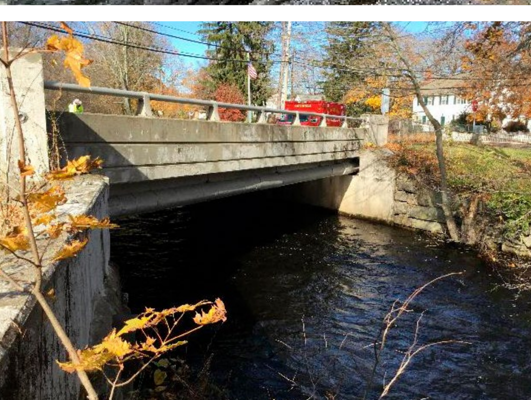
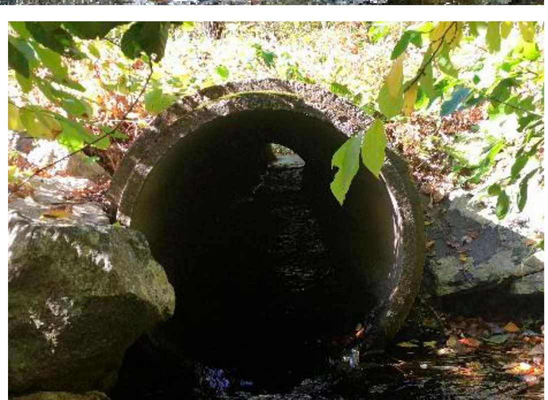
Rhode Island Department of Transportation

# Road-Stream Crossing Design Manual

August 2021 (March 2022 Revision)

prepared by vhb

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# Section 1: Introduction to the Manual

Rhode Island's approximately 3,578 miles of riverine ecosystems, which flow to Narragansett Bay and the Atlantic Ocean, provide unique and diverse habitats that support a variety of species (Narragansett Bay Estuary Program, 2017). Rivers and streams are particularly vulnerable to fragmentation—being broken into small or separate parts—due to the linear nature of riverine ecosystems. The Rhode Island Department of Transportation (RIDOT) has developed this Road-Stream Crossing Design Manual (the Manual) to provide designers and engineers with design criteria and associated standards to prevent habitat fragmentation of riverine ecosystems, improve stream crossing function, and provide long-term resilient infrastructure. This Manual is designed to be used in conjunction with the *RIDOT Road-Stream Crossing Assessment Handbook* (2019) (the Assessment Handbook). This Manual assumes, but does not require, that existing crossings have been reviewed using the Assessment Handbook.

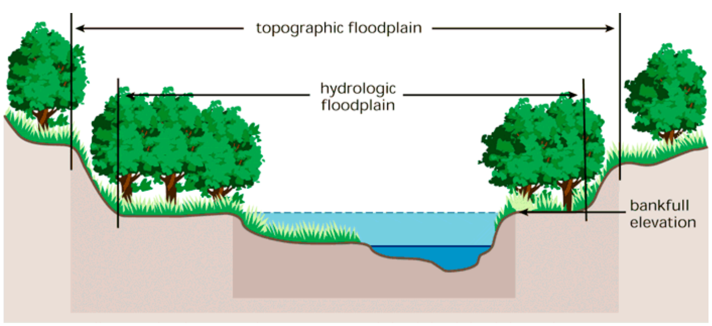
## 1.1 Scope of the Manual

This Manual is a guidance document focused on the design of safer, cost-effective stream crossings to meet transportation needs, improve hydraulic function, reduce maintenance costs, and enhance natural stream functions and wildlife migration. The design standards presented in this Manual (the Design Standards) apply to all RIDOT owned road-stream crossings. Other Rhode Island state agencies, municipalities, regulators, and stream crossing designers are strongly encouraged to implement these standards.

Prior to publication of this Manual, RIDOT did not have agency-specific guidance governing stream crossing hydraulic design storm requirements and required freeboard. This Manual presents stream crossing design guidance based on capacity relative to current-day peak discharge, ecological connectively, and resiliency for the future. Proposed crossing designs must also consider drainage area, highway functional classification, freeboard, flow velocities, backwater, and scour.

There are two levels of Design Standards presented in this Manual, the **Optimal Standards**, which must be achieved for all new and existing stream crossings, and the **Base Standards**. The Optimal Standards aim to match the natural floodplain geometry, as shown in *Figure 1-1* below. The Base Standards also allow for natural stream processes and aquatic passage but are less likely to accommodate movement of semi-aquatic and terrestrial wildlife or extreme flood events.

**Figure 1-1**: Diagram depicting the natural floodplain geometry of a stream corridor

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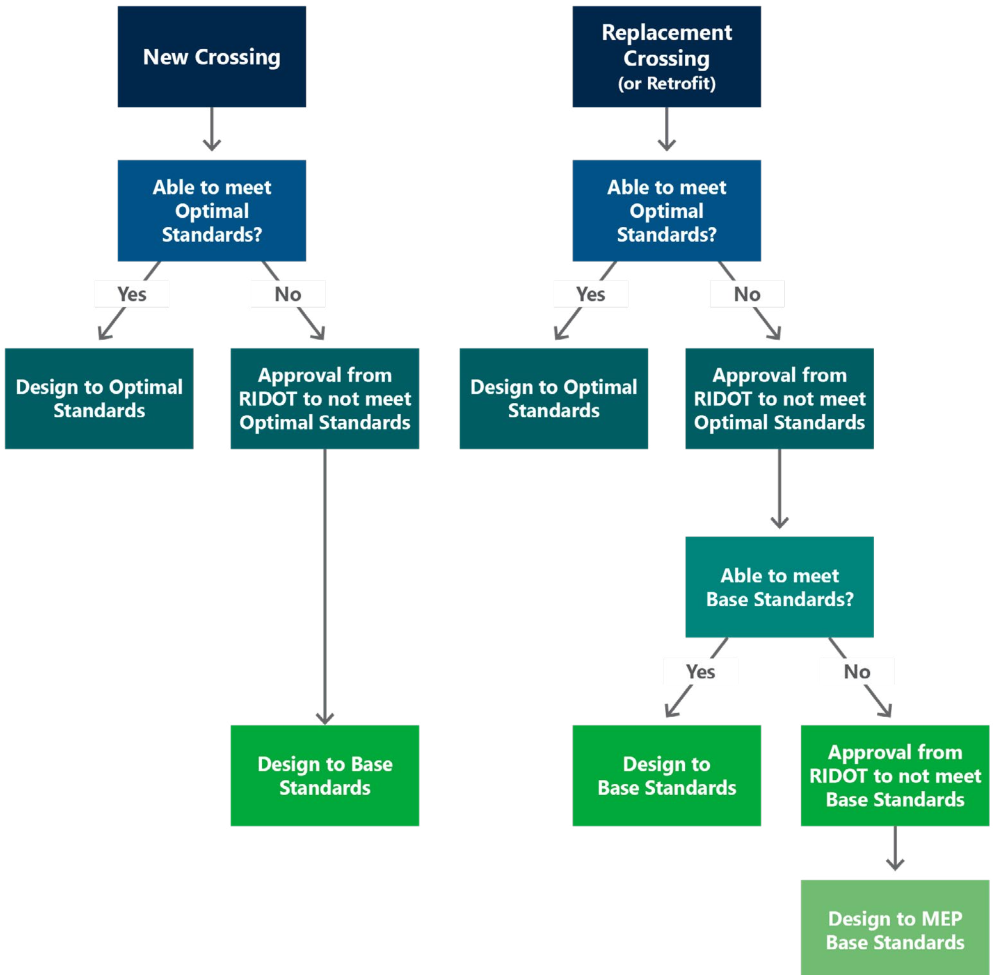
The Design Standards (Base and Optimal) apply to each of the Design Criteria categories. The Design Criteria are the topics that are impactful on the detailed design of a crossing structure and the project's decision-making process. **Each Design Criteria must be assessed individually for degree of compliance with the Design Standards.**

Road-stream crossing projects must adhere to these Design Standards for each Design Criteria as shown in *Figure 1-2* below and as follows:

- All **new road-stream crossings** are required to meet the Optimal Standards. If a new project is unable to meet Optimal Standards for all Design Criteria, the project must request written approval (via email) from the RIDOT Environmental Division to design to the Base Standards.
- All **replacement road-stream crossings** (or retrofits) are required to meet the Optimal Standards. If a replacement project is unable to meet Optimal Standards for all design criteria, the project must request written approval from the RIDOT Environmental Division (via email) to design to the Base Standards or the Base Standards to the maximum extent practicable (MEP).

The RIDOT Environmental Division will review and approve project requests for non-compliance with the Optimal or Base Standards and will consider the overall benefits of meeting the Design Standards

## **Figure 1-2**: Design Standard Requirements



compared to the constraints presented for non-compliance. **A crossing may meet the Optimal Standard for some Design Criteria and only meet the Base Standard for other Design Criteria, with RIDOT approval.**

### 1.1.1 Goal and Purpose of this Manual

As stated above, prior to publication of this Manual there had been no RIDOT-specific guidance governing stream crossing design. As a result, many existing crossings are undersized or improperly designed which can cause clogging, flooding, scour concerns, structural instability, or a variety of other issues discussed further in this Manual. These issues require RIDOT to utilize funding for maintenance, repairs, and frequent replacement. The Design Standards provided within this Manual require designers to provide crossings that are less likely to need RIDOT funding over time by creating standards for long-term resilience. *Section 2.2.10* below discusses case studies illustrating the reduction in life cycle costs by designing for organism passage and many of the other requirements described in this Manual.

### 1.1.2 What is a Stream Crossing?

Stream crossings include bridges, culverts, arches, and other similar structures that allow water to pass under infrastructure that would otherwise block the natural flow of rivers and streams. Crossings can vary significantly in size and shape, depending on the location and structure type. See *Assessment Handbook: Section 1.2.3* for additional detail.

### 1.1.3 How to use this Manual

The primary intended use of this Manual is to provide designers and engineers with criteria and guidelines to create more cost-effective, climate-resilient stream crossings that also improve wildlife passage and stream connectivity. A knowledge of hydrology, hydraulics, aquatic organism passage (AOP), geotechnical and structural design, at a minimum, is required for the proper design of a crossing. This Manual focuses on the design of road-stream crossings, but the Design Criteria can be applied to other stream crossing infrastructure (e.g., pedestrian paths, bike paths, railroads, and pipelines) and other waterbodies including wetlands and tidally influenced areas. After reviewing the Design Standards presented in the Manual (see *Section 4*), designers must complete the Road-Stream Crossing Standards Review Checklist(s) and Hydraulic Design Data Table, provided in *Appendix A*, to document the proposed crossing's compliance with the applicable Design Standards.

### 1.1.4 What this Manual is Not

This Manual is not intended for the following uses:

- A design guide for stormwater and other drainage pipes
- A replacement for the RIDOT Bridge Inspection Manual, the RIDOT Linear Stormwater Manual, or the Rhode Island Stormwater Design and Installation Standards Manual
- A guide for structural or geotechnical design and analysis of bridges, arches, or culverts
- An assessment guide for prioritizing stream crossing replacement
- A stream crossing permitting guidebook
- A guide for floodplain management or analysis

### 1.1.5 Important Definitions

This section provides only the specific key definitions with which all readers should become familiar. Additional definitions and abbreviations used in this Manual are provided in *Appendix D: Glossary of Terms*. Definitions for hydraulic analysis (design storm, scour, check scour, and climate check) are provided in *Section 4.1* below.

**Annual Exceedance Probability (AEP):** The probability of an event occurring in any year. For example, the 1% AEP flood has a 1% chance of occurring or being exceeded in any given year. The probability of flood occurrence is also commonly defined by a specific return period. This Manual refers to flood events in terms of AEP. *Table 1* shows the relationship between AEP and return interval for common flood events.

### Table 1: Flood Event AEP and Return Period

| Annual Exceedance Probability (AEP) (%) | Return Period (years) |
|---|---|
| 50 | 2 |
| 10 | 10 |
| 4 | 25 |
| 2 | 50 |
| 1 | 100 |
| 0.2 | 500 |

**Bankfull Width**: A measurement of the active stream channel top width at bankfull flow (the point at which water completely fills the stream channel and where additional water would overflow into the floodplain). See *Assessment Handbook: Section 3.5.2* for additional detail on determining bankfull width and flow.

**Bridge**[1]: A crossing that has a deck supported by abutments. Abutments may be earthen or constructed of wood, stone, masonry, concrete, or other materials. A bridge may have multiple cells, divided by one or more piers. See *Assessment Handbook: Section 1.2.3* for additional details.

**Culvert**: A culvert is any crossing structure that is not a bridge and is usually buried under some amount of fill. Culverts can be fully enclosed (contain a bottom) or have an open bottom. For the purpose of this Manual, an arch is considered an open-bottom culvert. See *Assessment Handbook: Section 1.2.3* for additional details.

**Freeboard**: Freeboard is the distance between the upstream water surface elevation and the low chord of the crossing structure. The location of the upstream water surface elevation will vary based upon the hydraulic model used in the design. Below is a description of this location for common hydraulic modeling software:

- **HEC-RAS (Hydrologic Engineering Center River Analysis System)**: Two cross sections upstream of the crossing (also known as Bridge Cross Section 4) where the flow has not yet been impacted by contraction of the crossing.
- **HydroCAD Stormwater Modeling Software**: The location of the upstream water surface elevation will vary based on the method of modeling. The designer should use engineering judgement to best interpolate the elevation approximately one to two bridge widths upstream of the crossing or where flow has not yet been impacted by contraction of the crossing.
- **HY-8 Culvert Hydraulic Analysis Program**: Due to the limitations of this model, the designer should utilize engineering judgement to determine if the predicted water surface elevation at the upstream face of the crossing is appropriate to use for freeboard calculations.

## 1.2 Development of the Manual

This Manual was developed with review and input from various stakeholder groups consisting of representatives from other state agencies, regulatory groups, research organizations, watershed groups, and Rhode Island municipalities. The Design Standards presented in this Manual are based on industry-leading standards and the most recently available research for road-stream crossing design. When developing the Design Criteria, emphasis was given to crossing standards required by other New England states. By providing two levels of standards, Base and Optimal

1 The RIDOT Bridge Inspection Manual defines a bridge as a structure over a depression or an obstruction with a length of more than 20 feet (2013, as amended). Designers should review the latest RIDOT Bridge Inspection Manual for updated definitions.

Standards, designers can balance ecological and biological objectives with the cost and logistics of implementing a design.

The stakeholder groups that assisted RIDOT in the development of this Manual include:

- Environmental Protection Agency (EPA)
- Narragansett Bay Estuary Program
- National Marine Fisheries Service (NMFS)
- National Park Service (NPS)
- RI Coastal Resources Management Council (CRMC)
- RI Department of Environmental Management (RIDEM)
- RI Department of Administration
- RI Emergency Management Agency (RIEMA)
- Save the Bay: Narragansett Bay
- University of Rhode Island
- U.S. Army Corps of Engineers (USACE)
- U.S. Fish and Wildlife Service (USFWS)
- Woonasquatucket River Watershed Council
- Various engineering firms and Rhode Island municipalities

## 1.3 Cost Comparison Analysis

A cost comparison analysis was conducted as part of the development of this Manual to provide guidance and context for upgrading existing crossings to allow for AOP. A common issue associated with stream crossing replacement is that many crossings damaged during large storm events are traditionally funded to be replaced in-kind, requiring the same structure design and size as prior to the storm event. This results in many undersized crossings being repeatedly damaged and replaced with a similarly poor functioning stream crossing. However, the Robert T. Stafford Disaster Relief and Emergency Assistance Act (the Stafford Act) signed into law November 23, 1988 and amended most recently in May 2019, does allow state DOTs and municipalities to apply for funding beyond replacing structures in-kind.

Prior to publishing this Manual, RIDOT reviewed the existing research available regarding cost-benefit analyses for a stream crossing, which ideally includes life cycle costs associated with design and construction, the benefits of a longer lifespan, and reduced maintenance costs. Available research-based case studies demonstrate that designing for AOP and stream continuity not only provides ecological and hydraulic benefits, but often reduces the overall life cycle cost because the crossing requires less maintenance and is less likely to fail and require subsequent replacement (Levine, 2013; Massachusetts Department of Fish and Game Division of Ecological Restoration, 2015; The Louis Berger Group Inc, 2017). It is also likely that the impacts of climate change, particularly the higher frequency of intense storms, will increase the costs of replacing undersized stream crossings in-kind by requiring more maintenance and earlier replacement (Levine, 2013). Further discussion and elaboration on this review is provided in *Appendix E: Synthesis of Existing Guidance Memorandum*.

This Manual aims to reduce the overall life cycle cost of road-stream crossings by providing more resilient, longer lasting crossings. The designer and the RIDOT Environmental Division should consider life cycle costs of a proposed crossing before presenting or accepting non-compliant crossings.

## 1.4 Funding Opportunities

Financial and technical support may be available to assist with upgrading, replacing, or installing new crossings. Below is a list of some funding sources that may be available for projects in Rhode Island:

- EPA Southeast New England Program (SNEP) Watershed Grants
- EPA Wetland Program Development Grants
- FEMA Building Resilient Infrastructure and Communities (BRIC) (former Pre-Disaster Mitigation Program)
- FEMA Flood Mitigation Assistant (FMA)
- FEMA Hazard Mitigation Grant Program (HMGP)

- Narragansett Bay Estuary Program (Narragansett Bay and Watershed Restoration Fund)
- National Fish and Wildlife Foundation
- National Fish Habitat Partnership
- National Oceanic and Atmospheric Administration's Restoration Center
- RIDEM Climate Resilience Fund
- RIDEM Riparian Buffer Restoration Grants
- U.S. Fish and Wildlife Service's National Fish Passage Program
- Wildlife Conservation Society Climate Adaption Fund

# Section 2: Background and Design Rationale

This section of the Manual provides an overview of the importance of maintaining stream continuity, potential issues of poorly designed crossings, and site-specific constraints that may influence crossing design. Other crossing design considerations include accounting for changes in precipitation and sea level rise due to climate change and evaluating the life cycle cost of different crossing designs.

## 2.1 Background and Importance of Road-Stream Crossing Design

There are currently an estimated 4,300+ road and railroad crossings affecting Rhode Island streams[2] (RI Resource Conservation & Development Area Council, 2013). Many crossings do not allow for the natural movement of water, sediment, and migratory species due to poor hydraulic and ecological design. Research in the Northeast United States found that stream sections located above impassable culverts had fewer than half the number of fish species and total fish counts compared to streams above and below passable culverts (Letcher et al., 2011). By understanding the importance of stream continuity and common consequences of poorly designed crossings, designers can avoid isolating habitats and create safer, more cost-effective stream crossings.

### 2.1.1 Rationale for Stream and Habitat Continuity

The concept of stream continuity focuses on passage of all species, including fish, insects, amphibians, reptiles, and mammals, at areas of potential habitat fragmentation. Stream continuity allows for various species to access vital habitats like feeding, breeding, and spawning locations. Many terrestrial animals, such as reptiles or mammals, are more tolerant of stream discontinuity but may experience negative impacts from road crossings if forced to cross where they are vulnerable to traffic and other dangers. Poorly designed or installed stream crossings can also degrade nearby habitat and create inhospitable conditions for native plants and animals.

### 2.1.2 Poor Existing Stream Crossings

Recognizing problems at existing stream crossings and their consequences is a critical step in evaluating crossings and designing to avoid problems in the future. Poor crossing design can lead to further degradation of stream quality, increase flood risk, and isolate habitats and species. Many existing road-stream crossings do not allow fish and other wildlife to freely migrate and do not meet the Design Criteria presented in this Manual. The *Assessment Handbook* provides extensive detail on reviewing and assessing existing crossings and understanding which design elements are priorities for improvement. The most common problems and consequences of poorly designed stream crossings are summarized below.

***Crossing Clogging***

Stream crossings can become clogged by woody debris, leaves, ice, and other material. This may create or exacerbate flooding and scour issues and make a crossing impassable to wildlife. Crossings usually clog at inlets because the structure is undersized. Clogging may be avoided by using a structure large enough to span the natural channel and provide sufficient freeboard to pass debris through the crossing opening. Routine maintenance can also help prevent clogging but can be costly. Debris loads (quantity and size) will vary based on project location and should be accounted for in the design.

2 Based on a 2013 GIS analysis conducted by the USDA Natural Resources Conservation Service (NRCS).


Example of clogged crossing

### Damage or Failure

Damaged or failed crossings can be the result of a variety of causes that destabilize a crossing structure, many of which are listed below. Damaged or failed crossings can prevent fish and wildlife from accessing food, breeding areas and other important habitats, cause damage to roadways, property damage, and in the worst-case scenario, loss of life. Replacement or repair of damaged crossings is costly and may be avoided by properly designing structures for hydraulic events and debris loads.

### Disruption of Transportation Services

A common and expensive consequence of poor stream crossing design is damage to infrastructure that disrupts transportation services. Washed-out and flooded roadways, railroads, or other infrastructure can make a location inaccessible and isolate homes, businesses, and institutions. Disruption of transportation services also creates a significant safety issue if used as an evacuation route or by emergency vehicles.

### High or Low Velocities

Both high and low flows can prevent organism passage and may alter the stream geomorphology by erosion or aggradation of bed material. Crossing structures should be designed to create water velocities similar to the natural stream under a variety of flow rates.

### Perched Crossings

Perched crossings are above the level of the stream bottom, typically at the downstream end, creating a waterfall effect from the crossing outlet. A perched crossing can further erode the natural streambed and is a significant barrier to wildlife migrating upstream or downstream.


Example of perched crossings

### Ponding and Flooding

Ponding and flooding are the unnatural backup of water upstream of a crossing. This usually occurs at undersized crossings and may occur year-round, during seasonal high water or floods, or when a structure becomes clogged. Flooding can lead to property damage, impassible roadways, road and bank erosion, and severe changes in habitat.

### Scouring

Scouring is the erosion of the natural substrate of a streambed, usually caused by increasing velocities due to the contraction or obstruction of flow. High water velocities and related flow alterations may cause a scour hole at the downstream end of a crossing and can also erode streambanks upstream and downstream of a crossing. Scouring may undercut a crossing or its foundations and compromise the stability of a crossing structure.

### *Shallow Crossings*

Shallow crossings have water depths too low for organism passage. Fish and other aquatic organisms need sufficient water depths to move through a stream crossing. Shallow crossings are often improperly designed or installed. Crossings should be designed to maintain water depths that are similar to the natural stream.

***Undersized Crossings***

Undersized crossings restrict natural streamflow, particularly during high flows, and may cause problems including scour, erosion, high flow velocity, clogging, ponding, and in extreme cases washout (failure) or flows overtopping the roadway. Crossings can also fail due to increased peak discharge rates as a result of climate change, watershed development, and other land use changes since the time of construction.

### *Unnatural or No Bed Material*

Materials like metal and concrete are not natural for species that travel along the streambed. These smoother surfaces also have a lower roughness coefficient which can increase velocities through the crossing. A continuous layer of substrate within a structure should match the natural substrate of the surrounding stream to maintain natural conditions (depth and flow velocity) and not disrupt stream continuity.

## 2.2 Designing for Each Project Site

Designers must account for the specific needs and constraints of each project location, stream geomorphic conditions, hydrologic conditions, surrounding ecology, safety and transportation needs, and cost and construction constraints. The design of each crossing must include, but is not limited to, the considerations in the following sections:

### 2.2.1 Selecting a Location

The location of a proposed road-stream crossing should minimize impact to geomorphic processes and habitat continuity. Designers should avoid placing crossings in sensitive areas such as rare species habitat or unstable reaches. A crossing hydraulic opening must span the natural channel and minimize disturbance by aligning the crossing perpendicular to a straight segment of the stream channel, whenever possible.

### 2.2.2 Site Assessment

Designers must evaluate the site of a proposed crossing prior to designing a crossing structure to incorporate site-specific information. The *Assessment Handbook* provides detailed guidance on data collection for accurate site assessments including collection of field data and desktop analyses.

RIDOT recommends that designers evaluate any existing crossings that need replacement or upgrade by using the methodology outlined in the *Assessment Handbook* prior to the redesign of the crossing. Risk and impact scores from the *Assessment Handbook* can indicate which Design Criteria are most critical for replacement or retrofit design, discussed in more detail in *Section 4*.

### 2.2.3 Geomorphic Conditions

The topographic and bathymetric conditions at a proposed crossing location must be analyzed during the pre-design process. Many elements of the design of the crossing, including the crossing alignment relative to the channel, crossing span, crossing slope, and substrate within the crossing, will be determined by the geomorphic conditions at the site. The observed upstream and downstream conditions of a crossing can also indicate potential issues with bank stability, changes in channel gradient, and habitat continuity to be addressed during the design process. See the *Assessment Handbook: Section 8* for analyzing the geomorphic processes that may impact the proposed project.

### 2.2.4 Hydrologic Conditions

The hydrology of the stream and contributing watershed at a crossing location are critical in the structural design and hydrologic and hydraulic (H&H) modeling of the crossing. Hydrologic analysis for determining the range of flows at a site can include the use of peak-flow data from nearby stream gages, rainfall-runoff analysis, and regional flood-flow regression equations (available from United States Geological Survey (USGS) Scientific Investigations Report 2014–5010 (Bent et. al., 2014). See the *Assessment Handbook: Section 5* for guidance on determining flows at a project site and *Section 6* for guidance on evaluating the hydraulic capacity of an existing crossing. Streamflow data (velocity, depth, and discharge rates) from the proposed design model results should be comparable to the natural stream. The locations of hydraulic features (e.g., reservoirs, dams, pump stations) must also be accounted for during modeling and design.

### 2.2.5 Natural Resources

Designers must review the potential for impacts to natural resources and may be required to perform studies to evaluate these impacts. Projects may require additional permitting and design considerations. Regulatory limitations to protect resources near the project may also limit construction timing to specific weeks or months during the year. Common natural resources that may impact the design and permitting of a project are discussed below.

#### *Threatened and Endangered Species*

If a crossing has the potential to occur in an area of state-listed or federally threatened or endangered species, the project may require review by the U.S. Fish and Wildlife Service (USFWS), the National Marine Fisheries Service (NMFS), RIDEM, or other regulating entities for compliance with the Endangered Species Act. The designer must assess if an aquatic species study is necessary to account for passage in the design when designing for passage of a specific organism.

Designers must review the most recent *list of threatened or endangered species* and their associated *critical habitats*, available from the USFWS, the NMFS, and the Rhode Island Natural History Survey (rinhs.org) to understand the requirements for design.

#### *Essential Fish Habitat*

If the proposed project has the potential to impact essential fish habitat (EFH) or NOAA trust resources, the project may require review by the National Marine Fisheries Service (NMFS) for compliance with the Magnuson-Stevens Fishery Conservation and Management Act (MSA). The designer must assess if an aquatic species study is necessary to account for passage in the design when designing for passage of a specific organism. If a crossing is located within EFH, designers may have to consult the NMFS to determine the impacts. A *map of EFH* is available online from the NMFS.

#### *Migratory Birds*

If a proposed project has the potential to impact migratory birds, the project will require compliance with the Migratory Bird Treaty Act (MBTA). The MBTA is regulated by the USFWS to promote the conservation of migratory bird populations. A list of bird species protected under the MBTA can be found in 50 CFR § 10.13. Common construction restrictions may include minimizing land disturbance, limiting the use of artificial lighting, noise restrictions, and material containment.

#### *Wild and Scenic Rivers*

The National Wild and Scenic Rivers System was created to preserve certain rivers with outstanding natural, cultural, and recreational values. Approximately 110 miles of Rhode Island's 1,392 miles of river are designated as Wild and Scenic Rivers (USFWS, 2021). If a crossing is located at a National Wild and Scenic River, designers must consult the National Park Service for early coordination. A map of *Rhode Island Wild and Scenic Rivers* is available online.

***Invasive Species***

If a proposed project has the potential to introduce or spread invasive species, methods must be implemented to prevent the introduction and spread of invasive species that comply with federal and state laws and regulations. The designers and planners shall consider and address, to the extent practicable, the impacts of invasive species in all aspects of project planning, design, construction and maintenance.

### 2.2.6 Cultural and Historical Resources

An existing crossing that needs replacement or upgrade may be listed or impact an entity on the National Park Service's National Register of Historic Places. Designers should consult the RIDOT Cultural Resources Unit, the *Rhode Island Historical Preservation & Heritage Commission*, the National Park Service and review the most recent information from the *National Register of Historic Places* to determine if the project will impact structures on the National Registry. The redesign of a structure on the National Register of Historic Places may be limited due to regulations required by the National Historic Preservation Act.

### 2.2.7 Wetland Areas

Crossings within wetlands should be designed to minimize disturbance to streambeds, wetland soils, other vegetation, and water surface elevations of the wetland. Designers should balance the goals of the project with any required clearing or filling of wetlands and should be designed to traverse a narrow section of the wetland, to the maximum extent practicable. Time-of-year (TOY) restrictions may be required by regulatory agencies to limit construction activities to low-flow periods to minimize impact to aquatic organisms (see *Section 5*).

The design of a crossing within a wetland or wetland buffer zone will need to comply with freshwater and/or coastal wetlands regulations as administered by the RIDEM and/or the RI CRMC. Designers must comply with the standards and avoidance, minimization, and mitigation measures established within the Rules and Regulations Governing the Administration and Enforcement of the Fresh Water Wetlands Act (250-RICR- 150-15-1) as administered by the RIDEM, or the Coastal Resources Management Program (650-RICR-20-00-1), or Rules and Regulations Governing the Protection and Management of Freshwater Wetlands in the Vicinity of the Coast (650-RICR-20-00-2) as administered by the RI CRMC. The location of the project will determine the jurisdiction of the regulatory agency and the applicable regulations. The jurisdictional boundary between RIDEM and RI CRMC is hosted on the *RIDEM Environmental Resource Map*. If a project includes the jurisdiction of both agencies, then it is generally RI CRMC that will take sole jurisdiction, though this should always be verified on a project-by-project basis with the regulatory agencies.

Section 404 of the Clean Water Act (CWA) establishes a program to regulate the discharge of dredged or fill material into waters of the United States, including wetlands (U.S. EPA, 2019). Therefore, approval from the United States Army Corps of Engineers is required for any projects proposing fill or dredging within a wetland area, although certain activities may be exempt. Projects are regulated through a permit review process in conjunction with RIDEM and/or RI CRMC for approval under the RI General Permit.

### 2.2.8 Crossing History

Crossing replacement projects must consider the hydraulic history of the existing crossing and the surrounding area. The designer must investigate if the crossing or surrounding area has a history of flood issues, overtopping, scouring, clogging, wash-out/collapse, or impacts to terrestrial or aquatic organism crossing. Evidence of wildlife passage issues may not always be obvious (for example, vernal pools near roadways but with no visible roadkill) and must be analyzed where topography and surrounding land use suggest that a crossing may be heavily trafficked by wildlife. Areas that serve as "critical linkages" for wildlife movement and connectivity in Rhode Island are available through the Critical Linkages data developed by the Landscape Ecology Lab at UMass Amherst as part of the Conservation Assessment and Prioritization System (CAPS) program **(see** *Assessment Handbook: Section 12.2* **of the** *Assessment Handbook)*. The designer should also inquire with the town, RIDOT, and community representatives to obtain any available records, reports, or photographs of the culvert history. If the crossing has a history of creating adverse conditions, RIDOT recommends that the crossing is not replaced-in-kind. The crossing should be analyzed and designed to improve conditions, reduce the risk of failure or damage, and meet the Standards described within this document.

### 2.2.9 Safety Concerns

The design of a crossing structure and factor of safety depend heavily on the roadway use, location, highway functional classification, and flood impact potential. During high flood events, a crossing must maintain safety for the intended use of the roadway and minimize impacts to surrounding areas and infrastructure. Flood frequency requirements based on highway functional classification and crossing span are summarized in *Table 3: Hydraulic Design Requirements*. The "RIDOT Roads" layer available online from the Rhode Island Geographic Information System (RIGIS) clearinghouse can be used to determine highway functional classifications, E-911 primary routes, and hurricane evacuation routes. See the *Assessment Handbook: Section 11* for further discussion on the importance of transportation safety concerns.

In addition to flood damage, some road-stream crossings may create safety concerns due to animal-vehicle collisions. Animal-vehicle collisions occur at higher rates in Rhode Island compared to the national average, with an average of 1 in 84 drivers colliding with an animal on the road (AASHTO Journal, 2018), likely due to higher densities of deer populations and roadways within the state (USDA, 2016; United States Department of Transportation, 2016). Animal-vehicle collision rates can be reduced by accommodating terrestrial animal passage within the crossing, discussed further in *Section 4*.

### 2.2.10 Cost and Logistics

Project cost and logistics are often the most significant constraints when designing a road-stream crossing. Construction feasibility, right-of-way (ROW) limitations, and regulatory requirements may limit the crossing location or structure design. ROW limitations are common for projects within roadways and often limit the project extents to the immediate area within the roadway easement. These constraints must be balanced with the overall safety, construction cost, life cycle cost, and the ecological and hydraulic requirements of a crossing to develop a design within the project scope.

## 2.3 Planning for Climate Change

The climate change predictions from the Intergovernmental Panel on Climate Change (IPCC) have had multiple iterations of publications and have increased the severity of climate change with each new publication (Collins et al., 2013). For this reason, climate change must be accounted for as part of the proposed stream-crossing manual. As part of its 1,045 square mile land mass, the State of Rhode Island has 384 miles of coastline resulting in a significant number of tidally influenced stream crossings (NOAA, 1975). The climate change planning requirements for crossing design are summarized in *Table 3: Hydraulic Design Requirements* and expanded upon in *Section 4.2.4*.

### 2.3.1 Precipitation

Average and extreme precipitation in the Northeast has increased during the last century. Intense rainfall events (heaviest 1% of all daily events from 1901 to 2012 in New England) have increased 71% since 1958 (Rhode Island Statewide Climate Resilience Action Strategy, 2018). More intense rainfall events lead to higher flood frequency and flood severity, which must be accounted for when designing a road-stream crossing. A crossing designed for the current 2% AEP storm event, for example, may not have the ability to accommodate the future 2% AEP storm event over the lifetime of the crossing. Therefore, precipitation projections must be considered in the design of all crossing. This Manual recommends analyzing climate change based on future planning horizons. A future planning horizon is the length of time into the future that is accounted for in a climate change projection. The future precipitation planning horizon that RIDOT requires for each project depends on the span and the highway functional classification at the crossing (as defined by RIDOT). The future planning horizon requirements are summarized in *Table 3: Hydraulic Design Requirements* and expanded upon in *Section 4.2.4*.

### 2.3.2 Sea Level Rise

As part of its 1,045 square mile land mass, the State of Rhode Island has 384 miles of coastline resulting in a significant number of tidally influenced the stream crossings (NOAA, 1975). The mean sea level has risen over 10 inches in Rhode Island since 1930, and the rate of sea level rise in Newport during the period of 1986 to 2016 has exceeded the global average mean at 0.16 inches per year over the same period (Rhode Island Statewide Climate Resilience Action Strategy, 2018). Rhode Island is also expected to experience increases in the frequency and intensity of coastal storms, storm surge, and increased high tides. The impacts of sea level rise must be evaluated or modeled at all tidally influenced crossings and for those that will be exposed to the future Mean Higher High Water (MHHW) level based on the projected sea level rise of the planning horizon (as a project location may be tidally influenced under the future sea level rise scenarios). The future sea level rise planning horizon that RIDOT requires for each project depends on the span and highway functional classification at the crossing (as defined by RIDOT).

# Section 3: Design Approaches

This section of the Manual discusses the recommended design approaches for designing a stream crossing and the benefits and drawbacks of each approach. The three design approaches presented are: (1) **Stream Simulation Design**, (2) **Aquatic Organism Passage Design**, and (3) **Modified Hydraulic Design**. The design approaches apply to all new, replacement, or retrofit crossings (as described in *Section 1.1*). Each approach has a unique methodology and area of focus for the basis of design.

The traditional design approach for road-stream crossings is to allow water to flow under roads, railroads, and other manmade infrastructure by conveying a specific design flow rate without washing-out or overtopping. However, with this traditional design approach, many of the existing crossings within Rhode Island are inadequately sized. A 2016 study of 421 stream crossings within the Wood-Pawcatuck Watershed found that 37% of the existing stream crossings were hydraulically undersized and unable to pass the 4% AEP peak discharge (Fuss & O'Neill). In addition to being undersized, many crossings were designed without considering AOP or stream continuity. This highlights the importance of incorporating appropriate hydraulic design and aquatic passage into stream crossing designs moving forward. The design approaches presented below provide a unique methodology for developing a stream crossing design that will provide AOP and will convey the applicable peak discharges.

*Sections 3.1-3.3* describe the **three main design approaches** that are currently acceptable to achieve hydraulic performance and provide a reasonable level of organism passage. Each design approach discusses the associated benefits and drawbacks which should be balanced with project goals and constraints.

## 3.1 Approach #1: Stream Simulation Design (Geomorphic Design) *Preferred Approach*

Stream Simulation, also known as geomorphic design, is the preferred design approach for road-stream crossings. Stream Simulation was developed by the United States Forest Service (USFS) and published in the 2008 document, *Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings (FSSWG)*.[3] Stream Simulation "is an approach to designing crossing structures (usually culverts), that creates a structure that is as similar as possible to the natural channel" (FSSWG, 2008). The premise of Stream Simulation design is to create a stream crossing that mimics the characteristics of the natural channel in as many facets as possible, so that the simulated channel presents no

3 The Stream Simulation technique was first formalized in the Washington Department of Fish and Wildlife's 1999 Fish Passage Design at Road Culverts and widely implemented in the Pacific Northwest from the Washington Department of Fish and Wildlife's 2003 Design of Road Culverts for Fish Passage (Bates).

more of an obstacle to aquatic animals than the natural channel and does not impede the natural movement of floodwater or sediment.

Designers utilizing this approach should reference the USFS Stream Simulation document for additional details on this approach. Stream Simulation has been widely accepted in New England and is often considered the top industry standard.

The design process should begin by identifying an undisturbed reference reach for the simulated channel to be based upon. The reference reach is preferably upstream, near the project location, and exists at a similar slope to the proposed crossing (FSSWG, 2008). If designing a crossing replacement, the reference reach should be outside of the influence of the existing crossing or other nearby infrastructure. The crossing structure is then designed over and around the proposed simulated channel. This method requires that the crossing's hydraulic opening span 1.2 times the bankfull width (BFW) with banks on both sides for dry passage for semi-aquatic and terrestrial wildlife and is embedded into the channel if using a closed-bottom structure. Whenever feasible, the banks within the crossing should be constructed out of natural streambank material and planted with native, shade-tolerant vegetation.

Regardless of the crossing structure, Stream Simulation structures have a continuous streambed that mimics the slope, dimensions, and material of the natural streambed to allow for unrestricted movement of aquatic species and some terrestrial species.

<u>Benefits</u>: Most likely to allow for unrestricted movement of terrestrial and aquatic organisms, account for hydraulic design requirements, and mimic natural channel characteristics.

<u>Drawbacks</u>: May result in a larger, more expensive crossing and requires additional survey of a reference reach.

## 3.2 Approach #2: Aquatic Organism Passage Design

Aquatic organism passage (AOP) design uses streambed sediment transport analysis to aid the design for AOP. This approach is outlined by the U.S. Department of Transportation Federal Highway Administration (FHWA) publication *Hydraulic Engineering Circular No. 26 (HEC-26)* and should be referenced by the designer if using this approach (2010). The size of stream crossing is primarily based on the minimum required hydraulic event, bed material composition, and permissible shear stress. Similar to the Stream Simulation approach, AOP design aims to mimic natural stream conditions under various flow rates to allow for movement of aquatic species but does not require a specified crossing span. Depending on the goals of the project, AOP design may also include using an aquatic species study to design for water depths and velocities that meet the swimming abilities of target fish populations and life stages during specific periods of fish movement. This method requires more complex analysis of friction and energy losses, bed material gradation, and use of one-dimensional energy and momentum equations, which may introduce error in the final design if inaccurate.

<u>Benefits</u>: Accounts for aquatic organism passage and hydraulic design requirements.

<u>Drawbacks</u>: Does not account for terrestrial organism passage, requires more detailed analyses, and may not be properly sized for extreme hydraulic events.

## 3.3 Approach #3: Modified Hydraulic Design

Modified hydraulic design is the analysis and design of a crossing structure based upon hydraulic and structural analyses which account for sufficient flow capacity (including freeboard requirements), bankfull width, channel slopes, and natural channel velocities. Similar to the AOP design approach, this method aims to mimic water depths and velocities of the natural channel to allow for movement of aquatic organisms, but with an emphasis on meeting flow capacity requirements. Modified hydraulic design is based on traditional hydraulic design, which accounts for flow capacity and regulated required freeboard and does not consider AOP. Traditional hydraulic design has been found to have negative impacts to AOP and is more likely to wash out or otherwise fail, and therefore, is generally no longer accepted within the discipline.

Modified hydraulic design is often used in retrofit projects including flow control structures such as baffles, weirs, or oversized substrate utilized to create acceptable hydraulic conditions. This technique may result in a smaller diameter crossing but installation costs are highly variable due to unique designs of baffles, weirs, steps, or other controls. Modified hydraulic design may require more detailed hydraulic calculations and produces a less conservative design for fish passage than Stream Simulation or AOP design.

Benefits: May result in a smaller, less expensive crossing

Drawbacks: Does not account for all organism passage and requires more detailed hydraulic calculations

# Section 4: Design Standards

This section of the Manual provides the Design Standards that apply to all RIDOT owned road-stream crossings. There are two levels of Design Standards presented in this Manual, the Base Standards and the Optimal Standards, each of which apply to each of the Design Criteria categories. All road-stream crossings (new, replacement, or retrofit), are required to meet the Optimal Standards for each Design Criteria. **If project specific needs or constraints do not allow the crossing (new, replacement, or retrofit) to meet the Optimal Standards for all Design Criteria, the crossing may reduce to meeting the Base Standards or the Base Standards to the MEP (for replacement/ retrofit only) for some or all Design Criteria. For either condition, the designer is required to obtain written approval from the RIDOT Environmental Division.** See *Section 1* and *Figure 1-2* for description and application of the Standards.

The following items must be included as part of the 30% Design Submission to be reviewed and approved by the RIDOT Environmental Division:

- Road-Stream Crossing Standards Review Checklist(s) (provided in *Appendix A*)
  - For replacements or retrofits, complete *A.1* and *A.2*. For new crossings, complete only *A.2*.
- Hydraulic Design Data Table (provided in *Appendix A*)
- The applicable Conceptual Design Figure (provided in *Appendix B*)
- Road-Stream Crossing Report (template provided in *Appendix C*)

Preapplication meetings with relevant agencies are important when balancing the goals of a project with regulatory requirements, particularly for new crossings. These meetings can reduce back-and-forth between agencies, lead to a better stream crossing design, can result in faster construction time, and reduced project costs. RIDOT recommends the designer schedules a preapplication meeting with relevant agencies, specifically RIDEM and USACE, early in the design process to allow for comment on the project intent as early as possible.

## 4.1 Road-Stream Crossing Design Standards

The following road-stream crossing Design Standards were developed to provide cost-efficient, low maintenance and resilient road-stream crossings for Rhode Island. *Table 2* (below) outlines the Design Criteria requirements associated with the Design Standards (Base and Optimal) with further definitions and descriptions of each Criteria provided in *Section 4.2*. The Standards apply to each of the Design Criteria categories, which are the categories that are impactful on the detailed design of a crossing structure and the project's decision-making process. Various scores from the *Assessment Handbook* can indicate which Design Criteria and Design Standards are most critical for re-design of existing crossings. The italicized language in *Table 2* specifies the applicable *Assessment Handbook* scores at which RIDOT recommends the Optimal Standard be met.

## Table 2: Overview of Road-Stream Crossing Design Standards

| Design Criteria | Optimal Standards[4] | Base Standards |
|---|---|---|
| *Design Approach* | • USFS Stream Simulation.<br>• *Scaled Crossing Priority Score >0.66* | • AOP Design or Modified Hydraulic Design. |
| *Structure Type* | • Bridge, 3-sided box culverts, open-bottom or arch culverts.<br>• *Binned Overall Geomorphic Impact Score ≥3* | • Pipe culvert or box culvert with embedment (see Embedment Criteria below). |
| *Channel Velocities* | • Velocity within the swimmable range of target species or comparable to a reference reach at bankfull flow and range of base flows (if no target species). Must also include AOP study for target species (when applicable).<br>• *Binned Aquatic Passability Score ≥3* | • Velocity comparable to natural channel at bankfull flow. |
| *Climate Change* | • Design for sea level rise and/or increased precipitation projections based upon Hydraulic Design Requirements (see *Table 3*). | |
| *Crossing Profile* | • Crossing profile to match existing natural stream using reference reach and vertical adjustment potential (VAP).<br>• *Binned Aquatic Passability Score ≥3* | • Crossing profile to match existing natural stream grade upstream and/or downstream of the crossing location |
| *Embedment, Substrate, and Channel Stability* | • 1 foot (minimum) of natural substrate material above any required scour protection material. Channel cross section within the crossing designed to mimic low flow depths of natural channel. Include grain size analysis and bed mobility/scour stability analysis.<br>• *Binned Overall Geomorphic Impact Score or Binned Aquatic Passability Score ≥3* | • Natural bottom substrate greater than or equal to (≥) 2 feet for all structures ≥ 8 feet in span; ≥ 25% of opening height for all spans less than 8 feet. Channel cross section designed within the crossing to mimic low flow depths of natural channel. |
| *Hydraulic Modeling* | • HEC-RAS (or equivalent) analysis required.<br>• See *Table 3* for hydraulic design requirements.<br>• *Binned Transportation Disruption Score ≥3* | • HY-8, CulvertMaster, HydroCAD, (or equivalent) analysis required.<br>• See Table 3 for hydraulic design requirements. |
| *Openness Ratio* | • Openness ratio ≥ 1.64 feet and height ≥ 6 feet. If conditions significantly inhibit wildlife, use openness of ≥ 2.46 feet and height ≥ 8 feet.<br>• *Binned Aquatic Passability Score ≥4* | • Openness ratio ≥ 0.82 feet to the maximum extent practicable. |
| *Stream Crossing Span* | • Hydraulic span ≥ 1.2 x BFW with banks on both sides designed for applicable wildlife passage.<br>• *Binned Flood Impact Potential Score ≥3* | • Hydraulic span ≥ 1.2 x BFW with banks on both sides. |
| *Structural Stability* | Design in accordance with Rhode Island and AASHTO LRFD standards. Structural design includes appropriate loading including streamflow, span configuration and freeboard, wingwall layout and design, and footing design. Hydraulic modeling and geotechnical analysis provide direction on foundation requirements and site-specific scour mitigation measures. | |
| *Tidal/Coastal Modeling* | • Velocity comparable to natural channel during the ebb and flow for high tide or maximum flow conditions and low tide/low flow conditions using a detailed unsteady hydraulic modeling analysis with an accompanying AOP study.[5]<br>• *Binned Climate Change Vulnerability Score ≥3* | • Designed to accommodate the exchange of the full tidal prism using a simplified quantitative analysis (i.e. spreadsheet).[5] |
| *Reporting Requirements* | • Road-Stream Crossing Report (with H&H computations), Geotechnical Investigation, Road-Stream Crossing Standards Review Checklist(s), Hydraulic Design Data Table, Conceptual Design Figure(s) | |

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4 Italicized language indicates the *Assessment Handbook* score at which the Optimal Standards are recommended.

5 Replacing existing tidal crossings may unintentionally alter water surface elevations in previously restricted areas and create flooding hazards. This potential result should be analyzed for risk and regulatory compliance before upgrading a crossing.

## Table 3: Hydraulic Design Requirements

| Highway Functional Classification[6] | Flood Frequency Requirements[7] | Design Storm Freeboard Requirements | Climate Change Projection Horizon[8,9,10] |
|---|---|---|---|
| *Span Less than 10 feet* | | | |
| *All Classes* | • Design Storm: 10% AEP<br>• Design Scour: 4% AEP<br>• Check Scour: 2% AEP<br>• Climate Check: 4% AEP | No freeboard required | Pass the design storm for the projections of the end of the service life: 75-year Horizon (unless crossing is atypical) |
| *Span 10 to 20 feet* | | | |
| *Bike or Walking Path, Rural Minor Collector, Rural Local, Urban Major and Minor Collector, Urban Local* | • Design Storm: 10% AEP<br>• Design Scour: 4% AEP<br>• Check Scour: 2% AEP<br>• Climate Check: 4% AEP | 1-foot | Pass the design storm for the projections of the end of the service life |
| *Rural Major Collector, Urban Minor Arterial* | • Design Storm: 4% AEP<br>• Design Scour: 2% AEP<br>• Check Scour: 1% AEP<br>• Climate Check: 2% AEP | 2-feet | Pass the design storm for the projections of the end of the service life |
| *Rural Principal Arterial, Rural Minor Arterial, Urban Principal Arterial, Or Any Structure on the NHS* | • Design Storm: 2% AEP<br>• Design Scour: 1% AEP<br>• Check Scour: 0.5% AEP<br>• Climate Check: 1% AEP | 2-feet | Pass the design storm for the projections of the end of the service life |
| *Span 20 feet or Greater* | | | |
| *Bike or Walking Path* | • Design Storm: 10% AEP<br>• Design Scour: 1% AEP<br>• Check Scour: 0.2% AEP<br>• Climate Check: 4% AEP | 1-foot | Pass the design storm for the projections of the end of the service life |
| *Rural Minor Collector, Rural Local, Urban Major and Minor Collector, Urban Local* | • Design Storm: 4% AEP<br>• Design Scour: 1% AEP<br>• Check Scour: 0.2% AEP<br>• Climate Check: 4% AEP | 2-feet | Pass the design storm for the projections of the end of the service life |
| *Rural Major Collector, Urban Minor Arterial* | • Design Storm: 4% AEP<br>• Design Scour: 1% AEP<br>• Check Scour: 0.2% AEP<br>• Climate Check: 2% AEP | 2-feet | Pass the design storm for the projections of the end of the service life |
| *Rural Principal Arterial, Rural Minor Arterial, Urban Principal Arterial, Or Any Structure on the NHS* | • Design Storm: 2% AEP<br>• Design Scour: 1% AEP<br>• Check Scour: 0.2% AEP<br>• Climate Check: 1% AEP | 2-feet | Pass the design storm for the projections of the end of the service life |

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6 All Rhode Island Department of Transportation roadways are categorized based on the Highway Functional Classification, available from the Rhode Island Division of Statewide Planning.

7 The Climate Check Event is only necessary if precipitation projections are not available for Rhode Island. If the Climate Check Event is utilized, the project must pass the Climate Check flood. If location specific flood discharges or precipitation projections become available for Rhode Island, projections shall be utilized according to the project's Climate Change Projection Horizon.

8 Climate Change projections often provide a range of scenarios for time horizons. RIDOT recommends the design utilizes the high (or equivalent) scenario at a minimum.

9 If exact future horizon year is not available, round to the nearest 10.

10 Projection Horizon based upon planned construction year.

*Table 3* describes the hydraulic capacity requirements for all crossings.

New, replacement, and retrofit projects for riverine and tidal crossings, regardless of meeting the Base or Optimal Standards, must meet the hydraulic capacity requirements.

The hydraulic design terms used in *Table 3* are defined below:

- The **Design Storm** is the flood producing storm event (based upon the applicable AEP) used to determine the required hydraulic capacity of a crossing, with the inclusion of freeboard.
- The **Design Scour** and **Check Scour** events are the flood producing storm events that the crossing's foundations, abutments, or piers must be designed to withstand, in accordance with the RIDOT Load and Resistance Factor Design (LRFD) Bridge Design Manual (2007).
    - ***Note for new crossings with spans greater than 20-feet***: *Refer to the RIDOT Load and Resistance Factor Design (LRFD) Bridge Design Manual (2007): New crossings may not use riprap or other scour countermeasures as a means of scour protection and must have foundations designed to withstand the conditions of scour for the design scour event and the check scour event.*
- The **Climate Check** event is the flood producing storm event used to determine the required hydraulic capacity of a crossing to account for climate change as part of the design; **the climate check event is only necessary if precipitation projections are not available for Rhode Island.**

### 4.1.1 Conceptual Design Guidance

This Manual provides Conceptual Design Figures in *Appendix B* that show profile views for four typical crossing types and illustrate some of the Design Standards that are described below. These design concepts are intended to aid the designer in determining key hydraulic design features. The figures are not intended to be used as a template for design, design plans, or final project deliverables. The figures do not represent structural, highway, or geotechnical features which may need to be considered. The typical crossing types also include a Hydraulic Features Table, which assists designers in conveying the key variables related to hydraulic modeling. **The applicable Conceptual Design Figure (including the completed Hydraulic Features Table) must be provided as part of the 30% Design Submission to the RIDOT Environmental Division**. Of the four Conceptual Design Figures provided in *Appendix B*, the designer should choose the figure that most similarly represents their crossing. If the provided Conceptual Design Figures do not address the key hydraulic features of the proposed crossing, such as piers or multiple openings, additional narrative or an equivalent figure must be provided to RIDOT Environmental Division for review and approval.

## 4.2 Design Criteria

The Design Criteria are the topics that engineering experience has shown to be impactful on the detailed hydraulic design of a crossing structure, the project decision making process, and which guide the industry standards. This section elaborates on each of the Design Criteria provided in *Table 2* and *3* above. Road-stream crossing designers must review each Design Criteria below for a complete understanding of each topic. Designers must also complete the Road-Stream Crossing Standards Review Checklist(s) and Hydraulic Design Data Table provided in *Appendix A* after reviewing this section. For replacements or retrofits, designers must complete checklist *A.1* (Existing) and *A.2* (Proposed). For new crossings, designers only need to complete checklist *A.2*. **The Road-Stream Crossing Standards Review Checklist(s) and Hydraulic Design Data Table must be included as part of the 30% Design Submission to the RIDOT Environmental Division**.

### 4.2.1 Design Approach

To achieve the Optimal Standard, a crossing must be designed using the Stream Simulation approach outlined by the U.S. Forest Service (FSSWG, 2008). Stream Simulation is the preferred design approach for road-stream crossings because it is most likely to allow for unrestricted movement of aquatic and terrestrial species and mimic characteristics similar to the natural channel. To achieve the Base Standard, a crossing must be designed using AOP Design or Modified Hydraulic Design, discussed in detail in *Section 3*.

An existing crossing with a high (>0.66) Scaled Crossing Priority Score (*Assessment Handbook: Section 13*) indicates an existing crossing creates a significant barrier to AOP and/or is more likely to fail. RIDOT recommends that existing crossings with a Scaled Crossing Priority Score >0.66 meet the Optimal Design Approach Standard by using the Stream Simulation approach to provide greater overall benefits related to flood resiliency and stream continuity.

### 4.2.2 Structure Type

To achieve the Optimal Standard, a bridge or open-bottom structure must be used to minimize impacts to stream geomorphology, sediment and debris transport, organism passage, and maintain the natural channel bed. An open-bottom structure spanning the stream and its banks is considered the preferred Optimal Standard because it maintains the original natural channel bed with limited alteration or disturbance. Depending on the span of the crossing, the structure may also accommodate valley and floodplain processes during the most extreme hydraulic events. To achieve the Base Standard, a crossing structure can be a pipe or box culvert with sufficient embedment of natural substrate (see *Section 4.2.6*). If possible, a crossing structure must maintain natural stream banks within the crossing (original banks or reconstructed) including wildlife benches for semi-aquatic and terrestrial animal passage. See *Section 4.2.9* for further discussion of wildlife bench recommendations. For crossings located on a smaller (less than 10 feet), rural roads, guardrail should be considered to prevent car wash-out during more frequent overtopping events.

An existing crossing with a Binned Overall Geomorphic Impact Score ≥3 (*Assessment Handbook: Section 8*) indicates that a crossing is currently impacting or has a high potential to impact geomorphic processes that threaten the structure itself, other adjacent infrastructure, or aquatic organism passage. RIDOT recommends that existing crossings with a Binned Overall Geomorphic Impact Score ≥3 meet the Optimal Structure Type Standard as the structure and surrounding area will likely significantly benefit from an open bottom that allows for natural geomorphic processes.

### 4.2.3 Channel Velocities

To achieve the Optimal Standard, the flow velocities at a crossing must within the swimmable range of the target aquatic species present in the channel. If there are no applicable aquatic target species within the waterway, the flow velocities at a crossing must be comparable to the reference reach channel at bankfull flow and range of baseflows to achieve the Optimal Standard. When a target aquatic species is known, the Optimal Standard requires an AOP study, which at a minimum compares the swimming velocities of any known species to base flow velocities of the proposed design. Specially, the maximum flow velocity at the crossing during baseflows must be swimmable by the weakest target species during migration periods. An AOP study is required within defined cold-water fisheries, diadromous fish habitat, or when otherwise required by the RIDOT Environmental Division. The swimming speeds of common *Atlantic Coast diadromous fish species* are included in *Appendix F* (Turek et al., 2016).

To achieve the Base Standard, the flow velocity within a stream crossing must be comparable to the natural channel at bankfull flow and a range of baseflows and does not require an AOP study. Regardless of the level of standard achieved, the channel must be designed with a five-point cross section to mimic low flow depths of the natural channel, further discussed in *Section 4.2.6* below. Maintaining natural channel velocities that support aquatic organism passage also allows for the movement of sediment and debris for increased habitat continuity. Channel velocities also impact the channel stability and structural stability as a factor for potential scour. See *Section 4.2.10* for further discussion of structural stability design criteria.

### 4.2.4 Climate Change

*Table 3* describes the requirements for accounting for climate changes as part of the crossing design. This Manual requires the proposed design to pass the future Design Storm according to the span and the highway functional classification of the roadway (i.e., frequency and type of road use). Climate change projections are updated as frequently as every year, and therefore, the most recent applicable information available should be used to meet the future hydraulic requirements of a stream crossing. The designer must research and utilize the most applicable and up-to-date sea level rise (if tidally influenced) and increased precipitation projections for the project location. This Manual provides the required projection horizon to be used for sea level rise or precipitation projection data. A projection horizon is how far ahead in the future the crossing must be designed to, based upon the planned construction year. For example, if the crossing is a 15-foot span Rural Major Collector with a planned construction year of 2025 and a service life of 75-years, then the Climate Change Projection Horizon is 75-years, and the designer must find the most applicable and up-to-date sea level rise and increased precipitation projections for the year 2100 and design the crossing to pass the 2100 4% AEP tidal event (if tidally influenced) and the 2100 4% AEP precipitation event. This Manual assumes the crossing service life of culverts and bridges to be 75-years, based upon the American Association of State Highway and Transportation Officials (AASHTO) LRFD Bridge Design Specifications (2020). If a crossing is atypical (e.g., a temporary bridge or structure specifically designed for a longer service life), then the designer may use an alternate service life.

At the time of this Manual publication, there are no Rhode Island specific projections for increased precipitation. As such, this Manual has developed an alternate approach to account for increased precipitation due to climate change based upon the studies completed in the surrounding region. If location-specific precipitation projections become available for Rhode Island, then the designer must design based on the Climate Change Projection Horizon provided in *Table 3*. Under the condition that no Rhode Island specific projections for increased precipitation are available, the crossing must be designed to pass the Climate Check Event according to the span and highway functional classification of the roadway provided in *Table 3*.

The Climate Check Event is based upon the review of other regional approaches to climate change and precipitation changes. RIDOT reviewed the approach by New York State to downscale projections of extreme rainfall and Massachusetts Department of Environmental Protection (MassDEP)'s approach, known as NOAA14 PLUS. The New York State approach is based upon downscaled projections of future global extreme rainfall, modified for the New York region (DeGaetano, 2017). The NOAA14 PLUS approach utilizes the upper limit of the current day NOAA Atlas 14 precipitation depths multiplied by 90% for future storm depths (MassDEP, 2020). The Climate Check Events provided in *Table 3* align with the determinations of both approaches.

Below is a list of reputable sea level rise and precipitation projection sources that should be included in the designer's research:

- Rhode Island Coastal Resources Management Council (RI CRMC)

- *Coastal Hazard Application Worksheet and Online Viewer*
- The State of Rhode Island Climate Change Office
- National Oceanic and Atmospheric Administration (NOAA)
- Northeast Climate Adaptation Science Center (NECASC)
- Intergovernmental Panel on Climate Change (IPCC)

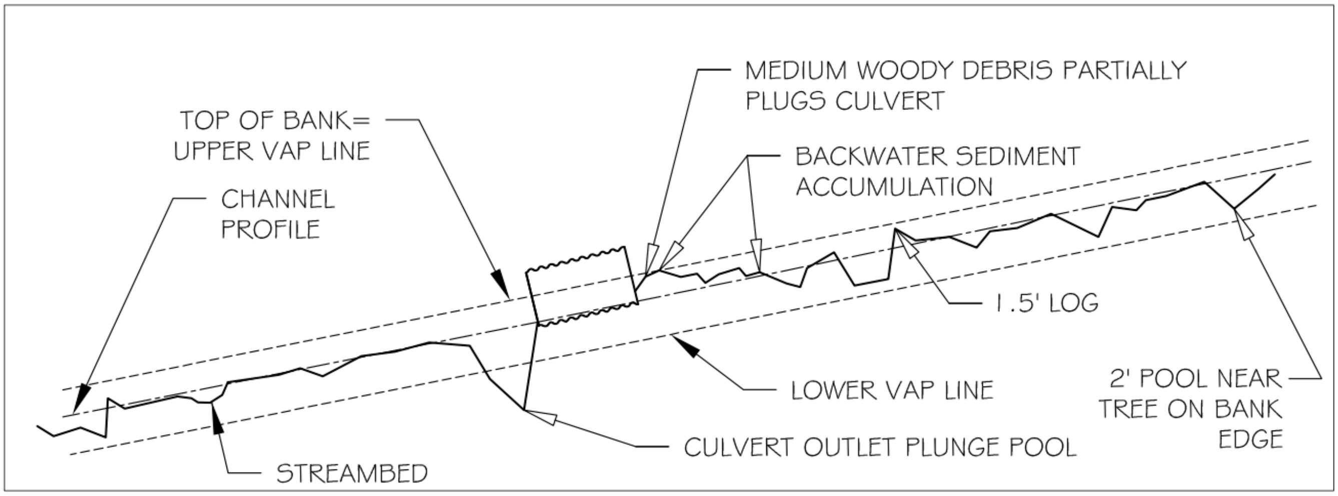
Climate Change projections often provide a range of scenarios for time horizons. RIDOT recommends the design utilizes the high (or equivalent) scenario at a minimum. Other applicable sea level rise and precipitation projection sources may be used if available after the publication of this Manual. If a crossing is not in a tidally influenced area (see Tidal/ Coastal Modeling below), only precipitation changes need to be considered.

### 4.2.5 Crossing Profile

To achieve the Optimal Standard, the crossing profile design must be based on a suitable reference reach that the designer has determined to be naturally stable based on the morphology (FSSWG, 2008). The profile must be designed using the vertical adjustment potential (VAP). The VAP is range of potential vertical streambed adjustment (due to erosion or deposition). The upper and lower VAP lines represent respectively the highest and lowest likely elevations of any point on the streambed surface (FSSWG, 2008). See *Figure 4-1* for an example below. By matching the vertical profile of a crossing structure to the natural stream, the structure has a greater likelihood of achieving similar flow velocities of the natural channel and accommodating bed material movement and future bed profiles. This may require adjustment of the existing inlet and outlet elevations, and potentially grading upstream and downstream of the crossing to match the slope of the reference reach. The horizontal profile of the crossing must also match the existing stream and banks to ensure slope stability and allow for AOP. To achieve the Base Standard, the road-stream crossing profile must match the existing natural stream grade upstream and/or downstream of the crossing location, but does not require use of a reference reach or determining the VAP.

For replacement crossing projects, further evaluation is needed to provide a design that will not disrupt stream stability and potentially cause unstable vertical profile movement. In certain locations, matching the natural stream profile may not be possible and should match to the maximum extent practicable, with approval from the RIDOT Environmental Division.

**Figure 4-1: The vertical adjustment potential (VAP) for a uniform streambed profile**




*© FSSWG, 2008*

An existing crossing with a *Binned Aquatic Passability Score ≥3* (*Assessment Handbook: Section 12*) indicates that a crossing creates a moderate to severe barrier for AOP that can be caused by issues relating to the crossing profile. RIDOT recommends that existing crossings with a *Binned Aquatic Passability Score ≥3* meet the Optimal Crossing Profile Standard by redesigning the crossing to match the longitudinal profile of the natural stream channel at a reference reach, so long as this can be done without impacting the overall stream stability.

### 4.2.6 Embedment, Substrate, and Channel Stability

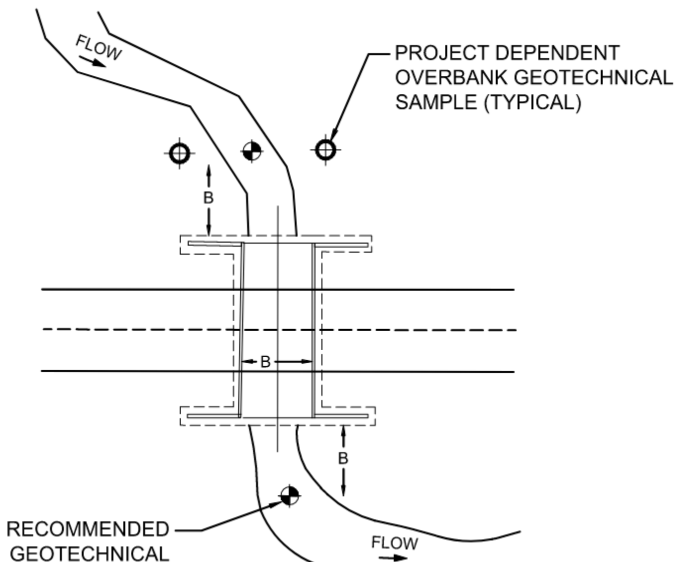
To achieve the Optimal Standard, all open-bottom crossing structures must have a minimum of 1 foot of natural substrate material above any required scour protection material and must include a grain size analysis and bed mobility/scour stability analysis. If there are target aquatic species present in the waterbody, the minimum flow depth during baseflows must also be at least 1.5 times the maximum body height of the largest target aquatic species to allow for species migration. The minimum recommended channel depths for common *Atlantic Coast diadromous fish species* are included in *Appendix F* (Turek et al., 2016). To achieve the Base Standard, all closed-bottom crossings greater than or equal to 8 feet in span must have a minimum embedment of 2 feet and crossings less than 8 feet in span must have a minimum embedment of 25% of the opening height. The channel cross section within the crossing must be designed to mimic low flow depths of natural channel.

Embedment with natural substrate in a crossing structure is based on the Stream Simulation design approach and allows for natural movement of bedload and formation of a stable bed inside the stream crossing without exposing or undermining the crossing structure. Embedment also provides adequate ecosystem connectivity and wildlife accessibility to both sides of the stream crossing. The substrate within all stream crossings must match the characteristics of the natural stream channel and the banks (mobility, slope, stability, confinement, grain and rock size) to ensure materials will migrate naturally under normal flow conditions. For new closed-bottom crossings (e.g., a pipe/box culvert), the natural channel substrate should be set aside during construction and placed or washed back into the structure upon completion. When completing hydraulic modeling for an embedded crossing, the hydraulic opening of the crossing should be the opening height, minus the embedment depth. For example, if a proposed culvert is 6 feet in height with 2 feet of embedment, the hydraulic opening in the model should be 4 feet. Hydraulic modeling and geotechnical analysis provide direction on foundation requirements and site-specific scour mitigation measures.

Grain size analysis and bed mobility/scour stability analysis for streambed material (not foundation material) should be performed based on guidance outlined by the FHWA's Hydraulic Engineering Circular Nos. 18 (HEC-18), HEC-20, HEC-23, and HEC-25 (2012; 2012; 2009; 2008). The designer should also review the NCHRP abutment scour approach and the HEC-14 guidance for energy dissipators for culverts (Ettema et. al., 2010; FHWA, 2006). *Figure 4-2* below illustrates recommended geotechnical sampling locations. Recommended sample locations may vary based upon the crossing opening design (see "Project Dependent Overbank Geotechnical Sample" on *Figure 4-2*). At a minimum, the designer must obtain the "Recommended Geotechnical Sample" locations upstream of the crossing, downstream of the crossing (as shown on *Figure 4-2*), and the upstream face of piers. Depending on the needs of the scour analysis, the geotechnical analysis should determine the grain size of the $D_{16}$, $D_{50}$, and $D_{84}$ based upon the American Society for Testing and Materials (ASTM) D6913, D7928 standards (or AASHTO T88), or USFS Pebble Count. The samples should obtain the erodible subsurface material immediately below any armor layer.

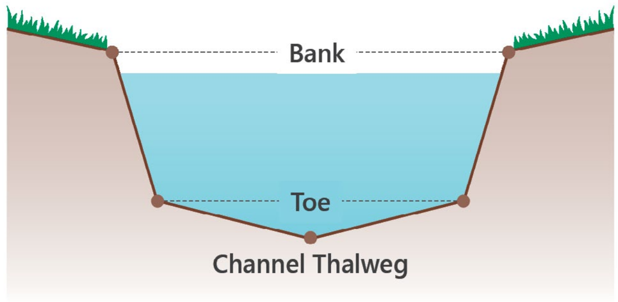
In accordance with the RIDOT LRFD Bridge Design Manual, new crossings with spans greater than 20 feet cannot use riprap or other scour countermeasures as a means of scour protection; all foundations, piers, or abutments must be designed to withstand the conditions of scour for the design flood and the check flood (2007).

## **Figure 4-2:** Recommended Soil Samples Locations




Many aquatic organisms travel during low flow conditions accommodated by a five-point cross section, see *Figure 4-3* below. The embedment and substrate of the proposed channel must be designed and constructed to mimic the natural channel cross section shape and low flow depths and velocities for both Optimum and Base Standards. As described above, the minimum flow depth at the channel thalweg must be at least 1.5 times the body height of the largest target species to achieve the Optimal Standard.

## **Figure 4-3:** Five Point Cross Section




If the project includes the replacement of an existing structure and/or substructure which interferes with the proposed design, such as existing piers, abutments or wingwalls, the existing structure and/or substructure must be removed to 2 feet below the streambed (or natural ground surface) at that location or below VAP line, whichever elevation is lower.

An existing crossing with a *Binned Aquatic Passability Score ≥3* (*Assessment Handbook: Section 12*) indicates a crossing may have partial or no substrate coverage or the substrate does not match the characteristics of the natural streambed. Additionally, if an existing crossing has a *Binned Overall Geomorphic Impact Score ≥3* (*Assessment Handbook: Section 8*) the crossing may significantly benefit from upgrade to an open-bottom structure to allow for natural geomorphic processes and would maintain the natural channel substrate. RIDOT recommends that crossings with a *Binned Aquatic Passability Score ≥3* or a *Binned Overall Geomorphic Impact Score ≥3* meet the Optimal Standard by using open-bottom crossing structures with ≥1 foot of natural substrate material above any required scour protection material and by including a grain size and bed mobility/scour stability analysis.

### 4.2.7 Hydraulic Modeling

To achieve the Optimal Standard, the designer must model the hydraulic capacity using U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Center—River Analysis System (HEC-RAS) or conduct an equivalent riverine analysis. The analysis must evaluate any potential downstream impacts when replacing an existing culvert with a new design, which may cause flooding, erosion, or failure of downstream structures. To achieve the Base Standard, the hydraulic capacity of a proposed crossing can be modeled with programs such as HydroCAD, CulvertMaster, or HY-8 Culvert Hydraulic Analysis Program, or equivalent software. The hydraulic analysis must utilize an applicable rainfall-runoff model, regional flood-flow regression equations, or statistical analysis of peak-flow records at representative stream gages to determine associated flood flows at the crossing. Detailed steps for determining hydrologic inputs using StreamStats and other appropriate methods to estimate peak flows are summarized in the *Assessment Handbook: Section 5.3*. When precipitation inputs are required, the designer must use best available data and confirm compliance with RIDEM Section 250-RICR-105-10 Part 8—Stormwater Management, Design and Installation Rules. At the time of publication of this Manual, RIDEM requires precipitation data to be sourced from Cornell University's Northeast Regional Climate Center (NRCC).

At existing crossings, the hydraulic analysis must model flows through the existing and proposed crossing to confirm the proposed structure will not worsen flow or velocity conditions. The results from this analysis can be used to identify the required structure size and configuration, as well as channel modifications that are required to protect the structure and adjacent infrastructure from damage during high flow events. The velocity results from the hydraulic analysis are used to confirm flows within the crossing are within the swimmable range of target species (see *Section 4.2.3*. Channel Velocities).

**All structures** must meet the minimum freeboard and design storm requirements based on the span and the highway functional classification as shown in *Table 3*. If a project is unable to meet requirements outlined in *Section 4.1* and in *Table 3* based on the project's specific needs and constraints, the project may pursue a waiver with the approval of the RIDOT Environmental Division. The crossing structure must also comply with any applicable Federal Emergency Management Agency (FEMA) requirements for floodplain areas, including evaluation of potential effects to the base flood and associated floodway elevations (referred to as a "No-Rise Certification").

An existing crossing with a *Binned Transportation Disruption Score ≥3* (*Assessment Handbook: Section 11*) is at a roadway that likely serves as a hurricane evacuation route, E-911 primary route, or is a principal arterial or high-traffic roadway. RIDOT recommends that existing crossings with a *Binned Transportation Disruption Score ≥3* meet the Optimal Hydraulic Design Standard by modeling the existing and proposed crossing with HEC-RAS (or equivalent analysis) and by meeting the hydraulic requirements listed in *Table 3*.

### 4.2.8 Openness Ratio

To achieve the Optimal Standard, a crossing structure must have an openness ratio greater than or equal to (≥) 1.64 feet and a height ≥6 feet. If conditions significantly inhibit wildlife passage, such as roads with frequent deer-vehicle collisions, designers must achieve an openness ratio ≥ 2.46 feet and a height ≥ 8 feet[11] (River and Stream Continuity Partnership, 2001). To achieve the Base Standard, a crossing structure must have an openness ratio ≥ 0.82 feet to the maximum extent practicable.

11 Openness standards for larger terrestrial passage are primarily based on a study by Reed et al. in 1979, which concluded that 0.6 meters (2.0 feet) is the minimum openness needed for mule and whitetail deer to use a structure.

Openness is the cross-sectional area of a structure opening (not including the embedded area) divided by its crossing length. See *Equation 4-1* below:

### Equation 4-1

$$\text{Openness Ratio} = \frac{\text{Cross-Sectional Area}}{\text{Length}}$$

The goal of achieving the Base or Optimal Openness Ratio Standard for a stream crossing is to provide dry passage for semi-aquatic and small terrestrial wildlife.[12] Greater openness not only allows larger animals to pass through the structure but creates adequate natural illumination, increasing the likelihood animals will use the crossing for passage. Structures that meet the Base or Optimal Openness Ratio Standard are also more likely to pass flood flows and woody debris that would otherwise obstruct water passage.

An existing crossing with a *Binned Aquatic Passability Score ≥4* (*Assessment Handbook: Section 12*) indicates that a crossing creates a significant to severe barrier for AOP. RIDOT recommends that existing crossings with a *Binned Aquatic Passability Score ≥4* meet the Optimal Openness Ratio Standard to improve wildlife passage and accommodate larger terrestrial and semi-aquatic species.

### 4.2.9 Stream Crossing Span

To achieve the Optimal Standard, the crossing structure must have a hydraulic span of a minimum of 1.2 times the natural bankfull width (BFW) with banks on both sides designed to allow for dry passage of semi-aquatic and terrestrial wildlife.[13] The bankfull flow and width of a stream should be determined based on the methodology outlined in the *Assessment Handbook: Section 3.5.2*. To achieve the Base Standard, the crossing structure must have a hydraulic span of a minimum of 1.2 times the natural BFW with defined banks on both sides. For the Base Standard, however, the banks within the structures do not need to be specifically designed for semi-aquatic and terrestrial wildlife (see specifics on wildlife bench design below) but must be constructed at the same slope and elevation of the upstream and downstream banks, such that there is clear connectivity. See *Equation 4-2* below:

### Equation 4-2

$$\text{Span} = 1.2 \times \text{BFW}$$

Example of bridge spanning the natural banks to allow for floodplain processes on the Woonasquatucket River

12 The United States Army Corps of Engineers New England District, Connecticut, Maine, Massachusetts and New Hampshire all require or recommend the same minimum openness ratio (≥ 0.82 feet) (U.S. Army Corps of Engineers, 2015; Connecticut Dept. of Environmental Protection, 2008; Greenwood, 2017; Massachusetts Department of Fish and Game Division of Ecological Restoration, 2018; University of New Hampshire, 2009).

13 This design criterion was first introduced in Washington State in 2003 and based on a study that observed structures 1.3 times the channel BFW to replicate natural stream processes and create similar passage conditions (Barnard, 2003). Similarly, wide-spanning culverts and open-bottom structures with widths greater than the natural BFW were found to provide a buffer against lateral and vertical stream adjustments (Bates, 2003). Many states and agencies have since found that using a span of 1.2 times BFW, compared to Barnard's result of 1.3, is sufficient to replicate natural stream processes and permit organism passage (Connecticut Dept. of Environmental Protection, 2008; Greenwood, 2007; Massachusetts Department of Fish and Game Division of Ecological Restoration, 2018; National Marine Fisheries Service, 2018).

Crossings should aim to span the natural channel and minimize surrounding disturbance. The designer should balance these two goals by shortening and aligning the crossing perpendicular to a straight segment of the stream channel or by skewing the crossing alignment to mimic the stream alignment. RIDOT recommends the designer follow Chapter 6 of the USFS Stream Simulation to provide the most resilient design for the stream and associated wildlife (FSSWG, 2008). The USFS Stream Simulation Design Approach is the requirement for the Optimal Standard of the Design Approach (summarized in *Section 3.1* and *Table 2*). *Figure 4-4* presents three alignment options for the most common alignment challenge, where the road is at an acute angle to the stream channel:

As shown in *Figure 4-4* Option C, there are cases where the best way to accommodate the stream alignment and reduce span length is to widen the crossing. This may result in a crossing that is larger than 1.2 times the bankfull width. Of the options above, Option B entails the greatest risk to channel instability by altering the natural streamflow path.

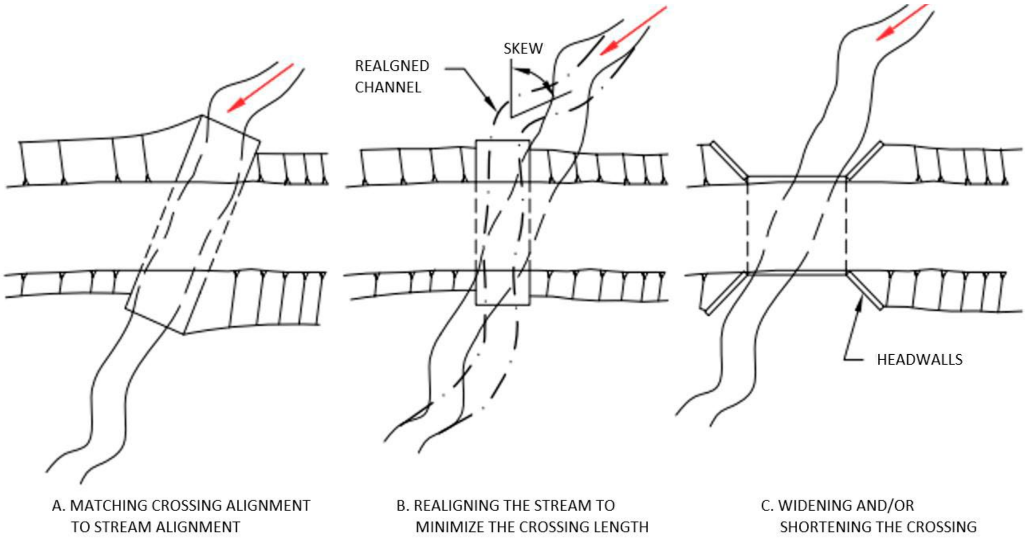
Example of wildlife bench ©*Minnesota Department of Natural Resources*

Properly designed wildlife benches can significantly improve road safety by reducing the number of animal-vehicle collisions (Peterson & McAllister, 2013). The following language details best practices for the design of wildlife benches:

- If feasible given the crossing span, wildlife benches should be a minimum of 3 feet wide and should be slightly above the bankfull elevation to prevent wash-out (Minnesota DNR, 2014).

*continued on next page*

## **Figure 4-4**: Alignment options for crossing where the road crosses the stream at an acute angle




*© Image adapted from USFS Stream Simulation (FSSWG, 2008)*

- The wildlife benches should be graded to meet the existing banks upstream and downstream of the crossing and should consist of native bank material and vegetation, whenever feasible.
- Native seeding or planting is particularly important on steep slopes near wildlife benches for reducing erosion and can provide shade, moisture, and cover for species. If the wildlife benches are constructed of larger stones or riprap for structural purposes, smaller material that is similar to the natural channel banks should be used to fill in the voids to create a walkable surface for wildlife passage, especially for hoofed animals and smaller species (e.g. non-stream dwelling salamanders).
- A stream crossing's value as a wildlife underpass can be further increased when fencing is constructed in a way that funnels animals into the crossing structure. This has been determined to be a very cost-effective method in reducing animal-vehiclecollisions (Clevenger et al., 2001; Huijser et al., 2007). However, the fencing may not always be appropriate for a project site and should be evaluated for potential impacts to a floodway for example. Additional wildlife fencing information and design elements may be found in the FHWA Wildlife Crossing Crossing Structure Handbook (Clevenger and Huijser 2011).
- For projects where new abutments are placed behind existing abutments that are infeasible to remove, the existing abutment surface can be cut to the appropriate elevation and covered with natural bank material to encourage wildlife passage.
- The wildlife bench design should also consider height of the animal for which it's designed. For example, roads in areas with significant deer populations should be designed with appropriate clearance to accommodate the height of deer, if feasible given the stream and roadway elevations.

An existing crossing with a *Binned Flood Impact Potential Score ≥3* (*Assessment Handbook: Section 10*) indicates that if the crossing fails, it's likely there will be severe impacts on existing infrastructure upstream and downstream of the crossing. These crossings usually constrict the natural channel or are in highly developed areas. RIDOT recommends that existing crossings with a *Binned Flood Impact Potential Score ≥3* meet the Optimal Standard of 1.2 times BFW with wildlife benches on both sides to allow for natural floodplain processes and terrestrial and semi-aquatic wildlife passage.

### 4.2.10 Structural Stability

All crossing structures must be designed in accordance with RIDOT and AASHTO LRFD standards. A crossing's structural design accounts for appropriate loading, span configuration, wingwall layout and design, and footing design. Hydraulic modeling and geotechnical analysis provide direction on foundation requirements and site-specific scour mitigation measures.

All existing crossings must be designed in accordance with the RIDOT and AASHTO standards. *The Binned Structural Condition Score* (*Assessment Handbook: Section 10*) may indicate areas of structural failure that must be closely examined and/or analyzed in more detail during the re-design process.

### 4.2.11 Tidal/Coastal Modeling

To achieve the Optimal Standard, tidally influenced crossings must have velocities comparable to the natural channel during the ebb and flow during high tide or maximum flow conditions and low tide/low flow conditions using a detailed hydraulic modeling analysis, such as an unsteady HEC-RAS model (or equivalent) with the inclusion of an AOP study. To achieve the Base Standard, tidally influenced crossings must be designed to accommodate the exchange of the full tidal prism without significant restriction using a simplified quantitative volume analysis (e.g., spreadsheet). Designers should also be aware that tidally influenced crossings experience greater variability in water levels, velocity, salinity, dissolved oxygen, temperature, and pH compared to non-tidal crossings. Tidally influenced crossings, like all other crossing structures, must meet the hydraulic requirements in *Table 3*, including freeboard. The designer may need to determine which water inflow (tidal or riverine) source governs the flow through the crossing, to choose the appropriate standards and modeling method.

Many existing tidal crossings currently restrict flow and therefore limit upstream water surface elevations. Replacing tidal crossings that restrict flow may unintentionally alter water surface elevations, jeopardize valuable habitats, or create flooding hazards. The introduction of salt water in areas where flow was previously restricted must be evaluated based on the project goals. Natural tidal flushing may be desired for some projects but may also cause marsh migration, changes in animal habitats or behavior (e.g. shorebird nesting areas), and saltwater intrusion. These potential impacts must be analyzed for risk and regulatory compliance before upgrading a crossing.

A crossing is considered tidally influenced if it is presently located waterward of the Rhode Island Mean Higher High Water (MHHW) line. To determine if a crossing is tidally influenced, the crossing location can be compared to the MHHW line from the Rhode Island Geographic Information System (RIGIS) open GIS data distribution clearinghouse or by using the StormTools application from the Rhode Island Coastal Resources Management Council (*Assessment Handbook: Section 2.3.2*). Tidal data for stations in Rhode Island is available from NOAA's Tides and Currents website. As discussed in *Section 4.2.4* Climate Change and *Table 3*, sea level rise projections must be considered for all crossings.

An existing crossing with a *Binned Climate Change Vulnerability Score* ≥*3* (*Assessment Handbook: Section 7*) indicates the crossing is undersized for future climate conditions, including peak flow rates, sea level rise, and storm surge. RIDOT recommends that existing crossings with a *Binned Climate Change Vulnerability Score* ≥*3* meet the Optimal Tidal/Coastal Modeling Standard using a detailed hydraulic modeling analysis.

### 4.2.12 Reporting Requirements

The following submittals are required as part of the RIDOT 30% Design Submission for all road-stream crossings to be reviewed and approved by RIDOT Environmental Division:

- Geotechnical Investigation
- Hydrologic and Hydraulic Computations
- Road-Stream Crossing Standards Review Checklist(s) (provided in *Appendix A*)
    - For replacements or retrofits, complete *A.1* and *A.2*. For new crossings, complete only *A.2*.
- Hydraulic Design Data Table (provided in *Appendix A*)
- The applicable Conceptual Design Figure (provided in *Appendix B*)
- Road-Stream Crossing Report (template provided in *Appendix C*)

The Road-Stream Crossing Report must summarize the results of the H&H analysis for the proposed structure. The Road-Stream Crossing Report should also include an operation and maintenance (O&M) plan to ensure safety and proper function of the crossing over the structure's lifetime (e.g. inspection frequency, debris removal, regrading, etc.). All reports, drawings, and computations must be prepared and stamped by a Rhode Island Registered Professional Engineer. All crossings must be designed in accordance with the Reporting Requirements Standard in *Table 2*, regardless of the scores from the *Assessment Handbook*.

## 4.3 Existing Crossing Upgrades: Replacements and Retrofits

Many existing road-stream crossings in Rhode Island were designed and installed without considering AOP and stream connectivity. The existing conditions and potential consequences from changes in flow should be examined prior to replacing or retrofitting a crossing. A common unintended consequence of upgrading a crossing that previously restricted flow is that a larger crossing may unintentionally raise water surface elevations downstream, potentially causing flooding hazards. This potential result must be analyzed for risk and regulatory compliance before upgrading a crossing. Upgrading a crossing may also cause headcutting upstream of the replaced crossing, as previously aggraded sediment becomes mobilized. The extent of potential headcutting should be determined as headcutting may travel upstream and can be substantial enough to affect buried infrastructure, destabilize streambanks, or modify aquatic habitats (FSSWG, 2008). If it is determined that the benefits of retrofitting or replacing a crossing are greater than the cost of the project, potential environmental consequences, and are within regulatory allowances, then the crossing should be upgraded.

An existing crossing with a *Hydraulic Capacity Score* of 5 (*Assessment Handbook: Section 6*) indicates the crossing should be replaced, not retrofitted. A score of 5 indicates a crossing is not capable of passing the 10% AEP storm event and a retrofit is unlikely to achieve the flood frequency requirements listed in *Table 3*. A *Binned Structural Condition Score ≥3* also indicates a crossing is likely to fail during a flood event and may need replacement if repair or retrofit is not sufficient.

### 4.3.1 Replacement

Road-stream crossing replacement may include replacing a structure in-kind or redesigning the structure for improved performance. When replacement is desirable, the design must meet the Optimal Standards. If a replacement project is unable to meet Optimal Standards due to project or site constraints, the project must be designed to the Base Standards or the Base Standards to the maximum extent practicable (MEP) with approval from the RIDOT Environmental Division.

A crossing should be replaced:

- If a crossing is structurally poor, degraded, or has failed
- If a crossing is undersized for the design flows listed in *Table 3*
- If a crossing cannot be retrofitted to allow wildlife passage
- If replacement will not impact critical wetlands or create flooding impacts

### 4.3.2 Retrofit

Road-stream crossing retrofit should be considered if an existing crossing meets (and would meet following the proposed retrofit) the flood frequency requirements based on the highway functional class (see *Table 3*). Retrofitting a crossing may include modifications to improve AOP such as grade controls, baffles, weirs, and other support structures. Slip-lining a culvert (inserting a new, smaller piece of pipe into the larger piece) is strongly discouraged because it reduces the openness ratio of the crossing and can exacerbate issues with fish and wildlife passage by increasing flow velocity and perching distance. Depending on the retrofit, the crossing may require more frequent maintenance activities to function as designed. The proposed retrofit design must still allow the crossing to meet the design requirements of *Table 2* and *3*.

A crossing should be retrofitted:

- If a crossing is structurally sound
- If a crossing is sufficiently sized for high flows, including future flows
- If a retrofit will allow wildlife passage
- If replacement will negatively affect critical wetlands or create flooding impacts

## 4.4 Intermittent Streams

Intermittent streams, also called seasonal or ephemeral streams, have active flow during certain times of the year. The flow may occur when the water-table is seasonally high due to precipitation or snow melt, but there will not be flow during drier periods of the year. Road-stream crossings at intermittent streams must adhere to the same Design Standards in *Table 2* and *3* as any perennial crossing to the maximum extent practicable.

In some cases, it may be difficult to determine if a stream is intermittent. RIDEM considers a stream intermittent if it flows long enough each year to develop and maintain a defined channel. According to the USGS, watershed size and geology are the most important characteristics for determining a streams status. The StreamStats application from USGS incorporates watershed size and geology into its calculations and can be used to determine the probability that a stream is intermittent or perennial (flows on a year-round basis). If a stream site's upstream drainage area is less than 0.50 square miles, the stream should always be classified as intermittent. If the upstream drainage area is between 0.50-1.00 square miles, the stream should be classified as intermittent, with one exception. If flow duration statistics from StreamStats at the stream location predict a flow rate greater than or equal to 0.01 cubic feet per second at the 99% flow duration rate, the stream is considered perennial, not intermittent (Bent & Steeves, 2006).

Intermittent streams located in small watersheds (<0.50 square miles) but with well-defined banks for determining the BFW, or streams illustrated as a Blue Line on USGS Quadrangle Topographic maps, should aim to meet the Optimal Standards. For intermittent streams without bank definition, the Design Standards must be met to the maximum extent practicable with approval from the RIDOT Environmental Division

# Section 5: Permitting Agencies

This section of the Manual provides a brief overview of the potential agencies that require review or permitting for a stream crossing project. As discussed previously, this Manual is not intended to guide the user through permits that may be required for each project. See the *Assessment Handbook: Section 14.3* for additional guidance. *Table 4* below provides a list of regulatory agencies that may require a project to be reviewed or obtain a permit:

### **Table 4**: Permitting Agencies

| Regulatory Agencies | |
|---|---|
| Federal | • Environmental Protection Agency (EPA)<br>• Federal Emergency Management Agency (FEMA)<br>• National Flood Insurance Program (NFIP)<br>• National Marine Fisheries Service (NMFS)<br>• National Park Service (NPS)<br>• United States Army Corps of Engineers (USACE)<br>• United States Coast Guard (USCG)<br>• United States Fish and Wildlife Service (USFWS) |
| State | • RI Coastal Resources Management Council (RI CRMC)<br>• RIDEM Freshwater Wetlands Program<br>• RIDEM Office of Water Resources<br>• Rhode Island Emergency Management Agency (RIEMA) |

As noted above, RIDOT recommends the designer schedules a preapplication meeting with relevant agencies, specifically RIDEM and USACE, early in the design process to allow for comment on the project intent as early as possible. Preapplication meetings will help to balance the goals of a project with regulatory requirements, especially for new crossings. These meetings can reduce back-and-forth between agencies, lead to a better stream crossing design, can result in faster construction time, and reduced project costs.

It should also be noted that some projects may need to meet standards that are stricter than the Design Standards presented in this Manual, if required by an applicable regulatory agency. These standards may include specific design criteria, conservation recommendations, and TOY restrictions. At a minimum, designers should review the TOY restrictions included below as well as the additional encroachment restrictions applied to work in tidal waters and non-tidal diadromous streams required by NMFS, USACE, and RIDEM. Encroachment activities are applied to projects that will require in-water soil erosion, sediment, and turbidity controls and may vary depending on the project location and time of year. TOY restrictions and proposed in-water controls should be discussed with the project's regulating agencies during design.

### **Table 5**: Time-of-Year Restrictions

| Regulating Group | TOY Restriction |
|---|---|
| NOAA: NMFS/FHWA | Rhode Island:<br>Winter Flounder: February 1 to June 30<br>Diadromous Fish: March 15 to June 30 and September 1 to November 30*<br>Shellfish: May 1 to October 14<br>(NOAA's National Marine Fisheries Service, 2018) |
| USACE | Rhode Island General Permits:<br>Unconfined, in-stream work, not including installation and removal of cofferdams, is limited to the low-flow period, July 1 through October 31 unless RIDEM requires different resource-driven time of year restriction (U.S. Army Corps of Engineers New England District, 2018). |
| RIDEM | RIDOT recommends discussing this topic during the project's preapplication meeting |

**All diadromous areas: Use the fall TOY restriction in cases where an action will substantially block the waterway in the fall.*

# Section 6: Final Design and Next Steps

This section of the Manual described the final steps required for completing and submitting a stream crossing design. The final crossing design should balance hydraulic and ecological objectives with crossing safety, life cycle cost, and other project or site constraints. All projects must be in accordance with State and Federal regulations. Once a design is complete, designers must submit the required plans and documents listed in *Section 4.2.12: Reporting Requirements*. After approval, the next steps include construction, inspection and long-term maintenance, outlined in this section below.

## 6.1 Construction Dewatering

During construction activities, streamflow should be managed to minimize impacts to the streambed, surrounding environment, and aquatic animals. If a structure has an open bottom, the stream should remain free flowing during installation when possible. If the project requires working “in the dry,” flow will need to be diverted or dammed, usually with a cofferdam. Cofferdams vary in design but act as a barrier to flow and are pumped out or otherwise dewatered after the dam is built, keeping the work area relatively dry until construction is complete. Diversion of flow may be preferred depending on the project and can be achieved with pipes, ditches, or other barriers. Pumped diversions may be appropriate for projects with low flows and a short duration but can cause high turbidity when pumped directly downstream and prevent upstream aquatic organism passage (Axness, 2013). Designers and planners should recommend a flow management technique in order to protect aquatic organisms and other resources based on the project. As mentioned in Section 5, any applicable TOY and encroachment restrictions should be discussed with the project’s regulating agencies.

## 6.2 Operation and Maintenance (O&M)

The project engineers and designers must coordinate with RIDOT to develop an inspection and maintenance plan to implement over the crossing structure’s lifetime. Regular inspection and maintenance of road-stream crossings is essential to ensuring their continued proper function.

<u>Key Items for Construction and Post-Construction Inspection:</u>

- Channel cross section through the crossing mimics the natural channel shape including banks and low flow depths
- Wildlife bench material, if present, is traversable for anticipated terrestrial species and transitions to existing bank grades beyond the crossing
- Natural channel material is present through the crossing installed to minimum required depth
- Native, shade tolerant vegetation is present on slopes disturbed during construction and on banks within the crossing, if applicable
- Inlet and outlet elevations tie into upstream and downstream channel appropriately. Observe for evidence of scour, including formation of scour holes at crossing outlet or inlet, perched inlet/outlet, and washout of natural channel material
- Evidence of organism passage concerns (e.g. roadkill)

<u>Standard O&M Practices:</u>

- Inspect the crossing regularly, especially after heavy rains
- Clear any debris or blockages. Check for beaver damming activities, especially at culverts

- Repair minor stream channel defects through periodic grading or the addition of stone due to erosion from high flows
- Repair of wildlife benches including proper width, grading upstream and downstream of the structure, smaller material over riprap or large rocks, and native vegetation
- Check wildlife fencing (if present) after high flow events and repair any damages immediately
- Maintain all concrete work, rock riprap, grouted rock, flagstone or precast panels
- Immediately repair any vandalism, vehicular, or livestock damage to earthfills, side slopes, spillways, outlets or other appurtenances
- Maintain the roadway surface in a good condition, which includes periodic grading or repair of the surface. Prevent surface ponding by grading to remove depressions

The O&M plan should be developed prior to the final design of a crossing to minimize required maintenance and lifetime costs. The O&M plan for a crossing must be submitted within the Road-Stream Crossing Report (see the template in *Appendix C*). Designers should review the most recent RIDOT Bridge Inspection Manual for information on required inspections on public roadways.

# Section 7: References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# Appendix A:

## RIDOT Road-Stream Crossing Standards Review Checklists

## A.1 Existing Crossing

| | Bridge#_______ and/or Group #________, Roadway Name __________________________, Waterbody Name__________________________ City/Town Name:__________________________ | |
|---|---|---|
| **Design Criteria** | Optimal Standards | Base Standards |
| **Structure Type** | ☐ Bridge<br>☐ 3-Sided Box Culvert<br>☐ Open-Bottom Culvert<br>☐ Arch Culvert<br>☐ *Binned Overall Geomorphic Impact Score ≥3* | ☐ Pipe Culvert with Embedment<br>☐ Box Culvert with Embedment |
| | ☐ Existing crossing does not meet Base or Optimal Standards. Structure type: ______________________ | |
| **Channel Velocities** | ☐ Velocity within the swimmable range of target species<br>☐ Velocity comparable to reference reach at bankfull flow and range of base flows (if no target species present)<br>☐ AOP study for target species<br>☐ *Binned Aquatic Passability Score ≥3* | ☐ Velocity comparable to natural channel at bankfull flow |
| | ☐ Existing Crossing does not meet Base or Optimal Standards. | |
| **Climate Change** | ☐ Hydraulic capacity designed for sea level rise and/or increased precipitation projections based upon Hydraulic Design Requirements | |
| | ☐ Existing Crossing does not meet Base or Optimal Standards. | |
| **Crossing Profile** | ☐ Crossing profile matches existing natural stream based upon reference reach<br>☐ Profile designed using vertical adjustment potential (VAP)<br>☐ *Binned Aquatic Passability Score ≥3* | ☐ Crossing profile matches existing natural stream grade upstream and/or downstream of the crossing location |
| | ☐ Existing crossing does not meet Base or Optimal Standards. Description of crossing profile: _______________________________________________________ | |
| **Embedment, Substrate and Channel Stability**<br><br>Embedment depth:<br><br>____________________ | ☐ 1 foot (minimum) of natural substrate material above any required scour protection material<br>☐ Channel cross section designed to mimic low flow depths of natural channel<br>☐ Included grain size analysis and bed mobility/scour stability analysis<br>☐ *Binned Overall Geomorphic Impact Score or Binned Aquatic Passability Score ≥3* | ☐ Natural bottom substrate ≥ 2 feet for all structures ≥ 8 feet in span; ≥ 25% of opening height for all spans < 8 feet<br>☐ Channel cross section designed to mimic low flow depths of natural channel |
| | ☐ Existing crossing does not meet Base or Optimal Standards. | |
| **Hydraulic Modeling used for Current Project** | ☐ HEC-RAS<br>☐ Equivalent Software: _____________________<br>☐ *Binned Transportation Disruption Score ≥3* | ☐ HY-8<br>☐ CulvertMaster<br>☐ HydroCAD<br>☐ Equivalent Software:_________________ |
| **Openness Ratio**<br><br>Openness ratio:<br><br>____________________ | ☐ Openness ratio ≥ 1.64 feet and height ≥ 6 feet<br>☐ If conditions significantly inhibit wildlife, openness of ≥ 2.46 feet and height ≥ 8 feet<br>☐ *Binned Aquatic Passability Score ≥4* | ☐ Greater than or equal to 0.82 feet to the maximum extent practicable |
| | ☐ Existing Crossing does not meet Base or Optimal Standards. | |
| **Stream Crossing Span**<br><br>Bankfull width: _______<br>Crossing span: _______ | ☐ Hydraulic span greater than or equal 1.2 x BFW with banks on both sides designed for applicable wildlife passage.<br>☐ *Binned Flood Impact Potential Score ≥3* | ☐ Hydraulic span greater than or equal to 1.2 x BFW with banks on both sides |
| | ☐ Existing crossing does not meet Base or Optimal Standards. | |
| **Structural Stability** | ☐ Designed in accordance with Rhode Island and AASHTO LRFD standards. Structural design includes appropriate loading including streamflow, span configuration and freeboard, wingwall layout and design, and footing design.<br>☐ Unknown | |
| **Tidal/Coastal Guidance** | ☐ Non-tidal<br>☐ Velocity comparable to natural channel during the ebb and flow for high tide or maximum flow conditions and low tide/ low flow conditions based upon a detailed unsteady hydraulic modeling analysis.<br>☐ *Binned Climate Change Vulnerability Score ≥3* | ☐ Non-tidal<br>☐ Designed to accommodate the exchange of the full tidal prism using a simplified quantitative analysis (i.e. spreadsheet) |
| | ☐ Existing crossing does not meet Base or Optimal Standards. | |

## A.2 Proposed Crossing

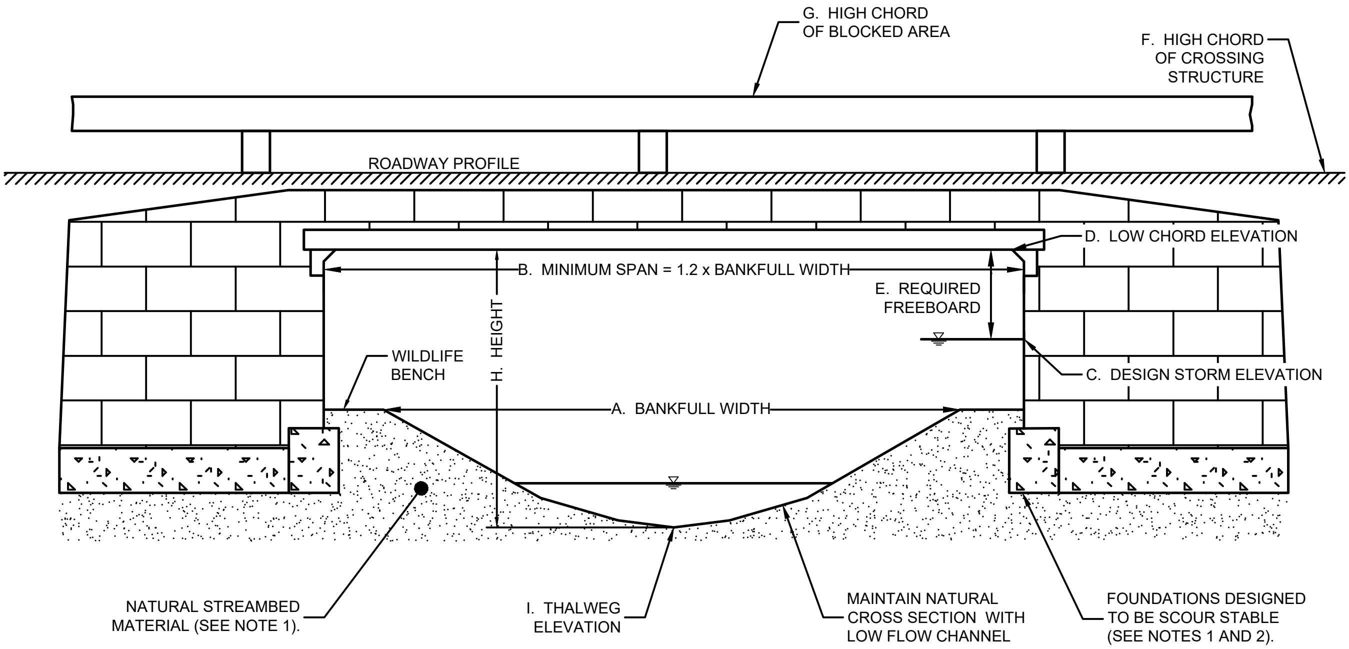
| | Bridge#_______ and/or Group #________, Roadway Name__________________________, Waterbody Name__________________________ City/Town Name:__________________________ | | |
|---|---|---|---|
| **Design Criteria** | Optimal Standards | Base Standards | **Replacement Crossing**: **MEP** Elaborate on reason for MEP within Road-Stream Crossing Report |
| **Design Approach** | ☐ Stream Simulation | ☐ AOP Design<br>☐ Modified Hydraulic Design | ☐ Maximum Extent Practicable |
| **Structure Type** | ☐ Bridge<br>☐ 3-Sided Box Culvert<br>☐ Open-Bottom Culvert<br>☐ Arch Culvert | ☐ Pipe Culvert with Embedment<br>☐ Box Culvert with Embedment | ☐ Maximum Extent Practicable |
| **Channel Velocities** | ☐ Velocity within the swimmable range of target species<br>☐ Velocity comparable to reference reach at bankfull flow and range of base flows (if no target species present)<br>☐ AOP study for target species | ☐ Velocity comparable to natural channel at bankfull flow | ☐ Maximum Extent Practicable |
| **Climate Change** | ☐ Designed for sea level rise and/or increased precipitation projections based upon Hydraulic Design Requirements | | |
| **Crossing Profile** | ☐ Crossing profile matches existing natural stream based upon reference reach<br>☐ Profile designed using vertical adjustment potential (VAP) | ☐ Crossing profile to match existing natural stream grade upstream and/or downstream of the crossing location | ☐ Maximum Extent Practicable |
| **Embedment, Substrate and Channel Stability**<br><br>Embedment depth:<br>____________________ | ☐ 1 foot (minimum) of natural substrate material above any required scour protection material<br>☐ Channel cross section designed to mimic low flow depths of natural channel<br>☐ Includes grain size analysis and bed mobility/scour stability analysis | ☐ Natural bottom substrate ≥ 2 feet for all structures ≥ 8 feet in span; ≥ 25% of opening height for all spans < 8 feet<br>☐ Channel cross section designed to mimic low flow depths of natural channel | ☐ Maximum Extent Practicable |
| **Hydraulic Modeling** | ☐ HEC-RAS<br>☐ Equivalent Software: ______________________ | ☐ HY-8<br>☐ CulvertMaster<br>☐ HydroCAD<br>☐ Equivalent Software:__________________ | ☐ Maximum Extent Practicable |
| **Openness Ratio**<br><br>Openness ratio:<br>____________________ | ☐ Openness ratio ≥ 1.64 feet and height ≥ 6 feet<br>☐ If conditions significantly inhibit wildlife, openness of ≥ 2.46 feet and height ≥ 8 feet | ☐ Greater than or equal to 0.82 feet to the maximum extent practicable | |
| **Stream Crossing Span**<br><br>Bankfull width: _______<br>Crossing span: ________ | ☐ Hydraulic span greater than or equal 1.2 x BFW with banks on both sides designed for applicable wildlife passage. | ☐ Hydraulic span greater than or equal to 1.2 x BFW with banks on both sides | ☐ Maximum Extent Practicable |
| **Structural Stability** | ☐ Design in accordance with Rhode Island and AASHTO LRFD standards. Structural design includes appropriate loading including streamflow, span configuration and freeboard, wingwall layout and design, and footing design. Hydraulic modeling and geotechnical analysis provide direction on foundation requirements and site-specific scour mitigation measures. | | |
| **Tidal/Coastal Guidance** | ☐ Non-tidal<br>☐ Velocity comparable to natural channel during the ebb and flow for high tide or maximum flow conditions and low tide/ low flow conditions based upon a detailed unsteady hydraulic modeling analysis. | ☐ Non-tidal<br>☐ Designed to accommodate the exchange of the full tidal prism using a simplified quantitative analysis (i.e. spreadsheet) | ☐ Maximum Extent Practicable |
| **Reporting Requirements** | ☐ Road-Stream Crossing Report (with H&H computations), Geotechnical Investigation, Hydraulic Design Data Table, Conceptual Design Figure(s) | | |

*March 2022 Revision*

## A.3 Hydraulic Design Data Table

| Project Background | |
|---|---|
| Bridge ID # and Group # (if applicable): | |
| Roadway Name: | |
| Waterbody Name: | |
| Town Name: | |
| Planned Construction Dates: | |
| Structure Service Life (years): | |
| Project within Special Flood Hazard Area and/or Floodway? If yes, provide FEMA Flood Zone details and elevation (if available): | |
| **Crossing Geometry** | |
| Existing Condition Low Chord Elevation (feet): | |
| Proposed Condition Low Chord Elevation (feet): | |
| **Hydraulic Design Requirements** | |
| Design Storm Event: | |
| Existing Condition Design Storm Event Elevation (feet): | |
| Proposed Condition Design Storm Event Elevation (feet): | |
| Freeboard Requirement (feet): | |
| Existing Freeboard (feet): | |
| Proposed Freeboard Provided (feet): | |
| Design Scour Event: | |
| Check Scour Event: | |
| Existing modeled FEMA Base Flood Elevation (if applicable)(feet): | |
| Proposed modeled FEMA Base Flood Elevation (if applicable)(feet): | |
| Climate Check Event: | |
| Pass Climate Check Event? (Y/N/N.A.): | |
| **Climate Change Requirements** | |
| Is the crossing currently impacted by tidal flow? (Y/N): | |
| Climate Change Projection Horizon Year (end of service life): | |
| Will the crossing be impacted by the future MHHW based upon sea level rise for the Climate Change Projection Horizon Year? (Y/N/N.A.): | |

# Appendix B:
## Conceptual Design Figures




ELEVATION VIEW

NOTES:

1. CHANNEL CROSSING MATERIAL BASED UPON NATURAL CHANNEL GRAIN SIZE ANALYSIS, BED MOBILITY, AND SCOUR STABILITY ANALYSIS.
2. ALL FOUNDATION, WINGWALL, AND ABUTMENT DESIGN SHALL BE IN ACCORDANCE WITH THE RIDOT BRIDGE DESIGN MANUAL, AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS AND STAMPED BY A PROFESSIONAL ENGINEER, LICENSED IN THE STATE OF RHODE ISLAND.
3. SCOUR ANALYSIS SHALL CONFIRM FOUNDATIONS ARE PROTECTED THROUGHOUT THE CHECK SCOUR STORM. PROVIDE PROTECTION AS NECESSARY.

| PROPOSED HYDRAULIC FEATURES | |
|---|---|
| A. BANKFULL WIDTH (FT) | |
| B. PROVIDED SPAN (FT) | |
| C. DESIGN STORM ELEVATION (FT) | |
| DESIGN STORM EVENT (% AEP) | |
| D. LOW CHORD ELEVATION (FT) | |
| E. PROVIDED FREEBOARD (FT) | |
| F. HIGH CHORD ELEVATION (FT) | |
| G. HIGH CHORD OF BLOCK AREA (FT) (IF APPLICABLE) | |
| H. HEIGHT (FT) | |
| I. THALWEG ELEVATION (FT) | |
| J. BRIDGE LENGTH (FT) (PARALLEL TO FLOW) | |

RHODE ISLAND DEPARTMENT OF TRANSPORTATION

OPEN SPAN BRIDGE (ALL SPAN LENGTHS)

| REVISIONS | | |
|---|---|---|
| NO. | BY | DATE |
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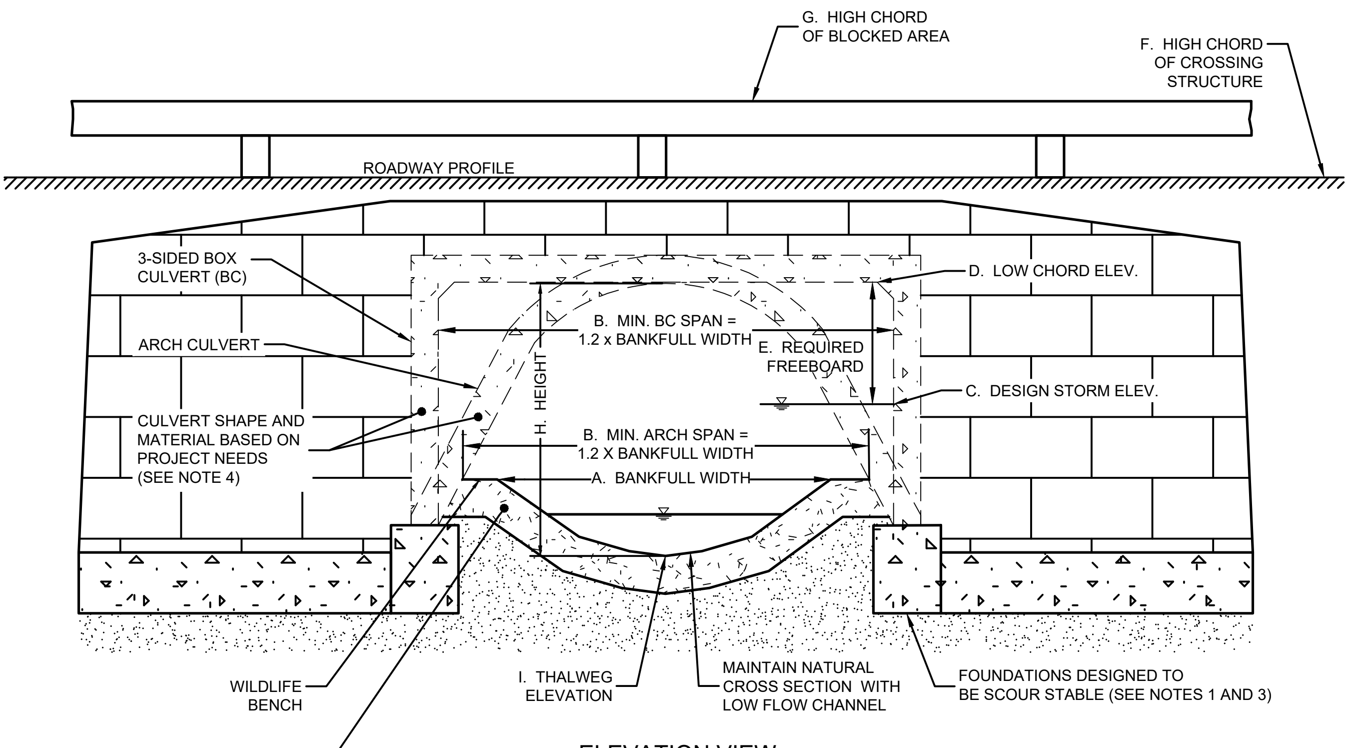
CHIEF ENGINEER TRANSPORTATION

CHIEF DESIGN ENGINEER TRANSPORTATION

ISSUE DATE

R.I. STANDARD




ELEVATION VIEW

NOTES:

1. CHANNEL CROSSING MATERIAL BASED UPON NATURAL CHANNEL GRAIN SIZE ANALYSIS, BED MOBILITY, AND SCOUR STABILITY ANALYSIS.
2. ALL FOUNDATION, WINGWALL, AND ABUTMENT DESIGN SHALL BE IN ACCORDANCE WITH THE RIDOT BRIDGE DESIGN MANUAL, AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS AND STAMPED BY A PROFESSIONAL ENGINEER, LICENSED IN THE STATE OF RHODE ISLAND.
3. SCOUR ANALYSIS SHALL CONFIRM FOUNDATIONS ARE PROTECTED THROUGHOUT THE CHECK SCOUR STORM. PROVIDE PROTECTION AS NECESSARY.
4. VIEW ILLUSTRATES BOTH 3-SIDED BOX CULVERT OPTION AND ARCH CULVERT. DESIGNER TO CHOOSE BASED UPON PROJECT NEEDS.

| PROPOSED HYDRAULIC FEATURES | |
|---|---|
| A. BANKFULL WIDTH (FT) | |
| B. PROVIDED SPAN (FT) | |
| C. DESIGN STORM ELEVATION (FT) | |
| DESIGN STORM EVENT (% AEP) | |
| D. LOW CHORD ELEVATION (FT) | |
| E. PROVIDED FREEBOARD (FT) | |
| F. HIGH CHORD ELEVATION (FT) | |
| G. HIGH CHORD OF BLOCK AREA (FT) (IF APPLICABLE) | |
| H. HEIGHT (FT) | |
| I. THALWEG ELEVATION (FT) | |
| J. BRIDGE LENGTH (FT) (PARALLEL TO FLOW) | |

RHODE ISLAND DEPARTMENT OF TRANSPORTATION

3-SIDED BOX CULVERT & ARCH CULVERT

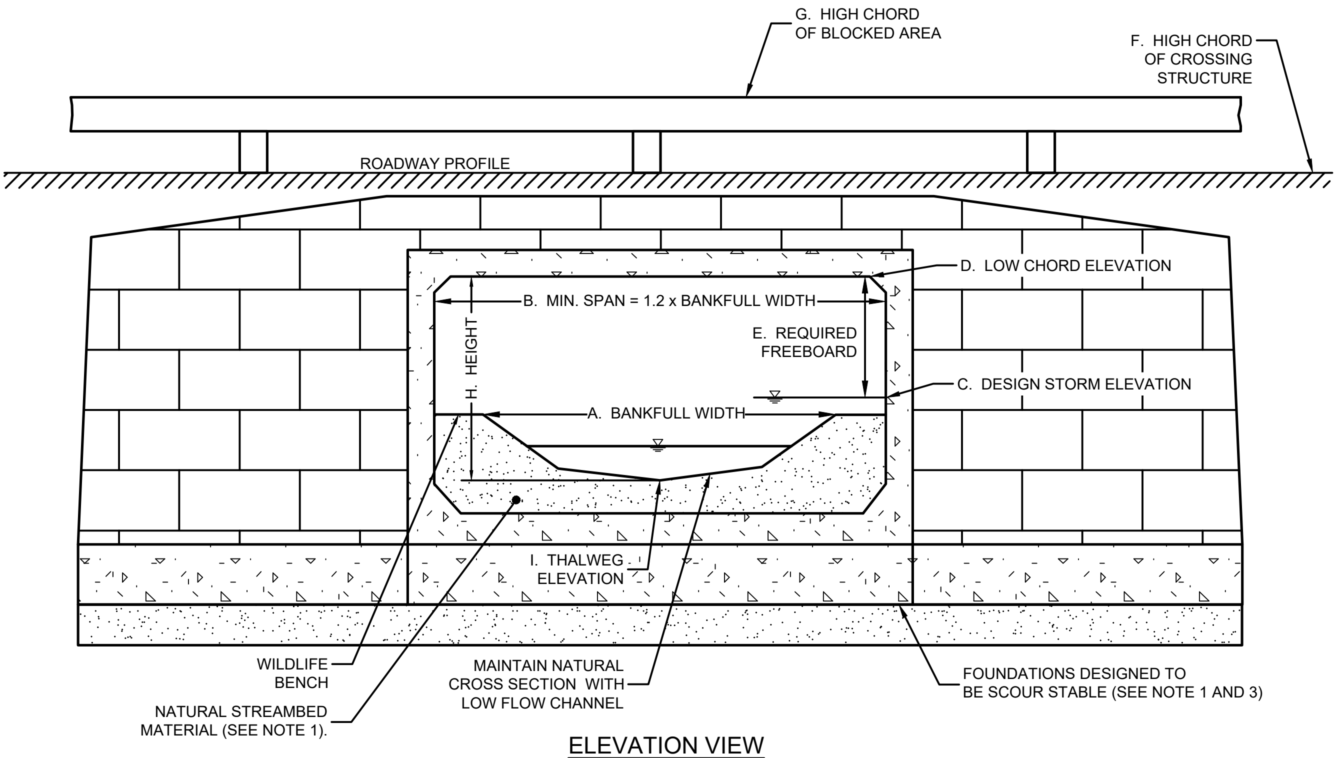
| REVISIONS | | |
|---|---|---|
| NO. | BY | DATE |
| | | |
| | | |
| | | |
| | | |
| | | |

CHIEF ENGINEER
TRANSPORTATION

CHIEF DESIGN ENGINEER
TRANSPORTATION

ISSUE DATE

R.I.
STANDARD




ELEVATION VIEW

NOTES:

1. CHANNEL CROSSING MATERIAL BASED UPON NATURAL CHANNEL GRAIN SIZE ANALYSIS, BED MOBILITY, AND SCOUR STABILITY ANALYSIS.
2. ALL FOUNDATION, WINGWALL, AND ABUTMENT DESIGN SHALL BE IN ACCORDANCE WITH THE RIDOT BRIDGE DESIGN MANUAL, AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS AND STAMPED BY A PROFESSIONAL ENGINEER, LICENSED IN THE STATE OF RHODE ISLAND.
3. SCOUR ANALYSIS SHALL CONFIRM FOUNDATIONS ARE PROTECTED THROUGHOUT THE CHECK SCOUR STORM. PROVIDE PROTECTION AS NECESSARY.

| PROPOSED HYDRAULIC FEATURES | |
|---|---|
| A. BANKFULL WIDTH (FT) | |
| B. PROVIDED SPAN (FT) | |
| C. DESIGN STORM ELEVATION (FT) | |
| DESIGN STORM EVENT (% AEP) | |
| D. LOW CHORD ELEVATION (FT) | |
| E. PROVIDED FREEBOARD (FT) | |
| F. HIGH CHORD ELEVATION (FT) | |
| G. HIGH CHORD OF BLOCK AREA (FT) (IF APPLICABLE) | |
| H. HEIGHT (FT) | |
| I. THALWEG ELEVATION (FT) | |
| J. BRIDGE LENGTH (FT) (PARALLEL TO FLOW) | |

RHODE ISLAND DEPARTMENT OF TRANSPORTATION

EMBEDDED BOX CULVERT

| REVISIONS | | |
|---|---|---|
| NO. | BY | DATE |
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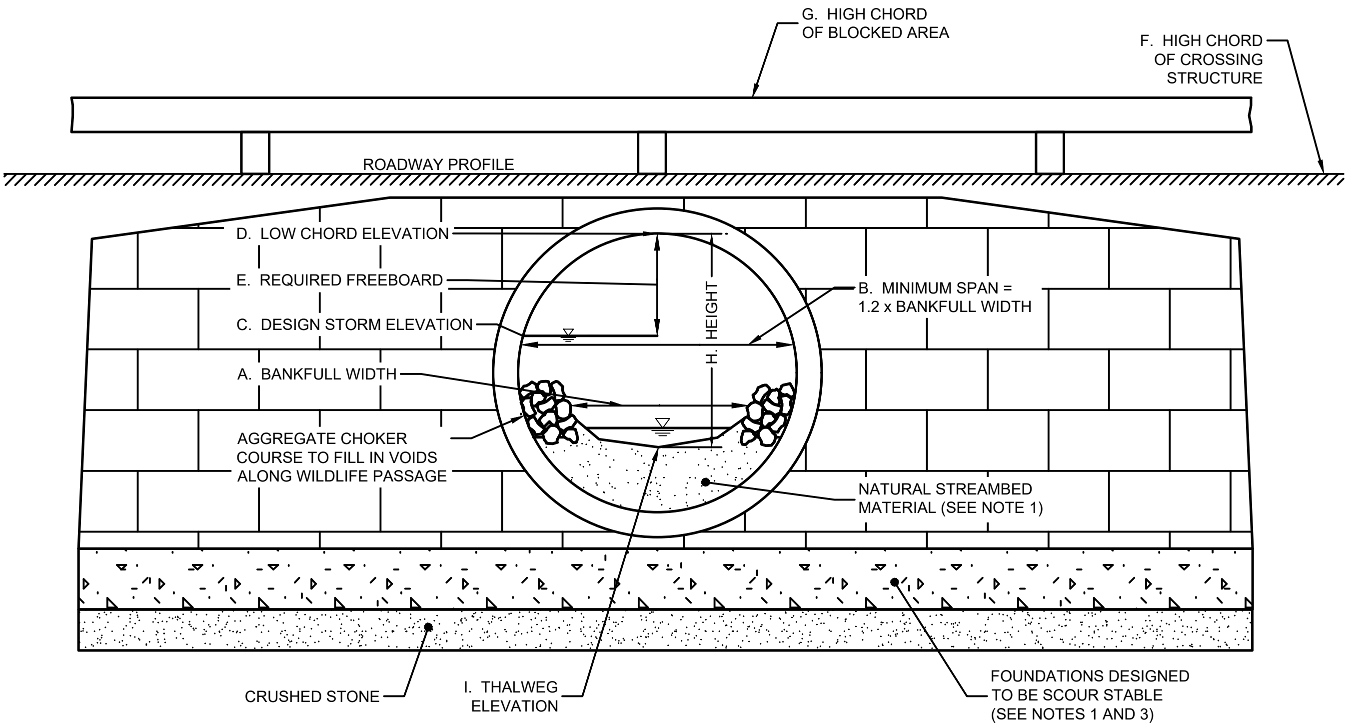
CHIEF ENGINEER TRANSPORTATION

CHIEF DESIGN ENGINEER TRANSPORTATION

ISSUE DATE

R.I. STANDARD




ELEVATION VIEW

NOTES:

1. CHANNEL CROSSING MATERIAL BASED UPON NATURAL CHANNEL GRAIN SIZE ANALYSIS, BED MOBILITY, AND SCOUR STABILITY ANALYSIS.
2. ALL FOUNDATION, WINGWALL, AND ABUTMENT DESIGN SHALL BE IN ACCORDANCE WITH THE RIDOT BRIDGE DESIGN MANUAL, AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS AND STAMPED BY A PROFESSIONAL ENGINEER, LICENSED IN THE STATE OF RHODE ISLAND.
3. SCOUR ANALYSIS SHALL CONFIRM FOUNDATIONS ARE PROTECTED THROUGHOUT THE CHECK SCOUR STORM. PROVIDE PROTECTION AS NECESSARY.

| PROPOSED HYDRAULIC FEATURES | |
|---|---|
| A. BANKFULL WIDTH (FT) | |
| B. PROVIDED SPAN (FT) | |
| C. DESIGN STORM ELEVATION (FT) | |
| DESIGN STORM EVENT (% AEP) | |
| D. LOW CHORD ELEVATION (FT) | |
| E. PROVIDED FREEBOARD (FT) | |
| F. HIGH CHORD ELEVATION (FT) | |
| G. HIGH CHORD OF BLOCK AREA (FT) (IF APPLICABLE) | |
| H. HEIGHT (FT) | |
| I. THALWEG ELEVATION (FT) | |
| J. BRIDGE LENGTH (FT) (PARALLEL TO FLOW) | |

RHODE ISLAND DEPARTMENT OF TRANSPORTATION

EMBEDDED PIPE CULVERT

| REVISIONS | | |
|---|---|---|
| NO. | BY | DATE |
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| | | |

CHIEF ENGINEER TRANSPORTATION

CHIEF DESIGN ENGINEER TRANSPORTATION

ISSUE DATE

R.I. STANDARD

# Appendix C:
## Road-Stream Crossing Report Template

**RIDOT Road-Stream Crossing Report Template**

Instructions: All black text within this template should remain as titles/headers in the final report, all blue text is guidance and should be updated or deleted by the consultant.

# Cover Page

Project Name and Location

PTSID Number

Bridge ID (If applicable)

RIDOT Contact Information

Consultant Contact Information

Stamp of Rhode Island P.E.

# Appendix D:

## Glossary of Terms

# Appendix D: Glossary of Terms

**Annual Exceedance Probability (AEP):** The probability of a flood event occurring in any year. For example, the 1% AEP flood has a 1% chance of occurring or being exceeded in any given year. The probability of flood occurrence is also commonly defined by a specific return period. Table 1 shows the relationship between AEP and return interval for common flood events.

**Flood Event AEP and Return Period**

| Annual Exceedance Probability (AEP) (%) | Return Period (years) |
|---|---|
| 50 | 2 |
| 10 | 10 |
| 4 | 25 |
| 2 | 50 |
| 1 | 100 |
| 0.2 | 500 |

**Aquatic Organism Passage (AOP):** The natural, unrestricted movement of aquatic species through a crossing structure. AOP design is the modification or removal of barriers that restrict or impede movement of aquatic organisms in order to facilitate that movement.

**Arch:** An arch or pipe-arch is a type of culvert that is arched to achieve a lower, wider crossing shape. Arches are usually open-bottom structures while pipe-arches are fully enclosed.

**Bankfull Flow:** The point at which water completely fills the stream channel and where additional water would overflow into the floodplain. See Assessment Handbook: Section 3.5.2 for additional detail on determining bankfull flow.

**Bankfull Width (BFW)**: A measurement of the width of the active stream channel at bankfull flow. See Assessment Handbook: Section 3.5.2 for additional detail on determining bankfull flow.

**Bridge:** A crossing that has a deck supported by abutments. Abutments may be earthen or constructed of wood, stone, masonry, concrete, or other materials. A bridge may have multiple cells, divided by one or more piers. The RIDOT Bridge Inspection Manual defines a bridge as a structure over a depression or an obstruction with a length of more than 20 feet (2013, as amended). Designers should review the latest RIDOT Bridge Inspection Manual for updated definitions. See Assessment Handbook: Section 1.2.3 for additional details.

**Check Scour:** The 24-hour storm event that the crossing's scour countermeasures must be designed to, and that must be scour stable but not necessarily available for use afterwards.

**Climate Check:** The 24-hour storm event used to determine the required hydraulic capacity of a crossings (without the inclusion of freeboard) to account for climate change.

**Culvert:** A culvert is any crossing structure that is not a bridge and is usually buried under some amount of fill. Culverts can be fully enclosed (contain a bottom) or have an open bottom. For the purpose of this Manual, an arch is considered an open-bottom culvert.

**Design Scour:** The 24-hour storm event that the crossing's foundations, abutments, or piers must be designed to, and that the crossing must be scour stable for and available for use afterwards.

**Design Storm:** The 24-hour storm event at a given AEP used to determine the required hydraulic capacity of a crossing, with the inclusion of freeboard.

**Designer:** The party contacted by RIDOT to complete the assessment and design of a particular stream crossing.

**Ecological:** Relating to or concerned with the relation of living organisms to one another and to their physical surroundings.

# Appendix D: Glossary of Terms

**Freeboard:** Freeboard is the distance between the upstream water surface elevation and the low chord of the crossing structure. The location of the upstream water surface elevation will vary based upon the hydraulic model used in the design. Below is a description of this location for common hydraulic modeling software:

HEC-RAS (Hydrologic Engineering Center River Analysis System): Two cross sections upstream of the crossing (also known as Cross Section 4) where the flow has not yet been impacted by contraction of the crossing.

HydroCAD Stormwater Modeling Software: The location of the upstream water surface elevation will vary based on the method of modeling. The designer should use engineering judgement to best interpolate the elevation approximately one to two bridge widths upstream of the crossing or where flow has not yet been impacted by contraction of the crossing.

HY-8 Culvert Hydraulic Analysis Program: The location of the upstream water surface elevation will vary based on the method of modeling. Due to the limitations of this model, the designer should utilize engineering judgement and will likely have to use the water surface elevation at the upstream face of the crossing.

**Geomorphic:** Relating to the shape of the landscape and landforms. Geomorphic impacts to road-stream crossings occur when the crossing alters the surrounding stream channel and landscape.

**Headcutting:** An erosional feature that causes an abrupt vertical drop in the channel bed elevation. Headcuts usually begin at a knickpoint (a sharp change in channel slope) and can migrate upstream within a channel.

**Hydraulic:** The study of fluid mechanics and the flow of water through a stream, river, channel, and/or stream crossing.

**Hydraulic Capacity:** The amount of water that a crossing can safely convey, usually corresponding to a specific design storm or flow rate.

**Hydrologic Engineering Center River Analysis System (HEC-RAS):** A software program from the U.S. Army Corps of Engineers Hydrologic Engineering Center that allows users to perform one-dimensional steady flow, one and two-dimensional unsteady flow calculations, sediment transport/mobile bed computations, and water temperature/water quality modeling.

**Hydrology:** The study of the occurrence, distribution, movement and properties of the water through the environment within each phase of the water cycle.

**Life Cycle Cost:** The total cost of a crossing structure over its life cycle including initial capital costs, maintenance costs, operating costs, and the structure's residual value at the end of its life.

**Maximum Extent Practicable (MEP):** For the purpose of this Manual, designing to the MEP means aiming to achieve the Base or Optimal Standards whenever possible while taking into consideration cost, available technology, and project site constraints.

**Mean Higher High Water (MHHW):** A measurement representing the vertical extent of tidal influence in a specific area, obtained by taking the average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch.

**North American Vertical Datum of 1988 (NAVD 88):** The vertical datum for orthometric heights established for vertical control surveying in the United States in 1991. NAVD 88 is the official vertical datum of the United States, having superseded the older National Geodetic Vertical Datum of 1929 (NGVD 29).

# Appendix D: Glossary of Terms

**Planning Horizon:** A length of time into the future that is accounted for in a particular plan. In this Manual planning horizon is used to describe a length of time into the future for the purpose of planning for climate change.

**Reference Reach:** A river or stream segment that represents the natural, stable channel and is used to develop crossing design criteria including bankfull width, slope, and other characteristics used in Stream Simulation design.

**Scour:** The erosion or degradation of a riverbed (vertical scour) or riverbanks (lateral scour) by flowing water.

**Stream Crossing:** A location where infrastructure (roadway, railroad, pipeline, etc.) crosses a stream channel. This includes crossings at intermittent streams that are dry during certain times of the year.

**Stream Simulation:** A method for designing and building road-stream crossings intended to permit free and unrestricted movements of any aquatic species. Stream Simulation is outlined in detail in the U.S. Forest Service document Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings (2008).

**StreamStats:** A web application from the United States Geological Survey that provides access to spatial analytical tools that are useful for water-resources planning and management, and for engineering and design purposes. The map-based user interface can be used to delineate drainage areas, get basin characteristics and estimates of flow statistics, among other features.

**Thalweg:** The deepest part of a stream channel. See *Figure 4-3*: Five Point Cross Section for illustration.

**Vertical Adjustment Potential (VAP):** The range of potential vertical streambed adjustment (due to erosion or deposition) over the service life of a crossing structure. The upper and lower VAP lines represent respectively the highest and lowest likely elevations of any point on the streambed surface (FSSWG, 2008).

# Appendix E:

## Synthesis of Existing Guidance Memorandum

To: Alisa Richardson, RIDOT
Nicole Leporacci, RIDOT

Date: December 4, 2020

Project #: 73052.03

From: Annique Fleurat, VHB
Ariana Wetzel, VHB

Re: RIDOT Road-Stream Crossing Design Manual: Synthesis of Existing Guidance Memorandum

# Memorandum

VHB is preparing the Road-Stream Crossing Design Manual ("the Manual") for the Rhode Island Department of Transportation ("RIDOT"). VHB has completed a literature review of existing road-stream crossing guidance throughout the United States, with a focus in the New England region, in preparation for determining the appropriate guidance for Rhode Island. This memorandum summarizes the literature review findings of the existing guidance, presents the design criteria and approaches, and presents the road-stream crossing proposed standards that VHB has determined to be most applicable and appropriate for Rhode Island.



## Literature Review of Existing Guidance

VHB reviewed over 30 existing stream crossing design manuals, guidance handbooks, regulatory documents, and online resources, which can be found in the attached list of references, to understand best practices and begin to provide recommendations for RIDOT's proposed Manual. VHB examined available literature associated with enhanced culvert conveyance, aquatic organism passage ("AOP"), stream continuity, and small bridge design. VHB also reviewed the *RIDOT Road-Stream Crossing Assessment Handbook* ("Assessment Handbook"), which provides guidance on evaluating and prioritizing existing crossings in Rhode Island. This memorandum assumes the reader has a general knowledge of the Assessment Handbook.

In order to summarize and organize the results of the literature review, VHB developed Figure 1, which is a quantitative bar graph of the design criteria covered within the various sources. The design criteria are the topics that VHB's engineering experience has determined to be the most impactful on the detailed design of a crossing structure, the project decision making process, and which guide the industry standards. The bar graph provides a visual representation of the popularity of each design topic within the existing literature. VHB examined each document for the various criteria related to stream crossing design, listed on the horizontal axis of the graph. For each design topic, the blue bar represents the number of documents that include design criteria or complete guidance for the associated topic and the green bar represents the number of documents that included partial design criteria or mention the associated topic but with no specific guidance.



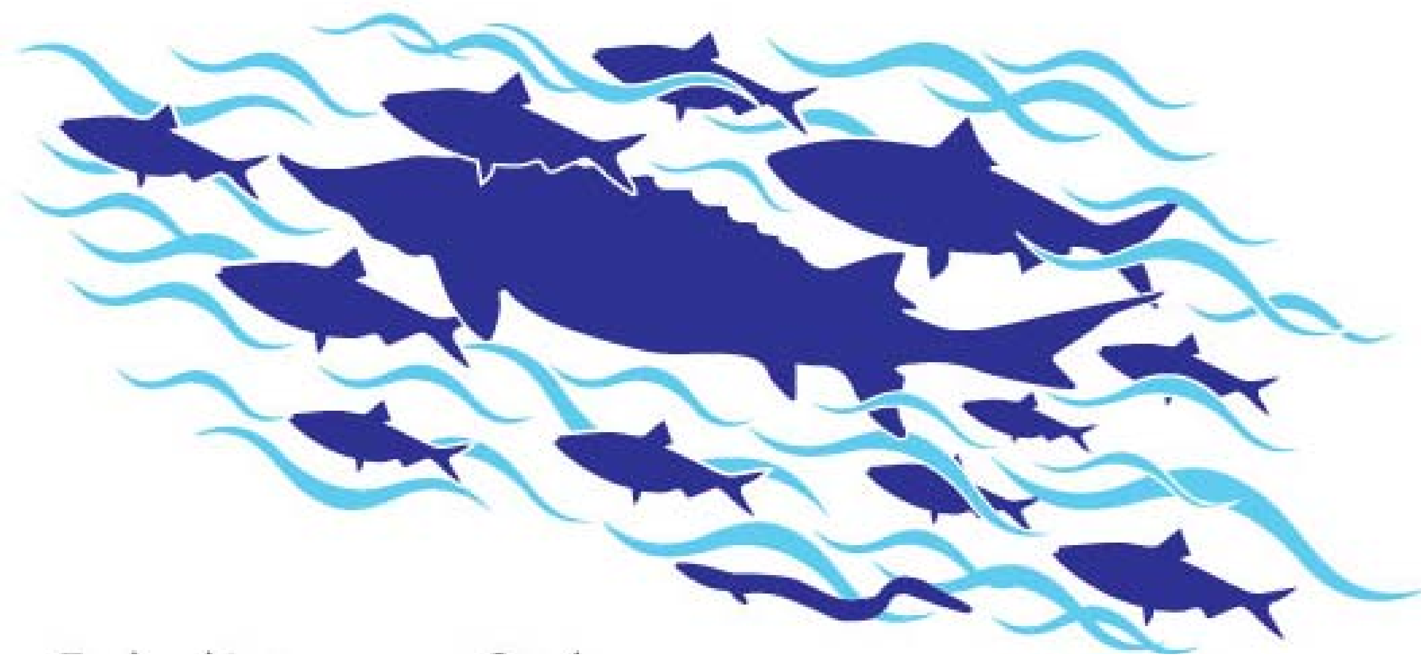
101 Walnut Street
PO Box 9151
Watertown, MA 02472-4026
P 617.924.1770

# Appendix F:

## Diadormous Fish Passage Guidelines

Technical Memorandum

# Federal Interagency
# Nature-like Fishway Passage Design Guidelines for Atlantic Coast Diadromous Fishes



**May 2016**