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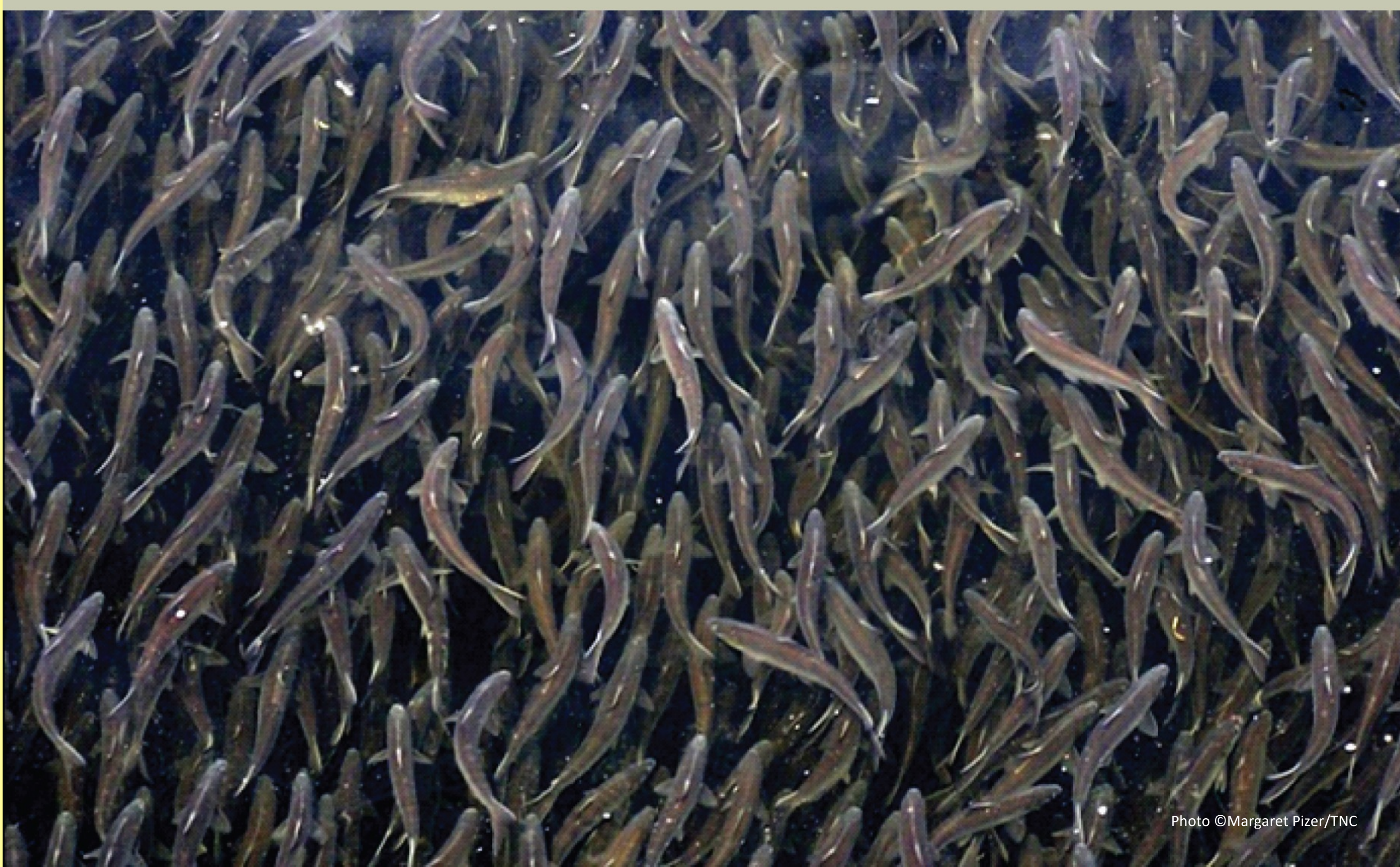
Maine Statewide Barrier Prioritization Tool

An Assessment of barriers to aquatic connectivity in Maine

9/1/2020



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1 Introduction

The Maine Statewide Barrier Prioritization Tool (SBPT) is a prioritization of dams and road-stream crossings that assesses each barrier for the potential ecological benefit that could be realized by removing or upgrading the barrier. With the stream restoration community as its target audience, the tool is designed to help users understand the physical and ecological context of each barrier to help inform an understanding of which barriers to focus resources on to help improve stream connectivity for species of interest. This information can be used in concert with other relevant data (social, economic, feasibility) to identify actionable projects

The project builds off of and expands the Penobscot Habitat Blueprint barrier prioritization that was developed by The Nature Conservancy (TNC) in Maine in 2018 and follows the approach described by Martin (2019).

2 Background, Approach, and Outcomes

2.1 Background

The anthropogenic fragmentation of river habitats through dams and poorly designed 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 spawning habitats and prevent brook trout populations from reaching thermal refuges.

Some dams provide valuable services to society including low carbon electricity, 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. However, these dams still create barriers to aquatic organism passage. Multiple agencies and organizations in Maine are committed to restoring habitat for anadromous and resident fish species including salmon, alewife and brook trout. Connectivity restoration projects including dam removals, culvert upgrades, and the installation of fish passage facilities have yielded ecological benefits such as increased anadromous fish runs, improved habitat quality for brook trout, and expanded mussel populations. These projects have been spearheaded by state agencies, federal agencies, municipalities, NGOs, and private corporations – often working in partnership. Substantial funding for these projects has come from the federal government (e.g. NOAA, USFWS), but funding has also come from state and private sources. All funding sources have been impacted by recent fiscal instability and federal funding for connectivity restoration is subject to significant budget tightening and increased accountability for ecological outcomes.

Figure 2-1: Many old dams are relics of the industrial history of the region

To many working in the field of aquatic resource management it is apparent that given likely future constraints on availability of funds and staffing, it will be critical to be more strategic about investments in connectivity restoration projects. One approach to strategic investment is to assess the likely ecological “return on investment” associated with connectivity restoration.

The sections that follow detail the data, methods, results, and tools developed for the Maine SBPT.

2.2 Approach

2.2.1 Workgroup

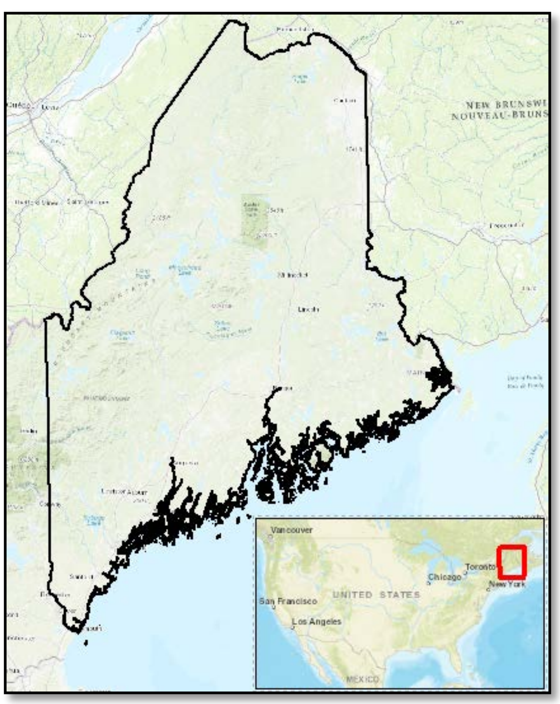
The SBPT project was structured around a project Workgroup, composed of members from federal & state agencies, NGOs, and academia. A full list of Workgroup participants can be found in Appendix I. Meeting via both in-person and virtual meetings, the Workgroup was involved in several key aspects of the project including data acquisition & review, key decision making, and draft result review. This collaborative workgroup approach built upon TNC's successful experience working with partners to complete the Northeast Aquatic Connectivity (Martin & Apse 2011) and subsequent projects. In addition to providing input at key points in the project, the Workgroup members form a core user base, active in aquatic connectivity restoration and with a direct interest in the results.

Central among the key decisions made by the Workgroup was to define the objectives of the prioritization. That is, 1) what's the objective: are we prioritizing for the benefit of? and 2) what aspects of a barrier or its location would make its removal help achieve the intended objective? This process of selecting objectives or targets and particularly the metrics that would be used to evaluate the barriers was both a collaborative and subjective process. The Workgroup selected five prioritization objectives: alewife, coastal anadromous fish, inland brook trout, ESA salmon, and American shad / blueback herring. Different metrics were used to create five separate prioritization scenarios for these five objectives. Further, each scenario was stratified by HUC8 watershed to produce relative results for each watershed as well as the statewide extent.

2.2.2 Project Extent & Input Barriers

The project extent covers the state of Maine. Within this extent, project results are available for all dams and public road stream crossings. In addition to the crossings included in the results, additional barriers were included in the input data as needed to generate metrics. For example, in order to calculate the number of downstream barriers for each barrier in the St John River basin, it was necessary to include Canadian barriers since the river drains into New Brunswick. After Canadian barriers were used to generate metrics, they were removed from the analysis. More information on the barriers used in the analysis can be found in Section 3.3.

Figure 2-2: Maine



3 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 metrics for each dam. The core datasets included river hydrography, dams, road-stream crossings and natural barriers (e.g. waterfalls). Additional datasets were brought in as needed to generate metrics of interest to the Workgroup. These datasets include land cover data, multiple salmon data layers, and brook trout data. A complete list of data used in the project can be found in Appendix II. A further description of the core datasets follows.

3.1 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.

3.1.1 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 3-1. 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 river network within which a fish could theoretically swim within if that particular barrier was removed or made passable.

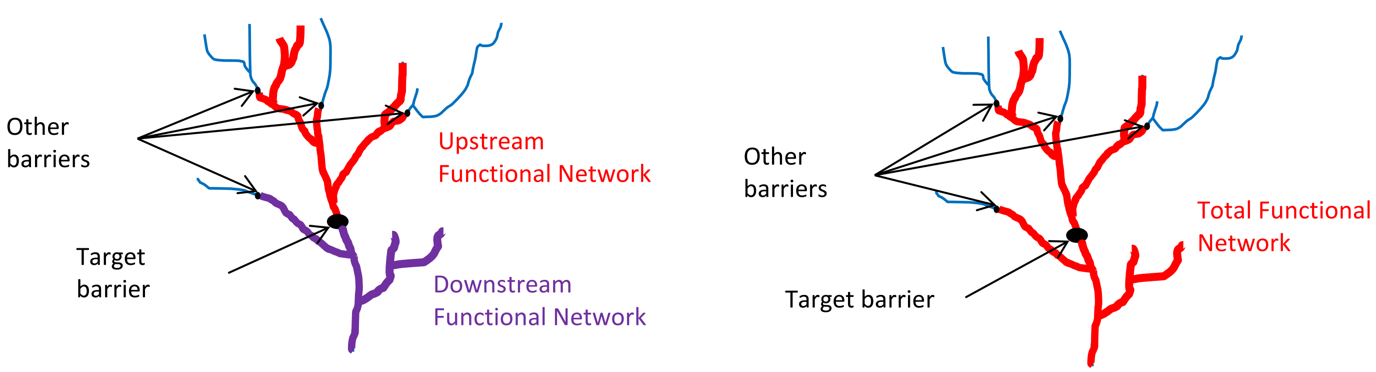


Figure 3-1: Conceptual illustration of functional river networks

3.1.2 Watersheds

For any given barrier, metrics involving three different watersheds are used in the analysis. The contributing watershed, or total upstream watershed, is defined by the total upstream drainage area above the target dam. Several metrics are also calculated within the local watershed of target dam'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.

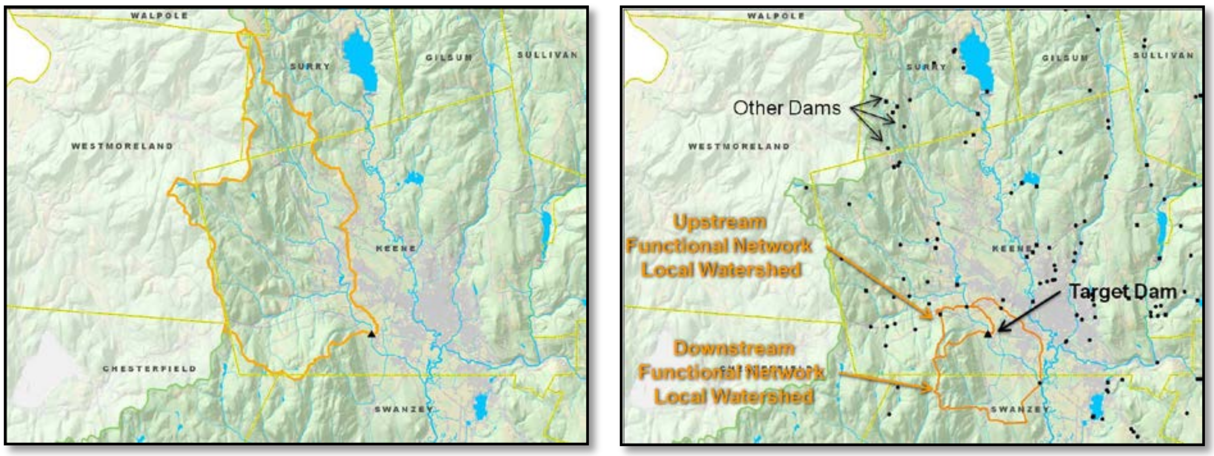


Figure 3-2: The contributing watershed is defined by the total drainage upstream of a target dam. The upstream and downstream functional river network local watersheds are bounded by the watershed for the next dams up and down stream.

3.1.3 Stream size class

Stream size is a critical factor for determining aquatic biological assemblages (Oliver and Anderson 2008, Vannote et al. 1980, Mathews 1998). In this analysis, river size classes, based on the upstream drainage area classes 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 dam (Figure 3-3).

Drainage area data was not immediately available for the many of the Canadian rivers, nor was it necessary for the analysis which used the Canadian Rivers only in so far as they were needed to generate metrics for barriers within Maine.

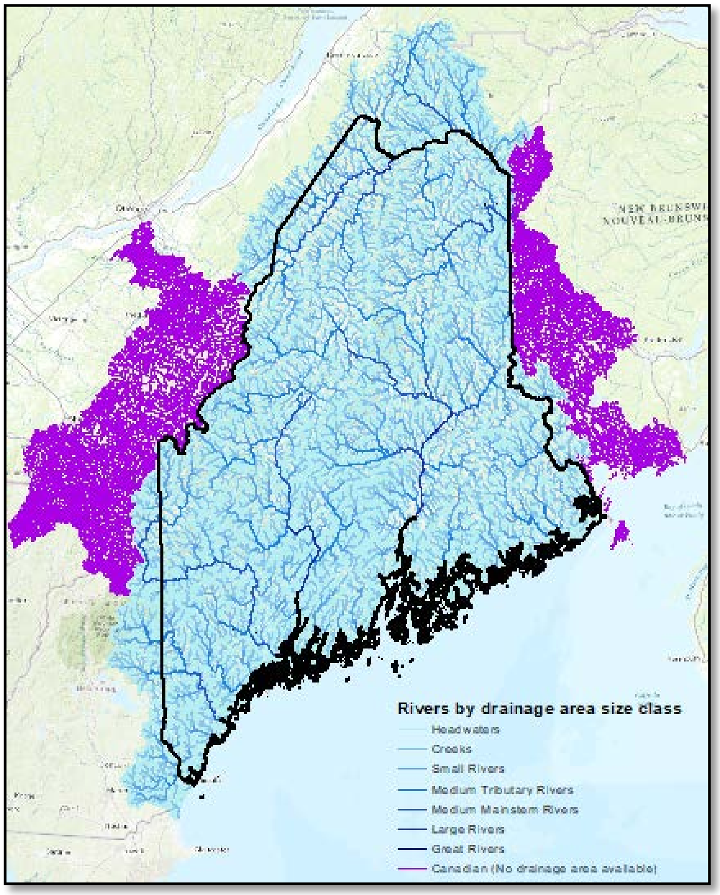


Figure 3-3: Upstream drainage area size class definitions and map of rivers by size class in the Maine.

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)

3.2 Hydrography

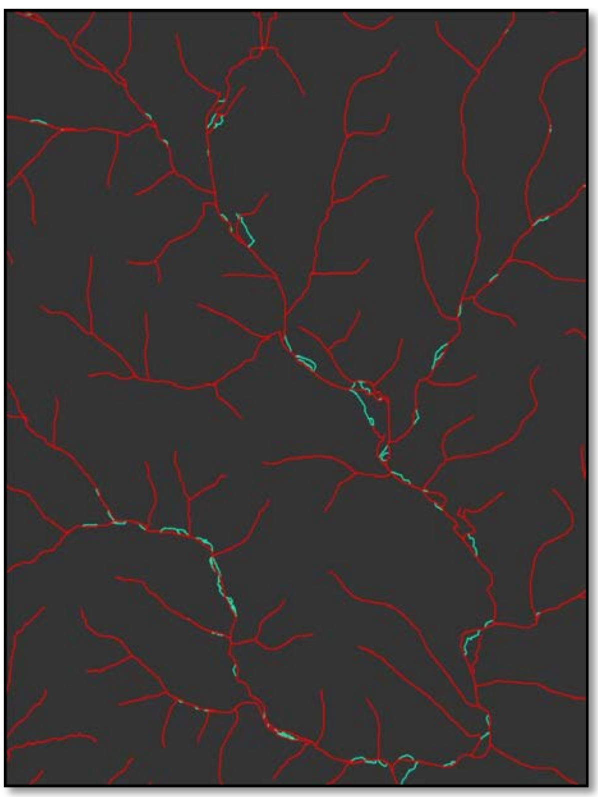
In order for dams to be included in the analysis, they had to fall on the mapped river network, or hydrography, that was used in the project: a modified version of the High Resolution National Hydrography Dataset Plus (NHDPlus HR). This hydrography was digitized by the United States Geological Survey primarily from 1:24,000 scale topographic maps.

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 3-4). To extract a dendritic network the following selection query was applied in ArcGIS 10.3:

NHDFlowline.FLOWDIR = 'With Digitized' AND NHDPlusFlowlineVAA.Divergence in (0,1) AND NHDPlusFlowlineVAA.StreamCalc <>0

Further manual modifications of this network were made by Alex Abbot, contractor to the USFWS Gulf Of Maine Office and TNC staff. A dendritic network was also necessary for the portions of Canada that lie downstream of Maine barriers (e.g. St John River). Unfortunately, although the High Resolution NHD flowlines are available for Canada, the "Plus" attributes that are required to use the above selection query were not available. Thus, to derive a dendritic network in Canada, a Geometric Network was created from the hydrography in ArcGIS 10.3 so that offending loops and bifurcations could be identified. Each offending section was then manually edited by selecting the mainstem or otherwise removing line segments to create a dendritic network.

Figure 3-4: Braided segments highlighted in blue needing to be removed to generate a dendritic network.



The result of this process was a single-flowline dendrite, based on the current High Resolution NHD, for Maine and downstream portions of Canada. This dendrite (hereafter referred to as the "project hydrography") was then further processed using custom Python scripts to build 'FromNode' and 'ToNode' for each segment in order to establish flow direction for the network. Additional processing using ArcGIS Spatial Analyst and custom Python scripts in ArcGIS was performed to accumulate upstream attributes. This processing produced values including the total upstream drainage area, percent impervious surface, and similar land cover metrics for each line segment.

3.3 Barriers

In stream barriers used in the analysis included dams, road-stream crossings, and natural barriers, as detailed in the sections that follow.

3.3.1 Dams

The dam data used in the project is maintained by TNC in Maine and was originally sourced from the Maine GIS (MEGIS) (see Appendix II: Input Datasets). In order to perform network analyses in a GIS, the points representing dams and must be topologically coincident with lines that represent rivers.

Figure 3-5: Illustration of snapping a dam to the river network

Over the course of several years, staff contracted to the USFWS Gulf of Maine Program along with TNC in Maine staff have invested substantial time in reviewing and refining the location of dams to ensure that they are in the correct location. This process involved "snapping" the dams in a GIS to the project hydrography (Figure 3-5). For this project, dams were further snapped using ArcGIS tools accessed via Python (arcpy) to ensure they were coincident to the project hydrography. A snapping tolerance of 100m was used, though in the vast majority of cases the dams were already coincident with the river network in which case the dams do not move.

3.3.2 Road-stream crossings

Road stream crossings can also act as a barrier to fish and other aquatic organisms attempting to move up or downstream. Culverts, in particular, can be completely impassible to aquatic organism passage (AOP) due to outlet perch, physical blockages, or elevated velocity. The degree to which a road-stream crossing is a barrier to AOP can vary substantially given the physical parameters of the structure and stream conditions. Thus, in order to understand the extent to which a given road-stream crossing is a barrier, it is necessary to survey the crossing from the perspective of AOP.

Over the last 13 years The Nature Conservancy has partnered with the USFWS, NRCS, Maine Audubon, Maine Forest Service and dozens of volunteer groups to survey all the accessible road stream crossings around the state of Maine. Based on TNC's review of these data, there were at least 225 individual surveyors who surveyed 969 dams in addition to road stream crossings. Of the 25,054 road stream crossings assessed, 6,677 (27%) are definite barriers while another 30% (7,609) are potential barriers and recent analysis suggest at least half of those are definitely barriers. There were also 7,646 (31%) that were not barriers to stream flow or fish passage. Twenty-four percent of the barriers were on town roads (including state assist), and 20% were on state managed roads. The majority of crossings surveyed (53%) were on private road systems, mostly in the Maine's large private timberland ownerships that cover 11 million acres of our 23 million acre state.

3.3.2.1 Private crossings

The Nature Conservancy has signed data sharing agreements with several large landowners in northern Maine. These data sharing agreements allow TNC to survey crossings on these lands and to use the data for planning purposes. The data themselves, however, are restricted and cannot be shared or displayed publicly.

In the SBPT, restricted road-stream crossings are used in the process of calculating metrics but are not included in the results or made available for viewing in the tool. For example, if a public crossing has two other public crossings and three restricted crossings downstream of it, then the metric "number of downstream barriers" would equal five. When the results are viewed in the map, however, only the two public crossings would be visible. Likewise, a barrier's upstream functional network (see Section 3.1.1) and any derived metrics are calculated based on the presence of restricted barriers.

3.3.2.2 Canadian barriers

Canadian barriers obtained from Nature Conservancy Canada from their Aquatic Connectivity tool (Noseworthy et al 2019). This dataset, which included dams as well as road-stream crossings, was treated in much the same way as restricted barriers. These barriers were used in the generation of metrics to understand their impact on the public crossings in Maine, but they are not included in the results.

3.3.3 Natural Barriers

Natural barriers, such as waterfalls, can also act as barriers to fish passage. Including them in the analysis was important due to the impact 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 amount of habitat that would be opened by removing that dam. Thus, although waterfalls are excluded from the project results (they are not intended to be removed or bypassed) they were included in the generation of functional networks.

The primary data source for waterfalls was the Maine stream barrier database. This database includes natural barriers that have been surveyed by field crews as part of the road-stream crossing survey efforts and classified as barriers, potential barriers, or non-barriers. Barrier and potential barriers were used in the generation of the functional river networks but were not included in the analysis results.

3.3.4 Barrier Passability

All barriers were assigned a “passability” score ranging from 0 – 1 to describe the degree to which that barrier is passable to aquatic organisms. Barriers classified as “no barrier” were assigned a score of 1 (fully passable) and were omitted from the analysis. (A bridge or a fully passable culvert with natural substrate are examples of crossings with a passability score of 1. As no further upgrades could be made to these structures, there is no reason to prioritize them for upgrade, nor to assess their influence on other barriers.) Barriers classified as “Barriers” were given a score of 0 while potential barriers were further refined (see Section 3.3.4.2) and assigned a decimal passability score between 0 and 1. Barriers with a passability score less than 1 were used to generate functional river networks for the analysis.

3.3.4.1 Dam passability

There is currently no authoritative scoring dataset or methodology for assigning passability scores at dams. Given this lack of data, passability at dams was estimated based on known fish passage facilities and a simple rubric to score them on a 0 - 1 scale.

- **0** – No passage facility, complete barrier. (Default assumption if no other info)
- **0.25** – Only the best swimmers can do it, some of the time. We know there’s a facility, but we know little about its effectiveness. (e.g. Bolster’s Mill Dam, Crooked River)
- **0.5** – Average passage facility. Facility, works okay, not the best; temporal passage, moderate amounts, for several species but likely not all (e.g. Brunswick Dam)
- **0.75** – State of the art, known to be effective, maybe not at all times. (Milford lift)
- **1.0** – totally passable (Howland bypass)

These scores were assigned by TNC staff based on a review of dams in the state and were further made available for review by partners at MEFIW Region A via web map.

3.3.4.2 Road-stream crossing passability

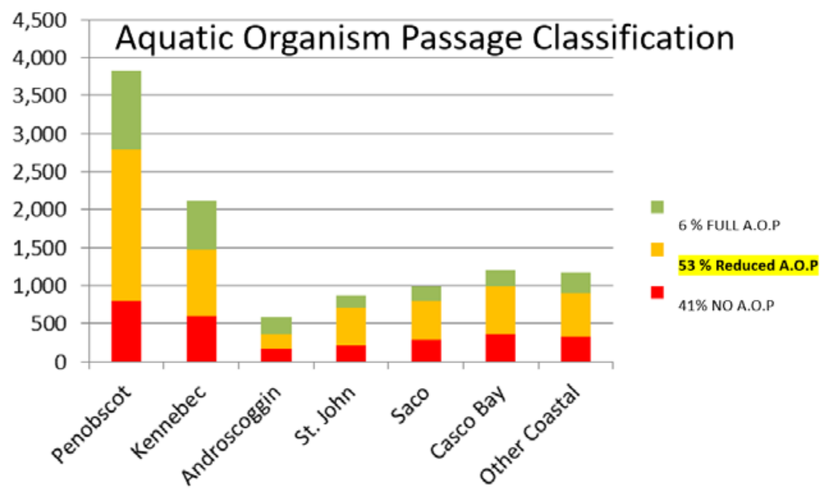
As noted above, road-stream crossings were first classified into three categories based on the physical condition of the crossing as described in Table 3-1. Crossings with significant outlet drops (waterfalls) or debris blockages are assumed to have no passage (passability = 0), crossings with no observable impediments to passage that are greater than or equal to the bank full width of the stream are assumed to be fully passable (passability = 1). All other crossings are catalogued as having reduced passage due to survey indicators of higher velocities in the crossing than observed in the stream channel (perched inlet/outlet, lack of substrate in the crossing, etc).

Table 3-1 A.O.P at road/stream crossings classification system

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

When applying this classification system to the surveyed data of more than 25,000 crossing point across the state of Maine, we observed that more than half of the crossings in the state (Figure 3-6) fall into the reduced A.O.P /velocity barrier classification, requiring a deeper level of analysis to better identify the severity of these velocity barriers and improve our understanding of which crossings would best benefit fish passage by replacement with rightly sized structures.

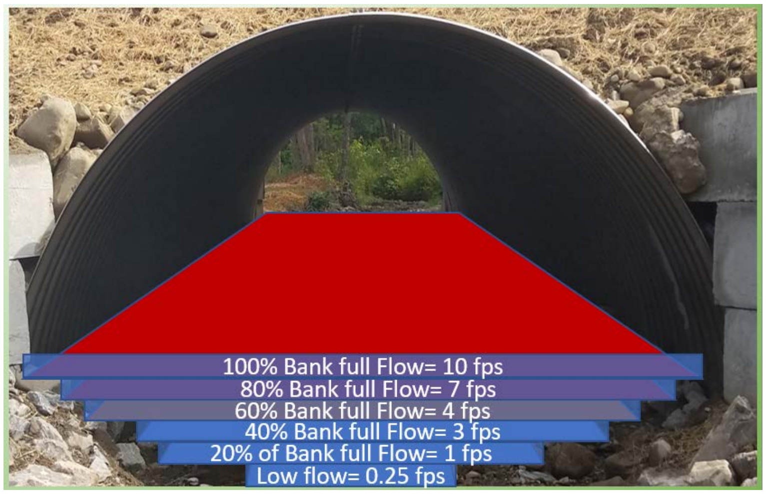
Figure 3-6 Road/Stream Crossing AOP Classification breakdown by major drainage basin



Refinement of Reduced AOP Classification:

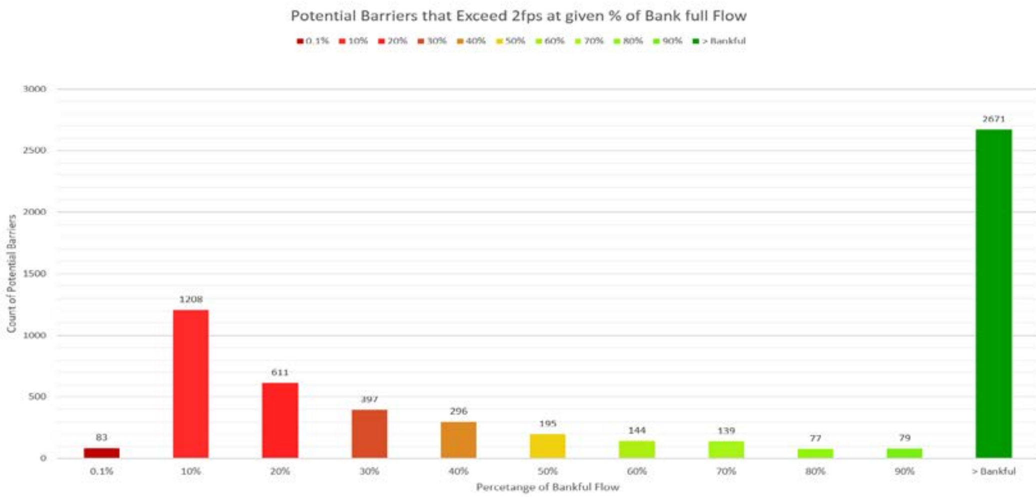
Filtering out crossings already designated as full AOP and no AOP using the above criteria, we re-analyzed the reduced AOP subset of “potential barrier” crossings to derive a rough quantitative estimate of the average velocity in the crossing for at given flow. Streamstats (USGS 2016) outputs for Bank full (Peak 1.1 Year recurrence interval) and low flow (Mean 10 year 7 day) flows were used to bound the upper and lower limit and define a range of flows that fish could experience when migrating.

Figure 3-7 Diagram of flow percentile stratification and example velocity outputs



This flow range was broken into 10% intervals and input into manning’s equation to develop an estimate of average flow velocity through the crossing at each interval. A threshold of 2 feet per second was chosen as a low enough velocity could that we could be confident that most fish species and life stages could navigate without significant metabolic impacts. When this threshold velocity exceeded, the corresponding flow percentile was reported as the crossings pass-ability score, based on the assumption that aquatic organism passage efficacy would increase as velocities stay below the threshold at bank full or near bank full flows (see Figure 3-7 and Figure 3-8).

Figure 3-8 Breakdown of Velocity Barriers Across Bank full flow percentile intervals



Important Notes:

This analysis contains compounded error vectors from the StreamStats Inputs, remote sensing of reach slope from NHD and qualitative field assessments methods. This method should not be used for anything other than a course screening method to identify the highest priority sites, and these errors should be assessed carefully when drawing conclusions from the model outputs. For the comprehensive methodology, please contact Benjamin.matthews@tnc.org for python I/O scripts, hydraulic geometry equations and model assumptions.

3.3.4.3 Natural barrier passability

Lacking consistent additional information to refine passability scores, natural barriers were simply assigned passability scores simply based on their classification: barriers were assigned a 0 while potential barriers were assigned a score of 0.5. Natural barriers classified as “No Barrier” were assigned a 1 and excluded from the analysis.

4 Analysis Methods

The conceptual framework of the Maine SBPT project rests on a suite of ecologically relevant metrics calculated for each barrier in the analysis. 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 dams. For example, if one is interested in passage projects to benefit diadromous fish then the dam’s upstream functional network, or the number of river miles that would be opened by that dam’s removal, could be used to prioritize dams. In this case, the dam with the longest upstream functional network—the dam whose removal would open up the most river miles—would rank out at the top of the list. 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.

4.1 Metric Calculation

A total of 83 metrics were calculated for each dam in the study area using ArcGIS 10.7.1. The process used of generate each metric was scripted using Python 2.7.16 using the arcpy module (ArcGIS Python package) as well as other freely available Python packages.

Metrics are organized into four categories for convenience: Network, Landcover, Salmon, Brook Trout, Sea Run Fish, and Feasibility. These categories help organize the metrics into a logical order but have no impact on the analysis. Additionally, 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 project that opens up a watershed with a high percentage of impervious surface. A table listing each of the metrics is presented in Table 3-1, and a more complete description of each metric can be found in Appendix III.

Depending on the objectives of a prioritization scenario, some metrics will be of greater importance than other metrics. Upstream functional network length may be of particular interest in a prioritization scenario focused on diadromous fish, for example, while the percent impervious surface in the floodplain of the dams upstream functional river network may be of less importance, and the presence of rare crayfish species 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 4-2 through Table 4-6 five scenarios, respectively.

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 alewife. To arrive at the weights presented in the tables below, the Workgroup went through an iterative process of selecting draft weights based on their knowledge of the species of interest, then adjusting them in light of draft results produced from the selected weights and their current on-the-ground removal priorities. This process was intended help calibrate the results to known priorities.

Table 4-1 Metrics calculated for each dam in the study

Category	Metric Name	Units	Sort Order
Network	Upstream Functional Network Length	m	D
	Count of Downstream Barriers	#	A
	Absolute Gain (min of upstream & Downstream functional network)	m	D
	Total length of upstream river network (Ignoring barriers)	m	D
	Total Functional Network Length (Upstream + Downstream)	m	D
	Density of barriers on upstream network	#/m	D

	Count of downstream natural barriers	#	A
	Count of downstream fish passage facilities	#	D
	Count of downstream hydropower facilities	#	A
	River Size Class (based on drainage area)	unitless score	A
	One of upstream barriers is a natural barrier	Boolean	A
Brook Trout	Aquifers are found in upstream functional network OR downstream functional network OR both (all treated the same)	Boolean	D
	Aquifer OR coarse sediments are found in upstream functional network OR downstream functional network OR both (all treated the same)	Boolean	D
	Calcareous or moderately calcareous geology is found in upstream functional network OR downstream functional network OR both	Boolean	D
	Probability of BKT occupancy (current temps)	%	D
	Probability of BKT occupancy (+2C)	%	D
	Probability of BKT occupancy (+4C)	%	D
	Probability of BKT occupancy (current temps) >= 50%	Boolean	D
	Probability of BKT occupancy (+2C) >= 50%	Boolean	D
	Probability of BKT occupancy (+4C) >= 50%	Boolean	D
	Miles of medium, high, or very high priority brook trout habitat in upstream + downstream networks	miles	D
	Miles of medium, high, or very high priority brook trout habitat in upstream functional network	miles	D
	Presence of High priority or Very High brook trout habitat upstream OR downstream of barrier	Boolean	D
	Presence of Medium, High, or Very High prioritybrook trout habitat upstream OR downstream of barrier	Boolean	D
	Presence of >=1/4 mile Very High priority brook trout habitat upstream OR downstream of barrier	Boolean	D
	Barrier is within EBTJV Wild Brook Trout Patches	Boolean	D
	Is the barrier between two networks with heritage fish ponds (heritage fish ponds in upstream functional network AND downstream functional network)	Boolean	D
Feasibility	Invasive species are found in the network on one side of a barrier and not the other	Boolean	A
	Invasive species (confirmed occurances) are found in the network on one side of a barrier and not the other	Boolean	A
	# of Invasive species that are blocked (confirmed occurances)	#	A
	Barrier is on conservation land	Boolean	D
	% Conserved land in 100m buffer of upstream functional network	%	D
	% Conserved land in 100m buffer of upstream functional network	%	D
Landcover	Percent Forested Landcover in upstream drainage area	%	D
	% forested landcover in 100m buffer of upstream network	%	D
	% forested landcover in 100m buffer of downstream network	%	D
	% forested landcover in 100m buffer of total network (upstream & downstream)	%	D
	% medium/high intensity developed landcover in 100m buffer of upstream network	%	A
	% medium/high intensity developed landcover in 100m buffer of downstream network	%	A
	% medium/high intensity developed landcover in 100m buffer of total network (upstream & downstream)	%	A
	% cultivated crops in 100m buffer of upstream network	%	A
	% cultivated crops in 100m buffer of downstream network	%	A
	% cultivated crops in 100m buffer of total network (upstream & downstream)	%	A
	% pasture/hay in 100m buffer of upstream network	%	A
	% pasture/hay in 100m buffer of downstream network	%	A
	% pasture/hay in 100m buffer of total network (upstream & downstream)	%	A
	% forested landcover in floodplain of upstream network	%	D
	% forested landcover in floodplain of downstream network	%	D
	% forested landcover in floodplain of total network (upstream & downstream)	%	D
	% medium/high intensity developed landcover in floodplain of upstream network	%	A
	% medium/high intensity developed landcover in floodplain of downstream network	%	A
	% medium/high intensity developed landcover in floodplain of total network (upstream & downstream)	%	A
	% cultivated crops in floodplain of upstream network	%	A
	% cultivated crops in floodplain of downstream network	%	A
	% cultivated crops in floodplain of total network (upstream & downstream)	%	A

	% pasture/hay in floodplain of upstream network	%	A
	% pasture/hay in floodplain of downstream network	%	A
	% pasture/hay in floodplain of total network (upstream & downstream)	%	A
Salmon	Cumulative upstream salmon habitat units, discounted by barrier pass	unitless score	D
	Cumulative upstream network length, discounted by barrier pass	unitless score	D
	DMR Priority Stream that the barrier is on	unitless score	D
	Barrier is in a Salmon Critical Habitat HUC10	Boolean	D
	Summed modeled salmon habitat units in the HUC10 the barrier is within	unitless score	D
	# salmon habitat units in US Functional network	unitless score	D
	Sum of salmon parr productivity in US functional network	unitless score	D
	Upstream salmon restoration potential	unitless score	D
Sea run fish	The product (multiplication) of downstream barrier passability scores	unitless score	D
	Miles of tidal habitat (current) upstream of barrier	miles	D
	Miles of tidal habitat (HAT +1m) upstream of barrier	miles	D
	Miles of tidal habitat (HAT +6ft) upstream of barrier	miles	D
	Barrier falls on SeaRunBrookTrout lines	Boolean	D
	Barrier is located on a tidal stream (HAT +1m)	Boolean	D
	Upstream acres of alewife ponds (total, ignoring any barriers in the way)	acres	D
	The are smelt sites upstream of the barrier	Boolean	D

4.2 Scenarios

The metrics noted in Table 4-1 serve as a menu of metrics by which barriers can be assessed. These metrics were weighted and combined (see Section 4.3) to produce five different "consensus" prioritization scenarios that were identified by the project workgroup. Each scenario represents a separate prioritization for a separate objective. A barrier that is a high priority for removal or improved passage in one scenario may be a low priority for removal in another scenario. Further, in some cases, scenarios only included a subset of barriers in the state. For example, the Coastal Anadromous Fish scenario only included those barriers on coastal streams. In other cases, all barriers in the state were included.

Each scenario was run for the applicable barriers throughout the state as well as stratified by HUC8 watershed. This allows users to see priorities displayed relative to the state or to a watershed of interest.

The following tables list the consensus scenarios the weights that were given to metrics in each scenario, and any filter that was applied to barriers to limit which barriers were included.

4.2.1 Coastal Anadromous Fish

The Coastal Anadromous Fish scenario was designed to prioritize barriers whose removal could benefit a suite of coastal anadromous fish species including sea run brook trout and smelt. The analysis was limited to barriers falling on small coastal streams. Coastal streams were defined as streams with an upstream drainage area less than 100 km^2 that drain into a tidal area (directly into the ocean or the tidal portion of a larger river). The metrics are weights used in this scenario are listed in Table 4-2

Table 4-2 Metric weights for the coastal anadromous fish scenario

Metric Name	Coastal Anadromous
Upstream Functional Network Length	10
Count of Downstream Barriers	20
Probability of BKT occupancy (+2C)	10
Percent Forested Landcover in upstream drainage area	20
The product (multiplication) of downstream barrier passability scores	10
Barrier falls on SeaRunBrookTrout lines	10
Barrier is located on a tidal stream (HAT +1m)	10
The are smelt sites upstream of the barrier	10

4.2.2 Inland Brook Trout

The inland brook trout scenario was designed to assess barriers whose removal or improvement could benefit inland brook trout. It was designed to provide a counter to the coast anadromous fish scenario and so explicitly excludes the coastal streams that were identified for the coastal anadromous scenario.

Table 4-3 Metric weights for the inland brook trout scenario

Metric Name	Inland Brook Trout
Absolute Gain (min of upstream & Downstream functional network)	20
Aquifers or Coarse Sediments found in upstream functional network OR downstream functional network OR both (all treated the same)	15
Calcareous or moderately calcareous geology is found in upstream functional network OR downstream functional network OR both	5
Probability of BKT occupancy (+2C) >= 50%	30
Miles of medium, high, or very high priority brook trout habitat in upstream + downstream networks	10
Presence of >=1/4 mile Very High priority brook trout habitat upstream OR downstream of barrier	10
Is the barrier between two networks with heritage fish ponds (heritage fish ponds in upstream functional network AND downstream functional network)	5
Invasive species (confirmed occurrences) are found in the network on one side of a barrier and not the other	5

4.2.3 ESA Salmon

The salmon scenario is focused on identifying barriers to benefit the Endangered Species Act-list Atlantic Salmon. This scenario was run for all barriers in the state using the metrics listed in Table 4-4

Table 4-4 ESA Salmon scenario metrics

Metric Name	Salmon
Upstream Functional Network Length	20
Count of Downstream Barriers	10
Count of downstream fish passage facilities	10
Percent Forested Landcover in upstream drainage area	10
Cumulative upstream salmon habitat units, discounted by barrier pass	15
DMR Priority Stream that the barrier is on	15
Barrier is in a Salmon Critical Habitat HUC10	10
The product (multiplication) of downstream barrier passability scores	10

4.2.4 Alewife

Given the importance of alewife spawning ponds to alewife n Maine, the alewife scenario was run for those barriers downstream of mapped alewife spawning ponds, whose removal could improve access to these critical ponds.

Table 4-5 Alewife scenario metrics

Metric Name	Alewife
Count of Downstream Barriers	10
Count of downstream fish passage facilities	20
Percent Forested Landcover in upstream drainage area	20
The product (multiplication) of downstream barrier passability scores	10
Upstream acres of alewife ponds (total, ignoring any barriers in the way)	40

4.2.5 American shad / blueback herring

Finally, American shad and blueback herring were assessed via a separate scenario from alewife using the weights listed in Table 4-6 for all barriers in the state.

Table 4-6 America shad / blueback herring metrics

Metric Name	Shad & Blueback Herring
Upstream Functional Network Length	20
Count of Downstream Barriers	10
Count of downstream fish passage facilities	20

Count of downstream hydropower facilities	20
Percent Forested Landcover in upstream drainage area	20
The product (multiplication) of downstream barrier passability scores	10

4.3 Prioritization

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.

This process can be expressed as:

For metric value $\boldsymbol{a}$ in set $\boldsymbol{A} = \{a_1, a_2, a_3, a_n\ldots\}$
$\mathbf{R}_a$ = ordinal number of value a in set A, sorted ascending or descending, depending on metric. Dense ranking, where tie values are both given the same rank and the following value is given the next sequential rank (e.g. '1223') was used for ties.

$$PR_a = 100\left(\frac{R_a - minA}{maxA - minA}\right) \quad \text{(descending)}$$

or

$$PR_a = 100 - \left(100\left(\frac{R_a - minA}{maxA - minA}\right)\right) \quad \text{(ascending)}$$

$$CS = \sum_{i=1}^{m} W_i PR_i$$

$FR = R_{CS}$

Where:
m = metric
R = rank
CS = Combined Score
W = weight
PR = percent rank
FR = final rank

In practice, this expression is manifested as in this hypothetical example ranking of four dams:

1

Dam Name	US Functional Network Length (m)	DS Functional Network Length (m)
Dam A	239,569	2,572
Dam B	342,665	62,525
Dam C	572,554	6,233
Dam D	125,664	87,425

2

Dam Name	US Functional Network Length (% rank)	DS Functional Network Length (% rank)
Dam A	25.49	0
Dam B	48.56	70.66
Dam C	100	4.31
Dam D	0	100

Dam Name	US Functional Network Length	DS Functional Network Length
Dam A	25.49 * 0.6	0 * 0.4
Dam B	48.56 * 0.6	70.66 * 0.4
Dam C	100 * 0.6	4.31 * 0.4
Dam D	0 * 0.6	100 * 0.4

3

Dam Name	US Functional Network Length (weighted rank)	DS Functional Network Length (weighted rank)
Dam A	15.29	0
Dam B	29.13	28.26
Dam C	60	1.73
Dam D	0	40

Summed Ranks
15.29
57.4
61.73
40

4

Dam Name	Final Ranks
Dam A	4
Dam B	2
Dam C	1
Dam D	3

5

Dam Name	Final Ranks
Dam C	1
Dam B	2
Dam D	3
Dam A	4

- Step 1: All values are normalized to a percent scale where the optimal value is assigned a score of 100 and the least desirable value is assigned a score of 0.
- Step 2: Multiply the percent rank by the chosen metric weight
    - In this hypothetical example, assume upstream functional network length weight = 60 and downstream functional network length weight = 40.
- Step 3: Sum the weighted ranks for each dam
    - All metrics which are included in the analysis (weight >0) are summed to give a summed rank.
- Step 4: Rank the summed ranks
    - The summed ranks are, in turn, ranked
- Step 5: Sort and display the results
    - The final ranks are sorted for presentation. In the analysis results, dams are grouped and displayed alphabetically within tiers which each contain 5% of the total dams.

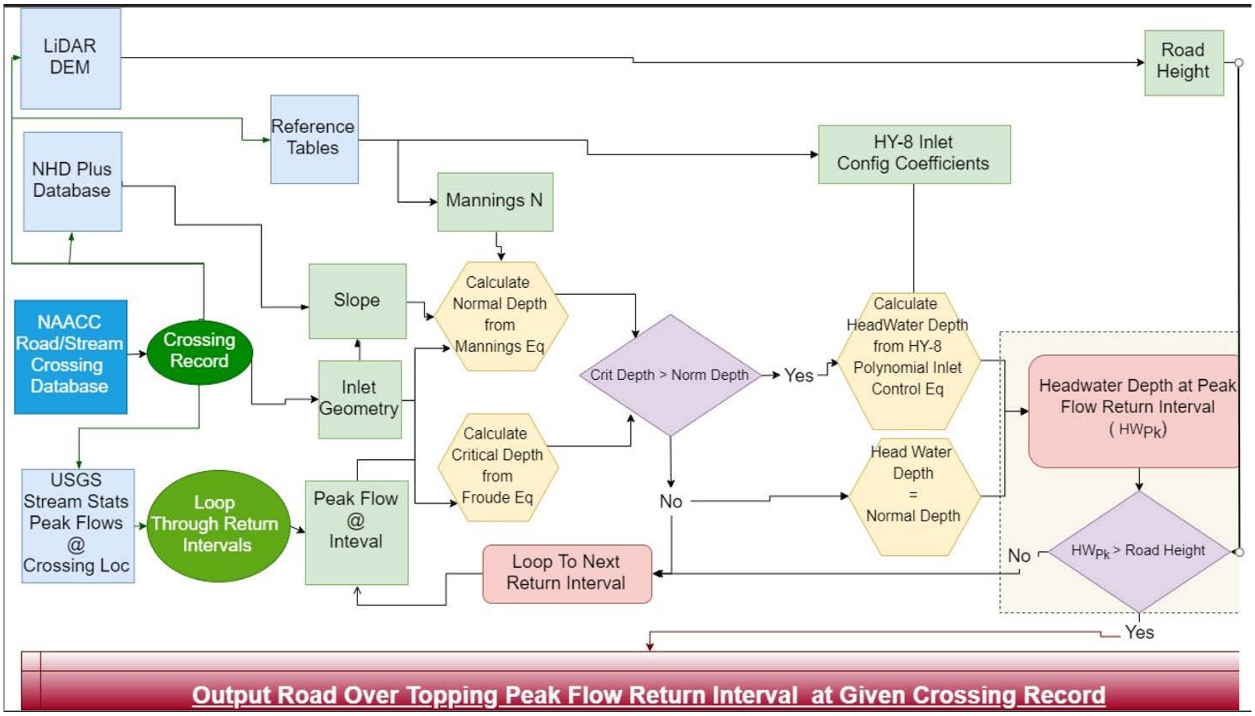
4.4 Flood Risk

Maine is predicted to experience increased intensity and frequency of extreme rainfall events which threaten to overwhelm its current road infrastructure integrity. In the Northeast, average annual precipitation has increased by 10% from 1895 to 2011, while precipitation from extreme storms has increased by 70% since 1958 (EPA, 2016). The IPCC Special Report on Extremes (Murray and Ebi, 2012) assessment finds that projected increases in heavy rainfall will contribute to increases in local flooding in certain regions (USGCRP 2017). In Maine specifically, "precipitation has increased at a rate of 0.107 inches per year since 1960, more than twice as fast as the long-term rate of increase of 0.048 inches per year" (Fernandez et al., 2020) . We can expect average annual precipitation and frequency of extreme rainfall events to continue to increase in the future, especially in the winter and spring when evaporation increases. The climate science special report further identifies a connection between extreme precipitation and flooding and reports that, "the number of extreme events (exceeding a 5-year return period) increases by two to three times the historical average in every region by the end of the 21st century, with the largest increases in the Northeast" (USGCRP 2017). This means that flooding events are likely to worsen, straining current road infrastructure. This poses two problems: (1) adverse effects on Maine's aquatic ecosystems as undersized culverts inhibit ecological connectivity which of multiple species of fish and other aquatic organisms that require migration to complete their lifecycles and (2) Maine's crossings are unsuited to handle excess flow from flooding events and present a significant risks public safety.

There is a correlation between culverts that are undersized for floods and problems for fish passage. O'Shaughnessy et al (2016) suggests that there are dual benefits to replacing undersized culverts in Maine that are both barriers to fish passage and unable to pass a 25-year flood event. The results found that 4,580 culverts out of the 24,501 stream crossings in Maine are barriers to fish passage and overtop during a 25-year event. The efficacy of a given road/stream crossing to allow the passage of fish and other aquatic organisms was determined using a barrier screening model that gives a A.O.P score based on various input variables. While many culverts in the state need to be addressed, focusing on those that present a flood risk to humans and a barrier to fish species enables road owners to prioritize crossings that have multiple benefits and provides other funding sources.

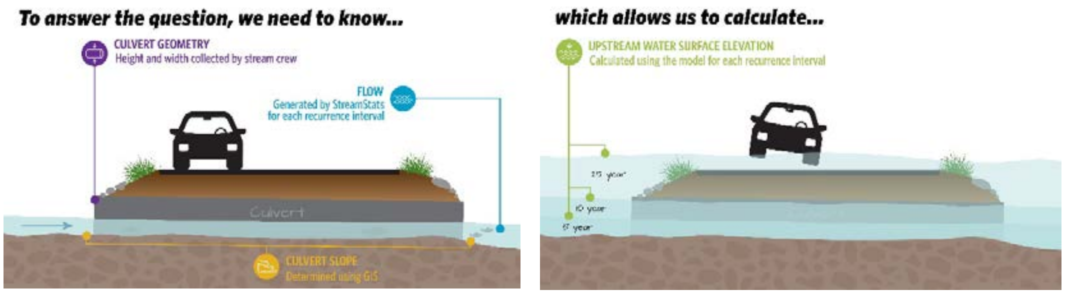
Flood risk at culverts was estimated using the conceptual process outlined in Figure 4-1. Using flow data from StreamStats (USGS 2016), culvert survey data from Maine's stream crossing surveys, LiDAR derived elevations and a river hydrography, the likelihood of a given road being overtopped within 30 years was calculated.

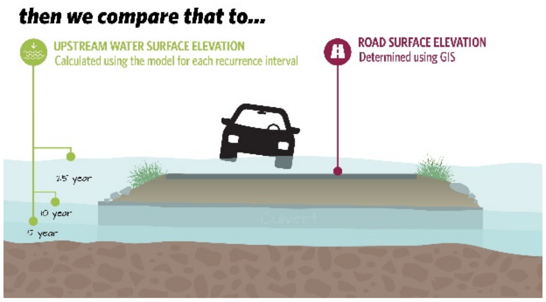
Figure 4-1 Flowchart of Flood Risk Programming Method



Using the measured crossing geometry from the North Atlantic Aquatic Connectivity Collaborative (https://naacc.org/) and querying USGS StreamStats website (https://streamstats.usgs.gov/ss/) for Flood Flows estimates of 1, 2, 5, 10, 25, 50, 100, 250 and 500 year events, we are able to solve polynomial equations derived for Federal Highways Administration HY-8 Model to solve for the headwater depth for each peak flow for at a given crossing.

Figure 4-2 Graphic Description of rick calculation methods

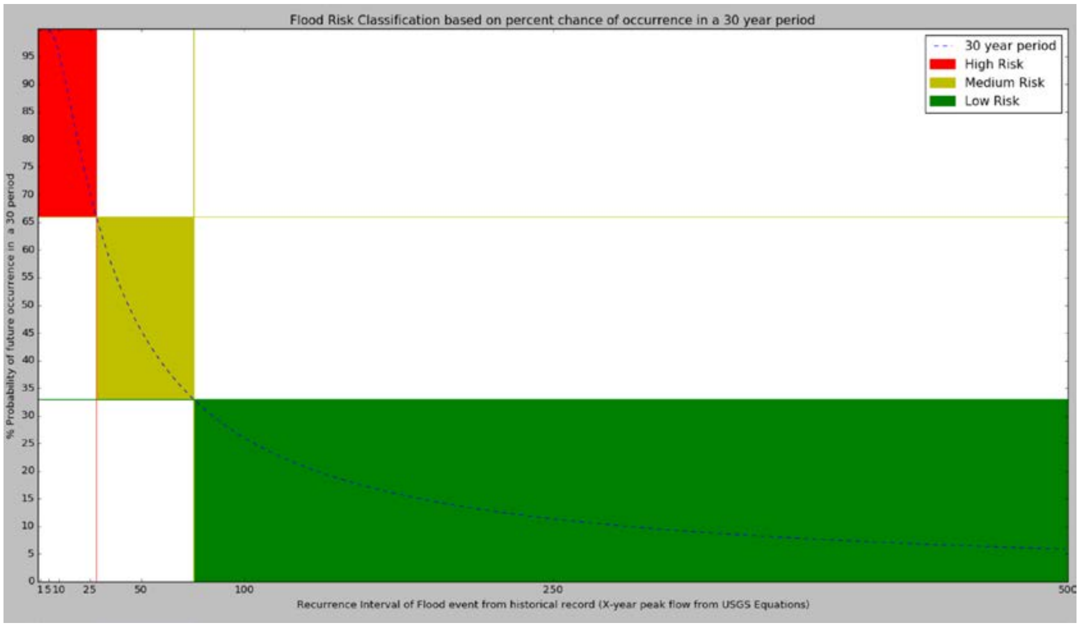




Comparing the headwater depth to the height of the road above the stream bottom at the crossing inlet (from lidar analysis conducted by TNC's spatial ecologist, Dan Coker), we can estimate what peak flow recurrence interval would likely overtop the road, and calculate the probability of this overtopping event happening in the next 30 years.

This flood risk analysis results are present as a complimentary component to the ecological prioritization with the intent that a culvert that is both a high priority for one or more ecological scenarios and is also a high-risk for flooding would be good candidate project that could address multiple concerns and potentially bring in additional partners and funding (e.g. town roads commissions, Maine DOT).

Figure 4-3 Peak Flows Plotted by probability of occurrence in a 30-year period. Colored squares indicate risk assignment.



5 Results, Uses, & Caveats

5.1 Results

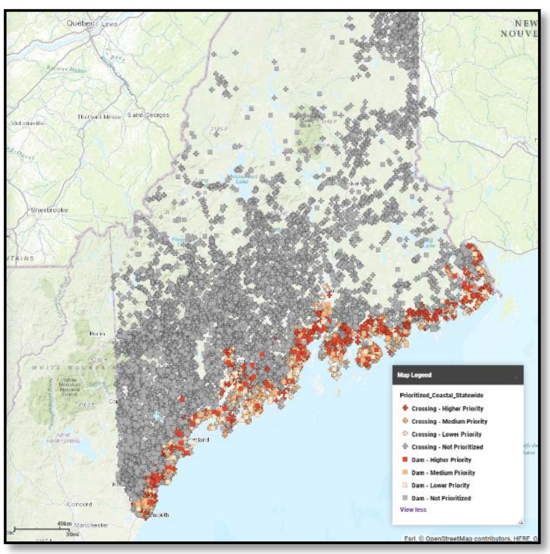
Results from the project include lists of barriers prioritized based on the five Workgroup – consensus scenarios listed in Section 4.2. These results can be viewed and downloaded from the Aquatic Barrier Prioritization app at https://maps.coastalresilience.org/maine/

As noted in Section 4.2 each scenario was run at a statewide extent, using the applicable input barriers for each scenario (e.g. see Section 4.2.1) . Each scenario was also run separately for each HUC 8 watershed in the state. This allows users to view results relative to the entire state or relative to their watershed of interest (results can also be run and viewed relative to other areas of interest using the custom analysis functionality of the tool, as described in Section 6.2). The subsections that follow focus on the results at a statewide extent for convenience. Depending on the particular question being asked, viewing the results at the extent of a given watershed may be more applicable than at a statewide extent (e.g. a watershed group working at the scale of a watershed may be more interested to find the highest priorities within that watershed, not how barriers within that watershed compare to others in the state).

Further, although the prioritization produces a sequential list of prioritized barriers, the precision with which metrics can be calculated in a GIS is not necessarily indicative of ecological differences. The workgroup was also keen to ensure that the results not portray the results with more nuance than is appropriate. Therefore, throughout this report and on the project web map, results are presented binned in Tiers where each Tier included 33% of the dams in the study area, representing “Higher”, “Medium,” and “Lower” priorities.

5.1.1 Coastal Anadromous Fish Scenario

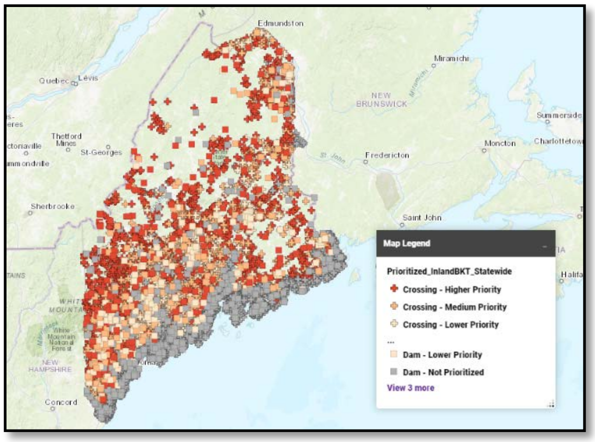
Figure 5-1 Result of the coastal anadromous fish scenario, displayed at the statewide extent



The first thing one notes when viewing the results of the coastal anadromous fish scenario at the statewide extent is that they are only calculated for barriers that fall on coastal streams. This was intended to limit the analysis to those barriers that are located in areas where coastal anadromous fish are likely to be found: smaller coastal streams and streams entering the tidal areas of larger rivers. Beyond this initial pattern, higher priority barriers are generally those that have no other downstream barriers, have a high percent of forest cover in their watersheds, and fall on mapped sea run brook trout streams.

5.1.2 Inland Brook Trout Scenario

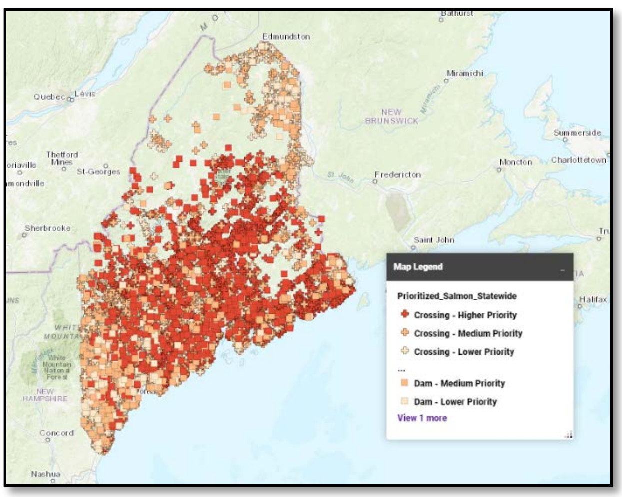
Figure 5-2 Inland Brook Trout scenario results



The inland brook trout scenario presents an inverse image to the coastal anadromous fish scenario - only those barriers that do NOT fall on coastal anadromous streams are prioritized. Given this input set of barriers, a clear pattern is visible: higher priority barriers tend to be found in the northern and western portions of the state. This pattern is driven, of course, by the input metrics selected for this scenario: there are many areas with aquifers or coarse sediments (selected as indicators of groundwater influence), rivers that have been modeled to have a high probability of having brook trout occurrence given a 2 C rise in water temperatures (largely owing to the high percent of forest cover and higher elevations in that part of the state, and rivers that have been identified by ME IF& W biologists as high priorities for brook trout. Note that the subset of barriers in the interior of the state that were not prioritized are on larger rivers and lack data for the brook trout occupancy metric.

5.1.3 Salmon Scenario

Figure 5-3 ESA Salmon Scenario results

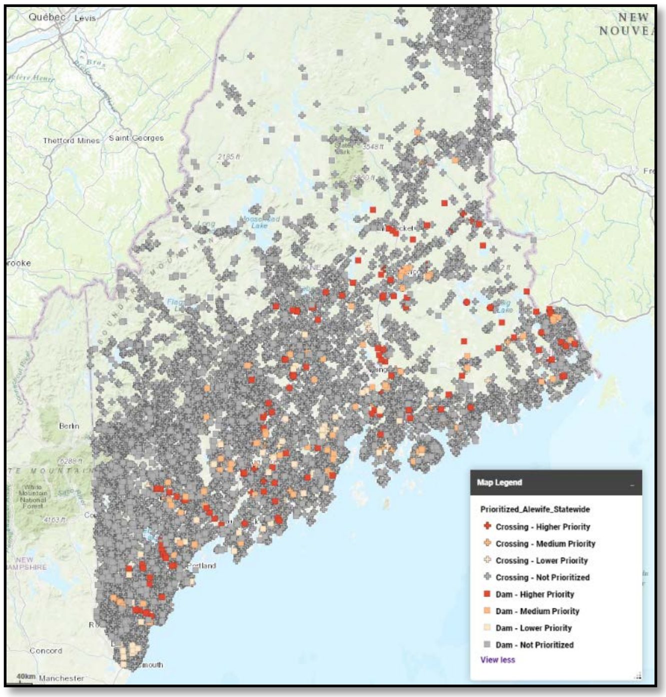


The ESA Salmon scenario was generated for all barriers in the state. This decision was made based on salmon's strong swimming ability and historic range throughout much of the state. High priority barriers are noted throughout much of the central portions of the state. This pattern is reflective of the delineation of NOAA's Critical Habitat designations. While several other metrics have equal or great weight, this metric is consistent across a large geography where others show much more variation across the region (e.g. the number of downstream barriers or upstream functional network length vary across the study area without consistent regard to where in the state they fall.

5.1.4 Alewife Scenario

The alewife scenario was run for those barriers that are located downstream of a mapped alewife spawning pond; that is they act as barriers to alewife trying to reach spawning ponds during the spring run. This scenario is possible due to both the clearly-defined habitat needs of alewife and the State of Maine's excellent data on the location of these ponds. When viewed at the statewide extent, the most striking aspect of these results is how sparse and evenly distributed they are. Simply identifying which barriers are downstream of alewife spawning ponds dramatically reduces the universe of barriers in the analysis and thus goes a long ways towards prioritizing which ones would be good candidates for restoration activities designed to benefit alewife. These are further refined using the size of the upstream alewife ponds, forest cover, and other downstream barriers.

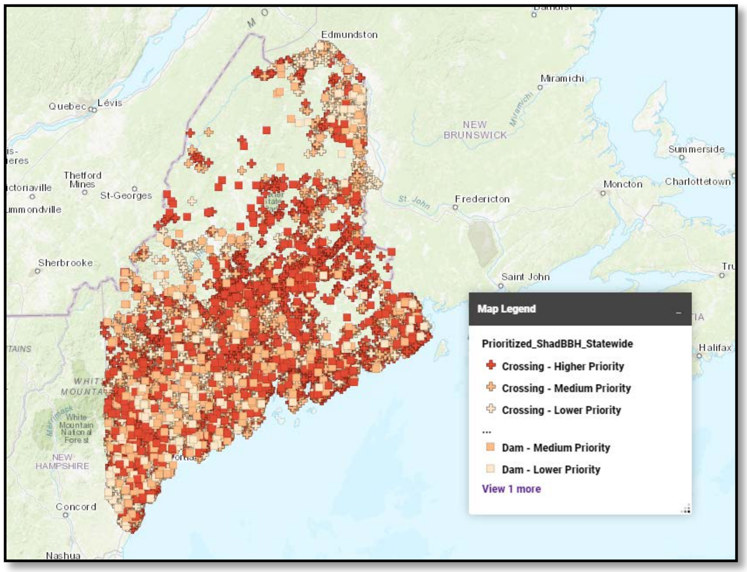
Figure 5-4 Alewife scenario



5.1.5 American Shad / Blueback Herring Scenario

The final consensus scenario was developed for American shad and blueback herring. Though these species share many of the same characteristics as alewife, the workgroup split them out as a separate scenario because they do not use spawning ponds as alewife do. All barriers in the state were included in this scenario.

Figure 5-5 American shad / blueback herring scenario results



5.2 Result Uses

The results in the Maine Statewide Barrier Prioritization Tool can be used in several different ways to inform and support on-the-ground efforts to restore aquatic connectivity. As discussed by McKay et al (2020) barrier prioritizations of this type include several strengths including their minimally prescriptive nature, allowing for the incorporation of additional site-specific knowledge. Thus, these results are best seen as a screening tool that can be layered with additional information on feasibility, opportunity, economic, and other factors.

- **Project Selection**: A primary use is to help managers direct their limited resources to projects that can have the greatest 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 do and will continue to play an important role in project selection). Directing resources where they can have the greatest impact is increasingly important as federal and state budgets shrink in our current fiscal environment.
- **Improve Understanding of Current Conditions**: Project results can be used to help direct managers to investigate previously unvisited dams to assess them for potential passage projects. In some cases this may reveal errors in the source data while in other cases it may direct attention to potential projects that hadn't been on considered previously.
- **Database of Ecologically Relevant Metrics**: Prioritization aside, the results form a database of metrics that can be used to investigate many aspects of aquatic connectivity on a dam-by-dam basis or other off-shoot analyses. As described further in Section 6, custom analyses can be run as if one or more dams have been removed. Metric values and the prioritization are recalculated as if that dam had been removed, thus allowing managers to assess the potential impacts of proposed projects.
- **Funding**: The prioritized results can be used both by managers seeking funding for a potential project as well as by funders looking for information to inform or support a funding allocation decision.
- **Watershed Analysis**: Subwatersheds can be assessed based on the project results. Summary statistics can be generated via the custom analysis tool to provide an understanding of potential opportunities for passage projects in watersheds across the region.
- **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.

5.3 Caveats & Limitations

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 among them, the results are *not intended to be a hit list* of dams for removal. There are many 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, by design, only considers ecological factors. It does *not include social, economic, or feasibility factors*, largely due to the fact that this information is difficult or impossible to capture through state-scale GIS data. These factors could be layered onto the project results through a subsequent site-scale analysis.

Results produced for 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 and if an opportunity arises it should not be rejected solely on the grounds that it does not rank out in one of the upper tiers in a scenario. 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 to help provide context for barriers and their impacts on aquatic connectivity across the state.

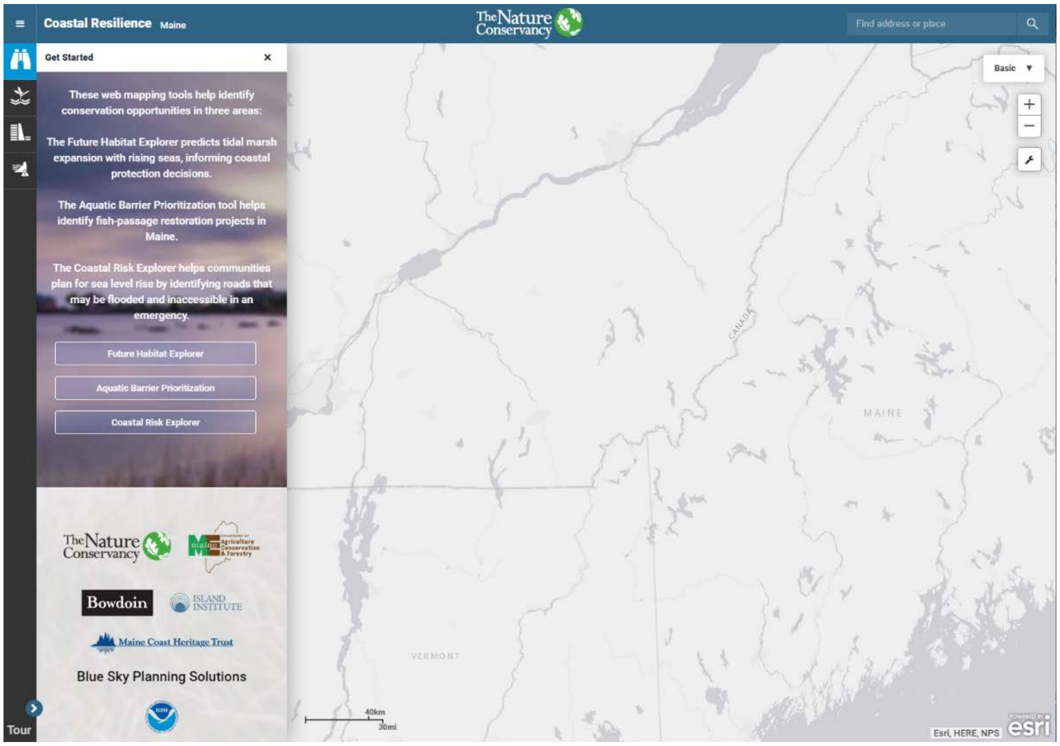
6 Web Map & Analysis Tools

Project results and a tool to run custom user-defined scenarios can be found at https://maps.coastalresilience.org/maine. This web mapping platform allows users to view results in the context of other relevant data including project data and various base maps, query results, download data, annotate a map, and print or save a map. 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). This data is consumed via a custom web map that was built using the Natural Solutions Toolkit (https://coastalresilience.org/natural-solutions/toolkit/), a web mapping framework built by TNC's Coastal Resilience program using the ArcGIS JavaScript API (https://developers.arcgis.com/javascript/). Likewise, the processing that underlies the custom analysis tool and upstream functional network generation tool runs on Python-based geoprocessing scripts served to the internet via ArcGIS Server Geoprocessing Services.

6.1 Web Map Organization

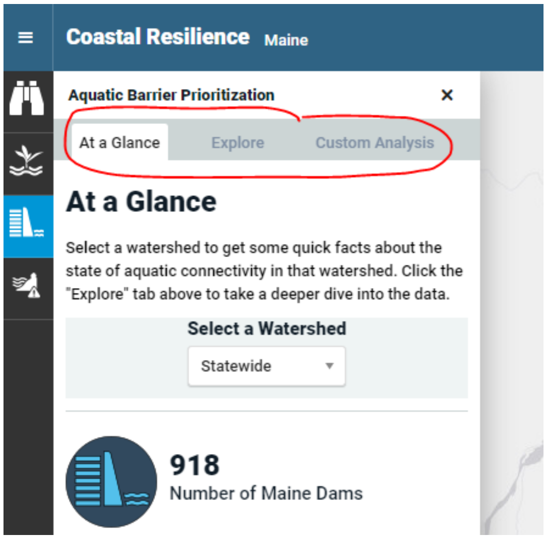
The Maine Statewide Barrier Prioritization tool resides within TNC Maine's Coastal Resilience platform. The platform hosts a variety of apps that are designed to support conservation planning in Maine. Upon first entering the map, a general welcome screen is presented to the user. Along the left side of this screen is a button to open the "Aquatic Barrier Prioritization" app (or other apps). It can also be opened by clicking on the dam icon on the far left side of the screen.

Figure 6-1: Web map welcome screen. Click on the dam icon or the “Aquatic Barrier Prioritization” button to open the and enter the map.



Once inside the app, the left side the map includes multiple tabs. The tabs are arranged from the more straightforward content to the more complex content. Thus, the “At-A-Glance” tab that is open by default presents simple summary statistics describing the number of barriers in the state and a simple measure of their impact on aquatic connectivity. Selecting a different HUC8 watershed with the dropdown menu will zoom to that watershed, display the barriers in the watershed and update the statistics to reflect the value for that watershed.

6.2 High-level navigation



There are 3 tabs within the tool:

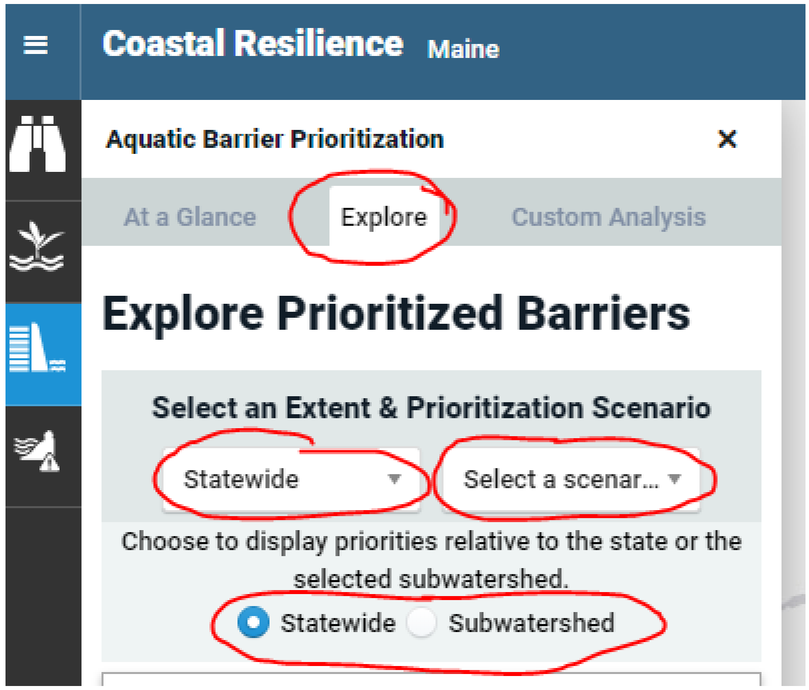
- *At-A-Glance*: provides simple, high-level summary info
- *Explore*: view and explore the details of the 5 consensus prioritization scenarios
- *Custom Analysis*: Run custom analyses using your own parameters

6.2.1 At A Glance

The At A Glance tab provides simple, high-level summary info for the whole state or by watershed on the tool pane on the left. Selecting a watershed from the dropdown will update the number of dams in Maine, number of public road-stream crossings barriers, and the average length of the functionally connected network in the watershed. The barriers displayed in the map (dams as black squares and road-stream crossings as black crosses) are updated and the watershed boundary appears when the selected watershed is changed.

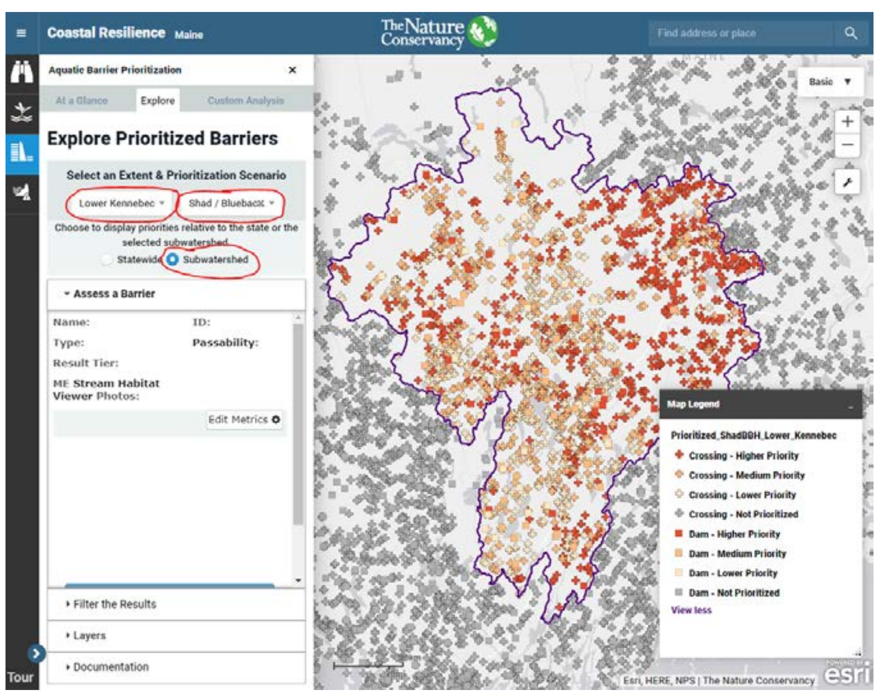
6.2.2 Explore

The explore tab contains the core functionality of the tool, allowing users to visualize, query, filter, and download the prioritized barrier data. After the Explore tab is clicked, the next step is to select an extent (statewide or a watershed), a scenario to display, and whether the results should be shown relative to the entire state or to the watershed.



When a watershed is selected, the map will automatically zoom to that watershed and display the watershed boundary. When a scenario is selected, a popup window will first provide a brief explanatory note about that scenario. Finally, if the option to display the priorities relative to the watershed is selected, the results in the map will be relative just to that watershed (e.g. a medium priority relative to the whole state may be a high priority relative to the watershed) .

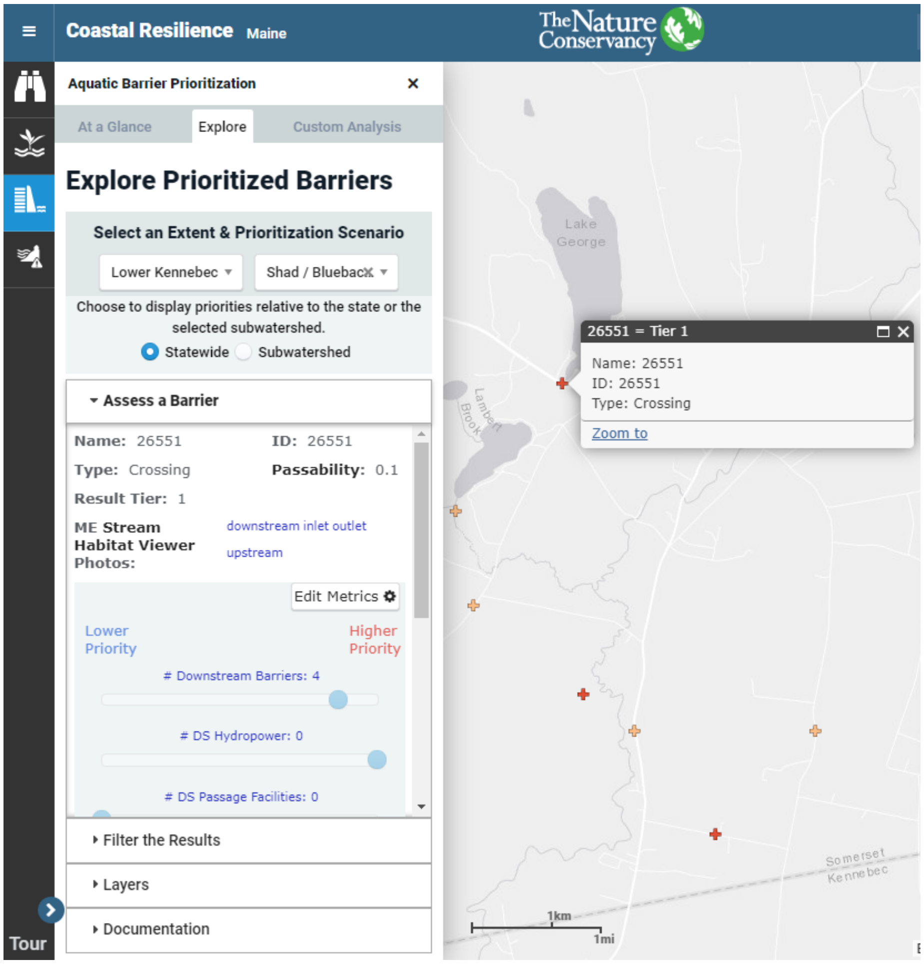
Figure 6-2 The shad/blueback herring scenario displayed relative to the Lower Kennebec watershed



Similar to the At A Glance tab, dams are represented by a square while road-stream crossings are represented by a cross. The color of the symbol represents its priority for the selected scenario. Dark red barriers are the highest priority, relative to the selected extent, while lighter shades of red are relatively lower priorities. Gray symbols are barriers that were not prioritized in that scenario. This could be due because they were explicitly excluded (e.g. only coastal barriers are assessed in the coastal anadromous scenario) or because they couldn't be prioritized due to a lack of data (e.g. some of the metrics used in the inland brook trout scenario are not available for barriers on large rivers).

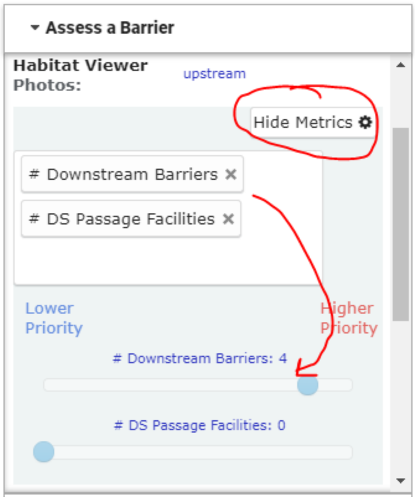
6.2.2.1 Assess a Barrier

When a barrier on the Explore tab is clicked, information about that barrier is displayed under the "Assess a barrier" pane of the tool. Information displayed includes the name, ID, type of barrier, passability score, flood vulnerability (if available), and result tier (relative to the selected extent) of the barrier. If available, links to photos of the barrier on the Maine Stream Habitat Viewer are included. Below this header information, individual metric values are displayed. In the screenshot at left, for example, the selected



barrier has 4 other barriers downstream. The blue dot below the metric name indicates how that barrier performs relative to other barriers (in the selected extent) for that metric. The further to the right the blue bot is, the higher priority the barrier is, based on that metric. So in this example having 4 other barriers downstream of it places this barrier towards the "higher priority" end of the spectrum.

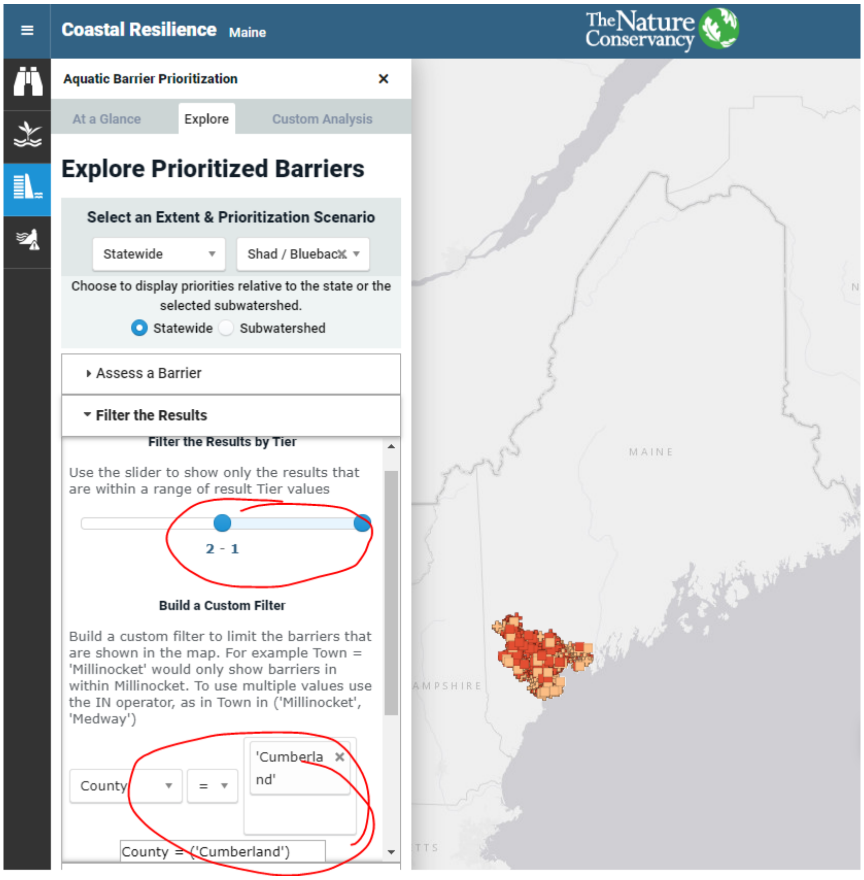
By default, the metrics that are displayed when a barrier is clicked are those that were used in the selected scenario (shad / blueback herring in this example). If the scenario is changed and the barrier is clicked again, the metrics displayed will correspond to the new scenario. Alternately, the "Edit Metrics" button can be clicked and the metrics that are displayed altered. Here, the metrics have been altered so only two are being displayed. Clicking in the white space will expose a dropdown menu with the full list of metrics that can be chosen.



Finally, at the bottom of the "Assess a barrier" pane are buttons to download the consensus results in either Excel format or as a zipped file geodatabase for use in GIS.

6.2.2.2 Filter the Results

Below the "Assess a barrier" pane is a pane that presents the option to "Filter the Results" in the map. This can be done either using a slider to show only, for example, medium and higher priority barriers, or by building an expression to apply a more complex filter. The slider and expression work together. In the example at left, only barriers in Tiers 1 & 2 in Cumberland County are shown in the map.



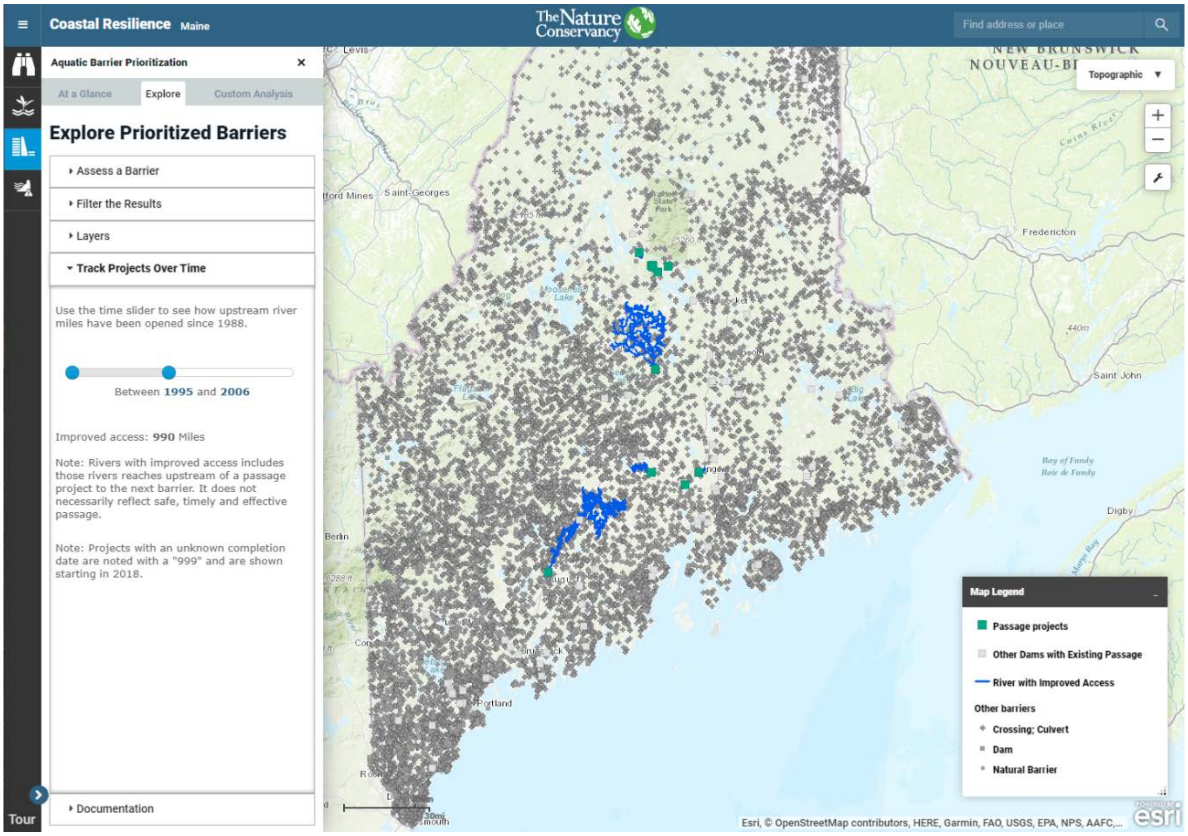
6.2.2.3 Layers

Below the filter pane is the Layers pane, which includes options to turn on other contextual layers and adjust the transparency of all layers.

6.2.2.4 Track Projects Over Time

Below the Layers pane is a pane that houses functionality to map connectivity projects over time. TNC in Maine has compiled aquatic connectivity projects (dam removals, culvert upgrades) performed since 1995 by TNC and partners. A slider bar is provided that can be sued to define a time period within which to track projects and the upstream river miles that have improved access as a result of the project.

Figure 6-3 Upstream river miles with improved access between 1995 and 2006



In addition to displaying the river network with improved access on the map, a cumulative value for the selected timeframe is shown. This value is based on the project a hydrography (see Section 3.2) and as it is not intended to be a species-specific value, does not distinguish by habitat type.

It is readily acknowledged that the upstream river miles with improved access is an imperfect measure of aquatic connectivity improvement. First, "improved access" does not necessarily equate to safe, timely and effective passage for all species of interest. The installation of a fish passage facility at a dam can be used as an example of a project which can improve upstream access for fish species of interest but not necessarily adequately for the needs of species of interest.

Further, upstream miles opened are not necessarily the best indicator of progress towards connectivity goals. For coastal anadromous species, increasing miles that are connected to the ocean may be a primary goal, whereas for inland brook trout, the length of the recombined connected network may be more important than the directional measure of upstream miles.

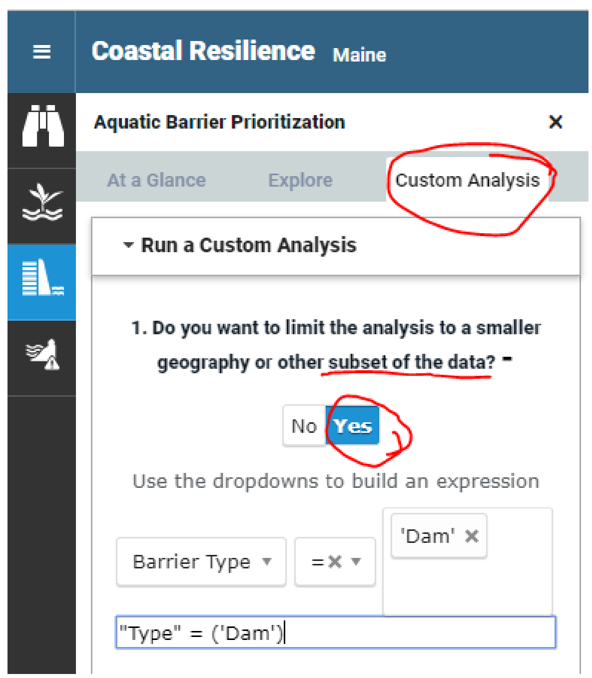
Nevertheless, assessing upstream miles provides a consistent measure that is not species-specific and that can be expressed as a cumulative value over years to track progress in a way that is more informative than simply the number of projects. As TNC in Maine refines its freshwater measures and goals in the coming months or years, the metric used to track projects over time may be updated.

6.2.2.5 Documentation

Finally, at the bottom of the tool window is a Documentation pane which includes descriptive text about the tool and a link to the instructions in this section of this report on the basic use of the tool.

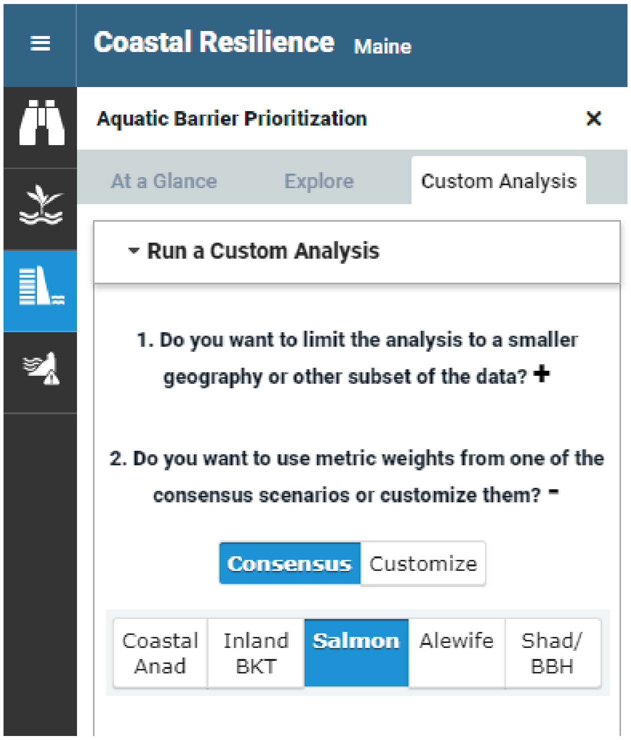
6.2.3 Custom Analysis

The Custom Analysis tab provides an interface for running a custom prioritization scenario. The interface is set up as a series of questions to guide the user through the process of entering parameters for a custom analysis.



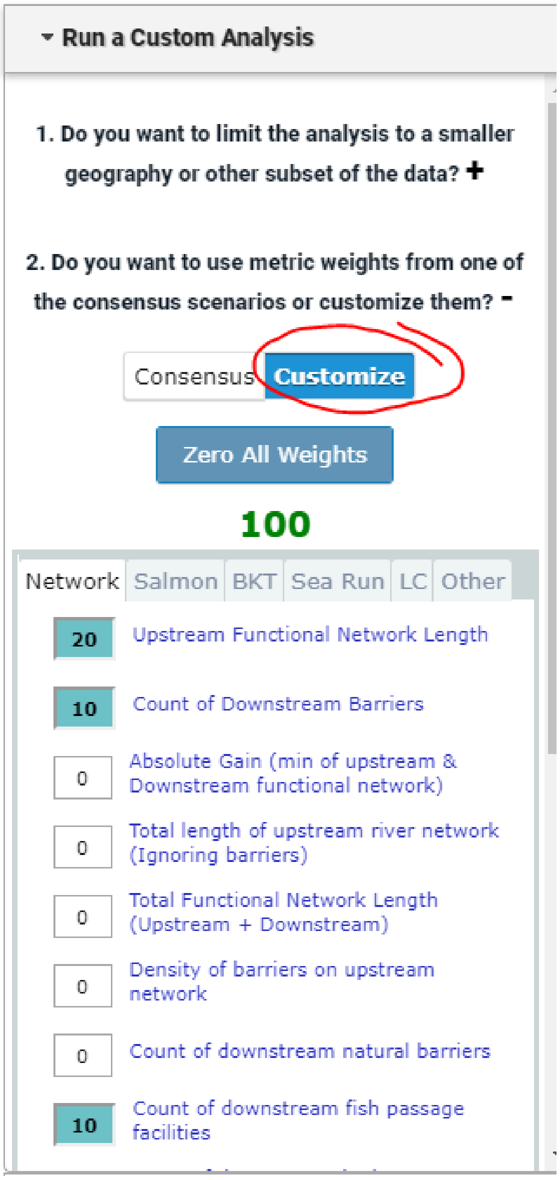
The first question asks: "Do you want to limit the analysis to a smaller geography or other subset of data?". Clicking on the question expands a toggle button where you can answer yes or no. If you select yes, a dialog, much like the filter dialog in the "Explore" tab, is exposed where you can define what barriers you want to include in the analysis. These can be by geography (e.g. County = 'Cumberland' will only prioritize barriers in Cumberland County) or by some other attribute (e.g. Barrier Type = Dam will only prioritize dams). Using the dropdown menus will help insure correct syntax, though it is also possible to type directly into the input box. Filter expressions must comply with ArcGIS definition query syntax (see the ArcGIS help for more info.) **Note**: filter barriers does not change the metric values themselves, only which barriers are being prioritized. So if only dams are included in custom analysis, the "Count of downstream barriers" metric will still include crossings.

The next question asks if you want to use the metric weights from one of the consensus scenarios or customize them. If you choose to use the consensus weights, you'll be given the option to select one of the 5 scenarios. Here, the "Salmon" scenario has been selected, so the custom analysis will use these weights.

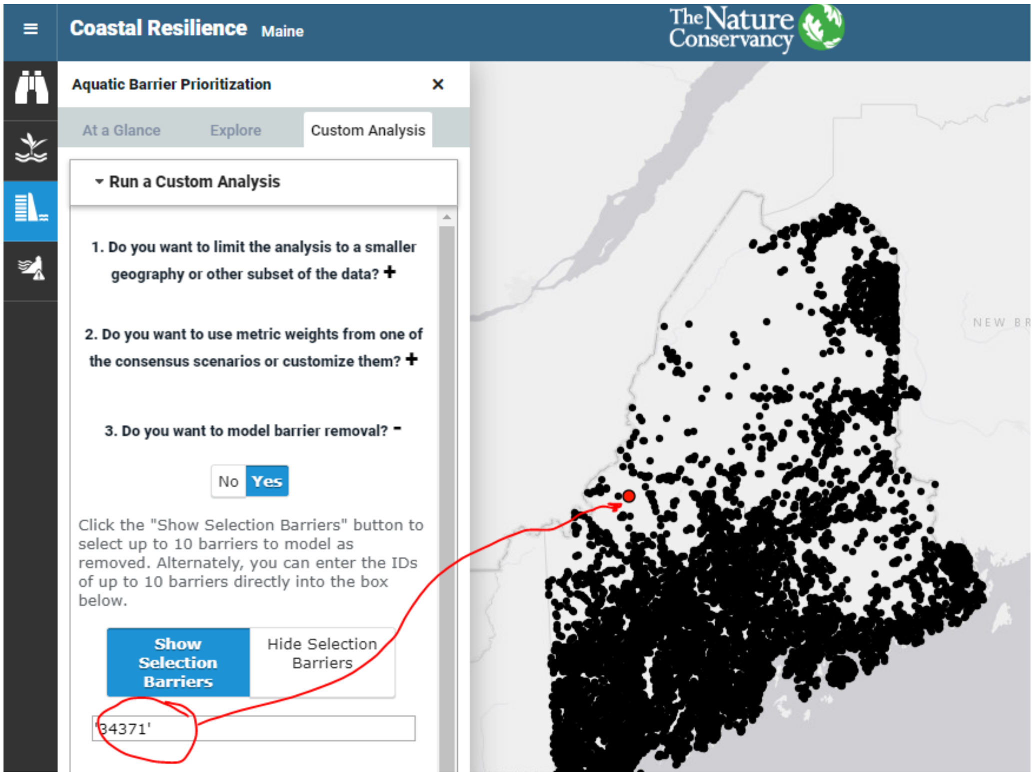


If you choose to customize metric weights, a list of all of the metrics, organized in tabs by theme will be displayed. Weights can be allocated according to your preference, so long as they sum up to 100. If you previously selected a consensus scenario, the weights for that scenario will be displayed.

Clicking on a metric name will bring up a popup with a definition for that metric. [**Note**: metric definition slides are still being developed and are not available for all metrics in the Development version of the tool].



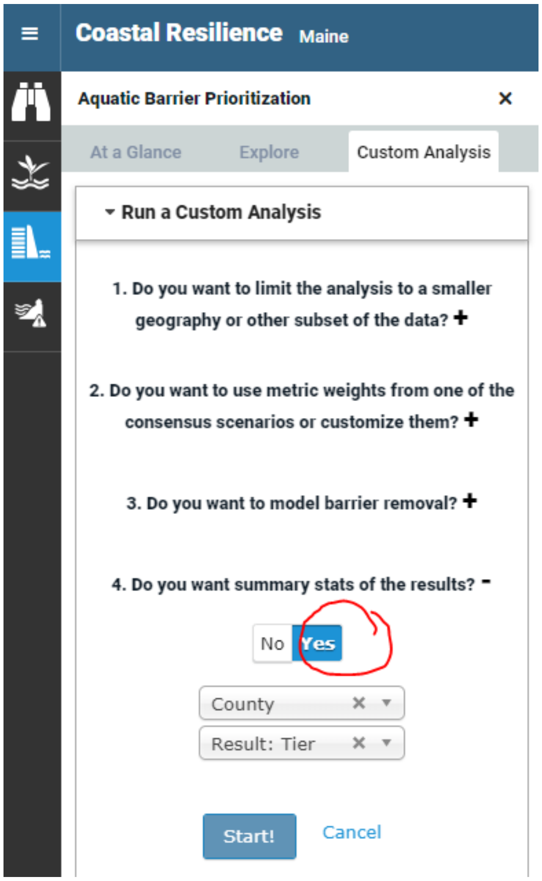
The next question asks if you'd like to model the removal of one or more barriers. Unlike applying a filter to the input barriers (the first question of the custom analysis), if barriers are modeled as removed they are truly removed from the analysis, meaning that the analysis will be run as if they didn't exists. Thus, all metric values for surrounding barriers are updated (e.g. the barriers upstream will have one fewer other barriers in the "Count of downstream barriers").



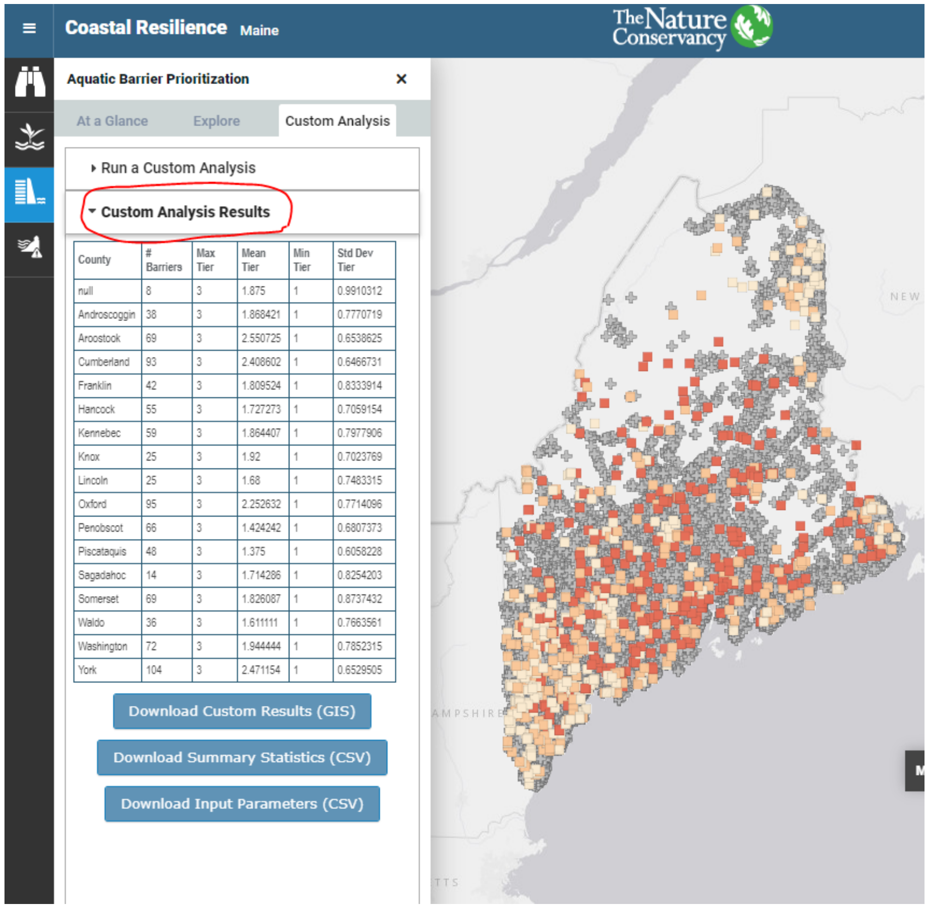
Selecting "Show Selection Barrier" will display a map of all of the barriers in the state. Clicking on one barrier will add it's site ID to the input box. If known, the SiteID can be type into the box as well. Up to 10 barriers may be modeled as removed in a custom analysis.

Finally, simple summary stats can be run on the custom analysis results. These stats can be run within a town, county or watershed and can be used to understand if there are, for example, many high priority barriers with a given extent.

Clicking the "Start" button will commence the custom analysis. The time required run the analysis will vary depending on the number of metrics used and especially whether any barriers are modeled as removed and can range from ~10 seconds to a couple minutes.



When complete, the results will display in the and the “Custom Analysis Result” pane will open with buttons to download the custom results and input parameters, as well as a table of summary stats (if used in the analysis). In this example, only dams were prioritized using the salmon scenario weights.



It is strongly recommended that input parameters always be saved with results. File names are set up with a date stamp so inputs and results can be easily tracked.

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8 Appendix I: Maine Statewide Barrier Prioritization Tool Workgroup

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Dan McCaw	Penobscot Indian Nation
Dan Coker	The Nature Conservancy in Maine
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Ed Basset	Passamaquoddy at Sipayik
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Erik Martin	The Nature Conservancy in Maine
Gail Whipplehauser	Maine Department of Marine resources
Hadley Couraud	The Nature Conservancy in Maine
Jacob Amen	Wells National Estuarine Reserve
Jeremy Bell	The Nature Conservancy in Maine
Joshua Royte	The Nature Conservancy in Maine
Jeff Reardon	Trout Unlimited
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Miranda Nemeth	Atlantic Salmon Federation
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Nicholas Popoff	Maine Department of Marine resources
Pat Sirois	Maine Forest Landowners
Sam Roy	University of Maine
Sean Ledwin	Maine Department of Marine resources
Sara Haggerty	Maine Audubon
Sharri Venno	Houlton Band of Maliseets
Shri Verrill	Mid Coast Conservancy
Slade Moore	Maine Coastal Program

9 Appendix II: Input Datasets

Dataset	Source	Description
Dams	Dams were originally source from the Maine Office of GIS. These data were maintained and edited by TNC in Maine and Alex Abbott, Contractor to USFWS	This dataset represents point locations of dams and impoundments in Maine at 1:24000 scale. These data were aligned *"snapped") to the project hydrography for use in the analysis.
Natural Barriers	Natural barriers were obtained from multiple sources and are maintained in the Maine barrier database by TNC in Maine and Alex Abbott, Contractor to the USFWS. Many natural barriers have been surveyed as part of the road-stream crossings barrier survey efforts and have been classified as barriers, partial barriers or non-barriers	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 results as potential candidates for fish passage projects.
Road-stream crossings	Road-stream crossing data are from the Maine stream survey crew database maintained by TNC in Maine and Alex Abbott, Contractor to the USFWS.	Point dataset representing road-stream crossings.
Hydrography	High-Resolution (1:24,000)National Hydrography Dataset. Modified to a single-flowline dendritic network.	This feature class is a single flowline dendrite derived from the high resolution NHD. Canadian data for rivers downstream of Maine were included.

Land Cover	2016 National land Cover Database (NLCD2016)	Land use / land cover data from the NLCD2016. This 30m gridded data was grouped into natural and agricultural. (Developed was addressed via the impervious surface data). 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.
Conservation Land	The Nature Conservancy	Dams that lie on conservation lands are identified. Additionally, the % of conservation land is assessed with a 100m buffer of each dam's upstream and downstream functional river networks.
Fish species of management concern	Maine Dept of Inland Fish and Wildlife	River and lakes with suspected and confirmed occurences of species of management concern including: black crappie, largemouth bass, muskellunge, northern pike, smallmouth bass and walleye
Alewife ponds	Maine Dept of Marine Resources	Ponds with known spawning runs of alewife.
Brook trout priority streams	Maine Dept of Inland Fish and Wildlife	Streams identified by MDIFW regional biologists are priorities for brook trout conservation
Heritage ponds	Maine Dept of Inland Fish and Wildlife	Heritage ponds for brook trout that are self sustaining; not stocked in at least 25 years
Smelt sites	Maine Dept of Marine Resources	Points symbolize documented rainbow smelt spawning sites and waterways. Sites have been identified as historical or active spawning grounds by one of three sources: MeDMR list of known spawning sites written in 1971; GIS file created in 1984 from information gathered by the USFW and MeDMR marking probable spawning sites and waterways used for passage for all diadromous species, attribute table allowing species specific information to be selected; and surveys conducted by Maine Marine Patrol in 2005, 2007, 2008 and 2009 in which officers visited streams identified in 1971 and 1984 as well as streams where they knew active spawning occurs. In 2005, 2007, 2008 and 2009, the presence of adults or the presence of eggs was used to confirm spawning at the location.
Aquifers	Maine office of GIS	Polygons of significant aquifers (glacial deposits that are a significant ground water resource) for Maine mapped at a scale 1:24,000, from the Department of Conservation, Maine Geological Survey.

Coarse sediments	The Nature Conservancy, Eastern Conservation Science	The Nature Conservancy's Ecological Land Units. Anderson et al 2006
Salmon Critical habitat	NOAA's National Marine Fisheries Service (NMFS)	CriticalHabitatWatershedOccupation is a digital hydrologic unit boundary layer of Level 5 (10-digit) WATERSHEDs for Maine that describe salmon critical habitat occupation status. The source data was developed by adding to the MeGIS Level 5 HUC 10 database, thus extending the spatial depiction of Watershed boundary regions to describe occupation status of salmon in Maine.
Salmon habitat model	Jed Wright and Alex Abbott, U.S. Fish and Wildlife Service, Gulf of Maine Coastal Program; Tara Trinko Lake, NOAA Fisheries Service, Maine Field Station; John Sweka, U.S. Fish and Wildlife Service, Northeast Fishery Center	GIS-based habitat model that predicts the amount of accessible Atlantic salmon rearing habitat throughout the Gulf of Maine Atlantic Salmon DPS. The model was developed using data from habitat surveys conducted in the Machias, Sheepscot, Dennys, Sandy, Piscataquis, Mattawmkeag, and Soudabscook Rivers. The model uses reach slope derived from contour and digital elevation model (DEM) datasets, cumulative drainage area, and physiographic province to predict the total amount of rearing habitat within a reach. The variables included in the model explain 73% of the variation in rearing habitat.
Salmon priority watersheds	Compiled by Jed Wright USFWS GOMCP, with input from USFWS, DMR and NOAA salmon biologists	This dataset presents HUC 12 subwatersheds in Maine classified by the total amount of modeled Atlantic salmon rearing habitat they contain. The data can be used alone or in combination with other fish habitat data to identify potential areas for habitat restoration. Each subwatershed represents one of three levels of priority based on how many salmon habitat units (100 square meters each) it contains. In particular, any of the Priority 1 and Priority 2 subwatersheds could be used as a "focus area" to direct restoration efforts for salmon habitat. Priority classifications were assigned separately for each of the three Salmon Habitat Recovery Units (SHRUs).
Sea run brook trout habitat	Trout Unlimited	NHD -HR river reaches identified as sea-run brook trout streams
Tidal waters	Maine Geological Survey	Extent of the highest annual tide under current conditions and various sea-level rise scenarios. https://www.maine.gov/dacf/mgs/hazards/slr_ss/index.shtml
Brook trout occupancy	EcoSheds.org	The SHEDS brook trout occupancy model predicts probability of occupancy for catchments smaller than 200 km^2 in the northeastern U.S. from Maine to Virginia.

10 Appendix III: Glossary and Metric Definitions