New Hampshire's Tidal Crossing Assessment Protocol

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July 14, 2017

Acknowledgements

We express sincere gratitude to the individuals and organizations that contributed to this project, including those listed as Advisors and Contributors below. The stakeholder engagement section details the points in the protocol's development when advisors and contributors provided feedback and insights that played an invaluable role in shaping this final product. And thank you to the Davis Family Foundation for your support of the project.

This project was funded, in part, by NOAA's Office for Coastal Management under the Coastal Zone Management Act in conjunction with the NH Department of Environmental Services (NHDES) Coastal Program. Thank you to NOAA and the NHDES Coastal Program for partnering with The Nature Conservancy (TNC) and providing essential support to the project.

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Cite as: Steckler, P., Lucey, K., Burdick, B., Glode, J., and Flanagan, S. 2017. New Hampshire's Tidal Crossing Assessment Protocol. The Nature Conservancy. Prepared for the New Hampshire Department of Environmental Services Coastal Program, Concord, NH.

Cover photos: Collecting the stream channel longitudinal profile at a Rye Harbor/Route 1A crossing in Rye, NH (top, TNC). High, mid, and low tide conditions at the downstream side of the Rye Harbor/Route 1A crossing (bottom—from left to right, TNC).

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Definitions:

Brief definitions are provided below for a selection of technical terms and acronyms that are referred to in the Tidal Protocol.

1% Annual Flood: "The flood event having a 1-percent chance of being equaled or exceeded in any given year. The 1-percent annual chance flood is also referred to as the base flood or 100-year flood."—From FEMA

Backsight: A survey reading looking "backwards" to a turning point from a subsequent level setup location (see Foresight definition below and Figure 4). The backsight is taken from a subsequent level setup location after a foresight was collected on the same position from a previous level setup location.

Ceiling of Crossing Structure: The high point inside of the crossing structure. This is where you'd bump your head (at the highest point for a round, elliptical, or arch) when crossing through the structure (see Figure 5).

Downstream: The seaward side of a tidal crossing.

Foresight: A survey reading taken on a turning point position looking "forward" from the initial level setup location (see Figure 4). A foresight is collected when multiple level setup locations are needed to complete the crossing cross section and stream longitudinal profile. It relates the elevations of positions collected from the initial level setup location to those collected from subsequent level setup locations.

HWI: Stands for 'high water indicator.' High water indicators are physical features (water stains or wrack) at the crossing structure that indicate high water elevations (see Figure 5).

Invert: The low point inside of the crossing structure, or the interior bottom of the crossing structure.

MHHW: Stands for 'mean higher high water.' "The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch."—From NOAA

NAVD 88: Stands for 'North American Vertical Datum of 1988.' A geodetic datum chosen to compare elevations so that elevation data can be consistent throughout North America.—see NOAA

SLAMM: Stands for 'sea level affecting marshes model.' A model used to "…simulate potential impacts of long-term sea level rise on wetlands and shorelines."—From NOAA

SLR: Stands for 'sea level rise.' The projected accumulation of ocean water volume associated with climate change that will cause sea levels to rise over time.

Thalweg: The longitudinal line that runs along the deepest portion of a river channel.

Turning point: A survey position used as a pivot between the initial level setup location and a subsequent level setup location (see Foresight, Backsight, and Figure 4).

Upstream: the landward or inland side of a tidal crossing.

Introduction & Overview

New Hampshire's Tidal Crossing Assessment Protocol ("Tidal Protocol") was developed to evaluate crossing structures that convey tidal flows. The Tidal Protocol is an assessment methodology used to inventory and prioritize tidal crossing replacements based on a set of management objectives, such as a structure's condition, inundation risk, and restrictiveness to tidal flows, among others. The Tidal Protocol is a first screen to identify infrastructure replacement and ecological restoration priorities; it is not designed to comprehensively assess tidal crossings to meet site-specific engineering and restoration requirements.

Assessment protocols to address tidal crossings are few and far between. There is an abundance of freshwater road-stream crossing protocols, but they do not address the unique and complex nature of tidal crossings. The Tidal Protocol defines a tidal crossing as a culvert or bridge associated with a road, railroad, or other form of infrastructure that is influenced by the ebb and flow of tides. The need for the Tidal Protocol, which incorporates the latest coastal resilience focused geospatial datasets, is warranted for the following reasons:

- Tidal crossing infrastructure are at the front lines of coastal challenges associated with climate change, including sea level rise and more frequent and intense storm events. Climate-ready infrastructure is necessary to adapt to these challenges, allowing for the continuous flow of people, goods and services across our coastal communities
- Tidal habitats are special systems with complex hydraulics and hydrology. On average, tidal systems experience two high tides and two low tides every day and they pass, store, and transport significant volumes of water, salt and sediment
- Tidal systems are home to critically important and imperiled habitats and species that are adapted to life in these dynamic places, which are often subject to a broad range of salinities, water temperatures and ever-fluctuating water levels
- Tidal crossings are the gateways to upstream freshwater habitat for diadromous fish, and to spawning and nursery habitat for estuarine and marine species. They are also gateways for the migration of tidal habitats inland with rising sea levels, which are critical to support the array of fish and wildlife that depend on tidal marshes
- Careful consideration of upstream infrastructure and property susceptible to flooding is necessary in the assessment of tidal crossings—both under current conditions and accounting for rising sea levels. For example, some existing tidal crossings may serve to protect inland communities by restricting tidal flows, but may also cause more severe flooding inland because of poor drainage seaward

The Tidal Protocol was developed and informed by a broad group of coastal resource and transportation managers. It also incorporates assessment methodologies from other protocols that align with the Tidal Protocol's objectives. Specifically, we relied on *The New Hampshire Stream Crossing Initiative AND Statewide Asset Data Exchange System (SADES)* (NHDOT 2017) protocol for crossing type and condition assessment parameters, and on the Parker River (Purinton and Mountain 1996) protocol for evaluating tidal restrictions. While the Tidal Protocol was developed to meet coastal zone management needs in New Hampshire, it is intended to have much broader geographic applicability. Coastal resource managers from other states and regions, including Maine, Massachusetts, Rhode Island, Connecticut, New York, Washington State, and the Canadian Maritimes either contributed to the Tidal Protocol or expressed interest in developing such a tool. As such, we are hopeful that the Tidal Protocol will be used beyond New Hampshire. We encourage other users of the Tidal Protocol to send suggestions for improvements and clarifications to the study authors listed on the cover page.

This section of the Tidal Protocol lays out the background and framework upon which the protocol was developed. It also includes logistical information for the safe and successful deployment of the protocol. Following the *Introduction and Overview*, the *Assessment Parameter* section describes each of the protocol's assessment parameters and provides instructions for their data collection. An *Evaluation Criteria* section details the rational for the evaluation criteria and the methodology for calculating evaluation scores, followed by a *Data Processing* section that details methods for post processing the assessment parameters. Lastly, a *Conclusion and Next Steps* section concludes the Tidal Protocol and identifies some additional steps for advancement and outreach.

Stakeholder Engagements

Development of the Tidal Protocol benefitted greatly from strong stakeholder engagements. From the effort's kick-off meeting through the final field trials, multiple organizations and professionals participated in nearly every step of the protocol's development. Table 1 summarizes these engagements:

Table 1. Details stakeholder engagements that occurred throughout the development of the Tidal Protocol including the engagement date, the type and description of the of the engagement, and organizations present.

Date	Type	Engagement Description (organizations present)
7/28/2015	Technical meeting and site visits	Initial discussion and site reviews considering management objectives and potential assessment parameters. (TNC, NHDES Coastal Program, NHDES NH Geological Survey, NH Fish and Game Department, UNH, Wright-Pierce Engineers)
9/10/2015	Tidal Crossing Assessment Workshop	Information sharing about tidal crossing assessment efforts by over 40 coastal resource managers across and beyond New England. NH's efforts to develop assessment parameters and evaluation criteria were explored in-depth. Organized by the Northeast Regional Ocean Council (NROC), Gulf of Maine Council (GOMC), and the North Atlantic Landscape Conservation Cooperative (NALCC). (Casco Bay Estuary Partnership, CT Department of Energy and Environmental Protection, Fisheries and Oceans Canada, MA Coastal Zone Management, ME Department of Transportation, ME Natural Areas Program, ME Coastal Program, New Brunswick Department of Environment and Local Government, New Brunswick Department of Transportation and Infrastructure, NH Sea Grant/Cooperative Extension, NH Department of Environmental Services, National Oceanic and Atmospheric Administration, Nova Scotia Department of Environment, NY

		Department of Environmental Conservation, RI Coastal Resources Management Council, The Nature Conservancy (NH & Long Island), University of Massachusetts Amherst, University of New Hampshire, US Environmental Protection Agency, US Fish and Wildlife Service, US Geological Survey, WA Department of Fish & Wildlife) Workshop Agenda at: http://northeastoceancouncil.org/wp-content/uploads/2015/11/Agenda_TCAW.pdf Workshop Participant List at: http://northeastoceancouncil.org/wp-content/uploads/2015/11/RegistrationList_TCAW.pdf
9/11/2015	Site visits	Field review tidal crossings and discuss management objectives, assessment parameters and evaluation criteria (TNC, NHDES, WA Department of Fish and Wildlife)
6/22/2016	Field Trial	First round of field trials, 2 sites (TNC, NHDES, UNH)
8/11/2016	Field Trial	Second round of field trials, 4 sites (TNC NH & Long Island, NHDES, UNH, UMass Amherst)
9/7/2016	Field Trial	Third round of field trials, 2 sites (TNC, NHDES, UNH, NH DOT, Wright-Pierce Engineering, Biological Conservation)
9/12/2016	Presentation	Present and solicit feedback on draft protocol at the Northeast Transportation and Wildlife Conference, Lake Placid, NY (TNC)
10/27/2016	Presentation	Present draft protocol to the NH Coastal Adaptation Workgroup, Portsmouth, NH (TNC, NHDES)
3/24/17	Presentation	Present draft protocol at the NH Water and Watersheds Conference (TNC, NHDES)
4/5/2017	Workshop	Present and solicit feedback at Using Technology and Emerging Practices to Improve Tidal Marsh Resilience. Organized by the Northeast Regional Ocean Council (NROC) and the North Atlantic Landscape Conservation Cooperative (NALCC). (Similar attendees as 9/10/2015 workshop).
5/30/2016	Field Trial	Final field trial of final draft Tidal Protocol (TNC, NHDES, UNH)

Management Objectives, Assessment Parameters, and Evaluation Criteria

The framework of the Tidal Protocol is organized by a set of management objectives to help stakeholders (e.g. state and federal agencies, municipalities, NGOs) prioritize tidal crossings for improvement and/or replacement. A management objective in this context is the degree that a site characteristic meets a certain management standard. For example, does the existing crossing meet the condition standard of "good" (i.e. is the crossing structure in good condition)? Or, does the existing crossing structure meet the standard of "not restricting tidal flow"?

The protocol follows a three-step process to understand how each site ranks against each management objective (see Figure 1). First, a set of assessment parameters are used to measure site specific crossing characteristics. Assessment parameters are addressed both in the field and from the "desktop". Field assessment parameters are collected on-site through quantitative and qualitative measures, while desktop assessment parameters are collected using local information (i.e. information collected from road managers) and a Geographic Information System (GIS). Second, evaluation criteria are applied to score a selection of the assessment parameters. Third, the evaluation criteria scores feedback to understand how each crossing ranks against the management objectives. The Tidal Protocol's management objectives are detailed in Table 2.

Figure 1. Depiction of the feedback loop between management objectives, assessment parameters, and evaluation criteria, which make up the framework for the Tidal Protocol.

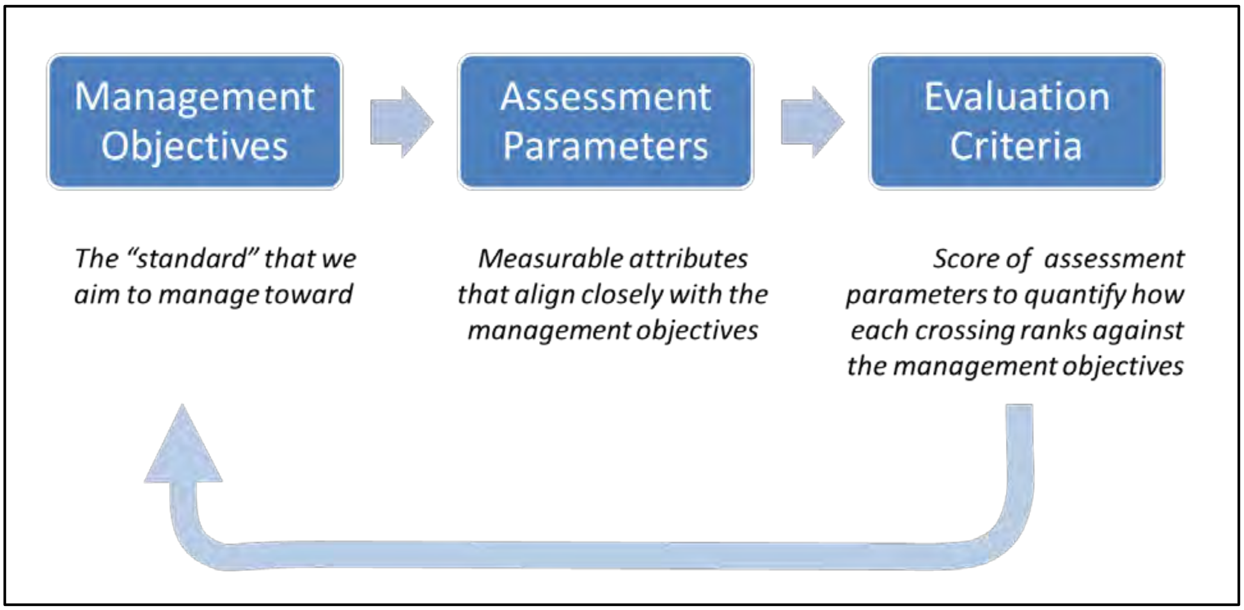


Table 2. A list of the management objectives that the Tidal Protocol addresses, including the management objective standard that respective evaluation criteria are measured against and an explanation of each objective's relevance.

Management Objective	Management Objective Standard	Management Objective Relevance
Crossing Condition	Crossing is in good condition	*Understand the condition of tidal crossings to address safety and transportation infrastructure management*
Tidal Restriction	Crossing does not restrict tidal flow	*Understand hydraulic compatibility of crossing structures with the tidal system*
Tidal Aquatic Organism Passage	Crossing does not impede fish or other aquatic organism passage	*Understand the compatibility of crossing structures for fish and other aquatic organism passage*
Salt Marsh Migration	Crossing will not impede upstream salt marsh migration	*Understand the upstream opportunity for salt marsh habitat to migrate inland with rising sea levels*
Vegetation	Crossing has no noticeable effect on upstream versus downstream marsh vegetation	*Understand the influence of crossing structures on the up and downstream plant community, which can indicate effects on hydrology, salinity, and sedimentation*
Infrastructure Risk	Crossing is climate-ready: it is not vulnerable to inundation currently and with 1.7 feet of sea level rise (i.e. 2050 high emissions projection)	*Understand the degree of risk at crossings, considering inundation risk and headwater buildup conditions*
Adverse Impacts	Restoring full tidal range at the crossing will not adversely affect upstream infrastructure	*Understand the likelihood of restoring full tidal range at a crossing given upstream low-lying infrastructure*

Assessment parameter instructions and evaluation criteria details are provided in their respective sections of this document.

Desktop and Field Assessment Components:

The Tidal Protocol includes desktop and field evaluation components to take full advantage of a variety of useful data sources. Desktop derived information is combined with site specific data that must be collected in the field. The desktop component relies partly on the use of a GIS to access geospatial data layers; it also relies on transportation infrastructure managers to provide site specific crossing information. The following geospatial data layers are recommended to complete the desktop evaluations:

- Hydrography flow lines
- Public and private roads
- Watershed boundary for each crossing
- National Wetlands Inventory (NWI) using all E2EM% records
- High resolution orthophotography
- USGS topographic maps
- High resolution topography (e.g. LiDAR)

A trained field crew should be able to complete the field assessment at most tidal crossings in approximately two hours. More complicated sites requiring multiple level setup locations to complete the longitudinal profile (because of steep road fill slopes or line of sight obstructions) will likely take longer. The field crew must plan accordingly, as **site visits must correspond with low tide conditions**. Visits to downstream (i.e. closest to the ocean) crossings need to be closely timed with low tide from the nearest tide chart; crossings further upstream will likely have a delayed and somewhat greater window of time at low-tide conditions.

Assessment Parameter Data Collection and Management

As of the protocol's publication date, desktop and field assessment data are captured in a Microsoft Excel based field data sheet (see field datasheet in Appendix A). Items in the *Assessment Parameters* section of the Tidal Protocol follow the order of items organized in the field data sheet, which groups field parameters and desktop parameters for efficient use. The Microsoft Excel field data sheet file includes three primary worksheets: (1) "Data Sheet – BLANK" is a blank version of the Tidal Crossing data sheet, (2) "Data Sheet – SITE" is the worksheet to enter site specific assessment parameters that feed into (3) "Data Sheet – SUMMARY", which is a template for summarizing site specific evaluation criteria and assessment parameters. These tools are still under development, and are detailed further in the *Data Processing* section. We intend to incorporate the Tidal Protocol's assessment parameters into ArcGIS Collector, Esri's mobile mapping application, for streamlined data collection and management prior to implementing the protocol in the Spring of 2018. A new set of reporting tools will be needed for that data collection and management platform.

Equipment for Field Assessments

Field evaluations are completed at each crossing site. The following list of equipment is required to complete the field evaluation:

- Datasheets, clip board, pencils (including extra copies of Page 2 for multiple structures at one crossing)
- Digital camera
- Tape measure (300' in decimal feet) with weight attachment for depth measurements and to anchor for longitudinal profile

- Level survey instrument, tripod, 25-foot leveling rod in decimal feet
- Mallet/Hammer and wooden survey stakes
- Machete/Loppers to remove obstructing vegetation
- Chest waders
- Safety equipment: Personal flotation device, sun block, water, insect repellent
- Cell phone
- First aid kit
- Boat (e.g. small kayak) for sites with deep pools
- Vegetation species identification field guide, e.g. A field Guide to Coastal Wetland Plants of the Northeastern United States, Ralph W. Tiner, 1987.

Before attempting to complete a tidal crossing assessment, it is critically important to understand your equipment and how to use it properly. Review the calibration protocol for your level instrument, and make sure you understand how to read elevations from the leveling rod (including the sequence of extending rod sections). Also, make sure that you consistently collect your measurements in decimal feet units.

Safety Precautions for Tidal Assessments:

The field crew's safety and the safety of the public at large is paramount, much more important than collecting every parameter of the protocol. Do not collect any parameter that puts you or others at risk. Below is a summary of some of the known safety risks and precautions that should be taken:

- **Traffic**: some assessment parameters will be collected in the roadway, and the field crew will likely need to cross the road to complete a site assessment. Wear a reflective safety vest and do not collect features that put you or motorists at risk. If it is a high-volume road follow the protocol instructions to collect alternate features, if needed
- The longitudinal profile collects elevations using a telescoping leveling rod up to 25 feet high. Be aware of **overhead utility lines** and take care not to collect any features that potentially puts the rod in contact with overhead utilities
- Follow **wader safety** guidelines, including:
    - Wear a personal flotation device
    - Move slowly to stay in control and minimize falling; expect slippery conditions
    - Beware of mucky substrate that you may sink into, uneven footing, poor visibility into the water, and variable water currents
    - Use the leveling rod as your third point of support. Always maintain two points of contact as you move. In deeper areas, test depths with the leveling rod to make sure you don't overtop the waders
    - Use of a wading belt is mandatory—if you fall over it keeps water from flowing into the legs and boots of the waders, allowing for easier escape from the river
    - Walk forward, not backward. Find stable footing around rocks and boulders rather than stepping on slippery high points
    - Use common sense- do not wade into an area that is clearly too deep or where water velocities are too fast

    - Use caution when entering a stream crossing structure. Be alert for hazards on the ceiling, uneven footing, and increased flow velocities in the structure. Never enter a structure without another person watching for your safety
- Marine clay, which is inevitable and abundant in tidal habits, is extremely **slippery**. Slippery conditions exist within the stream, along the stream banks, on the salt marsh, and along the road fill slope. Use caution when moving around and through these slippery conditions
- New Hampshire's salt marshes are lined with historic **ditches**, some fairly small and some deep and wide. Ditches can be grown over and present a hidden tripping or falling hazard. If you can't easily step over a ditch, or navigate across the ditch easily, walk around the ditch or to a point where you can easily step over. Take care when pushing off and landing, as ditch edges can be slippery, slough off, and be hidden under droopy tall grasses
- Be prepared for **biting insects**. Consider wearing long sleeved clothes and using insect repellent. Check closely for ticks after each field day
- Coastal roadsides and upland salt marsh edges are often infested with **poison ivy**. Take care to identify poison ivy and avoid contacting it, especially if you are allergic
- Many tidal crossing sites are exposed, with limited shading and relief from the **sun**. Be prepared with sunscreen, ample water, sunglasses and a hat

Assessment Parameters:

This section provides descriptions of the Tidal Protocol's assessment parameters and instructions to collect them. Assessment parameters are used to measure site specific crossing characteristics; they are collected both in the field and from the desktop. Field assessment parameters are collected on-site through quantitative and qualitative measures while desktop assessment parameters are collected using local information (i.e. information collected from road managers) and GIS.

The order of the assessment parameter descriptions and instructions follows the order of assessment parameters organized in the field data sheet (see Appendix A). The field data sheet includes multiple sections broken out by group; these groups are organized to maximize data collection completeness and efficiency. The groups of assessment parameters include:

- Site Visit Details (field assessment)
- Low Tide Photos (field assessment)
- Crossing Type & Condition (field assessment)
- Crossing Cross Section and Stream Longitudinal Profile (field assessment)
- Salt Marsh Vegetation (field assessment)
- Other Site Observation (field assessment)
- Infrastructure Management (desktop assessment)
- GIS-Based Crossing Information (desktop assessment)

The following table is a template that details how the assessment parameter name, location, description, list of attributes, and description of attributes are presented throughout this section of the protocol. Not every parameter consistently fits into this template; however, instructions are provided for each parameter to ensure that field assessment teams have the information needed to conduct assessments consistently.

Parameter Name ***List of multiple assessment locations (e.g. Upstream, Downstream)***	Parameter description
List of assessment parameter attributes (*in many cases this will be a list of pre-defined selection options; in others, it will be a list of attributes to collect*)	Descriptions of assessment parameter attributes

Site Visit Details *(field assessment)*

This section provides details about the site visit including who completed the assessment, the site location, when the assessment was completed, and tide cycle information.

Crossing ID	Predetermined unique identifier for each assessment site.

Observer(s) & Organization	Record all those involved in the field assessment and their organization or affiliation (e.g. volunteer, student).

Municipality	City or town where the crossing occurs.

Stream Name	Stream name as identified by the New Hampshire Hydrography Dataset (NHHD) program.

Road Name	Road name from the New Hampshire Department of Transportation roads data layer.

Date	Record the date that the field assessment was performed on (mm/dd/yyyy).

Start Time	Time that assessment started (hh:mm AM/PM).

End Time	Time that assessment concluded (hh:mm AM/PM).

Tide Prediction	These fields are intended to collect information from the nearest tide chart for the day of the field assessment. Fields include:

Time	Record the predicted time of high and low tides from the nearest tide chart (hh:mm AM/PM)
Elevation	Record the predicted elevation of high and low tides from the nearest tide chart
Tide Chart Location	Indicate the name of the tide chart location used for the Time and Elevation parameters

General Assessment Notes	Provide any general notes about the site visit and assessment. For example, document recent precipitation, encounters with landowners (and their names), etc.

Low Tide Photos *(field assessment)*

Photographs are collected to document the appearance of the crossing structure and the associated stream and tidal system. Photographs are especially useful during data processing and verification, and are essential for data quality control. Instructions are modified from NHDOT (2017).

Photo File Names	A minimum of four photos are required at low tide. Indicate the Photo File Name in the datasheet table for each of the respective photos required as detailed below and in the photo point illustration (Figure 2). Be sure to include scale in your photos, such as a person or a survey rod, especially when photographing the structure openings (photos 1 & 4).
① View of upstream opening	Photograph the upstream opening of the structure. The photo should be taken a reasonable distance upstream from the structure with the widest-angle setting. If site conditions permit, include the roadway approaches, the land adjacent to the channel, armoring features (e.g. riprap, if present), and any other notable or relevant assessment features.
② Upstream view from above structure	Positioned above the upstream side of the structure, photograph the upstream stream system, including the land adjacent to the channel upstream of the crossing.
③ Downstream view from above structure	Positioned above the downstream side of the structure, photograph the downstream stream system, including the land adjacent to the channel downstream of the crossing.

④ **View of downstream opening**	Photograph the downstream opening of the structure. The photo should be taken a reasonable distance downstream from the structure with the widest-angle setting. If site conditions permit, include the roadway approaches, the land adjacent to the channel, armoring features (e.g. riprap, if present), and any other notable or relevant assessment features.
	Additional spaces are available for additional photos. Photograph any other features or parameters from the field form that you feel might be questioned later, or a feature that you have uncertainty or questions about. Take additional photos if necessary to characterize the system and structure. Note the photo file and describe the photo.

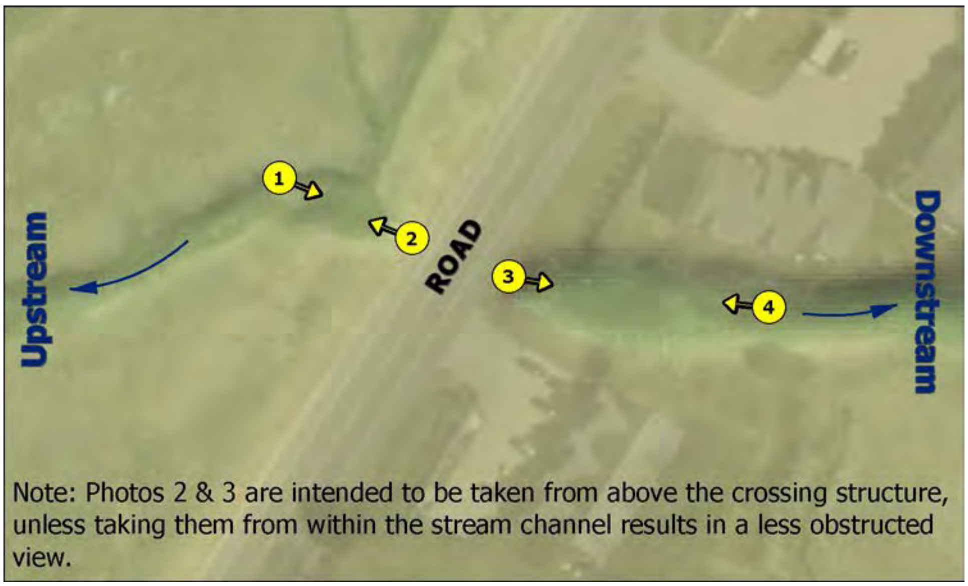


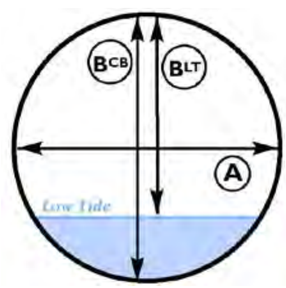
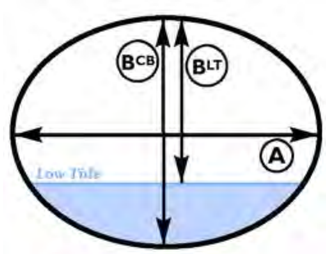
Figure 2. Sample illustration of photo point locations and photo directions for the four required photo points.

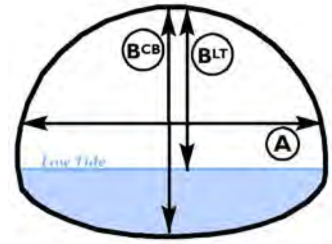
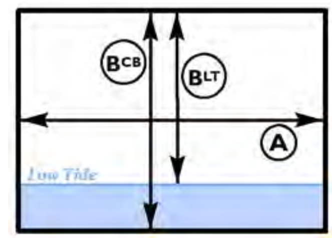
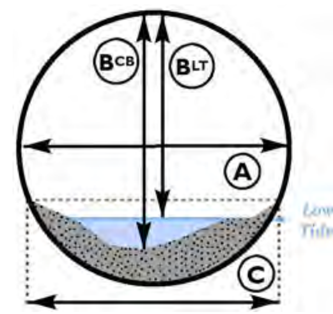
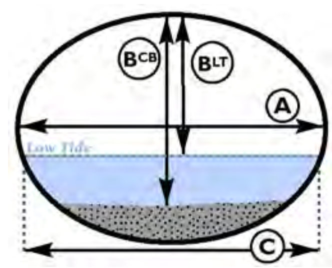
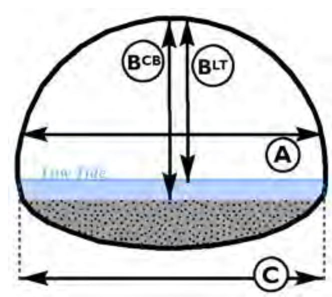
Photo Comments	Provide any relevant comments regarding the photos captured.

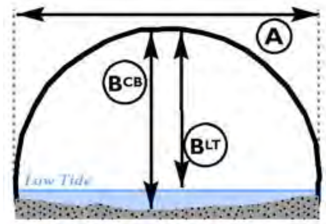
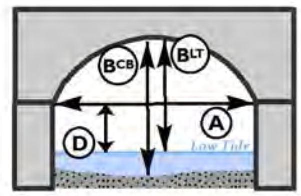
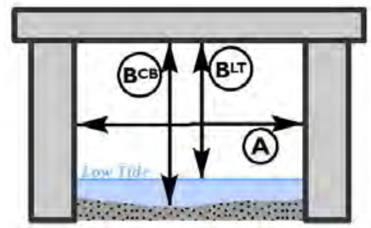
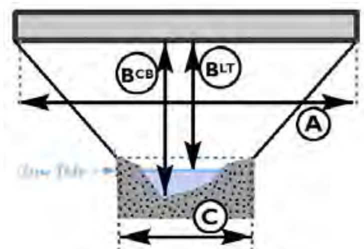
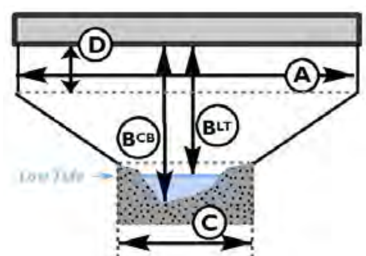
Crossing Type & Conditions *(field assessment)*

The crossing type and condition assessment characterizes the crossing structure and its components including the collection of crossing structure dimensions. The condition of the crossing structure and its components are also assessed, including assessments of scour that can compromise a crossing's structural stability. Many of the assessment parameters and attributes are borrowed or modified from NHDOT (2017).

Structure ____ of ____ at Crossing	For crossings with just one structure, enter "1" of "1". For crossings with multiple structures, record the structure you are assessing (the first as "1", the second as "2" and so on) and the total number of structures at the crossing. For example, if you are assessing the second structure at a crossing with three structures total, enter "2" of "3". Typically, there is one structure per road crossing, but situations exist where multiple structures occur at one crossing site. Count all structures that are installed at or below the existing high water indicator. Do not count overflow structures or nearby structures carrying tributary or road drainage flows (i.e. those not installed to carry typical tidal flow).

Crossing Type	Select the most appropriate crossing structure type based on the options below. The required crossing dimensions are shown for the respective crossing type, which will be addressed in the *Crossing Dimensions* assessment parameter.	
Round Culvert	A circular structure with a closed bottom	
Elliptical Culvert	An oval structure with a closed bottom	

Pipe Arch Culvert	An oval structure with a closed bottom; the shape of the lower portion of the structure appears "squashed"	
Box Culvert	A square or rectangular structure with a closed bottom, usually made of concrete or stone blocks	
Embedded Round Culvert	A circular structure with a closed bottom; the bottom of the structure is buried by streambed materials	
Embedded Elliptical Culvert	An oval structure with a closed bottom; the bottom of the structure is buried by streambed materials	
Embedded Pipe Arch Culvert	A pipe arch structure (as described above) that's bottom is buried by streambed materials	

Open Bottom Arch	A semi-circular structure with an open bottom	
Arch-Bridge	An arched bridge deck set on abutments with an open bottom	
Bridge with Abutments	A relatively flat bridge deck set on abutments with an open bottom	
Bridge with Side Slopes	A relatively flat bridge deck with angled side slopes and an open bottom; no abutments are visible or abutment height from side slopes are not measurable	
Bridge with Side Slopes & Abutments	A relatively flat bridge deck set on abutments with angled side slopes and an open bottom. The side slopes extend from the abutments toward the stream channel	
Other	Select “Other” if the crossing type is different from the available crossing type options. Provide a description in “Crossing Type/Condition Comments”	

Structure Materials	Identify the material listed below that best describes the construction of the crossing structure. Focus on the structure that conveys the stream beneath the road; headwall and wingwall materials are captured in subsequent assessment parameters.	
Concrete	**Stone**	**Aluminum-Corrugated**
Plastic-Corrugated	**Steel-Corrugated**	**Wood**
Plastic-Smooth	**Steel-Smooth**	**Other**

Crossing Dimensions ***Upstream*** ***Downstream***	Document the upstream and downstream structure dimensions as indicated in the diagrams provided in the "Crossing Type" section. Not all dimensions are required depending on the crossing type.
Dimension A	Measure the interior width of crossing
Dimension B^{CB}	Measure height from the ceiling of the crossing structure to the channel bottom (in the thalweg)
Dimension B^{LT}	Measure height from the ceiling of the crossing structure to the low tide water level
Dimension C	Measure width of stream channel at the break point between side slopes and the stream bed. For round or elliptical structures this is the embedded width of the natural bottom if exposed at low tide. *For any crossing type other than box and round culvert, if the embedded streambed is submerged at low tide, measure the width of the channel at the low tide water elevation (see embedded elliptical culvert example).*
Dimension D	**For Arch Bridge:** Measure height from low tide water elevation (or exposed streambed elevation at low tide) to the start of the arch **For Bridge with Side Slopes and Abutment:** Measure height of vertical abutments from underside of bridge to where sides start sloping.

Low Tide Perch

Upstream

Downstream

Measure the upstream and downstream low tide perch in decimal feet, or indicate if not applicable (N/A). Low tide perch is measured as the invert's height above the immediate upstream or downstream channel, respectively, if all the following conditions are present:

1. There is a vertical drop between the invert and the respective upstream or downstream channel at low tide
2. The vertical drop creates a waterfall or cascading barrier feature that impedes aquatic organism passage at low tide
3. The respective low tide water elevation is below the invert elevation (i.e. the invert and the respective upstream or downstream channel is not covered by relatively flat low tide water)

Low tide perch on the upstream side of the crossing is uncommon; it might present itself at sites where there is little or no flow at low tide or where flow is seeping underneath the crossing structure.

Photo document the low tide perch in the "Low Tide Photos" section, especially if there is any question about what features to measure. Measure multiple features if necessary and collect photos indicating the different features measured (use the leveling rod to indicate the location of the measurement and to provide scale).

Note: The longitudinal profile will capture the elevations of inverts and the upstream and downstream low tide water elevations (low tide water elevations should be taken where the water flattens out in the adjacent pool feature). ***The perch feature should also be captured in the longitudinal profile if it is present.***

High Tide Perch

Measure the downstream high tide perch in decimal feet, or indicate if not applicable (N/A). High tide perch is measured as the invert's height above the downstream channel if all the following conditions are present:

1. There is a vertical drop between the invert and the downstream channel at high tide
2. The vertical drop creates a waterfall or cascading barrier feature that impedes aquatic organism passage at high tide

	3. The high tide water elevation is below the invert elevation (i.e. the invert and the downstream channel is not covered by relatively flat high tide water) Since the assessment will occur around low tide, high tide perch can be calculated based on the difference between the downstream highwater stain indicator (MHHW) and the downstream invert elevation.

Headwalls, Wingwalls, and Scour Parameters

The following group of assessment parameters address upstream and downstream headwall materials, headwall condition, wingwall materials, wingwall condition, scour at structure, and scour severity. Complete the upstream assessment for all the parameters, followed by the downstream assessment. Figure 3 identifies the different structural components of a crossing structure, such as the headwall, wingwall, abutment, and footer.

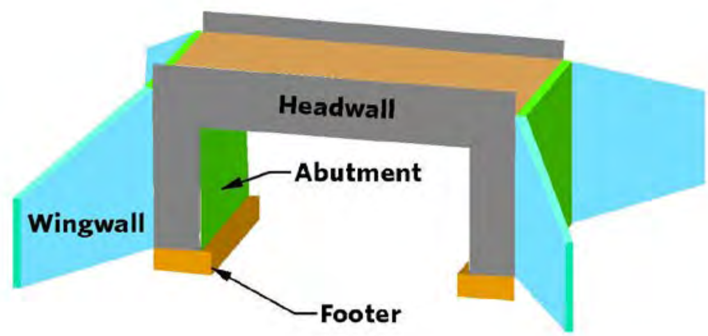


Figure 3. Schematic illustrating the headwall, wingwall, abutment, and footer of a crossing structure.

Headwall Materials ***Upstream*** ***Downstream***	Indicate the material of the upstream and downstream headwalls. The headwall is a retaining wall installed parallel to the fill slope of the crossing to protect against scour and erosion around the openings of the crossing structure.
Metal	Continuous metal wall, such as sheet piling
Concrete	Preformed or cast in place concrete
Masonry	Mortared stone or brick
Gabion	Wire filled cages of rock or stone
Riprap	Loosely placed large stone, often angular
Other	Other material not listed. Specify in “Crossing Type & Condition Comments” section
None	No headwall present

Headwall Condition ***Upstream*** ***Downstream***	Select the option that best describes the overall condition of the upstream and downstream headwalls.
Good	Headwall is intact and appears in good condition. • Metal: surficial rust may be present • Concrete: shows little or no sign of spalling/deterioration • Masonry: mortar joints are intact and tight • Gabion: cage is intact and shape is not malformed • Dry Fit Stone/Riprap: materials are in place as expected when originally installed
Fair	Signs of deterioration are present; headwall structure is still functional but will require maintenance in the near-future. • Metal: rust is beyond surficial resulting in loss of wall thickness • Concrete: consistent moderate spalling/deterioration of concrete is present (>¼”, <3”). Minor cracking may be visible • Masonry: mortar joints are loose or missing but overall headwall shape has not malformed • Gabion: cage is malforming or beginning to deteriorate • Dry Fit Stone/Riprap: materials have shifted/eroded and are not fully supporting themselves around the structure opening; scour into the road fill slope is limited
Poor	Significant signs of deterioration are present; headwall structure is failing and requires immediate maintenance. • Metal: holes are widespread • Concrete: consistent severe spalling/deterioration of concrete is present (<3”). Rebar reinforcement or large cracks may be visible • Masonry: mortar joints are missing and brick/stone material is falling out of place • Gabion: cage is malformed and disassembling • Dry Fit Stone/Riprap: materials have eroded and are not supporting themselves around the structure opening; scour is eroding into the road fill slope
N/A	Headwall is not present to evaluate condition.

Wingwall Materials ***Upstream*** ***Downstream***	Indicate the material of the upstream and downstream wingwalls. Wingwalls are retaining walls installed adjacent to the headwall to direct flow into the crossing structure. They are often installed at an angle extending out/away from the road fill slope. See "Headwall Materials" section for descriptions of selection options.

Wingwall Condition ***Upstream*** ***Downstream***	Select the option that best describes the overall condition of the upstream and downstream wingwalls. See "Headwall Condition" section for descriptions of selection options. If the wingwalls are separating from the headwall, indicate Wingwall Condition as **Poor**.

Scour at Structure ***Upstream*** ***Downstream***	Identify the crossing structure component(s) that is compromised by scour (select all that apply). Scour results from the removal of materials (e.g. fine sediment, sand, gravel, cobble, or boulders) by flowing water. Indicators of scour can include: • Exposed areas of a structure that are typically covered by stream bed material (e.g. bridge footings) • Leaning or hanging (perched) structures • Structure materials sloughing into the channel • Water visibly flowing under or to the side of a culvert • Deep water along one or both sides of a bridge or arch when the bed feature through the structure is a riffle Selection options include the following:

None	**Footer**	**Abutment**	**Armoring**
Culvert	**Wingwalls**	**Headwall**	

Severity of Scour ***Upstream*** ***Downstream***	Select the severity of scour for the respective upstream and downstream features identified in "Scour at Structure". **The severity rank should reflect the most severely scoured structure component.**
None	No scour is observed

Low	Limited scour is present that presents no apparent threat to the crossing structure (e.g. finer material is no longer present)
Medium	Noticeable scour is present. Left unmaintained, scour will continue to undermine and jeopardize the structure component
High	Severe scour is present that jeopardizes the crossing component or crossing structure as a whole. Immediate maintenance is required

Scour in Structure	Identify the crossing structure component(s) that is compromised by scour **inside the structure** (select all that apply). Scour results from the removal of materials (e.g. fine sediment, sand, gravel, cobble, or boulders) by flowing water. See "Scour at Structure" for examples of indicators of scour. Selection options include the following:	
None	**Footer**	**Channel**
Culvert	**Abutment**	**Armoring**

Scour Severity in Structure	Select the severity of scour inside the crossing structure for features identified in "Scour in Structure". The severity rank should reflect the most severely scoured structure component. See "Scour Severity" for descriptions of selection options.

Road Surface Condition	Select the condition of the road surface for the road segment that bisects the wetland system.
Good	Road surface is in sound structural condition; slight rutting or thin cracks may be present but are not deep or widespread. Road grade is uniformly smooth
Fair	Road surface shows signs of aging with moderate rutting, widespread cracking, loss of fine and coarse aggregate from the surface, patches, potholes (<2"), or pavement edge deterioration
Poor	Road surface is severely deteriorating or failing. Severe road surface distortion may be present such as heaves, ruts, or patches. Pavement is severely cracked or disintegrating with potholes prevalent. Road grade may be rough and/or bumpy

Structure Condition - Overall	Identify the condition of the overall structure (inlet, pipe, outlet) based on the following rating criteria.
Good	Like new, with little or no deterioration, consistent shape, minor joint misalignment, no movement, structurally sound and functionally adequate
Fair	Some deterioration or cracking, joint separation with minor infiltration but structurally sound, localized distortion in shape, functionally adequate
Poor	Significant deterioration or extensive cracking and/or spalling, extreme deflection in shape, joint separation with potential to create voids, significant movement and/or functionally inadequate requiring maintenance or repair

Sketch of Structure	A sketch box is provided to illustrate and provide detailed dimensions of the crossing structure, especially if the configuration of the crossing structure differs from the dimensions included in the "Crossing Dimensions" section. If additional space and/or sketches are needed, sketch them on a separate sheet, photograph the sketch and document the photo(s) in the "Low Tide Photos" section.

Crossing Type & Condition Comments	Provide any additional comments about the crossing type or condition.

Crossing Cross Section & Stream Longitudinal Profile *(field assessment)*

The Crossing Cross Section and Stream Longitudinal Profile collects relative elevations of multiple site features (i.e. assessment parameters). These assessment parameters apply to multiple management objectives and evaluation criteria including tidal restriction, aquatic organism passage, and infrastructure risk. An overview of the survey methodology is provided followed by details about the cross section and longitudinal profile assessment parameters.

Overview

The Crossing Cross Section and Stream Longitudinal Profile collects relative elevations of features at the crossing structure and in the stream channel. A cross section of features at the crossing structure are collected, including the ceiling of the crossing structure, high water indicators, marsh surfaces, and road surface elevations. The stream longitudinal profile captures the relative elevations and slopes of the stream channel and its features including pools, riffles, crossing structure inverts, and grade controls. The purpose of the longitudinal profile is to better understand the hydraulic performance of the crossing, its compatibility with the stream system, and the risk of flooding to the structure and roadway currently, and with sea level rise.

A survey instruments that captures relative elevations is required to complete this evaluation. A laser level system or optical level with a tripod, field tape and leveling rod are basic survey equipment essentials. A trained field crew will need to evaluate and determine how best to execute and complete the longitudinal profile survey at each site because of the variability in conditions at tidal crossings.

At a minimum, the field crew is likely to set up the survey instrument at the roadway (**R**) elevation to collect information about the road surface. In many cases the remainder of the elevation fields will be shot from the **R** setup. However, roads with considerable fill slopes or line of site obstructions to upstream and/or downstream features will require setting the level up upstream (**U**) or downstream (**D**) of the crossing to collect the remainder of the necessary elevation shots (see Process for Surveying Sites Requiring Multiple Level Setups section for more details). Each feature collected for the Crossing Cross Section and Stream Longitudinal Profile requires specification of the location from where the elevation was shot (i.e. **R** or **U** or **D**). This information is captured in the solid outlined box (☐) to the right of each feature's elevation field on the Microsoft Excel based field datasheet.

Establishing a Control Point

Once the field crew sets up the level at its initial **R** location it is necessary to establish a control point at the site. A control point is a location of a feature that will not change in the foreseeable future and that is easily locatable in the near-future. The control point serves as a reference point for quality control in case the survey instrument inadvertently shifts during the assessment, or if the assessment team needs to re-visit a crossing site to collect missed or additional information without having to recollect the entire longitudinal profile to relate elevations to one another.

To establish a control point, locate a relatively permanent surface beyond the road travel lanes that can be easily identified and described. A stable headwall, large stable boulder, or a point along the edge of the pavement are potential locations. Mark the location of the control point with a silver dollar sized dot of orange spray paint. This is the point that you will collect your control point elevation from at the beginning and end of the longitudinal profile survey and that you will need to describe the location of in the "Describe Control Point" field. Be as specific as possible in your description. For example, "orange dot on center of downstream headwall" or "orange dot along upstream edge of pavement at the center of the crossing". Field crews with GPS capabilities should consider collecting the location of the control point.

Quality Control and Quality Assurance

Collecting the height of the established control point at the beginning and end of the longitudinal profile is an important quality control and assurance measure. If the elevations are the same, then there is assurance that the level instrument didn't shift during the survey and that collected elevations are properly referenced relative to one another. If the before and after elevations are different (>0.1 feet @

100 feet away) then the relative elevations of the longitudinal profile might be inaccurate. Re-stabilize and level the instrument and recollect the elevations for the features in question.

Also, a somewhat common mistake when using a leveling rod is to have different sections of the rod improperly extended or extended out of sequence. This leads to erroneous height measurements. To properly use a laser level compatible leveling rod with a laser level make sure to extend the top most section to its desired length (elevation). If multiple sections of rod are necessary, make sure to extend the top section of the rod until fully extended, then extend the next highest section of rod to the desired height, or fully extend before extending the next highest section (and so on). **Make sure that all lower sections of rod are not extended until needed**. Read the elevation from the back of the rod; take the reading from the top of the smallest unextended section.

Note: when using an optical level the rod must be fully extended from the bottom most section first, followed by fully extending the next lowest section, and so on.

Process for Surveying Sites Requiring Multiple Level Setups

The characteristics at some sites will require setting up the survey instrument at multiple locations to collect the necessary elevation shots to complete the cross section and longitudinal profile. This might occur at crossings with very high fill slopes where the road surface is significantly higher than the stream channel, or at locations where line-of-sight obstructions, such as dense vegetation, prevent the collection of elevations with a level instrument. A 25-foot surveyor's leveling rod is recommended to maximize the elevation range of the longitudinal profile from a single level setup location. A 25-foot rod will allow for the collection of elevations up to 25 feet below the level instrument; elevations of longitudinal profile features greater than 25 feet below the instrument will require setting the instrument up at additional locations upstream and/or downstream to collect those features.

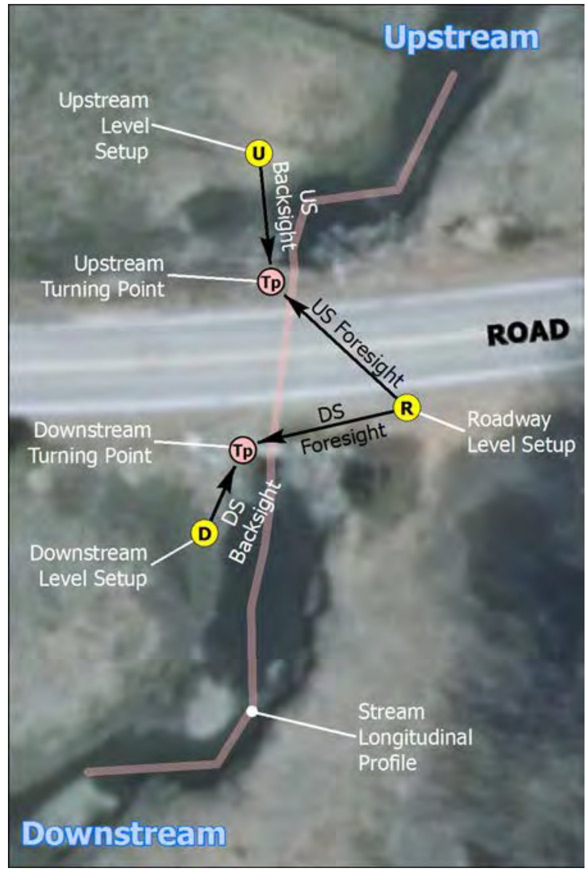
It is necessary to develop a well thought out plan to execute an efficient cross section and longitudinal profile where multiple level setups are needed. An example is provided in Figure 4, which illustrates three level setup locations and the turning point foresights and backsights required to relate elevations between them. Consider the location of your roadway level setup (the first place where the level is setup) in relation to your other potential level setup locations and turning points. You will need to establish or identify turning points (detailed further in step 5 below) and collect their elevations to relate the elevations from your roadway level setup to your upstream and/or downstream (secondary) setup(s) through a series of foresights and backsights (detailed further in steps 6 and 9 below, respectively). Consider potential line of sight obstructions when selecting turning points, such as structures or vegetation between your roadway level setup and turning point, as well as your secondary setups and turning points. Also, consider the elevation range limitations when determining turning points. If you are using a 25-foot leveling rod your turning point elevation must be within a 25-foot vertical range of the roadway level setup, and the secondary level setup must be higher than the elevation of the turning point.

Below are general steps to complete a longitudinal profile at a site that requires three setup locations for the level, including a roadway, upstream, and downstream location:

1. Review the crossing site layout and identify the location of the roadway level setup, turning point locations, and upstream and downstream level setup locations. Make sure that there are no visual obstructions between the respective level setups and the turning point locations.

2. Setup the level at the roadway. Establish and collect the elevation of the control point, road centerline at the center of the crossing, and road surface elevations.
3. Collect as many of the high-water indicator (HWI) features, ceiling of the crossing structure, and high marsh elevations upstream and downstream of the crossing as possible.
4. Starting from upstream, collect as many of the upstream and downstream longitudinal profile features as possible from the roadway level setup, including the low tide water elevation, if it is within the vertical range of the leveling rod and not limited by line of site obstructions.
    a. If it will be easier or more efficient to collect all the upstream and downstream longitudinal profile features from their respective upstream or downstream level setups, disregard step 4.
5. Establish upstream and downstream turning points. A turning point can be a stable, permanent or semi-permanent feature that will relate elevations between the roadway level setup and the respective secondary level setup. A large boulder, ledge, or headwall could serve as a turning point. For these features, spray paint a half dollar sized orange dot onto the feature at a flat surface or high point where the point's elevation will be taken. If no such feature is available drive a wooden survey stake into the ground at the desired turning point location until it is firmly in place and the elevation at the top of the stake is satisfactory. The top of the stake will be the turning point elevation.
    a. In many cases the turning point is different from the established control point. In some cases, the control point can be used as the turning point if it is within vertical and line of sight range of both the roadway and the respective secondary level setup.
6. Once the necessary turning points are established, collect the elevation (foresight) of the upstream and downstream turning points from the roadway level setup.
7. Re-collect the height of the established control point for quality control and assurance purposes. If the control point elevation is less than 0.1 feet different at a distance of 100 feet away, continue to the next step. If not, repeat steps 2 through 7
8. Reposition the level instrument to the upstream setup location
9. Collect the elevation (backsight) of the upstream turning point
10. Collect elevations for the remainder of the upstream longitudinal profiles features, low tide water elevation, HWI features, ceiling of structure, and high salt marsh elevations. Verify that all upstream features are collected.

Figure 4. Illustration of a site with three level setups, including the Roadway (R), Upstream (U), and Downstream (D) locations. Also shown are the turning points and the turning point foresights and backsights required to relate elevations between three level setups.



11. Re-collect the backsight elevation of the upstream turning point. If the backsight turning point elevation is less than 0.1 feet different at 100 feet away, continue to the next step. If not, repeat steps 9 through 11.
12. Follow steps 8 through 11 to complete the cross section and longitudinal profile for the downstream side of the stream crossing.

Crossing Cross Section and Stream Longitudinal Profile Assessment Parameters

Following are the assessment parameters, descriptions, list of attributes, and instructions for the crossing cross section and stream longitudinal profile.

Height of Established Control Point	Measure the height of the established control point in decimal feet. Establish the control point at an easily identifiable, describable, and relatively permanent surface beyond the road travel lanes. A stable headwall, large stable boulder, or a point along the edge of the pavement are potential locations. If no such feature is available drive a wooden survey stake into the ground at a desired control point location (away from the roadway) until it is firmly in place and the elevation at the top of the stake is satisfactory. In this case the top of the stake will be the control point elevation. Mark the location of the control point with a silver dollar sized dot of orange spray paint; this is the point where you will collect the control point elevation.

Describe Control Point:	Describe the location of the established control point. Be as specific as possible in your description. For example, “orange dot on center of downstream headwall” or “orange dot along upstream edge of pavement at the center of the crossing” or “wooden survey stake driven into north western quadrant of salt marsh 20’ from road edge”.

Height at Road Centerline	Traffic and safety permitting, collect the elevation of the road centerline at the center of the crossing structure in decimal feet. This parameter is collected as a reference point to tie the longitudinal profile into high resolution topographic information. The centerline of the road at the crossing structure is an easy feature to identify using high resolution orthophotography. Note the location of a different reference point used in the Comments field, if applicable (applies especially to high volume roads where surveying the centerline is dangerous). For alternative locations, attempt to use a broad flat surface that can be located on an aerial photo. For example, higher volume roads typically have a white stripe differentiating the travel lane from the breakdown lane. Collecting

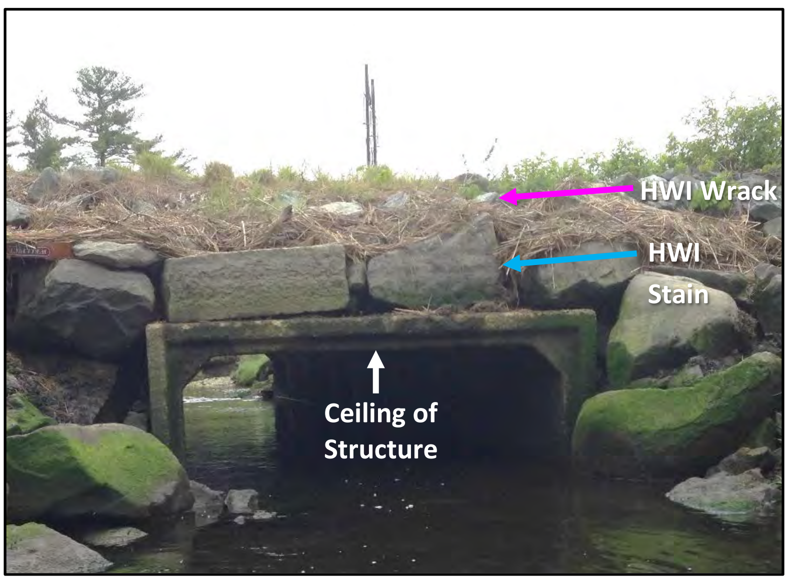
	the elevation of the white stripe centered over the up or downstream side of the crossing structure alignment is an option.

Low Tide Water Elevation ***Upstream*** ***Downstream***	Collect the upstream and downstream water level elevations at low tide in decimal feet. It is important to make sure that these elevations are collected as close to low tide conditions as possible. Collect the water level elevation at pooled or standing water elevations beyond any grade control features associated with the crossing.

Crossing Cross Section

The following group of assessment parameters captures elevations of features that can be used to generate a cross section of the crossing (e.g. an elevation profile perpendicular to the road). Features to collect include upstream and downstream high water indicators (HWI) for stains and wrack lines, the ceiling of the crossing structure, the road surface, and salt marsh plain elevations. Figure 5 depicts a selection of these features. Collection of these features are grouped together in the datasheet because they can be collected out of sequence with the Stream Channel Longitudinal Profile (these features can be collected well before or after low tide).

Figure 5. Examples of a selection of crossing cross section assessment parameters.



***HWI Wrack**: the magenta arrow indicates the upper extent of wrack deposits above the headwall*

***HWI Stain**: the blue arrow indicates the upper extent of the high-water stain. Collect the high-water stain elevation at the upper stain limit*

***Ceiling of Structure**: the white arrow indicates the location of the ceiling of the crossing*

***Not Shown**: Road surface and salt marsh plain*

The Stream Channel Longitudinal Profile is best collected at low tide conditions, so prioritize its collection when constrained for time around low tide. Invert elevations are collected in sequence in the longitudinal profile, thus their absence from this section. Collect upstream and downstream elevations for each of the features below, making sure to indicate the level setup where the elevation was shot from (specify **R** or **U** or **D** in the solid outlined box (☐).

HWI Stain ***Upstream*** ***Downstream***	Collect the elevation at the upper limit of the stain feature observed at or near the crossing structure in decimal feet (see Figure 5).

HWI Wrack ***Upstream*** ***Downstream***	Collect the elevation at the upper limit of wrack or debris accumulations at or around the crossing structure in decimal feet. Wrack lines may include matted clumps of vegetation deposited along the road fill slope at high tide elevations. Finer vegetation and other debris may also cling to the headwall and inside the crossing structure; look for lines of such materials above the stain features (see Figure 5).

Ceiling of Structure ***Upstream*** ***Downstream***	Collect the elevation of the ceiling of the crossing structure in decimal feet (i.e. where you'd bump your head at the highest point when crossing through the structure—see Figure 5).

Road Surface ***Upstream*** ***Downstream***	Collect the road surface elevation at the lowest point where the road crosses the tidal system (including the salt marsh and adjacent floodplain). For this assessment parameter, road surface is defined as the edge of pavement elevation where the road is most susceptible to inundation.

Marsh Plain Shots (1 through 4) ***Upstream*** ***Downstream***	A total of eight salt marsh plain elevations are to be collected in decimal feet, four upstream and four downstream. The purpose of collecting these elevations is to determine if the crossing structure has a noticeable influence on marsh subsidence (loss of elevation due to oxidation of peat) or accretion (i.e. the ability of the marsh to build in elevation with sediment deposition from frequent flooding). When identifying marsh plain locations, consider the following:
▪ Identify and collect elevations from marsh locations that are typical of the marsh system (whether high or low marsh) ▪ Where possible, collect marsh elevations on both sides of the channel	

- To collect representative elevations, avoid taking elevations within approximately 50 feet of one another
- The salt marsh plain is typically quite flat. Avoid locations where there are oddities in the terrain, such as near ditches, along or atop areas of historic fill such as berms, etc.
- The assessment team might need to identify marsh locations some distance beyond the crossing if the marsh directly adjacent to the crossing structure is altered, disturbed, or not present
- Where possible, key in on similar vegetation, such as *Spartina patens*, because it might be most competitive at a specific/consistent inundation regime both upstream and downstream that is valuable for comparison purposes
- Where possible, avoid locations where the marsh plain contains hummocks (small mounds of clumped vegetation) surrounded by hollows (lower unvegetated areas). This indicates that the marsh vegetation and marsh elevation is in transition (due to sea level rise). In these cases, the marsh is changing from high marsh to low marsh. If such conditions are widespread, collect elevations from the hummocks rather than the hollows, as the hummocks represent current and recent marsh plain elevations, while the hollows will represent future elevations once transitioned to low marsh.

Comments	Provide any additional comments or clarifications about the crossing cross section or stream channel longitudinal profile.

Survey Turning Points

At sites requiring multiple level setups (see Process for Surveying Sites Requiring Multiple Level Setups, above, and Figure 4), collection of turning points are necessary to relate the elevations collected from different locations. For example, if an upstream level setup is required you will need to establish an upstream turning point. Once established, collect the upstream foresight elevation of the turning point from the roadway level setup (record the value in the field corresponding to TP Foresight and US Height). Then move the level to its upstream location. From the upstream level setup location, collect the backsight elevation to the upstream turning point (record the value in the field corresponding to TP Backsight and US Height). Follow this procedure for downstream turning point foresights and backsights.

IF NEEDED	US Height	DS Height
TP Foresight	From the **ROADWAY** level setup, collect the upstream (US) turning point elevation in decimal feet	From the **ROADWAY** level setup, collect the downstream (DS) turning point elevation in decimal feet
TP Backsight	From the **UPSTREAM** level setup, collect the upstream (US) turning point elevation in decimal feet	From the **DOWNSTREAM** level setup, collect the downstream (DS) turning point elevation in decimal feet

Stream Channel Longitudinal Profile

The stream channel longitudinal profile captures elevations and attributes of stream channel features along the stream reach where the crossing occurs. These features are used to generate a profile based on distance and elevation measurements collected at specific features of interest, such as hydraulic controls, scour pools, grade controls, and crossing inverts, which are identified using feature codes. Streambed substrate is collected at each feature too.

The first step in collecting the longitudinal profile is to identify an upstream starting point. The starting point should be at least two hydraulic controls upstream of the upstream pool. To locate the starting point, work your way upstream from the crossing and locate the high point upstream of the pool (this will be the second hydraulic control in the longitudinal profile survey). Continue heading upstream in the channel thalweg to locate the next notable channel high point, which will be the starting point. If the stream channel profile is fairly uniform upstream of the first high point encountered, continue upstream a distance approximately equal to the distance between the crossing structure and the first high point location to locate the starting point. The distance at the starting point is 0.0 feet.

Anchor the end of a 300’ tape at the starting point using a heavy weight or some other anchoring device. It is important that the tape remain securely anchored to accurately collect the longitudinal profile. Run the tape measure along the length of the channel thalweg from the starting point to an endpoint located two hydraulic controls below the downstream pool (or similar point based on distance as described above). Attaching a second tape may be necessary to cover the distance of the longitudinal profile, or the anchor point may need to be shifted downstream once the first section of the profile exceeds the length of the tape.

The longitudinal profile characterizes the elevations and slopes of the stream channel and the crossing structure. Essential components of the longitudinal profile are shown in Figure 6, and include the following:

- **Hydraulic controls** are channel features that control the flow and depth of water
- **Scour pools** are erosional features above and below the crossing that can indicate incompatibilities of the crossing structure with the stream
- **Grade controls** include channel substrate hardening around the crossing structure to reduce scour and undermining of the structure.

- **Inverts** are the low points inside of the crossing structure at the upstream and downstream openings. Invert elevations are important to understand the vertical alignment of the crossing structure with the surrounding tidal system.
- **Channel bottom** features can be collected to provide additional detail about the channel slope that are not characterized by the features listed above. For example, at a perched downstream crossing at low tide, collect the channel bottom elevation just downstream of the perched invert to characterize the degree that the crossing structure is perched above the downstream channel.

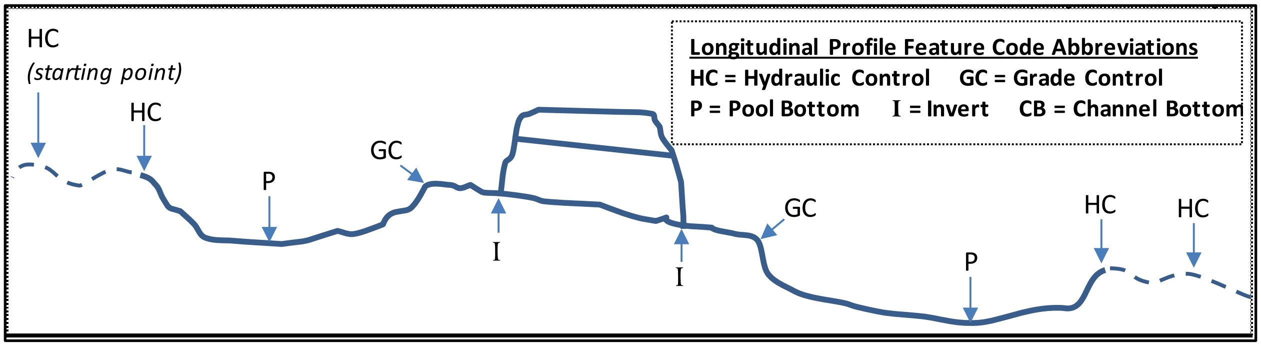


Figure 6. An example of a stream channel longitudinal profile, including the features of interest and their codes.

For the starting point feature of the stream channel longitudinal profile, and each feature to follow, collect the following information:

Distance	Collect the distance from the starting point along the tape measure in decimal feet.

Height	Collect the elevation of the feature in decimal feet using the survey instrument.

Feature Code	Identify the feature being collected using a feature code from the following list:
HC	Hydraulic Control
P	Pool Bottom
GC	Grade Control
I	Invert
CB	Channel Bottom

Substrate	Specify the dominant substrate type using the codes provided below:	
Substrate	**Substrate Code**	**Description/Size**
Clay/Silt	C/S	Smooth to touch, not gritty between fingers
Sand	S	<0.007', (approximately 1/16th of an inch or less)
Gravel	G	0.007' – 0.21' (1/16th of an inch to 2.5 inches)
Cobble	C	0.22' – 0.83' (2.5 inches to ~10 inches)
Boulder	B	0.92' – 13.3' (> ~10 inches, not ledge)
Bedrock	Bed	Ledge

Shot From (R/U/D)	Specify the level setup location from where the elevation is collected:
R	Roadway
U	Upstream
D	Downstream

QC Height of Established Control Point	At the end of the longitudinal profile collect the elevation of the established control point. For sites with multiple level setup locations, make sure to re-collect the elevation of the established control point and turning point(s) before moving the level to a new location or completing the longitudinal profile. Collecting the height of the established control point at the beginning and end of the longitudinal profile is an important quality control and assurance measure. If the elevations are the same, then there is assurance that the level instrument didn't shift during the survey and that collected elevations are properly referenced relative to one another. If the before and after elevations are different (>0.1 feet @ 100 feet away) then the relative elevations of the longitudinal profile might be inaccurate. Re-stabilize and level the instrument and recollect the elevations for the features in questions.

Salt Marsh Vegetation *(field assessment)*

This section characterizes the upstream and downstream vegetation communities at a crossing. Vegetation communities are indicators of inundation regimes (i.e. high tide elevations) and water salinity. Comparing upstream and downstream vegetation communities provides information about the effect of a crossing on these site characteristics.

Natural Community Classification ***Upstream*** ***Downstream***	Select the dominant upstream and downstream natural community at the crossing (adapted from Sperduto and Kimball 2011).
Sparsely vegetated intertidal habitat	Intertidal areas with sparse vegetation (e.g. rocky shores, intertidal flats)
Low salt marsh	Marshes regularly flooded by high tide, and dominated by smooth cord grass (*Spartina alterniflora*). Typically, along banks of tidal streams and rivers, and occupying lower depressions and pannes on the marsh surface
High salt marsh	Marshes between mean high tide and the upland edge. Typically, occupies a broader flat marsh surface, and usually dominated by short clonal grasses including saltmeadow cordgrass (*Spartina patens*), spike grass (*Disctichlis spicata*), and black grass (*Juncus gerardii*). May include pannes or pools which may be sparsely vegetated or open water
Marsh elder shrubland	Tidal community dominated by the shrub marsh elder (*Iva frutescens*)
Coastal salt pond marsh/meadow	Marshes that occupy a basin separated by the ocean by a cobble berm; basin is seasonally flooded with freshwater and periodically infused with salt water during storm events; water is brackish to slightly brackish
Brackish marsh	Marshes along the upland edge of a salt marsh, influenced by overland or groundwater freshwater flow. High marsh vegetation may be intermixed with taller sedges, cattail, and *Phragmites* at edges
Brackish riverbank marsh	Riverbank marshes that are flooded by seawater pushed in by the tides, which is diluted by freshwater flowing down rivers/streams draining the watershed above

Freshwater marsh	Marshes not flooded by seawater. Plant species can be very diverse, but are not adapted to salty environment. May include ferns, tussock sedge, arrow-heads, tearthumbs, and common three-square
Freshwater swamp	Shrub dominated wetlands not flooded by seawater. Plant species can be very diverse, and may include dogwoods, red maple, alder, and blueberries
Invasive dominant	Marshes where the salinity cannot be predicted because invasive species adapted to both saline and fresh environments are dominant. Typically, common reed is dominant (*Phragmites australis*)

Invasive Species Present ***Upstream*** ***Downstream***	Select the dominant invasive species present within the marsh plain upstream and downstream of the crossing, if present. If more than one invasive species is present, choose the most dominant. Indicate other invasive species present in the Comments box.
Phragmites	
Narrowleaf cattail	
Perennial pepperweed	
Purple loosestrife	
Japanese Knotweed	

Comments	Provide any additional comments about the natural community classification or the invasive species assessments.

Observations of Vegetation Die Back (due to salt water incursion or Expansion of Mudflat)	Describe observations of the following: • Dead or dying vegetation, such as trees or shrubs around the salt marsh periphery, that indicate salt water incursion • Salt marsh in transition, such as converting to mudflat, which might be observed in the following stages: o First, the marsh surface develops vegetated hummocks surrounded by unvegetated lower lying mud o The hummocks shrink in size and eventually collapse to the point where only a few or no hummocks remain and

	the mudflat surface is several inches below that of the previous marsh or other existing marsh areas

NWI Marsh Classification (from desktop evaluation)	This parameter is auto-filled from the desktop assessment, see *NWI classification immediately up and downstream of the crossing* for details.

Field confirmation (✓) or correction of NWI classification	If the NWI classification is correct, indicate with a check mark. If the NWI classification is incorrect, input the correct Cowardin classification (see Appendix B). Note in the *Comments* field (above) the reason for change.

Vegetation Comparison Matrix	Select the option most appropriate for the crossing site. First use the vertical axis to determine if invasive species are absent, prevalent, or present mostly on one side of the crossing. Then use the horizontal axis to determine if the up and downstream plant communities are the same, different but both tidal, or very different.

Other Site Observations *(field assessment)*

This section provides an opportunity to document other site observations from the field assessment relating to habitat condition, other infrastructure, fish and wildlife, low-lying infrastructure, ancillary uses and utilities at the crossing.

Condition of Salt Marsh or Wetland Habitat	Assess the condition of the salt marsh or wetland habitat. Select from the following condition categories:
Good condition	Habitat is natural and undisturbed
Somewhat altered or impacted	Signs of degradation such as encroachment by invasive species, visible signs of human use and disturbance, or dieback of native vegetation
Highly altered or impacted	Clear degradation such as invasive species, encroachments by surrounding land uses, sediment fill, dredging, dumping of waste, etc.

Other Infrastructure	Note any infrastructure other than the roadway at the crossing that constrains the salt marsh or wetland habitat. Select from the following:
N/A	Other infrastructure not observed
Berm	A flat strip of land, raised bank or terrace bordering a river, canal or other shoreline
Dike	An artificial wall built to regulate or hold back water from a downstream body of water (such as to prevent flooding from the ocean)
Ditch	A linear excavation for the purpose of draining water
Rip Rap	Rip Rap or Revetment Rip Rap: A sloping but orderly organization of rock, concrete or stone. Unorderly rock, concrete, stone, rubble or other material used to allow for water containment or to protect shorelines and structures from erosion by the sea, rivers or streams
Seawall	An orderly, vertical structure made of concrete, wood, steel, rocks, or other materials that runs “parallel to the beach at the land/water interface”

Comments	Provide any comments about the salt marsh or wetland habitat condition, or other infrastructure assessments.

Fish and Wildlife Observations/Comments	Document any fish and wildlife observations at or near the crossing (e.g., eels, otters, resident birds such as osprey and heron using the tidal habitat)

Observations of low-lying infrastructure visible from the crossing	Note any observations of low-lying infrastructure visible from the crossing, such as residential or commercial structures, driveways, lawns, etc.

Ancillary Uses at Crossing	Provide details about other uses occurring at the crossing (such as swimming, fishing, boating, lobster trapping etc.).

Utilities at Crossing	Note any utilities observed at the crossing (e.g. power lines, sewer pipes, buried utilities, etc.).

Other Comments	Provide any other comments about the crossing not captured in other sections of the assessment.

Field Assessment End Time	Time that assessment concluded (hh:mm AM/PM)

Infrastructure Management *(desktop assessment)*

This section captures infrastructure management information about the tidal crossing. For efficiency, the desktop evaluator might consider identifying all tidal crossings managed by the same department or municipality, creating a map of those locations, and scheduling a meeting with the appropriate staff to collect crossing information for all tidal crossings managed by a single entity.

Person Contacted	Name of person contacted to collect crossing information from.

Affiliation	Department/municipality that person contacted is affiliated with.

Date	Date of contact (mm/dd/yyyy).

Age of Structure	Year structure was installed or reasonable approximate.

Site Identified in Haz. Mit. Plan?	Is the crossing location identified in the town's hazard mitigation plan?

Replacement Plans	Does the owner/manager of the crossing have plans for replacement? If so, provide details regarding target date, replacement objectives (e.g. reduce flooding, enlarge crossing) etc.

History of Flooding	Is there a history of flooding at the crossing location? Provide available details such as frequency of flooding, dates, damage costs, etc.

Emergency Access or Evacuation Route	Is the crossing used for emergency access or as an evacuation route?

Other Comments	Provide any other relevant crossing information, especially any maintenance issues identified.

GIS-Based Crossing Information *(desktop assessment)*

This section collects GIS-based information about each crossing, including landscape position, channel and pool widths, salt marsh migration potential, ecological occurrences, inundation risk to the roadway, and inundation risk to low-lying development.

Landscape Position

Landscape position assessment parameters capture information relating the tidal crossing location to its position on the landscape.

Crossing Outlets Directly to ***(answer each of the following)***	Indicate whether the crossing outlets directly to the Atlantic Ocean and subtidal habitat.
Atlantic Ocean	Does the crossing outlet directly to the Atlantic Ocean (select Yes or No)
Subtidal	Does the crossing outlet directly to subtidal habitat (select Yes or No). Subtidal habitat includes an area dominated by open water at low tide (fringe salt marsh might be present)

Number of *(answer each of the following)*	Indicate the number of downstream and upstream tidal crossings and restrictions. This assessment might only be possible once all crossings are identified for the relevant watershed under evaluation. A tidal restriction is identified as any crossing with a Tidal Restriction Overall Score of ≥ 3.
Downstream Tidal Crossings	Number of downstream tidal crossings
Downstream Tidal Restrictions	Number of downstream tidal restrictions
Upstream Tidal Crossings	Number of upstream tidal crossings
Upstream Tidal Restrictions	Number of upstream tidal restrictions

Upstream *(answer each of the following)*	Using StreamStats (online tool at https://streamstatsags.cr.usgs.gov/streamstats/) or a GIS, delineate and calculate the crossing's upstream watershed area and the area of existing upstream salt marsh
Watershed Area	Calculate the crossing's upstream watershed area in square miles
Salt Marsh Area	Calculate the crossing's existing upstream salt marsh in acres. Use the latest available National Wetlands Inventory (NWI) mapping using E2EM% wetlands. Exclude impervious surfaces from the resulting upstream salt marsh area

Watershed Land Use *(answer each of the following)*	Use StreamStats Basin Characteristics or a GIS to generate percent land cover/use for the crossing's upstream watershed area
% wet.	Percentage of the crossing's upstream watershed that is wetland
% for.	Percentage of the crossing's upstream watershed that is forested
% imp.	Percentage of the crossing's upstream watershed that is impervious
% dev.	Percentage of the crossing's upstream watershed that is developed

Channel and Pool Widths

Channel widths are measured to evaluate the compatibility of the crossing structure's width with the tidal stream it conveys. Pool widths are measured to evaluate the expression of a tidal restriction through the erosion/scour features that a tidal restriction typically creates.

Channel Width ***Upstream*** ***Downstream***	Use high resolution aerial photos in ArcGIS, Google Earth, or an online web mapping application such as the NH GRANIT Coastal Viewer to measure the average upstream and downstream channel widths from 2 to 3 representative locations (round measurements to the nearest foot). Measure the channel widths beyond the extent of scour features associated with the crossing. Measure the width parallel to the flow direction; avoid measurements at sharp channel bends.

Max. Pool Width ***Upstream*** ***Downstream***	Use high resolution aerial photos in ArcGIS, Google Earth, or an online web mapping application such as the NH GRANIT Coastal Viewer to measure the maximum upstream and downstream scour pool width rounded to the nearest foot. Measure the width parallel to the flow direction. The stream may be channelized with bank armoring and/or grade control features. In these situations, the erosion feature(s) may not express themselves immediately up and downstream of the crossing; they may occur beyond the armoring features.

Channel and Pool Width Comments	Provide any comments about the channel and pool width measurements, such as the date, source, and resolution of the aerial photo used.

Salt Marsh Migration Potential

Salt marsh migration potential is measured upstream of tidal crossings to understand the availability of upstream salt marsh expansion areas under the 1.7-foot sea level rise scenario by year 2050. The dataset intended for this assessment was developed using the Sea Level Affecting Marshes Model (SLAMM) tool (NHFG 2014).

Area of Potential Upstream Salt Marsh Migration ***Upstream Watershed*** ***Upstream Evaluation Unit***	Using a GIS application, calculate the potential upstream salt marsh migration area in acres for both the entire upstream watershed and the upstream evaluation unit as shown in Figure 7. Use the 1.7' SLR by 2050 SLAMM return with connectivity "on" for both assessment parameters. The following steps can be used to perform these calculations in ArcMap:

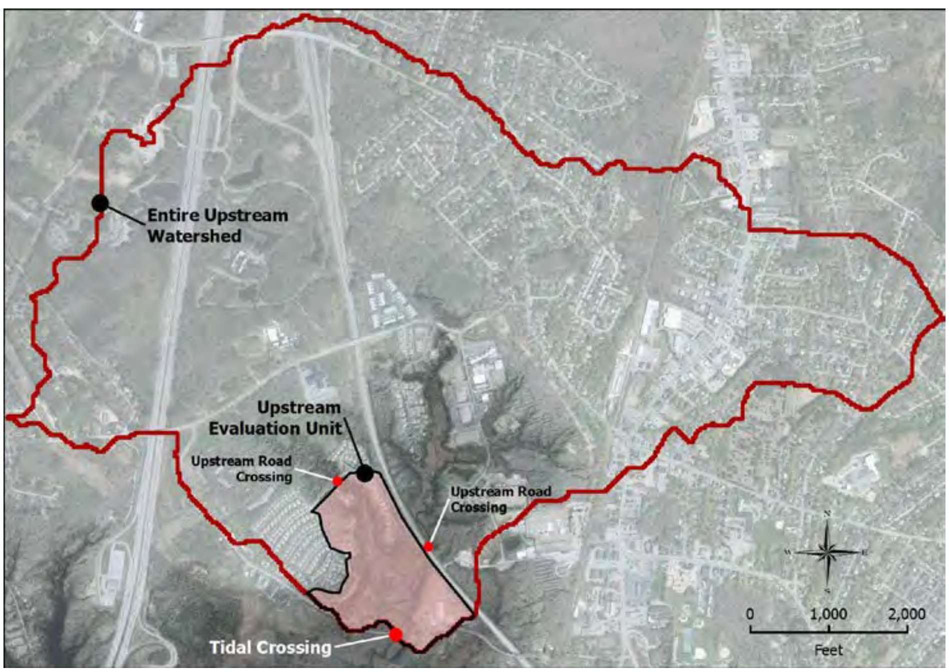
Upstream Watershed:

1. Delineate the watershed upstream of the crossing and add the polygon file to ArcMap. This can be done manually using a USGS topographic base layer or the watershed can be delineated and downloaded using the online StreamStats tool
2. Clip the SLAMM return referenced above to the watershed boundary
3. Erase impervious surfaces (high resolution preferred) from the result of step 2
4. Clip national wetland inventory intertidal emergent wetlands ("ATTRIBUTE" LIKE 'E2EM%') to the watershed boundary
5. Erase the result of step 4 from the result of step 3
6. Add an acreage field to the layer resulting from step 5, then calculate the acreage and summarize the acreage. This is the area of potential upstream marsh migration for the entire upstream watershed

Upstream Evaluation Unit:

7. Using the delineated entire upstream watershed from step 1 above, edit the upstream watershed by cutting the polygon along the lowest road feature in the watershed that crosses the watershed or the tidal system
8. Clip the result of step 5 above by the result of step 7
9. Calculate and summarize the acreage. This is the area of potential upstream marsh migration for the upstream evaluation unit

Figure 7. A map differentiating the entire upstream watershed from the upstream evaluation unit.



Ecological

Tidal habitats are uncommon ecological features that have a history of being highly altered and impacted by human use. Because of this history and their rarity in New Hampshire, tidal systems are extensively inventoried. The New Hampshire Natural Heritage Bureau (NHB) tracks rare, threatened, and endangered species, and exemplary natural communities. The National Wetlands Inventory (NWI) maintains remotely sensed boundaries of estuarine wetlands by wetland type. This information is useful to understand the ecological significance and characteristics of tidal crossings from other inventory efforts.

Natural Heritage Bureau Element Occurrences	Use ArcGIS to determine Natural Heritage Bureau (NHB) Element Occurrences (EOs) within 0.25 miles of the crossing, including federal and/or state rare, threatened, or endangered species, or exemplary natural communities. Summarize findings including G- and S-ranks, and date of last observation. If access to NHB is limited, contact NHB to request EOs within 0.25 miles of the crossing.

NWI Classification Immediately Upstream and Downstream of the Crossing ***Upstream*** ***Downstream***	Identify the National Wetlands Inventory (NWI) classification for the areas immediately upstream and downstream of the crossing using ArcMap, NH GRANIT's Coastal Viewer, or the US Fish and Wildlife Service's Wetlands Mapper, found here: http://www.fws.gov/wetlands/Data/Mapper.html. See Appendix B for the Wetlands and Deepwater Habitats Classification system. These assessment parameters are field verified in the Salt Marsh Vegetation section under the NWI Marsh Classification parameter.

Inundation Risk to the Roadway

Rising sea levels and storm events will adversely impact low-lying tidal crossings and associated transportation infrastructure. We use sea level rise (SLR) modeling results (NHFG 2014) to evaluate road surface flooding under the 1.7-foot sea level rise scenario by year 2050 for both mean higher high water (MHHW) and 1% annual flood hazard conditions. This information can be used in conjunction with field information from the crossing cross section assessment.

Is the Road Surface at the Crossing Inundated at 1.7' SLR by 2050 (MHHW)?	Use the 1.7' SLR by 2050 (MHHW) model return to determine if the road surface at the crossing will be inundated (select Yes or No). This data layer is available for viewing on the NH Coastal Viewer web mapping application, where it can also be downloaded for use in a desktop GIS.

Is the Road Surface at the Crossing Inundated at 1.7' SLR by 2050 with 1% Annual Flood Hazard?	Use the 1.7’ SLR by 2050 with 1% Annual Flood Hazard model return to determine if the road surface at the crossing will be inundated (select Yes or No). This data layer is available for viewing on the NH Coastal Viewer web mapping application, where it can also be downloaded for use in a desktop GIS.

Comments	Provide any comments about the inundation risk desktop assessment.

Inundation Risk to Low-Lying Development (Non-Transportation)

Tidal crossings are at the intersection of seaward and landward flowing water. Undersized or restricted crossing structures can “protect” upstream low-lying development by muting high tide elevations, allowing for development to occur or remain where otherwise it wouldn’t. We use sea level rise modeling results (NHFG 2014) to evaluate the number of low-lying non-transportation infrastructure that might be affected (i.e. flooded) assuming no tidal restriction. Scenarios evaluated include the 1.7-foot sea level rise by year 2050 for mean higher high water and 2015 conditions with the 1% annual flood hazard. These evaluations allow for the comparison of future risk on a regular MHHW basis and current risk from severe storm events.

Number of Upstream Infrastructure Impacts Associated with 1.7' SLR by 2050 (MHHW)?	Use the 1.7’ SLR by 2050 (MHHW) model return and high resolution aerial photography with digital tax parcels to count the number of parcels with low lying non-transportation infrastructure impacts (i.e. number of parcels with structures inundated or affected by inundation, such as limiting access via driveway flooding, lawn flooding, etc.). Using high resolution impervious cover data will also be helpful. If more than 20 parcels are affected by infrastructure impacts, input “>20”.

Number of Upstream Infrastructure Impacts Associated with the 2015 SLAMM Return with 1% Annual Flood Hazard?	Use the 2015 SLAMM with 1% annual flood hazard model return and high resolution aerial photography with digital tax parcels to count the number of parcels with low lying non-transportation infrastructure impacts (i.e. number of parcels with structures inundated or affected by inundation, such as limiting access via driveway flooding, lawn flooding, etc.). Using high resolution impervious cover data will also be helpful. If more than 20 parcels are affected by infrastructure impacts, input “>20”.

Evaluation Criteria

Evaluation criteria are applied to a selection of the assessment parameters to score tidal crossings based on the set of management objectives in Table 2. The intent of the evaluation criteria is to understand how individual tidal crossings perform against each management objective. Applying the evaluation criteria is a first screen toward prioritizing crossings for replacement and/or restoration based on individual or collective management objectives. While not every assessment parameter feeds into evaluation criteria, every parameter is intended to enhance our ability to better understand a site remotely following the field and desktop assessments.

The evaluation criteria thresholds described below are a framework for site prioritization based on the management objectives. The thresholds can be modified to further stratify or condense the classes based on any given set of tidal crossings. As a starting point from the established framework, all evaluation criteria meeting or exceeding a scoring threshold of 3 indicate causes for concern.

The evaluation criteria are organized below by the following management objectives:

- Crossing Condition
- Tidal Restriction
- Tidal Aquatic Organism Passage
- Salt Marsh Migration
- Vegetation
- Infrastructure Risk
- Adverse Impacts

Each evaluation criteria includes a description of its relevance to the management objective and a description of the evaluation process.

Crossing Condition Evaluation

Our society depends heavily on a functional, reliable, and safe transportation infrastructure network. Tidal crossings are a critical component of that network, which allow for the continuous flow of people, goods and services across our coastal communities. Reliable tidal crossings are especially important when we need them most, which also corresponds to when they may be most susceptible to failure during major storm events. Crossing condition is evaluated to get ahead of the storm by identifying tidal crossing structures that are at risk based on assessment parameters in the *Crossing Type & Condition* section. These include:

- Structure Condition – Overall
- Headwall Condition (upstream and downstream)
- Wingwall Condition (upstream and downstream)
- Scour Severity at Structure (upstream and downstream)
- Scour Severity in Structure

Table 3 details the crossing condition evaluation scores and criteria. Lower scores correlate to crossings in better condition, while higher scores indicate crossings are increasingly compromised.

Table 3. Crossing condition evaluation scores and criteria.

Evaluation Score	Evaluation Criteria
1	Condition mostly good (3 or more condition scores are good and no poor's)
2	Condition mostly fair (3 or more condition scores are fair and no poor's)
3	One poor condition score, or one high scour severity score
4	Two poor condition scores or two high scour severity scores
5	Three or more poor condition scores or three high scour severity scores

Tidal Restriction Evaluation

Tidal habitats are special systems with complex hydraulic and hydrologic processes. Tidal crossings often affect these processes by restricting the tidal range upstream of the crossing. That said, even tidal restoration projects that are deemed successful may still restrict up to 20% of the tide range (Konisky et al. 2006). From an estuary health standpoint, an optimal tidal crossing will not affect upstream tidal range.

There are three individual tidal restriction evaluations: tidal range ratio, crossing ratio, and erosion classification, which each look at different indicators of tidal restriction.

Tidal Range Ratio

The tidal range ratio compares the tidal range (elevation difference between high tide and low tide) at the upstream side of the crossing to the downstream side. A crossing where the tidal range is similar on both sides indicates no tidal restriction from a tidal range standpoint. Increasing differences in tidal range between the upstream and downstream sides indicates increasing severity of a tidal restriction.

The tidal range ratio is determined from assessment parameters collected in the *Crossing Cross Section and Stream Longitudinal Profile* section. The following describes the process for calculating the tidal range for the upstream side. Use the same process for calculating the tidal range on the downstream side using the appropriate downstream assessment parameters.

1. Adjust the elevation survey values for all shots taken so that they are relative to the elevation of the established control point
2. Using the adjusted values, subtract the *Upstream Low Tide Water Elevation* from the *Upstream HWI Stain* elevation

The HWI Stain is used for this evaluation because it is the most consistent and reliable field indicator of higher high tide elevations. Once the upstream and downstream tidal ranges are calculated, divide the upstream tidal range by the downstream tidal range and multiply by 100 to get the percent upstream tidal range. Scores are applied to the percent upstream tidal range as described in Table 4.

Table 4. Tidal range ratio evaluation scores and criteria.

Evaluation Score	Evaluation Criteria
1	No downstream invert perch at low tide; stream grade through the crossing matches that of the natural system (upstream tidal range is >90% of downstream tidal range)
2	Tidal range upstream is between 80 and 90 percent of downstream range
3	Tidal range upstream is between 70 and 80 percent of downstream range
4	Tidal range upstream is between 50 and 70 percent of downstream range
5	Downstream invert is perched at high tide, or tidal range upstream is less than 50 percent of downstream range

Crossing Ratio

Crossing ratio is an evaluation developed by Purinton and Mountain (1996) that compares the width of the upstream and downstream channels to the width of the crossing structure. A crossing structure that spans the stream channel should be adequately sized in terms of the width dimension. Narrowing structure widths, when compared to the stream channel, are indicative of increasingly severe tidal restrictions. A relatively narrow structure will act like a funnel and result in greater water velocities through the structure and headwater buildup from the direction of flow (depending on the tide direction). This can result in a reduced upstream tidal range and the desynchronization of tidal flows from the normal tide cycle.

Crossing ratio is determined from assessment parameters collected in the *Crossing Type & Condition* and *GIS-Based Crossing Information* sections. The following describes the process for calculating the crossing ratio for the upstream side. Use the same process for calculating the tidal range on the downstream side using the appropriate downstream assessment parameters.

1. Divide the *Upstream Channel Width* by the *Upstream Dimension A* for all structures that are not a bridge with side slopes. For bridges with side slopes, use the average of *Upstream Dimension A* and *Upstream Dimension C* instead of *Upstream Dimension A*

Once the upstream and downstream crossing ratios are calculated, apply the evaluation scores as described in Table 5.

Table 5. Upstream and downstream crossing ratio evaluation scores and criteria.

Evaluation Score *Upstream*	 *Downstream*	Evaluation Criteria
1	**1**	Channel Width < Opening Width
2	**2**	Channel Width = Opening Width
3	**3**	Channel Width up to 2 times Opening Width
4	**4**	Channel Width 2 to 5 times Opening Width
5	**5**	Channel Width greater than 5 times Opening Width

Erosion Classification

Erosion classification is an evaluation of the effect of a tidal restriction. It evaluates the degree that the tidal crossing is causing erosion immediately upstream and downstream of the crossing. Erosion or scour pools are indicators that the crossing structure is undersized or incompatible with the stream system; the width of the scour pool relative to the channel width is used as a surrogate to characterize the degree of the incompatibility.

Erosion Classification is determined from assessment parameters collected in the G*IS-Based Crossing Information* section. The following describes the process for calculating erosion classification for the upstream side. Use the same process for calculating the erosion classification on the downstream side using the appropriate downstream assessment parameters.

1. Divide the *Upstream Max. Pool Width* by the *Upstream Channel Width*.

Once the upstream and downstream erosion classifications are calculated, apply the evaluation scores as described in Table 6.

Table 6. Upstream and downstream erosion classification evaluation scores and criteria.

Evaluation Score *Upstream*	 *Downstream*	Evaluation Criteria
1	**1**	Unrestricted/ No Pooling (erosion classification <=1)
2	**2**	Flow Detained/ Slight Erosion (>1, <=1.2, pool width is up to 20% wider than channel)
3	**3**	Minor Pooling/ Erosion Present (>1.2, <=1.5, pool width is between 20 and 50% wider than channel)
4	**4**	Significant Pooling/Erosion Present (>1.5, <=2, pool width is between 50 and 100% wider than channel)

5	**5**	Major Pooling/ Major Erosion Present (>2, pool width is more than twice as wide as channel)

Tidal Restriction Overall Score

Three evaluations of tidal restriction are detailed above, each addressing different site specific features that indicate or are an expression of a tidal restriction. The tidal restriction overall score rolls up these individual tidal restriction evaluations into a single score. To calculate, average evaluation scores for tidal range ratio, crossing ratio, and erosion classification. For crossing ratio and erosion classification, use the higher of the upstream and downstream evaluation scores.

Tidal Aquatic Organism Passage

Tidal crossings can serve as gateways or barriers to upstream estuarine and freshwater habitats for fish and other aquatic organisms. Anadromous species' complex life cycles and habitat needs rely on passage through tidal systems to access spawning and nursery habitat, as do resident estuarine fish. Fish passage, or lack thereof, at tidal crossings can have much broader ecosystem implications than just at a specific crossing site scale. Successful passage supports higher trophic levels across the land and ocean-scape from the headwaters, through the estuaries, and out to the Atlantic.

Tidal aquatic organism passage (TAOP) is affected by multiple factors at a tidal crossing. Crossings with perched downstream inverts can block passage throughout a portion of the tide cycle or even across the entire cycle if the invert is perched at high tide. High velocity tidal flows through moderate and severe tidal restrictions are likely to impede passage for less capable swimmers. Moderate and severely restricted crossings will also desynchronize the tidal hydrograph between the downstream and upstream sides, meaning that high and low tide water elevations will be delayed or out of sync. This also reduces the window of opportunity for passage at slack tide (the period in the tide cycle when there is no flow in either direction) because the water elevations on both sides of the crossing are in a near constant state of change. This is especially problematic for species that advance upstream at the front of incoming tides.

It is challenging to identify one or a set of evaluation criteria for TAOP in such dynamic systems. This assessment protocol is designed as a rapid first screen to be performed at low tide conditions to balance efficiency (i.e. study feasibility) with effectiveness. Certain information pertinent to TAOP, such as mid-tide flow velocities, are not feasible given the intent of this protocol. The tidal range ratio (also used in the *Tidal Restriction Evaluation*) is well suited to evaluate TAOP.

Tidal Range Ratio

The tidal range ratio and its calculation is described in the *Tidal Restriction Evaluation* section above. The evaluation criteria correlate decreasing tidal range ratio (i.e. greater restriction) with reduced TAOP. Tidal range ratio was selected as the evaluation criteria for TAOP for the following reasons:

1. It combines downstream invert perch information, including at low and high tide, which has different effects on the severity of the crossing's barrier effect
    - A low tide downstream invert perch presents a barrier to passage during a portion of the tidal range, not all of it
    - A high tide downstream perch presents a complete barrier to passage at all stages of the tide cycle
2. Reduced tidal range on the upstream side of the crossing can indicate at least two different TAOP barrier conditions that increase in severity relative to the reduction in tidal range, including:
    - The crossing structure is undersized, which causes:
        - Excessive flow velocities that reduce pass-ability
        - Desynchronization of tidal flows from the normal tide cycle, which can affect species behavior and slack tide conditions (below)
        - Limited and out of sync slack tide conditions, which may eliminate passage opportunities for weak swimming species
    - The entire crossing structure is perched above the natural downstream tidal system
        - The crossing acts like a dam, often with a grade-controlled riffle between the downstream invert and the downstream pool that could impede passage
        - The upstream invert and/or grade control serve as the hydraulic control through the crossing structure, which may result in very shallow water through the crossing structure, especially under low-flow conditions

Salt Marsh Migration Evaluation

Rising sea levels are a major threat to existing salt marshes, which are home to critically important and imperiled habitats and species that are adapted to life in these dynamic places. It is likely that rapidly rising sea levels will outpace the rate that existing salt marsh habitat can build and sustain themselves. Sea levels around the world are rising at a faster pace in the past 20 years than the previous century. In the last 20 years, global sea level rise has increased from 1.7 to 3.3 mm/year (Nicholls and Cazenave 2010) and are expected to increase even more (Parris et al. 2012). Migration of salt marshes inland is necessary for ecologically significant assemblages of salt marsh habitats to persist under projected sea level rise scenarios. Tidally restrictive crossings reduce the ability of a salt marsh system to meet its upstream migration potential by limiting high tide inundation of salt water. This process is necessary for the conversion of upstream low-lying areas to salt-tolerant marsh habitat.

Salt Marsh Migration Potential

The salt marsh migration potential evaluation is performed for both the entire upstream watershed and the upstream evaluation unit, as described in the *GIS-Based Crossing Information* section under the *Area of Potential Upstream Salt Marsh Migration* assessment parameter. The entire upstream watershed evaluation addresses the salt marsh migration potential regardless of upstream crossings; the upstream evaluation unit addresses the salt marsh migration potential only to the next upstream crossing. This information is useful to understand the marsh migration potential from a watershed approach (e.g. addressing a series of in-line tidally restrictive crossings) and to understand the upstream potential enabled by addressing a single tidal restriction.

Both salt marsh migration potential evaluations have the same evaluation scores and criteria, where increasingly larger migration potential is correlated with a higher score. The salt marsh migration potential evaluation framework is provided in Table 7.

Table 7. Salt marsh migration evaluation scores and criteria for both the entire upstream watershed and the upstream evaluation unit.

Evaluation Score	Evaluation Criteria
1	0-1 acre potential salt marsh increase
2	1-2 acre potential salt marsh increase
3	2-5 acre potential salt marsh increase
4	5-10 acre potential salt marsh increase
5	>10 acre potential salt marsh increase

Vegetation Evaluation

Wetland plants in the tidal zone have specialized adaptations to inhabit and compete in areas subject to flooding, salinity changes, and a combination of the two. Wetland plant communities at tidal crossings are an expression of site conditions, both in terms of flooding frequency/duration and salinities. Comparing dominant upstream and downstream plant communities at a tidal crossing provides a field indicator of a crossing's potential effect on upstream flooding and salinity. Ideally, a tidal crossing will not cause differences in upstream and downstream plant community types.

Vegetation Comparison Matrix

The vegetation comparison evaluation is completed in the *Salt Marsh Vegetation* section using the *Vegetation Comparison Matrix*. The matrix combines upstream and downstream observations of plant communities with observations of invasive species. Three selection options for each observation type is included in the matrix, which are described below:

Plant Community Comparison

1. The plant community appears to be the same on both sides of the crossing; both sides are occupied by tidal marsh of similar species and structure
    - These conditions suggest that the tidal crossing does not affect upstream flooding or salinity to the extent that there is an observable difference in the dominant plant community
2. The upstream and downstream plant communities appear different (i.e. two different expressions of tidal marsh are on either side of the crossing)
    - These conditions suggest that the tidal crossing does affect upstream flooding and/or salinity, but the crossing is not a complete tidal restriction since tidal marsh is present on both sides

3. The up and downstream plant communities are different. One side is tidal marsh, while the other side is unvegetated, open water, un-naturally modified (i.e. armored, channeled), or is occupied by a completely different structure or suite of plants
    - These conditions suggest that the crossing is a complete or near-complete tidal restriction, or that the upstream habitat is completely altered or disturbed

Presence of Invasive Species

1. Native plant species only
    - Invasive species are absent from the upstream and downstream plant communities, indicating an unaltered tidal inundation regime on both sides of the crossing
2. Invasive plants prevalent over a wide area of the marsh plain on both sides of the crossing
    - These conditions suggest a problem above and beyond the influence of the tidal crossing structure. The vegetation comparison is unlikely to help understand tidal restriction at the site
3. Invasive plants present within the marsh plain near one side of the crossing, and absent (or present in a constricted area close to the crossing) on the other side
    - These conditions suggest that the tidal crossing is affecting the salinity at the crossing site, which provides an opportunity for invasive species colonization

The vegetation comparison matrix evaluation scores are provided in Table 8. Higher scores correspond to more severe indications of a crossings impact on upstream flooding and salinity.

Table 8. Vegetation comparison matrix used to determine a vegetation comparison evaluation score.

Vegetation Comparison Matrix	The plant community appears to be the same on both sides of the crossing; both sides are occupied by tidal marsh of similar species and structure	The up and downstream plant communities appear different (i.e. two different expressions of tidal marsh are on either side of the crossing)	The up and downstream plant communities are different. One side is tidal marsh, while the other side is unvegetated, open water, un-naturally modified (i.e. armored, channeled), or is occupied by a completely different structure or suite of plants
Native plant species only	**1 point**	**3 points**	**5 points**
Invasive plants prevalent over a wide area of the marsh plain on both sides of the crossing*	**No Score**	**No Score**	**No Score**
Invasive plants present within the marsh plain near one side of the crossing, and absent (or present in a constricted area close to the crossing) on the other side	**3 points**	**4 points**	**5 points**
* If invasive species are prevalent in the plant community on both sides of the crossing, there is another issue beyond the crossing that is affecting the vegetation. A vegetation comparison is unlikely to help understand inundation and salinity conditions at a site with these conditions.			

Infrastructure Risk Evaluation

Tidal crossing infrastructure are at the front lines of coastal challenges associated with climate change, including sea level rise and more frequent and intense storm events. Our transportation infrastructure is critical to facilitate the flow of people, goods and services across our coastal communities, but that infrastructure could be at serious risk. Much of our transportation infrastructure was not designed or constructed with sea level rise in mind. Therefore, it is important to identify tidal crossings that are at immediate and near-term risk to prioritize their replacement, which will support a network of climate-ready transportation infrastructure.

The infrastructure risk evaluation includes two evaluations: inundation risk to the roadway and inundation risk to the crossing structure. Inundation risk to the roadway addresses the upstream and downstream vertical distance between the high water indicator and the road surface (e.g. does the road flood, or what distance is the high water indicator from the road surface vertically). The inundation risk to the crossing structure addresses upstream and downstream headwater buildup conditions (i.e. is the high water indicator above the ceiling of the crossing structure, and if so, by how much). These evaluations are detailed as follows:

Inundation Risk to the Roadway

Upstream and downstream Inundation risk to the roadway is determined from assessment parameters collected in the *Crossing Cross Section and Stream Longitudinal Profile* section. The following describes the process for calculating the inundation risk to the roadway on the upstream side. Use the same process for calculating the downstream side using the appropriate downstream assessment parameters.

1. Adjust the elevation survey values for all shots taken so that they are relative to the elevation of the established control point
2. Using the adjusted values, subtract the *Upstream HWI Wrack* elevation from the *Upstream Road Surface* elevation.

The HWI Wrack is used for this evaluation because it captures a field indicator most representative of highest observable tide. In the absence of HWI Wrack, HWI Stain should be used to calculate inundation risk to the crossing structure. Once upstream and downstream vertical distances are calculated, apply the evaluation scores in Table 9 based on the evaluation criteria.

Table 9. Upstream and downstream inundation risk to the roadway scores and criteria.

Evaluation Score		**Evaluation Criteria**
Upstream	*Downstream*	
1	**1**	High water indicator is greater than 6' from road surface
2	**2**	High water indicator is between 3 and 6' from road surface
3	**3**	High water indicator is between 1.5 and 3' from road surface
4	**4**	High water indicator is less than 1.5' from road surface

5	**5**	High water indicator suggests road is occasionally inundated

Inundation Risk to the Crossing Structure

Upstream and downstream inundation risk to the crossing structure is determined from assessment parameters collected in the *Crossing Cross Section and Stream Longitudinal Profile* section. The following describes the process for calculating the inundation risk to the crossing structure on the upstream side. Use the same process for calculating the downstream side using the appropriate downstream assessment parameters.

1. Adjust the elevation survey values for all shots taken so that they are relative to the elevation of the established control point
2. Using the adjusted values, subtract the *Upstream HWI Wrack* elevation from the *Upstream Ceiling of Structure* elevation.

As with inundation risk to the road, the HWI Wrack is used for this evaluation because it captures a field indicator most representative of highest observable tide. In the absence of HWI Wrack, HWI Stain should be used to calculate inundation risk to the crossing structure. Once upstream and downstream vertical distances are calculated, apply the evaluation scores in Table 10 based on the evaluation criteria.

Table 10. Upstream and downstream inundation risk to the crossing structure scores and criteria.

Evaluation Score		**Evaluation Criteria**
Upstream	*Downstream*	
1	**1**	High water indicator is greater than 3' from ceiling of structure
2	**2**	High water indicator is between 2 and 3' from ceiling of structure
3	**3**	High water indicator is between 1 and 2' from ceiling of structure
4	**4**	High water indicator is less than 1' from ceiling of structure
5	**5**	High water indicator is above ceiling of structure

Adverse Impacts Evaluation

Careful consideration of upstream infrastructure and property susceptible to flooding is necessary in the assessment of tidal crossings—both under current conditions and accounting for rising sea levels. For example, some existing tidal crossings may serve to protect inland communities by restricting tidal flows, but may also cause more severe flooding inland because of poor drainage seaward. It is important to understand potential adverse impacts associated with replacing a tidal crossing, which plays into the feasibility of restoring full or even partial upstream tidal range at some crossings.

Inundation Risk to Low-Lying Development (Non-Transportation)

Inundation risk to low-lying development is assessed in the *GIS-Based Crossing Information* section. The assessment parameter for *Number of upstream infrastructure impacts associated with 1.7' SLR by 2050 (MHHW)* is used. The 1.7' SLR scenario is used in the assessment because it captures MHHW under a near-term (2050) high emissions scenario and a longer term low emissions scenario. Planning for this sea level rise is relevant because it hedges against extreme rises and accounts for low and moderate rises at a relevant time-scale.

The evaluation scores are scaled so that crossings with many upstream private property impacts have lower scores, meaning that the feasibility of restoring full upstream tidal range may be more difficult. Crossings with fewer upstream private property impacts are likely to be more feasible in terms restoring full upstream tidal range because there are limited impacts to private property. The Adverse Impacts evaluation framework is provided in Table 11.

Table 11. Inundation risk to low-lying development evaluation scores and criteria.

Evaluation Score	Evaluation Criteria
1	> 5 impacts identified
2	3-5 impacts identified
3	2 impacts identified
4	1 impact identified
5	No impacts identified

Draft Overall Crossing Evaluations

Following are draft conceptual frameworks to potentially roll-up the evaluations detailed above into overall crossing scores. The first framework maintains separation between infrastructure and ecological management objectives; the second attempts to integrate all the management objectives into one overall score.

This protocol development effort did not create a large enough dataset of assessed crossings to adequately test and vet these frameworks to understand their utility and limitations. We include them in draft form for further consideration and refinement. They can be can be modified to weigh different management objectives more or less heavily.

Infrastructure and Ecological Scores

This method results in an overall infrastructure score and overall ecological score, both rated on a scale of 1 (low replacement priority) through 5 (high replacement priority). These evaluations are structured to prioritize crossing replacements solely on infrastructure or ecological conditions, respectively. The

Adverse Impacts Evaluation is not evaluated in this framework; that evaluation can be used as a feasibility and management screen once the scores are determined.

Infrastructure Score:

Evaluation Score	Evaluation Criteria
1	**Good Crossing Condition, Low Inundation Risk** Crossing Condition = 1, AND Infrastructure Risk ≤ 2
2	**Fair Crossing Condition, Low/Moderate Inundation Risk** Crossing Condition = 2, OR Infrastructure Risk ≤ 3
3	**Poor Crossing Condition <u>OR</u> Moderate Infrastructure Risk** Crossing Condition = 3, OR Infrastructure Risk = 3
4	**Very Poor Crossing Condition <u>OR</u> High Infrastructure Risk** Crossing Condition ≥ 4, OR Infrastructure Risk ≥ 4
5	**Failing Crossing Condition OR Very High Infrastructure Risk** Crossing Condition = 5, OR Infrastructure Risk = 5

Ecological Score:

Evaluation Score	Evaluation Criteria
1	**Limited Tidal Restriction** Tidal Restriction ≤ 2, AND Vegetation = 1 Aquatic Organism Passage (not included because of limited tidal restriction) Salt Marsh Migration (not included because of limited tidal restriction)
3	**Moderate Tidal Restriction, TAOP Reduced, <u>OR</u> Moderate Salt Marsh Migration Potential** Tidal Restriction = 3, OR Aquatic Organism Passage = 3, OR Salt Marsh Migration = 3, OR Vegetation = 3
4	**Severe Tidal Restriction, TAOP Very Reduced, High Salt Marsh Migration Potential if Tidally Restricted, <u>OR</u> Vegetation Different** Tidal Restriction ≥ 4, OR Aquatic Organism Passage ≥ 4, OR Salt Marsh Migration ≥ 4 AND Tidal Restriction ≥ 3, OR Vegetation ≥ 4

5	**Very Severe Tidal Restriction, TAOP Barrier, Very High Salt Marsh Migration Potential if Tidally Restricted, OR Vegetation Very Different if Tidally Restricted** Tidal Restriction = 5, OR Aquatic Organism Passage = 5, OR Salt Marsh Migration = 5 AND Tidal Restriction ≥ 3, OR Vegetation = 5 AND Tidal Restriction ≥ 3

Overall Combined Crossing Score

This method results in single overall crossing score rated on a scale of 1 (low replacement priority) through 5 (high replacement priority). These evaluations are structured to prioritize crossing replacements based on a combination of infrastructure and ecological conditions. The Adverse Impacts Evaluation is not evaluated in this framework; that evaluation can be used as a feasibility and management screen once the scores are determined.

Evaluation Score	Evaluation Criteria
1	**Good Crossing Condition <u>AND</u> Limited Tidal Restriction** Crossing Condition = 1, AND Tidal Restriction ≤ 2, AND Vegetation = 1, AND Infrastructure Risk ≤ 2 Aquatic Organism Passage (not included because of limited tidal restriction) Salt Marsh Migration (not included because of limited tidal restriction)
2	**Fair Crossing Condition, Limited Tidal Restriction <u>OR</u> Low/Moderate Infrastructure Risk** Crossing Condition = 2, OR Tidal Restriction ≤ 2, OR Vegetation = 1, OR Infrastructure Risk ≤ 3 Aquatic Organism Passage (not included because of limited tidal restriction) Salt Marsh Migration (not included because of limited tidal restriction)
3	**Poor Crossing Condition, Moderate Tidal Restriction, TAOP Reduced, Moderate Salt Marsh Migration Potential, <u>OR</u> Moderate Infrastructure Risk** Crossing Condition = 3, OR Tidal Restriction = 3, OR Aquatic Organism Passage = 3, OR Salt Marsh Migration = 3, OR Vegetation = 3, OR Infrastructure Risk = 3

4	**Very Poor Crossing Condition, Severe Tidal Restriction, TAOP Very Reduced, High Salt Marsh Migration Potential if Tidally Restricted, Vegetation Different, <u>OR</u> High Infrastructure Risk** Crossing Condition ≥ 4, OR Tidal Restriction ≥ 4, OR Aquatic Organism Passage ≥ 4, OR Salt Marsh Migration ≥ 4 AND Tidal Restriction ≥ 3, OR Vegetation ≥ 4, OR Infrastructure Risk ≥ 4
5	**Failing Crossing Condition, Very Severe Tidal Restriction, TAOP Barrier, Very High Salt Marsh Migration Potential if Tidally Restricted, Vegetation Very Different if Tidally Restricted, <u>OR</u> Very High Infrastructure Risk** Crossing Condition = 5, OR Tidal Restriction = 5, OR Aquatic Organism Passage = 5, OR Salt Marsh Migration = 5 AND Tidal Restriction ≥ 3, OR Vegetation = 5 AND Tidal Restriction ≥ 3, OR Infrastructure Risk = 5 Adverse Impacts (not included, consider after overall score is determined)

Data Processing

As of the Tidal Protocol's publication date, an initial set of data processing and summarization tools have been developed. This section provides information about the tools and the methods for processing and summarizing a crossing's assessment parameters and evaluation criteria. To-date the tools are set up in Microsoft Excel. We intend to incorporate the Tidal Protocol's assessment parameters into ArcGIS Collector, Esri's mobile mapping application, for streamlined data collection and management prior to implementing the protocol in the Spring of 2018. A new set of reporting tools will be needed for that data collection and management platform.

Data Management File Structure and Outputs

Data collection, management, and processing for the Tidal Protocol was developed upon a Microsoft Excel platform. One Microsoft Excel Macro-Enabled file, "Tidal Protocol Data Collection and Processing 201707.xlsm", includes three primary worksheets. The first worksheet is titled "Data Sheet – BLANK"; it is a blank version of the Tidal Crossing data sheet. The second worksheet is titled "Data Sheet – SITE", which is the data entry worksheet to enter assessment parameters for a given site. The third worksheet is titled "Data Sheet – SUMMARY", which is a template for summarizing site specific evaluation criteria and assessment parameters that are entered into the "Data Sheet - SITE" worksheet.

Figure 8 is an example of a Tidal Crossing Summary Sheet, which is exported from the "Data Sheet – SUMMARY" worksheet. The Tidal Crossing Summary Sheet is structured to include the *Site Visit Details*, *Evaluation Criteria* scores, *Low Tide Photos*, and a graphical representation of the *Crossing Cross Section and Stream Longitudinal Profile*.

Evaluation criteria scores in the "Data Sheet – SUMMARY" worksheet need to be manually generated based on evaluation criteria in the *Evaluation Criteria* section. We had hoped to automate the translation of evaluation criteria from the assessment parameters into the "Data Sheet – SUMMARY" worksheet but project constraints didn't allow for its completion; this is an area identified for advancement of the Tidal Protocol's reporting tools at a later date, hopefully with a more robust database and data management structure.

The "Data Sheet – SUMMARY" worksheet is setup to auto-translate the *Crossing Cross Section and Stream Longitudinal Profile* assessment parameters into a graphical output as shown in Figure 8. These calculations can be confusing, especially for sites with multiple level setups. The "Data Sheet – SUMMARY" worksheet was developed to streamline the processing of survey data and reduce confusion and error.

The *Data Processing Methodology* section below describes the steps to process assessment parameters once collected for a given tidal crossing and generate a Tidal Crossing Summary Sheet.

Figure 8. An example of a Tidal Crossing Summary Sheet, which is generated from the "Data Sheet – SUMMARY" worksheet in the "Tidal Protocol Data Collection and Processing 201707.xlsm" file.

Tidal Crossing Summary Sheet

New Hampshire's Tidal Crossing Assessment Protocol

Crossing ID: 010600031004-XXX

Observer(s) & Organization:	P. Steckler, Shea Flanagan, Joanne Glode (TNC), Kevin Lucey (NHCP), David Burdick *UNH
Municipality:	Hampton
Stream Name:	Drakes River
Road Name:	Drakeside Road

Date:	5/30/2017	
Start Time:	9:36:00 AM	
End Time:	1:00:00 PM	
Tide Prediction	**High**	**Low**
Time:	3:22 AM	10:07 AM
Elevation:	9.0	-1.0
Tide Chart Location:	Hampton Harbor	

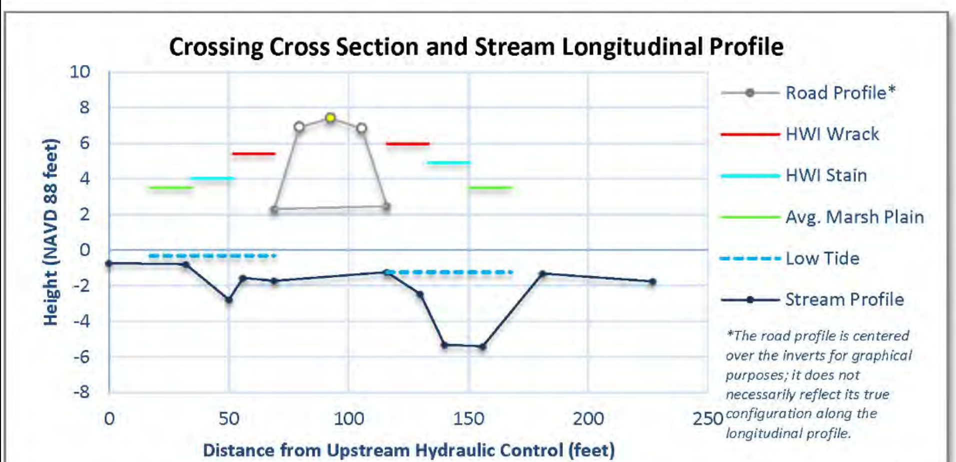
	Score
Crossing Condition Evaluation	
Crossing Condition	3
Tidal Restriction Evaluation	
Tidal Range Ratio	3
Crossing Ratio (US, DS)	4,4
Erosion Classification (US, DS)	2, 1
Tidal Restriction Overall Score	3
Tidal Aquatic Organism Passage	
Tidal Range Ratio	3
Salt Marsh Migration Evaluation	
Salt Marsh Migration Potential (Eval. Unit)	4
Salt Marsh Migration Potential (Wshed.)	5
Vegetation Evaluation	
Vegetation Comparison Matrix	4
Infrastructure Risk Evaluation	
Inundation Risk to the Roadway (US, DS)	3, 4
Inun. Risk to the Crossing Structure (US, DS)	5, 5
Adverse Impacts Evaluation	
Inundation Risk to Low-Lying Development	5
Overall Scores (Draft)	
Infrastructure	5
Ecological	4
Combined	4

DS view toward structure

US view above structure

US view toward structure

DS view above structure



Long. Profile

Dist.	Hght.	Feat.	Sub.
0	-0.73	HC	G
32	-0.79	HC	C
50	-2.78	P	C
56	-1.56	GC	C
69	-1.73	I	B
116	-1.23	I	B
130	-2.48	GC	B
140	-5.32	P	C
156	-5.4	P	G
181	-1.31	HC	C
227	-1.75	HC	G
0	0		
0	0		
0	0		
0	0		
0	0		
0	0		

Data Processing Methodology

The following outlines the steps to process assessment parameters once collected for a given site using the "Tidal Protocol Data Collection and Processing 201707.xlsm" file:

1. Save the "Tidal Protocol Data Collection and Processing 201707.xlsm" file to a site-specific file, such as "SiteID_River_Road_Date"
   (e.g. 010600031004-XXX_DrakesRiver_DrakesideRoad_20170530)
2. In the "Data Sheet – SITE" worksheet, enter all field and desktop assessment parameters
3. In the "Data Sheet – SUMMARY" worksheet:
   A. *Site Visit Details* will automatically populate from the "Data Sheet – SITE" worksheet
   B. Manually generate evaluation criteria scores based on the evaluation criteria defined in the *Evaluation Criteria* section
   C. Insert the appropriate photos under their respective headings (right click on the example photo, select "Change Picture…", then browse to the appropriate file)
   D. To update and generate the Crossing Cross Section and Stream Longitudinal Profile, do the following:
      i. Scroll down to the second page of the "Data Sheet – SUMMARY" worksheet. Manually input values in the fields highlighted in yellow on rows 54 and 55 for the following:
         a. <u>LiDAR Height @ CL</u>: In GIS, use the highest resolution LiDAR coverage available to identify the **elevation** (in NAVD 88 feet) of the feature collected for the *Height at Road Centerline* assessment parameter. This will typically be the road centerline at the center of the crossing structure as it is an easy feature to identify using high resolution aerial photos. The Comments field (A108) within the "Data Sheet – Site" worksheet will describe an alternative elevation reference point if used. Make sure the LiDAR elevation is in or is converted to NAVD 88 feet – check the metadata for the LiDAR data layer to see whether it is in NAVD 88 meters or feet. If in meters, convert to feet before entering the value in the spreadsheet field
         b. <u>Road Width</u>: Use the highest resolution and most recent orthophoto to measure the **width** of the road at the crossing structure in feet from pavement edge to pavement edge.
         c. <u>US Invert Distance</u>: From the *Stream Channel Longitudinal Profile*, input the **distance** of the upstream invert in feet.
         d. <u>DS Invert Distance</u>: From the *Stream Channel Longitudinal Profile*, input the **distance** of the downstream invert in feet.
      ii. If necessary, update the stream profile data selection in the Crossing Cross Section and Stream Longitudinal Profile graph. The graph template is setup up to include the 10 standard longitudinal profile features shown in Figure 6. If more or less features are collected, the stream profile data series will need to be updated
         a. Right click on the Crossing Cross Section and Stream Longitudinal Profile graph at the bottom of page 1 of the "Data Sheet – SUMMARY" worksheet
         b. Click "Select Data…"

c. In the “Legend Entries (Series)” window (lower left), scroll down and select the “Stream Profile” entry
d. Click the “Edit” button
e. Update the “Series X values” data range starting at cell U60 and continuing to the last feature captured in the Stream Channel Longitudinal Profile in column U by selecting the upward pointing arrow
    - If you accidentally make an incorrect selection, select cancel to return to the original selection and try again
f. Update the “Series Y values” data range starting at cell X60 and continuing to the last feature captured in the Stream Channel Longitudinal Profile in column X by selecting the upward pointing arrow
    - If you accidentally make an incorrect selection, select cancel to return to the original selection and try again
g. Once the X and Y data series are updated, select “OK” and “OK” again in the “Select Data Source” window. The graph should update to reflect the number of features collected as part of the Stream Channel Longitudinal Profile

Once these steps are taken, the Tidal Crossing Summary Sheet should be complete and ready to print or export. The Tidal Crossing Summary Sheet can also be customized to display other assessment parameters or represent the displayed assessment parameters differently.

Conclusion and Next Steps:

With the help of so many project advisors and contributors, we are excited to roll-out New Hampshire's Tidal Crossing Assessment Protocol. The Tidal Protocol is over two years in the making with multiple iterations, field trials, and innumerable revisions. Our efforts focused on identifying tidal crossing assessment parameters and evaluation criteria to address our management objectives. We've boiled down a large set of assessment parameters to a core group that balances efficiency and effectiveness as a screening tool, all while meeting the management objective needs identified at the project's outset. Adherence to our management objectives and development of focused evaluation criteria allow for rapid generation of infrastructure and ecological scores as well as an overall combined score for crossing assessments. Ultimately these data will allow planning and prioritization of tidal crossing upgrades at both local and regional levels.

Next Steps

With plans to implement the Tidal Protocol across New Hampshire's tidal crossings in 2018, we intend to streamline data collection, management, and processing using ArcGIS Collector, Esri's mobile mapping application. For this reason, we did not over-invest in data management and processing tools up to this point. We hope to develop more robust data management and processing tools in conjunction with our anticipated assessment project in 2018. For example, currently an individual tidal crossing is entered into a single Microsoft Excel file. A database structure that includes all tidal crossings with reporting and query functions will be more efficient and effective at prioritizing tidal crossing replacements at a landscape scale.

We also expect to identify areas for improvement of the Tidal Protocol as it is deployed at a variety of sites, both in New Hampshire and beyond. We are eager to collect and incorporate feedback to update and improve the Tidal Protocol as it is rigorously used by our field crews and others. We will consider issuing an updated version of the protocol if warranted based on the feedback we receive; please send your comments and feedback to the protocol's authors listed on the protocol's cover page.

Finally, please contact the study authors for training opportunities to deploy the Tidal Protocol. We hope to share the protocol and support others' efforts to address tidal crossings as we turn the corner from protocol development to implementation.

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Appendix A: Tidal Protocol Field Form

New Hampshire's Tidal Crossing Assessment Protocol Data Sheet

(v. 7/17)

SITE VISIT DETAILS (*field assessment*)

Crossing ID:

Observer(s) & Organization:	
Municipality:	
Stream Name:	
Road Name:	

Date:		
Start Time:		
End Time:		
Tide Prediction	High	Low
Time:		
Elevation:		
Tide Chart Location:		

General Assessment Notes:

LOW TIDE PHOTOS (*field assessment*)

Photo File Names:		**Photo Comments**
①	Downstream view toward structure	
②	Upstream view from above structure	
③	Downstream view from above structure	
④	Upstream view toward structure	
	describe:	
	describe:	
	describe:	
	describe:	
	describe:	
	describe:	

Page 1

Tidal Protocol Data Collection and Processing 201707.xlsm

Data Sheet - BLANK

CROSSING TYPE & CONDITION (*field assessment*)

Structure ____ **of** ____ **at Crossing**

Crossing Dimensions (feet):

	Upstream	Downstream
Dimension A:		
Dimension B^{CB}:		
Dimension B^{LT}:		
Dimension C:		
Dimension D:		

	Upstream	Downstream
Low Tide Perch:		
High Tide Perch:	N/A	

Crossing Type:

Round Culvert
Elliptical Culvert
Pipe Arch Culvert
Box Culvert
Embedded Round Culvert
Embedded Elliptical Culvert
Embedded Pipe Arch Culvert
Open Bottom Arch
Arch Bridge
Bridge with Abutments
Bridge with Side Slopes
Bridge w/ S. Slopes and Abutments
Other

Structure Materials:

Concrete
Plastic-Corrugated
Plastic-Smooth
Stone
Steel-Corrugated
Steel-Smooth
Aluminum-Corrugated
Wood
Other

	Headwall Materials:	Headwall Condition:	Wingwall Materials:	Wingwall Condition:	Scour at Structure	Scour Severity
UPSTREAM	Metal Concrete Masonry Gabion Dry Fit Stone Riprap Other None	Good Fair Poor N/A	Metal Concrete Masonry Gabion Dry Fit Stone Riprap Other None	Good Fair Poor N/A	None Culvert Footer Wingwalls Abutment Headwall Armoring	None Low Medium High
DOWNSTREAM	Metal Concrete Masonry Gabion Dry Fit Stone Riprap Other None	Good Fair Poor N/A	Metal Concrete Masonry Gabion Dry Fit Stone Riprap Other None	Good Fair Poor N/A	None Culvert Footer Wingwalls Abutment Headwall Armoring	None Low Medium High

Scour in Structure

None
Culvert
Footer
Abutment
Channel
Armoring

Scour Severity in Structure

None
Low
Medium
High

Road Surface Condition

Good
Fair
Poor

Structure Condition - Overall

Good
Fair
Poor

Sketch of Structure

Crossing Type & Condition Comments:

CROSSING CROSS SECTION AND LONGITUDINAL PROFILE (*field assessment*)

Indicate in the solid outlined boxes if the elevation was taken from the:
- **R**oadway level setup (**R**)
- **U**pstream level setup (**U**)
- **D**ownstream level setup (**D**)

	US Height		DS Height	
Low Tide Water Elevation				

Height of Established Control Point: ____ ☐

Describe Control Point: ____

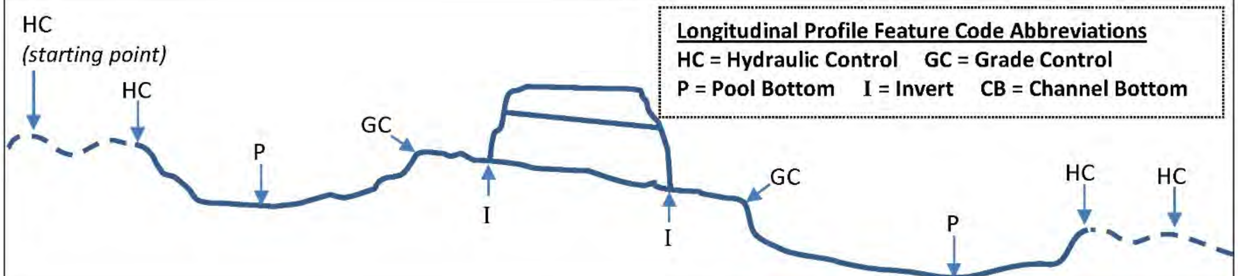
Height at Road Centerline: ____ ☐

Crossing Cross Section

Feature	**US Height**		**DS Height**	
HWI Stain				
HWI Wrack				
Ceiling of Structure				
Road Surface				
Marsh Plain Shot 1				
Marsh Plain Shot 2				
Marsh Plain Shot 3				
Marsh Plain Shot 4				

Comments:

IF NEEDED:	**US Height**		**DS Height**	
TP Foresight				
TP Backsight				



Longitudinal Profile Feature Code Abbreviations

HC = Hydraulic Control GC = Grade Control

P = Pool Bottom I = Invert CB = Channel Bottom

Stream Channel Longitudinal Profile

Distance	Height	Feature Code	Sub-strate	Shot From (R/U/D)

QC - Height of Established Control Point: ____ ☐

SALT MARSH VEGETATION (*field assessment*)

	Upstream	Downstream	Comments:
Natural Community Classification	Sparsely vegetated intertidal habitat Low salt marsh High salt marsh Marsh elder shrubland Coastal salt pond marsh/meadow Brackish marsh Brackish riverbank marsh Freshwater marsh Freshwater swamp Invasives dominant	Sparsely vegetated intertidal habit Low salt marsh High salt marsh Marsh elder shrubland Coastal salt pond marsh/meadow Brackish marsh Brackish riverbank marsh Freshwater marsh Freshwater swamp Invasives dominant	*(note invasives if present on road fill but not within marsh plain)*
Invasive Species Present within Marsh Plain	Phragmites Narrowleaf cattail Perennial pepperweed Purple loosestrife Japanese Knotweed	Phragmites Narrowleaf cattail Perennial pepperweed Purple loosestrife Japanese Knotweed	

Observations of Vegetation Die Back (due to salt water incursion) or Expansion of Mudflat:

	Upstream	Downstream
NWI marsh classification (from desktop evaluation):	0	0
Field confirmation (✓) or correction of NWI classification:		

Vegetation Comparison Matrix ***(check the box that applies)***	The plant community appears to be the same on both sides of the crossing; both sides are occupied by tidal marsh of similar species and structure.	The up and downstream plant communities appear different (i.e. two different expressions of tidal marsh are on either side of the crossing).	The up and downstream plant communities are different. One side is tidal marsh, while the other side is unvegetated, open water, un-naturally modified (ie. armored, channelled), or is occupied by a completely different structure or suite of plants.
Native plant species only	☐	☐	☐
Invasive plants prevalent over a wide area of the marsh plain on both sides of the crossing*	☐	☐	☐
Invasive plants present within the marsh plain near one side of the crossing, and absent (or present in a constricted area close to the crossing) on the other side	☐	☐	☐

* If invasive species are prevalent in the plant community on both sides of the crossing, there is another issue beyond the crossing that is affecting the vegetation. A vegetation comparison is unlikely to help understand inundation and salinity conditions at a site with these conditions.

OTHER SITE OBSERVATIONS (*field assessment*)

	Condition of Salt Marsh or Wetland Habitat:	Other Infrastructure:
Upstream:	Good condition Somewhat altered or impacted Highly altered or impacted	N/A Berm Dike Ditch Rip Rap Seawall
Downstream:	Good condition Somewhat altered or impacted Highly altered or impacted	N/A Berm Dike Ditch Rip Rap Seawall

Comments:

Fish and Wildlife Observations/Comments:

Observations of low-lying infrastructure visible from the crossing:

Ancillary Uses at Crossing (e.g. fishing, swimming)

Utilities at Crossing:

Other Comments:

Field Assessment End Time:

INFRASTRUCTURE MANAGEMENT (*desktop assessment*)

Person Contacted:

Affiliation:

Date:

Age of Structure:

Site Identified in Haz. Mit. Plan?

Replacement Plans:

History of Flooding:
(frequency or dates)

Emergency Access or Evacuation Route?

Other Comments:

GIS-BASED CROSSING INFORMATION (*desktop assessment*)

Landscape Position

	Atlantic Ocean		Subtidal	
Crossing Outlets Directly to:	☐ Yes	☐ No	☐ Yes	☐ No

	Downstream tidal crossings	Downstream tidal restrictions	Upstream tidal crossings	Upstream tidal restrictions
Number of:		TBD	TBD	TBD

	Watershed Area (mi.^{2})	Salt Marsh Area (acres)	Watershed Land Cover/Use			
Upstream:			% wet.	% for.	% imp.	% dev.

Channel and Pool Widths

	Channel Width (ft.)	**Max. Pool Width (ft.)**
Upstream:		
Downstream:		

Channel & Pool Width Comments:

Salt Marsh Migration Potential

	Entire Upstream Watershed (acres)	Upstream Evaluation Unit (acres)
Area of potential upstream salt marsh migration using the 1.7' SLR by 2050 SLAMM return with connectivity "on":		

Ecological

Natural Heritage Bureau Element Occurrences (within 0.25 miles of the crossing):

EOs or Exemplary Natural Communities:

	Upstream	Downstream
NWI Classification Immediately Upstream and Downstream of the Crossing:		

Inundation Risk to the Roadway

Is the Road Surface at the Crossing Inundated at 1.7' SLR by 2050 (MHHW):	☐ Yes	☐ No
Is the Road Surface at the Crossing Inundated at 1.7' SLR by 2050 <u>with 1% Annual Flood Hazard:</u>	☐ Yes	☐ No

Comments:

Inundation Risk to Low-Lying Development (Non-Transportation)

Number of Upstream Infrastructure Impacts Associated with 1.7' SLR by 2050 (MHHW):	
Number of Upstream Infrastructure Impacts Associated with the 2015 SLAMM Return with <u>1% Annual Flood Hazard:</u>	

Comments:

Appendix B: Wetlands and Deepwater Habitats Classification

WETLANDS AND DEEPWATER HABITATS CLASSIFICATION

System: M - Marine

Subsystem	1 - Subtidal				2 - Intertidal			
Class	RB – Rock Bottom	UB – Unconsolidated Bottom	AB – Aquatic Bed	RF – Reef	AB – Aquatic Bed	RF – Reef	RS – Rocky Shore	US – Unconsolidated Shore
Subclass	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud	1 Algal 3 Rooted Vascular	1 Coral 3 Worm	1 Algal 3 Rooted Vascular	1 Coral 3 Worm	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic

System: E - Estuarine

Subsystem	1 - Subtidal				2 - Intertidal							
Class	RB – Rock Bottom	UB – Unconsolidated Bottom	AB – Aquatic Bed	RF – Reef	AB – Aquatic Bed	RF – Reef	SB – Streambed	RS – Rocky Shore	US – Unconsolidated Shore	EM – Emergent	SS – Scrub-Shrub	FO – Forested
Subclass	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic	1 Algal 3 Rooted Vascular 4 Floating Vascular	2 Mollusk 3 Worm	1 Algal 3 Rooted Vascular 4 Floating Vascular	2 Mollusk 3 Worm	1 Bedrock 2 Rubble 3 Cobble-Gravel 4 Sand 5 Mud 6 Organic	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic	1 Persistent 2 Non-persistent 5 *Phragmites australis*	1 Broad-Leaved Deciduous 2 Needle-Leaved Deciduous 3 Broad-Leaved Evergreen 4 Needle-Leaved Evergreen 5 Dead 6 Deciduous 7 Evergreen	1 Broad-Leaved Deciduous 2 Needle-Leaved Deciduous 3 Broad-Leaved Evergreen 4 Needle-Leaved Evergreen 5 Dead 6 Deciduous 7 Evergreen

System: R - Riverine

Subsystem: 1 - Tidal; 2 – Lower Perennial; 3 – Upper Perennial; 4* - Intermittent; 5* – Unknown Perennial

Class	RB** – Rock Bottom	UB – Unconsolidated Bottom	SB** – Streambed	AB – Aquatic Bed	RS – Rocky Shore	US – Unconsolidated Shore	EM – Emergent
Subclass	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic	1 Bedrock 2 Rubble 3 Cobble-Gravel 4 Sand 5 Mud 6 Organic 7 Vegetated	1 Algal 2 Aquatic Moss 3 Rooted Vascular 4 Floating Vascular	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic 5 Vegetated	2 Nonpersistent

* **Intermittent** is limited to the **Streambed** Class;
Unknown Perennial is limited to **Unconsolidated Bottom** Class code **R5UB** only
** **Rock Bottom** is not permitted for the **Lower Perennial** Subsystem;
Streambed is limited to **Tidal** and **Intermittent** Subsystems

Classification of Wetlands and Deepwater Habitats of the United States, Cowardin *et al.* 1979

February, 2011

WETLANDS AND DEEPWATER HABITATS CLASSIFICATION

System: L - Lacustrine

Subsystem: 1 - Limnetic

Class	RB – Rock Bottom	UB – Unconsolidated Bottom	AB – Aquatic Bed
Subclass	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic	1 Algal 2 Aquatic Moss 3 Rooted Vascular 4 Floating Vascular

Subsystem: 2 - Littoral

Class	RB – Rock Bottom	UB – Unconsolidated Bottom	AB – Aquatic Bed	RS – Rocky Shore	US – Unconsolidated Shore	EM – Emergent
Subclass	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic	1 Algal 2 Aquatic Moss 3 Rooted Vascular 4 Floating Vascular	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic 5 Vegetated	2 Nonpersistent

System: P - Palustrine

Class	RB – Rock Bottom	UB – Unconsolidated Bottom	AB – Aquatic Bed	US – Unconsolidated Shore	ML – Moss-Lichen	EM – Emergent	SS – Scrub-Shrub	FO – Forested
Subclass	1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic	1 Algal 2 Aquatic Moss 3 Rooted Vascular 4 Floating Vascular	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic 5 Vegetated	1 Moss 2 Lichen	1 Persistent 2 Nonpersistent 5 *Phragmites australis*	1 Broad-Leaved Deciduous 2 Needle-Leaved Deciduous 3 Broad-Leaved Evergreen 4 Needle-Leaved Evergreen 5 Dead 6 Deciduous 7 Evergreen	1 Broad-Leaved Deciduous 2 Needle-Leaved Deciduous 3 Broad-Leaved Evergreen 4 Needle-Leaved Evergreen 5 Dead 6 Deciduous 7 Evergreen

MODIFIERS

In order to more adequately describe the wetland and deepwater habitats, one or more of the water regime, water chemistry, soil, or special modifiers may be applied at the class or lower level in the hierarchy. The farmed modifier may also be applied to the ecological system.

Water Regime			Special Modifiers	Water Chemistry			Soil
Nontidal	**Saltwater Tidal**	**Freshwater Tidal**		**Coastal Halinity**	**Inland Salinity**	**pH Modifiers for all Fresh Water**	
A Temporarily Flooded	L Subtidal	S Temporarily Flooded-Tidal	b Beaver	1 Hyperhaline	7 Hypersaline	a Acid	g Organic
B Saturated	M Irregularly Exposed	R Seasonally Flooded-Tidal	d Partly Drained/Ditched	2 Euhaline	8 Eusaline	t Circumneutral	n Mineral
C Seasonally Flooded	N Regularly Flooded	T Semipermanently Flooded-Tidal	f Farmed	3 Mixohaline (Brackish)	9 Mixosaline	i Alkaline	
E Seasonally Flooded/ Saturated	P Irregularly Flooded	V Permanently Flooded-Tidal	h Diked/Impounded	4 Polyhaline	0 Fresh		
F Semipermanently Flooded			r Artificial	5 Mesohaline			
G Intermittently Exposed			s Spoil	6 Oligohaline			
H Permanently Flooded			x Excavated	0 Fresh			
J Intermittently Flooded							
K Artificially Flooded							