTURE 6

OUTLET

pp. 19-35

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

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

Outlet Armoring ☐ NONE ☐ NOT EXTENSIVE ☐ EXTENSIVE

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

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

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

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

INLET

pp. 35-43

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

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

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

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

ADDITIONAL CONDITIONS

pp. 43-56

Slope % ________ Slope Confidence ☐ HIGH ☐ LOW

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

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

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

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

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

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

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

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

Dry Passage through Structure? ☐ YES ☐ NO ☐ UNKNOWN

Height above Dry Passage________

STRUCTURAL CONDITION ASSESSMENT

pp. 57-70

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

STRUCTURE COMMENTS

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STRUCTURE 7

OUTLET

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

pp. 19-35

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

Outlet Armoring ☐ NONE ☐ NOT EXTENSIVE ☐ EXTENSIVE

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

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

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

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

INLET

pp. 35-43

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

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

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

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

ADDITIONAL CONDITIONS

pp. 43-56

Slope % __________ Slope Confidence ☐ HIGH ☐ LOW

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

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

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

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

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

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

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

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

Dry Passage through Structure? ☐ YES ☐ NO ☐ UNKNOWN

Height above Dry Passage__________

STRUCTURAL CONDITION ASSESSMENT

pp. 57-70

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

STRUCTURE COMMENTS

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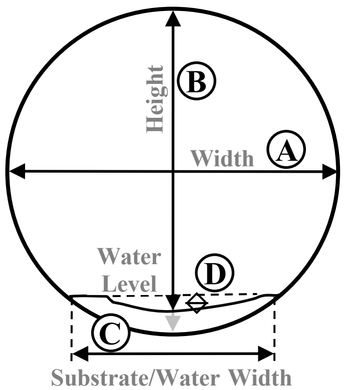
Structure Shape & Dimensions

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

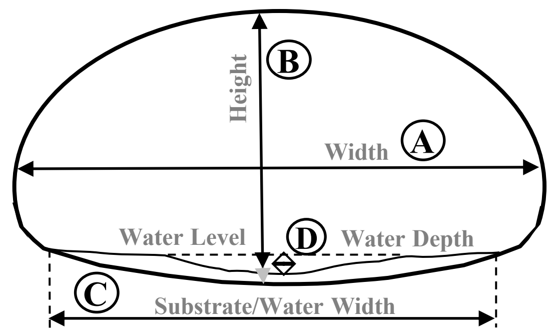
NOTE: Culverts 1, 2 & 4 may or may not have substrate in them, so height measurements (B) are taken from the level of the "stream bed", whether that bed is composed of substrate or just the inside bottom surface of a culvert (grey arrows below show measuring to bottom, black arrows show measuring to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

1



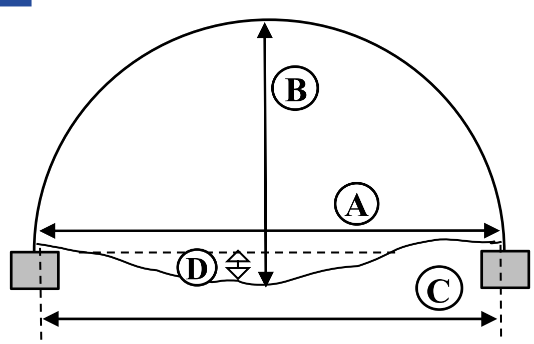
Round Culvert

2



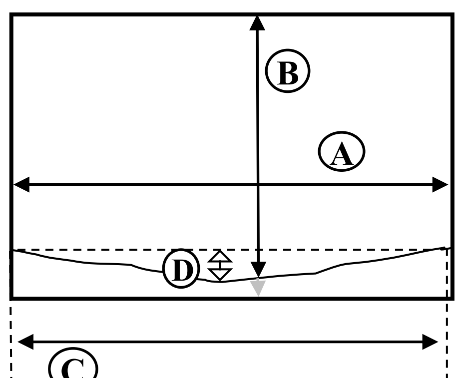
Pipe Arch/Elliptical Culvert

3



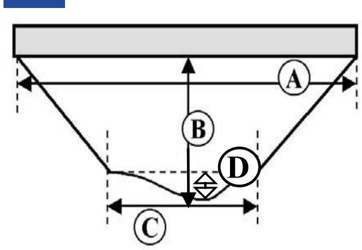
Open Bottom Arch Bridge/Culvert

4



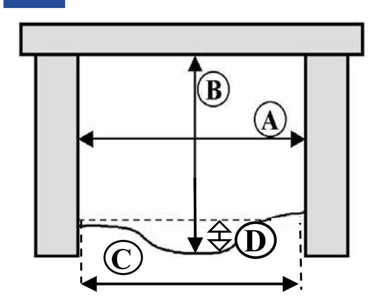
Box Culvert

5



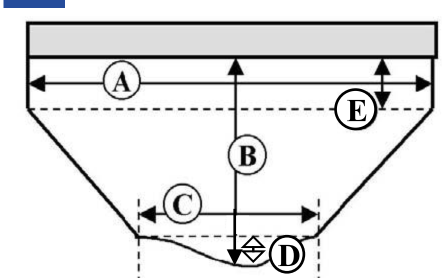
Bridge with Side Slopes

6



Box/Bridge with Abutments

7



Bridge with Abutments and Side Slopes

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Appendix B

Road-Stream Crossing Scoring and Prioritization Results

FUSS & O'NEILL

Appendix B—Table 1. Road-Stream Crossing Scoring and Prioritization Results, organized by watershed and overall crossing priority scores.
State roads are presented separately on page 3 and shaded in beige. Green highlighted cells indicate crossings that could not be fully assessed for hydraulic risk due to insufficient data. (Page 1 of 3)

XY Code	Road Name	Stream Name	HUC 12 Watershed Name	Existing Hydraulic Capacity Score-Binned	Future Hydraulic Capacity Score-Binned	Geomorphic Vulnerability Score	Structural Condition Score	Transportation Disruption Score	Flood Impact Potential Score	AOP Score	Ecological Benefit Score	Impact Score	Hydraulic Risk Score	Future Hydraulic Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Crossing Priority Score	Scaled Crossing Priority	Binned Prioritization Score
xy42271247245312	Rural St	Weston Brook	Batchelor Brook	4	5	3	5	1	4	3	4	4	16	20	12	20	12	20	36	0.72	High
xy42286187241920	George Hannum	unnamed	Batchelor Brook	4	5	4	2	2	4	3	3	4	16	20	16	8	9	20	34.5	0.69	High
xy42273367244577	Boardman St	unnamed	Batchelor Brook	5	5	3	2	2	4	2	3	4	20	20	12	8	6	20	33	0.66	High
xy42271187244989	Boardman St	Weston Brook	Batchelor Brook	1	1	4	5	2	4	1	4	4	4	4	16	20	4	20	32	0.64	High
xy42298327242189	Hamilton St	unnamed	Batchelor Brook	5	5	3	5	1	2	5	3	2	10	10	6	10	15	10	27.5	0.55	High
xy42307617245536	Bay Rd	unnamed	Batchelor Brook	5	5	4	5	3	3	3	3	3	15	15	12	15	9	15	27	0.54	Medium
xy42281947242724	George Hannum St	Unnamed	Batchelor Brook	2	3	3	5	2	3	2	3	3	6	9	9	15	6	15	25.5	0.51	Medium
xy42302227244738	Bay Rd	Unnamed	Batchelor Brook	1	1	3	5	3	2	2	3	3	3	3	9	15	6	15	25.5	0.51	Medium
xy42272957243199	Underwood St	unnamed	Batchelor Brook	1	1	3	5	1	3	2	3	3	3	3	9	15	6	15	25.5	0.51	Medium
xy42302957244850	Bay Rd	Unnamed	Batchelor Brook	5	5	2	5	3	3	2	3	3	15	15	6	15	6	15	25.5	0.51	Medium
xy42307157245493	Bay Rd	unnamed	Batchelor Brook	5	5	2	5	3	2	2	3	3	15	15	6	15	6	15	25.5	0.51	Medium
xy42288797242558	Hamilton St	unnamed	Batchelor Brook	5	5	3	2	1	3	2	3	3	15	15	9	6	6	15	25.5	0.51	Medium
xy42303587244948	Bay Rd	unnamed	Batchelor Brook	5	5	2	5	3	3	1	3	3	15	15	6	15	3	15	24	0.48	Medium
xy42309137242419	Federal St	unnamed	Batchelor Brook	1	1	2	5	2	3	1	3	3	3	3	6	15	3	15	24	0.48	Medium
xy42279397241169	Jackson St	Unnamed	Batchelor Brook	3	4	4	5	2	2	4	3	2	6	8	8	10	12	10	23	0.46	Medium
xy42256957244726	Barton Rd	Unnamed	Batchelor Brook	3	4	4	5	1	2	4	3	2	6	8	8	10	12	10	23	0.46	Medium
xy42305857244957	Old Bay Rd	unnamed	Batchelor Brook	5	5	3	5	1	2	4	3	2	10	10	6	10	12	10	23	0.46	Medium
xy42283657242220	Jackson St	unnamed	Batchelor Brook	2	3	3	1	2	4	2	3	4	8	12	12	4	6	12	21	0.42	Medium
xy42263237244442	Barton Rd	Unnamed	Batchelor Brook	5	5	4	5	1	2	3	3	2	10	10	8	10	9	10	19.5	0.39	Medium
xy42292597244603	Stebbins St	tributary to Batchelor Brook	Batchelor Brook	5	5	3	5	2	2	2	3	2	10	10	6	10	6	10	18	0.36	Medium
xy42263097245485	Dressel Ave	Unnamed	Batchelor Brook	5	5	3	5	1	2	2	3	2	10	10	6	10	6	10	18	0.36	Medium
xy42302867243935	Metacomet St	N/a	Batchelor Brook	1	2	2	5	1	2	2	3	2	2	4	4	10	6	10	18	0.36	Medium
xy42259957245067	Dressel Ave	Unnamed	Batchelor Brook	5	5	2	1	1	2	2	3	2	10	10	4	2	6	10	18	0.36	Medium
xy42307527242306	Federal St	unnamed	Batchelor Brook	0	0	4	1	2	1	3	3	2	0	0	8	2	9	8	17.5	0.35	Medium
xy42279117245625	George Hannum	Batchelor Brook	Batchelor Brook	4	5	2	5	2	1	1	4	2	8	10	4	10	4	10	17	0.34	Low
xy42256327243332	Oak Ridge Dr	Unnamed	Batchelor Brook	1	1	3	2	1	2	3	3	2	2	2	6	4	9	6	16.5	0.33	Low
xy42303187244623	Old Bay Rd	N/a	Batchelor Brook	5	5	2	5	1	2	1	3	2	10	10	4	10	3	10	16.5	0.33	Low
xy42254537244452	Barton Ave	unnamed	Batchelor Brook	4	4	4	5	1	1	3	3	1	4	4	4	5	9	5	16	0.32	Low
xy42269377243094	Underwood St	Weston Brook	Batchelor Brook	0	0	3	1	1	3	2	2	3	0	0	9	3	4	9	15.5	0.31	Low
xy42301627242593	Bay Rd	Batchelor Brook	Batchelor Brook	2	3	3	1	3	2	1	3	3	6	9	9	3	3	9	15	0.3	Low
xy42277717244338	George Hannum St	unnamed	Batchelor Brook	4	4	3	2	2	1	2	3	2	8	8	6	4	6	8	15	0.3	Low
xy42287767241617	Hickory Hill	unnamed	Batchelor Brook	1	1	2	1	1	4	1	3	4	4	4	8	4	3	8	13.5	0.27	Low
xy42270387242730	Jon Dr	unnamed	Batchelor Brook	1	1	2	1	1	3	2	3	3	3	3	6	3	6	6	12	0.24	Low
xy42261197244401	Barton Rd	Unnamed	Batchelor Brook	5	5	3	2	1	1	2	3	1	5	5	3	2	6	5	11.5	0.23	Low
xy42287367241736	George Hannum	unnamed	Batchelor Brook	1	1	1	1	2	4	1	3	4	4	4	4	4	3	4	7.5	0.15	Low
xy42196347237760	South St	unnamed	Danforth Brook-Ware River	1	1	3	5	1	1	3	2	1	1	1	3	5	6	5	11.5	0.23	Low
xy42344447244064	Gulf Rd	Scarboro	Fort River	5	5	4	2	1	4	5	3	4	20	20	16	8	15	20	37.5	0.75	High
xy42339157245883	North St	Unnamed	Fort River	5	5	4	5	1	4	3	3	4	20	20	16	20	9	20	34.5	0.69	High
xy42349617243556	North Gulf Rd	Scarboro Brook	Fort River	4	5	4	2	1	4	2	3	4	16	20	16	8	6	20	33	0.66	High
xy42340487244354	Gulf Rd	Scarboro Brook	Fort River	5	5	4	1	1	4	2	3	4	20	20	16	4	6	20	33	0.66	High
xy42326717244614	Federal St	Scarboro brook	Fort River	5	5	3	5	2	4	1	3	4	20	20	12	20	3	20	31.5	0.63	High
xy42335057244654	Gulf Rd	Scarboro Brook	Fort River	4	5	2	1	1	4	1	3	4	16	20	8	4	3	20	31.5	0.63	High
xy42343517246154	Old Amherst	Montague Brook	Fort River	1	1	3	5	1	3	5	3	3	3	3	9	15	15	15	30	0.6	High
xy42337347244652	North St	Scarboro Brook	Fort River	5	5	5	2	1	3	5	3	3	15	15	15	6	15	15	30	0.6	High
xy42348827243612	Gulf Rd	Scarboro Brook	Fort River	3	4	4	2	1	4	3	3	4	12	16	16	8	9	16	28.5	0.57	High
xy42318407245188	Orchard St	unnamed	Fort River	1	1	5	3	1	2	5	3	2	2	2	10	6	15	10	27.5	0.55	High
xy42318157246200	Orchard St	Unnamed	Fort River	5	5	2	2	1	2	5	3	2	10	10	4	4	15	10	27.5	0.55	High
xy42343667246344	Old Amherst Rd	Unnamed	Fort River	4	5	4	1	1	2	5	3	2	8	10	8	2	15	10	27.5	0.55	High
xy42323817245701	Goodell St	unnamed	Fort River	5	5	3	1	1	2	5	3	2	10	10	6	2	15	10	27.5	0.55	High
xy42339547244388	Gulf Rd	Scarboro Brook	Fort River	5	5	5	5	1	3	3	3	3	15	15	15	15	9	15	27	0.54	Medium
xy42333577246606	Warren Wright Rd	unnamed	Fort River	4	5	4	1	1	3	3	3	3	12	15	12	3	9	15	27	0.54	Medium
xy42326487244592	Federal St	Scarboro Brook	Fort River	5	5	3	2	2	3	2	3	3	15	15	9	6	6	15	25.5	0.51	Medium
xy42350307243212	Gulf	Unnamed	Fort River	5	5	3	2	1	3	2	3	3	15	15	9	6	6	15	25.5	0.51	Medium
xy42322207244007	Federal St	Hop Brook	Fort River	5	5	2	1	2	3	1	4	3	15	15	6	3	4	15	24.5	0.49	Medium
xy42349857243458	Gulf Rd	Scarboro Brook	Fort River	5	5	2	1	1	3	2	2	3	15	15	6	3	4	15	24.5	0.49	Medium
xy42346107243689	South Gulf Rd	Unnamed	Fort River	5	5	2	1	1	3	1	3	3	15	15	6	3	3	15	24	0.48	Medium
xy42318537244156	Orchard St	Unnamed	Fort River	1	1	3	3	1	1	5	3	1	1	1	3	3	15	3	24	0.48	Medium
xy42338277245042	North St	Unnamed	Fort River	5	5	3	2	1	2	3	3	2	10	10	6	4	9	10	19.5	0.39	Medium
xy42320517243424	Cheryl Drive	unnamed	Fort River	1	2	3	2	1	3	3	3	3	3	6	9	6	9	9	18	0.36	Medium
xy42338367246207	North St	Unnamed	Fort River	1	1	3	1	1	3	3	3	3	3	3	9	3	9	9	18	0.36	Medium
xy42338197245237	North St	Unnamed	Fort River	5	5	2	5	1	2	2	3	2	10	10	4	10	6	10	18	0.36	Medium
xy42352267242368	Gulf Rd	Unnamed	Fort River	5	5	2	5	1	2	2	3	2	10	10	4	10	6	10	18	0.36	Medium
xy42353887242333	Gold St	Unnamed	Fort River	5	5	4	2	1	2	2	3	2	10	10	8	4	6	10	18	0.36	Medium
xy42311147246145	Bay Path Rd	Unnamed	Fort River	5	5	3	1	1	2	2	3	2	10	10	6	2	6	10	18	0.36	Medium
xy42328927246282	Warren Wright Rd	unnamed	Fort River	1	1	3	1	1	3	2	3	3	3	3	9	3	6	9	16.5	0.33	Low
xy42353657242055	Gold St	Unnamed	Fort River	5	5	3	2	1	1	2	3	1	5	5	3	2	6	5	11.5	0.23	Low
xy42318487245910	Orchard St	unnamed	Fort River	2	3	2	2	1	1	2	3	1	2	3	2	2	6	3	10.5	0.21	Low
xy42319747246091	Warren Wright Rd	Hop Brook	Fort River	0	0	2	1	1	3	0	4	3	0	0	6	3	0	6	9	0.18	Low
xy42317777246406	Orchard St	unnamed	Fort River	0	0	5	1	1	1	0	3	1	0	0	5	1	0	5	7.5	0.15	Low

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Appendix B—Table 1 (continued). Road-Stream Crossing Scoring and Prioritization Results, organized by watershed and overall crossing priority scores. (Page 2 of 3 pages)

XY Code	Road Name	Stream Name	HUC 12 Watershed Name	Existing Hydraulic Capacity Score-Binned	Future Hydraulic Capacity Score-Binned	Geomorphic Vulnerability Score	Structural Condition Score	Transportation Disruption Score	Flood Impact Potential Score	AOP Score	Ecological Benefit Score	Impact Score	Hydraulic Risk Score	Future Hydraulic Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Crossing Priority Score	Scaled Crossing Priority	Binned Prioritization Score
xy42237747241085	Ludlow St	Roaring Brook	Headwaters Chicopee River	4	5	3	2	1	5	3	4	5	20	25	15	10	12	25	43.5	0.87	High
xy42236607241026	Granby Road	Roaring Brook	Headwaters Chicopee River	5	5	3	2	2	5	2	3	5	25	25	15	10	6	25	40.5	0.81	High
xy42256567241778	Ledgewood Dr	unnamed	Headwaters Chicopee River	0	0	4	5	1	4	3	2	4	0	0	16	20	6	20	33	0.66	High
xy42257497241598	Ledgewood Circle	unnamed	Headwaters Chicopee River	5	5	3	5	1	4	2	3	4	20	20	12	20	6	20	33	0.66	High
xy42257507241394	Forest Rd	Unnamed	Headwaters Chicopee River	5	5	2	5	1	4	1	3	4	20	20	8	20	3	20	31.5	0.63	High
xy42240567242502	Granby Rd	Unnamed	Headwaters Chicopee River	5	5	4	2	2	3	3	3	3	15	15	12	6	9	15	27	0.54	Medium
xy42218067238830	Barrett St	unnamed	Headwaters Chicopee River	3	4	3	2	1	4	4	1	4	12	16	12	8	4	16	26	0.52	Medium
xy42253457238912	North Washington St	Jabish Canal	Headwaters Chicopee River	5	5	3	1	3	1	2	3	3	15	15	9	3	6	15	25.5	0.51	Medium
xy42235207241680	Ludlow St	unnamed	Headwaters Chicopee River	5	5	4	5	1	1	5	3	1	5	5	4	5	15	5	25	0.5	Medium
xy42240797243792	Rockrimmon St	Axe Factory Brook	Headwaters Chicopee River	5	5	4	5	1	2	4	3	2	10	10	8	10	12	10	23	0.46	Medium
xy42211327238655	West St	unnamed	Headwaters Chicopee River	2	2	3	2	1	4	5	1	4	8	8	12	8	5	12	20.5	0.41	Medium
xy42249607242421	Rockrimmon Rd	Roaring Brook	Headwaters Chicopee River	5	5	3	5	2	1	3	3	2	10	10	6	10	9	10	19.5	0.39	Medium
xy42241537243000	Maple Crest Dr	Unnamed	Headwaters Chicopee River	1	1	3	5	1	2	2	3	2	2	2	6	10	6	10	18	0.36	Medium
xy42233277239449	North Washington St	Unnamed	Headwaters Chicopee River	5	5	2	2	1	2	2	3	2	10	10	4	4	6	10	18	0.36	Medium
xy42231617242196	Ludlow St	Axe factory Brook	Headwaters Chicopee River	5	5	4	2	1	2	5	1	2	10	10	8	4	5	10	17.5	0.35	Medium
xy42250237241115	Springfield Rd	unnamed	Headwaters Chicopee River	5	5	4	2	1	2	2	2	2	10	10	8	4	4	10	17	0.34	Low
xy42222177239279	South Washington St	unnamed	Headwaters Chicopee River	5	5	3	2	1	2	2	2	2	10	10	6	4	4	10	17	0.34	Low
xy42241307238795	North Washington	unnamed	Headwaters Chicopee River	5	5	3	1	1	1	3	3	1	5	5	3	1	9	5	16	0.32	Low
xy42228677239360	South Washington St	unnamed	Headwaters Chicopee River	0	0	4	2	1	2	1	3	2	0	0	8	4	3	8	13.5	0.27	Low
xy42232417239701	Bardwell St	Broad Brook	Headwaters Chicopee River	1	1	2	1	1	3	1	5	3	3	3	6	3	5	6	11.5	0.23	Low
xy42204027239592	Mills Rd	Unnamed	Headwaters Chicopee River	2	3	3	5	1	1	2	3	1	2	3	3	5	6	5	11.5	0.23	Low
xy42192237238784	South St	unnamed	Headwaters Chicopee River	5	5	3	2	1	1	3	2	1	5	5	3	2	6	5	11.5	0.23	Low
xy42245927243936	Mountain View Dr	Unnamed	Headwaters Chicopee River	5	5	3	2	1	1	2	3	1	5	5	3	2	6	5	11.5	0.23	Low
xy42244387243693	Maplecrest drive	0	Headwaters Chicopee River	1	1	3	2	1	2	1	3	2	2	2	6	4	3	6	10.5	0.21	Low
xy42255387240582	Springfield Rd	Broad brook	Headwaters Chicopee River	3	4	2	5	1	1	1	4	1	3	4	2	5	4	5	9.5	0.19	Low
xy42265367240456	Springfield Rd	unnamed	Headwaters Chicopee River	5	5	4	2	1	1	2	1	1	5	5	4	2	2	5	8.5	0.17	Low
xy42234657243174	Green Ave	Axe Factory Brook	Headwaters Chicopee River	1	1	4	3	1	1	4	1	1	1	1	4	3	4	4	8	0.16	Low
xy42209647237979	West St	unnamed	Jabish Brook	1	1	3	5	1	3	2	3	3	3	3	9	15	6	15	25.5	0.51	Medium
xy42220167236911	Bardwell St	N/a	Jabish Brook	5	5	2	5	2	3	2	3	3	15	15	6	15	6	15	25.5	0.51	Medium
xy42303037239399	Allen St	Unnamed	Jabish Brook	5	5	4	1	1	3	2	2	3	15	15	12	3	4	15	24.5	0.49	Medium
xy42302807240726	Old Pelham Rd	unnamed	Jabish Brook	4	4	4	2	1	3	4	3	3	12	12	12	6	12	12	24	0.48	Medium
xy42302867239142	Brandwine Dr	N/a	Jabish Brook	5	5	4	5	1	2	4	3	2	10	10	8	10	12	10	23	0.46	Medium
xy42217827238045	Barrett St	unnamed	Jabish Brook	1	1	3	5	1	2	4	3	2	2	2	6	10	12	10	23	0.46	Medium
xy42207707236647	South St	Unnamed	Jabish Brook	4	5	4	2	1	2	4	3	2	8	10	8	4	12	10	23	0.46	Medium
xy42311927240530	Kopiac Ave	Jabish Brook?	Jabish Brook	5	5	3	2	1	2	3	4	2	10	10	6	4	12	10	23	0.46	Medium
xy42210327236206	River St	unnamed	Jabish Brook	5	5	3	5	2	2	3	3	2	10	10	6	10	9	10	19.5	0.39	Medium
xy42245367235274	Cold Spring St	unnamed	Jabish Brook	5	5	3	2	1	2	3	3	2	10	10	6	4	9	10	19.5	0.39	Medium
xy42226767238607	Bardwell St	Unnamed	Jabish Brook	5	5	3	1	1	2	3	3	2	10	10	6	2	9	10	19.5	0.39	Medium
xy42257867236831	Cordner road	Unnamed	Jabish Brook	5	5	4	5	1	2	2	3	2	10	10	8	10	6	10	18	0.36	Medium
xy42216947235743	Pine St	unnamed	Jabish Brook	5	5	3	5	1	2	2	3	2	10	10	6	10	6	10	18	0.36	Medium
xy42258237236675	Cordner Rd	unnamed	Jabish Brook	5	5	3	5	1	2	2	3	2	10	10	6	10	6	10	18	0.36	Medium
xy42307117240714	Old Pelham Rd	Unnamed	Jabish Brook	5	5	3	5	1	2	2	3	2	10	10	6	10	6	10	18	0.36	Medium
xy42312137240392	Kopiac Ave	N/a	Jabish Brook	1	1	3	5	1	2	2	3	2	2	2	6	10	6	10	18	0.36	Medium
xy42353577241739	Gold St	Unnamed	Jabish Brook	5	5	3	2	1	2	2	3	2	10	10	6	4	6	10	18	0.36	Medium
xy42337227241047	Munsell St, at Gold St	Unnamed	Jabish Brook	5	5	3	1	1	2	2	3	2	10	10	6	2	6	10	18	0.36	Medium
xy42340707241045	Gold St	Unnamed	Jabish Brook	4	5	3	1	1	2	2	3	2	8	10	6	2	6	10	18	0.36	Medium
xy42301437238550	Allen Rd	unnamed	Jabish Brook	5	5	2	1	1	2	2	3	2	10	10	4	2	6	10	18	0.36	Medium
xy42306277239337	Sheffield Drive	N/a	Jabish Brook	3	4	4	2	1	2	3	3	2	6	8	8	4	9	8	17.5	0.35	Medium
xy42215857237651	North Liberty St	unnamed	Jabish Brook	1	1	3	2	2	3	3	2	3	3	3	9	6	6	9	16.5	0.33	Low
xy42310357240668	Old Pelham Rd	unnamed	Jabish Brook	5	5	3	5	1	2	1	3	2	10	10	6	10	3	10	16.5	0.33	Low
xy42298957238499	Old Enfield Rd	unnamed	Jabish Brook	5	5	3	2	1	2	1	3	2	10	10	6	4	3	10	16.5	0.33	Low
xy42302917239497	Allen St	unnamed	Jabish Brook	5	5	3	5	1	1	3	3	1	5	5	3	5	9	5	16	0.32	Low
xy42353117240894	Knight St	Unnamed	Jabish Brook	5	5	3	5	1	1	3	3	1	5	5	3	5	9	5	16	0.32	Low
xy42274707236020	Sabin St	Unnamed	Jabish Brook	1	1	4	2	1	2	2	3	2	2	2	8	4	6	8	15	0.3	Low
xy42282327238021	Blue Meadow Road	Unnamed	Jabish Brook	3	4	3	2	1	2	2	3	2	6	8	6	4	6	8	15	0.3	Low
xy42239837236955	Kennedy Drive	unnamed	Jabish Brook	2	3	3	1	1	1	3	3	1	2	3	3	1	9	3	15	0.3	Low
xy42285507239096	Old Enfield Rd	unnamed	Jabish Brook	4	4	2	2	1	2	1	3	2	8	8	4	4	3	8	13.5	0.27	Low
xy42312127240421	Kopiac ave	Jabish Brook?	Jabish Brook	1	1	3	5	1	1	2	3	1	1	1	3	5	6	5	11.5	0.23	Low
xy42218277237511	Barrett St	Unnamed	Jabish Brook	5	5	2	5	1	1	2	3	1	5	5	2	5	6	5	11.5	0.23	Low
xy42297797238544	Old Enfield Rd	N/a	Jabish Brook	5	5	2	5	1	1	2	3	1	5	5	2	5	6	5	11.5	0.23	Low
xy42347457240928	Gold St	Unnamed	Jabish Brook	4	5	3	2	1	1	2	3	1	4	5	3	2	6	5	11.5	0.23	Low
xy42302077240528	Allen St	Jabish Brook	Jabish Brook	1	1	2	1	1	3	1	4	3	3	3	6	3	4	6	11	0.22	Low
xy42216287237666	North Liberty St	Unnamed	Jabish Brook	1	1	3	2	2	2	3	1	2	2	2	6	4	3	6	10.5	0.21	Low
xy42351457241004	Gold St	Jabish Brook	Jabish Brook	1	1	3	2	1	2	1	3	2	2	2	6	4	3	6	10.5	0.21	Low
xy42296987239357	Sherwood	Unnamed	Jabish Brook	1	1	3	2	1	1	2	3	1	1	1	3	2	6	3	10.5	0.21	Low
xy42216557236634	Bardwell St	Jabish Brook	Jabish Brook	1	1	2	1	2	2	1	5	2	2	2	4	2	5	4	9.5	0.19	Low
xy42270437237937	Aldrich Rd	Jabish Brook	Jabish Brook	1	2	2	1	1	2	1	4	2	2	4	4	2	4	4	8	0.16	Low
xy42329927240096	Kimball St	Jabish Brook	Jabish Brook	1	1	3	1	1	1	1	4	1	1	1	3	1	4	3	7.5	0.15	Low
xy42199827236851	South St	unnamed	Quabbin Reservoir-Swift River	2	3	3	5	1	3	5	3	3	6	9	9	15	15	15	30	0.6	High
xy42203997236734	South St	unnamed	Quabbin Reservoir-Swift River	5	5	4	5	1	2	5	3	2	10	10	8	10	15	10	27.5	0.55	High
xy42246967233731	East St	unnamed	Quabbin Reservoir-Swift River	5	5	5	5	1	2	4	3	2	10	10	10	10	12	10	23	0.46	Medium
xy42265457234004	East St	unnamed	Quabbin Reservoir-Swift River	5	5	4	5	1	2	3	3	2	10	10	8	10	9	10	19.5	0.39	Medium
xy42244687234586	Cold Spring St	unnamed	Quabbin Reservoir-Swift River	5	5	3	2	1	2	3	3	2	10	10	6	4	9	10	19.5	0.39	Medium
xy42252577234080	East St	Unnamed	Quabbin Reservoir-Swift River	3	4	2	2	1	1	2	2	1	3	4	2	2	4	4	8	0.16	Low

Appendix B—Table 1 (continued). Road-Stream Crossing Scoring and Prioritization Results, organized by watershed and overall crossing priority scores. State roads are presented and shaded in beige. (Page 3 of 3)

HUC 12 Watershed Name	Existing Hydraulic Capacity Score-Binned	Future Hydraulic Capacity Score-Binned	Geomorphic Vulnerability Score	Structural Condition Score	Transportation Disruption Score	Flood Impact Potential Score	AOP Score	Ecological Benefit Score	Impact Score	Hydraulic Risk Score	Future Hydraulic Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Crossing Priority Score	Scaled Crossing Priority	Binned Prioritization Score
Batchelor Brook	4	4	3	1	4	3	3	3	4	16	16	12	4	9	16	28.5	0.57	High
Batchelor Brook	3	3	4	1	4	2	3	2	4	12	12	16	4	6	16	27	0.54	Medium
Batchelor Brook	4	4	3	1	3	3	1	3	3	12	12	9	3	3	12	19.5	0.39	Medium
Fort River	3	4	4	1	4	1	5	3	4	12	16	16	4	15	16	31.5	0.63	High
Fort River	1	1	4	1	4	1	5	3	4	4	4	16	4	15	16	31.5	0.63	High
Fort River	1	1	4	2	4	4	5	2	4	4	4	16	8	10	16	29	0.58	High
Fort River	0	0	4	2	4	2	3	3	4	0	0	16	8	9	16	28.5	0.57	High
Fort River	4	4	3	1	4	4	2	4	4	16	16	12	4	8	16	28	0.56	High
Fort River	0	0	3	1	4	2	4	3	4	0	0	12	4	12	12	24	0.48	Medium
Headwaters Chicopee River	5	5	4	5	3	3	5	3	3	15	15	12	15	15	15	30	0.6	High
Headwaters Chicopee River	5	5	3	1	3	3	2	4	3	15	15	9	3	8	15	26.5	0.53	Medium
Headwaters Chicopee River	2	2	2	5	3	2	2	3	3	6	6	6	15	6	15	25.5	0.51	Medium
Headwaters Chicopee River	1	2	3	1	3	5	1	4	5	5	10	15	5	4	15	24.5	0.49	Medium
Jabish Brook	5	5	3	2	4	3	3	3	4	20	20	12	8	9	20	34.5	0.69	High
Jabish Brook	4	5	3	1	4	2	2	4	4	16	20	12	4	8	20	34	0.68	High
Jabish Brook	5	5	4	5	4	1	2	3	4	20	20	16	20	6	20	33	0.66	High
Jabish Brook	5	5	3	2	4	2	2	3	4	20	20	12	8	6	20	33	0.66	High
Jabish Brook	5	5	2	5	4	2	2	3	4	20	20	8	20	6	20	33	0.66	High
Jabish Brook	5	5	4	2	4	2	2	2	4	20	20	16	8	4	20	32	0.64	High
Jabish Brook	1	1	3	5	4	1	2	2	4	4	4	12	20	4	20	32	0.64	High
Jabish Brook	1	1	3	5	4	2	1	4	4	4	4	12	20	4	20	32	0.64	High
Jabish Brook	3	4	3	1	4	4	3	3	4	12	16	12	4	9	16	28.5	0.57	High
Jabish Brook	1	1	3	1	4	2	3	3	4	4	4	12	4	9	12	22.5	0.45	Medium
Jabish Brook	1	1	3	1	4	1	2	3	4	4	4	12	4	6	12	21	0.42	Medium
Jabish Brook	1	1	2	1	4	3	1	4	4	4	4	8	4	4	8	14	0.28	Low
Jabish Brook	1	1	2	1	4	3	1	4	4	4	4	8	4	4	8	14	0.28	Low
Jabish Brook	1	1	2	1	4	2	1	3	4	4	4	8	4	3	8	13.5	0.27	Low
Jabish Brook	0	0	2	1	3	2	2	3	3	0	0	6	3	6	6	12	0.24	Low
Quabbin Reservoir-Swift River	2	3	2	5	4	1	2	3	4	8	12	8	20	6	20	33	0.66	High

Appendix B—Table 2. Top-ranked crossings based on hydraulic risk score under existing conditions.

XY Code	Road Name	Stream Name	HUC 12 Watershed Name	Impact Score	Hydraulic Risk Score	Future Hydraulic Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Scaled Crossing Priority	Relative Priority Rating
xy42236607241026	Granby Road	Roaring Brook	Headwaters Chicopee R.	5	25	25	15	10	6	25	0.81	High
xy42237747241085	Ludlow St	Roaring Brook	Headwaters Chicopee R.	5	20	25	15	10	12	25	0.87	High
xy42344447244064	Gulf Rd	Scarboro	Fort River	4	20	20	16	8	15	20	0.75	High
xy42339157245883	North St	Unnamed	Fort River	4	20	20	16	20	9	20	0.69	High
xy42273367244577	Boardman St	unnamed	Batchelor Brook	4	20	20	12	8	6	20	0.66	High
xy42340487244354	Gulf Rd	Scarboro Brook	Fort River	4	20	20	16	4	6	20	0.66	High
xy42257497241598	Ledgewood Circle	unnamed	Headwaters Chicopee R.	4	20	20	12	20	6	20	0.66	High
xy42326717244614	Federal St	Scarboro brook	Fort River	4	20	20	12	20	3	20	0.63	High
xy42257507241394	Forest Rd	Unnamed	Headwaters Chicopee R.	4	20	20	8	20	3	20	0.63	High
xy42271247245312	Rural St	Weston Brook	Batchelor Brook	4	16	20	12	20	12	20	0.72	High
xy42286187241920	George Hannum	unnamed	Batchelor Brook	4	16	20	16	8	9	20	0.69	High
xy42349617243556	North Gulf Rd	Scarboro Brook	Fort River	4	16	20	16	8	6	20	0.66	High
xy42335057244654	Gulf Rd	Scarboro Brook	Fort River	4	16	20	8	4	3	20	0.63	High
xy42337347244652	North St	Scarboro Brook	Fort River	3	15	15	15	6	15	15	0.6	High
xy42307617245536	Bay Rd	unnamed	Batchelor Brook	3	15	15	12	15	9	15	0.54	Medium
xy42339547244388	Gulf Rd	Scarboro Brook	Fort River	3	15	15	15	15	9	15	0.54	Medium
xy42240567242502	Granby Rd	Unnamed	Headwaters Chicopee R.	3	15	15	12	6	9	15	0.54	Medium
xy42302957244850	Bay Rd	Unnamed	Batchelor Brook	3	15	15	6	15	6	15	0.51	Medium
xy42307157245493	Bay Rd	unnamed	Batchelor Brook	3	15	15	6	15	6	15	0.51	Medium
xy42288797242558	Hamilton St	unnamed	Batchelor Brook	3	15	15	9	6	6	15	0.51	Medium
xy42326487244592	Federal St	Scarboro Brook	Fort River	3	15	15	9	6	6	15	0.51	Medium
xy42350307243212	Gulf	Unnamed	Fort River	3	15	15	9	6	6	15	0.51	Medium
xy42253457238912	North Washington St	Jabish Canal	Headwaters Chicopee R.	3	15	15	9	3	6	15	0.51	Medium
xy42220167236911	Bardwell St	N/a	Jabish Brook	3	15	15	6	15	6	15	0.51	Medium

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Appendix B—Table 3. Top-ranked crossings based on future hydraulic risk score under projected future climate (precipitation and peak flow) conditions.

XY Code	Road Name	Stream Name	HUC 12 Watershed Name	Impact Score	Hydraulic Risk Score	Future Hydraulic Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Scaled Crossing Priority	Relative Priority Rating
xy42237747241085	Ludlow St	Roaring Brook	Headwaters Chicopee R.	5	20	25	15	10	12	25	0.87	High
xy42236607241026	Granby Road	Roaring Brook	Headwaters Chicopee R.	5	25	25	15	10	6	25	0.81	High
xy42344447244064	Gulf Rd	Scarboro	Fort River	4	20	20	16	8	15	20	0.75	High
xy42271247245312	Rural St	Weston Brook	Batchelor Brook	4	16	20	12	20	12	20	0.72	High
xy42339157245883	North St	Unnamed	Fort River	4	20	20	16	20	9	20	0.69	High
xy42286187241920	George Hannum	unnamed	Batchelor Brook	4	16	20	16	8	9	20	0.69	High
xy42273367244577	Boardman St	unnamed	Batchelor Brook	4	20	20	12	8	6	20	0.66	High
xy42340487244354	Gulf Rd	Scarboro Brook	Fort River	4	20	20	16	4	6	20	0.66	High
xy42257497241598	Ledgewood Circle	unnamed	Headwaters Chicopee R.	4	20	20	12	20	6	20	0.66	High
xy42349617243556	North Gulf Rd	Scarboro Brook	Fort River	4	16	20	16	8	6	20	0.66	High
xy42326717244614	Federal St	Scarboro brook	Fort River	4	20	20	12	20	3	20	0.63	High
xy42257507241394	Forest Rd	Unnamed	Headwaters Chicopee R.	4	20	20	8	20	3	20	0.63	High
xy42335057244654	Gulf Rd	Scarboro Brook	Fort River	4	16	20	8	4	3	20	0.63	High
xy42348827243612	Gulf Rd	Scarboro Brook	Fort River	4	12	16	16	8	9	16	0.57	High
xy42218067238830	Barrett St	unnamed	Headwaters Chicopee R.	4	12	16	12	8	4	16	0.52	Medium

Appendix B—Table 4. Top-ranked crossings based on geomorphic risk score.

XY Code	Road Name	Stream Name	HUC 12 Watershed Name	Impact Score	Hydraulic Risk Score	Future Hydraulic Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Scaled Crossing Priority	Relative Priority Rating
xy42344447244064	Gulf Rd	Scarboro	Fort River	4	20	20	16	8	15	20	0.75	High
xy42339157245883	North St	Unnamed	Fort River	4	20	20	16	20	9	20	0.69	High
xy42286187241920	George Hannum	unnamed	Batchelor Brook	4	16	20	16	8	9	20	0.69	High
xy42340487244354	Gulf Rd	Scarboro Brook	Fort River	4	20	20	16	4	6	20	0.66	High
xy42349617243556	North Gulf Rd	Scarboro Brook	Fort River	4	16	20	16	8	6	20	0.66	High
xy42256567241778	Forest Rd	unnamed	Headwaters Chicopee R.	4	0	0	16	20	6	20	0.66	High
xy42271187244989	Boardman St	Weston Brook	Batchelor Brook	4	4	4	16	20	4	20	0.64	High
xy42348827243612	Gulf Rd	Scarboro Brook	Fort River	4	12	16	16	8	9	16	0.57	High
xy42237747241085	Ludlow St	Roaring Brook	Headwaters Chicopee R.	5	20	25	15	10	12	25	0.87	High
xy42236607241026	Granby Road	Roaring Brook	Headwaters Chicopee R.	5	25	25	15	10	6	25	0.81	High
xy42337347244652	North St	Scarboro Brook	Fort River	3	15	15	15	6	15	15	0.6	High
xy42339547244388	Gulf Rd	Scarboro Brook	Fort River	3	15	15	15	15	9	15	0.54	Medium

Appendix B—Table 5. Top-ranked crossings based on structural risk score.

XY Code	Road Name	Stream Name	HUC 12 Watershed Name	Impact Score	Hydraulic Risk Score	Future Hydraulic Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Scaled Crossing Priority	Relative Priority Rating
xy42271247245312	Rural St	Weston Brook	Batchelor Brook	4	16	20	12	20	12	20	0.72	High
xy42339157245883	North St	Unnamed	Fort River	4	20	20	16	20	9	20	0.69	High
xy42256567241778	Ledgewood Dr	unnamed	Headwaters Chicopee R.	4	0	0	16	20	6	20	0.66	High
xy42257497241598	Ledgewood Circle	unnamed	Headwaters Chicopee R.	4	20	20	12	20	6	20	0.66	High
xy42271187244989	Boardman St	Weston Brook	Batchelor Brook	4	4	4	16	20	4	20	0.64	High
xy42326717244614	Federal St	Scarboro brook	Fort River	4	20	20	12	20	3	20	0.63	High
xy42257507241394	Forest Rd	Unnamed	Headwaters Chicopee R.	4	20	20	8	20	3	20	0.63	High
xy42199827236851	South St	unnamed	Quabbin Reservoir-Swift R.	3	6	9	9	15	15	15	0.6	High
xy42343517246154	Old Amherst	Montague Brook	Fort River	3	3	3	9	15	15	15	0.6	High
xy42339547244388	Gulf Rd	Scarboro Brook	Fort River	3	15	15	15	15	9	15	0.54	Medium
xy42307617245536	Bay Rd	unnamed	Batchelor Brook	3	15	15	12	15	9	15	0.54	Medium
xy42281947242724	George Hannum St	Unnamed	Batchelor Brook	3	6	9	9	15	6	15	0.51	Medium
xy42302227244738	Bay Rd	Unnamed	Batchelor Brook	3	3	3	9	15	6	15	0.51	Medium
xy42272957243199	Underwood St	unnamed	Batchelor Brook	3	3	3	9	15	6	15	0.51	Medium
xy42209647237979	West St	unnamed	Jabish Brook	3	3	3	9	15	6	15	0.51	Medium
xy42302957244850	Bay Rd	Unnamed	Batchelor Brook	3	15	15	6	15	6	15	0.51	Medium
xy42307157245493	Bay Rd	unnamed	Batchelor Brook	3	15	15	6	15	6	15	0.51	Medium
xy42220167236911	Bardwell St	N/a	Jabish Brook	3	15	15	6	15	6	15	0.51	Medium
xy42303587244948	Bay Rd	unnamed	Batchelor Brook	3	15	15	6	15	3	15	0.48	Medium
xy42309137242419	Federal St	unnamed	Batchelor Brook	3	3	3	6	15	3	15	0.48	Medium

Appendix B—Table 6. Top-ranked crossings based on aquatic organism passage benefit score.

XY Code	Road Name	Stream Name	HUC 12 Watershed Name	Impact Score	Hydraulic Risk Score	Future Hydraulic Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Scaled Crossing Priority	Relative Priority Rating
xy42344447244064	Gulf Rd	Scarboro	Fort River	4	20	20	16	8	15	20	0.75	High
xy42199827236851	South St	unnamed	Quabbin Reservoir-Swift R.	3	6	9	9	15	15	15	0.6	High
xy42343517246154	Old Amherst	Montague Brook	Fort River	3	3	3	9	15	15	15	0.6	High
xy42337347244652	North St	Scarboro Brook	Fort River	3	15	15	15	6	15	15	0.6	High
xy42203997236734	South St	unnamed	Quabbin Reservoir-Swift R.	2	10	10	8	10	15	10	0.55	High
xy42298327242189	Hamilton St	unnamed	Batchelor Brook	2	10	10	6	10	15	10	0.55	High
xy42318407245188	Orchard St	unnamed	Fort River	2	2	2	10	6	15	10	0.55	High
xy42318157246200	Orchard St	Unnamed	Fort River	2	10	10	4	4	15	10	0.55	High
xy42343667246344	Old Amherst Rd	Unnamed	Fort River	2	8	10	8	2	15	10	0.55	High
xy42323817245701	Goodell St	unnamed	Fort River	2	10	10	6	2	15	10	0.55	High
xy42235207241680	Ludlow St	unnamed	Headwaters Chicopee R.	1	5	5	4	5	15	5	0.5	Medium
xy42318537244156	Orchard St	Unnamed	Fort River	1	1	1	3	3	15	3	0.48	Medium

Appendix B—Table 7. Top-ranked crossings based on impact score.

XY Code	Road Name	Stream Name	HUC 12 Watershed Name	Impact Score	Hydraulic Risk Score	Future Hydraulic Risk Score	Geomorphic Risk Score	Structural Risk Score	AOP Benefit Score	Crossing Risk Score	Scaled Crossing Priority	Relative Priority Rating
xy42237747241085	Ludlow St	Roaring Brook	Headwaters Chicopee R.	5	20	25	15	10	12	25	0.87	High
xy42236607241026	Granby Road	Roaring Brook	Headwaters Chicopee R.	5	25	25	15	10	6	25	0.81	High
xy42344447244064	Gulf Rd	Scarboro	Fort River	4	20	20	16	8	15	20	0.75	High
xy42271247245312	Rural St	Weston Brook	Batchelor Brook	4	16	20	12	20	12	20	0.72	High
xy42339157245883	North St	Unnamed	Fort River	4	20	20	16	20	9	20	0.69	High
xy42286187241920	George Hannum	unnamed	Batchelor Brook	4	16	20	16	8	9	20	0.69	High
xy42256567241778	Ledgewood Dr	unnamed	Headwaters Chicopee R.	4	0	0	16	20	6	20	0.66	High
xy42257497241598	Ledgewood Circle	unnamed	Headwaters Chicopee R.	4	20	20	12	20	6	20	0.66	High
xy42349617243556	North Gulf Rd	Scarboro Brook	Fort River	4	16	20	16	8	6	20	0.66	High
xy42273367244577	Boardman St	unnamed	Batchelor Brook	4	20	20	12	8	6	20	0.66	High
xy42340487244354	Gulf Rd	Scarboro Brook	Fort River	4	20	20	16	4	6	20	0.66	High
xy42271187244989	Boardman St	Weston Brook	Batchelor Brook	4	4	4	16	20	4	20	0.64	High
xy42326717244614	Federal St	Scarboro brook	Fort River	4	20	20	12	20	3	20	0.63	High
xy42257507241394	Forest Rd	Unnamed	Headwaters Chicopee R.	4	20	20	8	20	3	20	0.63	High
xy42335057244654	Gulf Rd	Scarboro Brook	Fort River	4	16	20	8	4	3	20	0.63	High
xy42348827243612	Gulf Rd	Scarboro Brook	Fort River	4	12	16	16	8	9	16	0.57	High
xy42218067238830	Barrett St	unnamed	Headwaters Chicopee R.	4	12	16	12	8	4	16	0.52	Medium
xy42283657242220	Jackson St	unnamed	Batchelor Brook	4	8	12	12	4	6	12	0.42	Medium
xy42211327238655	West St	unnamed	Headwaters Chicopee R.	4	8	8	12	8	5	12	0.41	Medium
xy42287767241617	Hickory Hill	unnamed	Batchelor Brook	4	4	4	8	4	3	8	0.27	Low
xy42287367241736	George Hannum	unnamed	Batchelor Brook	4	4	4	4	4	3	4	0.15	Low

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Appendix C

Road-Stream Crossing Scoring and Prioritization Methods

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

Road-Stream Crossing Structure Type and Material	Allowable Headwater Depth[1]
Stone Masonry or Wood Culvert	HW = 1.0 x D
Smooth or Corrugated Metal or Plastic Culvert[2]	HW = 1.2 x D
Concrete Culvert	HW = 1 foot below lowest point in roadway surface
Bridge	HW = 1 foot below lowest point of bottom of bridge deck

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

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

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

Table 3: Hydraulic Capacity Score

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

Equation 1: Hydraulic Capacity Ratio

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

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

Crossing has sufficient capacity to convey the return interval peak discharge

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

Crossing is undersized for the return interval peak discharge

Geomorphic Vulnerability Worksheet
Massachusetts Road-Stream Crossing Assessment
Belchertown Town-Wide Road-Stream Crossing Assessment and
Climate Change Adaptation Plan
June 2019

Table 1: Crossing Alignment Impact Potential Ratings

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

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

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

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

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

Table 4: Channel and Crossing Structure Slope Impact Potential Ratings

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

Table 5: Sediment Continuity Impact Ratings

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

Table 6: Bank Erosion and Outlet Armoring Impact Ratings

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

Table 7: Inlet and Outlet Grade Impact Ratings

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

Table 8: Combined Geomorphic Potential Impact Ratings

Combined Potential Impact Rating	Likelihood for Geomorphic Impacts
3	Very unlikely
4-6	Unlikely
7-9	Possible
10-12	Likely
13-15	Very likely

Table 9: Combined Observed Geomorphic Impact Ratings

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

Table 10: Overall Geomorphic Impact Score

Sum of Geomorphic Potential Impact Ratings and Observed Geomorphic Impact Ratings	Geomorphic Impact score
6	1
7-12	2
13-18	3
19-24	4
25-30	5

Structural Condition Worksheet
Massachusetts Road-Stream Crossing Assessment
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Table 1: Level 1 Variables

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

Table 2A: Level 2 Variables – Part I

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

Table 2B: Level 2 Variables – Part II

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

Table 3: Level 3 Variables

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

Table 4: Structural Condition Binned Score

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

Equation 1: Level 3 Condition Score

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

Aquatic Organism Passage Worksheet
Massachusetts Road-Stream Crossing Assessment
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Table 1: Component Scores for AOP Field Variables

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

Equation 1: Openness Measurement (feet)

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

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

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

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

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

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

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

Table 3: Binned Aquatic Passability Score

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

Table 4: Binned Ecological Integrity Score

Aquatic Index of Ecological Integrity (IEI) Value	Binned Ecological Integrity Score
0.0-0.3	1
0.31-0.5	2
0.51-0.7	3
0.71-0.9	4
0.91-1.0	5

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

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

Equation 5: Aquatic Passability Score

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

Transportation Services Disruption Worksheet
Massachusetts Road-Stream Crossing Assessment
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Table 1: Transportation Disruption Component Scores

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

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

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

Table 1: Stream Buffer Distance as a Function of Crossing Structure Width and Degree of Constriction

(for use where bankfull width not available)

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

Table 2: Flood Impact Rating – Developed Area

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

Table 3: Flood Impact Rating – Upstream and Downstream Crossings

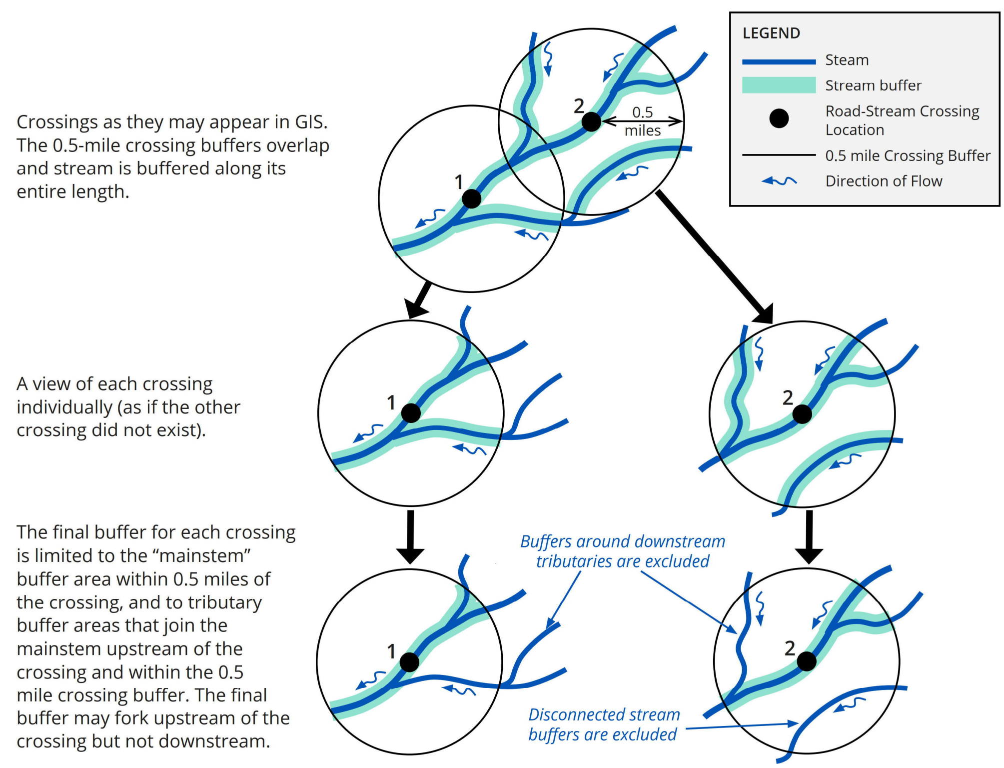
Flood Impact Rating	Number of Upstream and Downstream Crossings within Potential Flood Impact Area Buffer Polygon
1	0
2	--
3	1
4	--
5	>1

Note: -- indicates category not used

Table 4: Binned Flood Impact Potential Scores

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

Figure 1: Stream Crossing Buffer Diagram



Prioritization Worksheet
Massachusetts Road-Stream Crossing Assessment
Belchertown Town-Wide Road-Stream Crossing Assessment and
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Equation 1: Crossing Failure Risk

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

Equation 2: Impact Score

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

Equation 3: Existing Hydraulic Risk Score

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

Equation 4: Future Hydraulic Risk Score

$$Future\ Hydraulic\ Risk\ Score = Binned\ Future\ Hydraulic\ Capacity\ Score \times Impact\ Score$$

Equation 5: Geomorphic Risk Score

$$Geomorphic\ Risk\ Score = Binned\ Geomorphic\ Vulnerability\ Score \times Impact\ Score$$

Equation 6: Structural Risk Score

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

Equation 7: Crossing Risk Score

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

Equation 8: Aquatic Passage Benefit Score

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

Equation 9: Crossing Priority Score

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

Table 1: Relative Priority Ratings

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

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