Increasing Resiliency for Culverts, Roads, and Riverine Ecosystems via Collaborative Culvert Assessment in the North Atlantic Region:

Development of the North Atlantic Aquatic Connectivity Collaborative

Final Report to the North Atlantic Landscape Conservation Cooperative

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Table of Contents

Introduction

Road-stream crossings, which include culverts and bridges, are an essential element of our transportation networks, allowing roads to pass over rivers and streams. Our communities and economies depend on functioning, reliable road networks and safe crossings, and we also depend on healthy rivers and streams.

Road-stream crossings have the potential to undermine the ecological integrity of river and stream systems in multiple ways. If not properly designed, crossings may fragment streams and bring a range of negative impacts for freshwater ecosystems. Crossings may disrupt the natural movement of water, sediment, and aquatic organisms. As barriers to the movement of aquatic organisms, crossings may impede access to vital habitats, including spawning areas, nursery habitat for young fish, and seasonal cold water refuges. These upstream refuges are becoming increasingly important in a warming climate. Undersized crossings can also contribute to erosion, exacerbate flood impacts, and cause unsafe conditions on roads.

As recognition of the impacts of road-stream crossings on the movement of fish and aquatic organisms has grown, individuals and organizations in the northeastern U.S. have created a number of assessment protocols to examine the barrier effects of these crossings. These protocols were independent, though often parallel and overlapping, approaches to crossing assessment.

While much of the focus of road-stream crossing assessment has been on aquatic organism passage, there is increasing interest in passage for terrestrial wildlife. This is based on an acknowledgment that road-stream crossings often provide the most practical sites for passage structures (due to high road clearances and the need to pass water) as well as recognition that many wildlife use riverine and riparian systems as movement corridors, especially through highly developed landscapes.

In addition to improving fish and wildlife passage, well-designed road-stream crossings may also build the resilience of local communities to flood events. A recent study found that stream crossings that are more severe barriers to fish and wildlife are also the most vulnerable to failure during large storms (Jospe 2013). During Tropical Storm Irene, stream crossings in Vermont's Green Mountain National Forest that had been designed to mimic the natural stream channel and allow for unimpeded movement of aquatic organisms and water avoided major damage, while there was extensive damage at multiple crossings constructed with more traditional designs (Gillespie et al. 2014).

The scale of problems associated with poorly designed crossings is extensive. In New York State alone, there are an estimated 1.2 million crossings. An analysis of field data on 9,064 road-stream crossings from five New England states found that 45.0% are moderate to severe barriers, 52.5% are minor or insignificant barriers, and only 2.5% provided full aquatic organism passage. Of the 6,440 culvert crossings (not including open bottom arches), 61.3% were moderate to severe barriers, 35.3% were minor barriers, and none provided full aquatic organism passage (S. Jackson, unpublished data from the Stream Continuity Project Online Database).

With so many crossings on the landscape and limited resources for restoration, well-planned assessment and prioritization are essential. To assess connectivity at road crossings and set regional priorities for restoring aquatic and terrestrial connectivity, it is necessary to reconcile disparate assessment approaches and knit them together into a compatible system for use across state lines and over large areas.

Project Overview and Structure

Goals and Objectives

At its outset, this project had two overarching objectives:

(1) Develop an infrastructure – including stream crossing assessment protocols, databases, data sharing applications, scoring algorithms, training programs, data quality procedures, and GIS data – to support road-stream crossing assessments and priority setting for the restoration of aquatic connectivity across the North Atlantic region. This infrastructure will provide information about where restoration projects are likely to bring the greatest improvements in aquatic connectivity through the identification of high-priority bridges and culverts for upgrade and replacement.

(2) Create a network of individuals and organizations from across the thirteen-state region to assess stream crossings, set priorities, and implement projects. The network includes practitioners from conservation organizations, universities, and state and federal natural resource and transportation agencies.

Project Structure and Process

A core group was created to implement the project as the decision-making body, with input from a work group of experts. The core group brought together, for the first time, representatives of all the major road-stream crossing assessment protocols in the Northeast. These included leaders of the River and Stream Continuity Project (University of Massachusetts Amherst), Maine Stream Connectivity Work Group (US Fish and Wildlife Service Gulf of Maine Coastal Program), Vermont's Aquatic Organism Passage Program (Vermont's Department of Fish and Wildlife), the United States National Forest crossing assessment program (US Forest Service), and the Northeast Aquatic Connectivity Assessment (The Nature Conservancy). Early on in the project, the core group named the overall effort the North Atlantic Aquatic Connectivity Collaborative (NAACC). Core group members are listed in Appendix A.

At the outset of the project, the core group invited participation of expert practitioners through a broad outreach effort to natural resource and transportation agencies from the thirteen states, federal agency personnel in the region, universities and conservation organizations. During the course of the project, over 80 individuals joined the work group. Work group members represented all thirteen states from the region and included personnel from nine state natural resource agencies, four state transportation agencies, five federal agencies, nine conservation organizations, and five universities. Work group members are listed in Appendix B.

For each of the major project objectives, the core group members first researched the topic and developed a proposal for the work group. Through interactive teleconferences, each topic was presented and input invited from the work group, with materials made available for those unable to participate. Each teleconference was followed by an online survey to solicit more extensive feedback from work group members. After reviewing input from the work group, the initial proposals were revised and each product was finalized and presented during a subsequent teleconference.

All of the webinar documents, along with links to listen to the webinar recordings, are available on the North Atlantic Aquatic Connectivity Collaborative website at http://streamcontinuity.org/resources/naacc_documents.htm.

Funding

Funding for this work was provided by a grant from the North Atlantic Landscape Conservation Cooperative (NALCC) and a companion grant provided by the Disaster Relief Appropriations Act of 2013 through the U.S. Department of the Interior's Hurricane Sandy Mitigation funds.

Developing a Regional Road-Stream Crossing Assessment Protocol

Objectives

A central task for the NAACC was the development of a regional stream crossing assessment protocol. Use of a variety of existing protocols across the NAACC region has limited the utility of the data collected, and has meant individual state approaches are incompatible for regional use. Development of the regional protocol was led by Alex Abbott of the US Fish and Wildlife Service Gulf of Maine Coastal Program. In the process of developing the stream crossing survey protocol, the NAACC core group focused on several important elements:

(1) Creating a method that quickly collects essential data to evaluate aquatic organism passage (AOP). Rapid assessment allows more sites to be assessed in a given area and field season.

(2) Allowing for additional assessment modules to complement the core AOP protocol. Examples of additional modules include assessment methodologies for terrestrial wildlife passage, geomorphic vulnerability, and aquatic organism passage on tidal streams.

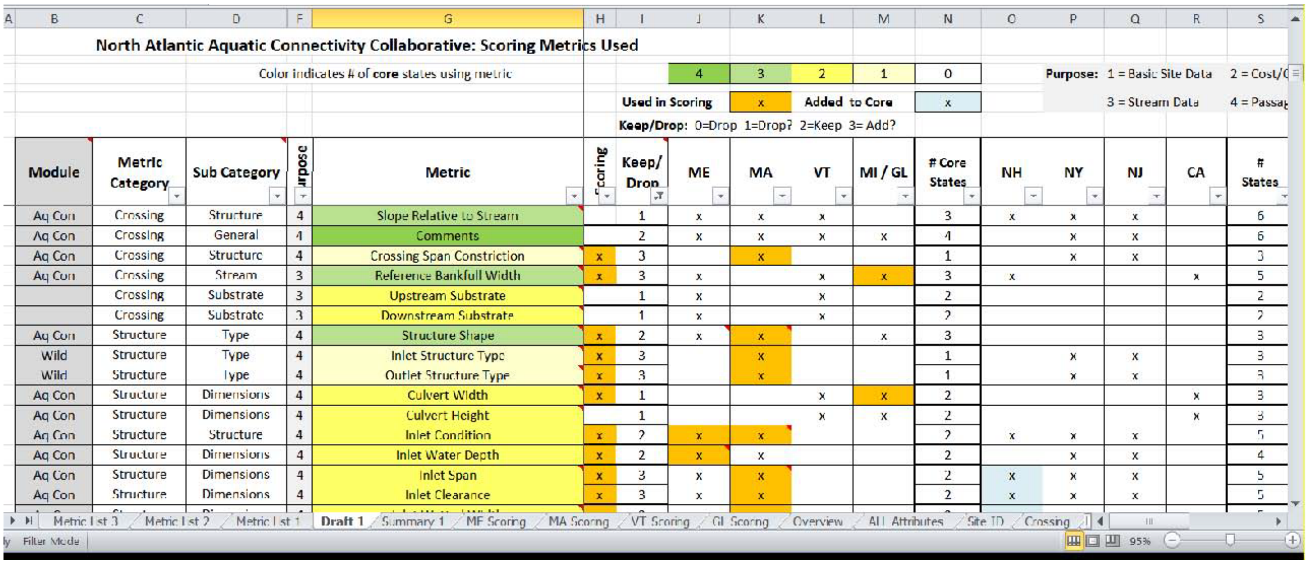
(3) Enabling filtering of crossing sites based on coarse screen scoring approaches. Multiple filters allow for different restoration prioritization approaches.

(4) Providing a protocol to be used by professionals and trained volunteers. Highly trained seasonal technicians collect data in some areas, but volunteers are essential to other survey efforts.

(5) Meeting the needs of a diverse group of public and private partners – each with its own goals, interests, and capabilities – from across the region. These partner organizations include the US Fish and Wildlife Service, state fish and wildlife departments, transportation agencies, and conservation organizations.

Methods

To begin development of a regional protocol we compiled information on existing road-stream crossing survey protocols from several states, regions, and organizations. This initial survey of protocols provided a broad view of the structure and specific metrics used in each approach and enabled the NAACC core group to compare existing approaches and choose those best fitting the region's and partners' needs. A variety of summary documents were prepared to help to compare protocols and to identify common metrics (Figure 1).


North Atlantic Aquatic Connectivity Collaborative: Scoring Metrics Used

Color indicates # of core states using metric: 4 | 3 | 2 | 1 | 0

Used in Scoring: x   Added to Core: x

Keep/Drop: 0=Drop 1=Drop? 2=Keep 3= Add?

Purpose: 1 = Basic Site Data 2 = Cost/(3 = Stream Data 4 = Passa

Module	Metric Category	Sub Category	urpose	Metric	coring	Keep/ Drop	ME	MA	VT	MI / GL	# Core States	NH	NY	NJ	CA	# States
Aq Con	Crossing	Structure	4	Slope Relative to Stream		1	x	x	x		3	x	x	x		6
Aq Con	Crossing	General	4	Comments		2	x	x	x	x	4		x	x		6
Aq Con	Crossing	Structure	4	Crossing Span Constriction	x	3		x			1		x	x		3
Aq Con	Crossing	Stream	3	Reference Bankfull Width	x	3	x		x	x	3	x			x	5
	Crossing	Substrate	3	Upstream Substrate		1	x		x		2					2
	Crossing	Substrate	3	Downstream Substrate		1	x		x		2					2
Aq Con	Structure	Type	4	Structure Shape	x	2	x	x		x	3					3
Wild	Structure	Type	4	Inlet Structure Type	x	3		x			1		x	x		3
Wild	Structure	Type	4	Outlet Structure Type	x	3		x			1		x	x		3
Aq Con	Structure	Dimensions	4	Culvert Width	x	1			x	x	2				x	3
Aq Con	Structure	Dimensions	4	Culvert Height		1			x	x	2				x	3
Aq Con	Structure	Structure	4	Inlet Condition	x	2	x	x			2	x	x	x		5
Aq Con	Structure	Dimensions	4	Inlet Water Depth	x	2	x	x			2		x	x		4
Aq Con	Structure	Dimensions	4	Inlet Span	x	3	x	x			2	x	x	x		5
Aq Con	Structure	Dimensions	4	Inlet Clearance	x	3	x	x			2	x	x	x		5

Metric List 3 / Metric List 2 / Metric List 1 / Draft 1 / Summary 1 / ME Scoring / MA Scoring / VT Scoring / GL Scoring / Overview / ALL Attributes / Site ID / Crossing

Figure 1: One Approach for Categorizing and Summarizing Metrics from Existing Crossing Survey Protocols.

Included in this initial survey were crossing survey protocols from Maine, Massachusetts, Vermont, Michigan (Great Lakes), New Hampshire, New York, New Jersey, California, and from the U.S. Forest Service. We developed summary tables with metrics from all protocols to evaluate which metrics fell into various categories of assessment, and which were most and least common. The core group used these summaries to develop a draft set of metrics representing the essential measures needed to assess aquatic organism passage at stream crossings across the region.

The draft metrics were presented to the NAACC work group. Work group members evaluated and commented on the list of draft metrics. Based on the work group feedback, we modified the metrics, leading to successive drafts with increasing levels of detail, including the specific naming, format, and values for each metric. The table in Figure 2 shows a portion of one of the later drafts of the metric list showing specific values assigned to individual metrics.

Challenges

The NAACC core group held many in-person and web-based meetings to review and evaluate the large amount of information needed to develop a unified crossing survey protocol. The group tackled some challenging questions and tradeoffs. For example, a protocol that can be used fairly rapidly precludes the collection of data needed to run certain models and software applications. A protocol that can be used by trained volunteers means that certain more complicated survey metrics, particularly those related to stream characteristics, could not be included. The core group addressed these tradeoffs, and the primary challenge of sorting through data on existing survey protocols, through clear communication and a collective focus on creating a truly useful tool that will provide vital data to improve aquatic organism passage and road infrastructure across the region.

	Crossing Metrics	Values	Description	Notes & Questions
19	**Bankfull Width**	**Optional**	Average of 3 widths in undisturbed reach; NOT taken in wetlands, highly developed areas, inaccessible sites; to nearest half foot	If done, must be measured before constriction assessment
+	**Bankfull Width Confidence**	High, Low/Estimated	*High* = High confidence in identification of indicators and direct measurement of multiple widths; *Low/Estimated* – low confidence in indicators or indirect width estimates or only one or two estimates	
20	**Constriction**	Severe, Moderate, Spans Channel, Spans Channel & Banks	*Severe* : total crossing < 50% of active/bankfull *Moderate* : total crossing > 50% and < 100% of active/bankfull *Spans Channel* : about the same as active/bankfull width *Spans Channel & Banks* : clearly exceeds bankfull channel width	Must be assessed after bankfull width (if done)
21	Tailwater Scour Pool	Large, Small, None	Relative to natural stream reach (Large > 2x width or depth, Small < 2x and > 1x width or depth, None < 1x)	
~~22~~	~~Maximum Pool Depth~~			Replaced by Tailwater Scour Pool
23	Photos	Inlet, Outlet, Upstream, Downstream, Other		
24	Comments			
	Structure Metrics	**Values**	**Description**	**Notes & Questions**
+	Structure #		For multiple culverts and bridge cells only	Essential for database
25	Inlet Structure Shape	Round, Pipe Arch/Elliptical, Open Bottom Arch, Box/Bridge w/abutments, Bridge w/side slopes, Bridge w/side slopes and abutments, Unknown	Used to calculate open area for flow, and openness ratio	Diagrams essential
26	Structure Material	Metal, Concrete, Plastic, Stone, Wood, Other	Primary material exposed to flow	*Other* can include combinations
27	Inlet Grade	At Grade, Inlet Drop, Submerged, Uknown	Situation of inlet invert	NOT slope or elevation
28	**Physical Barrier Type**	None, Debris, Sediment, Deformation, Free Fall, Fencing, Other	Other than Inlet/Outlet Grade issues; barriers for all of multiple structures at site (e.g., beaver dam) must be assessed for each structure	Should there be other options? Need clear guidance & examples
29	**Physical Barrier Severity**	None, Minor, Moderate, Severe	Defines degree of barrier based on examples and clear definitions for each type of barrier (e.g., debris blockage of ≤ 10% of inlet opening = Minor, >10% and < 50% = Moderate, > 50% = Severe)	Need clear definitions of categories for each type of barrier.

Figure 2: Screen Shot of a Working Draft of Proposed Metrics for Stream Crossing Assessment Protocol.

Final Protocol

In the spring of 2015, a draft of the protocol was presented at two-day training workshops in Annapolis, Maryland and Albany, New York. Feedback from these workshops resulted in some revisions and clarifications in the protocol. By June 2015, the NAACC core group finalized the protocol, along with an instruction guide, in time for the summer field season. The *NAACC Stream Crossing Survey Data Form Instruction Guide* contains detailed instructions for completion of the data form and important information to help partners plan for crossing surveys, including links to other documents developed by the NAACC. The instruction guide and data form may be downloaded from https://streamcontinuity.org/resources/naacc_documents.htm.

The stream crossing assessment protocol contains two sections:

(1) *Crossing Data*, which consist of metrics related to the overall site, and

(2) *Structure Data*, which are data specific to each crossing structure (i.e., culvert or bridge cell) at the site.

Crossing data include locational and site identification information essential to the site, such as who conducted the survey and when, where the site is located in latitude-longitude coordinates as well as road and stream names, and several metrics that relate to the overall site rather than individual structures (e.g., alignment, road fill height, and bankfull width). Structure data include dimensions and attributes of each structure necessary for assessing aquatic organism passage, such as whether the outlet is set above the stream bottom, and whether any physical barriers are associated with the structure. Refer to the instruction guide for a full explanation of the assessment protocol.

Prioritizing for Field Surveys

Given the large size of the NAACC area and the vast number of crossings within the region, completing field assessments of all crossings would take many years. To help focus initial field survey efforts in places where the assessment information is likely to be of greatest use, we developed a prioritization approach. This work was led by Erik Martin of The Nature Conservancy.

A Geographic Information Systems (GIS)-based approach was used for the prioritization because of the project's large regional scope. Further, due to the paucity of site-specific field data – in fact, the purpose of the analysis is to help direct field data collection efforts to particular places – we assumed that no field data could be used in the prioritization. Therefore, we derived all metrics for the prioritization from regionally available datasets.

To increase the flexibility of the prioritization and allow for customized intra-state comparisons, we designed the prioritization to accept data that may be specific to a given state. Thus, for example, the presence of a state-listed species of concern could be incorporated into the prioritization, thereby raising the priority of surveying crossings in a watershed where the species of concern is found.

Unit of Analysis

The unit of analysis is the type of feature being prioritized. Possible units of analysis for this task included the road-stream crossings themselves (i.e., a given crossing could be a high priority), subwatersheds that the crossings are within (i.e., all of the crossings in a subwatershed could be priorities) , stream reaches (i.e,. all of the crossings on a given reach could be a priority), or road segments (i.e., all of the crossings on a given road segment could be a priority).

After extensive discussion among the core group and work group, we selected USGS 12-digit hydrologic unit (HUC12) subwatersheds as the unit of analysis for the study. These subwatersheds, generally on the order of 100 square kilometers in size, were attributed with the metrics selected to measure each of the chosen objectives.

Targets

The NAACC core team determined the targets of the prioritization through an iterative process in close consultation with the work group.

Brook trout emerged as a primary target for the prioritization. Brook trout are the only trout native to the study area. They require cold, clean water, and they are an important recreational fish species. Additionally, the small streams that comprise essential brook trout habitat are frequently crossed by roads using culverts, thereby increasing the importance of gathering field survey data to identify underperforming culverts that restrict brook trout passage.

Surveying road-stream crossings in areas where **diadromous fish** are found was identified as another key target of the prioritization. Diadromous fish runs, including those of river herring, shad, and salmon, have been declining for decades in the region. In-stream barriers, including inadequate road-stream crossings, can limit the ability of these sea-run fish to access critical spawning habitats.

Recent storm events in the northeastern U.S., such as Hurricane Irene and Superstorm Sandy, have spurred interest in increasing the resiliency of road infrastructure to such storm events. In addition to concerns about aquatic habitat connectivity, the core team and work group were interested in identifying places where the **risk of crossing failure** was high, due to factors such as slope or stream size. Further, if a road-stream crossing fails during a storm event, the **impact of that failure** is not uniform across all crossings. For example, a culvert failure on a major thoroughfare could have a greater impact on the local population than a failure on a seldom traveled dirt road.

The **uncertainty surrounding the passability** of a crossing was another target for the prioritization. For example, at a site where a road crosses a large river (e.g., the Connecticut River in Hartford) the crossing structure is much more likely to be a bridge – which is much more likely to be passable for aquatic organisms – than a culvert, and therefore uncertainty about passability is lower. Areas where uncertainty is higher should be higher priorities for field surveys.

Through the process of determining these targets, several work group members expressed an interest in including targets specific to their state(s). Therefore, we included a **state-specific target** to accommodate some states' wishes to incorporate state-specific data.

The **estimated restoration potential** achieved by upgrading an underperforming culvert was the final target of interest to the core team and work group. In simplistic terms, upgrading a culvert that is at the very top of a headwater stream may only restore access to a very short reach of habitat, whereas an upgrade lower in the system may reconnect more habitat and thus have a higher restoration potential.

Metrics and Weighting

For each chosen target, we identified and calculated one or more metrics that could be measured using GIS for each HUC12 subwatershed. The metrics are summarized in Table 1. Appendix C provides more detail about these metrics and their data sources.

The output of the prioritization is a ranking of HUC12 subwatersheds, derived by weighting the various metrics. As metric weights are subjective in nature and meant to reflect the relative importance of each objective, the NAACC core team sought input from the work group on appropriate weights for the selected metrics. The NAACC work group reviewed a series of draft prioritization outputs and provided feedback on the different weighting schemes based on their assessment of the draft results and knowledge of the areas of interest. Thus, the chosen metric weights reflect work group members' priorities on the ground.

This process resulted in a prioritization with the metrics relative weights as summarized in Table 1. Metrics that have a weight of 0 in the table were not incorporated into the prioritization

Table 1: Metrics and Weights in NAACC Prioritization.

Target	Metric	Weight in Prioritization
Brook Trout	Eastern Brook Trout Joint Venture – Area Weighted Score	15
Brook Trout	DeWeber & Wagner: % of catchments with predicted brook trout in HUC	15
Diadromous Fish	The Nature Conservancy Alosine HUC12 Prioritization	30
Risk of Failure	Maximum drainage area in HUC	0
Risk of Failure	Mean slope at crossings in HUC	10
Risk of Failure	Max slope at crossings in HUC	5
Risk of Failure	Gravelius' Shape Index	5
Impact of Failure	% of crossings on size 1 roads (e.g. interstate)	0
Impact of Failure	% of crossings on size 2 roads (e.g. primary)	5
Impact of Failure	% of crossings on size 3 roads (e.g. secondary)	5
Impact of Failure	% of crossings on size 4 roads (e.g. tertiary)	5
Impact of Failure	% of crossings on size 5 roads (e.g. residential)	0
Impact of Failure	% of crossings on size 6 roads (e.g. unpaved)	0
Impact of Failure	Population within HUC12	0
Other	% of crossings on US Fish and Wildlife Service land (refuges)	0
Uncertainty of Passability	% of crossings on smaller streams (drain <100 km^2)	5
State-Specific Priorities	Varies by state	0
Estimated Restoration Potential	Individual crossings assessed within HUC12s using University of Massachusetts Critical Linkages data	0

Prioritization Methodology

Once metric values were calculated and relative weights assigned to the metrics of interest, metrics were combined through a weighted ranking process to develop a prioritized list for each scenario. The ranking process involves four steps and simple mathematical operations, as illustrated in Figure 3.

Step		HUC12	Slope (%)	Brook Trout Catchments (%)
1	Raw Values	10101010101	10	15
		10101010102	12	78
		10101010103	17	49
		10101010104	2	93

Step		HUC12	Slope (rank)	Brook Trout Catchments (rank)
2	Ranked Values	10101010101	3	4
		10101010102	2	2
		10101010103	1	3
		10101010104	4	1

Step		HUC12	Slope (% rank)	Brook Trout Catchments (% rank)
3	% Ranked Values	10101010101	33	0
		10101010102	66	66
		10101010103	100	33
		10101010104	0	100

Step		HUC12	Slope	Brook Trout Catchments
4	Multiply by Weight	10101010101	33 * 0.75	0 * 0.25
		10101010102	66 * 0.75	66 * 0.25
		10101010103	100 * 0.75	33 * 0.25
		10101010104	0 * 0.75	100 * 0.25

Step		HUC12	Slope (weighted rank)	Brook Trout Catchments (weighted rank)
5	Weighted Rank Values	10101010101	25	0
		10101010102	50	16.6
		10101010103	75	8.3
		10101010104	0	25

Step		HUC12	Combined Score
6	Combined Score	10101010101	25
		10101010102	66.6
		10101010103	83.3
		10101010104	25

Step		HUC12	Final Rank
7	Final Rank	10101010101	3
		10101010102	2
		10101010103	1
		10101010104	3

Figure 3: Prioritization Ranking Process.

The steps for the process are as follows:

1: Raw values were calculated for each metric in each HUC12 subwatershed in GIS.

2: Raw values were ranked so values which are a higher priority for survey have higher ranks (e.g., a HUC12 with steeper slopes would have a higher rank).

3: For each metric, ranks depend on whether large values are desirable in a scenario (e.g. upstream functional network length) or small values are desirable (e.g. % impervious surface).
4: Ranked values were converted to a percent scale where the top ranked value is assigned a score of 100 and the lowest ranked value is assigned a score of 0.
5: The percent rank was multiplied by the chosen metric weight.
6: The weighted ranks for each metric were added together for each HUC12 subwatershed.
7: The summed values for each HUC12 were then ranked.

The final ranks were binned into 5% tiers for presentation, where Tier 1 subwatersheds are the highest priority and Tier 20 subwatersheds are the lowest priorities. Tiering the results was an important step in acknowledging that the precision with which metrics can be calculated in a GIS is not necessarily indicative of on-the-ground differences. For example, a HUC12 whose average slope at crossings is 12.12% is not necessarily at a greater risk of failure as a HUC12 whose average slope at crossings is 12.11%.

For the NAACC regional analysis, we stratified the prioritization by state, for several reasons. First, stratifying by state allows for the inclusion of state-specific data. Second, stratifying by state ensures that high priority HUC12 subwatersheds are distributed evenly across states. Third, given regional differences across the thirteen-state region, it may not be appropriate to compare two subwatersheds in faraway places, such as Maine and Virginia. In practice, the analysis was stratified by running the prioritization algorithm separately for each state and then stitching the results together.

In addition to a regional prioritization map based on the metrics and weights above and reflecting the NAACC's work group's consensus priorities, we developed a custom prioritization tool that allows users to select their own metrics and weights from the "menu" of metrics.

Downscaling

The prioritization of HUC12 subwatersheds can help inform where to conduct road-stream crossing field surveys at a fairly broad level. Subwatersheds provide a manageably-sized unit for a field survey crew to work within. There may be cases, however, where time or resource limitations prevent surveying all crossings in a subwatershed. For these situations, we prioritized individual crossings within subwatersheds, based on each crossing's estimated restoration potential, or the value of the reconnected habitat if an unpassable crossing is upgraded.

We used the Conservation Assessment and Prioritization System (CAPS) and regional data compiled by the Landscape Ecology Lab at the University of Massachusetts and methods developed for the Critical Linkages project (McGarigal et al. 2012) to assess the estimated restoration potential of each crossing. The Critical Linkages analysis utilizes a resistant kernel approach to assess the aquatic connectivity of rivers and streams and assess the potential to restore connectivity via road-stream crossing upgrades. This is done by calculating the change in Aquatic Connectedness (a CAPS metric) scores for wetland and aquatic ecosystems when each crossing is upgraded and treated in the model as completely permeable. A crossing with a larger effect on

Aquatic Connectedness would have greater potential for restoring aquatic connectivity based on the crossing's passability, proximity to other barriers (dams and other crossings) on the same stream, and its location within the watershed (e.g. how far from the terminus of the stream). Overall restoration potential is a function of the potential to restore aquatic connectivity and habitat quality (ecological integrity) of the affected streams. The specific attribute used in the prioritization is the "effect" score, calculated as the product of the "delta aquatic-connectedness" score (change in the CAPS Aquatic Connectedness metric) and the CAPS "Index of Ecological Integrity" score for each cell and summed for all cells affected by each hypothetical crossing replacement. The "effect" score is essentially the change in aquatic connectedness ("delta aquatic-connectedness") weighted by habitat quality ("index of ecological integrity").

Web Map

The results of this analysis include a web map showing the regional subwatershed prioritization, along with individual crossings symbolized based on their estimated restoration potential and a tool allowing users to customize a subwatershed prioritization by selecting from among the available metrics and assigning their own weights to the selected metrics.

The web map is available at http://arcg.is/1F2rPJu. Figure 4 is a screen capture of the web map, where warmer colors represent higher priority subwatersheds for survey and cooler colors represent lower priorities. Clicking on one of the subwatersheds raises the popup dialog box which indicates the tiered result for the subwatershed as well as the raw metric values for the full suite of metrics.

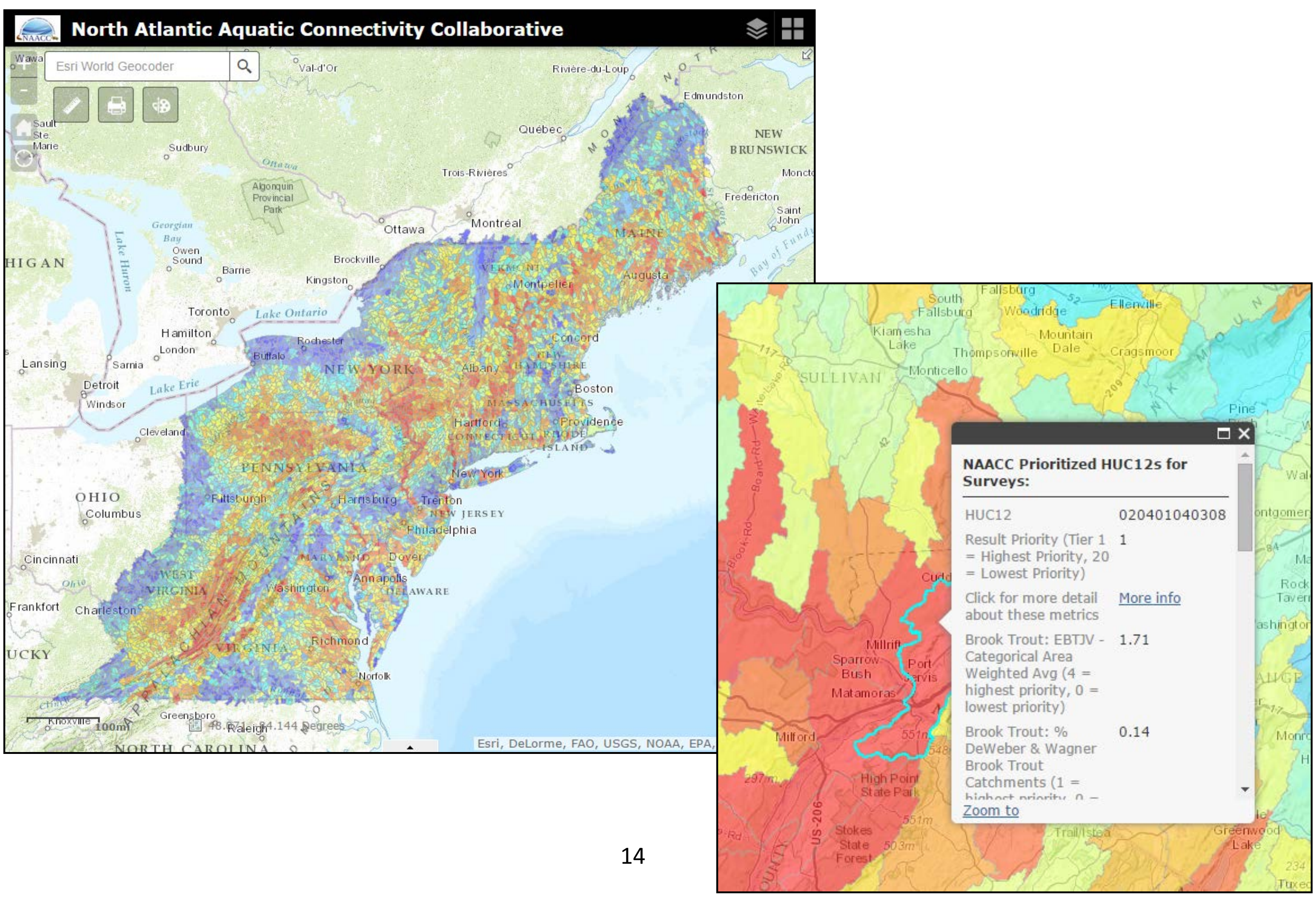


Figure 4: Regional Subwatershed Prioritization and Popup Box.

When the scale of the map is larger (zoomed in closer) than 1:250,000, individual crossings become visible as well (Figure 5). The points representing each crossing are sized relative to their estimated restoration potential. Thus, a larger point in a "red" subwatershed would be among the highest priorities for field surveys. Clicking on a crossing calls a pop-up dialog box with the Critical Linkages "impact" score for that crossing as well as a link to more information about the Critical Linkages study.

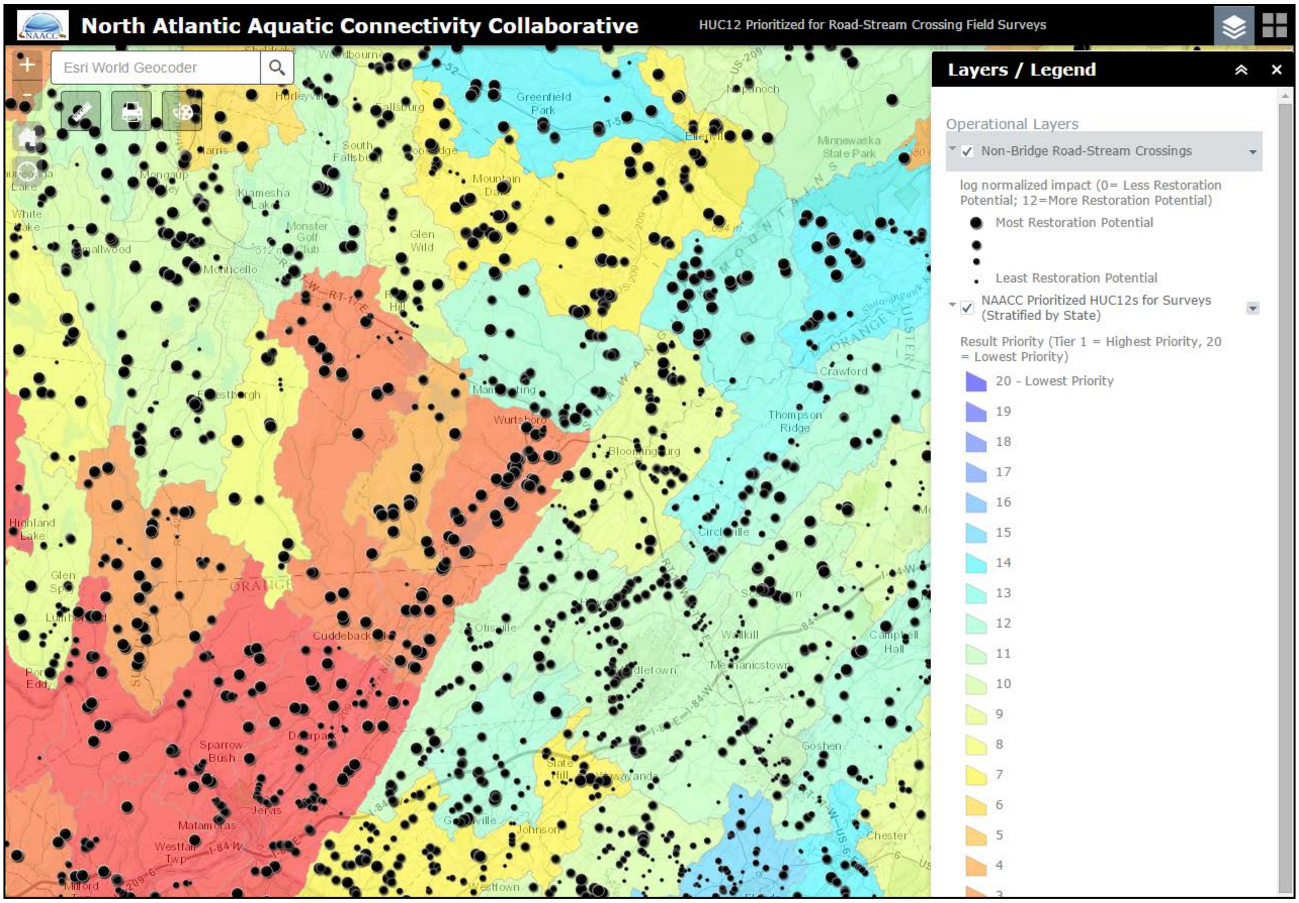


Figure 5: Closer View of Prioritization Map.

Beyond the project specific data, the web map includes functionality that is common to modern web maps. Figure 6 highlights the functionality that is included in the map.

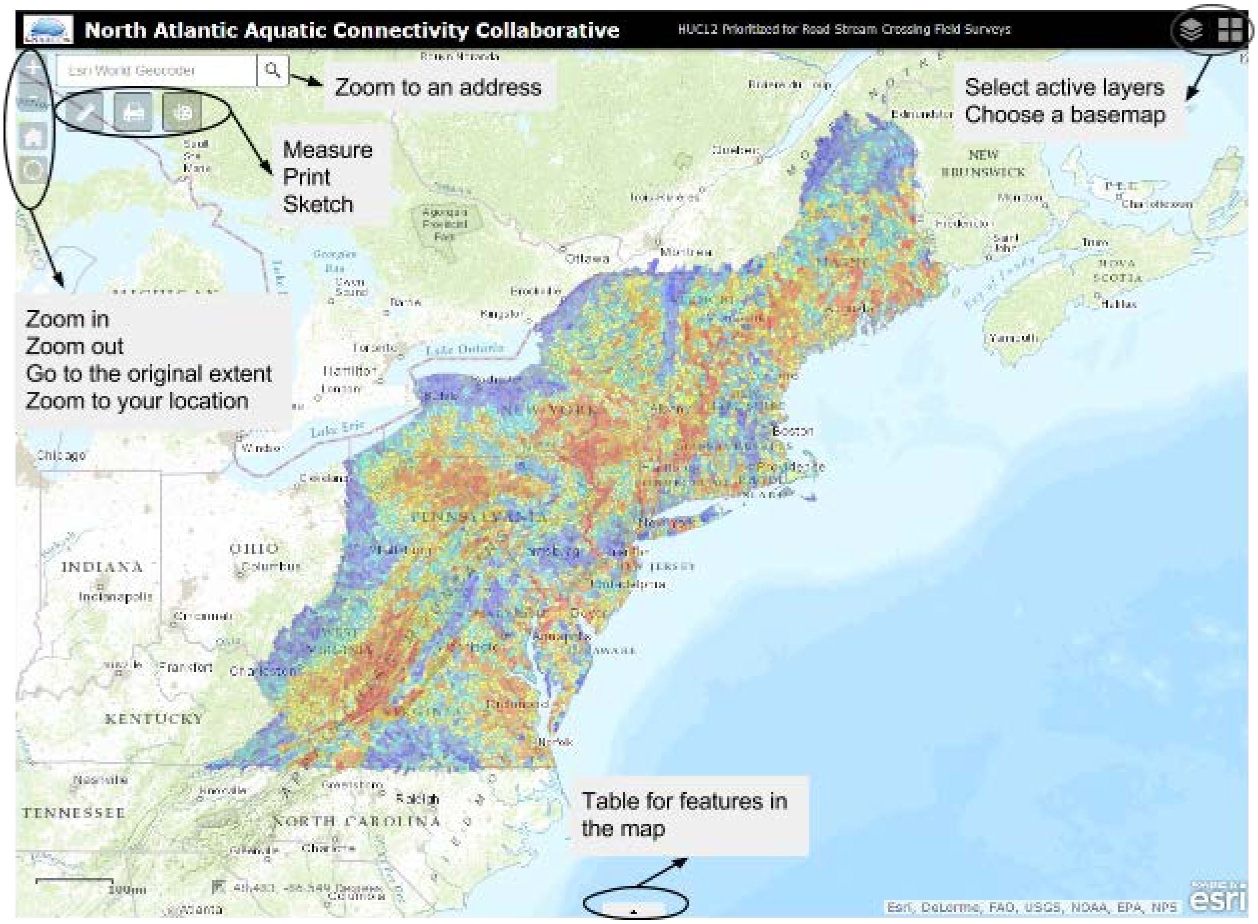


Figure 6: Functionality of Subwatershed Prioritization Map.

Custom Analysis Tool

The custom analysis tool is run as a script tool within Esri's ArcMap Desktop software and can be run with any level ArcGIS license. We designed the analysis tool for, and tested it with novice GIS users. The tool including the input datasets and setup instructions (README.txt) can be downloaded from https://tnc.box.com/s/vob8eep7s4k4xif4j2aoe3bb1k8lfp86.

After downloading and unzipping the tool and data to a location of the user's choice on their local system, the contents should be accessed only via ArcGIS software (ArcMap or ArcCatalog). An ArcMap project file (PrioritizeForFieldSurveys.mxd) can be opened to display a local copy of the data that is presented in the web map.

Opening the folder in the ArcCatalog window reveals a file geodatabase with the consensus prioritization, the road-stream crossing points, the input data for custom analyses, as well as a geoprocessing "Toolbox" with a single tool labeled "Prioritize." After extraction, the contents of the download should not be rearranged. In particular, in order for the tool to work the "scripts" folder must be in the same parent folder as the file geodatabase.

Double clicking on the “Prioritize” tool opens the tool dialog, as shown in Figure 7. The dialog box includes a list of metrics available for inclusion in the prioritization, as well as options to stratify by state or filter the input data (e.g., limit an analysis to a single state). If the “Stratify By State” option is not selected, the prioritized results will be relative to the entire region as opposed to forcing high-to-low priorities for each state. If prioritized results are desired relative to another spatial extent (e.g. HUC4 watersheds) these can be run for individual watersheds by applying a filter. For example, to see the priorities within the Connecticut River basin the following filter could be added as a the “UserFilter”: “HUC4” = ‘0108’. By default, the tool is pre-loaded with the metric weights used in the consensus scenario. These values can be altered to reflect the user’s objectives, so long as the metric weights sum to 100.

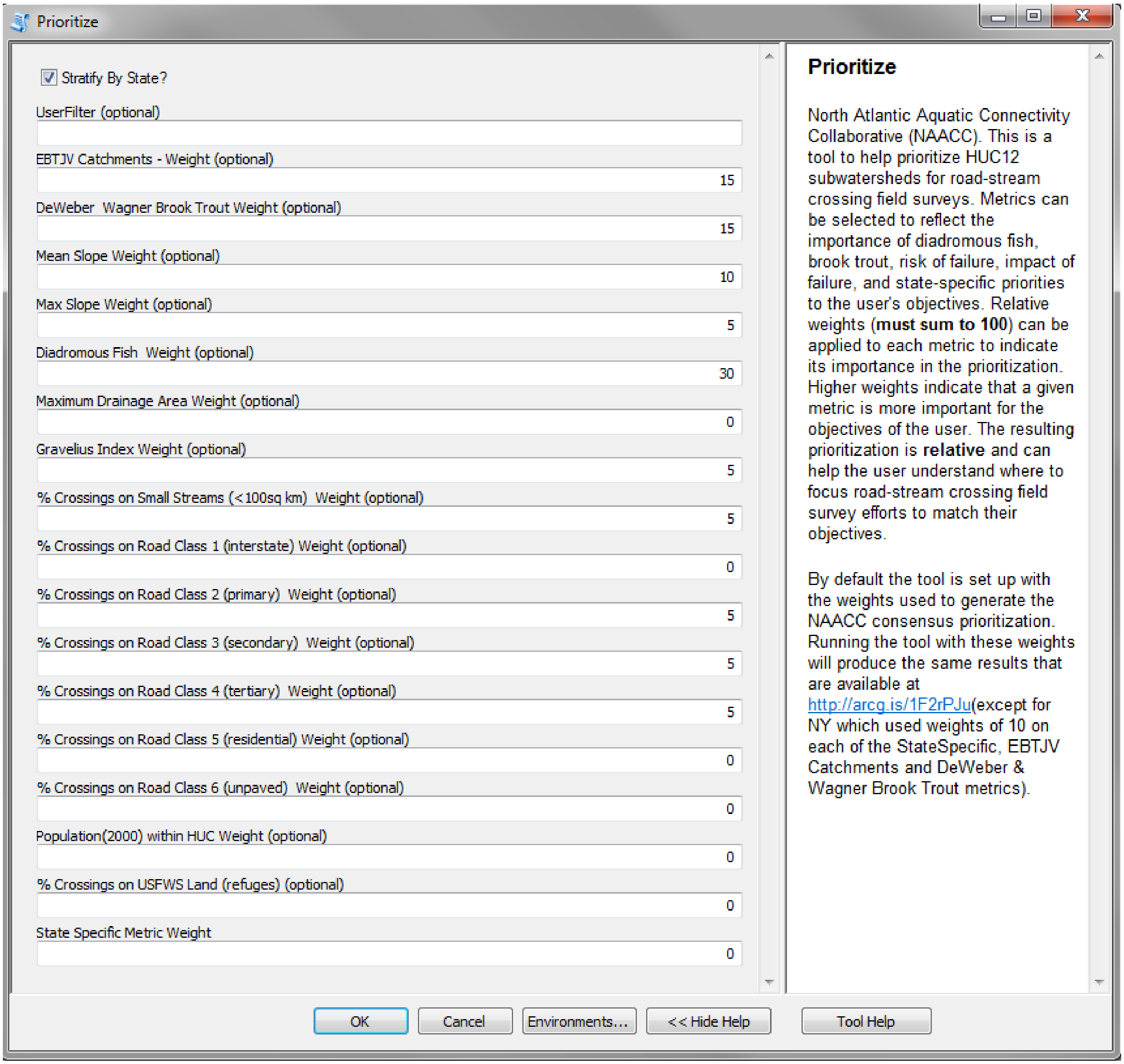


Figure 7: “Prioritize” Tool Dialog.

The time required to run an analysis depends on several parameters, such as the number of metrics selected, whether the analysis is stratified by state, and the processing speed of the computer being used. An analysis should generally take between 15 and 45 seconds to run. To optimize processing speed, the results are stored in a temporary workspace in the computer’s memory. The results of a custom analysis can be saved to disk using any of the methods available for copying data in ArcMap, such as right-clicking on the result layer and selecting Data → Export Data as well as the “Copy Features” tool within the “Features” toolset of the “Data Management” toolbox. By default, custom scenario results are symbolized using the same thermal color ramp as the consensus scenario where warm colors are higher priorities and cooler colors are lower priorities.

Database and Data Collection

Regional Stream Crossing Database

The NAACC database is a repository for all stream crossing data from across the thirteen-state region collected by certified observers using the NAACC field survey protocol. In addition, data is being compiled from a variety of protocols that were in use prior to the creation of NAACC. Data are generally available to the general public for viewing and download. Some data, such as those collected on private land, will not be public and will only be available to certain individuals. Database development was led by the University of Massachusetts.

Although most data are readily available for download, we restrict the ability to upload data to those who are trained and certified by the NAACC. Database credentials are available to those who have completed various levels of training and agree to abide by the protocols and data quality procedures set out by the NAACC. Once entered, data are automatically scored by the NAACC coarse screening tool and numerical passability algorithm, and results from those scoring systems become available for download.

The database allows users to implement customize searches to filter the data and then either view it online (in tabular form and via a mapping interface) or download the data as either an Excel file or GIS-ready shapefile. The map interface and shapefiles include all crossings identified by GIS, including unassessed crossings and crossings that have been assessed in the field. These are used by survey coordinators to plan and implement crossing surveys. The database is online at https://streamcontinuity.org/cdb2.

Each crossing is distinguished in the database by its crossing xy code, which is composed of the prefix "xy" followed by the latitude and longitude of the site, with decimal degree latitude and longitude values as seven-digit numbers.

Digital Data Collection System (DDCS)

Field surveyors using the NAACC protocol and stream crossing survey data form have the option of collecting data with paper forms or using a mobile device. The ability to collect data with a mobile device is made possible by the NAACC Digital Data Collection System (DDCS), developed as a part of this project by the University of Massachusetts. The DDCS includes three key components:

(1) GPS navigation to road-stream crossings to be surveyed using a tablet or other mobile device;
(2) Collection of road-stream crossing data with digital PDF data forms using mobile devices;
(3) Bulk upload of road-stream crossing data to the online NAACC database.

The process of digitally collecting field data for road-stream crossings with location information is evolving but is still in its early stages. The NAACC core group, with input from the work group, considered several technology options in the process of creating this system, including Collector for ArcGIS, Terrago, and custom apps for iOS and Android. Several options were found not to be programmable enough to allow for the complex data validation and other features needed, and building custom apps for iOS and Android devices was cost prohibitive both initially and over time. Ultimately, the core group selected Adobe PDF forms because they are free and highly programmable, can be used on a variety of devices, and have low programming costs. Further recommendations on software and setup can be found in the DDCS Users' Guide.

The DDCS has been configured to promote data quality. Data validation elements ensure that data meet certain conditions. These conditions include completion of all mandatory fields on the form and setting an acceptable range of measurements for certain metrics. These data validation rules are applied at data collection when electronic forms are used and at the time of upload to the database when paper data forms are used.

Digital and paper data forms, the Survey Form Instruction Guide, and the DDCS users' guide are available on the NAACC website at http://streamcontinuity.org/resources/naacc_documents.htm.

Data Quality and Training

Data Quality Procedures

To ensure the credibility of data collected, the NAACC has implemented a number of Quality Assurance/Quality Control (QA/QC) procedures. In developing these QA/QC procedures, the core group sought to balance the need for data quality with the need to create a protocol that would be broadly used across the region. Although in some states agencies use trained technicians to conduct crossing assessments, in other states assessments are conducted by conservation organizations and volunteer groups. A protocol with highly rigorous QA/QC procedures could serve as a barrier to recruitment and undermine the objective of providing a means for rapid assessment of road-stream crossings over large geographic areas.

The NAACC core group was cognizant of a range of potential data quality issues – many of which were identified in a 2008 study by the University of Massachusetts Amherst of an early version of Massachusetts' crossing assessment protocol – and worked proactively to mitigate them. For example, wording on the field survey form has been carefully vetted and reviewed, and the instruction manual contains clear and thorough instructions. Electronic data forms include embedded links to ensure that explanatory information is readily available during surveys. Data validation rules, described in the previous section on the NAACC DDCS, are another component of data QA/QC.

The NAACC has developed a system of distributed coordination with defined expectations for coordinators and those involved in data collection. Data collection teams must include a lead observer who has been trained and certified by the NAACC. Coordinators of surveys must complete specific training. Coordinators play an important role in NAACC QA/QC procedures: they review and approve all data and new (previously unmapped) crossings entered by lead observers and field audit 10% of each new lead observer's first 50 crossing assessments.

Training and Certification of Surveyors

The training program for field surveyors is another key component of the NAACC QA/QC procedures. Lead observers must complete a half-day classroom training session or an online training session (developed by the University of Massachusetts) as well as field training, and they must shadow a certified lead observer for a minimum of twenty assessments. As part of this training, they must pass an online quiz (also created by the University of Massachusetts) to become certified. Survey coordinators must first be certified as lead observers and then must complete an online coordinator training unit and pass an online quiz. Certification for lead observers expires after two years of inactivity. Period recertification of lead observers and coordinators is encouraged.

Recognizing that there are many experienced surveyors across the region who previously used another state- or organization-specific protocol, some grandfathering procedures are in place. For those who have participated in comparable field training prior to the adoption of the NAACC protocols and have conducted ten or more field assessments, the field training component may be waived. Similarly, the shadowing requirement may be waived for those who have conducted twenty or more field assessments using a similar protocol to that of the NAACC.

Classification and Scoring Systems

Data collected using the regional NAACC protocol becomes most useful when it is scored or classified to indicate the degree to which each crossing is a barrier to aquatic connectivity. Fundamental to this process is the acknowledgement that evaluating aquatic connectivity can be done in many different ways, from looking at the ability of individual species to pass specific crossings, to assessments that attempt to encompass broad suites of species, including more than just strong-swimming adult fish. While data from the NAACC protocol may be used to evaluate passage of individual species, they are most applicable to assessing connectivity for a range of aquatic and semi-aquatic organisms that include weak-swimming and juvenile fish, as well as reptiles and amphibians. This sort of broad assessment – used as a coarse filter to identify potential restoration sites – is the focus of the NAACC scoring and classification systems.

Two scoring systems for evaluating aquatic passability at road-stream crossings were adopted by the NAACC. The first is a classification/coarse screen where crossings are classified into one of three categories: "Full AOP" (Aquatic Organism Passage), "Partial AOP," and "No AOP." The second system is an algorithm for computing an aquatic passability score, ranging from 0 (low) to 1 (high), for each road-stream crossing. Development of the scoring systems was led by Alex Abbott of the US Fish and Wildlife Service Gulf of Maine Coastal Program and Scott Jackson of the University of Massachusetts.

The values or categories provided by the NAACC scoring and classification approaches may be used to make comparisons between crossings, and they can be applied in both simple and sophisticated systems of prioritization to identify sites locally or regionally for replacement and restoration. It should be noted that, regardless of which system is used, these ratings are based upon a limited suite of physical measurements and therefore additional on-site evaluations of the structure, aquatic habitat quality, aquatic community and undocumented barriers will be necessary to fully determine the benefit of restoration. These two scoring systems are not particular to any taxonomic or functional group but instead seek to evaluate passability for the full range of aquatic organisms likely to be found in rivers and stream.

Classification/Coarse Screen

One approach – classification or a coarse screen approach – uses a set of decision rules that places crossings in broad classes defining aquatic organism passage (AOP) at each site. This is a method used for many years in states within the NAACC region, and in other parts of the country, including Vermont, Maine and California, as well as by the U.S. Forest Service. The NAACC classification approach, shown in Table 2, shows the decision rules used to classify each crossing based on metrics derived from site surveys.

The key strength of this system is its simplicity, wherein all crossings are sorted into one of three classes. While the decision rules may at first seem simplistic, we have seen, from a comparison of results using this approach with expert field evaluations of the same sites, that this approach effectively captures these broad categories of connectivity. Individual decision rules often overlap with other rules, providing some measure of redundancy and internal verification. For instance, while most species and age classes of aquatic and semi-aquatic organisms normally cannot pass a crossing with even a small *outlet drop to water surface*, defining the decision rule for *No*

AOP using that metric at ≥ 1 foot is not as extreme as it may seem. Most sites with much smaller outlet drops also have other factors such as shallow water depths in the crossing and below the outlet such that many additional sites receive the *No AOP* designation based on other decision rules.

Table 2: NAACC Crossing Classification Approach

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

Perhaps the greatest limitation of the classification approach is the majority of crossings are typically grouped in the *Reduced AOP* class, which then includes a very wide range of potential sites for work to improve passage. Yet, while these sites are all grouped together in terms of their passage potential, evaluating priorities among these sites is fairly simple when considering additional factors such as aquatic habitat quality, aquatic community composition, and the length and size of stream affected by each site. The classification of crossings is an important step in assessing crossings, but is only one among several that must be undertaken to determine priority sites for restoration.

Continuous Scoring

The numeric scoring algorithm was developed through consultation with experts who determined both the relative importance of all the available predictors of passability as well as a way to score each predictor. Scoring involves three steps: (1) generating a component score for each predictor variable, (2) combining these predictions with a weighted average to generate a composite score for the crossing, and (3) assigning a final score based on the minimum of the composite score or the component score for the *outlet drop* variable. This numeric score, also referred to as the passability score, is used in Critical Linkages analyses to evaluate aquatic connectivity (CAPS Aquatic Connectedness metric) and the restoration potential of culvert replacement options (see pages 13-14).

Variables Used

Crossing assessments are generally done during "typical low-flow conditions." Some variables are important for assessing conditions at the time of the survey; others provide indirect evidence of likely conditions at higher flows. Variables included in the score include:

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

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

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

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

Water Depth: This variable indicates how water depth in the structure compares to water depths found in the natural channel at the time of survey.

Water Velocity: This variable indicates how water velocity in the structure compares to water velocities found in the natural channel at the time of survey.

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

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

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

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

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

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

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

Step 1: Component Scores

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

Scoring categorical predictors is simply a matter of assigning a score for each possible category. Table 3 lists all of the categorical predictors and the scores associated with each category.

Scoring continuous predictors requires a function to convert the predictor to a score. There are three continuous predictors (Figure 8) and three associated functions. The functional forms used were chosen because they have shapes desired by the expert team or because they fit the series of points specified by the expert team. Appendix D includes the r code defining each of these functions.

The scoring equation for *Openness* is

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

Where S_o is the score for openness, a=1, k=15, and d = 0.62

The equation for *Height* is

$$(2)\quad s_h = \frac{ax^2}{b^2 + x^2}$$

Where S_h is the component score for height, a = 1.13, and b=3.5

The equation for *Outlet Drop* is

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

Where S_{od} is the Outlet Drop component score, a=1.029412, and b=6.173949

Table 3: Component Scores for Categorical Variables Used in Calculating the Crossing Score

Parameter	Level	score
Constriction	Severe	0
Constriction	Moderate	0.5
Constriction	Spans only bankfull/active channel	0.9
Constriction	Spans full channel and banks	1
Inlet grade	At stream grade	1
Inlet grade	Inlet drop	0
Inlet grade	Perched	0
Inlet grade	Clogged/collapsed/submerged	1
Inlet grade	Unknown	1
Internal structures	None	1
Internal structures	Baffles/weirs	0
Internal structures	Supports	0.8
Internal structures	Other	1
Outlet armoring	Extensive	0
Outlet armoring	Not extensive	0.5
Outlet armoring	None	1
Physical barriers	None	1
Physical barriers	Minor	0.8
Physical barriers	Moderate	0.5
Physical barriers	Severe	0
Scour pool	Large	0
Scour pool	Small	0.8
Scour pool	None	1
Substrate coverage	None	0
Substrate coverage	25%	0.3
Substrate coverage	50%	0.5
Substrate coverage	75%	0.7
Substrate coverage	100%	1
Substrate matches stream	None	0
Substrate matches stream	Not appropriate	0.25
Substrate matches stream	Contrasting	0.75
Substrate matches stream	Comparable	1
Water depth	No (significantly deeper)	0.5
Water depth	No (significantly shallower)	0
Water depth	Yes (comparable)	1
Water depth	Dry (stream also dry)	1
Water velocity	No (significantly faster)	0
Water velocity	No (significantly slower)	0.5
Water velocity	Yes (comparable)	1
Water velocity	Dry (stream also dry)	1

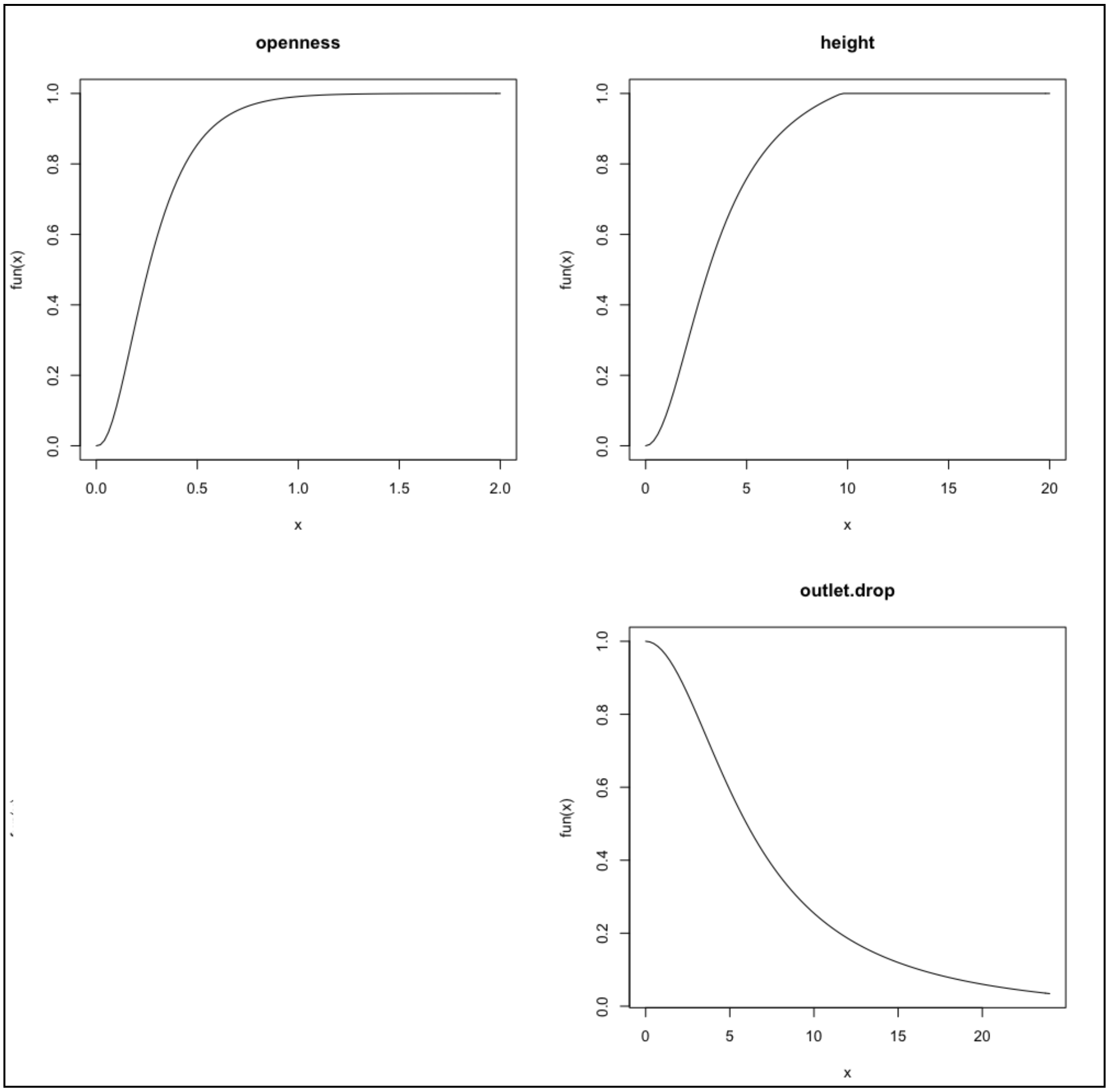


Figure 8: Continuous Predictor Variables (Height and Outlet Drop are in inches; Openness is in feet)

Some notes about the component scores:

(1) The option "clogged/collapsed/submerged" for *Inlet Grade* is an option surveyors use to indicate that it was not possible to measure the structure's dimensions. If the inlet is clogged or collapsed enough to affect passability, it will be covered under *Physical Barriers*. It receives a "1" instead of a "0" because problems associated with this option are covered by the *Physical Barriers* variable.

(2) The rationale for giving a component score of "1" to "unknown" for *Inlet Grade* is similar to that for "clogged/collapsed/submerged." It is hard to know how to interpret "unknown." However, if conditions at the inlet are creating a physical barrier to passage it will be covered under *Physical Barriers*.

(3) We included *Inlet Grade* as a variable in addition to *Physical Barriers* because inlet drops create both velocity and physical barrier (jump barrier) issues. The physical barrier issues are covered by the *Physical Barriers* variable. The *Inlet Grade* variable captures the velocity issues at the inlet. Perched inlets can create depth issues at low flows (if water can't get into the structure inlet). These may not be apparent at the time of the survey. Thus, the presence of a perched inlet is a concern even if it doesn't represent a physical barrier ("dry") at the time when the survey is conducted.

(4) The variable *Internal Structures* is included to account for turbulence issues. There is likely to be turbulence associated with weirs and baffles when these are included inside crossing structures. If they also create physical barriers they will be covered by the *Physical Barriers* variable. While they are often included in structures to help aquatic organism passage, they sometimes do more harm than good. Further, they may be good for some species while creating problems for others. The inclusion of well-designed weirs or baffles is likely to improve the component scores for water depth and water velocity. They get docked a little in our scoring system for introducing turbulence.

(5) It is difficult to know how to score the "other" option under *Internal Structures* because it is difficult to know what, if any, impact these other structures will have on turbulence. If, however, they represent a physical barrier they will be covered under the *Physical Barriers* variable.

Step 2: Weighted Composite Scores

A team of nine experts provided their professional judgement about how the variables should be weighted. The weights used with the component scores are listed in Table 4. The weights are simply the means of the nine weights for each variable provided by the experts rescaled so that the sum of the weights equals one. We display the weights out to three decimal places to reduce overall error in the model by not introducing an additional source of error (rounding error). This is not to suggest that we know the weights to this level of precision. The composite score is the sum of the products of each component score and its weight.

Step 3: Final Aquatic Passability Score

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

Aquatic Passability Score = Min[Composite Score, Outlet Drop score]

Table 4: Weights Associated with Each Parameter in the Scoring Algorithm

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

NAACC Regional Network

Network Structure

The NAACC has evolved into a network of organizations, agencies, and individuals working across a large region to assess road-stream crossings. This network is structured into different levels:

> **Level 3 coordinators** are central coordinators who maintain key components of the NAACC. They update field protocols, create and update scoring systems, develop data quality assurance procedures, maintain the online database, and disseminate news and updates to the NAACC community.
>
> **Level 2 coordinators** are regional coordinators who oversee crossing surveys across a fairly large geographic area, such as a state or large watershed. Their responsibilities are to oversee surveys in their geographic area, recruit and supervise Level 1 coordinators, coordinate training on field protocols, and ensure implementation of quality assurance procedures.
>
> **Level 1 coordinators** are local coordinators who oversee and organize observers. They recruit and supervise lead observers to assess road-stream crossings, determine survey locations, establish standards and expectations for field safety, ensure adherence to protocols and QA/QC procedures, and review and approve data entered into the database.
>
> **Lead observers** are certified to assess stream crossings in the field. They lead survey teams, coordinate survey schedules, collect data, ensure that surveys are conducted in the right locations, ensure safety in the field, and enter data into the regional database.

Training of Personnel

Integral to development of the NAACC regional network was the training of personnel from across the region to serve as lead observers and level 1 and 2 coordinators.

Core group members hosted six trainings for lead observers in the spring and summer of 2015 (Table 5), and those who were trained then went on to host other trainings in New York, Connecticut, and Massachusetts to certify observers from across the region.

Table 5: Training of Personnel by NAACC Core Group

Training Dates	Location	Number of Trainees	Trainees' States
April 8-9, 2015	Annapolis, MD	13	CT, DE, MD, VA, VT, WV
May 18-19, 2015	Albany, NY	21	CT, MA, NJ, NY, PA, VT
June 1-3, 2015	Wells, ME	5	ME
June 26, 2015	Buckfield, ME	10	ME
July 1-2, 2015	Hadley, MA	12	CT, MA, MD, VT
August 4-5, 2015	Lamar, PA	6	PA, WV

Network Growth and Survey Efforts

By November 2015, the NAACC network had grown to include:

- 9 level two coordinators, from 5 different states;
- 20 level one coordinators, from 7 different states; and
- 65 lead observers, from 8 different states.

Thanks to the efforts of the partners involved in the NAACC, over 5,000 stream crossing sites were surveyed using the NAACC field protocol during the 2015 field season and data entered into the online database (as of September 30, 2015). New field survey efforts were launched in Connecticut, Maine, Massachusetts, New Jersey, New York, Pennsylvania, Virginia, and West Virginia. Funding to states and conservation organizations from the US Fish and Wildlife Service enabled many of the newest efforts. The regional NAACC database contains these new field data.

Next Steps

Database Expansion and Decision Support Tools

Previously collected stream crossing survey data is now being incorporated into the regional database. Once these existing survey data from the project region are added, we expect that the NAACC database will contain information for about 35,000 stream crossing sites. In the coming year, the NAACC will incorporate this survey data into two aquatic connectivity decision support tools that span the project region.

The Nature Conservancy's 2012 Northeast Aquatic Connectivity Project (https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/freshwater/stream/Pages/default.aspx), which also utilizes data on existing dams across the region, will be updated with stream crossing data to support a more thorough prioritization of barriers to the movement of migratory fish, based on their potential restoration benefit. The results will be made available through an interactive web map and custom analysis tool, allowing users to query the data and view them in the context of other data.

The University of Massachusetts Amherst's Critical Linkages program uses passability scores based on field assessments of road-stream crossings to set resistant values for those crossings as part of the resistant kernel approach for evaluating aquatic connectedness. Where field assessments have not yet been conducted, Critical Linkages uses a model to predict aquatic passability and set resistance values for those crossings. New NAACC survey data will be used to assess the potential to restore aquatic connectivity – for resident fish and other aquatic organisms – via crossing upgrade and replacement and to improve their existing road-stream crossing passability prediction model. The collection of high-quality field data ensures that assessments of restoration potential computed by Critical Linkages are credible for those crossings that have been assessed and improves our ability to predict passability and restoration potential for crossings that have not been assessed.

At the end of each year for two years (2015 and 2016), aquatic passability data will be downloaded from the NAACC database and use to conduct a Critical Linkages analysis of crossings in the thirteen-state NAACC region. The results will be made available to partners by posting them on our web site (www.streamcontinuity.org) and integration into the online database's mapping interface. We are also developing a spatial data viewer as part of the ECOSHEDS web site to provide additional ability to parse the data and visualize results. We expect that these annual Critical Linkages analyses will continue beyond 2016.

The Future of the NAACC

The NAACC initiative has moved from its infrastructure development phase – during which the survey protocol, prioritization tools, databases, scoring approaches, and training programs were developed – into an implementation phase. The work group has been replaced by an advisory committee that will guide the overall effort and convene in smaller subcommittees to address new tasks. All former work group members were invited to join the advisory committee. The core group reconfigured itself into a steering committee and broadened its membership to include representation from several other states in the region. Communication with a larger community of practitioners is managed through a list-serve.

A charter for the collaborative (Appendix E) was written and adopted by the core group as one of its final official acts. The NAACC steering committee (Table 6) was formed with an initial membership of 14 individuals.

Table 6: NAACC Steering Committee

Name	Organization
Alex Abbott	US Fish and Wildlife Service (ME)
Carrie Banks	MA Division of Ecological Restoration, Department of Fish and Game (MA)
Mindy Barnett	CT Department of Energy and Environmental Protection (CT)
Seth Coffman	Trout Unlimited (VA)
Shane Csiki	NH Department of Environmental Services (NH)
Robert Gubernick	USDA Forest Service
Phil Herzig	US Fish and Wildlife Service (Regional)
Scott Jackson	University of Massachusetts Amherst (Regional)
Rich Kirn	VT Fish and Wildlife Department (VT)
Jessica Levine	The Nature Conservancy (NY/Canada)
John Magee	NH Department of Fish and Game (NH)
Erik Martin	The Nature Conservancy (Regional)
Andrew Milliken	US Fish and Wildlife Service – North Atlantic Landscape Conservation Cooperative (Regional)
Josh Thiel	NYS Department of Environmental Conservation (NY)

The steering committee convened in the fall of 2015. Its first official act was the adoption of the two scoring systems for aquatic passability described previously.

Future work of the NAACC, through its advisory and steering committees, is likely to include the development of additional crossing assessment modules. Some possibilities include:

- Aquatic passability for crossings on tidal streams (funded, work begins January 2016)
- Culvert condition and risk of structural failure (funded, work begins in 2016)
- Terrestrial passability (preliminary work began in early 2016)
- Hydraulic capacity and risk of failure
- Geomorphic assessment and risk of failure

For the time being, the NAACC database will be hosted and maintained by the University of Massachusetts Amherst. With annual hosting and maintenance costs for the database of $10,000 - $15,000 per year, the University of Massachusetts will continue to seek grant support for maintenance and growth of the database. In addition, the steering committee will recommend that NAACC partners that they include a small amount of funding to support the database in future grant proposals for stream crossing assessment work. As the NAACC grows and becomes better established, and as its work broadens to address issues of importance to emergency management and transportation agencies, the steering committee will need to identify a more permanent home and funding mechanism for the database.

Conclusions

In less than one year, the NAACC has developed a consensus-based regional road-stream crossing field survey protocol, two scoring approaches for data collected, prioritization tools to help guide survey efforts, a regional database, a system for training surveyors, a robust set of data quality assurance procedures, and a large network of collaborators. By bringing together a range of partners from state and federal government, academia, and the nonprofit sector, the NAACC has catalyzed new partnerships and facilitated information exchange across the region. With the completion of the first field season of data collection using the regional protocol, the NAACC is now providing vital information in support of aquatic connectivity planning and decision making. These are key steps toward meeting the ultimate goal of this collaborative: the reconnection of streams and rivers to benefit fish and wildlife and bolster the resiliency of our road networks.

Quarterly Progress Report: Summary by Task

TASK	TASK DESCRIPTION	% DONE	PROGRESS NARRATIVE
1.1	Assemble and coordinate a team of Northeast Partners	100%	Core and work group continued to participate regularly; will continue to coordinate and add participants to advisory group by request.
1.2	Create a broad network of individuals and organizations to conduct assessments of stream crossings	100%	Have transitioned to a Steering Committee and Advisory Committee structure.
2.1	Identify sources of road-stream crossing data currently available in the region	100%	Have identified all sources of data.
2.2	Reconfigure River and Stream Continuity online database to accept data from NY and data collected using other protocols	100%	The NAACC database can accept data from all 13 states.
2.3	Compile currently available data into the River and Stream Continuity Project's online database	80%	Data have been compiled for CT, VT, NH and UMass protocols; ME data are not yet available but will be incorporated into the database as soon as they are available (probably January 2016).
3.1	Compile information on the various protocols and scoring systems currently being used in the region or in neighboring regions	100%	Completed in previous quarters.

3.2	Crosswalk assessment data fields across protocols and implement scoring algorithms that will yield comparable scores for multiple data collection methodologies	90%	Two components: continuous and classification scoring systems were approved by the new Steering Committee with slight modifications; a system for modifying the scoring algorithms to deal with incomplete data from other protocols has been developed and awaits approval by the NAACC Steering Committee.
4.1	Create categories for assessment protocols based on objective or level of rigor	100%	Completed in previous quarters.
4.2	Evaluate the strengths and weaknesses of the various protocols available for use in the region	100%	Completed in previous quarters.
4.3	Make recommendations on protocols that should be broadly used throughout the region	100%	Completed in previous quarters.
5.1	Identify road-stream crossings across the North Atlantic region and make available by state and for the region as a whole	100%	Completed in previous quarters.
5.2	Assign xycodes to all identified crossings across the region	100%	Completed in previous quarters
5.3	Make recommendations for an online database that can store, score and make available data on road-stream crossings across the region	100%	The Core Group has recommended that the existing UMass Stream Continuity database be updated and expanded to accommodate the needs of the entire region; Recommendations for maintaining this database over time are included in this report.

5.4	Identify existing data gaps and prioritize areas for new field surveys	100%	Completed in previous quarters.
6.1	Complete report of results and recommendations of next steps	100%	This document
6.2	Make road-stream crossing assessment and GIS data available for download	100%	Data can be exported as Excel files or shapefiles.

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Acknowledgments

We are grateful for the contributions of all colleagues from the NAACC core group, listed in Appendix A.

The many achievements of this project were dependent upon the time, commitment, and advice of the NAACC work group (see Appendix B), which included over eighty partners from state and federal agencies, conservation organizations, and universities. We thank all those who lent their expertise to this collaborative work.

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Appendices

Appendix A: NAACC Core Group Members

First name	Last name	Organization
Alex	Abbott	US Fish and Wildlife Service Gulf of Maine Coastal Program
Michelle	Brown	The Nature Conservancy
Bob	English	University of Massachusetts Amherst
Scott	Jackson	University of Massachusetts Amherst
Rich	Kirn	Vermont Fish and Wildlife Department
Jessica	Levine	The Nature Conservancy
Erik	Martin	The Nature Conservancy
Keith	Nislow	US Forest Service
Melissa	Ocana	University of Massachusetts Amherst
Jed	Wright	US Fish and Wildlife Service Gulf of Maine Coastal Program

Appendix B: NAACC Work Group Members

First name	Last name	Location	Organization
Mindy	Barnett	CT	Connecticut Department of Energy and Environmental Protection
Margot	Burns	CT	Lower Connecticut River Valley Council of Governments
Neal	Hagstrom	CT	Connecticut Department of Energy and Environmental Protection
Sally	Harold	CT	The Nature Conservancy
Michael	Jastremski	CT	Housatonic Valley Association
Brian	Boutin	DE	The Nature Conservancy
Jerry	Kaufmann	DE	University of Delaware
Carrie	Banks	MA	Massachusetts Department of Fish and Game
Alison	Bowden	MA	The Nature Conservancy
Tim	Chorey	MA	Massachusetts Department of Fish and Game
Tim	Dexter	MA	Massachusetts Department of Transportation
Kristen	Ferry	MA	Massachusetts Department of Fish and Game
Marie-Francoise	Hatte	MA	University of Massachusetts
Martha	Naley	MA	US Fish and Wildlife Service
Erin	Rodgers	MA	Trout Unlimited
Amy	Singler	MA	American Rivers
Mary	Andrews	MD	National Oceanic and Atmospheric Administration
Nora	Bucke	MD	Maryland State Highway Administration
Julie	Devers	MD	US Fish and Wildlife Service
John	Gill	MD	US Fish and Wildlife Service
Andrzej	Kosicki	MD	Maryland State Highway Administration
Ray	Li	MD	US Fish and Wildlife Service, Chesapeake Bay Office
Mark	Secrist	MD	US Fish and Wildlife Service, Chesapeake Bay Office
Howard	Weinberg	MD	Chesapeake Bay Program
Charles	Hebson	ME	Maine Department of Transportation
Josh	Royte	ME	The Nature Conservancy
Mark	Fedora	MI	United States Forest Service
Shane	Csiki	NH	New Hampshire Department of Environmental Services
Colin	Lawson	NH	Trout Unlimited
John	Magee	NH	New Hampshire Department of Fish and Game

Peter	Steckler	NH	The Nature Conservancy
Matt	Urban	NH	New Hampshire Department of Transportation
Ellen	Creveling	NJ	The Nature Conservancy
Gretchen	Fowles	NJ	NJ Division of Fish and Wildlife
Brian	Zarate	NJ	NJ Division of Fish and Wildlife
Natalie	Sherwood	NJ	Passaic River Institute, Montclair University
Meiyin	Wu	NJ	Passaic River Institute, Montclair University
Jim	Vasslides	NJ	Barnegat Bay Partnership
Marc	Carabetta	NY	Milone and MacBroom
Nicole	Maher	NY	The Nature Conservancy
Andrew	Meyer	NY	New York State Department of Environmental Conservation
Debra	Nelson	NY	New York State Department of Transportation
Carl	Schwartz	NY	US Fish and Wildlife Service
Josh	Thiel	NY	New York State Department of Environmental Conservation
Eric	Chapman	PA	Western Pennsylvania Conservancy
Su	Fanok	PA	The Nature Conservancy
Chuck	Keeports	PA	US Forest Service, Allegheny National Forest
Eli	Long	PA	Western Pennsylvania Conservancy
Benjamin	Lorson	PA	Pennsylvania Fish and Boat Commission
Brad	Maurer	PA	The Nature Conservancy
Tom	Shervinskie	PA	Pennsylvania Fish and Boat Commission
Dave	Urban	PA	Pennsylvania Fish and Boat Commission
Amy	Wolfe	PA	Trout Unlimited
Nathan	Welker	PA	US Forest Service, Allegheny National Forest
Kevin	Ruddock	RI	The Nature Conservancy
Alice	Allen-Grimes	VA	United States Army Corps of Engineers
Kevin	Anderson	VA	Trout Unlimited
Dave	Byrd	VA	US Fish and Wildlife Service
Pat	Calvert	VA	James River Association
Seth	Coffman	VA	Trout Unlimited
Lisa	Havel	VA	Atlantic Coastal Fish Habitat Partnership
Karen	Horodysky	VA	Virginia Department of Game and Inland Fisheries
Dawn	Kirk	VA	US Forest Service

Nina	O'Malley	VA	Virginia Department of Environmental Quality
Kathy	Purdue	VA	US Army Corps of Engineers
Kelly	Ramsey	VA	Natural Resources Conservation Service
Heather	Richards	VA	Piedmont Environmental Council
Craig	Roghair	VA	US Forest Service
Kimberly	Smith	VA	US Fish and Wildlife Service
Carolyn	Sedgwick	VA	Piedmont Environmental Council
Albert	Spells	VA	United States Fish and Wildlife Service
Jessie	Thomas-Blate	VA	American Rivers
Alan	Weaver	VA	Virginia Department of Game and Inland Fisheries
Glenn	Gingras	VT	Vermont Agency of Transportation
Madeleine	Lyttle	VT	US Fish and Wildlife Service
Rose	Paul	VT	The Nature Conservancy
Roy	Schiff	VT	Milone and MacBroom
Chris	Smith	VT	US Fish and Wildlife Service
Matt	Diebel	WI	Wisconsin Department of Natural Resources
Danny	Bennett	WV	West Virginia Division of Natural Resources
Callie	McMunigal	WV	US Fish and Wildlife Service
Andrew	Millken	regional	North Atlantic Landscape Conservation Cooperative
Phillip	Herzig	regional	US Fish and Wildlife Service
Megan	Tyrrell	regional	North Atlantic Landscape Conservation Cooperative
Lia	McLaughlin	regional	US Firsh and Wildlife Service
Rebecca	Kern	regional	US Fish and Wildlife Service Refuges
Trish	Garrigan	regional	US Environmental Protection Agency
Bob	Gubernick	regional	US Forest Service

Appendix C: Metrics in Prioritization, Descriptions, Data Sources

<table>
<tr><th>Target</th><th>Metric</th><th>Description and Sort Order[1]</th><th>Data Source</th></tr>
<tr><td>Brook Trout</td><td>EBTJV – Area Weighted Score</td><td>This metric assesses brook trout habitat in each HUC12 using catchment scale data from the Eastern brook Trout Joint Venture (EBTJV). This data classifies individual NHD catchments (many within a HUC12) for brook trout habitat. These classes were binned into four ranked categories, where catchments with allopatric brook trout populations were ranked highest (4) and catchments with no trout (brook trout nor exotics) were ranked lowest (1):
<table>
<tr><th>Category (Codes)</th><th>Rank</th></tr>
<tr><td>Allopatric brook trout (1.1, 1.1P, 0.5)</td><td>4</td></tr>
<tr><td>Sympatric with non-native browns & rainbow (1.3, 1.3P, 1.2, 1.2P, 1.4, 1.4P)</td><td>3</td></tr>
<tr><td>Exotics Only (0.1, 0.1P, 0.2, 0.2P, 0.3, 0.3P, 0.4, 0.4P)</td><td>2</td></tr>
<tr><td>No trout / Unknown (0, 0P, -1)</td><td>1</td></tr>
</table>
For each HUC12, the percent area of each ranked category was calculated and multiplied by its rank. For example, if a HUC12 is occupied by 75% Allopatric BT catchments & 25% rainbow trout only catchments:
(0.75 * 4) + (0.25 * 2) = 3.5

Sort Order: Descending.</td><td>EBTJV. Data provided in Feb 2015. “VA_North_Catchments.zip”. Data provided as DRAFT. Revisions were still underway in some states at the time this data was incorporated. These revisions are not reflected in this analysis.</td></tr>
</table>

[1] When sort order is descending, high values are higher priorities; when sort order is ascending, low values are higher priorities.

Objective	**Metric**	**Description and Sort Order**	**Data Source**
Brook Trout	DeWeber & Wagner: % of Catchments w/ predicted BT in HUC	This metric assess brook trout habitat in each HUC12 using data from DeWeber & Wagner (2015). This data predicts brook trout occurrence by NHD catchment (binary present/absent). The “occur 46” classification was used which is “based on a threshold that was equal to prevalence in the training data set, which produces near-optimal classification accuracy.” Sort Order: Descending.	DeWeber and Wagner (2015)
Diadromous Fish	The Nature Conservancy (TNC) Alosine HUC12 Prioritization	TNC’s Atlantic Coast Whole System diadromous fish analysis. This analysis prioritized HUC12 subwatersheds for Alosine restoration and protection activities (agnostic of any specific action). Similar to this analysis, multiple metrics were calculated to assess fish population (run counts), habitat quantity and access, water quality and water quantity. Sort Order: Ascending.	The Nature Conservancy. Incorporates input data from Dauwalter and Hall (2012), NHDPlus (2012), Smith et al (2008), USFWS (2011), Martin and Apse (2011), Martin et al (2014), USGS (2014), Anderson et al (2013)
Risk of Failure	Maximum Drainage Area in HUC	This metric identifies the largest stream (based on drainage area) in the HUC12. Sort Order: Descending.	High resolution NHD (USGS)

Objective	Metric	Description and Sort Order	Data Source
Risk of Failure	Mean slope at crossings in HUC	This metric assesses the mean slope at road-stream crossings in each HUC based on the slope of the stream reach that the crossing is on. Crossings on steeper slopes are at greater risk of failure in storm events, therefore HUC12s with a higher average slope are higher priorities for field surveys. The slope of the stream reach was calculated using a modified version of the High Resolution NHD and a 30m DEM. For each reach, slope (rise over run) was claculated based on the beginning and end elevations of each reach. Sort Order: Descending.	High resolution NHD (modified by B Compton, University of Massachusetts), NHDPlus v2 NED snapshot (ned_elev_cm)
Risk of Failure	Maximum slope at crossings in HUC	This metric assesses the maximum slope at road-stream crossings in each HUC based on the slope of the stream reach that the crossing is on. Crossings on steeper slopes are at greater risk of failure in storm events, therefore HUC12s with very steep slopes are higher priorities for field surveys. The slope of the stream reach was calculated using a modified version of the High Resolution NHD and a 30m DEM. For each reach, slope (rise over run) was claculated based on the beginning and end elevations of each reach. Sort Order: Descending.	High resolution NHD (modified by B Compton, University of Massachusetts), NHDPlus v2 NED snapshot (ned_elev_cm)

Objective	Metric	Description and Sort Order	Data Source
Risk of Failure	Gravelius' Shape Index	The Gravelis Shape Index assesses the shape of each HUC12's watershed which can influence the shape of the hydrograph. A long shape watershed generates, for the same rainfall, a lower outlet flow, as the concentration time is higher whereas a watershed having a fan-shape (more circular) presents a lower concentration time, and it generates higher flow (http://echo2.epfl.ch/VICAIRE/mod_1a/chapt_2/text.htm). Sort Order: Ascending.	HUC12 subwatersheds (NRCS et al, 2014)
Impact of Failure	% of crossings on size 1 roads (e.g. interstate)	The % of crossings on various size class roads in a subwatershed can inform an understanding of the impacts of culvert failures in a subwatershed. If a crossing on a large road fails in a storm event, it could pose a greater disruption to the local population. Sort Order: Descending.	Open Street Map, © OpenStreet Map contributors http://www.openstreetmap.org/copyright
Impact of Failure	% of crossings on size 2 roads (e.g. primary)	The % of crossings on various size class roads in a subwatershed can inform an understanding of the impacts of culvert failures in a subwatershed. If a crossing on a large road fails in a storm event, it could pose a greater disruption to the local population. Sort Order: Descending.	Open Street Map, © OpenStreet Map contributors http://www.openstreetmap.org/copyright

Objective	Metric	Description and Sort Order	Data Source
Impact of Failure	% of crossings on size 3 roads (e.g. secondary)	The % of crossings on various size class roads in a subwatershed can inform an understanding of the impacts of culvert failures in a subwatershed. If a crossing on a large road fails in a storm event, it could pose a greater disruption to the local population. Sort Order: Descending.	Open Street Map, © OpenStreet Map contributors http://www.openstreetmap.org/copyright
Impact of Failure	% of crossings on size 4 roads (e.g. tertiary)	The % of crossings on various size class roads in a subwatershed can inform an understanding of the impacts of culvert failures in a subwatershed. If a crossing on a large road fails in a storm event, it could pose a greater disruption to the local population. Sort Order: Descending.	Open Street Map, © OpenStreet Map contributors http://www.openstreetmap.org/copyright
Impact of Failure	% of crossings on size 5 roads (e.g. residential)	The % of crossings on various size class roads in a subwatershed can inform an understanding of the impacts of culvert failures in a subwatershed. If a crossing on a large road fails in a storm event, it could pose a greater disruption to the local population. Sort Order: Descending.	Open Street Map, © OpenStreet Map contributors http://www.openstreetmap.org/copyright

Objective	Metric	Description and Sort Order	Data Source
Impact of Failure	%of crossings on size 6 roads (e.g. unpaved)	The % of crossings on various size class roads in a subwatershed can inform an understanding of the impacts of culvert failures in a subwatershed. If a crossing on a large road fails in a storm event, it could pose a greater disruption to the local population. Sort Order: Descending.	Open Street Map, © OpenStreet Map contributors http://www.openstreetmap.org/copyright
Impact of Failure	Population within HUC12	Population within HUC12 (2000 census). Higher population in a HUC could potentially mean a failure would impact more people, conversely, rural areas may have populations of people who could be isolated by a failure – fewer detour options. Sort Order: Descending	US Census Block centroid population, Esri Data Team
Other	% of Crossing on US Fish and Wildlife Service (USFWS) land (refuges)	A high percentage of crossings on USFWS could increase the feasibility of surveys by USFWS technicians. Sort Order: Descending.	TNC Secured Lands (2012)
Uncertainty of Passability	% of Crossings on Smaller Streams (drain <100 km^2)	Larger streams more likely to be bridges with full AOP. Small streams, here defined as those draining <100 km^2, are more likely to be crossed using culverts, which have a higher degree of uncertainty regarding passability. Sort Order: Descending.	High resolution NHD (modified by B Compton, University of Massachusetts), NHDPlus v2 NED snapshot (ned_elev_cm)

Objective	Metric	Description and Sort Order	Data Source
State Specific / Existing Priorities	Varies by state	The metric varies by state. As of July 2015, only NY had provided state specific data on brook trout. Sort Order: depends upon data.	Varies by state
Estimated Restoration Potential	Individual crossings will be assessed with a prioritized HUC12 using UMass' Critical Linkages data -- (late April)	This metric is separate from the others. Rather than attribute HUC12s with a value for this metric, the UMass Critical Linkages crossings are layered on top of the prioritized HUC12s. These can be used to further refine and direct field surveys within a prioritized HUC12. Sort Order: N/A.	McGarigal et al (2012)

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Appendix D: R code for continuous scoring functions.

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

#------------------------------------------------------------------------------#
# Define Function for Calculating Height Scores
#------------------------------------------------------------------------------#
calc.height.score <- function(x){
	a <- 1.13
	b <- 3.5
	# Use Holling Type II function (Bolker pg 92):
	result <- a*x^2/(b^2 + x^2)
	result[result > 1] <- 1 # Truncate results to 1
	return(result)
}


#------------------------------------------------------------------------------#
# Define Function for Calculating Outlet Drop Scores
#------------------------------------------------------------------------------#
calc.outlet.drop.score <- function(x){
	a <- 1.029412
	b <- 6.173949
	score <- 1 - a*x^2/(b^2 + x^2)
	score[x > 36] <- 0
	return(score)
}
```

Appendix E: Charter of the North Atlantic Aquatic Connectivity Collaborative

Adopted by the NAACC founding members on October 6, 2015

This charter describes the mission and organization of the North Atlantic Aquatic Connectivity Collaborative (NAACC). The NAACC is a voluntary, non-regulatory network of individuals from state and federal natural resource and transportation agencies, conservation organizations, universities, and private companies, working together to improve aquatic connectivity across the thirteen-state North Atlantic region, from Maine to West Virginia.

Mission

The mission of the NAACC is to foster collaboration among diverse partners and support decision making by providing tools and information to improve aquatic connectivity across the thirteen-state North Atlantic region.

Background and Achievements

The NAACC was established in 2014 with initial funding support from the North Atlantic Landscape Conservation Cooperative and U.S. Department of Interior Hurricane Sandy Mitigation funds. In 2014 and 2015, a project team from the University of Massachusetts Amherst, The Nature Conservancy, the USDA Forest Service and the U.S. Fish and Wildlife Service, with input from a work group comprised of expert partners across the region, established the NAACC through completion of the following tasks:

1. Development of unified protocols for road-stream crossing assessments that can help identify bridges and culverts that are problematic from an aquatic connectivity perspective,
2. Formulation of scoring systems for data from stream crossing assessments,
3. Creation of an online database, maintained by the University of Massachusetts, that serves as a common repository for crossing assessment data from across the region,
4. Development of data quality assurance procedures,
5. Launch of an online stream crossing assessment training program,
6. Development of an NAACC website, streamcontinuity.org, hosted and maintained by the University of Massachusetts,
7. Creation of a customizable GIS-based tool to identify high priority watersheds and crossings for assessment, and
8. Support of efforts to conduct assessments throughout the region.

Governance

As of October 2015, a Steering Committee oversees decision making and work products of the NAACC, and a technical advisory committee provides input to the steering committee as needed. For collection and quality assurance of field data, the NAACC has a separate, distinct structure of distributed coordination, as detailed on the NAACC website (www.streamcontinuity.org).

1. Steering Committee

The ten- to twenty-member NAACC Steering Committee provides overall coordination, support, and guidance for the NAACC. The Steering Committee makes decisions by consensus when possible, and by 2/3 majority when consensus is not possible.

The initial composition of the Steering Committee includes personnel involved in the NAACC project development team as well as several former work group members who were active participants in project development.

The Steering Committee includes:

- Principal Investigators or Project Leads for NAACC projects underway (currently University of Massachusetts Amherst serves as PI for existing grants and manages the NAACC database)
- The coordinator of the NAACC Advisory Committee (currently The Nature Conservancy)
- Personnel from at least two federal agencies involved in aquatic connectivity in the 13-state region, which may include: the U.S. Fish and Wildlife Service, the North Atlantic Landscape Conservation Cooperative, U.S. Forest Service, U.S. Environmental Protection Agency, National Oceanic and Atmospheric Administration
- Personnel from at least three state natural resource agencies from the region
- Personnel from at least two conservation organizations

The Steering Committee meets by teleconference and as needed for specific tasks, in person. The Steering Committee meets at least four times a year. A staff member from the University of Massachusetts provides coordination support for the Steering Committee.

As Steering Committee participation is voluntary and unpaid, it is expected that the composition of the committee will change over time based on the availability of resources to support members' participation.

2. Advisory Committee

The NAACC Advisory Committee provides feedback and advice to the Steering Committee. The Advisory Committee includes representatives of state natural resource and transportation agencies, federal natural resource agencies, conservation organizations, universities, and private companies.

Advisory Committee members serve on subcommittees to work with the Steering Committee on specific tasks of the NAACC. These subcommittees may focus on topics such as decision support tools, development of a tidal culvert assessment protocol, development of a module for assessing structure resiliency, and development of a module for assessing terrestrial connectivity.

The Advisory Committee is coordinated by a member of the Steering Committee. The Advisory Committee meets as needed by teleconference and provides input through teleconference participation and online surveys.

Advisory Committee participation is voluntary and unpaid.