Northeast Aquatic Connectivity Assessment Project – Version 2.0

Assessing the ecological impacts of barriers on Northeastern rivers

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1.1 Background

The fragmentation of river habitats through dams and poorly functioning culverts is one of the primary threats to aquatic species in the United States (Collier et al, 1997; Graf, 1999). The impact of fragmentation on aquatic species generally involves loss of access to quality habitat for one or more life stages of a species. For example, dams and impassable culverts limit the ability of anadromous fish species to reach preferred freshwater spawning habitats from the sea and prevent brook trout populations from reaching thermal refuges.

Some dams provide valuable services to society including low-carbon hydro power, flood control, and irrigation. Many more dams, however, no longer provide the services for which they were designed (e.g. old mill dams) or are inefficient due to age or design. Nonetheless, these dams still create barriers to the safe and timely passage of fish and other aquatic organisms. Fish passage facilities, such as fish ladders, have long been used to provide fish passage in situations where dam removal is not a feasible option. In many cases, these connectivity restoration projects have yielded ecological benefits such as increased anadromous fish runs, improved habitat quality for resident fish species, and expanded mussel populations. In many other cases, however, the passage facilities are ineffective and do not adequately pass the targeted species.

Similarly, road-stream crossings are a critical element of our nation's transportation infrastructure, permitting the free movement of people and goods around the country. From a fish's perspective, not all road-stream crossings are the same. A suspension bridge, for example, may have little to no impact on aquatic organism passage (AOP) while a culvert whose outlet is perched several feet above the stream could represent as significant a barrier as a dam. In recent years, there has been a growing movement in the Unites States to identify and upgrade road-stream crossings to better permit the passage of aquatic organisms. Further, crossings designed for adequate AOP (e.g. using stream simulation design) are often more resilient to failure in large storm events (Gillespie et al 2014), thus providing a compelling social rationale, beyond the ecological rationale, for designing crossings for AOP.

The original Northeast Aquatic Connectivity project (Martin and Apse 2011), the Chesapeake Fish Passage Prioritization Project (Martin and Apse 2013), and the Southeast Aquatic Connectivity Assessment Project (Martin et al 2014) assessed dams in their respective geographies based on the potential for each dam to provide ecological benefits for one or more targets (e.g. anadromous fish species or resident fish species) if removed or bypassed. This report, funded by the North Atlantic Landscape Conservation Cooperative of the U.S. Fish and Wildlife Service, extends the work of these dam-focused projects by incorporating road-stream crossings as well as dams into the assessment and through the development of an interactive web map for viewing and analyzing the barrier data in the Northeast U.S. The sections that follow detail the data, methods, results, and tools developed for this project.

1.2 Approach

1.2.1 Project organization

The Northeast Aquatic Connectivity Assessment Project 2.0 (NEACAP) was performed as a discrete task under the umbrella of the North Atlantic Aquatic Connectivity Collaborative (NAACC, or the Collaborative). The NAACC was initiated with funding from the North Atlantic Landscape Conservation Cooperative (NALCC) to help organizations in the Northeast to align efforts to identify and prioritize repairs, upgrades, and replacements of road-stream crossings. With funding from the NALCC and the Department of the Interior's Hurricane Sandy Mitigation Funds, the NAACC brought together partners working on aquatic connectivity issues throughout the 13-state region. Spearheaded by the U.S. Fish and Wildlife Service (USFWS), the University of Massachusetts, The Nature Conservancy, the Vermont Agency of Natural Resources, and NALCC, the NAACC is further guided by a multi-partner Steering Committee and Advisory Committee. See Appendix I: NEACAP Subcommittee and NAACC Steering and Advisory Committees for a list of participants in these groups.

Since its founding in 2014, the NAACC has produced a unified culvert assessment protocol including data quality standards and digital data collection tools, a regional culvert assessment database, tools to prioritize crossings for field assessment, and tools to prioritize individual barriers for connectivity restoration projects. Along with the University of Massachusetts' Critical Linkages work, NEACAP is focused on the last item: prioritizing barriers for restoration based on their potential to benefit fish and other aquatic organisms if passage is restored. An ad-hoc work group, comprised of members of the NAACC Steering Committee and Advisory Committee, along with participants from the original Northeast Aquatic Connectivity project, provided data, reviewed draft products, and offered guidance on the adaption of the original NE Aquatic Connectivity work to include culverts.

2 Data Collection and Preprocessing

Spatial data for the project were gathered from multiple data sources and processed in a Geographic Information System (GIS) to generate descriptive, ecologically relevant metrics for each barrier which were used to develop the prioritization. The core input datasets included river hydrography, dams and road-stream crossings, natural barriers (e.g. waterfalls), and anadromous fish habitat. Additional datasets were used to generate metrics of interest to the workgroup. These datasets include data representing land cover and impervious surface, stream temperature data, brook trout habitat, roads, rare fish, mussel, and crayfish watersheds and fish species richness. A complete list of the input data used in the project can be found in Appendix II: Input Datasets. A further description of the core datasets follows.

2.1 Definitions

Several terms are used throughout the discussion of data and metrics. The sections below detail some important terms for understanding the data and how metrics were calculated.

2.1.1 Functional River Networks

A barrier's functional river network, also referred to as its connected river network or simply its network, is defined by those stream reaches that are accessible to a hypothetical fish within that network. A given barrier's functional river network is bounded by other barriers, headwaters, or the river mouth, as is illustrated in Figure 2-1. A barrier's total functional river network is simply the combination of its upstream and downstream functional river networks. The total functional network represents the total habitat a fish could theoretically access if that particular barrier was removed.

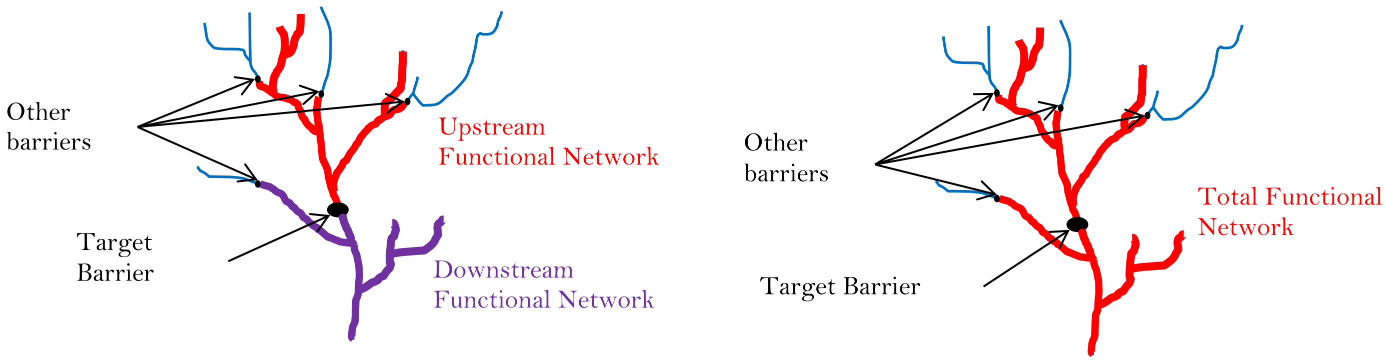
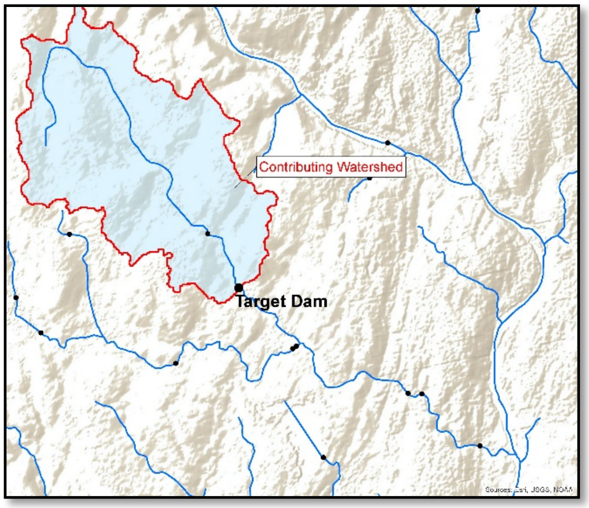


Figure 2-1: Conceptual illustration of functional river networks

2.1.2 Watersheds

For any given barrier, metrics involving three different watershed scales are used in the analysis. The contributing watershed, or total upstream watershed, is defined by the total upstream drainage area above the target barrier. Several metrics are also calculated within the watershed of a target barrier's upstream and downstream functional river networks. These local watersheds are bounded by the watersheds for the next upstream and downstream functional river networks, as illustrated in Figure 2-2.



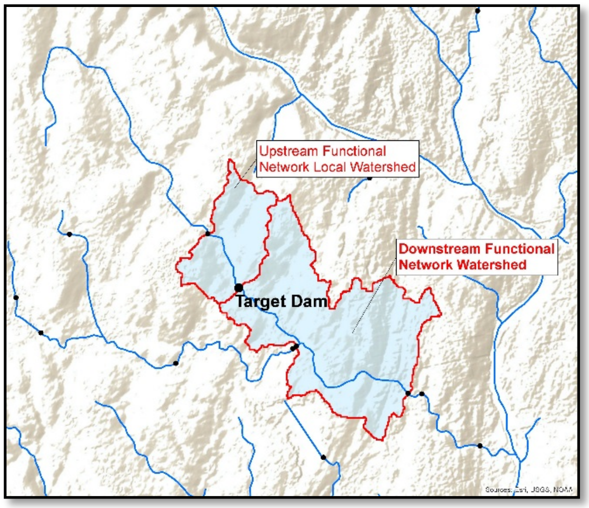


Figure 2-2: The contributing watershed is defined by the total drainage upstream of a target barrier. The upstream and downstream functional river network local watersheds are bounded by the watershed for the next barriers up and down stream.

2.2 Hydrography

Barriers included in the analysis are those that fall on the mapped river network, or hydrography, used in the project: a modified version of the Medium Resolution National Hydrography Dataset Plus, Version 2 (NHDPlus v2) (Horizon Systems 2012). This hydrography was originally digitized by the United States Geological Survey, primarily from 1:100,000 scale topographic maps. Substantial additions and improvements were applied to the USGS NHD data by Horizon Systems Corporation to create the NHDPlus v2.

For this analysis, the hydrography was processed to create a dendritic network, or dendrite, defined here as a single-flowline network with no braids or other downstream bifurcations (Figure 2-3). Attributes in the medium-resolution NHDPlusV2 were queried to identify the mainstem of a river from a braided section. (NHDFlowline.FLOWDIR = 'With Digitized' AND NHDPlusFlowlineVAA.Divergence in (0,1) AND NHDPlusFlowlineVAA.StreamCalc <>0). Additional information on the NHDPlus v2 and these attributes can be found in the NHDPlus v2 User Guide (Horizon Systems 2012).

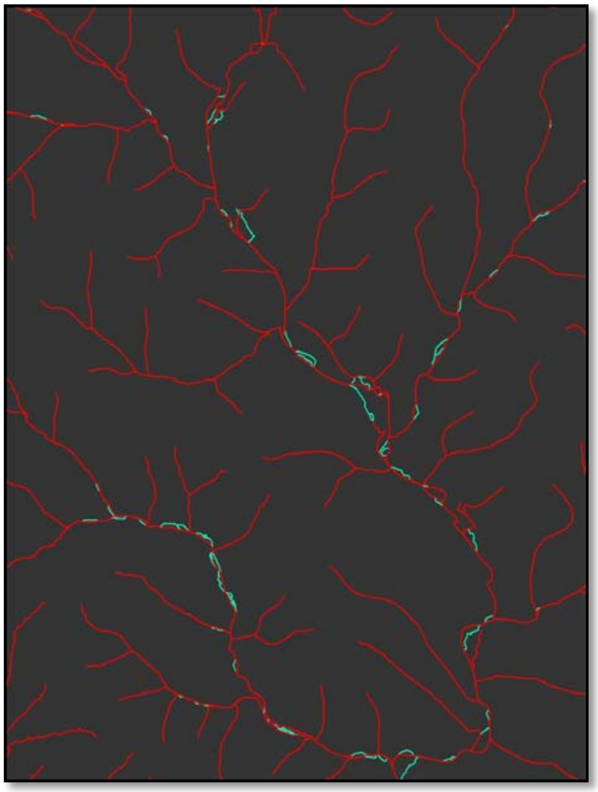


Figure 2-3: Braided segments highlighted in blue were removed to generate a dendritic network.

The result of this process was a single-flowline dendrite, based on the current Medium Resolution NHD, for the project area. This dendrite (hereafter referred to as the "project hydrography") was then further processed using the ArcGIS Geometric Network toolset in ArcGIS 10.3 to establish flow direction for each segment. Additional processing using ArcGIS Spatial Analyst and custom Python scripts in ArcGIS was performed to accumulate upstream attributes for each line segment in the project hydrography. These processes produced values including the total upstream drainage area, percent impervious surface, and percent forested land cover for each river segment.

2.2.1 Stream size class

Stream size is a critical factor for determining aquatic biological assemblages (Olivero and Anderson 2008; Vannote et al. 1980; Mathews 1998). In this analysis, river size classes, based on the catchment drainage size thresholds developed for the Northeast Aquatic Habitat Classification System (Olivero and Anderson 2008), were calculated for each segment of the project hydrography and in turn assigned to each barrier. Size classes were used in several ways throughout the analysis including as a proxy for habitat diversity and to define fish habitat (e.g., American shad use size classes ≥Size 2).

1a) Headwaters (<3.861 mi^2)
1b) Creeks (>= 3.861<38.61 mi^2)
2) Small River (>=38.61<200 mi^2)

3a) Medium Tributary Rivers (>=200<1000 mi^2)
3b) Medium Mainstem Rivers (>=1000<3861 mi^2)
4) Large Rivers (>=3861 < 9653 mi^2)
5) Great Rivers (>=9653 mi^2)
(Defining measure = upstream drainage area)

2.2.2 Active River Area

The Active River Area (ARA) is a spatially explicit framework for modeling rivers and their dynamic interaction with the land through which they flow (Smith et al 2008). Distinct portions of the ARA include the meander belt, riparian wetlands, floodplains, terraces, material contribution areas. The ARA is different from, but was calibrated to and compared against the FEMA 100-year floodplain. NEACAP uses the ARA as a unit within which various landcover metrics, such as impervious surface, were summarized.

2.3 Database of Barriers

2.3.1 Compilation of Existing Dam Databases

Dam data for the NEACAP 2.0 was updated from the original NE Aquatic Connectivity project (NAC 2011) based on data newly acquired from state dam databases (see Appendix II: Input Datasets and **Error! Reference source not found.** for a complete list of dam data sources), with additional edits provided by reviewers in the NEACAP subcommittee and original NE Aquatic Connectivity workgroup.

In order to perform network analyses in a GIS, the points representing barriers must be topologically coincident with lines that represent rivers. This was rarely the case in the dam datasets as they were received from various data sources and generally were not organized to be coincident with hydrography data. To address this problem, dams were "snapped" in a GIS to spatially align them with the project hydrography (Figure 2-4).

Figure 2-4: Conceptual illustration of snapping a dam to the river network

Dams were snapped as part of the processing workflow for the original NE Aquatic Connectivity analysis in 2011 (Martin & Apse 2011, hereafter referred to as the NAC 2011) using the methods described in

Section 3 of that report. For this update, processing was undertaken to preserve the data processing that was implemented for the NAC 2011 while incorporating source data updates that were made to state databases since the NAC 2011 was completed.

To accomplish this, the dam IDs from the NAC 2011 were first matched with the IDs of dams in the newly acquired state databases. Where the dam IDs matched, the distance between the dams was calculated. If the representation of a dam in the two databases was less than 100 meters apart, the location from the NAC 2011 was retained. If the distance was greater than 100 meters the dams were manually reviewed and if needed, edits were made to dams from the NAC 2011 database to incorporate changes reflected in the newly acquired state database. If there was no match between the NAC 2011 data and the newly acquired data, the newly acquired dam location was added and manually reviewed.

The available information on existing fish passage facilities is incomplete across the region. In some (but not all) cases, the presence of an existing fish passage structure is included in the source dam database. However, the effectiveness of fish passage facilities varies widely and almost no information on fish passage effectiveness is available across the region. For these reasons, all dams are considered to be "severe barriers" (see Section 2.3.2.2 for a discussion of barrier passability scores). However, as described further in Section 5.5, there is an option in the custom analysis tool, to allow for analyses that are focused solely on dams without passage facilities (meaning that dams with passage facilities are considered permeable).

2.3.2 Road-Stream Crossing Database

The road-stream crossing data used in NEACAP originated from the NAACC database and was acquired from the University of Massachusetts after processing as part of the Critical Linkages work (the current version of McGarigal et al 2012). The NAACC database includes field-surveyed crossing data contributed by surveyors across the 13-state region of the NAACC. Additional crossings are included in the database based on the intersection in a GIS of Open Street Map (OSM) roads and streams modified from the High Resolution (1:24,000 scale) National Hydrography Dataset (High Res NHD) performed by the University of Massachusetts. Each crossing, whether surveyed or not, is assigned a unique "xycode" in the NAACC database. This code is based on the latitude and longitude coordinates of the crossing in the database prepended with the letters "xy."

2.3.2.1 Crossing Migration to the NHD Plus

For use in the NEACAP, these crossings were migrated from their location at the intersection of the OSM roads and High Res NHD to the intersection of the OSM Roads and the Medium Resolution (1:100,000 scale) NHD Plus. The NHD Plus was used in this analysis for several reasons, primary among them was the need for a single-flowline (dendritic) river network to support the network analyses used to generate several of the metrics by which barriers are prioritized. While the NHD Plus includes attributes which can be used to extract a dendrite, the High Res NHD did not include these attributes. After migration to the NHD Plus, the crossings are assigned the xycode of the analogous crossing in the original NAACC database. The process used to migrate the crossings onto the medium resolution NHD included the following steps:

1. Assign the OSM Road ID and NHD "REACHCODE" attribute to the original NAACC crossings.
2. Create a new point in a GIS at the intersection of the OSM roads and NHD Plus and include the Road ID and "REACHCODE" attributes. (Note: the REACHCODE is included in both the High Res NHD and the NHD Plus.)
3. For each crossing on the NHD Plus generated in step 2, the closest of the original crossings is identified. If both the road ID and REACHCODE attributes match, the xycode from the original crossing is assigned to the crossing on the NHD Plus. The crossing is flagged as a match.
4. For crossings that did not match in step 3, the closest of the original crossings is identified. If the OSM Road ID matches and the REACHCODE does not, but the drainage area at the crossing is <10% different, the crossing is flagged as a match and the xycode is assigned to the NHD Plus crossing.
5. For crossings that did not match in the previous steps, if either the REACHCODE or OSM Road ID match with the closest crossing in the original dataset, and the distance to the nearest crossing is <30 meters, the crossing is flagged as a match and the xycode is assigned to the NHD Plus crossing.
6. For crossings that did not match in the previous steps, the second-closest crossing in the original NAACC dataset was identified and matched based on the OSM Road ID and REACHCODE, as described above.
7. Finally, if more than one crossing on the NHD Plus was matched to the same crossing in the original NAACC dataset, only the closest matched was retained while the other matched were flagged as unmatched.

This process resulted in a GIS dataset of road-stream crossings that are spatially coincident with the project hydrography (dendrite version of the NHD Plus) but retain the xycodes from (and therefore a link to all of the attributes associated with) the original crossings from the NAACC database. Crossings on streams which were not mapped at the 1:100,000 scale of the NHD Plus were not included in the analysis.

2.3.2.2 Crossing passability

Crossings in the NAACC database are assigned both a coarse screen categorical score (Full AOP, Reduced AOP, No AOP) and numeric passability score based on a set of field-measured variables (NAACC 2015, https://streamcontinuity.org/pdf_files/Aquatic_Passability_Scoring.pdf). For this analysis, the numeric passability score was used to determine what crossings should be considered barriers. The numeric scores range between 0 (completely impassable, e.g. a culvert with a large outlet perch) to 1 (completely passable, e.g., a bridge with an unobstructed natural stream bed). These numeric scores were binned into the categories described in NAACC 2015 and assigned a corresponding descriptive score:

Descriptor	Aquatic Passability Score(s)
No barrier	1.0
Insignificant Barrier	0.80 – 0.99
Minor Barrier	0.60 – 0.79

Moderate Barrier	0.40 – 0.59
Significant Barrier	0.20 – 0.39
Severe Barrier	0.00 – 0.19

Many crossings, however, have not been visited by field survey crews and thus no field survey measurements are available to generate a passability score. In these cases, numeric scores were calculated as part of the spring 2016 run of the University of Massachusetts' Critical Linkages analysis (McGarigal et al 2012) and adopted for this analysis. The Critical Linkages workflow uses landscape variables available in a GIS, including flow accumulation (upstream drainage area), stream gradient, local topography, and incisement, to predict passability using a Random Forest predictive model. While this approach uses the best available to data and processes to predict passability, there are many factors which influence the passability of a barrier which cannot be obtained from a landscape-scale analysis. When modeled scores are compared against scores developed from site surveys, the adjusted $r^2 = 0.26$. Thus, it is clear that the modeled passability predictions are noisy. Attempts are made to compensate for this uncertainty by allowing users to select a degree of passability within the custom analysis tool. Ultimately, it is our hope that the survey efforts currently underway under the NAACC umbrella will replace the need to model passability scores. Nevertheless, although this approach is a coarse approximation of likely passability, it nonetheless provides a starting point for our understanding of passability at unsurveyed crossings. The use of the passability category in this analysis is described in Section 3.3.2.

2.3.3 Final Database

There were 287,221 barriers in the entire NEACAP database when all sources were combined: 33,361 dams, 253,236 road-stream crossings, and 624 natural barriers. This number included duplicates, dams outside the study area which are needed to bound the network analysis but which were not evaluated, dams on small streams which are not mapped in the NHD Plus hydrography, as well as other dams or structures which are not barriers such as breaches, levees, and removed dams. In the end, 14,273 dams and 169,329 road-stream crossings were evaluated in the analysis.

2.4 Anadromous Fish Habitat

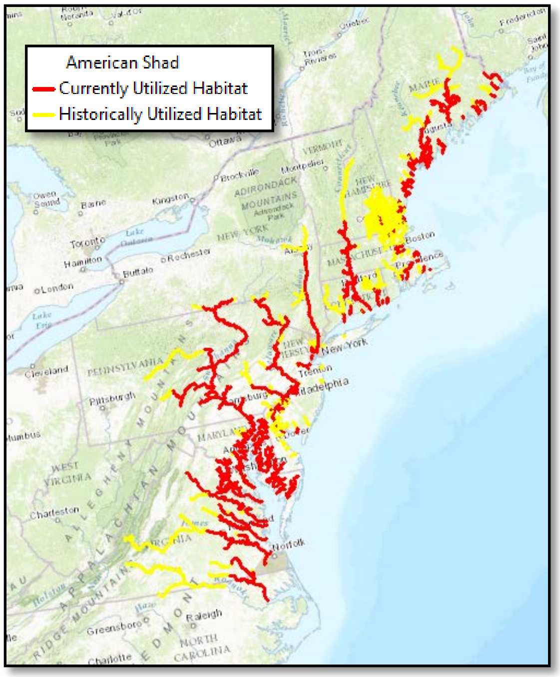


Figure 2-5: Final project data for American shad.

Identifying opportunities to improve aquatic connectivity for the benefit of anadromous fish populations was one of the key goals of the project. Anadromous fish habitat downstream of a barriers was one of the most important factors used for the Anadromous Fish Scenario to determine which barriers have the greatest potential for ecological benefit if removed or upgraded.

Baseline habitat data were collected for alewife, blueback herring, American shad, hickory shad, striped bass, Atlantic sturgeon, and Atlantic salmon. These data were updated from data collected for the NAC 2011 from multiple sources, including the Atlantic States Marine Fisheries Commission (ASMFC 2004) and several regional sources (Houston et al 2007, Odell et al 2006, and Zimmerman, J., unpublished). These data were further reviewed and edited by biologists as part of the NAC 2011 project. This review process incorporated additional fish observance data as well as expert knowledge from biologists.

2.5 Resident Fish Data

A suite of metrics was calculated to enable barriers to be prioritized for resident fish species using data from several sources.

Distribution information on rare fish, mussel, and crayfish species as well as fish species richness were obtained for each HUC 8 watershed from NatureServe (NatureServe 2008a, 2008b, 2008c). Rare species data were represented by the current presence of globally rare (G1-G3) fish, mussels, or crayfish. Fish species richness data were represented as a count of species currently found within each subwatershed. Barriers were evaluated with respect to the presence of rare species and fish species richness within the HUC8 subwatershed within which the barrier was situated.

Two datasets were used to assess brook trout habitat in the region. First is the catchment-scale data from the Eastern Brook Trout Joint Venture (EBTJV 2012) and the second is modeled brook trout occurrence predictions (DeWeber and Wagner 2015). These data were used as provided to generate the respective brook trout metrics listed in Table 3-1.

2.6 Waterfalls

Waterfalls, like dams and road-stream crossings, can act as barriers to fish passage. Including them in the analysis was important due to the impact natural barriers have across a network. For example, a waterfall just upstream of a dam would drastically affect the length of that dam's upstream functional network, or the number of river miles that would be opened by providing passage at that dam. Thus, although waterfalls are excluded from the project results, they were included in the generation of functional networks.

Data for waterfalls was primarily sourced from data compiled for the NAC 2011. This includes data from the USGS Geographic Names Information System (GNIS) database, which is comprised of named features from 1:100,000 scale topographic maps. Additional waterfalls that were part of an initial effort of the USGS Aquatic GAP Program to compile a national waterfall database (Daniel Wieferich, personal communication) were also included. Finally, additional waterfalls were provided by reviewers as part of this project and the NAC 2011. All waterfall data were merged together and snapped to the project hydrography using the same method previously described for dams.

2.7 Additional Datasets

Beyond the core datasets described above, several other secondary datasets were used in the generation of the metrics which underpin the prioritization.

2.7.1 Active River Area

The Active River Area (ARA) is a spatially explicit framework for modeling rivers and their dynamic interaction with the land through which they flow (Smith et al. 2008). Key features of the ARA include the meander belt, riparian wetlands, floodplains, terraces, material contribution areas. The ARA is different from the FEMA 100-year floodplain, but was calibrated to and compared to the floodplain. The NEACAP project used the ARA as a unit within which various landcover metrics, such as forest cover and impervious surface, were summarized.

2.7.2 National Land Cover Database

The 2011 National Land Cover Database (NLCD 2011) was used to assess land cover condition within the Active River Area of each barrier's upstream and downstream connected networks as well as within the contributing watershed of each barrier. Land cover data were grouped into three classes: natural, forested, and agricultural. Natural land cover was defined by the following NLCD classes: deciduous, evergreen, and mixed forest, scrub/shrub, grassland, barren land, open water, and woody & emergent wetlands. Forested land cover was defined by deciduous, evergreen, and mixed forest classes. Agricultural land cover was defined by pasture/hay and cultivated crop classes. Developed lands were accounted for using the NLCD impervious surface data.

2.7.3 TNC Secured Lands

The Nature Conservancy's Eastern Division 2014 secured lands dataset identifies those parcels that have permanent protection from development. The presence of secured lands adjacent to streams has implications over time for both water quality and the ability of a river to maintain its natural processes (Abell et al 2007). Each barrier in the analysis which was were situated on secured lands were attributed with this information.

2.7.4 Northeastern Aquatic Habitat Classification System

Data from the Northeastern Aquatic Habitat Classification System (Olivero and Anderson 2008) were used in several aspects of the analysis as proxies for aquatic habitat diversity and quality. Like the NAC 2011, the NEAHCS project used the NHD Plus as its base hydrologic network. Therefore, all of the attributes calculated during the NEAHCS project could be easily used to assess barriers and their upstream and downstream connected networks. Variables that were used in the analysis included size (calculated as a function of upstream watershed size) and modeled expected natural water temperature class. Several metrics were calculated from this data including the number of size classes & miles of each size class in each barrier's upstream and downstream connected networks, as well as the miles of cold & cool transitional water in each barrier's networks.

3 Analysis Methods

As with the NAC 2011, the conceptual framework of the NEACAP rests on a suite of ecologically relevant metrics calculated for every barrier in the study area. These metrics are then used to evaluate the benefit of removing or providing passage at any given barrier relative to any other barrier. At its simplest, a single metric could be used to evaluate barriers. For example, if one is interested in passage projects to benefit diadromous fish, a barrier's upstream functional network length, or the number of river miles that would be opened by that barrier's removal, could be used as the sole metric in the prioritization. In this case, the barrier with the longest upstream functional network—the barrier whose removal would open up the most river miles—would be the highest priority in the result. As multiple metrics are evaluated, weights can be applied to indicate the relative importance of each metric in a given scenario, as described in further detail in Section 3.2.

3.1 Metric Calculation

A total of 38 metrics were calculated for each barrier in the study area using ArcGIS 10.3. Metrics were organized into five categories: Network, Land Cover / Watershed Condition, Anadromous, Resident, and System Type. Further, each metric is sorted in either ascending order or descending order to indicate whether large values or small values are desirable in a given scenario. For example, upstream functional network length is sorted descending because large values are desirable – a passage project on a barrier that opens up more river miles is desired over a passage project which opens up few miles. Conversely, percent impervious surface is sorted ascending because small values are desirable – a passage project that opens up a watershed that has little or no impervious surface is desired over a barrier that opens up a watershed with a high percentage of impervious surface. Another way to think of the sort order is the desired direction: a descending metric is one which is to be maximized in a high priority project while an ascending metric is one which is to be minimized. Each of the metrics is presented in Table 3-1, and a more complete description of each metric can be found in Appendix IV: Glossary and Metric Definitions

Table 3-1: Metrics calculated for each barrier in the study.

Metric Category	Metric	GIS Attribute Name	Unit	Sort Order
Network	Upstream (US) Functional Network Length	batFuncUS	m	D
	Total Upstream River Length	batLenUS	m	D
	The Total Length of US and DS (Downstream) Functional Network	batTotUSDS	m	D
	Absolute Gain	batAbs	m	D
	# DS Barriers	batCountDS	#	A
	DS Hydropower Dam Count on Flowpath	DSHydro	#	A
	DS Natural Barrier Count on Flowpath	DSFalls	#	A
	Product of All DS Passability Scores	dsPassabilityProduct	unitless score	D
Land Cover / Watershed Condition	% Impervious surface in US Drainage Area	DA_PercImp	%	A
	% Natural Landcover (LC) in US Drainage Area	DA_PercNat	%	D
	% Forested LC in US Drainage Area	DA_PercFor	%	D
	% Agriculture in US Drainage Area	DA_PercAg	%	A
	% Impervious Surface in Active River Area (ARA) of Upstream Functional Network	usImpARA	%	A
	% Impervious Surface in ARA of DS Functional Network	dsImpARA	%	A
	% Agriculture in ARA of US Functional Network	usAgARA	%	A
	% Agriculture in ARA of DS Functional Network	dsAgARA	%	A
	% Natural LC in ARA of US Functional Network	usNatARA	%	D
	% Natural LC in ARA of DS Functional Network	dsNatARA	%	D
	% Forested LC in ARA of US Functional Network	usForARA	%	D
	% Forested LC in ARA of DS Functional Network	dsForARA	%	D
	Barrier is Located on Conservation Land	onConsLand	Boolean	D
	NFHAP Cumulative Disturbance Index	CumDistInd	unitless score	A
Anadromous	Presence of Anadromous Species in DS Network	QDSANAD	Boolean	D
	# Anadromous Species in DS Network	QDSNUMANAD	#	D
Resident	Resident Fish Species Richness (NatureServe - all resident fish)	fishRich	#	D
	# of rare (G1-G3) fish HUC8	g123Fish	#	D
	# of rare (G1-G3) mussel HUC8	g123Mussel	#	D
	# of rare (G1-G3) crayfish HUC8	g123Cray	#	D
	Barrier is within Eastern Brook Trout Joint Venture (EBTJV) Catchment with Trout	in_EBTJV_2012	Boolean	D
	Barrier w/ in a Catchment with Modeled Trout Presence (DeWeber & Wagner)	in_deWeberTrout	Boolean	D
	Barrier blocks EBTJV 2012 Trout Catchments	block_EBTJV_2012	Boolean	D
	Barrier blocks with Modeled Trout Catchments (DeWeber & Wagner)	block_deWeberTrout	Boolean	D
	River Size Class	NSEZCL_Int	#	A

Metric Category	Metric	GIS Attribute Name	Unit	Sort Order
Size / System Type	Total Reconnected # Stream Sizes (US + DS) >0.5 Mile	TotNumSzCl	#	D
	Number of US Size Classes >0.5 miles	usNumSzCl	#	D
	Number of New US Size Classes >0.5 mi Gained by removal/bypass	usSzClGn	#	D
	Miles of Cold Water Habitat in Total Functional Network	totMiCold	Miles	D
	Miles of Cold or Cool Water Habitat in Total Functional Network	totMiCC	Miles	D

3.2 Metric Weighting

Depending on the objectives of a prioritization scenario, some metrics will be of greater importance than others. Thus, metrics are selected and weighted to develop a scenario for a given objective. For example, if the objective of a prioritization scenario is to identify barriers which would benefit anadromous fish if removed or bypassed, upstream functional network length may be of particular interest, while the percent impervious surface in a barrier's watershed may be of less importance, and the presence of rare crayfish species in the barrier's watershed may be of no interest. Relative weights, which must sum to 100, can be assigned to each metric to indicate its importance in a given scenario. Table 3-2 lists the consensus weights reviewed by the NEACAP Workgroup through an iterative process for the anadromous fish scenario.

Metric weights are subjective in nature; there are no hard and fast rules regarding how to properly select and weight metrics for a given target like anadromous fish. To arrive at the weights presented in the tables below, the workgroup assessed the results produced by draft weights adopted from the NAC 2011 in light of their knowledge existing barrier priorities and metric weights were refined. This process served to calibrate the results to known priorities.

Table 3-2: Workgroup-Consensus metric weights for the Anadromous Fish Scenario

Metric Category	Metric Name	Anadromous Scenario Weight
Network	Upstream functional network length	20
	Count of Downstream Barriers	10
	Product of all downstream barrier passability scores	5
Land Cover / Watershed Condition	% Natural Land Cover in total contributing watershed	10
	% Impervious surface in total contributing watershed	10
	% Natural Land Cover in Active River Area of Upstream Functional Network	5
	Barrier is located on Conservation Land	5
Anadromous	Presence of 1 or more anadromous species found downstream of barrier	20

	# of anadromous species found downstream of barrier	10
System Type	# of new River Size Classes gained in upstream network	5

For information on how a resident fish prioritization is handled in this analysis see Section 4.1.2.

3.3 Prioritization

3.3.1 Prioritization Approach

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 basic process for prioritizing barriers using this process can be summed up as:

For metric value *a* in set *A*, R_a = rank of *a* in set *A*. Sorted ascending or descending, depending on metric. Dense ranking ('1223') used for ties.

$PR_a = 100(\frac{Ra-minA}{maxA-minA})$ (descending)

or

$PR_a = 100-(100(\frac{Ra-minA}{maxA-minA}))$ (ascending)

$$FR = R(\sum_{i=1}^{n} W_i PR_i)$$

Where:
R = rank
W = weight
PR = percent rank
FR = final rank

In practice, this simple process works as follows in this hypothetical ranking of 4 barriers for 2 metrics:

- Upstream Functional Network Length weight = 75
- Downstream Functional Network Length weight= 25

- Step 1: Raw values are calculated for each metric in GIS
- Step 2: Raw values are ranked. For each metric, ranks are determined based on whether large values are desirable in a scenario (e.g. upstream functional network length) or small values are desirable (e.g. % impervious surface)
- Step 3: Ranked values are 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.
- Step 4-5: Multiply the percent rank by the chosen metric weight
    - o In this hypothetical example, assume upstream functional network length weight = 75 and downstream functional network length weight = 25.
- Step 6: Sum the weighted ranks for each metric for each barrier
    - o All metrics which are included in the analysis (weight >0) are summed to give a summed rank.
- Step 7: Rank the summed ranks
    - o The summed ranks are, in turn, ranked

Figure 3-1:A hypothetical example ranking four barriers based on two metrics.

Raw Values		Upstream Functional Network Length (m)	Downstream Functional Network Length (m)
	Barrier A	239,541	2,572
	Barrier B	342,654	62,525
	Barrier C	572,594	6,233
	Barrier D	125,213	87,425

Ranked Values		Upstream Functional Network Length (rank)	Downstream Functional Network Length (rank)
	Barrier A	3	4
	Barrier B	2	2
	Barrier C	1	3
	Barrier D	4	1

% Ranked Values		Upstream Functional Network Length (% rank)	Downstream Functional Network Length (% rank)
	Barrier A	33	0
	Barrier B	66	66
	Barrier C	100	33
	Barrier D	0	100

Multiply by Weight		Upstream Functional Network Length	Downstream Functional Network Length
	Barrier A	33 * 0.75	0 * 0.25
	Barrier B	66 * 0.75	66 * 0.25
	Barrier C	100 * 0.75	33 * 0.25
	Barrier D	0 * 0.75	100 * 0.25

Weighted Rank Values		Upstream Functional Network Length (weighted rank)	Downstream Functional Network Length (weighted rank)
	Barrier A	25	0
	Barrier B	50	16.6
	Barrier C	75	8.3
	Barrier D	0	25

Combined Score		Combined Score
	Barrier A	25
	Barrier B	66.6
	Barrier C	83.3
	Barrier D	25

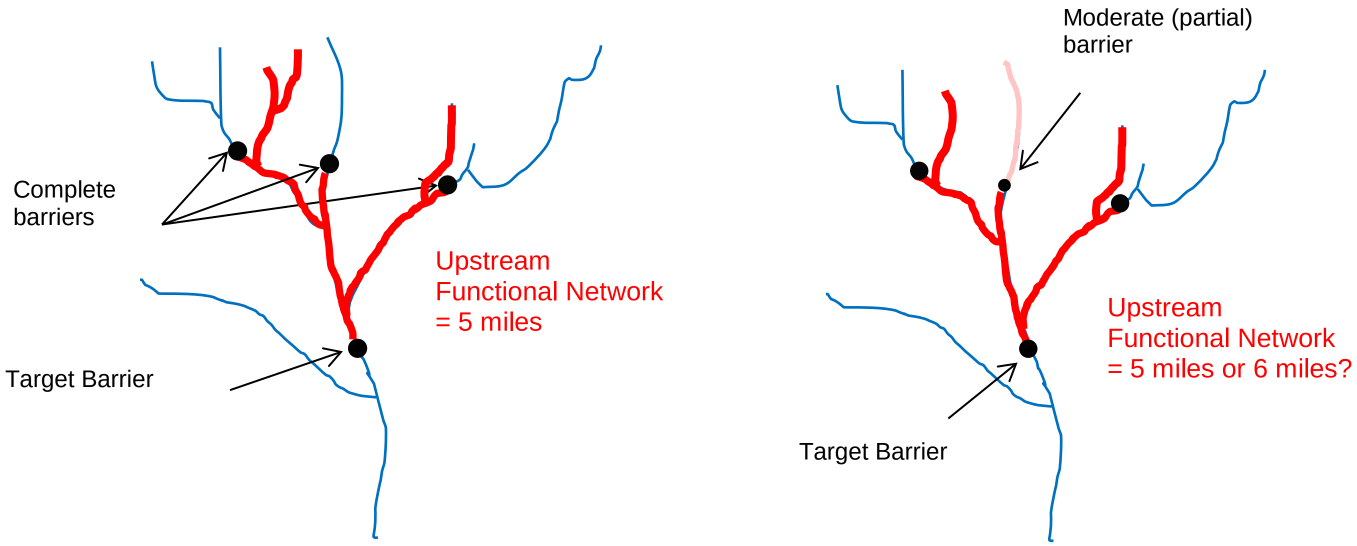
Final Rank		Final Rank
	Barrier A	3
	Barrier B	2
	Barrier C	1
	Barrier D	3

The final ranks are then binned into 5% tiers for presentation. This is 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 barrier which opens up 3.24 miles of river habitat may not provide greater ecological benefit than a barrier which opens up 3.25 miles of habitat.

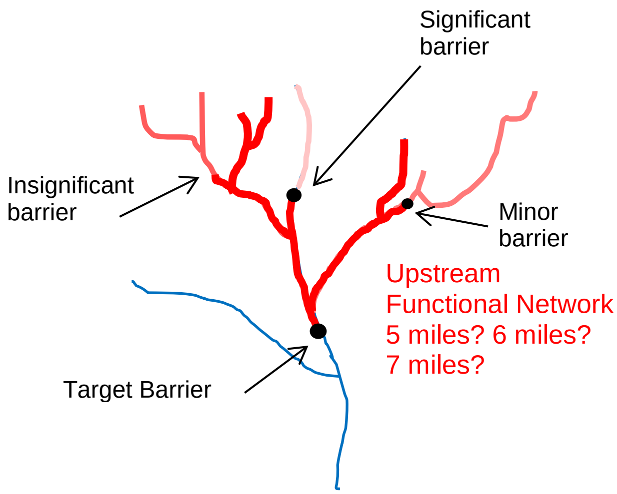
3.3.2 Crossing Passability Iterations

3.3.2.1 The problem with assessing partial passability

Unlike the NAC 2011 and subsequent projects in the same vein conducted by TNC (e.g. Martin and Apse 2013, Martin et al 2014) which were focused exclusively on dams, the NEACAP assessed both dams and road-stream crossings. The inclusion of road-stream crossings in the analysis raised the confounding issue of partial passability. As outlined in Section 2.3.2.2, numerical passability scores were assigned to each road-stream crossing in the database. However, the partial passability of barriers is fundamentally at odds with the concept of functional river networks, which are defined by the barriers upstream and downstream of each given barrier (see Section 2.1.1 for an illustration and further discussion about functional river networks). For example, if the barriers upstream of a given barrier are "moderate barriers," meaning they may be passable for some species under some flow conditions but impassable for others, how many miles of river would be opened by the removal of the barrier in question? This dilemma can be illustrated as follows:



This issue is further complicated by the fact that there are multiple degrees of passability, or multiple shades of gray, included in the analysis (insignificant barrier, minor barrier, moderate barrier, significant barrier, severe barrier). Therefore, a characterization of the upstream functional network length for a given barrier could actually look like more like:



As this simple drawing illustrates, when partially passable barriers are included, it is no longer straightforward to generate functional river networks.

Further, it is not sufficient to simply include all barriers regardless of their degree of passability because of the impact of barriers on their surrounding barriers. Take, for example, an insignificant barrier located just upstream of a dam and assume that insignificant barrier is included in the analysis run, as illustrated in Figure 3-2A. In this circumstance, the upstream functional network of the dam will be quite small and therefore, it would be a lower priority for removal/passage enhancement in an anadromous fish scenario because of the relatively small amount of river habitat that would become accessible after the dam's removal. Conversely, as illustrated in Figure 3-2B, if the insignificant barrier is considered passable, the dam's upstream functional network would be much larger, and therefore the dam would be a higher priority for removal / passage in an anadromous fish prioritization scenario.

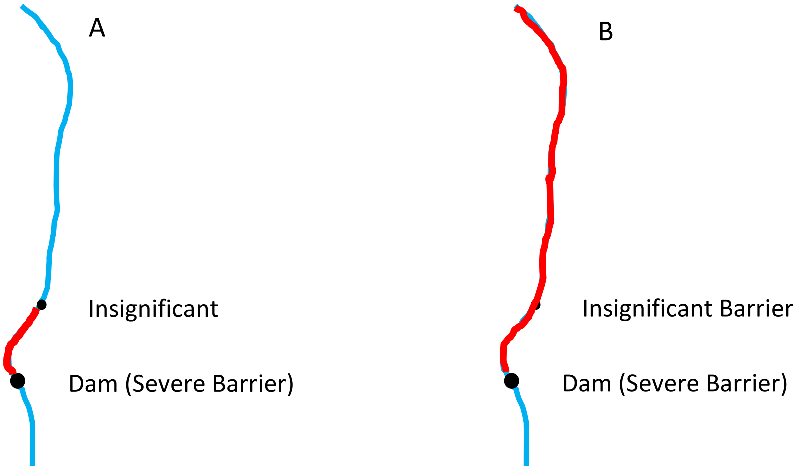


Figure 3-2: The impact of barriers with partial passability on the prioritized result of surrounding barriers.

As illustrated in Figure 3-2, the inclusion of the insignificant barrier may erroneously depress the priority of the severe barrier near it, particularly if the objective of the prioritization is focused on species with moderate to strong swimming abilities for whom an "Insignificant" barrier may pose little obstacle.

3.3.2.2 Approach to Addressing Partial Passability

If the objective of a prioritization is a single species or a suite of species with comparable swimming capabilities, those barriers with a degree of passability which are likely to be actual barriers for the species in question can be included in an analysis using the custom analysis tool (see Section 5.5 for discussion of running a custom analysis). For example, if the objective of a prioritization is to identify high-priority barriers for a strong-swimming fish such as Atlantic salmon, a prioritization could be run using only Significant and Severe barriers. Conversely, if weak-swimming fish such as rainbow smelt are the objective of a prioritization, all barriers (insignificant, minor, moderate, significant, and severe) could be included in the analysis.

For the anadromous consensus scenarios, a different approach was taken given that the objective of the prioritization was not for a single species or guild with comparable swimming capabilities. For these prioritizations, multiple iterations of the analysis were run to address the problem presented by barriers with partial passability. Using the same metric weights presented in Table 3-2, respectively, the prioritization was run for each degree of barrier severity (and all of those barriers that are more severe). Thus, the first iteration included severe barriers only, the next iteration included severe and significant barriers, the next included severe, significant, and moderate, the next severe, significant, moderate, and minor and finally all barriers, including insignificant barriers, were included. These five iterations resulted in five prioritizations, as illustrated in Figure 3-3 Illustration of the five iterations of the anadromous fish scenario. Each iteration was run using identical metric weights, but with input barriers corresponding to the 5 classes of barrier passability., whose input barriers varied based on degree of passability, but whose metric weights were identical.

Figure 3-3 Illustration of the five iterations of the anadromous fish scenario. Each iteration was run using identical metric weights, but with input barriers corresponding to the 5 classes of barrier passability.

After the five iterations of the prioritization were run, an average result (Tier) value was taken for each barrier from the five iterations. Average tier results were rounded to the nearest integer. Barriers that were not present in a given iteration were assigned a result Tier of 20 (lowest priority), to reflect the fact that a barrier considered permeable in a given iteration would be the lowest priority for removal or passage, since it is already considered permeable. Thus, a barrier that was a Tier 1 in all iterations would be a Tier 1 in the final anadromous scenario results. A Severe barrier that was a Tier 4 in the Severe iteration, Tier 4 in the Significant iteration, Tier 2 in the Moderate iteration, Tier 1 in the Minor iteration and Tier 1 in the Insignificant iteration would have a final average Tier of 2 (Round((4+4+2+1+1)/5)). Finally, a Moderate barrier that was a Tier 3 in the Moderate iteration, Tier 1 in the Minor iteration, and Tier 1 in the Insignificant iteration would have a final average Tier of 9 (Round((1+1+3+20+20)/5)).

The process of running iterations as described above has the effect of lowering the priority of barriers that are more permeable (e.g. Insignificant barriers, minor barriers). Even an Insignificant barrier that is a Tier 1 in the Insignificant iteration would have a final result Tier of 16 (Round((1+20+20+20+20)/5)). This is part of the desired effect of this approach; an insignificant barrier *shouldn't* be a high priority when compared against more severe barriers, since it is largely permeable. At the same time, the presence of the Insignificant barrier in the analysis does have an impact on surrounding barriers. Given the situation depicted in Figure 3-2, a dam with an insignificant barrier just upstream of it would have a slightly lower priority than one that had *no* barrier above it because in one of the five iterations, the dam would be a lower priority, thus depressing the priority of the dam somewhat but not to the extent that it cannot come out as a high priority if it is in the other iterations. As noted above, if the focus of a prioritization is a species or guild with known swimming abilities, a degree of passability can be assessed to reflect those swimming abilities, as described in Section 5.4.15.5.

4 Results, Uses, & Caveats

4.1 Results

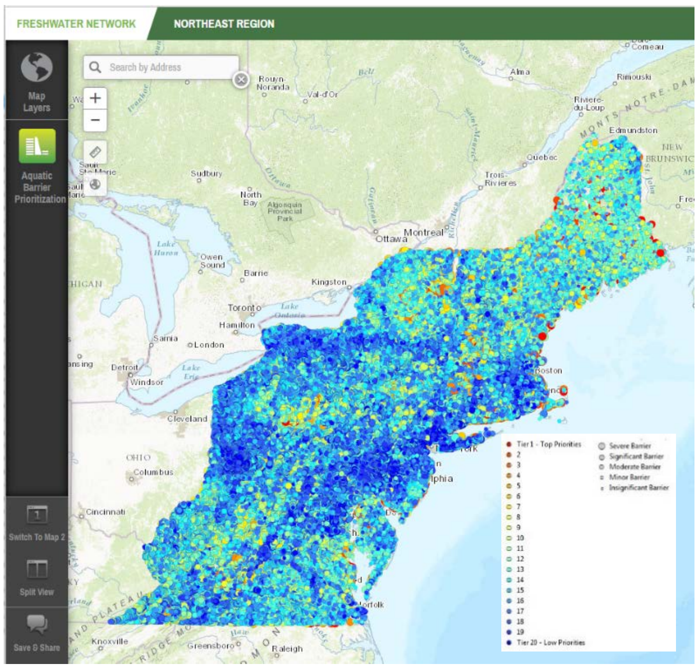
Results from the project include barriers in the region prioritized based on two scenarios agreed upon by the workgroup: anadromous fish scenario and resident fish scenario. These consensus-based scenarios were developed by selecting metrics and applying relative weights (see Section 3.2) for the barriers and data compiled for the project (see Section 2). These consensus results can be viewed and downloaded from http://maps.freshwaternetwork.org/northeast/.

As noted above, dams with existing fish passage facilities are included in the results. Given the variability of fish passage functionality and the species passed during various flow conditions, as well as the relative lack of data to describe passage success rates, it was determined that these dams should remain in the analysis. Even dams with passage facilities are barriers to one degree or another and, if circumstances are conducive, their removal will benefit aquatic connectivity. Further, given the lack of information on fish passage facility effectiveness, all dams are considered Severe barriers. However, an option is included in the custom analysis tool to run a prioritization only on dams that do not have fish passage facilities (i.e. dams with fish passage facilities are considered permeable).

4.1.1 Anadromous Fish Scenario

The consensus anadromous fish scenario prioritizes barriers based on their potential to benefit diadromous fish species if removed or bypassed. This scenario was developed using the metric weights presented in Table 3-2, run five times (once for each degree of barrier severity), then the Tier results were averaged to produce the prioritization depicted in Figure 4-1. As one would expect in a scenario designed to benefit diadromous fish, the barriers in the higher tiers, those whose removal would provide the greatest benefit to diadromous fish, tend to be found closer to the ocean and on the larger mainstem rivers. These include the major rivers and many smaller coastal streams. These results directly reflect the metrics chosen and weights applied to them including anadromous fish presence (weight=20), number of barriers downstream (weight = 10), and upstream functional network size (weight = 20) as well as the barrier severity.

Figure 4-1: A screen capture of the NEACAP consensus anadromous fish prioritization scenario results in the Aquatic Barrier Prioritization. Note that the density of barriers at the regional scale obscures many barriers.



4.1.2 Resident Fish Scenario

Contrary to the approach taken in the NAC 2011, this analysis did not produce a consensus resident fish scenario. Rather, the University of Massachusetts' Critical Linkages results (http://www.umasscaps.org/applications/critical-linkages.html) are incorporated into the web map and tool (see Section 5.4.6). The Critical Linkages analysis produces results which are conceptually similar to the NAC 2011 resident fish results. This landscape-scale analysis assesses each barrier for the cold water (16° C) restoration potential that can be gained by removing any barrier, and is appropriate for identifying crossings whose upgrade could benefit cold water fish species, such as brook trout. Additional information on this analysis can be found in the Critical Linkages report (http://www.umasscaps.org/pdf/Critical-Linkages-Phase-1-Report-Final.pdf) and in the Stream Crossings Explorer tool (http://sce.ecosheds.org).

For users who are interested in a resident fish prioritization separate from the Critical Linkages work, the metric weights in Table 4-1, which were adapted from the NAC 2011, may serve as a useful starting point for a custom analysis (see Section 5.5 for more information on running a custom analysis).

Table 4-1: Suggested resident fish scenario weights, adapted from the NAC 2011, for use in a custom analysis.

Metric Category	Metric Name	Suggested Resident Weight (Adapted from NAC 2011)
Network	The total length of upstream and downstream functional network	15
	Absolute Gain	15
Land Cover / Watershed Condition	% Impervious Surface in Contributing Watershed	5
	% Natural LC in Contributing Watershed	5
	% Impervious Surface in Active River Area (ARA) of Upstream Functional Network	5
	% Impervious Surface in Active River Area (ARA) of Downstream Functional Network	5
	% Natural LC in ARA of Upstream Functional Network	5
	% Natural LC in ARA of Downstream Functional Network	5
Resident	Current # of rare (G1-G3) fish species in HUC8 (Max #)	2
	Current # of rare (G1-G3) mussel HUC8 (@ barrier)	2
	Current # of rare (G1-G3) crayfish HUC8 (@ barrier)	2
	Current Native fish species richness - HUC 8 (@ barrier)	2
	Barrier is within EBTJV 2012 Trout Catchment	5
	Barrier is within a modeled Catchment for Trout (DeWeber & Wagner)	5
	Barrier blocks EBTJV 2012 trout catchments	5
	Barrier blocks modeled trout catchments (DeWeber & Wagner)	5
System Type	Miles of Cold Water Habitat (any stream size)	6
	Total Reconnected # stream sizes (upstream + downstream) >0.5 Mile	6

4.2 Potential Uses of Results

The NEACAP results and custom analysis tool can be used to inform and support on-the-ground efforts to restore aquatic connectivity in ways such as:

- **Project Identification**: A key use of the results is to help managers identify potential projects that can have the greatest ecological benefit; to help them move away from a purely opportunistic approach to more of an ecological benefits approach (recognizing that opportunity among other non-ecological factors does and will continue to play an important role in project selection).

- **Funding Requests**: The prioritized results can also be used reactively by managers seeking funding for a potential project. In the context of a grant application, citing the prioritized result of a potential project helps frame the project in a regional context and can help show potential funders the value of the project for a consensus objective, like anadromous fish.
- **Funding Allocation**: Similarly, funders can use the prioritization results reactively to help inform their assessment of a proposed projects, whether the project aligns with their priorities or not, and ultimate whether or not to contribute funds to that project.
- **Communication**: Results can be used to communicate the value of a given project to the local community, elected officials, or others with an interest in aquatic connectivity issues.
- **Database of Ecologically Relevant Metrics**: Prioritization aside, the results form a database of barriers with 38 ecologically relevant metrics such as length of connected network, species present downstream, and land cover characteristics. These metrics can be used to investigate many aspects of aquatic connectivity on a barrier-by-barrier basis or as inputs to a more customized assessment. For instance, a project manager with an opportunistic passage project can benefit from easy access to metric data, quickly identifying the barrier's restoration potential if removed or bypassed. In addition, as described further in Section 5, custom analyses can be performed as if one or more barriers have been removed. Metric values and the prioritization are recalculated as if that barrier had been removed, thus allowing managers to assess the potential impacts of proposed projects and treat a series of barriers as if they were a single barrier.

4.3 Comparison of the NEACAP prioritization approach to optimization approaches

Several manuscripts in the aquatic connectivity literature have criticized the relatively simple scoring and ranking prioritization method that is used in many aquatic connectivity exercises, including NEACAP, (e.g. O'Hanley and Tomberlin 2005, Kemp and O'Hanley 2010, O'Hanley et al 2013) in favor of optimization approaches which produce a mathematically optimal set of barriers for removal for a given budget. This section outlines potential advantages and drawbacks of the NEACAP approach relative to optimization approaches such as the OptiPass tool (O'Hanley 2016).

4.3.1 The critique against, and defense of, scoring and ranking prioritizations

O'Hanley's critiques of a scoring and ranking prioritization approach (2005, 2010, 2013) focus on two main weaknesses: inefficiency and the focus on individual barriers as opposed to sets of barriers (i.e. barriers in a series).

First, the approach is criticized as financially inefficient based on the premise that the highest priority barriers are removed first, followed by the next highest priority barrier, until the budget is exhausted (O'Hanley and Tomberlin 2005). However, this critique doesn't account for how the results of a regional scoring and ranking analysis like NEACAP are used in a real-world context. Rather than move down the list of priorities until the budget is exhausted, NEACAP results are explicitly intended to be used as a screening-level tool to provide an ecological framework for barriers which then must be further assessed in the context of social, economic, feasibility, and opportunity factors (most of which cannot be captured in a regional analysis) before any action is taken. The authors do not and would not suggest that the results should or can be used as a "hit list" of barriers to remove, let alone in sequential order, as is presumed in the critique. The binning of results into 5% Tiers is a concrete example of how the use of the results in the manner described by O'Hanley and Tomberlin (2005) is discouraged.

Second, because they do not take into consideration the spatial interdependency of barriers, O'Hanley et al (2013) suggest that scoring and ranking prioritizations can lead to results which may prioritize upstream barriers, which if mitigated, would provide no benefit to anadromous fish until lower barriers are first mitigated. Similarly, barriers in a scoring and ranking prioritization are treated independently in the results and so the synergistic impacts of removing multiple barriers is not captured.

The NEACAP tool has been designed to address these potential pitfalls. Regarding the potential prioritization of upstream barriers over downstream impassable barriers, the inclusion of multiple metrics limits the possibility that upstream barriers will appear as high priorities. For example, the count of downstream barriers, the downstream passability product, and the current presence of anadromous fish species metrics all serve to depress the rank of barriers which would not immediately benefit anadromous fish if removed. While it is still possible that an interior barrier could be so exemplary in another metric (e.g. open the most upstream habitat of any barrier in the analysis) that it becomes a high priority, one could argue that this would be a barrier worth considering for future work. Further, via a custom analysis, it is possible to apply a filter so that barriers which do not meet one or more criteria are excluded from the analysis (e.g. only prioritize the downstream most barriers).

Likewise, the assertion that the barriers are treated individually in the results of scoring and ranking prioritization is true for NEACAP. But again, the tool has been designed to address this shortcoming. Specifically, the barrier removal functionality, as described in Section 5.5.1.5 can be used to assess the priority of a series of barriers in an analysis. Indeed, this is not the same as an optimization which assesses all possible combinations of barriers, but nonetheless can be used interactively to inform an understanding of barriers in a series at scales likely to be used by conservation practitioners (e.g. in the evaluation of potential projects at a watershed scale).

Of note, it is important to recognize the limitations of any regional-scale approach to assessing aquatic connectivity and to consider them screening-level assessments. Neither approach should be assumed to provide the "best" answer that can be taken as-is and implemented on the ground. For example, the project cost information which is required for each barrier in an optimization is notoriously difficult to estimate, particularly lacking field-survey data. Likewise, budgets are notoriously prone to change resulting from changes in the political or economic landscape. Errors in these values can have a substantial impact on the results of an optimization. Similarly, metrics that are derived for a score and rank prioritization at the regional scale can lack the resolution necessary to detect important physical or ecological characteristics and can lead to results which, given better information and on-the-ground knowledge, can be seen to be false. See Section 4.4 for additional discussion of the limitations and caveats of this analysis.

4.3.2 Advantages of NEACAP's Prioritization Approach

The strengths of NEACAP's scoring and ranking approach lie in its flexibility, both in terms of the analysis itself and in terms of how the results can be used. As is described further in Section, the NEACAP tool can be tailored in many ways to suits the needs of a user. These include the ability to change the metrics which underlie the prioritization, apply filters to limit the universe of barriers that are prioritized, and model the removal of barriers.

However, a greater strength may lie in how the results can be used, particularly when compared to optimization results. As described above in Section 4.2, the results can be used in both proactive and reactive ways. Proactive uses include the use of the results to identify potential restoration projects (which must then be evaluated in the context of important social, economic, feasibility and opportunity factors before any action is taken) and for use in support of funding requests for restoration projects.

Unlike optimization results, the NEACAP results can also be readily used reactively, in response to requests from third parties. For example, if a funder is approached by a watershed group with a request for funding to support their dam removal project, the funder can cross reference the proposed project against the NEACAP results and assess whether it is a high priority project for anadromous fish and therefore in line with their objectives and worthy of funding. Put another way, a scoring and ranking prioritization is flexible enough to leave room for opportunity. If an opportunity arises, that opportunity can be assessed in the context of the prioritization and an appropriate action determined. Conversely, optimizations are far more prescriptive, dictating not just that a barrier is a good candidate for removal, but that a set of barriers are the optimal solution. If not all of the barriers are removed together then the solution is no longer optimal (and may in fact be very suboptimal).

The prescriptiveness of optimization approaches is both their biggest strength and weakness. By being highly prescriptive, they can identify exactly which barriers are the most efficient set to remove for a given budget. At the same time, if the implementation of the optimal solution set is derailed for some reason (e.g. change in dam ownership), the optimization is no longer valid. A new optimization must be run and any work done to date may detract substantially from the efficiency that is the strength of optimizations. Likewise, if removal costs are inaccurate, the budget of an optimization changes, or all of the actors working on barrier removal in a given study area are not coordinated in their efforts to implement the optimization it will not live up to its promised efficiency. Thus, in a controlled world where estimated removal costs are accurate, long-term budgets are known, and all actors are coordinated across large study areas optimizations can live up to their mathematical potential as highly efficient solutions for maximizing a value (e.g. upstream miles opened) for a given budget. In our messy real world, the benefits of optimizations recede and the benefits of score and rank prioritizations become more apparent.

4.4 Data Limitations & Caveats

As with any modeled analysis, there are several caveats and limitations that are important to bear in mind when considering the results and data produced by this project and the custom analysis tool. First and foremost, the results are *not intended to be a "hit list"* of barriers for removal. For example, there may be cases where the benefits provided by a given dam outweigh the ecological benefits of removing it, although other passage projects can be considered when removal is not the best option.

Next, this project is based on data from many different sources (see Section 2), none of which is entirely perfect. For example, the river hydrography, as represented in the NHD, does not perfectly represent flowing rivers on the ground. Any inaccuracies in the source data will be reflected in the metrics calculated using that data. For example, if a river segment is missing from NHD, the upstream functional river length for the barrier below the missing segment will be too short.

Similarly, the prioritization is sensitive to inaccuracies in the barrier database. If a barrier is erroneously included in the database, the error ripples beyond the barrier itself since its presence will impact the metrics for surrounding barriers. For example, the calculated upstream functional network of the next barrier downstream will be too short, the downstream functional network of upstream barriers will be too short, the count of downstream barriers for all barriers upstream of the error will be too high, and so on. Although the project team put substantial effort into compiling and revising the barrier data using desktop GIS techniques, it should be expected that some errors remain. Thus, it is particularly important that results be examined on an individual basis using the best available local-scale data and on-the-ground knowledge before any actions are taken.

Additionally, this project, by design, only considers ecological factors depicted by data available at a regional scale. It does *not include social, economic, or feasibility factors*, largely due to the fact that this information is extremely difficult to capture through regionally-available GIS data. These factors could be layered onto the project results through a subsequent site-scale analysis, as has been done in Connecticut using results from the NAC 2011 (Steve Gephard, CT Department of Energy & Environmental Protection, personal communication).

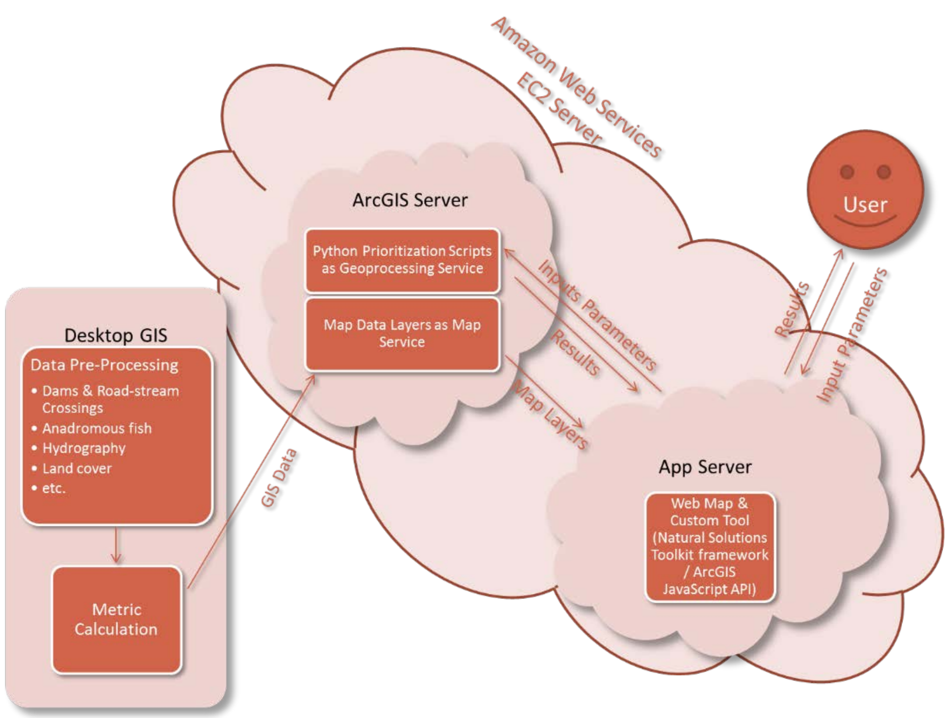
Results from this project are intended to be *screening-level* information that can *help* inform on-the-ground decision making, using the best available regional data. They are not a replacement for site-specific knowledge and field work.

Finally, it is important to note that any aquatic connectivity project will have ecological benefits. If an opportunity arises, it should not be rejected solely on the grounds that it does not rank in one of the upper tiers of this project. Ultimately, whether the benefits provided by a given passage project justify the costs is a decision that rests with managers using all of the best information at their disposal. We hope that this project will be a useful and important tool in the aquatic connectivity toolkit, not the only one.

5 Web Map & Custom Analysis Tool

Project results and a tool to run custom user-defined scenarios can be found at http://maps.freshwaternetwork.org/northeast. This web mapping platform allows users to view results in the context of other relevant data and base maps, apply filters to view a subset of the results, query results, download data, share the current map via a URL, and print or save a map as PDF. Map data is served to the internet using a cloud-based (Amazon Web Services) instance of ArcGIS Server (http://www.esri.com/software/arcgis/arcgisserver). Likewise, the custom analysis which underpins the Aquatic Barrier Prioritization tool on the web map was developed using Python geoprocessing scripts and the ArcGIS acrpy module (http://desktop.arcgis.com/en/arcmap/10.3/analyze/arcpy/what-is-arcpy-.htm). These geoprocessing scripts are served to the internet via ArcGIS Server and consumed in the web map via an implementation of TNC's Natural Solutions Toolkit (NST) framework on the Freshwater Network. The NST was originally developed for TNC's Coastal Resilience program (http://coastalresilience.org/) and is a modular, open source web mapping platform that leverages the ArcGIS JavaScript API and modern web development techniques (the source code for the NST can be accessed at https://github.com/CoastalResilienceNetwork). The Freshwater Network is an association of TNC's web mapping applications which utilize the NST with a focus on freshwater issues. Figure 5-1 illustrates the conceptual architecture of the web map and custom analysis tool.

Figure 5-1: Conceptual architecture of web map & custom prioritization tool



One advantage of using a platform like the NST for this purpose is that it is actively maintained and new features and design refinements are constantly being implemented. Because of this and the modular nature of the platform, the functional life of the application is expected to be longer than more static platforms. However, one side effect of the dynamic nature of the platform is that the description provided below may become outdated as design and functionality improvements are implemented. Within the app, though, there will always be help documentation specific to the current design, functionality and format of the map and the “Aquatic Barrier Prioritization” app.

5.1 Basic features of the web map

Upon first entering the map, the Northeast U.S. is visible, along with the base functionality of the NST platform (e.g. Search by Address, zoom, measure, change basemaps). Along the left side of the map are a series of “apps” each with distinct functionality. The “Aquatic Barrier Prioritization” app contains all of the functionality related to the NEACAP results and custom analysis tool. Of note, it is possible that additional apps with a thematic focus on freshwater issues in the Northeast U.S. will be added in the future.

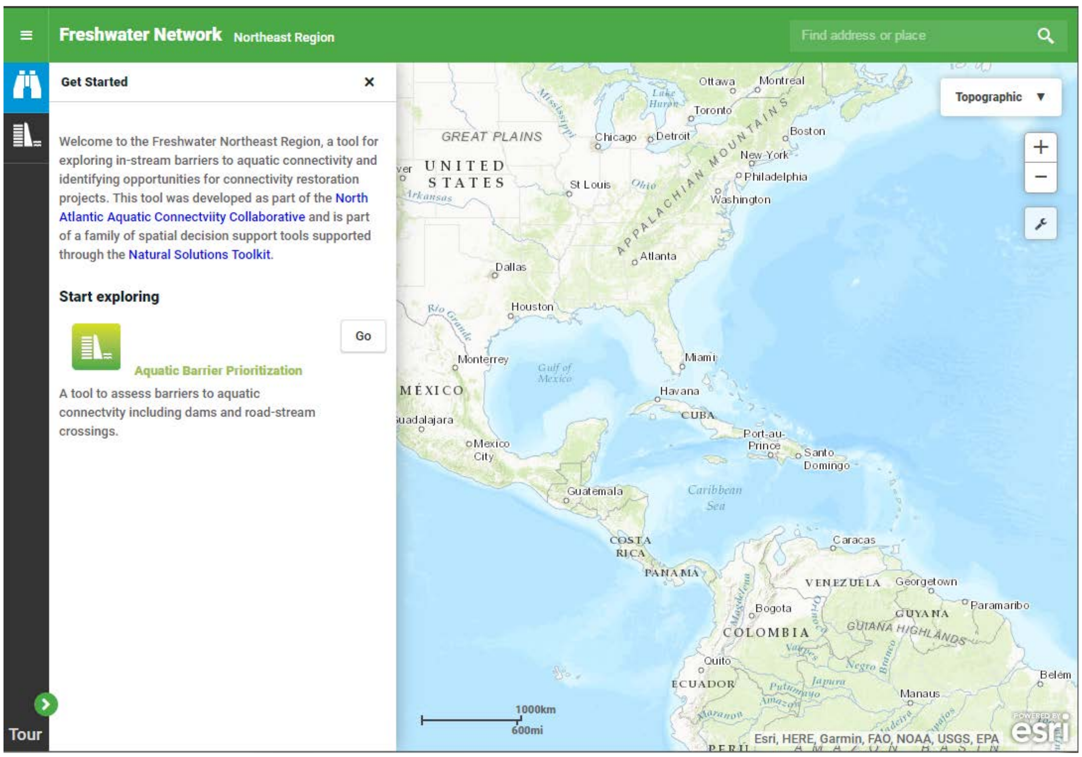


Figure 5-2: Map of the Northeast U.S. that is visible upon first entering the web map.

Clicking on the “Aquatic Barrier Prioritization” app brings up a welcome screen with important information about the project, links to additional information and use limitations, and adds the prioritized barriers to the map window. The “Start Using Aquatic Barrier Prioritization” button at the top of the welcome screen allows users to enter the map.

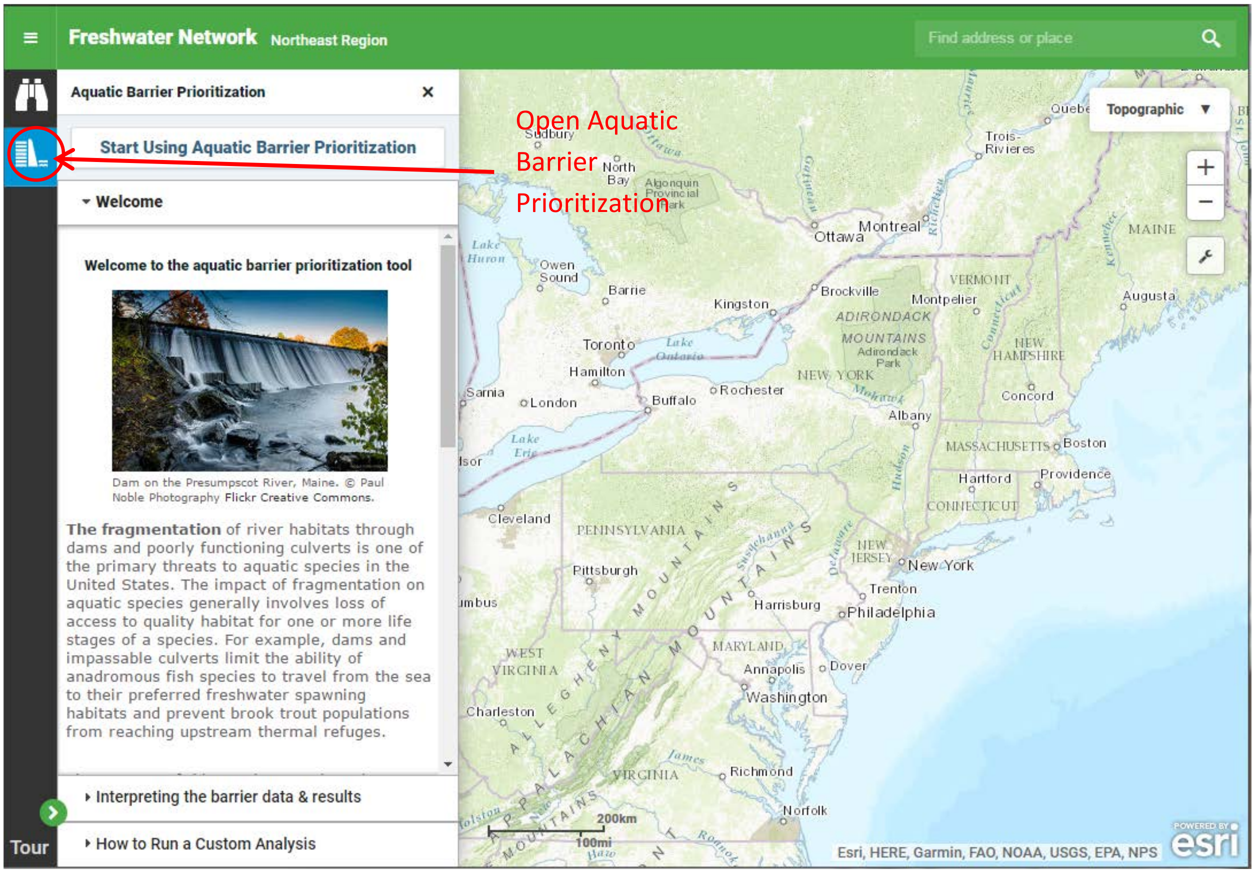


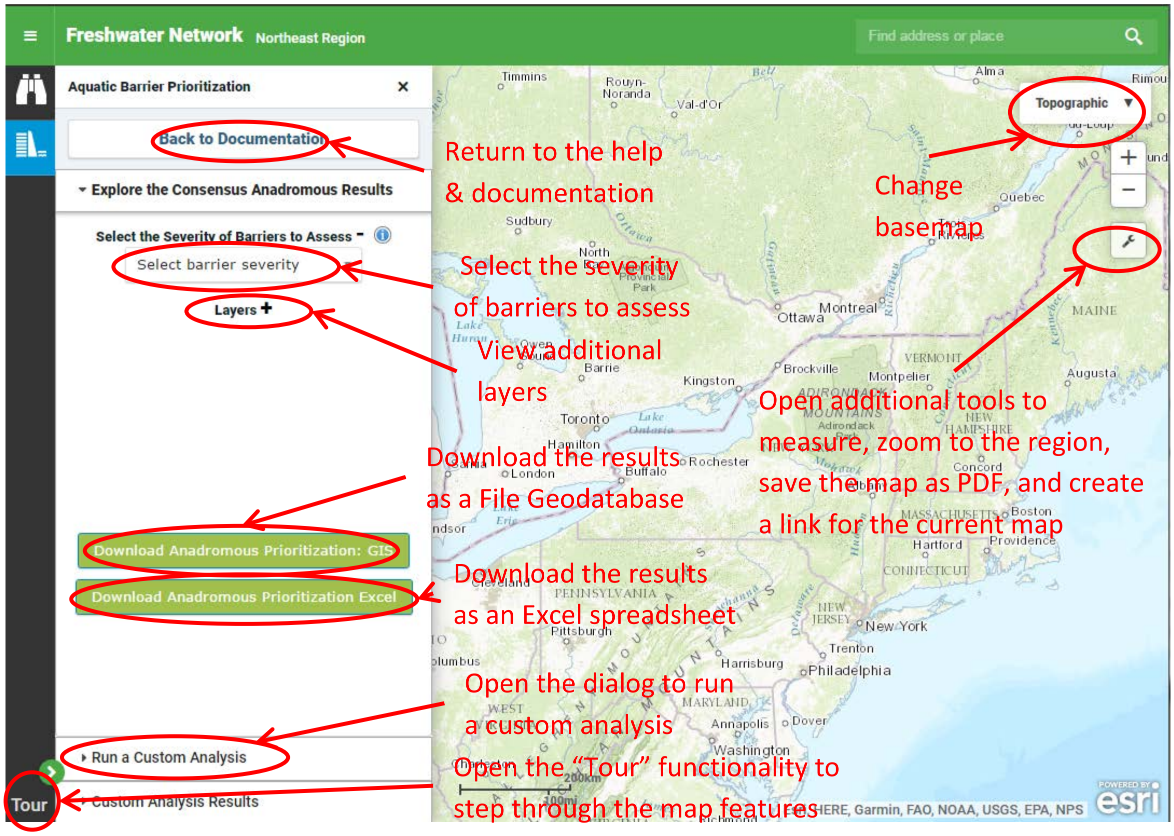
Figure 5-3: Welcome screen of the Aquatic Barrier Prioritization app. Additional help is included in the "accordion" panes along the left side of the map window.

By default, the map is loaded with the consensus anadromous fish scenario results displayed. Clicking on a barrier point brings up attribute information including the anadromous fish consensus result tier, the values for all of the metrics that were calculated for the barrier, and select contextual attributes.

5.2 Contextual and Base Data

Associated, non-barrier, base data layers are available in the map via the "Map Layers" app. Expanding the "+" signs opens the list of nested map layers and includes a checkbox to toggle the layers on or off. The magnifying glass on the right side of each layer name can be used to zoom to the extent of that layer while the information ("i") icon can be clicked to view a description of the layer. Initially these layers include a handful of contextual datasets such as rivers, watershed boundaries and states. Other contextual data layers may be added to this data over time.

Figure 5-4: Basic features of the web map



5.3 Save and Share

The "Save and Share" function can be used to save the current state of the map and share it with other users via a custom URL. The map extent, layers, filters applied to the data (see Section 5.4), and input parameters for a custom analysis are all stored within the custom URL when the "Save and Share" button is clicked, as shown in Figure 5-5 . In the case of a custom analysis, the input parameters are stored. When the saved map is entered, the "Submit" button must be clicked to start the custom analysis defined by the saved parameters and return a result.

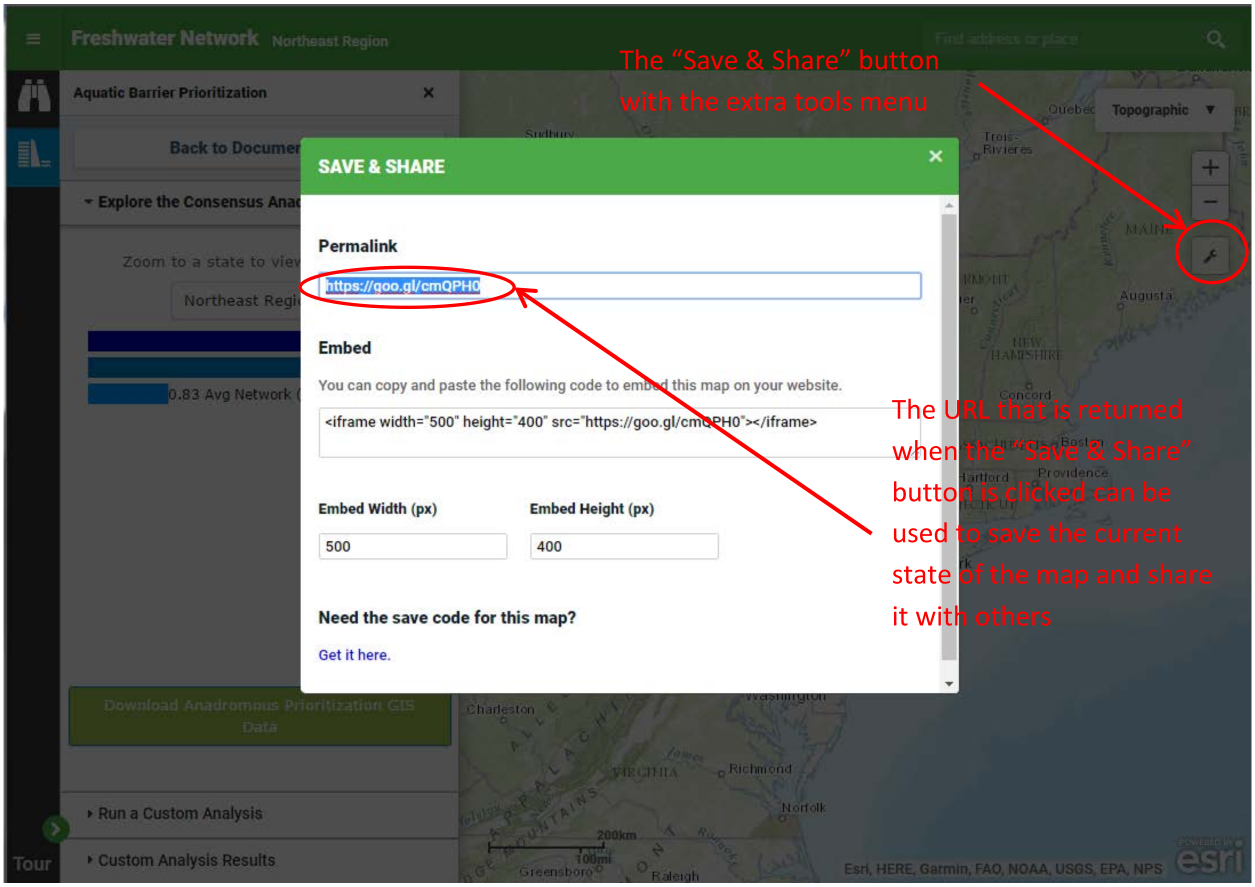


Figure 5-5: Using the "Save & Share" functionality to obtain a URL which, when opened by others, will return the map in the state it was in when the "Save & Share" button was clicked.

5.4 Explore the consensus results

Upon entering the Aquatic Barrier Prioritization app, and selecting “Start Using Barrier Aquatic Barrier Prioritization”, the user is presented with options for exploring the consensus anadromous fish results. This begins by selecting the severity of barriers to view and interact with.

5.4.1 Select barrier severity

A dropdown menu presents the user with a list of the barrier severities. As is described in Section 2.3.2.2, each barrier is assigned a passability, or barrier severity, score that indicates the extent to which that barrier is an impediment to aquatic organisms. Road stream crossings that have been surveyed are assigned a score using the NAACC numerical scoring system, which is described in detail on the NAACC website. Road-stream crossings which have not been assessed are assigned a score using landscape-scale GIS data in a Random Forest predictive model, as part of the UMass Critical Linkages project as described further in Section 2.3.2.2. In both cases, the passability scores are binned into severity classes ranging from severe barriers to insignificant barriers, corresponding to the classes used in the five iterations described in Section 3.3.2.2. When selecting a barrier severity to display, all severity classes that are more severe are also shown. Thus, selecting “Moderate” barriers will also display “Significant” and “Severe” barriers.

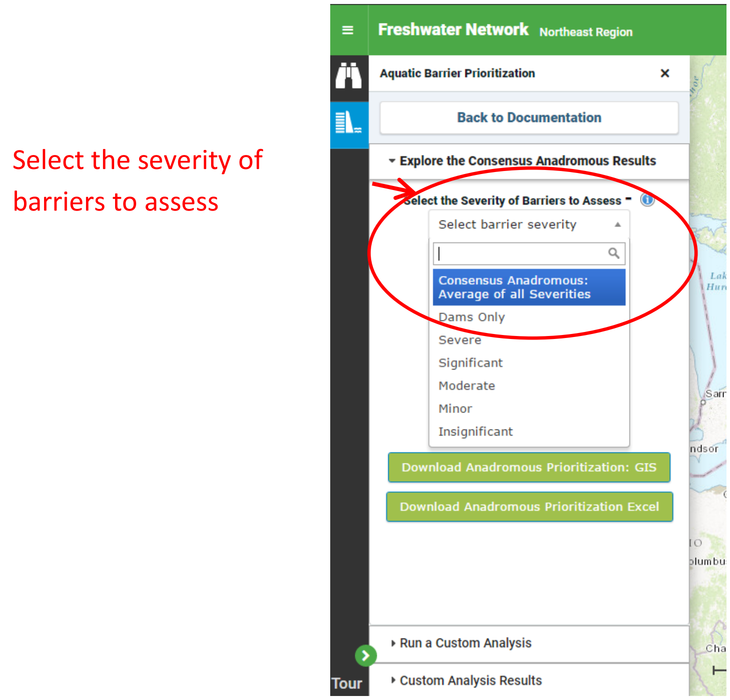


Figure 5-6: Selecting the severity of barriers to assess

In addition to the individual severity classes, the consensus anadromous results, which takes the average value across the five iterations, are available to view. Note, however, that individual metric values are not available via the radar plot (see below) or popups for the consensus anadromous scenario because the metric values are not averaged (nor would it make sense to do so) to produce the consensus anadromous results. For example, a given barrier might have 20 barriers downstream of it in the “Insignificant” iteration, 18 in the “Minor” iteration, 15 in the “Moderate” iteration, 10 in the “Significant” iteration, and 5 in the “Severe” iteration. But this given barrier does not have 13.6 barriers below it in the anadromous consensus results.

Finally, due to a lack of consistent information to the contrary, dams are always considered Severe barriers. However, it is possible to run a custom analysis that excludes (consider permeable) dams with documented fish passage facilities. See Section 5.5.1.1 for more details on running a custom analysis whilst excluding dams with passage facilities.

5.4.2 Radar plots

Clicking on a barrier will reveal a popup of the barrier's result Tier as well as a "radar plot" of the barrier's attributes. The radar plot is designed to provide a quick and intuitive way to visualize the qualities of that barrier.

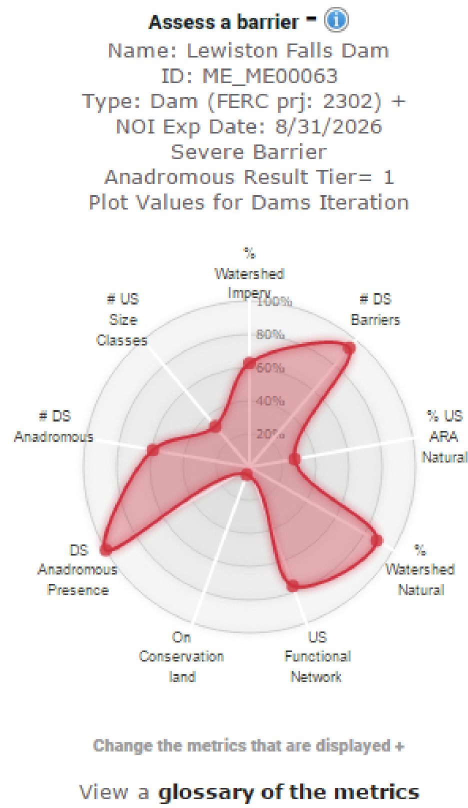


Figure 5-7: Example of a "radar" plot depicting the relative performance of a given barrier across a range of metrics

Above the radar plot is a header with key information about the barrier including its name, the type of barrier, its unique ID from this analysis, its FERC project number and NOI expiration date if available (for dams only), a link to its NAACC survey page, if available (for crossings only), and its result tier for the currently displayed severity iteration. Below that the metrics are arrange on the radar plot. Each attribute is arranged so that values that are desirable in a fish passage restoration project are at the margin of the plot. For example, a barrier that has the potential to open 200 miles of upstream habitat would have a value towards the margin of the plot since opening up a lot of upstream habitat is desirable in a passage restoration project for anadromous fish. Likewise, a barrier with 0% impervious surface in its watershed would have a value at the margin of the plot since no impervious surface (urban paved landcover) is a proxy for good water quality.

Importantly, the values that are displayed in the radar plot correspond to the barrier severity that is currently selected (see Section 5.4.1 above). The metric values can change depending on the severity of barriers that are currently being viewed.

The axes of the radar plot are normalized relative to the other barriers. Thus, using the example in Figure 5-7 , Lewiston Falls Dam performs relatively well on the Upstream Functional Network length metric; when compared to the other barriers in the analysis, it would open more upstream habitat than approximately 80% of them (if the point for US Functional Network was on the outer margin of the radar plot, it would open more upstream habitat than 100% of the barriers in the region). Conversely, Lewiston Falls Dam performs relatively poorly on the number of upstream size classes metric; relative to other barriers in the analysis, it has few different size classes in its upstream functional network, and so would add little to the habitat diversity of a reconnected network. Hovering the mouse over the red dot for a metric that displays the real-world value for that metric.

Below the radar plot is an expandable dialog which can be used to change the metrics that are displayed in the radar plot, as well as a link to a document with definitions for each metric.

5.4.3 Using basic filters to interact with the consensus results

There are three options for filtering how the results are displayed. The first two filters are applied using "slider" bars and can be used in combination, while the third option to build a custom filter cannot be combined with the first two. Importantly, these filters identify a subset of the results for display in the map but do not alter the analysis; they simply exclude some results from the map window. Conversely, a custom analysis allows application of a filter to define the universe of barriers that are included as inputs to the analysis. Custom analyses are described further in Section 5.5.

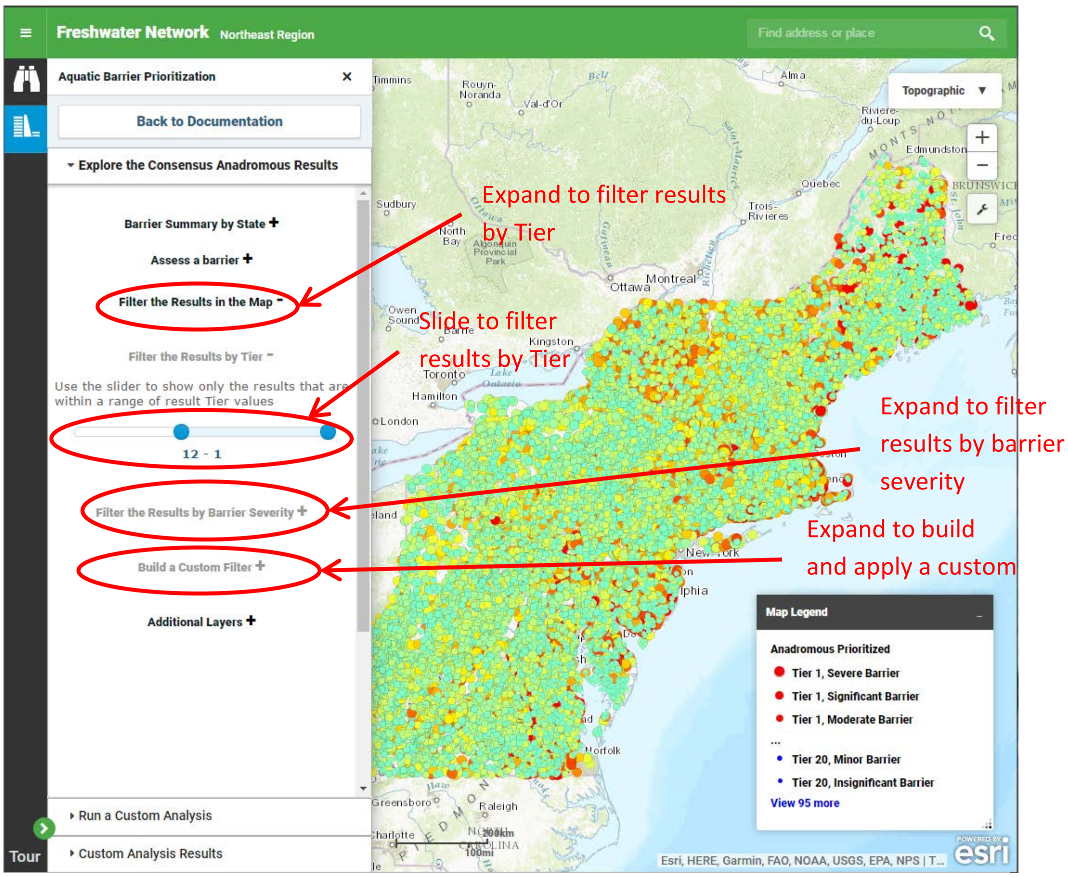


Figure 5-8: Filtering the consensus results

The first filter is used to filter the results by tier to only show result from certain tiers, as depicted in Figure 5-8. This can be useful to quickly highlight certain levels of priority barriers. Similarly, the results can be filtered based on barrier severity. As described further in Section 3.3.2, barrier severity is the degree to which a barrier is passable and is calculated for each road-stream crossing. The results can be filtered based on this value.

Further, these two sliders can be used in combination, as illustrated in Figure 5-9**Error! Reference source not found.**.

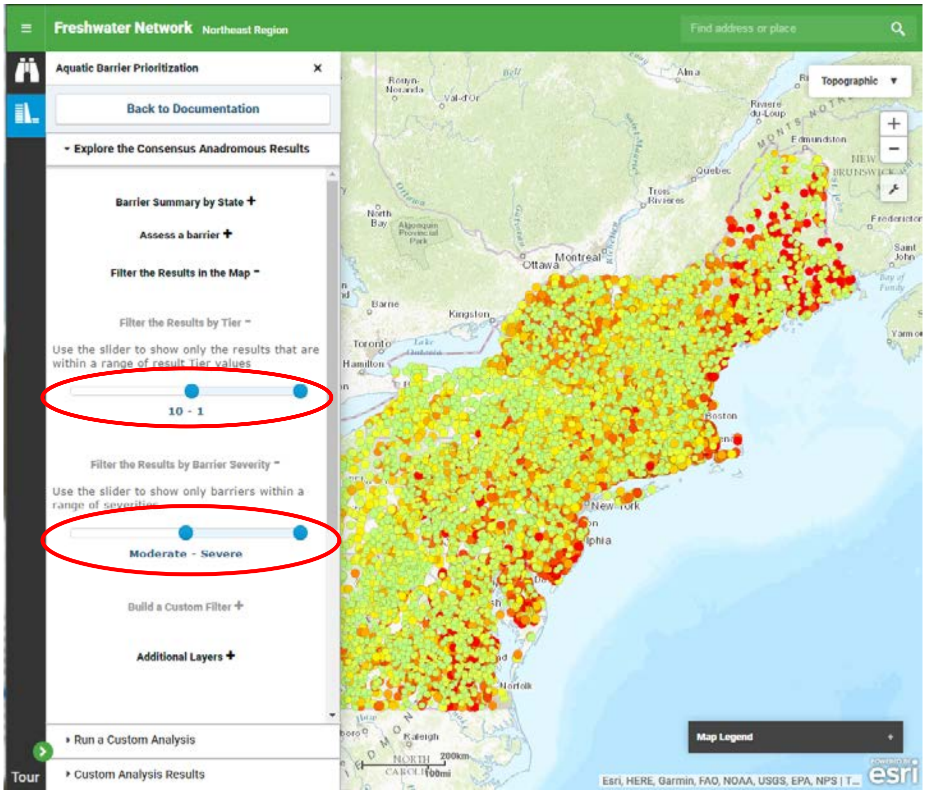


Figure 5-9 Applying filters based on both the anadromous result Tier and barrier severity.

5.4.4 Using custom filters to interact with the consensus results

Custom filters can be developed and applied to restrict the displayed results based on other attributes, such as barrier type (dam vs road-stream crossing), stream size, state, and the presence of particular anadromous fish species. Drop-down menus are used to build a custom filter by first selecting an attribute to filter on (e.g. state), selecting an operator to define the relationship between that attribute and its values (e.g. "=") and finally selecting one or more values to include (e.g. "ME"). These selections then populate a text input field with the completed filter statement, for example, *STATE = ('ME')* as is shows in Figure 5-10.

A complete list of the attributes available in the consensus results for use in custom filters is presented in Appendix III: Attributes Available for Use in Custom Filters.

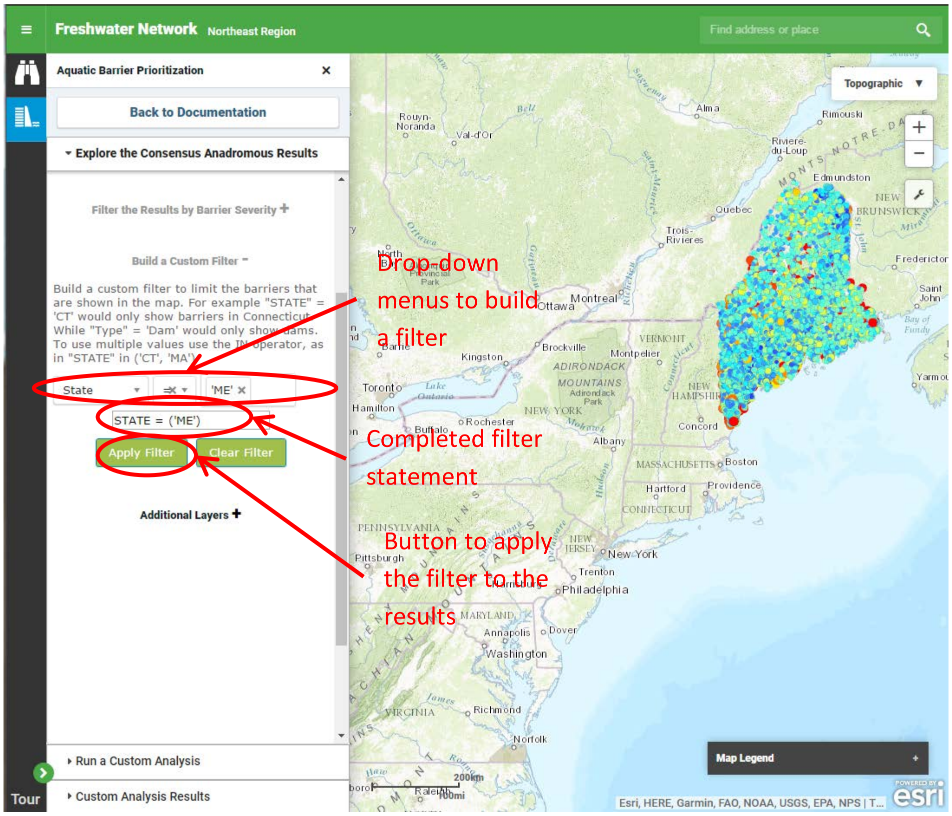


Figure 5-10 Using drop down menus to build a custom filter statement.

Note: If multiple values are selected, the "IN" operator should be used as in: *STATE **IN** ('ME', 'NH', 'VT')*.

For more advanced users, the completed filter statement can be manually edited to further customize a filter statement. Importantly, this can include the development of compound filters. For example, the filter statement *STATE = ('ME') AND Type = ('Dam')* would return dams (not crossings) in Maine. A compound statement can be easily built by copying and pasting a filter statement into another statement and connecting them with *AND* or *OR*.

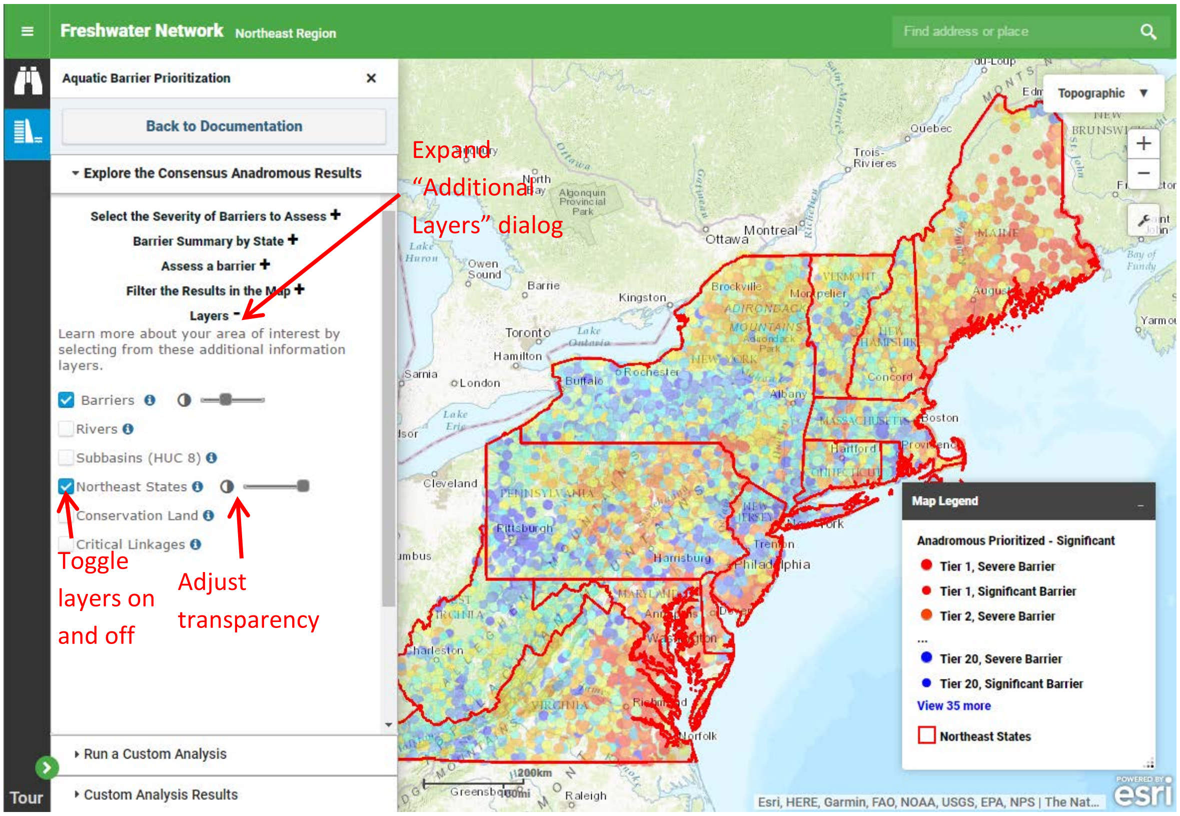
Manually customized filters can also include the use of wildcards in text values (for example *STATE LIKE ('M%')* would return results from Maine, Massachusetts and Maryland. Note that the 'LIKE' operator is required when using wildcards. Any ArcGIS-compliant SQL statement can be used to define a filter. The following ArcGIS help page describes the types of queries that can be used: https://pro.arcgis.com/en/pro-app/help/mapping/navigation/sql-reference-for-elements-used-in-query-expressions.htm.

5.4.5 Download the consensus anadromous results

The Download Anadromous Prioritization GIS Data button at the bottom of the "Explore the Consensus Anadromous Results" pane can be used to downloaded results for the entire region as a zipped ArcGIS file geodatabase. Current versions of the free Quantum GIS (http://www.qgis.org/) software are able to read ArcGIS geodatabases. These data can also be downloaded as an Excel spreadsheet in .xlsb format. Note that this file is quite large, at almost 100 MB.

5.4.6 Additional Layers

Additional layers can be viewed along with the prioritized barriers. These layers can be toggled on and off and their transparency can be adjusted. Included amongst the additional layers are the Critical Linkages cold water (16°C) restoration priorities. These can be used to inform resident fish / brook trout restoration planning efforts. For additional information about this dataset see http://sce.ecosheds.org.



5.5 Run Custom Analysis

The aquatic barrier prioritization app allows users to run customized prioritizations drawing on the menu of metrics calculated for every barrier in the study (see Table 3-1 for a list of these metrics). To run a custom analysis, click the "Run a Custom Analysis" pane along the left side of the app.

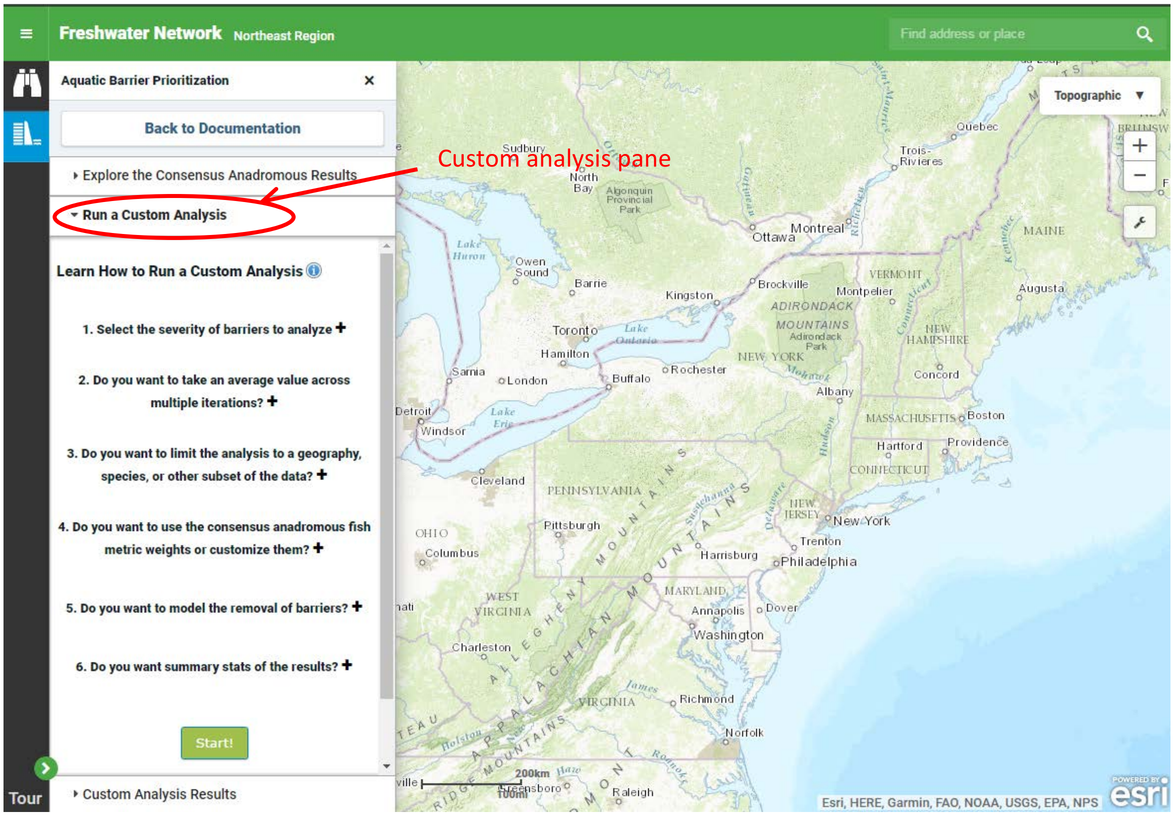


Figure 5-11 The "Run a Custom Analysis" inputs pane

Within the Run Custom Analysis pane are a series of questions which step through the inputs of a custom analysis and a “Start!” button at the bottom of the pane. If no parameters are changed within the 5 steps of the analysis, the custom analysis will run using the consensus anadromous fish parameters for dams only.

5.5.1 Custom Analysis Inputs

There are two required and three optional steps for running a custom scenario. The first required step is to select the degree of barrier severity that will be included in the analysis (defaults to dams only). The second required step is to select a set of metrics and apply relative weights to those metrics to indicate the importance of each for the objectives of the analysis (defaults to consensus anadromous weights). Additional optional steps include: (1) filtering the inputs of the analysis to limit it to a given geographic region or based on another attribute, (2) modeling the removal of up to 10 barriers and (3) calculating summary statistics of the results by state or watershed.

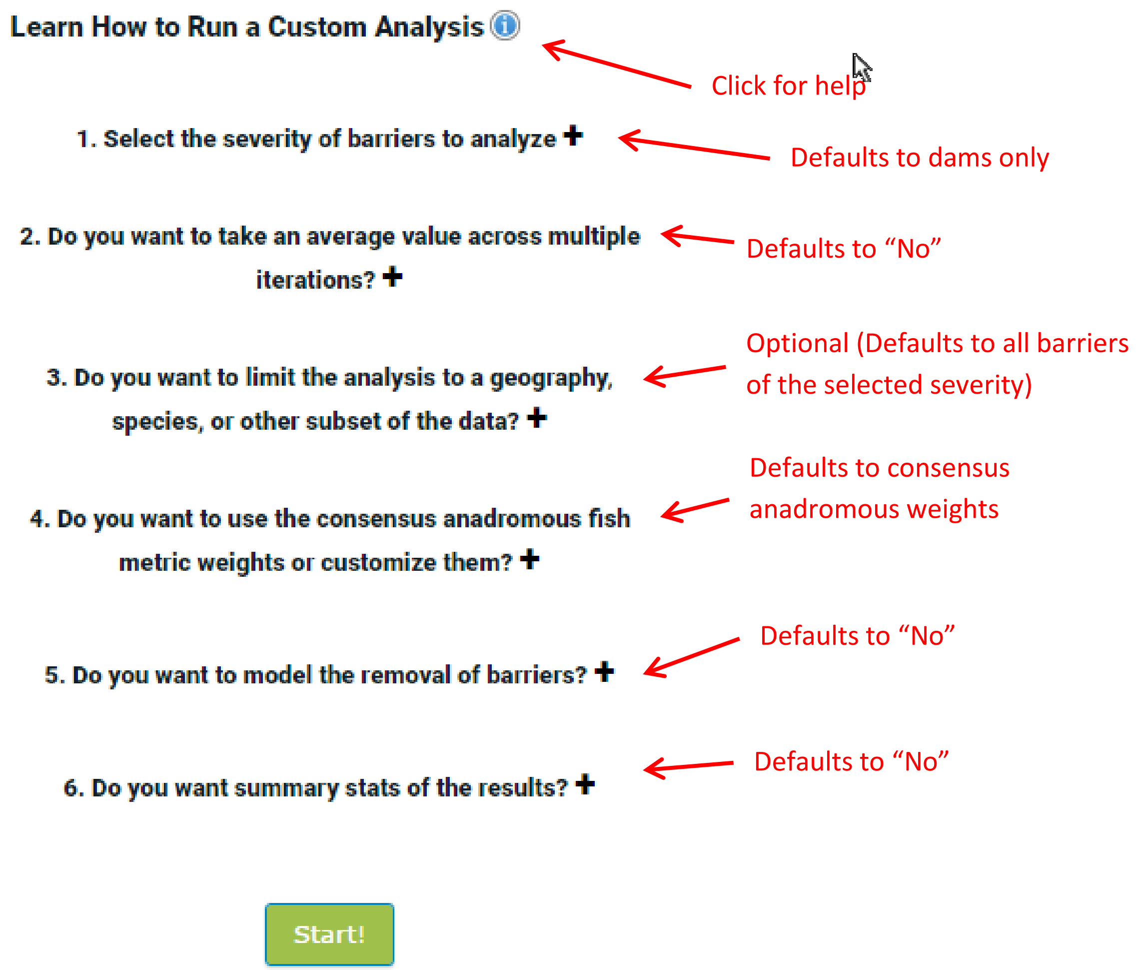


Figure 5-12: Inputs to a custom analysis

Clicking on any of the question headings (with a "+" sign) will expand that heading and expose the input dialogs. Clicking on another question will close any that is currently open. In some cases, there is a further yes/no question within the dialog. Clicking "yes" will expose the input parameters. Clicking "no" will prevent the parameters from being applied to the analysis, even if they have been entered.

5.5.1.1 Select the Severity of Barriers to Include in the Analysis

The first step for a custom analysis is to select the severity barriers that will be included in the analysis. This can include dams only, only dams without fish passage facilities (thus considering dams with fishways passable), severe barriers with all dams and severe road crossings), severe barriers with only dams with no passage), significant barriers, moderate barriers, minor barriers and insignificant barriers. As described further in Section 3.3.2, all barriers of a given severity and those that are more severe are included in the analysis. For example, if "Moderate barriers" are selected, the analysis will include moderate barriers, significant barriers, and severe barriers.

The barriers to include should be determined by the objectives of the analysis. For example, if the objective of the prioritization is to identify priority barriers to restore Atlantic salmon runs, significant barriers might be selected, given the strong swimming ability of salmon. Conversely, if the objective of the prioritization is to identify barriers whose removal could support smelt runs it might be appropriate to select "minor" barriers, given weaker swimming abilities of smelt.

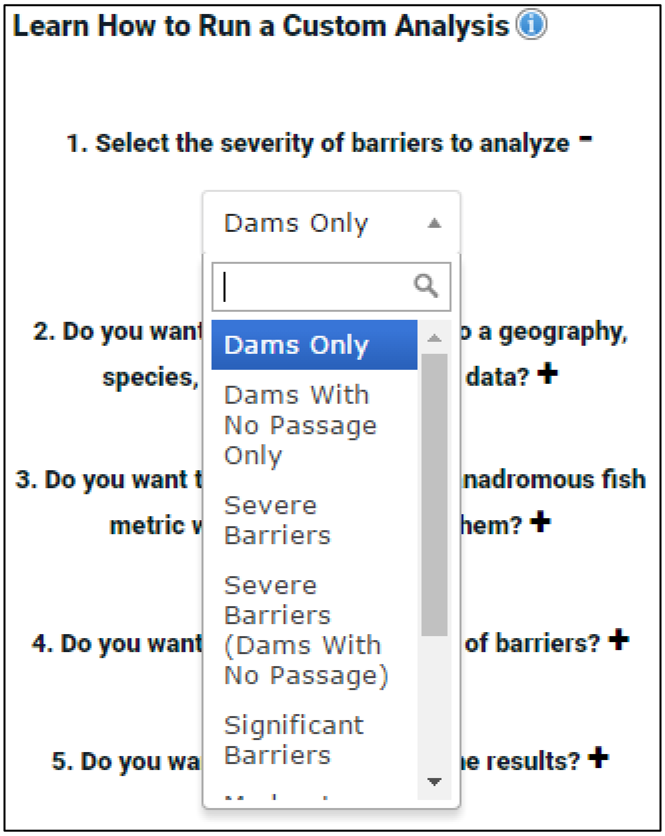


Figure 5-13: Selecting the severity of barriers to include in a custom analysis

Of note, selecting barrier severity to define the barriers used in the analysis is not the same as filtering the input barriers. In practical terms, the barrier severity should be determined by the objective of the prioritization (e.g. swimming ability of a species) while the filter should be used to focus the results on a given geography or other subset of barriers where there is interest in taking on-the-ground action. When the barrier severity is selected, those barriers that are not included do not impact the analysis in any way; it is as if they don't exist. Thus, if, for example, "Dams Only" is selected for the barrier severity then road-stream crossings impact the analysis in no way. This is particularly relevant for the calculation of the functional river networks and derived metrics; if there is a "severe" road-stream crossing barrier just upstream of a dam, that crossing would have no impact on the upstream functional of the dam if "Dams Only" are used in the analysis, whereas if "Severe Barriers" is selected for the analysis, the presence of the upstream "severe" road-stream crossing would reduce the upstream functional network of the dam and thus reduce its priority in the results. Conversely, a filter simply removes the barriers from inclusion in the prioritization. So in this example, if "Severe" barriers are used in the analysis but a filter is applied to prioritize just dams, then the "Severe" road-stream crossing would be excluded from the results, but the upstream functional network of the dam would be reduced by the presence of the “Severe” barrier just upstream of it and its result rank impacted accordingly.

5.5.1.2 Take Average Value of Multiple Runs

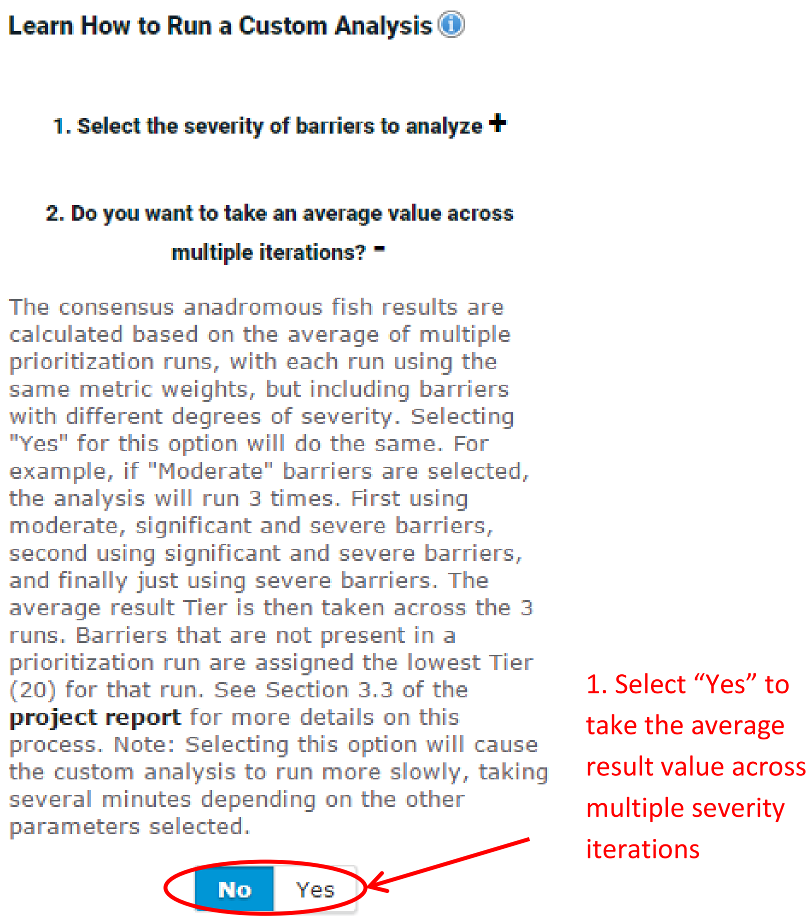


Figure 5-14: Option to take average value across multiple iterations

As the consensus, anadromous prioritization results did, this option can be selected to take an average value across multiple runs. If the “Moderate” barrier severity option is selected and this option is set to “No” (the default), then a single prioritization iteration will be run, including moderate, significant, and severe barriers. If “Yes” is selected for this option, three prioritization iterations will be run. These will include 1) moderate, significant and severe 2) significant and severe and 3) just severe barriers. The average values of the results is then taken across these three iterations. See Section 3.3.2 of this report for more discussion about taking the average result value across iterations. Selecting “Yes” for this option will increase the time required for a custom analysis.

5.5.1.3 Apply a filter to the input data (Optional)

The input barriers for an analysis can be filtered based on state, watershed, presence of anadromous fish habitat, or other attributes. As described above, filtering the barriers limits which barriers are included in the prioritization analysis. However, barriers that are excluded from the analysis through an input filter are still "present" via the metrics calculated based on the location of other barriers. If, for example, a filter is applied to prioritize only barriers in New Hampshire and Vermont the results will include only those barriers in within New Hampshire and Vermont. However, the "Count of Downstream Barriers," for example, will be calculated including barriers outside those states. Thus, the count of downstream barriers metric for Vermont's Bellows Falls dam will include the dams in Holyoke and Turners Falls, Massachusetts and the prioritization will be calculated accordingly.

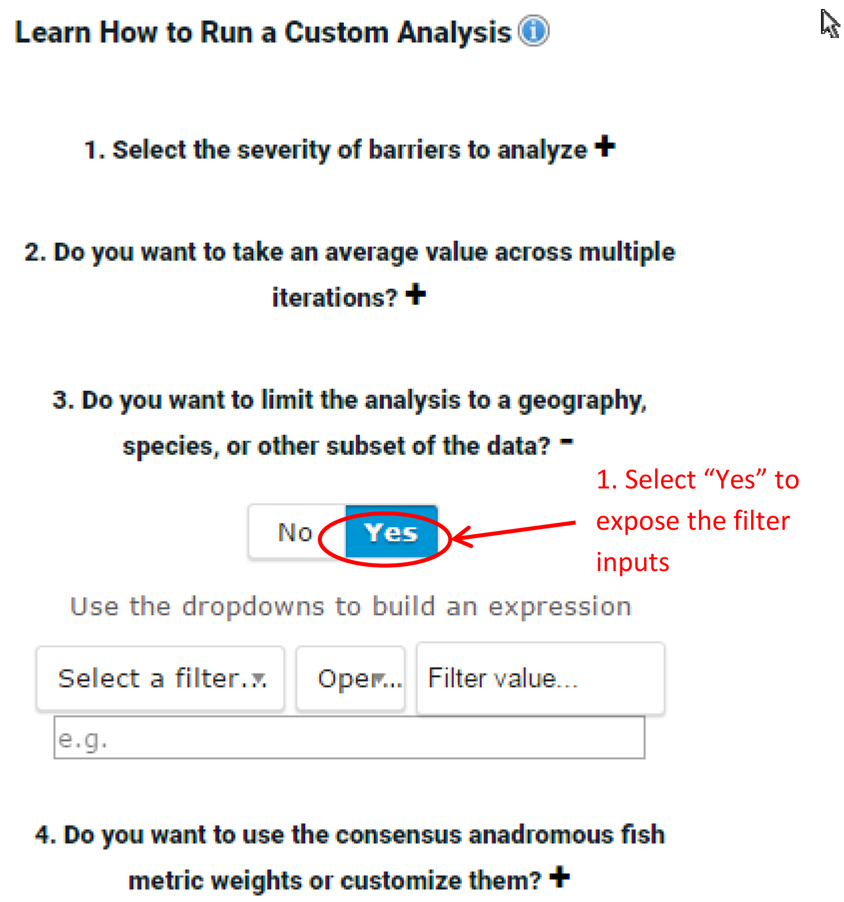


Figure 5-13 Applying a filter on the input barriers of a custom analysis

To apply a filter on the input dataset, the "Filter Barriers?" checkbox must be checked. This will expose the filter inputs, as depicted in **Error! Reference source not found.**. With the filter inputs visible, the process of building a filter is identical to the process described in Section 5.4.4.

5.5.1.4 Select and weight metrics

As described in Section 3.2, weights applied to metrics indicate the relative importance of each metric in a given prioritization scenario. The consensus anadromous fish scenario uses a set of weights determined by the NAACC NE Aquatic Connectivity subcommittee, but alternate scenarios could be developed, using different metrics and weights, to reflect different objectives. For example, if the primary objective is to maximize the number of open upstream river miles, then 100% of the weight could be applied to "Upstream Functional Network Length." The results of this prioritization would be analogous to sorting the barriers so that the one with the longest upstream functional network was on top.

Metrics are weighted by simply typing in a value between 0 and 100 in the input box next to the metric name. Clicking on a metric name opens a pop-up window with a simple description of the metric, its source data and units. A running tally of metric weights is provided and a warning message will appear if the weights do not sum to 100. Metrics are divided into five categories to provide a logical organization of metrics. However, the grouping has no bearing on the prioritization and the total metrics weights (which must = 100) can be spread across the metric categories in any manner desired. Clicking on the “Anadromous” button will populate the weights with the consensus values for those scenarios.

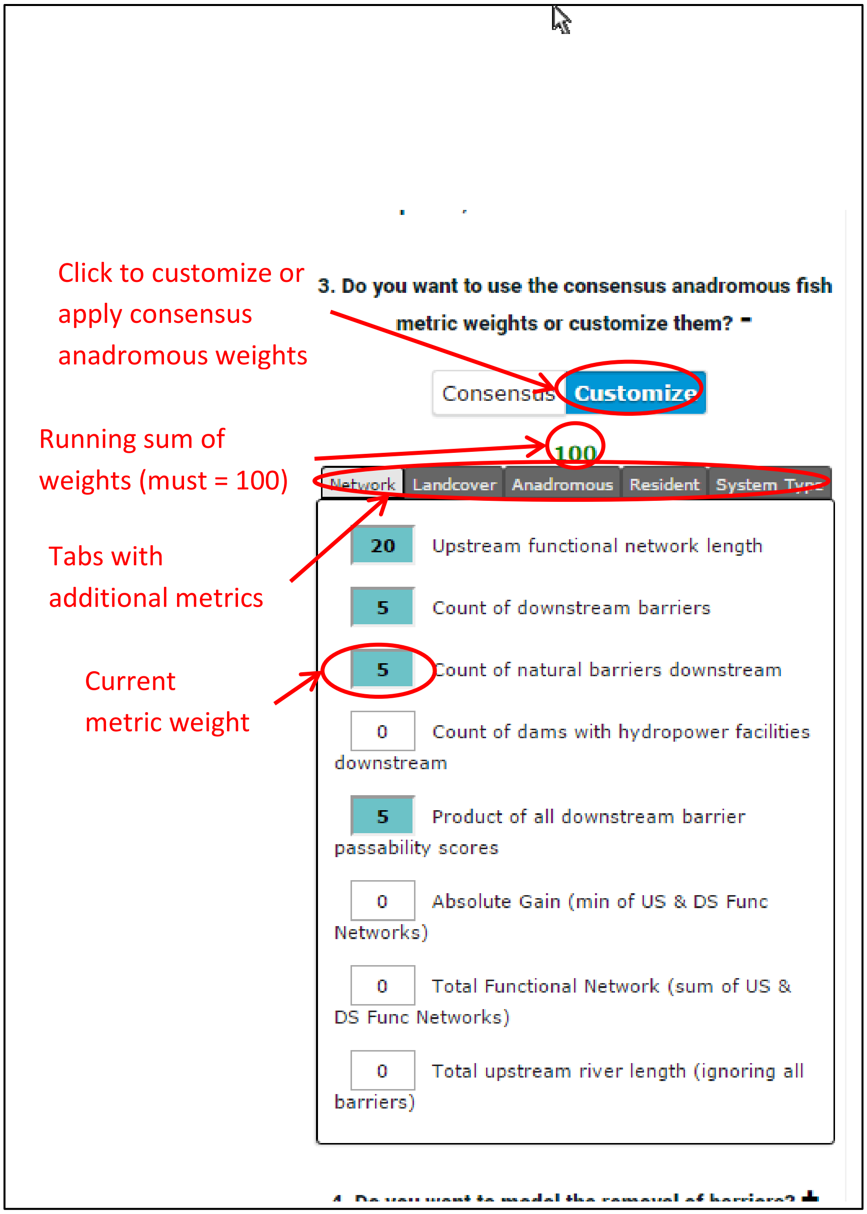


Figure 5-15 Weighting metrics to develop a prioritization scenario

Implicit in the prioritization is the idea that for each metric, either large values are desirable or small values are desirable. Generally speaking, “Upstream Functional Network Length” is a metric where large values are desirable in a potential passage project – the intent is to open up the most upstream miles of river habitat. In this case, the metrics are sorted in descending order where large values rank at the top. Conversely, the percent impervious surface in a barrier’s watershed is a metric where small values are generally desirable – the intent is to open habitat that is in a more natural state to support healthy fish populations. In this case, the metric is sorted in ascending order where small values rank at the top. The sort order for each metric is described in the metric description slide which can be access by clicking on a metric name.

5.5.1.5 Model barrier removal (Optional)

One or more barriers can be selected for “removal” when a prioritization is run. Doing so recalculates new metric values as if the selected barriers do not exist. This functionality can be useful for several reasons. First, it allows users to assess the impact of a proposed project on the priorities of the remaining barriers in the network. By removing a barrier, it becomes possible to see, for example, that the next upstream barrier becomes a priority.

Second, it can be used to address known data errors in an analysis. For example, if a user with first-hand knowledge of a particular barrier knows that it is actually not a barrier, then it can be removed and the priorities of the remaining barriers more accurately assessed. Removing a barrier in this fashion does not update the input database, it only persists for the duration of the user’s session. Future version of the tool may include functionality to directly incorporate user edits.

Third, and perhaps more importantly, removing barriers before running a custom prioritization can be used to assess potential projects that may include a series of barrier removals. This can be useful when a series of barriers are individually relatively low priorities, but when treated together may be a higher priority. Take, for example, the situation illustrated in Figure 5-16 where two barriers are in close succession on a river in a prioritization scenario and where the weights are split between two metrics: upstream functional network length and presence of anadromous species downstream of the barrier. The downstream barrier has anadromous species which get up to its base and the upper stream barrier

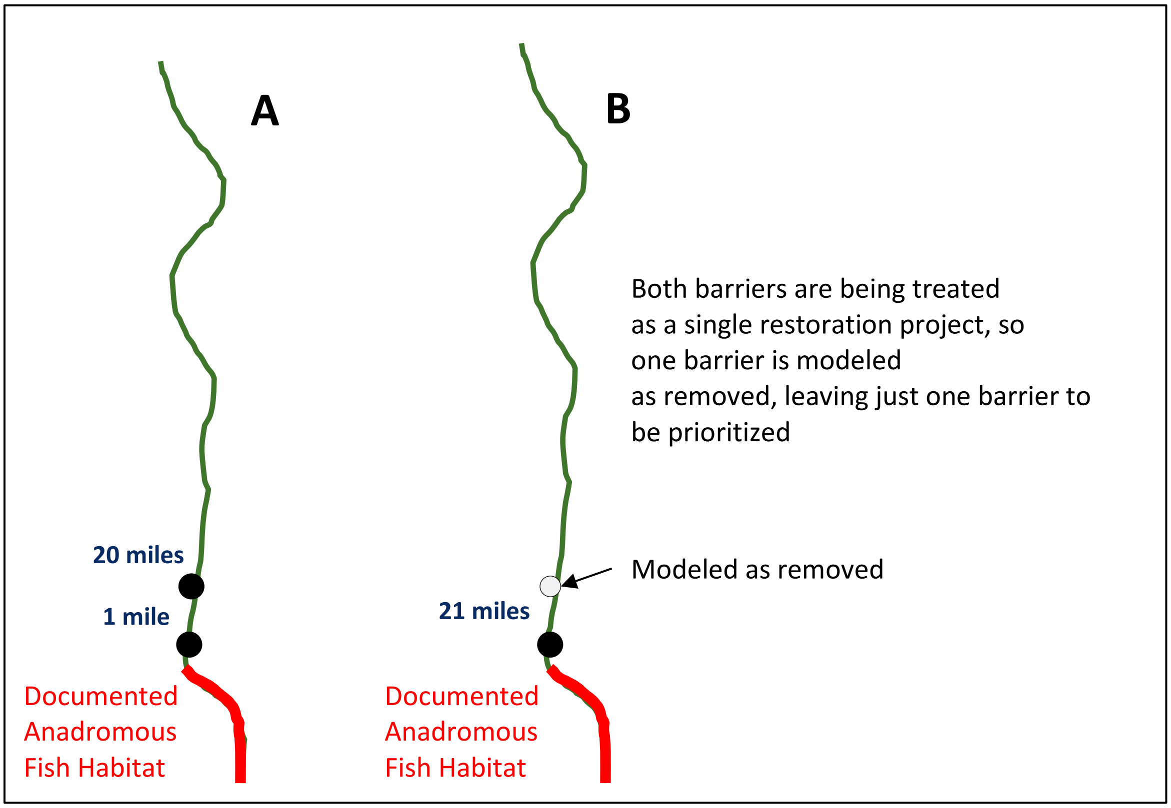


Figure 5-16: Using the "model removal" functionality to assess a series of barriers as a single restoration project

would open many upstream river miles. Treated individually, as in Figure 5-16A, removal of the downstream barrier would only open accesses to relatively few upstream miles of habitat because the next barrier is very close, while removal of the upper barrier may open many miles of upstream habitat, but there are no anadromous fish species reaching the downstream side of the barrier to take advantage of that habitat once opened. Therefore, neither of the two barriers come out as high priorities individually. However, if the two are treated together as a single restoration project by modeling one of the barriers as removed (Figure 5-16B), the barrier which remains in the prioritization will both have anadromous species downstream of it and open many miles of habitat, thereby becoming a higher priority than either of the two barriers on their own.

To run a prioritization scenario that includes modeled removals, first check the “Model Barrier Removal?” check as illustrated in . Checking this box reveals a text input box and loads a layer of barriers, all represented as black points. (Note: the barriers loaded will equate to the severity of barriers selected for the analysis; e.g. Dams Only, Severe, etc). If the UNIQUE_ID for the barriers of interest is known, then can be entered in the text box enclosed in single quotes and separated by commas. The UNIQUE_ID is the NEACAP project-specific identifier for each barrier. In the case of dams, it is based on the ID from the source dam database, but is specific to this project. In the case of crossings, it is the NAACC “xycode”. The UNIQUE_ID can be obtained by clicking on an individual barrier. Entering UNIQUE_IDs directly can be useful when running the same or similar scenarios multiple times (by copying and pasting a list of IDs).

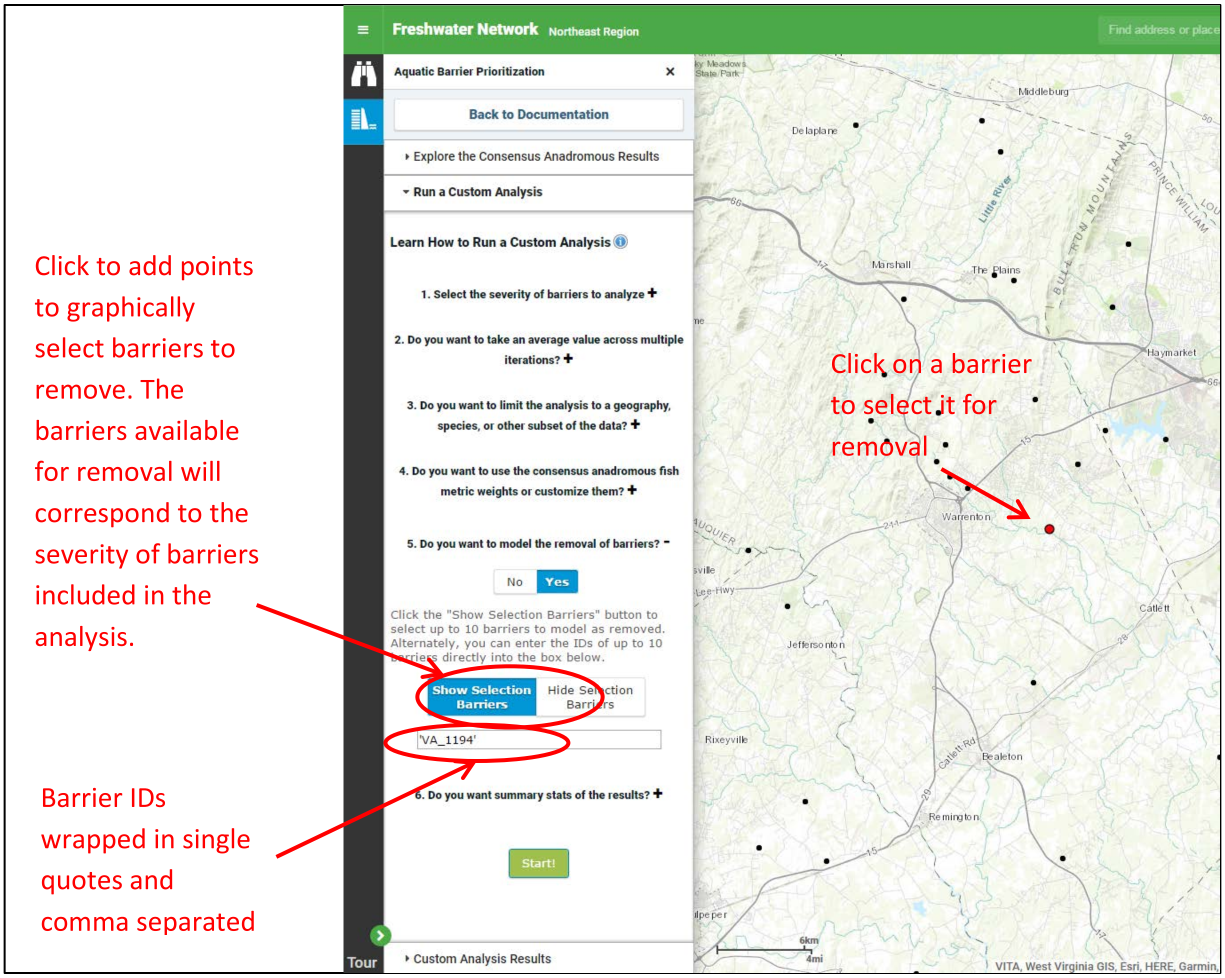


Figure 5-17: Selecting the option to model barriers for removal

It is also possible to select barriers manually on the map. This can be done by clicking on a barrier which will turn it red and it populate its UNIQUE_ID in the text input box with the proper formatting. Currently, users are limited to selecting up to ten barriers for removal to keep processing times reasonable. If a mistake is made, clicking on a red barrier will return it to its original black state and remove its UNIQUE_ID from the text input box.

When the prioritization is complete, the values displayed in the results are calculated as if the chosen barriers had been removed – this is true of the prioritization outputs (Final Rank and Tier) as well as all of the metric values that were included in the analysis (those whose weight >0).

5.5.1.6 Generating Summary Statistics (Optional)

Optionally, summary statistics can be produced for the custom prioritization scenario results. These summary statistics can be used to evaluate and make relative comparisons between watersheds or states. If summary statistics are desired, simply check the “Calculate Summary Statistics” box towards the bottom right corner of the Tool. This will reveal options to generate summary statistics for either the Result Tier or the Final Rank (the un-binned sequential results) by either State, Watershed, or a handful of other attributes. The output table enables users to makes statements such as “Watershed X has a mean Tier value of 8 while Watershed Y has a mean Tier value of 5.” From this statement we can deduce that Watershed Y has more barriers with greater potential to benefit the target of interest, based on the metric weights chosen by the user, than Watershed X.

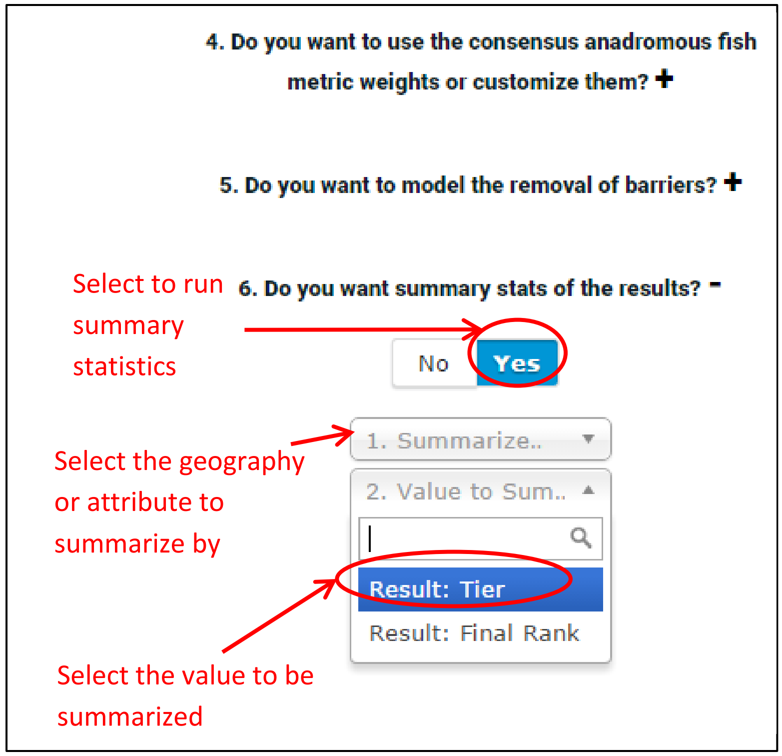
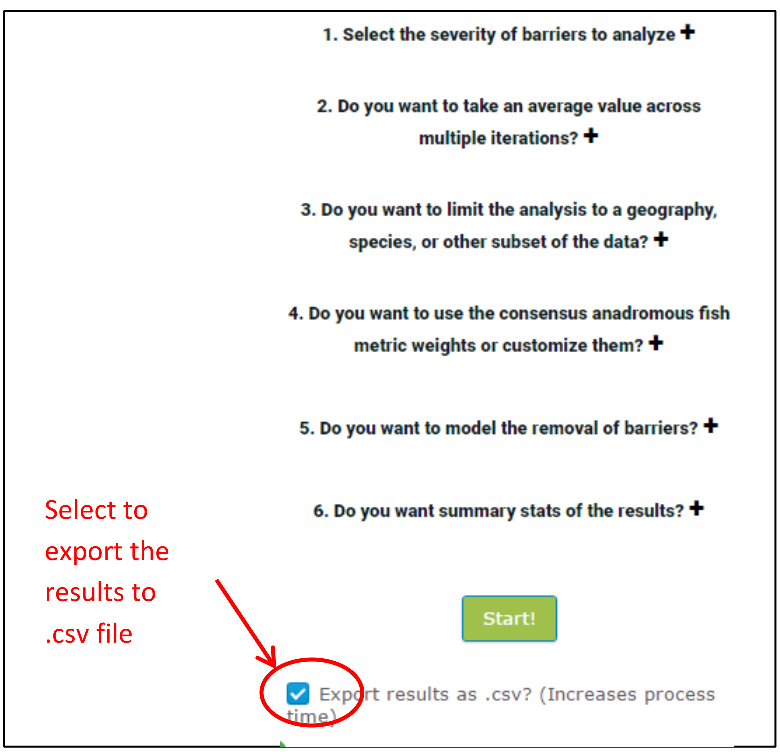


Figure 5-18: Selecting the option to run summary statistics on custom prioritization results

5.5.1.7 Export the results as .csv

Finally, an option is included to export the results as a comma separate values (.csv) file. This text file format can be opened with Microsoft Excel, or many other spreadsheet programs or text editors. If the option is selected a button to access the results as .csv will be included in the “Custom Analysis Results” pane when the analysis is complete. Note that this option can increase processing time, particularly if the analysis includes the insignificant or minor barrier severities which include many more barriers than the other severity classes.



5.5.2 Viewing and Exporting Results

When an analysis is started, the app will display a running dialog to report the status of the analysis, as illustrated in Figure 5-19**Error! Reference source not found.**. The other functionality of the map can be used while an analysis is running. The time required to run a prioritization varies based on the number of barriers included in the analysis, the number of metrics included in the analysis, the number of barriers being modeled for removal, whether summary statistics are being calculated, as well as server load. Generally, a custom analysis can be expected to run between 15 seconds and 2 minutes.

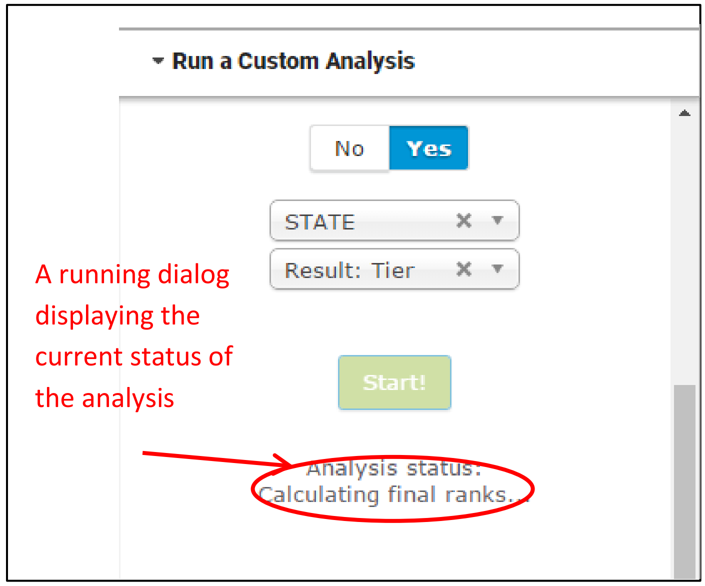
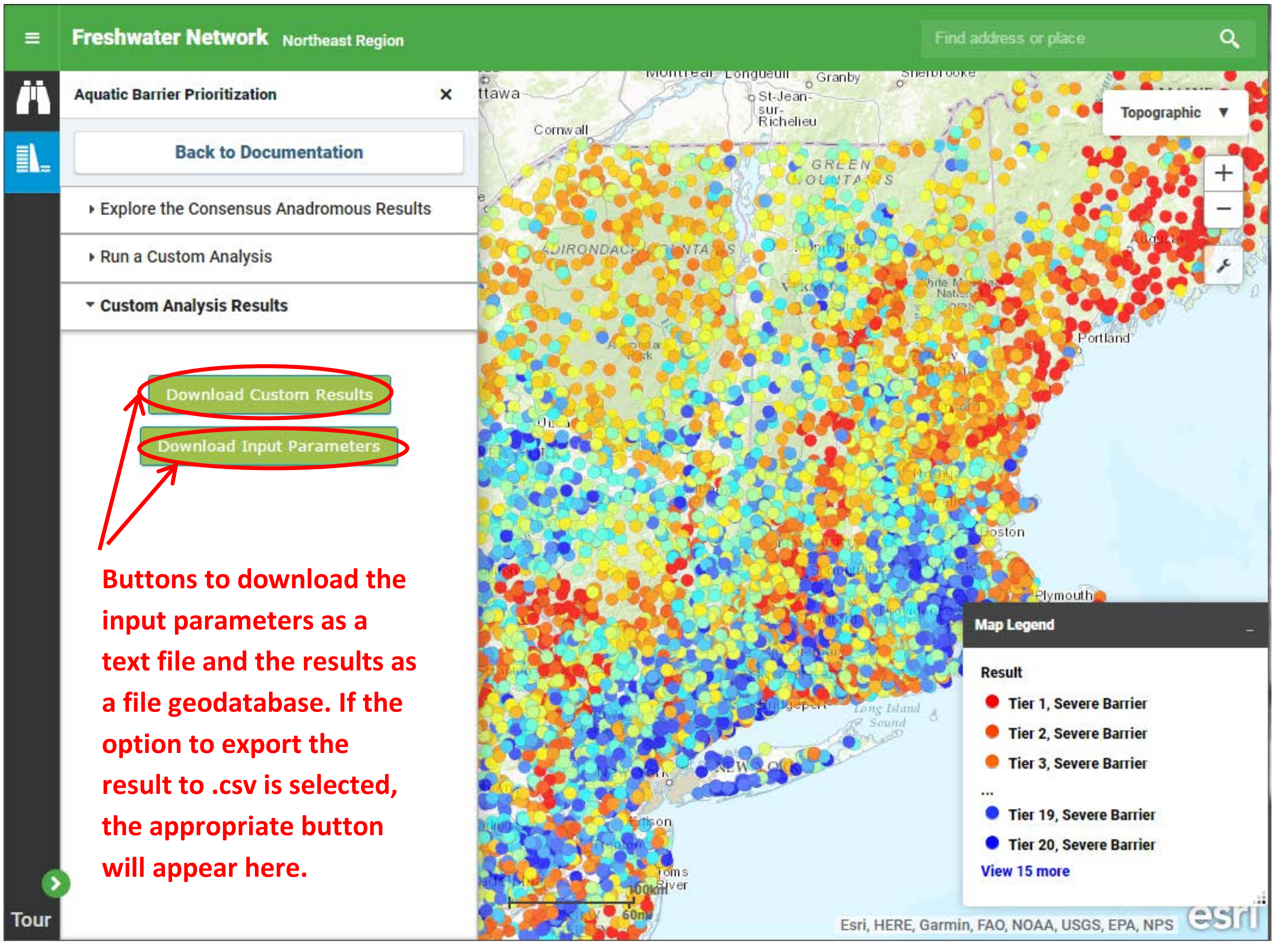


Figure 5-19:The "Status" display of the Tool displaying updates on a current analysis.

5.5.2.1 Results screen

Results are presented in the map and are accessible for download as an ArcGIS File Geodatabase via the “Custom Analysis Results” pane of the app, as show in Figure 5-20. In addition to the results, the input parameters can be saved as a text file. *It is strongly recommended that input parameters always be saved with results, and that the file names be made to correspond to each other*.

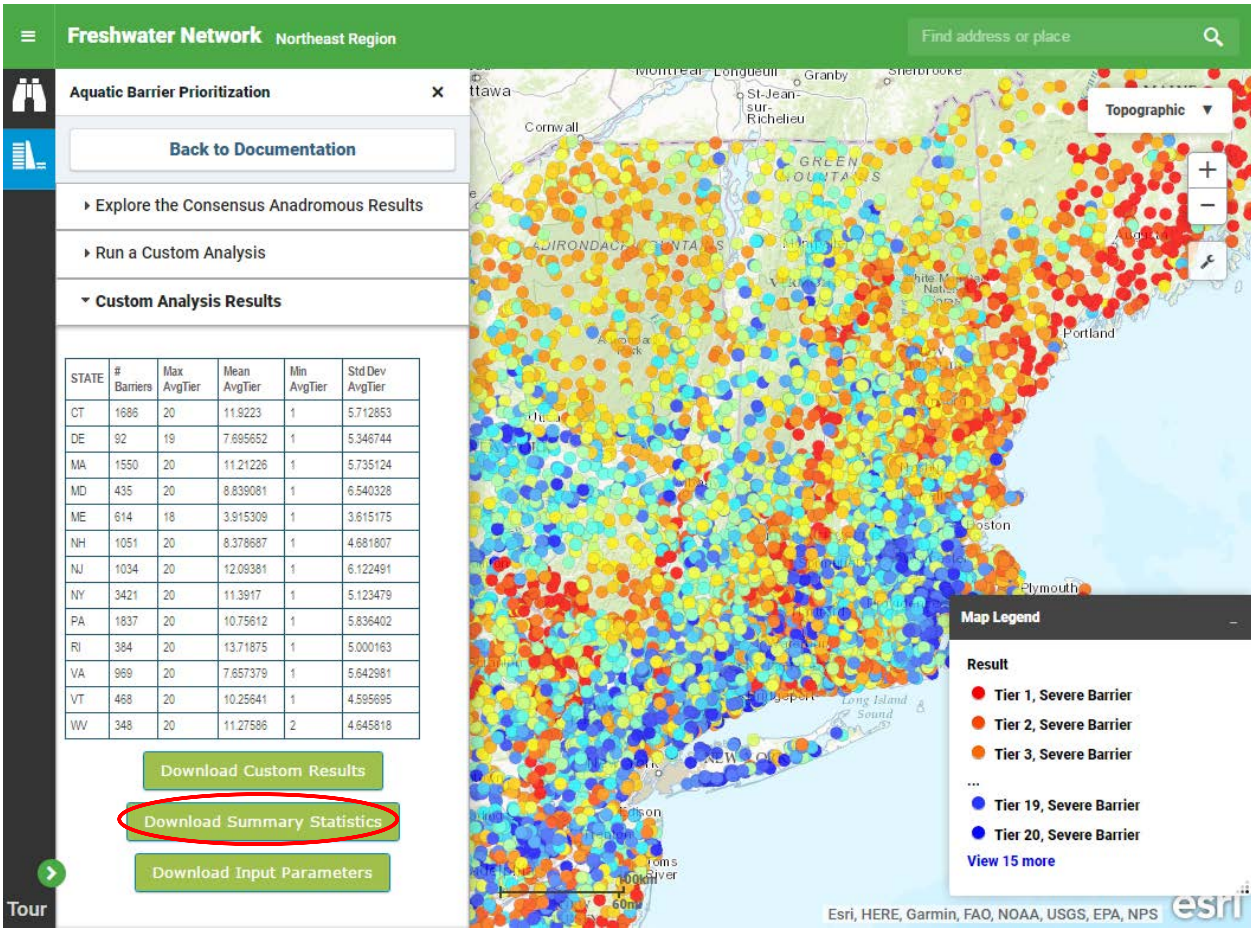
Figure 5-20: The results and input parameters can be downloaded from the results Custom Analysis Results pane.



The symbols of the resulting features in the map use the same color ramp as the pre-loaded consensus results to indicate Tier (Tier 1 = red, Tier 20 = blue). To help avoid confusion the default results are automatically turned off when a custom scenario result is added to the map. The consensus results can be turned back on at any time using via the "Layers" dialog at the bottom of the "Explore the Consensus Anadromous Results" pane.

5.5.2.2 Summary Statistics Screen

Optionally, summary statistics can be performed on either the Result Tier or Final Rank (the un-binned, sequential rank) and by states or watersheds. If this option is selected, the summary statistics will be available to view and download in the results pane (Figure 5-21). In the example below, summary statistics are shown by state for Tier in an example custom analysis. Thus, all of the states in the analysis have at least one Tier 1 barrier, except for West Virginia whose highest priority barrier in this hypothetical example is a Tier 2.



STATE	# Barriers	Max AvgTier	Mean AvgTier	Min AvgTier	Std Dev AvgTier
CT	1686	20	11.9223	1	5.712853
DE	92	19	7.695652	1	5.346744
MA	1550	20	11.21226	1	5.735124
MD	435	20	8.839081	1	6.540328
ME	614	18	3.915309	1	3.615175
NH	1051	20	8.378687	1	4.681807
NJ	1034	20	12.09381	1	6.122491
NY	3421	20	11.3917	1	5.123479
PA	1837	20	10.75612	1	5.836402
RI	384	20	13.71875	1	5.000163
VA	969	20	7.657379	1	5.642981
VT	468	20	10.25641	1	4.595695
WV	348	20	11.27586	2	4.645818

Figure 5-21: Summary statistics in the custom scenario results pane

6 Feedback

Feedback on any aspect of this project is welcome. Comments, including edits to dam data to be included in future runs of the analysis can be made via this form:

https://goo.gl/forms/z6baaub5hmUVitFS2

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8 Appendix I: NEACAP Subcommittee and NAACC Steering and Advisory Committees

NAACC Steering Committee	
Name	**Affiliation**
Scott Jackson	UMass
Erik Martin	TNC
Jessie Levine	TNC
Rich Kirn	VT ANR
Josh Thiel	NY DEC
Mindy Barnett	CT DEEP
Andrew Milliken	NALCC/USFWS
Alex Abbott	USFWS
Seth Coffman	TU
Phil Herzig	USFWS
Shane Csiki	NH DES
Bob Gubernick	USFS
Carrie Banks	MA DFG
John Magee	NH DFG
Tom Hoffman	USFWS
Scott Schwenk	USFWS
Bart Wilson	USFWS

NAACC Advisory Committee	
Name	**Affiliation**
Michael Jastremski	Housatonic Valley Association
Rebecca Kern	USFWS National Wildlife Refuges
Andrew Meyer	NYS DEC
Callie McMunigal	USFWS
Eric Chapman	Western PA Conservancy
Pete Steckler	TNC
Su Fanok	TNC
Tim Chorey	MA DER
Michelle Brown	TNC
Erin Rodgers	TU
Tom Hoffman	USFWS
Carolyn Sedgwick	Piedmont Environmental Council
Jed Wright	USFWS/Gulf of Maine Coastal Program
Megan Tyrrell	USFWS/NALCC
Anne Wakeford	WV DNR
James Vasslides	Barnegat Bay Partnership

Anne Kuhn	EPA
Amy Wolfe	TU
Eric Chase	Penn State

Additional NE Aquatic Connectivity Subcommittee Members	
Name	**Affiliation**
Alan Weaver	VA DGIF
Amy Singler	American Rivers / TNC
Ben Lorson	PA Fish & Boat Commission
Betsy Trometer	USFWS
Cathy Bozek	USFWS
Cheri Patterson	NH DFG
Dan Farrell	TNC
Ellen Creveling	TNC
Josh Royte	TNC
Jim Thompson	MD DNR
Phil Thomas	TU
Su Fanok	TNC
Will Duncan	USFWS
William Thomas	NH DES

9 Appendix II: Input Datasets

Dataset	Source	Description
Dams	Adapted from the original Northeast Aquatic Connectivity project (Martin & Apse 2011). Multiple sources including: state agencies, the National Inventory of Dams, National Anthropogenic Barrier Dataset. Review and edits made by the NAACC NE Aquatic Connectivity subcommittee	This dataset represents dams in the Northeast region that are spatially linked to the stream flowline in the NHDPlus v2 dataset. Dams that do not fall on mapped streams in the NHDPlus v2 are not included in the results. Complete metadata is available via http://maps.freshwaternetwork.org/northeast/plugins/barrier-prioritization/html/helpFiles/NEAquaticConnectivity_Metadata.xml
Road-stream crossings	North Atlantic Aquatic Connectivity Collaborative. Obtained with additional metrics from the University of Massachusetts March 2016	Road-stream crossings originally generated by the University of Massachusetts by intersecting Open Street Map roads and a modified version of the High Resolution (1:24,000) NHD. Additional attributes, including an estimated aquatic passability score where a field-surveyed passability score was not available, were generated by the University of Massachusetts for the Critical Linkages analysis. These crossing were then migrated to the project hydrography as described in Section 2.3.2.1.
Waterfalls	USGS GNIS database, USGS draft data (Daniel Wieferich, personal communication)	Point dataset representing potential natural barriers to fish passage. Waterfalls were used in the development of functional river networks, but are not included in the prioritization results as potential candidates for fish passage projects.
Hydrography	NHDPlus version 2	In order for barriers to be included in the analysis, they had to fall on the mapped river network, or hydrography, that was used in the project: a modified version of the Medium Resolution National Hydrography Dataset Plus, Version 2 (NHDPlus v2) (Horizon Systems 2012). This hydrography was originally digitized by the United States Geological Survey primarily from 1:100,000 scale topographic maps. Substantial additions and improvements were applied to the USGS NHD data by Horizon Systems Corporation to create the NHDPlus v2. In order to be used in this analysis the hydrography had to be processed to create a dendritic network, or dendrite: a single-flowline network with no braids or other downstream bifurcation (Figure 2-3). The medium-resolution NHDPlus used in this project includes attributes which were used to select the mainstem of a river from a braided section using a simple definition query to extract a dendrite.

		(NHDFlowline.FLOWDIR = 'With Digitized' AND NHDPlusFlowlineVAA.Divergence in (0,1) AND NHDPlusFlowlineVAA.StreamCalc <>0). Additional information on the NHDPlus v2 and these attributes can be found in the NHDPlus v2 User Guide (Horizon Systems 2012).
Anadromous fish habitat	ASMFC 2004 Houston et al 2007 Odell et al 2006 and personal communication with state biologist participating in the original NE Aquatic Connectivity Project Workgroup and subsequent NE Aquatic Connectivity subcommittee of the NAACC.	Critical habitats (spawning, nursery or other critical habitats) assigned to segments of the project hydrography. Segments needed to reach the uppermost documented location for alewife, blueback herring, American shad, hickory shad, Atlantic sturgeon, Gulf sturgeon, Atlantic salmon, and striped bass
Active River Area	Smith et al. 2008, https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/freshwater/floodplains/Pages/default.aspx	The Active River Area (ARA) is a spatially explicit framework for modeling rivers and their dynamic interaction with the land through which they flow (Smith et al. 2008). Key features of the ARA include the meander belt, riparian wetlands, floodplains, terraces, material contribution areas. The ARA is different from, but was calibrated to and compared against the FEMA 100-year floodplain. NEACAP used the ARA as a unit within which various landcover metrics, such as forest cover and impervious surface, were summarized.
Cold & cool water habitat	Olivero and Anderson 2008.	Modeled cold and cool water habitats developed by relating differences in water temperatures to differences in stream sizes, air temperatures, gradient, and groundwater inputs.
Land Cover	2011 National land Cover Database (NLCD2011)	Land use / land cover data from the NLCD2011. This 30m gridded data was grouped into forested, natural and agricultural classes. (Developed was addressed via the impervious surface data). Forested landcover includes: , deciduous forest, evergreen forest, and mixed forest. Natural landcover includes the following classes: open water, barren land, deciduous forest, evergreen forest, mixed forest, scrub/shrub, grassland/herbaceous, woody wetlands, emergent wetlands. Agricultural includes the following classes: pasture/hay, cultivated crops. The percentages of both agricultural and natural land cover are assessed for the contributing watershed of each dam, as well as within the active

		river area of the dam's upstream and downstream networks.
Impervious Surface	2011 National land Cover Database (NLCD2011)	% Impervious surface data from the NLCD2011. This 30m gridded data describes the % of impervious surface within each 30m cell. The percentages of impervious surface is assessed for the contributing watershed of each dam, as well as within the active river area of the dam's upstream and downstream networks.
Resident fish, rare fish, mussels & rare crayfish	NatureServe 2008a NatureServe 2008b NatureServe 2008c	Fish, mussel and crayfish data was assigned to HUC8s on a presence/absence basis. See Section 2.5 for more details.
Brook trout catchments	Eastern Brook Trout Joint Venture ;	NHDPlus v2 catchments coded for presence of brook trout. Any catchment with observed or predicted brook trout was used for the development of the metrics (Catchment classification codes 1.1, 1.2, 1.3, 1.4, 1.5). For more information see http://easternbrooktrout.org/reports/ebtjv-salmonid-catchment-assessment-and-habitat-patch-layers
Predicted brook trout occurrence	DeWeber, J.T. and T. Wagner, 2015	Predicted brook trout occurrence by NHDPlus v1 catchment. Brook trout presence/absence was determined using the 'occur46' classification which is based on a threshold that was equal to prevalence in the training data set, which produces near-optimal classification accuracy (DeWeber and Wagner 2015).
Cumulative Disturbance Index	National Fish Habitat Action Plan (NFHAP) 2010 HCI Scores and Human Disturbance Data for Conterminous United States linked to NHDPLUSV1	Description from source metadata: Various measures of human land use, infrastructure, and other anthropogenic landscape-scale characteristics were summarized in both local and network catchments of stream arcs of the NHDPlusV1 and assumed to represent anthropogenic disturbances to landscapes that would likely impact stream habitats. Within each of 9 aggregated Omernik (1987) ecoregions as defined by the EPA's Wadeable Streams Assessment (Paulsen et al., 2008), key biological metrics were selected following an approach to identify those metrics that were most sensitive to anthropogenic disturbance and that were widely distributed throughout ecoregions (Stoddard et al. 2008). Habitat condition scores were created based on responsiveness of biological metrics to anthropogenic landscape disturbances throughout ecoregions, and separate scores were created by considering disturbances within local catchments (LDistIndex), network catchments

		(NDistIndex), and a cumulative score that accounted for the most limiting disturbance operating on a given biological metric in either local or network catchments (CumDistIndex) (Esselman et al. 2011)
Conservation Land	The Nature Conservancy Eastern Division Secured Areas dataset (2014)	Dams that lie on conservation lands are identified.

10 Appendix III: Attributes Available for Use in Custom Filters

The following table lists the metric values that are available to be used in custom filters as described in Section 5.4.4. Of note, the attribute data type will determine the syntax for the filter expression. The values of text attributes must be wrapped in single quotes (State = **'**ME**'**) while numeric values are not (batFuncUS > 5000). Numeric values include the following data types: SHORT, LONG, FLOAT, DOUBLE. For more information on the syntax used to build custom filters (ArcGIS SQL expressions) see https://pro.arcgis.com/en/pro-app/help/mapping/navigation/sql-reference-for-elements-used-in-query-expressions.htm. **Error! Reference source not found.** includes additional information which may be helpful for building a filter expression (e.g. categorical field values).

Table 10-1: Attributes available for custom filters on the consensus results

GIS Attribute Name	Description	Unit (if applicable)	Attribute Data Type
batFuncUS	Upstream Functional Network Length	m	DOUBLE
batLenUS	Total Upstream River Length	m	DOUBLE
batTotUSDS	The total length of upstream and downstream functional network	m	DOUBLE
batAbs	Absolute Gain	m	DOUBLE
batCountDS	# Barriers Downstream	#	SHORT
DSHydro	Downstream Hydropower Dam Count on Flowpath	#	SHORT
DSFalls	Downstream Natural Barrier Count on Flowpath	#	SHORT
dsPassabilityProduct	Product of all downstream passability scores	unitless score	DOUBLE
DA_PercImp	% Impervious surface in Upstream Drainage Area	%	DOUBLE
DA_PercNat	% Natural landcover in Upstream Drainage Area	%	DOUBLE
DA_PercFor	% Forest cover in Upstream Drainage Area	%	DOUBLE
DA_PercAg	% Agriculture in Upstream Drainage Area	%	DOUBLE
usImpARA	% Impervious Surface in ARA of Upstream Functional Network	%	DOUBLE
dsImpARA	% Impervious Surface in ARA of Downstream Functional Network	%	DOUBLE
usAgARA	% Agriculture in ARA of Upstream Functional Network	%	DOUBLE
dsAgARA	% Agriculture in ARA of Downstream Functional Network	%	DOUBLE
usNatARA	% Natural LC in ARA of Upstream Functional Network	%	DOUBLE
dsNatARA	% Natural LC in ARA of Downstream Functional Network	%	DOUBLE
usForARA	% Forested LC in ARA of Upstream Functional Network	%	DOUBLE
dsForARA	% Forested LC in ARA of Downstream Functional Network	%	DOUBLE

GIS Attribute Name	Description	Unit (if applicable)	Attribute Data Type
onConsLand	Barrier is Located on Conservation Land	Boolean	SHORT
CumDistInd	NFHAP Cumulative Disturbance Index	unitless score	DOUBLE
QDSANAD	Presence of Anadromous Species in DS Network	Boolean	SHORT
QDSNUMANAD	# Anadromous Species in DS Network	#	SHORT
DSALEWIFE	Presence of alewife in downstream functional network of barrier	Categorical	SHORT
DSBLUEBACK	Presence of blueback herring in downstream functional network of barrier	Categorical	SHORT
DSAMSHAD	Presence of American shad in downstream functional network of barrier	Categorical	SHORT
DSHICKSHAD	Presence of hickory shad in downstream functional network of barrier	Categorical	SHORT
DSSTRBASS	Presence of striped bass in downstream functional network of barrier	Categorical	SHORT
DSATLSTUR	Presence of Atlantic sturgeon in downstream functional network of barrier	Categorical	SHORT
DSATLSALM	Presence of Atlantic Salmon in downstream functional network of barrier	Categorical	SHORT
fishRich	Resident fish species richness (NatureServe - all resident fish)	#	SHORT
g123Fish	# of rare (G1-G3) fish HUC8	#	SHORT
g123Mussel	# of rare (G1-G3) mussel HUC8	#	SHORT
g123Cray	# of rare (G1-G3) crayfish HUC8	#	SHORT
in_EBTJV_2012	Barrier is within EBTJV Catchment with Trout	Boolean	SHORT
in_deWeberTrout	Barrier w/ in a catchment with Modeled Trout Presence (DeWeber & Wagner)	Boolean	SHORT
block_EBTJV_2012	Barrier blocks EBTJV 2012 Trout Catchments	Boolean	SHORT
block_deWeberTrout	Barrier blocks with Modeled Trout Catchments (DeWeber & Wagner)	Boolean	SHORT
NSEZCL_Int	River Size Class	#	SHORT
TotNumSzCl	Total Reconnected # stream sizes (upstream + downstream) >0.5 Mile	#	SHORT
usNumSzCl	Number of upstream size classes >0.5 miles	#	SHORT
usSzClGn	Number of new upstream size classes >0.5 miles gained by removal / bypass	#	SHORT
totMiCold	Miles of cold water habitat in total functional network	Miles	DOUBLE
totMiCC	Miles of cold or cool water habitat in total functional network	Miles	DOUBLE
UNIQUE_ID	A unique identifier for each barrier in the analysis		TEXT
STATE	Two letter state abbreviation		TEXT
Barrier_Name	Name of the barrier. In the case of road-stream crossings this is the same as the NAACC xycode, which is also the UNIQUE_ID		TEXT
Type	Barrier type: 'Dam', 'Crossing'		TEXT
ROADCLASS	Open Street Map road class. From 1= interstate to 6=unpaved. 0= no data		SHORT
Passability	Numerical score ranging from 0-1 where 0=complete barrier and 1=no barrier. Field surveyed crossings scored based on NAACC numerical scoring algorithm. Unsurveyed crossings scroed based on UMass Critical Linkages estimate from landscape factors		DOUBLE
Passability_Desc	A descriptive passability category. See Section 2.3.2.2. All dams are in the "Severe Barrier" category		TEXT
HUC4	4-digit Hydrologic Unit Code ID		TEXT

GIS Attribute Name	Description	Unit (if applicable)	Attribute Data Type
HUC4_Name	4-digit Hydrologic Unit Code Name		TEXT
HUC6	6-digit Hydrologic Unit Code ID		TEXT
HUC6_Name	6-digit Hydrologic Unit Code Name		TEXT
HUC8	8-digit Hydrologic Unit Code ID		TEXT
HUC8_Name	8-digit Hydrologic Unit Code Name		TEXT
HUC10	10-digit Hydrologic Unit Code ID		TEXT
HUC10_Name	10-digit Hydrologic Unit Code Name		TEXT
HUC12	12-digit Hydrologic Unit Code ID		TEXT
HUC12_Name	12-digit Hydrologic Unit Code Name		TEXT
GNIS_Name	Two stream name that the barrier is located on, obtained from the NHDPlus v2 reach that the barrier falls on		TEXT
FinalRank	The raw, sequential rank that results from the prioritization		LONG
AvgTier	The average of the tiered values (5% bins) of the FinalRank attribute across the 5 iterations of the analysis. See Section 3.3.2.2 for more information on how the AvgTier is calculated		SHORT

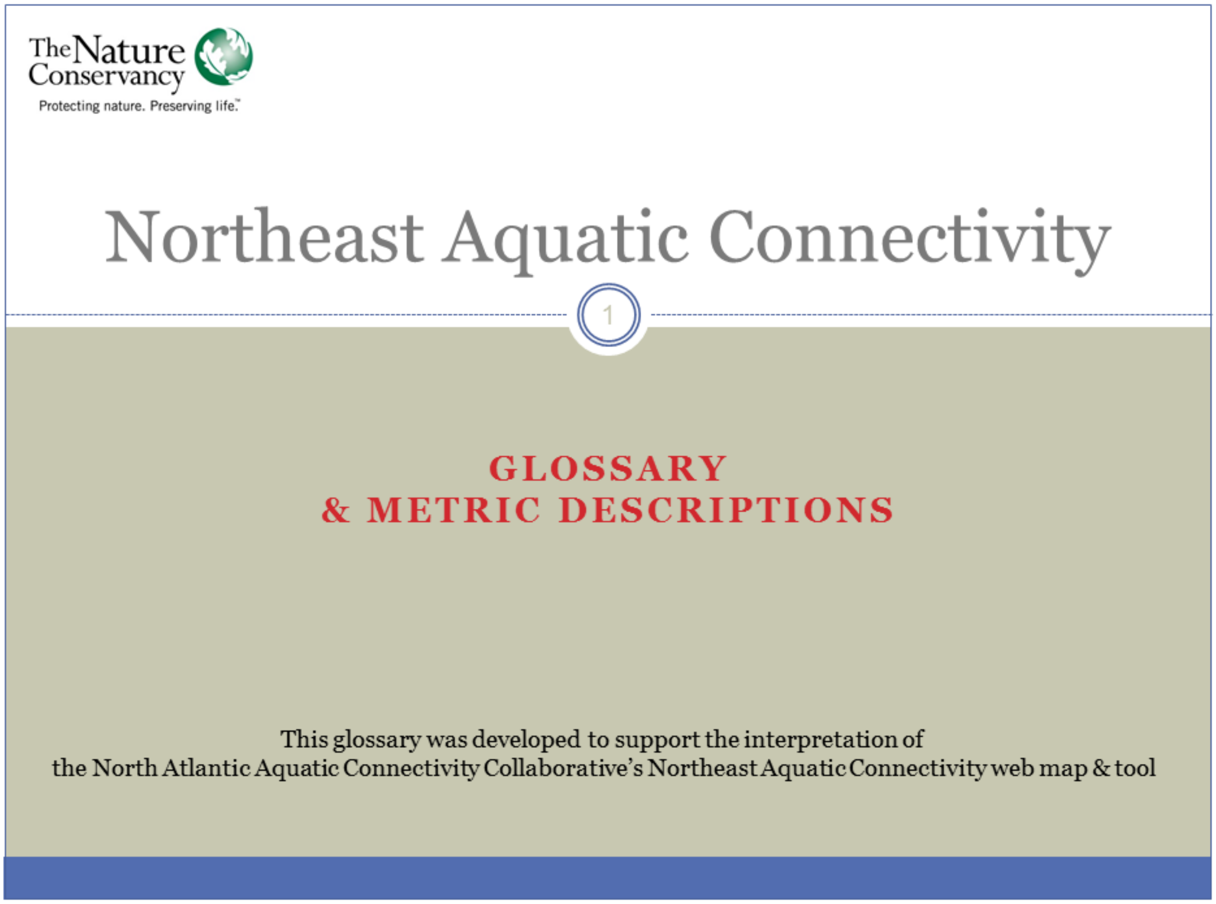
Table 10-2: Additional attributes available for custom analysis filters. (See Section 5.5.1.3)

GIS Attribute Name	Description	Unit (if applicable)	Attribute Data Type
TYPE_ID	Construction type of the dam. Does not apply to crossings. See **Error! Reference source not found.** for more information about possible attribute values. Multiple values are concatenated so wildcards (%) will be needed to identify all dams of a given type.		TEXT
P_CODE	The dam purpose (e.g. Hydropower, flood control). Does not apply to crossings. See **Error! Reference source not found.** for more information about possible attribute values. Multiple values are concatenated so wildcards (%) will be needed to identify all dams of a given type.		TEXT
HEIGHT	Dam height in feet. No data values are given as 0. Does not apply to crossings. See **Error! Reference source not found.** for more information about possible attribute values.		DOUBLE
SURFAREA	Dam reservoir surface area in acres. No data values are given as 0. Does not apply to crossings. See **Error! Reference source not found.** for more information about possible attribute values.		DOUBLE
NORMSTOR	Dam reservoir normal storage capacity in acre feet. No data values are given as 0. Does not apply to crossings. See **Error! Reference source not found.** for more information about possible attribute values.		DOUBLE
slope	The slope of the NHDPlus v2 reach that the barrier is on. Calculated as part of the NHDPlus attributes based on a smoothed rise/run in meters for the end points of the line segment. See ftp://ftp.horizon-systems.com/NHDplus/NHDPlusV21/Documentation/NHDPlusV2_User_Guide.pdf		DOUBLE

11 Appendix IV: Glossary and Metric Definitions

The following is a glossary of metrics that were calculated for each barrier in the NEACAP study area. It is available as a PDF file with working hyperlinks at http://maps.freshwaternetwork.org/northeast/plugins/barrier-prioritization/images/Metric_Glossary.pdf

Each metric within the Aquatic Barrier Prioritization tool is also linked to it associated glossary slide.



Tiered Results (5% bins)

2

- Analysis results grouped into 20 bins where each bin has 5% of the barriers in the analysis area.
- The “Consensus” results are the average of five analysis runs, or iterations. Each analysis run includes barriers of different severities. The runs are named based on the least severe class of barriers. Thus, the “Moderate” run includes barriers that are “Moderate”, “Significant”, and “Severe”. See Section 3.3.2 of the NE Aquatic Connectivity report for more detail.
- Tiers for individual iterations are available within the web map and downloadable data. These are based on the metrics calculated for the given set of barriers included in the analysis.
- These are the results that should be used for barrier assessments

Sequential Rank

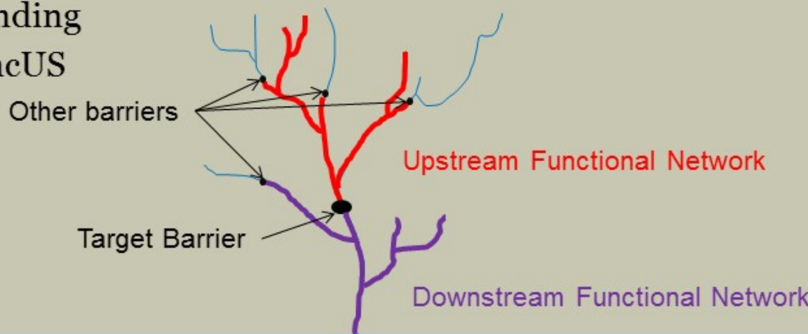
3

- The sequential list of barriers produced by the analysis.
- This list should be used with extreme caution: the precision with which GIS can calculate metrics and rank barriers is not necessarily indicative of ecological differences
- The Tiered Results (5% bins) should be used to assess barriers for their potential ecological benefit

Upstream Functional Network Length

4

- Category: Network
- Length of the functional network upstream of a barrier. The functional network is defined by those sections of river that a fish could theoretically access from any other point within that functional network. Its terminal ends are barriers, headwaters, and/or the river mouth.
- Unit: meters
- Sort Order: Descending
- GIS Name: batFuncUS

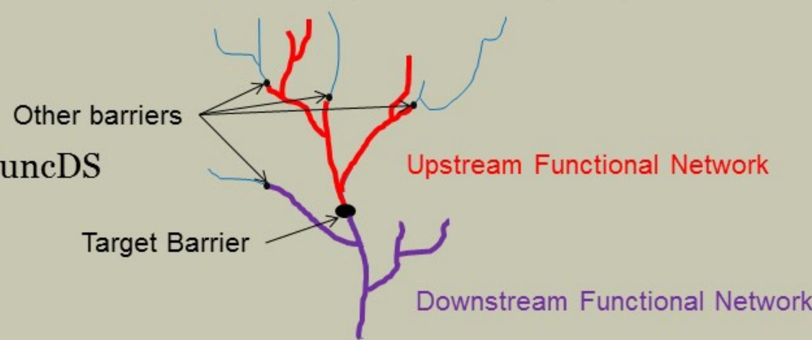


Downstream Functional Network Length

- Category: Connectivity Improvement

- Length of the functional network downstream of a barrier. The functional network is defined by those sections of river that a fish could theoretically access from any other point within that functional network. Its terminal ends are barriers, headwaters, and/or the river mouth.

- Unit: meters
- GIS Name: batFuncDS



Downstream Barrier Count

6

- Category: Network
- The number of barriers downstream of a given barrier
- Includes natural waterfalls, which are included in network generation
- Does not include barriers excluded from network generation
- Unit: #
- Sort Order: Ascending
- GIS Name: batCountDS

Downstream Natural Barrier Count

7

- Category: Network
- The number of natural barriers (e.g. waterfalls) downstream of a given barrier
- Unit: #
- Sort Order: Ascending
- GIS Name: DSFalls

Downstream Hydropower Facility Count

- Category: Network
- The number of hydropower facilities downstream of a given barrier.
- Includes all dams which include hydropower as one of the listed dam purpose in the source dam data
- Unit: #
- Sort Order: Ascending
- GIS Name: DSHydro

Product of all downstream barrier passability scores

9

- Category: Network
- Each barrier is assigned a passability score from 0 (no passage) to 1 (full passage). Dams are assigned a score of 0. Crossings which have been surveyed are assigned a score based on the NAACC's numeric scoring system. Crossings which have not been surveyed are assigned an estimated score as part of the UMass Critical Linkages project.
- This metric is the product of the passability scores of all downstream barriers. It is a measure of the difficulty an aquatic species would have to reach the base of the barrier in question.
- Unit: unitless score
- Sort Order: Descending
- GIS Name: dsPassabilityProduct

Absolute Gain

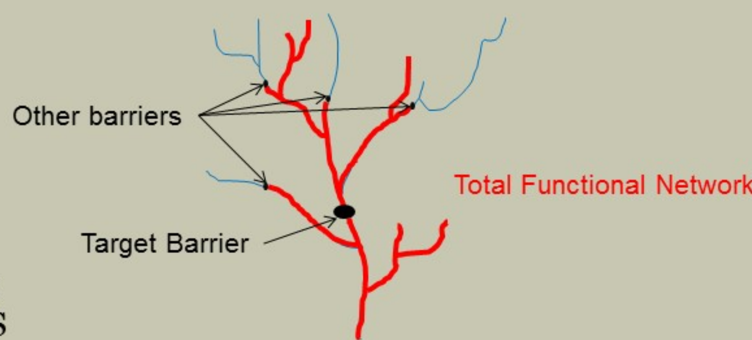
10

- Category: Network
- This metric is the minimum of the two functional networks of a barrier. For example if the upstream functional network was 10 kilometers and downstream functional network was 5 kilometers, then the Absolute Gain will be 5 kilometers.
- Unit: meters
- Sort Order: Descending
- GIS Name: batAbs

Total Functional Network Length

11

- Category: Connectivity Improvement
- Summed length of the upstream and downstream functional networks of a barrier. The functional network is defined by those sections of river that a fish could theoretically access from any other point within that functional network. Its terminal ends are barriers, headwaters, and/or the river mouth.

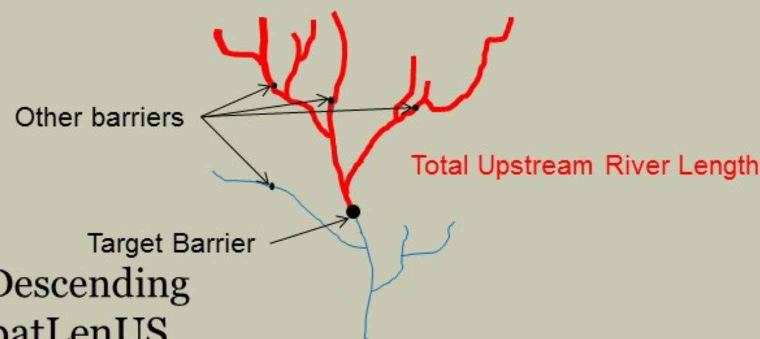


- Unit: meters
- Sort Order: Descending
- GIS Name: batTotUSDS

Total Upstream River Length

12

- Category: Network
- Total length of river network upstream of a given barrier, regardless of any upstream barriers.
- Unit: meters



- Sort Order: Descending
- GIS Name: batLenUS

% Forested LC in Contributing Watershed

13

- Category: Watershed & Local Condition
- % forested landcover in entire upstream watershed. Calculated from the 2011 National Land Cover Database.
- Forested landcover aggregated from the following classes: deciduous forest, evergreen forest, mixed forest
- Unit: %
- Sort Order: Descending
- GIS Name: DA_PercFor

% Natural LC in Contributing Watershed

14

- Category: Watershed & Local Condition
- % natural landcover in entire upstream watershed. Calculated from the 2011 National Land Cover Database.
- Natural landcover aggregated from the following classes: open water, barren land, deciduous forest, evergreen forest, mixed forest, scrub/shrub, grassland/herbaceous, woody wetlands, emergent wetlands
- Unit: %
- Sort Order: Descending
- GIS Name: DA_PercNat

% Agricultural LC in Contributing Watershed

15

- Category: Watershed & Local Condition
- % agricultural landcover in entire upstream watershed. Calculated from the 2011 National Land Cover Database.
- Agricultural landcover aggregated from the following classes: cultivate crops, pasture/hay
- Unit: %
- Sort Order: Ascending
- GIS Name:DA_PercAg

% Impervious Surface in Contributing Watershed

16

- Category: Watershed & Local Condition

- % Impervious surface in entire upstream (contributing) watershed. Calculated from the 2011 National Landcover Database percent developed imperviousness.

- Unit: %
- Sort Order: Ascending
- GIS Name: DA_PercImp

% Forested in ARA of Upstream Functional Network

17

- Category: Watershed & Local Condition
- % forested landcover within Active River Area of the upstream functional river network.
- National Landcover Database 2011 data. Includes the following classes: deciduous, evergreen & mixed forest
- Unit: %
- Sort Order: Descending
- GIS Name: usForARA

% Forested in ARA of Downstream Functional Network

18

- Category: Watershed & Local Condition

- % forested landcover within Active River Area of the downstream functional river network.

- National Landcover Database 2011 data. Includes the following classes: deciduous, evergreen & mixed forest

- Unit: %
- Sort Order: Descending
- GIS Name: dsForARA

% Natural LC in ARA of Upstream Functional Network

19

- Category: Watershed & Local Condition
- % natural landcover within Active River Area of the upstream functional river network.
- National Landcover Database 2011 data. Includes the following classes: open water, barren land, deciduous forest, evergreen forest, mixed forest, scrub/shrub, grassland/herbaceous, woody wetlands, emergent wetlands
- Unit: %
- Sort Order: Descending
- GIS Name: usNatARA

% Natural LC in ARA of Downstream Functional Network

20

- Category: Watershed & Local Condition
- % natural landcover within Active River Area of the downstream functional river network.
- National Landcover Database 2011 data. Includes the following classes: open water, barren land, deciduous forest, evergreen forest, mixed forest, scrub/shrub, grassland/herbaceous, woody wetlands, emergent wetlands
- Unit: %
- Sort Order: Descending
- GIS Name: dsNatARA

% Agricultural LC in ARA of Upstream Functional Network

21

- Category: Watershed & Local Condition
- % agricultural landcover within Active River Area of the upstream functional river network.
- National Landcover Database 2011 data. Includes the following classes: cultivated crops, pasture/hay
- Unit: %
- Sort Order: Ascending
- GIS Name: usAgARA

% Agricultural LC in ARA of Downstream Functional Network

22

- Category: Watershed & Local Condition
- % agricultural landcover within Active River Area of the downstream functional river network.
- National Landcover Database 2011 data. Includes the following classes: cultivated crops, pasture/hay
- Unit: %
- Sort Order: Ascending
- GIS Name: dsAgARA

% Impervious Surface in ARA of Upstream Functional Network

- Category: Watershed & Local Condition
- % impervious landcover within Active River Area of the upstream functional river network.
- National Landcover Database 2011 data
- Unit: %
- Sort Order: Ascending
- GIS Name: usImpARA

% Impervious Surface in ARA of Downstream Functional Network

24

- Category: Watershed & Local Condition
- % impervious landcover within Active River Area of the downstream functional river network.
- National Landcover Database 2011 data
- Unit: %
- Sort Order: Ascending
- GIS Name: dsImpARA

Barrier is located on Conservation Land

25

- Category: Watershed & Local Condition
- Barrier is located on conservation land
- Based on TNC's 2014 Eastern Division secured areas database
- Includes conserved lands in GAP Status 1, 2, & 3 that do not have parcel-level restrictions on data distribution
- Unit: Boolean
- GIS Name: onConsLand

NFHP Risk of Degradation Score

26

- Category - Watershed & Local Condition

- Relative risk of habitat degradation based on the mapped level of disturbance to fish habitats
- Based on National Fish Habitat Partnership data
- Scores are passed to each barrier from the NHD Plus catchment it is located within, where:
  - 1.0 – 1.5 = Very High Relative Risk of Habitat Degradation
  - 1.6 – 2.5 = High Relative Risk of Habitat Degradation
  - 2.6 – 3.4 =Moderate Relative Risk of Habitat Degradation
  - 3.5 – 4.2 = Low Relative Risk of Habitat Degradation
  - 4.3 – 5.0 = Very Low Relative Risk of Habitat Degradation

- GIS Name: CumDisInd (numerical score)
- GIS Name: CumDistTXT (text description)

Presence of 1 or more Anadromous Species in Downstream Network

27

- Category: Ecological - Anadromous
- Presence of habitat for 1 or more of the 7 anadromous species included in this analysis based on the data and methods described for each species:
  - alewife, blueback herring, American shad, hickory shad, striped bass, Atlantic sturgeon, Atlantic salmon
- Habitat for each species is coded as "Current", "Historical", or "None Documented"
- If current and historical habitat are documented in the downstream functional network for different species, the current habitat trumps the historical habitat. So if alewife habitat is "Current", American shad habitat is "Historical" this metric will be "Current", indicating that habitat for 1 or more anadromous species is currently documented in the Barriers downstream network (based on the methods described for each species).
- Unit: presence / absence
- Sort Order: Asending
- GIS Name: QDSANAD

Number of Anadromous Species

28

- Category: Ecological - Anadromous

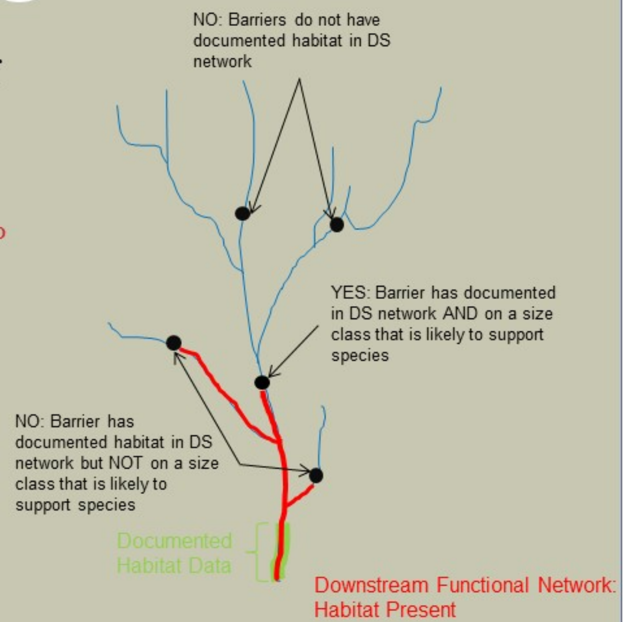
- The number of anadromous species with documented *current* habitat in the downstream functional network of each barrier based on the data and methods described for each species:
  - alewife, blueback herring, American shad, hickory shad, striped bass, shortnose sturgeon, Atlantic sturgeon, Atlantic salmon

- Unit: #
- Sort Order: Descending
- GIS Name: QDSNUMANAD

Alewife habitat in Downstream Functional Network

29

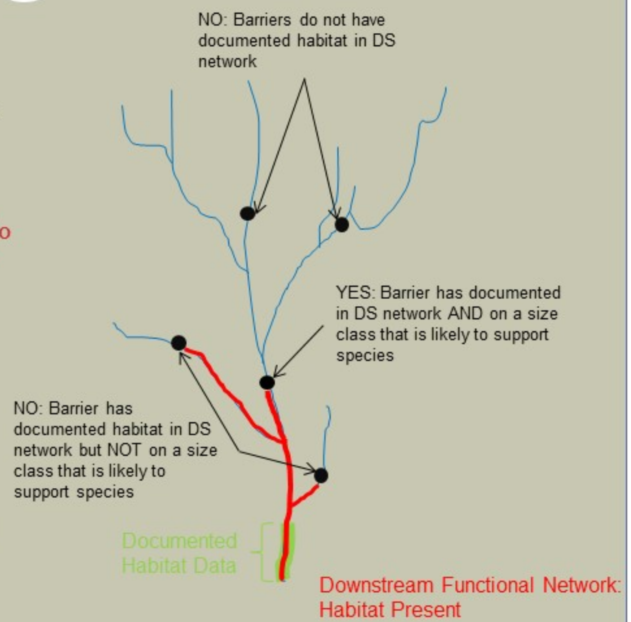
- Category: Ecological
- Presence of alewife downstream of Barrier. Based on:
  1. Documented habitat in some portion of the Barrier's downstream functional network
  2. **AND** Barrier is on a stream that is likely to support that species based on stream size
     1. Size 1a+
- Fish habitat data from multiple sources. See the Map Layer descriptions for more details.
- Unit: Unitless Classes: "Current", "Historical", "None Documented"
- GIS Name: DSALWWIFE



Blueback Herring habitat in Downstream Functional Network

30

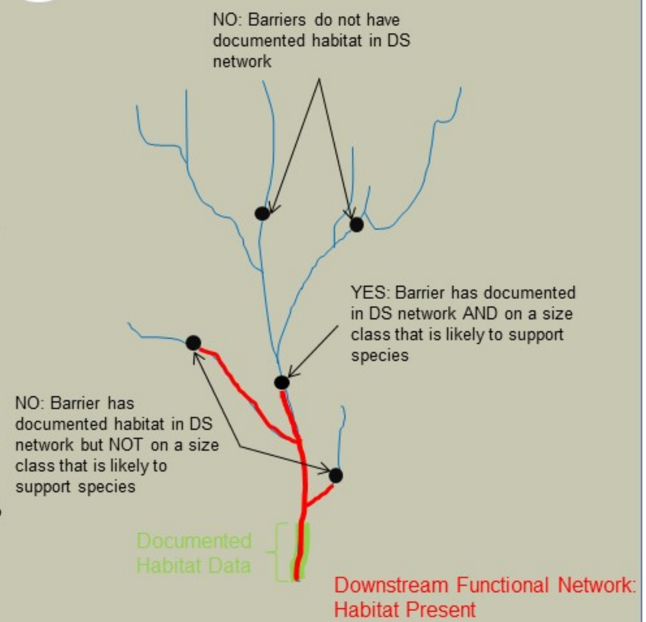
- Category: Ecological
- Presence of blueback herring downstream of Barrier. Based on:
  1. Documented habitat in some portion of the Barrier's downstream functional network
  2. **AND** Barrier is on a stream that is likely to support that species based on stream size
     1. Size 1a +
- Fish habitat data from multiple sources. See the Map Layer descriptions for more details.
- Unit: Unitless Classes: "Current", "Historical", "None Documented"
- GIS Name: DSBLUEBACK



American Shad habitat in Downstream Functional Network

31

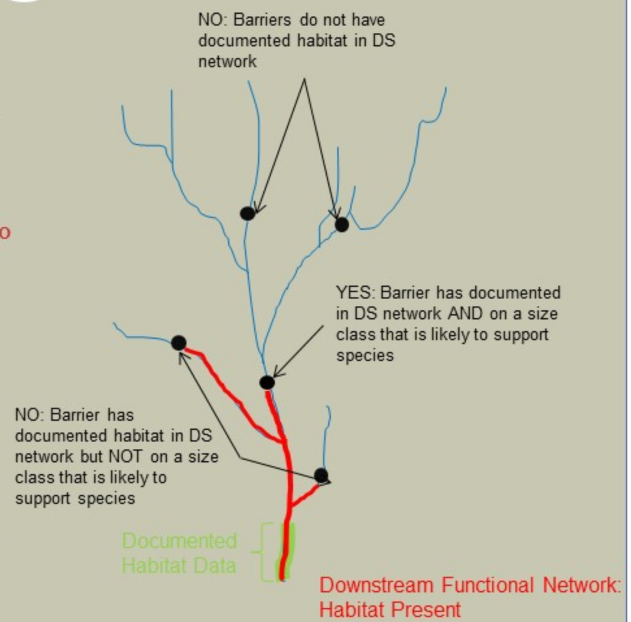
- Category: Ecological
- Presence of American shad downstream of Barrier. Based on:
  1. Documented habitat in some portion of the Barrier's downstream functional network
  2. **AND** Barrier is on a stream that is likely to support that species based on stream size
     1. Size 2+ Rivers
- Fish habitat data from multiple sources. See the Map Layer descriptions for more details.
- Unit: Unitless Classes: "Current", "Historical", "None Documented"
- GIS Name: DSAMSHAD



Hickory Shad habitat in Downstream Functional Network

32

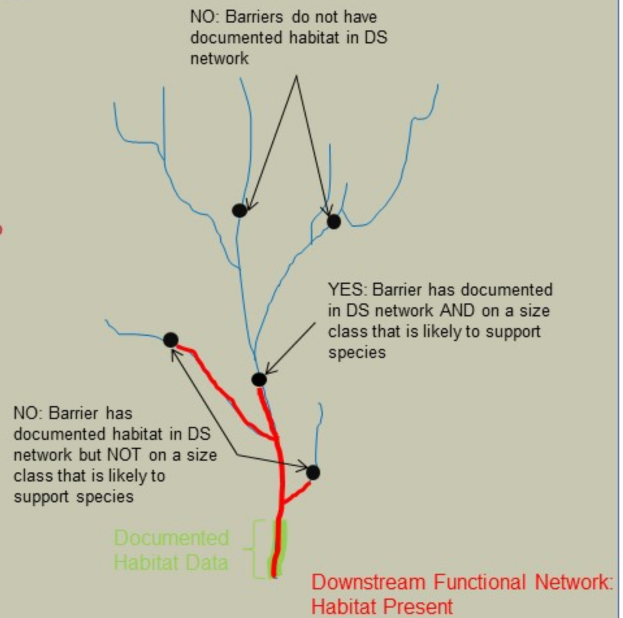
- Category: Ecological
- Presence of Hickory shad downstream of Barrier. Based on:
  1. Documented habitat in some portion of the Barrier's downstream functional network
  2. **AND** Barrier is on a stream that is likely to support that species based on stream size
     1. Size 2+ Rivers
- Fish habitat data from multiple sources. See the Map Layer descriptions for more details.
- Unit: Unitless Classes: "Current", "Historical", "None Documented"
- GIS Name: DSHICKSHAD



Striped Bass habitat in Downstream Functional Network

33

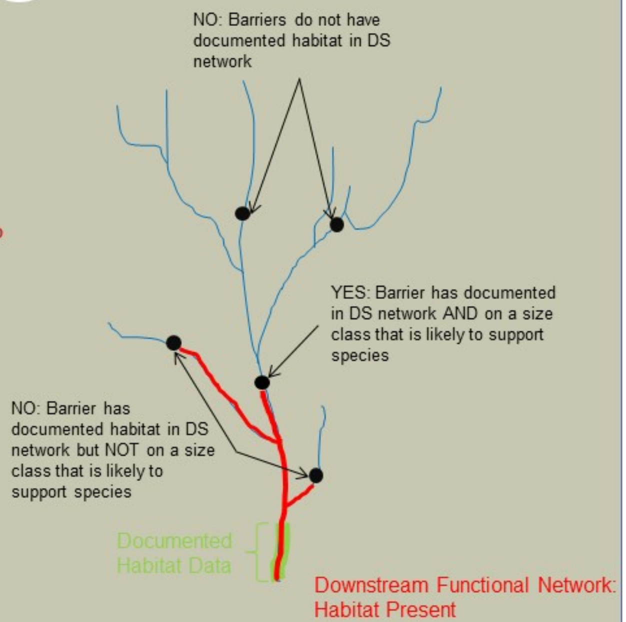
- Category: Ecological
- Presence of striped bass downstream of Barrier. Based on:
  1. Documented habitat in some portion of the Barrier's downstream functional network
  2. **AND** Barrier is on a stream that is likely to support that species based on stream size
     1. Size 3b+ Rivers
- Fish habitat data from multiple sources. See the Map Layer descriptions for more details.
- Unit: Unitless Classes: "Current", "Historical", "None Documented"
- GIS Name: DSSTRBASS



Atlantic Sturgeon habitat in Downstream Functional Network

34

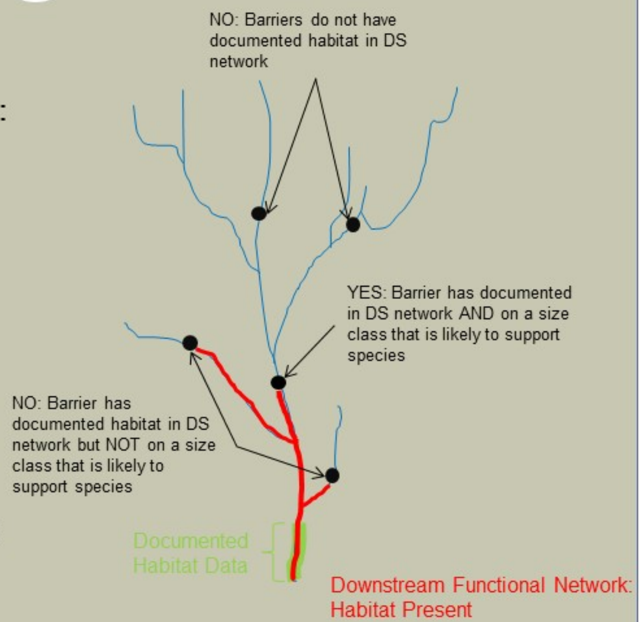
- Category: Ecological
- Presence of Atlantic sturgeon downstream of barrier. Based on:
  1. Documented habitat in some portion of the barrier's downstream functional network
  2. **AND** barrier is on a stream that is likely to support that species based on stream size
     1. Size 4+ Rivers
- Fish habitat data from multiple sources. See the Map Layer descriptions for more details.
- Unit: Unitless Classes: "Current", "Historical", "None Documented"
- GIS Name: DSATLSTUR



Atlantic Salmon habitat in Downstream Functional Network

35

- Category: Ecological
- Presence of Atlantic Salmon downstream of barrier. Based on:
  1. Documented habitat in some portion of the barrier's downstream functional network
  2. **AND** barrier is on a stream that is likely to support that species based on stream size
     1. Size 1a+ Rivers
- Fish habitat data from multiple sources. See the Map Layer descriptions for more details.
- Unit: Unitless Classes: "Current", "Historical", "None Documented"
- GIS Name: DSATLSALM



Native Fish Species Richness - HUC 8

36

- Category: Ecological - Resident
- Current native fish species richness in the watershed within which the barrier is located
- Based on NatureServe watershed (8-digit HUC) data
- Unit: #
- Sort Order: Descending
- GIS Name: fishRich

Rare Fish in HUC8

- Category: Ecological - Resident
- Count of rare (G1-G3) fish species in the watershed within which the barrier is located
- Based on NatureServe watershed (HUC8) data
- Unit: #
- Sort Order: Descending
- GIS Name: g123Fish

Rare Mussels in HUC8

38

- Category: Ecological - Resident
- Count of rare (G1-G3) mussel species in the watershed within which the barrier is located
- Based on NatureServe watershed (HUC8) data
- Unit: #
- Sort Order: Descending
- GIS Name: g123Mussel

Rare Crayfish in HUC8

39

- Category: Ecological - Resident
- Count of rare (G1-G3) crayfish species in the watershed within which the barrier is located
- Based on NatureServe watershed (HUC8) data
- Unit: #
- Sort Order: Descending
- GIS Name: g123Cray

Barrier within EBTJV Catchment with Trout

40

- Category: Ecological - Resident
- Barrier within an NHD catchment occupied by trout based on Eastern Brook Trout Joint Venture (EBTJV) data. (Mark Hudy 2012)
- Catchments with trout identified by the query "Trout =1"

- Unit: Boolean
- Sort Order: Descending
- GIS Name: in_EBTJV_2012

Barrier within Modeled Trout Catchment

41

- Category: Ecological - Resident
- Barrier within a catchment with modeled brook trout occupancy. (DeWeber & Wagner 2015)
- Catchments occupied by brook trout identified using the "occur46" scenario from DeWeber & Wagner 2015:
  - a binary classification (1 = present; 0 = absent) of Brook Trout occurrence based on a threshold that was equal to prevalence in the training data set, which produces near-optimal classification accuracy and could be used when false positives and false negatives have equal costs.
- Unit: Boolean
- Sort Order: Descending
- GIS Name: in_deWeberTrout

Barrier blocks EBTJV 2012 Catchments

42

- Category: Ecological – Resident
- NHD catchments occupied by trout are in one of a barriers functional networks – either upstream or downstream, but not both
- Based on 2012 EBTJV data

- Unit: Boolean
- Sort Order: Descending
- GIS Name: block_EBTJV_2012

Barrier blocks Modeled Trout Catchments

43

- Category: Ecological – Resident
- NHD catchments occupied by trout are in one of a barriers functional networks – either upstream or downstream, but not both
- Based on DeWeber & Wagner 2015 data

- Unit: Boolean
- Sort Order: Descending
- GIS Name: block_BT_DeWeber

River Size Class

44

- Category: Size or System Type
- River size class based on NE Aquatic Habitat Classification

1 = Size 1a - Headwaters (<3.861 sq.mi.)
2 = Size 1b: Creeks (>= 3.861<38.61 sq.mi.)
3 = Size 2: Small River (>=38.61<200 sq. mi.)
4 = Size 3a: Medium Tributary Rivers (>=200<1000 sq.mi.)
5 = Size 3b: Medium Mainstem Rivers (>=1000<3861 sq mi)
6 = Size 4: Large Rivers (>=3861 < 9653 sq.mi.)
7 = Size 5: Great Rivers (>=9653 sq.mi.)

(measure = upstream drainage area)

- Unit: Class based on drainage area
- Sort Order: Ascending
- GIS Name: NESZCL_Int

Total # Reconnected Stream Size Classes >0.5 Miles(upstream + downstream)

- Category: Size or System Type
- Number of unique stream size classes >0.5 miles in total upstream and downstream functional networks
- Where stream size defined as:
  - 1a: Headwaters (<3.861 sq.mi.)
  - 1b: Creeks (>= 3.861<38.61 sq.mi.)
  - 2:   Small River (>=38.61<200 sq. mi.)
  - 3a: Medium Tributary Rivers (>=200<1000 sq.mi.)
  - 3b: Medium Mainstem Rivers (>=1000<3861 sq.mi.)
  - 4:   Large Rivers (>=3861 < 9653 sq.mi.)
  - 5:   Great Rivers (>=9653 sq.mi.)

  (measure = upstream drainage area)
- GIS Name: TotNumSzCl

Upstream Size Classes

46

- Category: Size or System Type
- Number of upstream stream size classes in a barrier's upstream functional network
- e.g. If a downstream functional network had small rivers (size 2) and medium tributary rivers (size 3a), while an upstream functional network had these as well as 2 miles of creek (size 1b), the gain would be 1.
- Unit: #
- Sort Order: Descending
- GIS Name: usNumSzCl

Upstream Size Classes Gained by Removal / Bypass

47

- Category: Size or System Type
- Number of upstream stream size classes gained if Barrier were to be removed. Stream segments must be >0.5 miles to be considered a gain and the size class must not be present in the downstream functional network.
- e.g. If a downstream functional network had small rivers (size 2) and medium tributary rivers (size 3a), while an upstream functional network had these as well as 2 miles of creek (size 1b), the gain would be 1.
- Unit: #
- Sort Order: Descending
- GIS Name: usSzClGn

Miles of Cold Water Habitat in Total Functional Network

48

- Category: Size or System Type
- Miles of Cold Water habitat in the total functional network of a barrier
- Cold water habitat data from the Northeast Aquatic Habitat Classification

- Unit: Miles
- Sort Order: Descending
- GIS Name: totMiCold

Miles of Cold or Cool Water Habitat in Total Functional Network

49

- Category: Size or System Type
- Miles of Cold or Cool Water habitat in the total functional network of a barrier
- Cold water habitat data from the Northeast Aquatic Habitat Classification

- Unit: Miles
- Sort Order: Descending
- GIS Name: totMiCC

Critical Linkages: Cold Water Restoration Potential

50

- Restoration potential from the UMass Critical Linkages Cold Water analysis
- Based on the 16°C run (log normalized values)
- See http://sce.ecosheds.org/ for more information about this data and access additional Critical Linkages analysis runs and associated data