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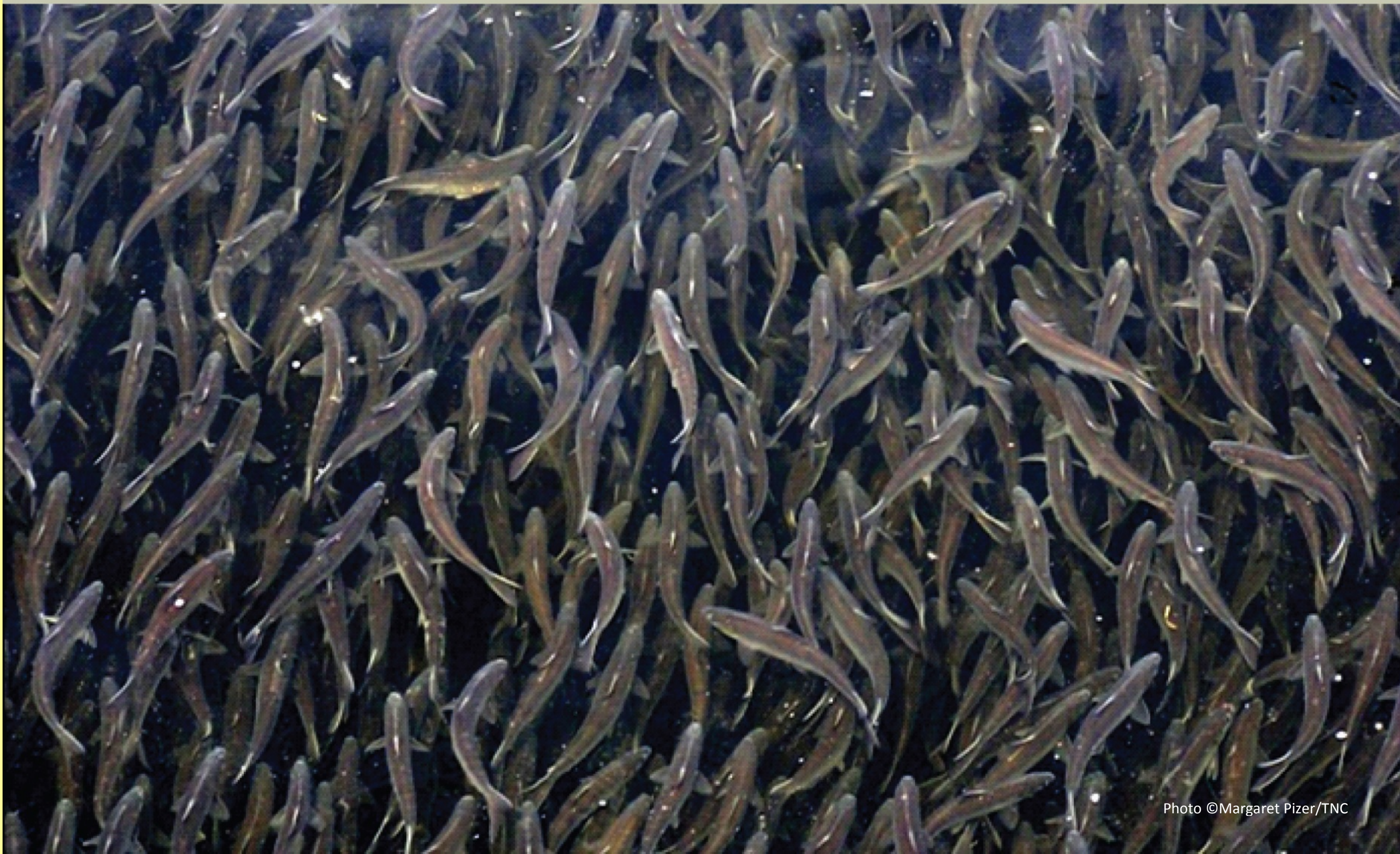
Chesapeake Fish Passage Prioritization

An Assessment of Dams in the Chesapeake Bay Watershed

2019 Revision

August 2, 2019



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Technical support for tool was provided by TNC's Spatial Data Infrastructure and Freshwater Network teams including Jeff Zurakowski and Dave Harlan.

Finally, the 2019 revision of the tool would not have been possible without the involvement and support of all of those who worked on the original version of the tool, please refer to the Acknowledgements of that report (Martin and Apse 2013) for a more complete listing of those involved.

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1 Foreword to the 2019 Revision

The Chesapeake Fish Passage Prioritization has been used since 2013 to help identify potential dam removals and fish passage projects, secure and allocate funds for these projects, and help to communicate the importance of aquatic connectivity in the Chesapeake Bay watershed. Starting in 2017, The Nature Conservancy began a revised version of this analysis. Revisions completed include:

1. Updates to the web map & tool to use a modern, JavaScript-based, web mapping framework. Originally, the tool was built using the Flash programming language which is being phased out of most browsers.
2. Incorporation of data updates that had been gathered since the publication of the original analysis. These primarily include updates to the dam data, but also other datasets including anadromous fish habitat, land cover, and other data.
3. Incorporation of road-stream crossings (i.e. culverts) which, like dams, can inhibit aquatic organism passage, into the analysis.
4. Development of new functionality in the tool that allows users to generate an upstream functional river network from any point selected in the map,
5. Development of new functionality to track upstream river miles opened over time.
6. Automation of the analysis so that changes resulting from updates to the dam data, due to on-the-ground actions or data improvements, are manifested in the tool on a weekly basis.

This revised report adds sections to address these changes (in particular Sections 6 and 7), modifies the original report elsewhere as needed (e.g. revised weights for the resident fish scenario in Table 4-3), while leaving other sections unaltered from the original 2013 version.

For additional information on the approach used in this analysis, please refer to the peer reviewed journal article that covers this and its sibling projects: Assessing and Prioritizing Barriers to Aquatic Connectivity in the Eastern United States (Martin 2018).

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. Through the signing of multiple Chesapeake Bay program agreements, the fish passage workgroup has committed to opening 3,357 stream miles to benefit Alewife, blueback herring, American shad, hickory shad, American eel or brook trout. In addition, 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 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. Notably, essentially all projects have had state resource agency involvement. The majority of the 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: Bloede Dam, the first barrier to migratory fish on the Patapsco River before its removal in 2018

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 Northeast Aquatic Connectivity project (Martin and Apse 2011) assessed dams in the Northeast United States based on their potential to provide ecological benefits for one or more targets (e.g. anadromous fish species or resident fish species) if removed or bypassed. Funded by the NOAA Restoration Center and USFWS, the Chesapeake Fish Passage Prioritization (CFPP or “the project”) project grew out of and builds on the conceptual framework of the Northeast Aquatic Connectivity. The sections that follow detail the data, methods, results, and tools developed for the CFPPP.

2.2 Approach

2.2.1 Workgroup

The CFPP project was structured around a project Workgroup, the Chesapeake Fish Passage 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 regular virtual meetings as well as in-person 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 a state agency team to complete the Northeast Aquatic Connectivity project. In addition to providing input throughout the project, the Workgroup members form a core user base, active in aquatic connectivity restoration and with a direct and vested 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 are we prioritizing for the benefit of? and 2) what aspects of a dam or its location would make its removal help achieve the objective? This process of selecting targets and particularly the metrics that would be used to evaluate the dams was both a collaborative and subjective process. The Workgroup selected three targets: diadromous fish, resident fish, and more specifically brook trout. Different metrics were used to create three separate prioritization scenarios for these three targets resulting in three prioritized lists of dams.

Figure 2-2: Chesapeake Bay watershed

2.2.2 Project Extent

The Chesapeake Bay watershed covers over 64,000 square miles, has over 140,000 miles of mapped rivers and streams, and over 5,000 dams. With the bulk of the project funding coming from NOAA and its focus on migratory fish species, the project was focused on the three main states of the Chesapeake Bay watershed with significant diadromous fish habitat: Virginia, Maryland, and Pennsylvania.

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, diadromous fish habitat, and natural waterfalls. Additional datasets were brought in as needed to generate metrics of interest to the Workgroup. These datasets include land cover & impervious surface data, roads, rare species data, 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 dam'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 target dam's functional river network is bounded by other dams, headwaters, or the river mouth, as is illustrated in Figure 2-1. A dam's total functional river network is simply the combination of its upstream and downstream functional river networks. The total functional network represents the total distance a fish could theoretically swim within if that particular dam was removed.

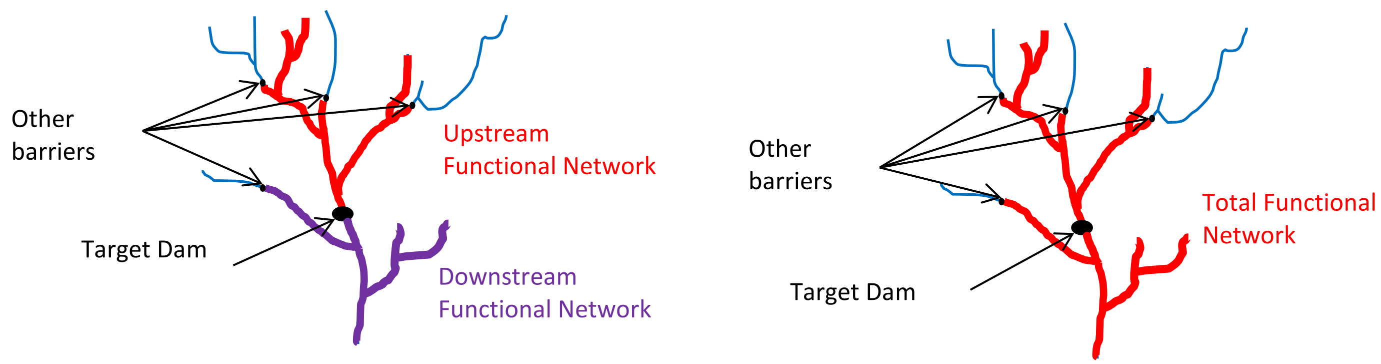


Figure 3-1: Conceptual illustration of functional river networks

3.1.2 Watersheds

For any given dam, 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.

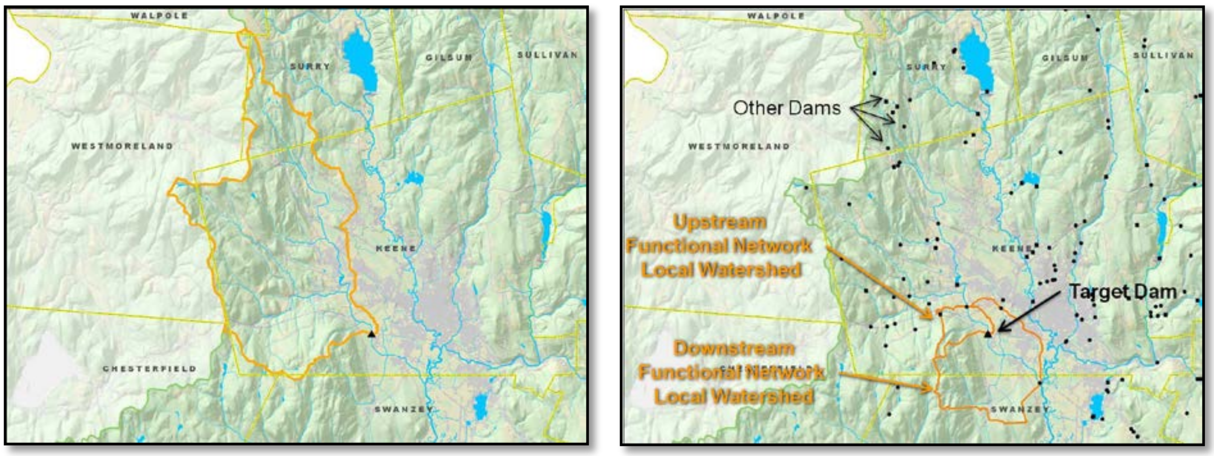


Figure 3-2: The contributing watershed is defined by the total drainage upstream of a target dam. The upstream and downstream functional river network local watersheds are bounded by the watershed for the next dams up and down stream.

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 catchment drainage size thresholds developed for the Northeast Aquatic Habitat Classification System (Olivero and Anderson 2008), calculated for each segment of the project hydrography and in turn assigned to each dam (Figure 2-3). Size classes are 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).

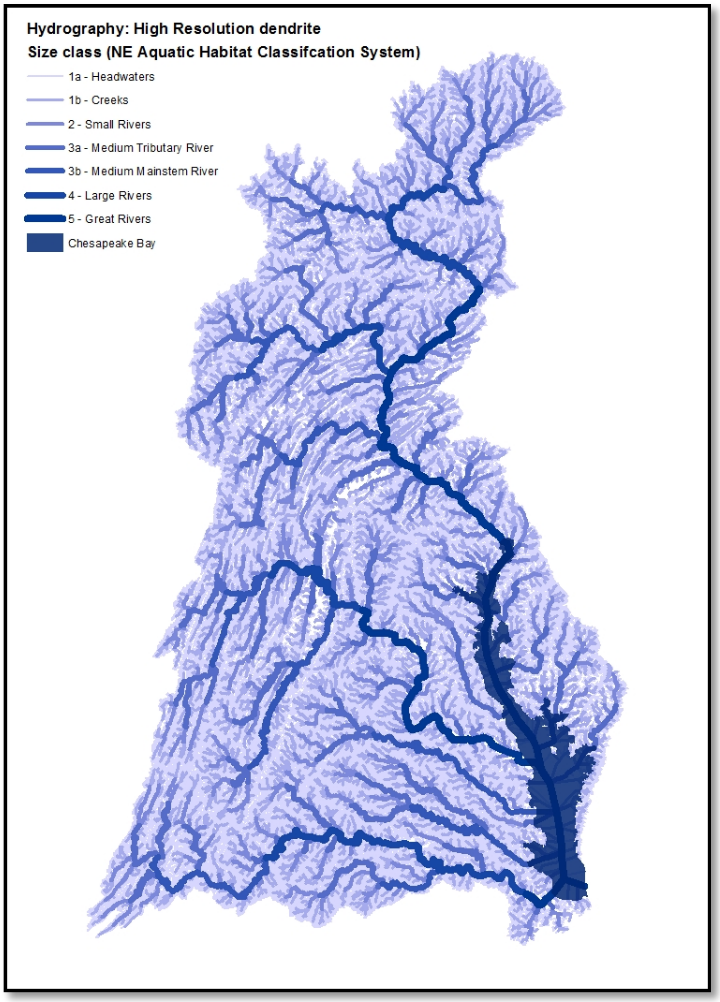


Figure 3-3: Size class definitions and map of rivers by size class in the Chesapeake Bay watershed.

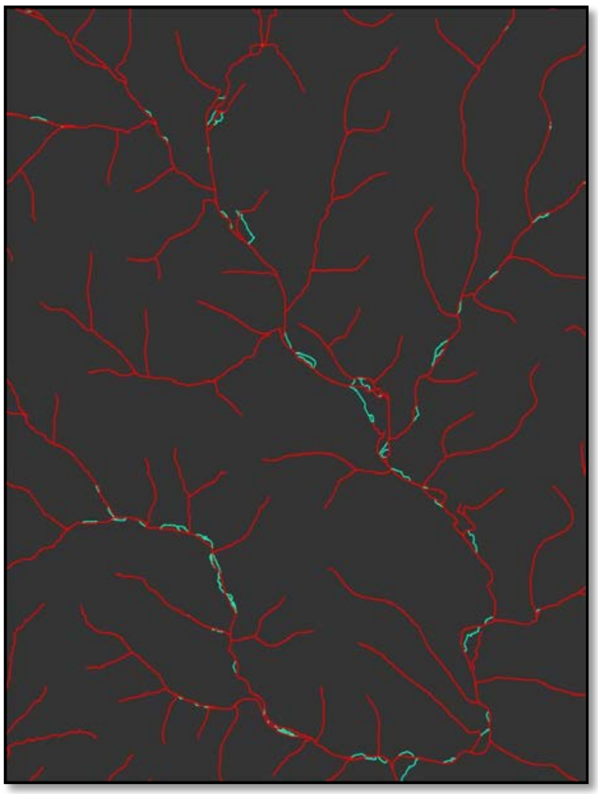
1a) Headwaters (<3.861 mi^2)
1b) Creeks (>= 3.861<38.61 mi^2)
2) Small River (>=38.61<200 mi^2)
3a) Medium Tributary Rivers (>=200<1000 mi^2)
3b) Medium Mainstem Rivers (>=1000<3861 mi^2)
4) Large Rivers (>=3861 < 9653 mi^2)
5) Great Rivers (>=9653 mi^2)
(Defining measure = upstream drainage area)

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 (NHD). 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 2-4). Unlike the medium-resolution NHDPlus, which includes an attribute to select the mainstem of a river from a braided section, the High-Resolution NHD has no such attribute, thus this process was largely a manual one. To do this, a Geometric Network was created from the hydrography in ArcGIS 10.0 so that offending loops and bifurcations could be selected. 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.



In Maryland and Pennsylvania dendrites had been previously developed by USGS using an older (2004) hydrography for their StreamStats program. To speed up the editing process, these older dendrites were obtained from the USGS and joined to the current hydrography using the “REACHCODE” attribute. Those records in the current data which did not join were therefore loops or other extraneous line segments. This process identified and removed the vast majority of problem segments. However, since the hydrography had changed between the two versions, some additional manual editing was required. In Virginia, where no previous dendrite existed, TNC partnered with the USGS Virginia Water Science center which had an unrelated need for the same dendrite. Subwatersheds in Virginia were divvied up and manually edited.

The result of this process was a single-flowline dendrite, based on the current (as of 2011) High Resolution NHD, for the entire Chesapeake Bay watershed. This dendrite (hereafter referred to as the "project hydrography") was then further processed using the ArcHydro toolset in ArcGIS 10 to establish flow direction, consistent IDs, and the 'FromNode' and 'ToNode' for each segment. Additional processing using ArcGIS Spatial Analyst, ArcHydro 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 slope for each line segment.

3.3 Dams

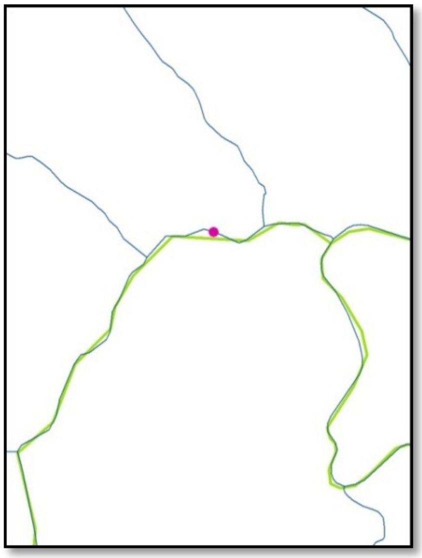
Dam data was obtained primarily from the Northeast Aquatic Connectivity project. Dam data for the Northeast Aquatic Connectivity project was obtained from several sources including state agencies the US Army Corps' National Inventory of Dams (NID), and the USGS Geographic Names Information System (GNIS) database. Additional dams were provided by the Chesapeake Bay Program office, as well as by Workgroup members.

Data preprocessing and review began after all available data was obtained for each state from the sources listed above. In order to perform network analyses in a GIS, the points representing dams and must be topologically coincident with lines that represent rivers. This was rarely the case in the dam datasets as they were received from the various data sources. To address this problem, dams were "snapped" in a GIS to the project hydrography (Figure 2-5).

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

Dams that were obtained from the Northeast Aquatic Connectivity project had previously been snapped to the medium resolution (1:100,000) NHD and error checked as part of that project's review process. Thus, it was assumed that dams obtained from that project were in the correct location, and only needed to be snapped to the project hydrography from the medium resolution hydrography (Figure 2-6).

Figure 3-6:Dam point snapped to the project hydrography (blue) from the medium-resolution NHD (green).



Snapping was performed using the ArcGIS Geospatial Modeling Environment extension (Beyer 2009). Although snapping is a necessary step which must be run prior to performing the subsequent network analyses, it also can introduce error into the data. For example, if the point in Figure 2-5 is, in fact, a dam on the main stem of the pictured river, the snapping will correctly position it on the hydrography. If, however, the point represents a farm pond next to the main stem the snapping will still move it, incorrectly, onto the hydrography. A snapping tolerance, or "search distance" can be set to help control which points are snapped. The project team selected a 100m snapping tolerance and developed a review process to error check the results.

The review process for dams that were obtained from the Northeast Aquatic Connectivity project involved comparing the snapping distance as well as the "REACHCODE" attribute, which persists between different versions of the NHD. Dams which snapped to the project hydrography within the 100m snap tolerance and which had matching REACHCODEs were considered to be in the correct location. All other dam locations were manually reviewed and edited if necessary.

For the 2019 version, edits to dam data were solicited and collected from Workgroup members. Many of these edits had been submitted in the intervening years following the conclusion of the 2013 analysis. Edits included new dams that had not been included in any of the source databases, dams that were moved to their correct location, and dams were taken out that had been removed as a result of on-the-ground actions. Moving forward, authorized users are able to make edits to the dam data through the data editing portal (See Section 7.1). These edits are used to update the analysis on a weekly basis, thus helping to keep the analysis relevant as data improves.

3.4 Diadromous Fish Habitat

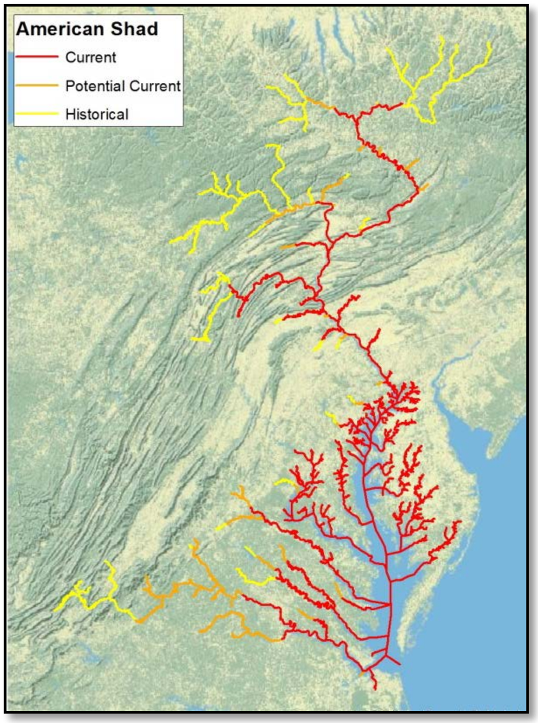
Identifying opportunities to best improve aquatic connectivity for the benefit of diadromous fish populations was one of the key goals of the project. Diadromous fish habitat downstream of a dam was one of the most important factors chosen by the Workgroup for the diadromous fish benefits scenario to determine which dams have the greatest potential for ecological benefit if removed or mitigated.

Figure 3-7: Field sampling fish on the Patapsco River in Maryland. Field observations for 8 diadromous fish were incorporated into the project's diadromous fish habitat layers.

Baseline habitat data was collected for American shad, hickory shad, blueback herring, alewife, striped bass, Atlantic sturgeon, and shortnose sturgeon from the Atlantic States Marine Fisheries Commission (ASMFC 2004). This data was extensively reviewed and edited by fisheries biologists in the fall of 2011 through a series of in-person meetings and follow-up virtual meetings. This review process incorporated additional fish observance data as well as field knowledge from on-the-ground biologists. A new dataset for American eel was also developed through the meeting process in the fall of 2011. For the 2019 revisions, edits to the anadromous fish data were solicited and collected from Workgroup members. These edits were generally minor. Authorized users are able to make edits to the anadromous fish data through the data editing portal (See Section 7.1) and these edits are used to update the analysis on a weekly basis.

Fish habitat was categorized into four categories. Each line segment in the hydrography was assigned one of the four categories for each species in the study.

Figure 3-8: Final project data for American shad. All reaches not depicted are coded as



1. Current – there is documentation (observance record or other direct knowledge) of a given species using a given reach. “Using” in this context refers to spawning or other critical life stages *and the reaches that would need to be traversed to access that reach from the Bay.*
2. Potential Current – there is not documented evidence of a given species using a given reach, but based on similar streams/rivers, there is an expectation that they might be or could be using that reach.
3. Historical – a given species does not currently use a given reach, but historically (prior to the erection of anthropogenic barriers), they would be expected to.
4. None Documented – no use or expected historical use of a given reach by a given species.

Potential Current and Historical categories were assigned based on the consensus of the Workgroup using simple size class and/or gradient rules or professional judgment. The data used to categorize each reach for each species can be accessed by clicking on a given reach of a species layer, which can be found under the “Layers” section of the web map: https://maps.freshwaternetwork.org/chesapeake/

3.5 Waterfalls

Waterfalls, like dams, can 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 number of river miles that would be opened by removing that dam. Thus, although waterfalls are excluded from the project results, they were included in the generation of functional networks.

The primary data source for waterfalls was the USGS GNIS database, which includes named features from 1:24,000 scale topographic maps. Additional waterfalls were available for portions of Pennsylvania Waterfall data were subjected to a similar review process as dams were. Waterfalls were snapped to the project hydrography the same method described above for dams. For the 2019 revisions, edits to the waterfall data were solicited and collected from Workgroup members. These edits were generally minor. Authorized users are able to make edits to the waterfall data through the data editing portal (See Section 7.1) and these edits are used to update the analysis on a weekly basis.

4 Analysis Methods

The conceptual framework of the Chesapeake Fish Passage Prioritization project rests on a suite of ecologically relevant metrics calculated for every dam in the study area. These metrics are then used to evaluate the benefit of removing or providing passage at any given dam relative to any other dam. 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 64 metrics were calculated for each dam in the study area using ArcGIS 10.3.1. The process used of generate each metric was scripted using Python 2.7.8 using the arcpy module (ArcGIS Python package) as well as other freely available Python packages. All metrics are recalculated automatically when source data changes, on a weekly basis.

Metrics are organized into four categories for convenience: Network, Landcover, Ecological, and System Type. These categories help organize the metrics into a logical order but they 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 dam 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 dam 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.

Category	Metric	Unit	Order
	# Dams Downstream	#	A
	# Fish Passage Facilities Downstream	#	D
	# Natural Barriers Downstream	m	D
	# Hydropower Facilities Downstream	#/m	A
Network	Total Upstream River Length	#/m	A
	Upstream Barrier Density	#/m²	A
	Upstream Functional Network Length	m	D
	The total length of upstream and downstream functional network	m	D
	Absolute Gain	m	D
	% Impervious Surface in Contributing Watershed	%	A
	% Natural LC in Contributing Watershed	%	D
	% Forested LC in Contributing Watershed	%	D
	% Agricultural LC in Contributing Watershed	%	A
	% Impervious Surface in ARA of Upstream Functional Network	%	A
	% Impervious Surface in ARA of Downstream Functional Network	%	A
	% Agricultural LC in ARA of Upstream Functional Network	%	A
	% Agricultural LC in ARA of Downstream Functional Network	%	A
	% Natural LC in ARA of Upstream Functional Network	%	D
	% Natural LC in ARA of Downstream Functional Network	%	D
	% Forested LC in ARA of Upstream Functional Network	%	D
	% Forested LC in ARA of Downstream Functional Network	%	D
	% Conserved Land within 100m Buffer of Upstream Functional Network	%	D
	% Conserved Land within 100m Buffer of Downstream Functional Network	%	D
	% Tree Cover in ARA of Upstream Functional Network (Ches Bay Land Cover)	%	D
Watershed / Local Condition	% Tree Cover in ARA of Downstream Functional Network (Ches Bay Land Cover)	%	D
	% Herbaceous Cover in ARA of Upstream Functional Network (Ches Bay Land	%	D
	% Herbaceous Cover in ARA of Downstream Functional Network (Ches Bay Land	%	D
	% Barren Cover in ARA of Upstream Functional Network (Ches Bay Land Cover)	%	D
	% Barren Cover in ARA of Downstream Functional Network (Ches Bay Land Cover)	%	D
	% Road Impervious Surface in ARA of Upstream Functional Network (Ches Bay	%	A
	% Road Impervious Surface in ARA of Downstream Functional Network (Ches Bay	%	A
	% Non-Road Impervious Surface in ARA of Upstream Functional Network (Ches	%	A
	% Non-Road Impervious Surface in ARA of Downstream Functional Network (Ches	%	A
	Barrier is on Conservation Land	Boolean	D
	NFHAP Cumulative Disturbance Index by Catchment	unitless class	D
	Density of Off-Channel Dams in Upstream Functional Network Local Watershed	#/m²	A
	Density of Off-Channel Dams in Downstream Functional Network Local	#/m²	A
	Density of road-stream Xings in Upstream Functional Network Local Watershed	#/m²	A
	Density of road-stream Xings in Downstream Functional Network Local	#/m²	A
	Rare fish or mussel species in HUC12	Boolean	D
	Globally rare (G1, G2, G3) or federally listed fish/mussel sp in HUC12	Boolean	D
	Rare fish or mussel species in US or DS functional network	Boolean	D
	Globally rare (G1, G2, G3) or federally listed fish/mussel sp in US or DS func net	Boolean	D
	# Diadromous Spp in DS Network (incl Eel)	#	D
	Presence of Anadromous Spp in DS Network	unitless class	D
	CBP Stream Health	unitless class	D
	MBSS Stream Health - BIBI	unitless class	D
	MBSS Stream Health - FIBI	unitless class	D
	MBSS Stream Health - CIBI	unitless class	D
	INSTAR Stream Health - MIBI	unitless class	D
Ecological	PA Stream Health	unitless class	D
	# of rare (G1-G3) fish species in HUC8	#	D
	# of rare (G1-G3) mussel HUC8	#	D
	# of rare (G1-G3) crayfish HUC8	#	D
	Native fish species richness - HUC 8	#	D
	Barrier within Eastern Brook Trout Joint Venture 2012 Catchments	Boolean	D
	Barrier Block EBTJV 2012 Catchment	Boolean	D
	Barrier within DeWeber & Wagner modeled Brook Trout Catchment	Boolean	D
	Barrier blocks DeWeber & Wagner modeled Brook Trout Catchment	Boolean	D
	# Upstream Size Classes >0.5mi gained	#	D
Size / System Type	Total Reconnected # stream sizes (upstream + downstream) >0.5 Mile	#	D
	# Upstream Size Classes >0.5mi	#	D
	Miles of Cold-Water Habitat in Total Functional Network	Miles	D
	Miles of Cold / Cool water habitat in Total Functional Network	Miles	D

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

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 Active River Area (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, Table 4-3, and Table 4-4 depict the weights chosen by the Workgroup for the Diadromous Fish Scenario, Resident Fish Scenario, and Brook Trout Scenario, 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 diadromous fish. 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 allowed the Workgroup to both understand the impact of making an adjustment to a given metric weight, and also served to better calibrate the results to known priorities.

Table 4-2 Workgroup-Consensus metric weights for the Diadromous Fish Scenario

Metric Category	Metric	Diadromous Weight
Network	# Dams Downstream	10
	# Fish Passage Facilities Downstream	5
	Total Upstream River Length	10
	Upstream Functional Network Length	10
Watershed / Local Condition	Density of Road & Railroad / Small Stream Crossings in Upstream Functional Network Local Watershed	5
	% Impervious Surface in Contributing Watershed	5
	% Impervious Surface in ARA of Upstream Functional Network	5
	% Natural LC in ARA of Upstream Functional Network	5
Ecological	# Diadromous Spp in DS Network (incl Eel)	10
	Presence of Anadromous Spp in DS Network	20
	CBP Stream Health	10
Size / System Type	# Upstream Size Classes >0.5mi gained	5

Table 4-3: Workgroup-Consensus metric weights for the Resident Fish Scenario. These weights were modified by the workgroup as part of the 2019 revision.

Metric Category	Metric	Resident Weight
Network	Total Upstream River Length	5
	Upstream Barrier Density	5
	Upstream Functional Network Length	5
	The total length of upstream and downstream functional network	5
	Absolute Gain	20
Watershed / Local Condition	Density of Road-Stream Crossings in US Functional Network Local Watershed	5
	Density of Road-Stream Crossings in DS Functional Network Local Watershed	5
	% Natural LC in ARA of Upstream Functional Network	10
	% Natural LC in ARA of Downstream Functional Network	10
Ecological	CBP Stream Health	5
	# of rare (G1-G3) fish species in HUC8	5
	# of rare (G1-G3) mussel HUC8	5
	Native fish species richness - HUC 8	5
Size / System	Total Reconnected # stream sizes (upstream + downstream) >0.5 Mile	10

Table 4-4: Workgroup-Consensus metric weights for the Brook Trout Scenario. In addition to the weights listed below, a stream size class filter was used to restrict dams in the analysis to those on size 1a and 1b streams (draining less than 100 sq km)

Metric Category	Metric	Brook Trout Weight
Network	The total length of upstream and downstream functional network	10
	Absolute Gain	20
Watershed / Local Condition	Density of Off-Channel Dams in Upstream Functional Network Local	5
	Density of Off-Channel Dams in Downstream Functional Network Local	5
	Density of Road-Stream Crossings in Upstream Functional Network Local	5
	Density of Road-Stream Crossings in Downstream Functional Network Local	5
	% Impervious Surface in Contributing Watershed	10
	% Forested LC in Contributing Watershed	10
	% Conserved Land within 100m Buffer of Upstream Functional Network	3
	% Conserved Land within 100m Buffer of Downstream Functional Network	2
Ecological	CBP Stream Health	5
	Barrier Block EBTJV 2012 Catchment	10
	Barrier blocks DeWeber & Wagner modeled Brook Trout Catchment	10

As noted in the caption for Table 4-4 above, in addition to assigning relative weights for metrics, the universe of dams that are included in an analysis can be define. Thus, in the Workgroup-consensus Brook Trout Scenario, only dams on small streams are included in the prioritization. Filters like this can be based on geography (e.g. state, watershed) or any attribute (e.g. dam purpose, presence of a specific diadromous species). Additional details on using filters can be found in Section 6.2.

4.2 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. The ranking process used involves four steps and simple mathematical operations, as illustrated Figure 4-2.

Figure 4-1: A hypothetical example ranking four dams based on two metrics.

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

1

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

2

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

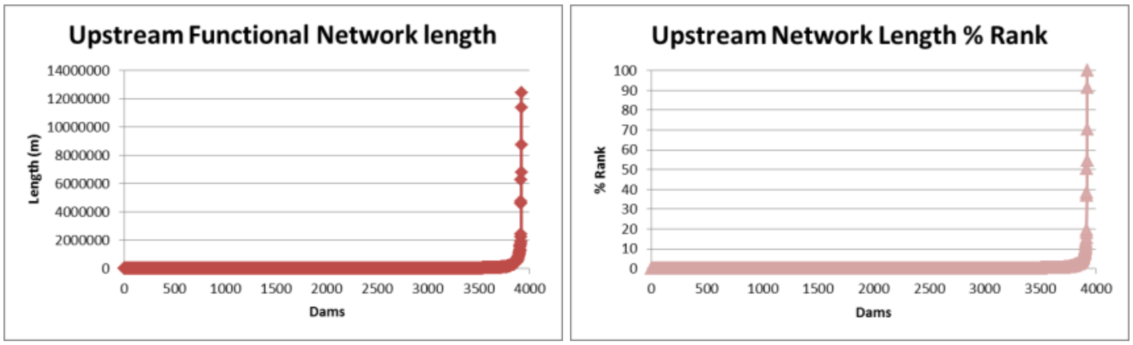
5

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.

One consequence of converting values directly to a percent scale rather than first ranking them is that metrics with outliers can bias the results. For example, if a handful of dams have vastly larger upstream functional networks these values can overwhelm other metrics, even if the weight on those other metrics is greater. As can be seen in Figure 4-2, converting the values to percent ranks preserves the magnitude of difference between dams.

Figure 4-2: Graph of upstream functional networks showing outliers in their original values (m) and converted to a percent scale.



This is an accurate representation within this metric; the outlying dams have upstream networks that are proportionally that much larger than the other dams. However, when this metric is combined with another metric that has a more even distribution the value of the metric is diminished for most dams.

Figure 4-3: A comparison of metrics with outliers and with a more even distribution.

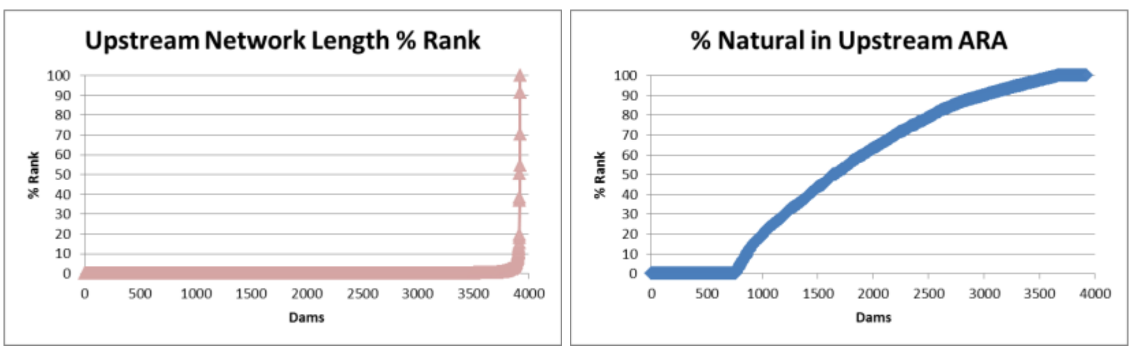
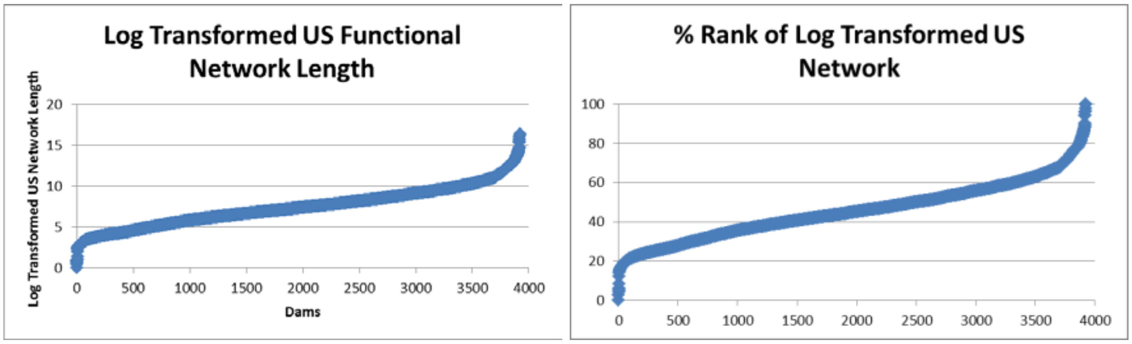


Figure 4-4 compares the distribution of upstream functional network length with percent natural landcover in the Active River Area of each dam's upstream functional network for dams in the study (where natural landcover is an aggregation of National Landcover Database categories, as detailed in Appendix II). As can be seen, the percent natural landcover metric has a much more even distribution: a middle value has a percent rank of 60, whereas a middle value for the upstream network length metric is <1. When these metrics are combined, the dams with the large outlying values rise to the top, while dams with mid-range values become dominated by the other metric.

To address this problem, metric values can be log transformed prior to converting to percent ranks. This has the effect of smoothing the distribution of values so that outliers to not distort the results, as illustrated in Figure 4-5.

Figure 4-4: Log transformed upstream functional network values for dams in the Chesapeake Bay watershed & those values converted to a percent scale.



When this log-transformed metric is combined with other metrics, outliers no longer have the same dominating impact as without the log transformed values.

Figure 4-5 compares a hypothetical example of a prioritization run first without log transforming values (left side) and a second time first log transforming (ln) values (right side). When values aren't log transformed, Dam C which has a vastly longer upstream functional network than all of the other dams, is ranked as the top dam even though it has along the lowest percentages of natural land cover—the metric which is given greater weight. Likewise, Dam D, which has a very short upstream network, ranks out disproportionally high relative to Dam B, when its values aren't first log transformed.

The Workgroup elected to log transform the values of the following metrics prior to the prioritization: Upstream Functional Network Length, Absolute Gain, Total Functional Network Length, Total Length Upstream, Upstream & Downstream Crossing Density and Upstream & Downstream Off-Channel Dam Density.

Figure 4-5: Hypothetical example of a prioritization with a metric having outlying values. The prioritization on the right log transforms the values before converting to a percent rank.

Values in real units

Name	Upstream Functional Network Length (m)	% Natural LC in ARA of Upstream Functional Network
Dam A	10124	98
Dam B	6539	93
Dam C	572554	81
Dam D	451	95
Dam E	1560	91
Dam F	8912	60
Dam G	12102	89

1: Percent Rank

Name	Upstream Functional Network Length (% rank)	% Natural LC in ARA of Upstream Functional Network (% rank)
Dam A	1.690779	100
Dam B	1.064144	86.8421
Dam C	100	55.26316
Dam D	0	92.10526
Dam E	0.193846	81.57895
Dam F	1.47893	0
Dam G	2.036521	76.31579

2: Weighted Rank

Name	Upstream Functional Network Length (weighted rank) Weight=40	% Natural LC in ARA of Upstream Functional Network (weighted rank) Weight=60
Dam A	0.676312	60
Dam B	0.425658	52.10526
Dam C	40	33.15789
Dam D	0	55.26316
Dam E	0.077538	48.94737
Dam F	0.591572	0
Dam G	0.814609	45.78947

3: Summed Rank

Name	Summed Ranks
Dam A	60.67631
Dam B	52.53092
Dam C	73.15789
Dam D	55.26316
Dam E	49.02491
Dam F	0.591572
Dam G	46.60408

4: Final Rank

Name	FinalRank
Dam A	2
Dam B	4
Dam C	1
Dam D	3
Dam E	5
Dam F	7
Dam G	6

Values in real units

Name	Upstream Network Length (m) --> *Log Transformed (ln)*	% Natural LC in ARA of Upstream Functional Network
Dam A	10124 --> ***9.223***	98
Dam B	6539 --> ***8.786***	93
Dam C	572554 --> ***13.258***	81
Dam D	451 --> ***6.111***	95
Dam E	1560 --> ***7.352***	91
Dam F	8912 --> ***9.095***	60
Dam G	12102 --> ***9.401***	89

1: Percent Rank

Name	Upstream Functional Network Length (% rank)	% Natural LC in ARA of Upstream Functional Network (% rank)
Dam A	43.53519	100
Dam B	37.41848	86.8421
Dam C	100	55.26316
Dam D	0	92.10526
Dam E	17.36503	81.57895
Dam F	41.75093	0
Dam G	46.03242	76.31579

2: Weighted Rank

Name	Upstream Functional Network Length (weighted rank) Weight=40	% Natural LC in ARA of Upstream Functional Network (weighted rank) Weight=60
Dam A	17.41408	60
Dam B	14.96739	52.10526
Dam C	40	33.15789
Dam D	0	55.26316
Dam E	6.946013	48.94737
Dam F	16.70037	0
Dam G	18.41297	45.78947

3: Summed Rank

Name	Summed Ranks
Dam A	77.41408
Dam B	67.07265
Dam C	73.15789
Dam D	55.26316
Dam E	55.89338
Dam F	16.70037
Dam G	64.20244

4: Final Rank

Name	FinalRank
Dam A	1
Dam B	3
Dam C	2
Dam D	6
Dam E	5
Dam F	7
Dam G	4

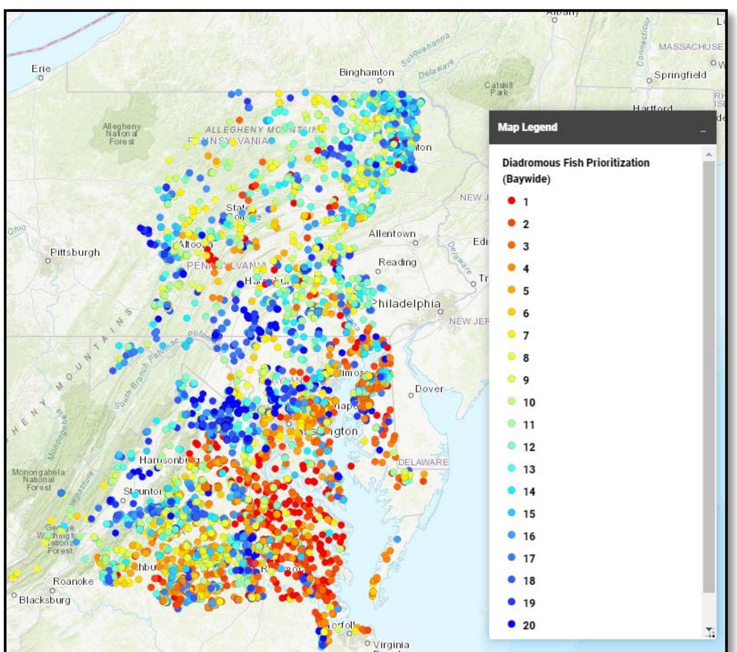
5 Results, Uses, & Caveats

5.1 Results

Results from the project include lists of dams prioritized based on three Workgroup – consensus scenarios: diadromous fish scenario, brook trout scenario, and resident fish scenario. These scenarios were developed by selecting metrics and applying relative weights (see Section 4.2) from the dams and data compiled for the project (see Section 3). These results can be viewed and downloaded from https://maps.freshwaternetwork.org/chesapeake/.

Of note, dams with existing fish passage facilities are included in the results. The Workgroup considered whether or not these dams should be included – if a passage project has already been completed why should it remain in the analysis as a candidate for a passage project? However, given the variability of fish passage efficacy 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 they 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.

Figure 5-1: Workgroup-consensus Diadromous Fish Scenario results



Although the prioritization produces a sequential list of dams, the precision with which metrics can be calculated in a GIS is not necessarily indicative of ecological differences. Therefore, throughout this report and on the project web map, results are presented binned in Tiers where each Tier included 5% of the dams in the study area. Thus, 5% of the total dams are in the top Tier, Tier 1. These dams would provide the greatest ecological benefit to the given target if removed or otherwise remediated.

5.1.1 Diadromous Fish Scenario

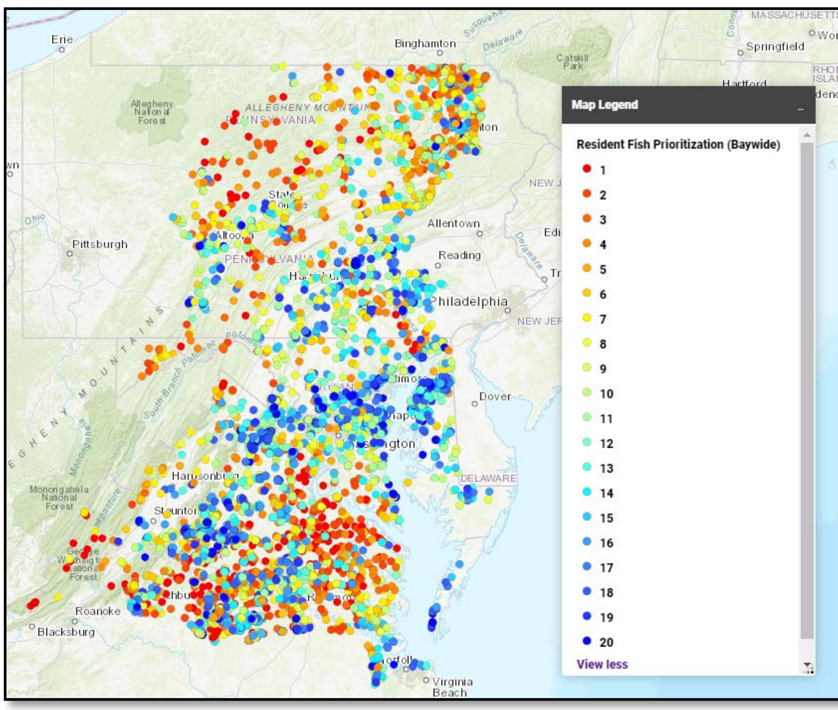
Of particular interest to the Workgroup was a scenario to prioritize dams based on their potential to benefit diadromous fish species if removed or bypassed. This scenario was developed using the metric weights presented in Table 4-2**.**, and produced the results depicted in Figure 5-1 one would expect in a scenario designed to benefit diadromous fish, the dams in the higher tiers, those whose removal would provide the greatest benefit to diadromous fish, tend to be found closer to the Bay and on the larger mainstem rivers. These include the major rivers in Virginia and Maryland on the west side of the Bay (Rappahannock, James, Potomac, Mattaponi, Rapidan) as well as the mainstem Susquehanna and many smaller coastal streams. These results directly reflects the metrics chosen and weights applied to them including anadromous fish presence (weight=20), number of dams downstream (weight = 10), and total upstream network length (weight = 10).

Since dams with existing passage facilities are included in the results, they provide a convenient way to cross check results against existing priorities; if a dam already has a fish passage structure on it, then it was considered to be enough of a priority to justify the cost of building that structure. Of the 191 dams in Tier 1, 28 (15%) have existing fish passage facilities. This represents 56% of the dams in the study that are known to have existing fish passage facilities.

5.1.2 Resident Fish Scenario

Using the metrics and metrics weights that were revised in 2019 by the Workgroup (presented in Table 4-3), a Resident Fish Scenario was developed. This scenario was intended to reflect priorities for a set of non-migratory fish species like brook trout, shiners, or darters (though a brook trout-specific scenario was also developed by the Workgroup). As illustrated in Figure 5-2, these results differ substantially from the Diadromous Fish Scenario result. They are driven by absolute gain (weight=20), and a suite of land cover condition metrics.

Figure 5-2: Workgroup-consensus Resident Fish Scenario results

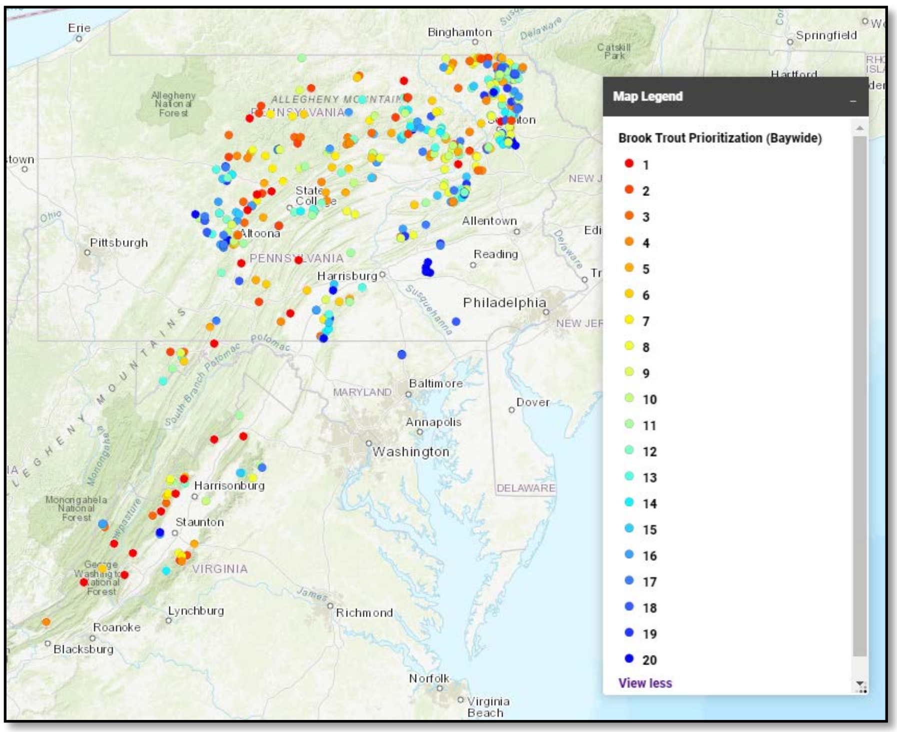


High priorities in this scenario are clustered in areas with a high proportion of natural land cover and long functional networks like the West Branch of the Susquehanna and western Virginia. A cluster of high priority dams is also found in the Rappahannock and Mattaponi drainages where relatively high percentages of natural land cover can be found, despite their proximity to Richmond and Washington D.C.

5.1.3 Brook Trout Scenario

In addition to the Resident Fish Scenario, the Workgroup elected to produce a brook trout-specific scenario. This scenario is based on the weights in Table 4-4 and prioritizes dams as presented in Figure 5-3. In addition to the weights selected by the Workgroup, this scenario is limited to dams in catchments with documented brook trout populations, based on either the EBTJV data (Hudy 2012) or the DeWeber and Wagner (2015) data. Dams outside these catchments were excluded.

Figure 5-3: Workgroup consensus Brook Trout Scenario



This scenario is driven to a large extent by the absolute gain, land cover metrics, and whether a dam is a barrier to either EBTJV catchments or DeWeber and Wagner's modeled brook trout catchments. As can be seen in Figure 5-3, this puts an even greater emphasis on those regions where brook trout would be expected, notably in the mountainous areas in the western parts of the watershed.

5.2 Result Uses

The Chesapeake Fish Passage Prioritization project can be used in several different ways to inform and support on-the-ground efforts to restore aquatic connectivity.

- **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 have already been used to help direct managers to investigate previously unvisited dams to assess them for potential passage projects (Jim Thompson, personal communication March 13, 2013). 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.

Figure 5-4: Simkins dam on the Patapsco River, before and after its removal in 2011

- **Database of Ecologically Relevant Metrics**: Prioritization aside, the results form a database of 40 ecologically relevant metrics. These metrics 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 any social, economic, or feasibility factors*, largely due to the fact that this information is difficult or impossible 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 Northeast Aquatic Connectivity project.

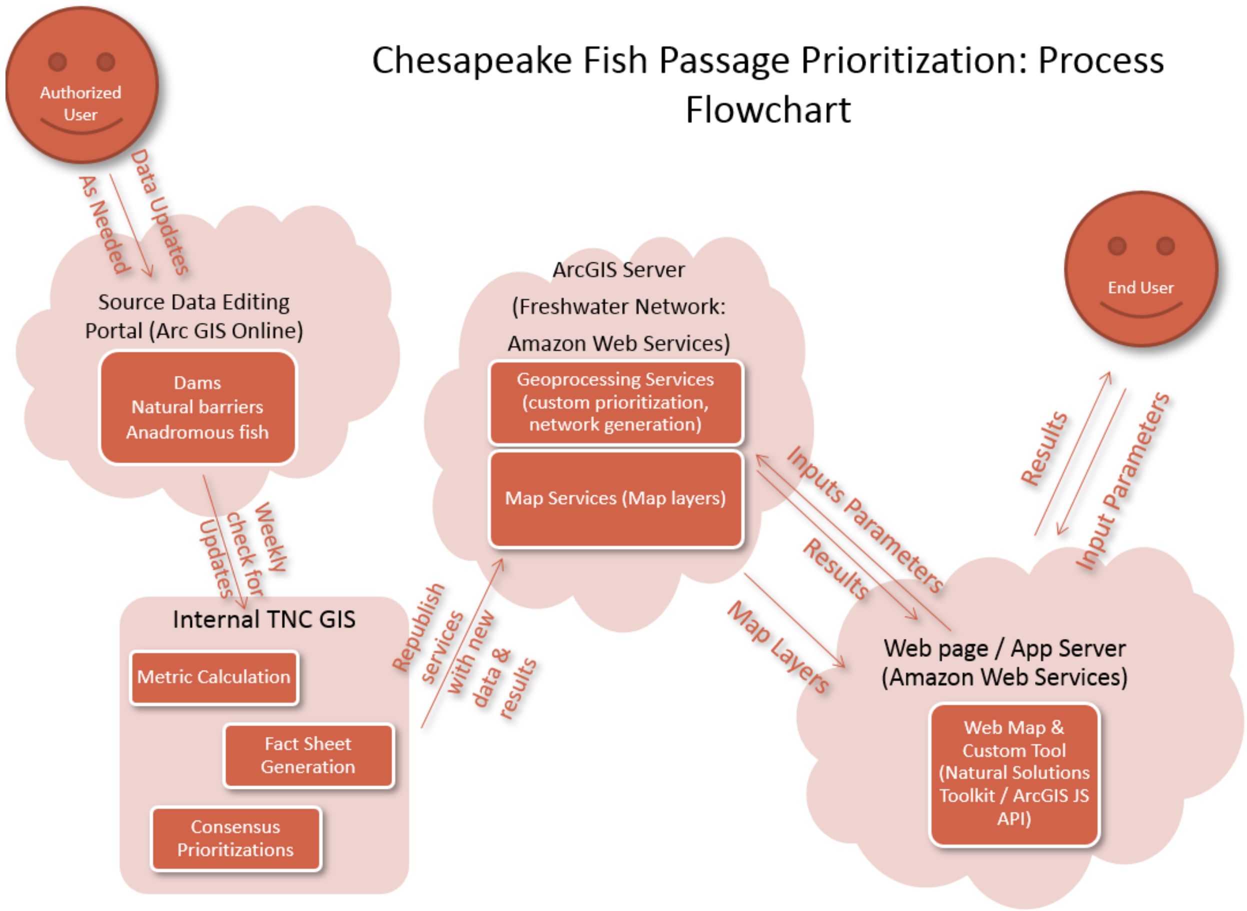
Results produced for this project are intended to be *screening-level* information that can *help* inform on-the-ground decision making, using the best available regional data. They are not a replacement for site-specific knowledge and field work.

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 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.

6 Web Map & Analysis Tools

Project results and a tool to run custom user-defined scenarios can be found at https://maps.freshwaternetwork.org/chesapeake/. 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. Figure 5-1 illustrates the conceptual architecture of the web map & custom analysis tool.

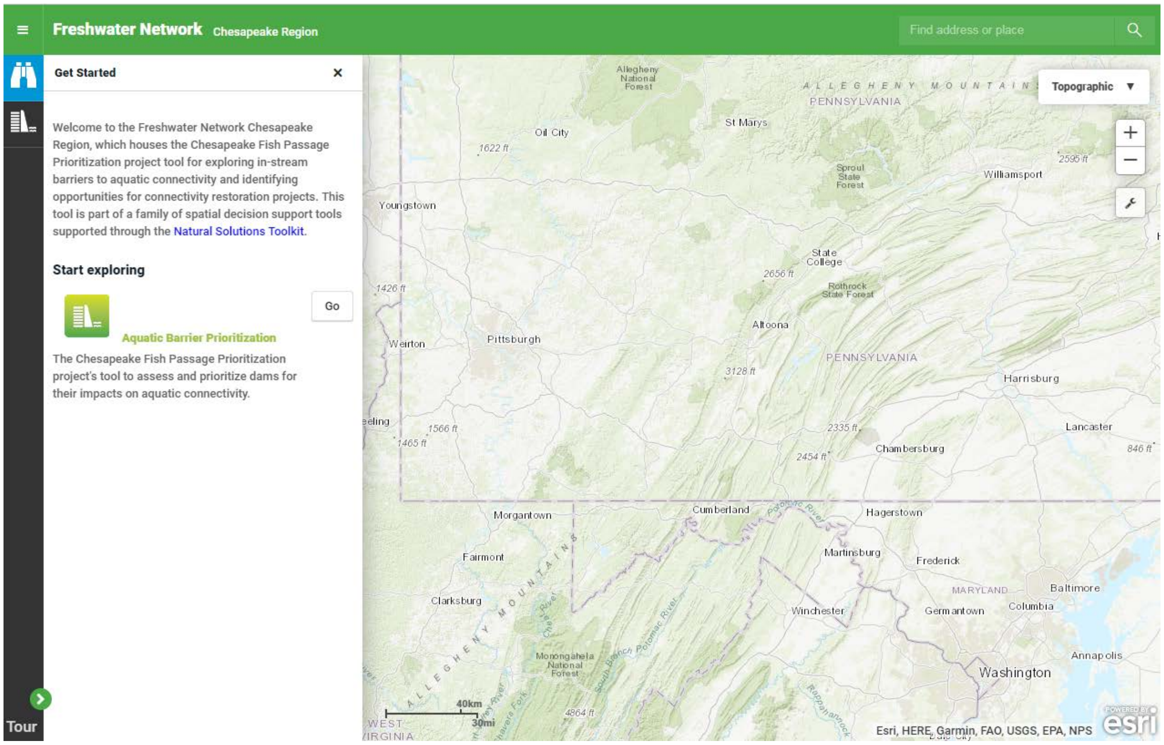
Figure 6-1: Conceptual architecture of web map & custom prioritization tool



6.1 Web Map Organization

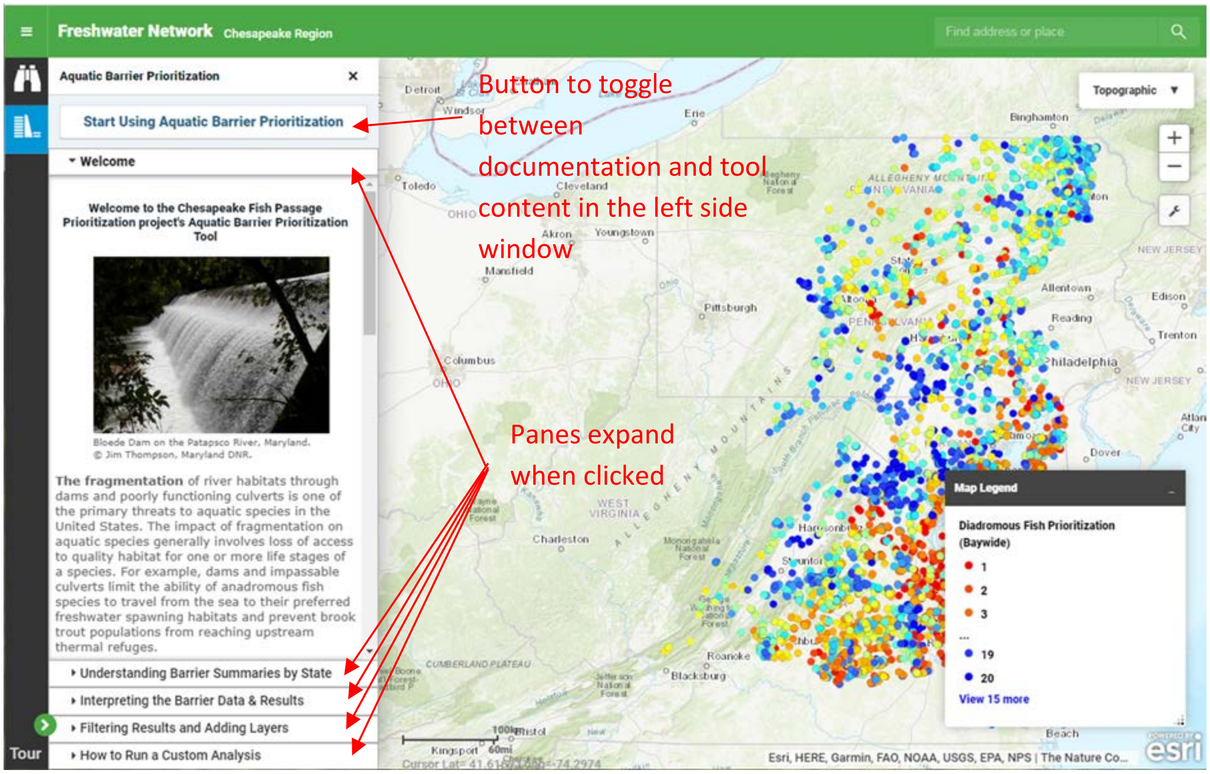
Upon first entering the map, a general welcome screen is depicted to the user. Within this screen is a "Go" button which opens the Aquatic Barrier Prioritization app. At the time of writing, this is the only app within the web, though in the future, additional apps on related topics may be added.

Figure 6-2: Web map welcome screen. Click on "Go" to open the Aquatic Barrier Prioritization tool and enter the map.



The left side window of the map includes multiple “panes.” that can be expanded to reveal content or functionality. When one pane is opened, by clicking on it, any other open panes will be closed. Further this left-side window can exist in two different states: one with the tool content and the other with relevant documentation. The button at the top of the left side window can be used to move between the documentation and the tool. Alternately, certain features within the tool have an “info” icon that, when clicked, will link directly to the relevant section of the documentation.

Figure 6-3 Map in its initial state with the documentation showing in the left side window.



When the app is first opened, the map is loaded with the Workgroup-consensus Diadromous Fish Scenario results and the Documentation pane is visible on the left side of the screen. Click on “Start Using Aquatic Barrier Prioritization” to flip the tool’s documentation to the content in the left window.

6.1.1 Explore the Consensus Results

The primary pane in the tool content allows users to explore the consensus prioritization scenarios and includes several aspects of functionality within it.

6.1.1.1 Select a region and consensus scenario

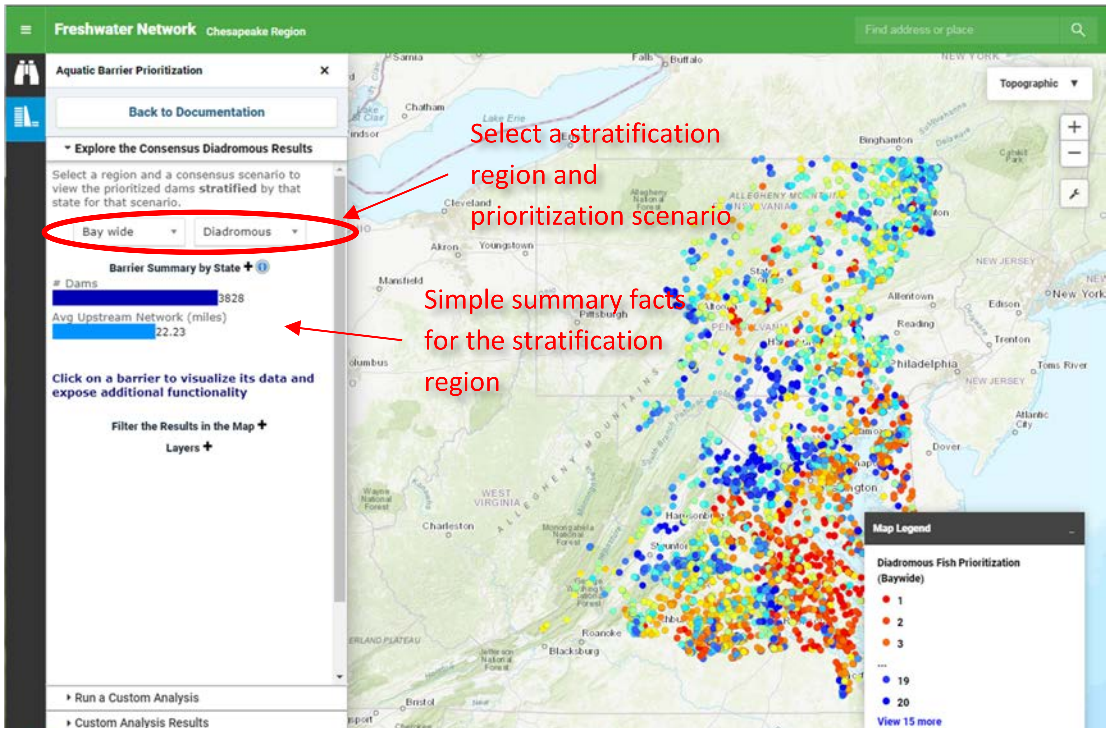
A region, either “Bay wide” or one of the three states, along with a prioritization scenario can be selected using dropdown menus at the top of the “Explore the Consensus Results” pane. When a region is selected, the results for the selected scenario will be displayed, stratified by (relative to) that region.

Analyses based on other regions (e.g. watershed) can be run by applying a filter in a custom analysis (see Section 6.2.1)

6.1.1.2 Barrier Summary by State

Within the tool, simple summary statistics, including the number of dams and the average length of their upstream functional river networks, are initially displayed. Values for these statistics correspond to the stratification region selected.

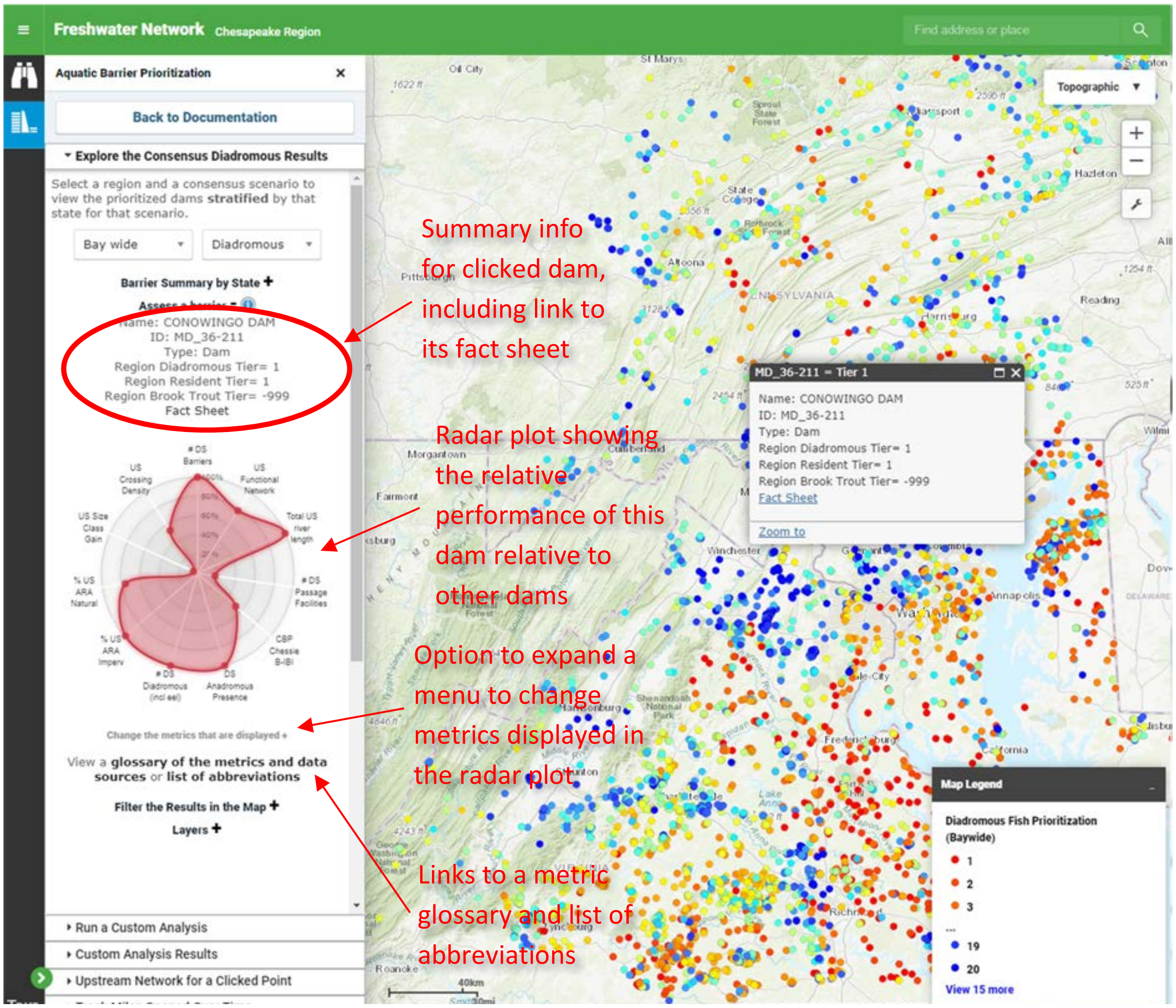
Figure 6-4 Selecting a stratification region and prioritization scenario



6.1.1.3 Assess a Barrier

Clicking on a barrier will expose, in the left window, information about that barrier including its name, ID, result tier for each of the consensus scenarios, a link to a fact sheet with all of the metric information for that dam, and a radar plot that displays the relative values for each metric. The radar plot can be used to see what factors are driving its prioritized result – values near the perimeter of the plot perform better for a given metric than most other barriers. That is, the radar plot shows the relative performance of the barrier for each metric, relative to the other barriers in the stratification region. Hovering the cursor over a metric in the plot will display the actual value for that metric. By default, the metrics show in the radar plot correspond to the metrics that are used in the selected consensus scenario (diadromous, resident, or brook trout). Below the radar plot is an option to “Change the metrics that are displayed” in the radar plot. Clicking this option will expand a box where metrics can be removed, by clicking on the “X” next to each metric, or added, by clicking in empty space within the box and choosing a metric from the dropdown menu that appears. Below this box are links to a glossary of all the metrics as well as a list of abbreviations used in the metrics.

Figure 6-5 "Assess a barrier" functionality that is exposed when a barrier is clicked in the map



6.1.1.4 Filter the results in the map

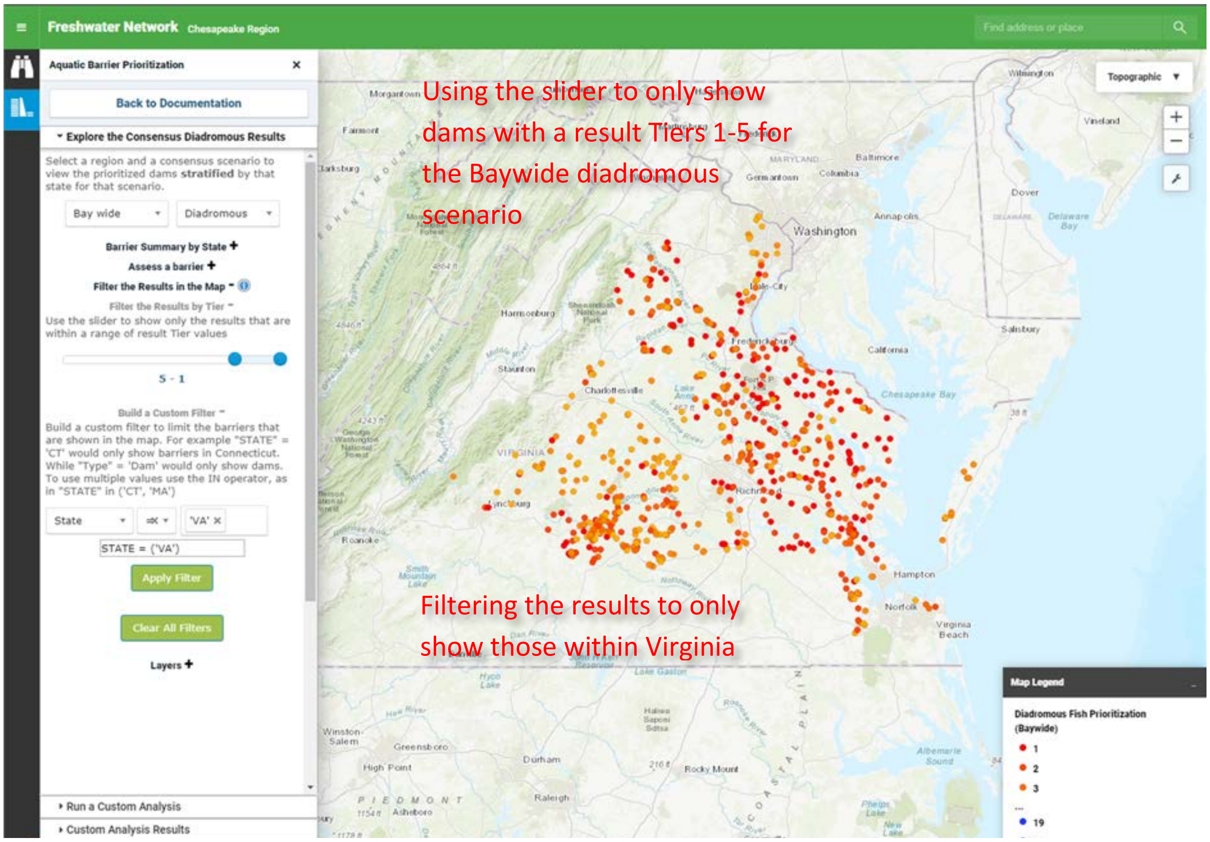
The consensus results that are currently displayed in the map can be filtered by Tier or using a custom filter. To filter results, first click on the “Filter the Results in the Map” text to expand it. Next select whether to filter by Tier or using a custom filter.

Selecting the option to filter by Tier will reveal a slider bar that can be used to only show those dams with result Tiers in the range selected, for the prioritization and stratification that are currently selected.

Custom filters can be built using the dropdown menus provided to build simple query expressions. Using these dropdowns to build an expression will help ensure that the syntax is correct, but any ArcGIS-compliant query expression can be typed directly into the text input. For more information on ArcGIS query expressions see: http://desktop.arcgis.com/en/arcmap/10.3/map/working-with-layers/building-a-query-expression.htm. When the expression is complete, be sure to click the “Apply Filter” button.

Note that filters applied via these two methods work together. That is, if results are filtered to only show result Tiers 1-5 and a custom filter is applied to only show dams in Virginia, the map will display dams in Virginia in Tiers 1-5.

Figure 6-6 Applying a filter to limit the barriers that are displayed in the map



6.1.1.5 Layers

Additional contextual data can be added to the map. Clicking on the "Layers" option will reveal a list of layers with check boxes to turn each one on or off. These layers include road-stream crossings, diadromous fish habitat compiled for the project, river hydrography, watershed boundaries, natural land cover & percent impervious surface, non-native fish observations, natural waterfalls, and previously removed dams.

Note that when the layers menu is expanded, the radar plots are disabled. To view the radar plot for a dam, click on the "Assess a barrier" option again.

6.2 Custom Dam Prioritization Tool

The Custom Dam Prioritization tool allows users to modify and build off of the three scenarios developed by the Chesapeake Fish Passage Workgroup (see Section 5.1) by altering metric weights, filtering out the input dams (e.g. by state or watershed), running “removal scenarios” as if one or more dams had been removed from the network, and generating summary statistics of the results.

Custom prioritizations can be run by first clicking on the “Run a Custom Analysis” pane and going through the questions that walk through the steps of the analysis.

6.2.1 Limiting the analysis to a geography, species, or other subset of the data

The first option allows users to limit the dams that are included in the analysis based on geography or some other subset of data. The process of applying a filter on the input dams is similar to that used for a custom filter on the consensus scenarios (Section 6.1.1.4). When the “Yes” button is selected, dropdown menus will appear which allow for a query expression to be built. This interactive dialog helps users build filter statements. Plain-English is displayed in the dropdown menus and the appropriate GIS field names and syntax is automatically applied in the expression. First, the attribute to filter by is selected (e.g. “State”). Next the operator is selected (e.g. “=”) and finally the desired parameter value is selected (e.g. “Virginia”). Note that if there are multiple values, the “IN” operator must be used, as in: “STATE” IN (‘VA’, ‘MD’)

6.2.2 Applying Custom Weights

As described in Section 4.2, relative weights can be applied to metrics to indicate the relative importance of each metric in a given prioritization scenario. The Chesapeake Fish Passage Workgroup developed three weighting scenarios for diadromous fish, resident fish, and brook trout, respectively, but any number of alternate scenarios could be developed based on the needs and objectives of the user. For example, if the primary objective of a user was to open up the most possible 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 dams so that the one with the longest upstream functional network was on top. Weights can be distributed as desired by the user so long as they sum to 100. A running tally of metric weights is provided, and a warning message will appear if an analysis is attempted with weights that do not sum to 100. Metric names in this pane are links that, when clicked, open a glossary definition for that metric.

It is important to note that a handful of metrics, namely the state-specific water quality metrics, are only available for certain geographies. Thus, if weight is applied to one of these metrics, a filter must be applied to limit the analysis to the respective state.

6.2.3 Dam Removal Scenarios

Up to ten dams can be selected for “removal” when a prioritization is run. This functionality allows users to model the impact of a proposed project on the remaining dams in the network. When dams are modeled for removal, all of the metric values are recalculated as if that dam doesn’t exist so users can assess the impact on a metric by metric level. For example, if a given dam is “removed” all of the upstream dams will have one fewer dam downstream of them, the next downstream dam will have a longer upstream functional network, the next upstream dam will have a longer downstream functional network, etc. This can be particularly useful when there are multiple dams in a series which might be treated as a single removal project. That is, by "removing" all but one of a series of dams, the one remaining dam will have metric values which reflect the group, rather than its individual components.

To run a prioritization scenario that includes modeled removals, expand the "Do you want to model the removal of barriers" text and select "Yes". If you know the UNIQUE_ID for your dams of interest, you can simply enter these in the text box enclosed in single quotes and separated by commas. (e.g. : 'MD_AN027', 'MD_EL030', 'PA_08_079'). The UNIQUE_ID is the CFPP project-specific identifier for each dam. It is based on the ID from source database, but is specific to this project. The UNIQUE_ID can be obtained by clicking on a dam. This can be useful when running the same or similar scenarios multiple times.

More convenient in many cases will be the option to select dams interactively through the web map. This can be done by clicking on the "Show Selection Barriers" button which adds a layer of all dams (symbolized as black points) that is used for graphic selection. This is simply done by clicking on a point, at which point it will turn red and its UNIQUE_ID will be populated into the text input box. If a mistake is made, clicking on a red dam will turn it black again and remove its UNIQUE_ID from the text input box.

Note that dams that are modeled as "removed" in a custom analysis do not alter the source dam database. The custom analysis results are only valid for the current user's session. Dam removals intended to update the master database must be made by authorized users, as described in Section 7.

6.2.4 Generating Summary Statistics

Optionally, summary statistics can be run 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, select "Yes" under "Do you want summary stats of the results." This will reveal options to generate summary statistics for either Tier or the Final Rank (the un-binned sequential results) by either State or Watershed. The output table will enable users to make 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 dams with greater potential to benefit the target of interest, based on the metric weights chosen by the user, than Watershed X.

6.2.5 Starting the Analysis, Viewing and Exporting Results

A checkbox which gives the option to export results as a .csv file is the final input parameter. When all inputs are completed, the "Start!" button can be clicked to begin the analysis. The time required to run a prioritization varies based on the number of dams included in the analysis, the number of metrics included in the analysis, the number of dams 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 & 2 minutes.

6.2.5.1 Results

When the analysis is complete, the results are added to the map and the "Custom Analysis Results" pane is opened. The pane will include buttons to download the results for use in a GIS (as a zipped File

Geodatabase), the input parameters as a .csv text file, the results as a .csv text file if the option was selected, and the summary statistics table as a .csv text file, if that option was selected.

In the map, symbols of the result features in the map use the same color ramp as the pre-loaded Workgroup-consensus results to indicate Tier (Tier 1 = red, Tier 20 = blue).

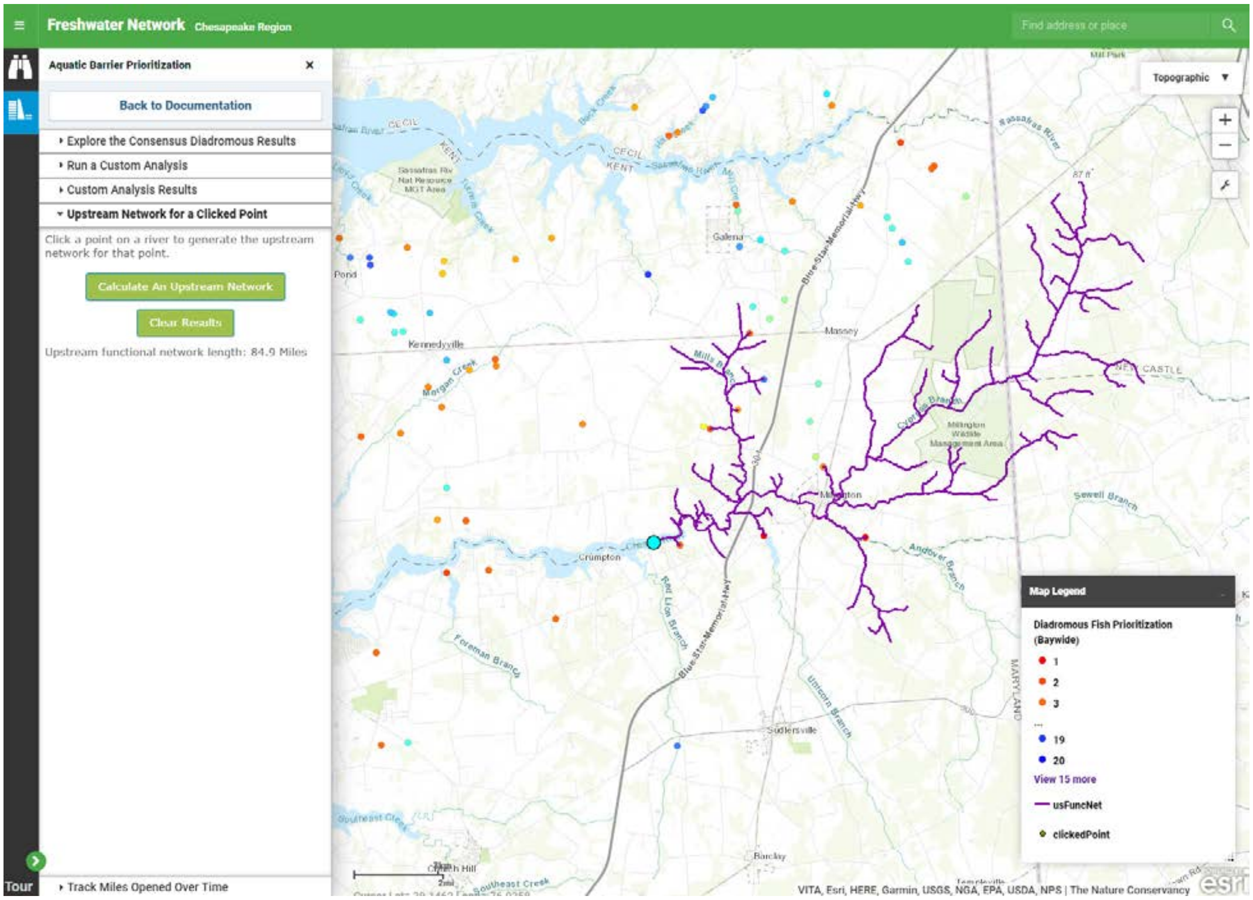
As long as the “Custom Analysis Results” pane is open, clicking on a dam in the map will bring up information about the dam from the results. Thus, if dams are modeled as removed, the metrics for the remaining dams will reflect those removals. Exiting the Custom Analysis Results pane will remove the results. So, for example, clicking on the “Explore the Consensus Diadromous Results” pane will remove the custom results and load in the consensus results.

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.

6.3 Upstream Network for a Clicked Point

New functionality in the 2019 revision of the Chesapeake Fish Passage Prioritization tool includes the ability to generate an upstream functional river network for any location on the river network. First, select the “Upstream Network for a Clicked Point” pane. Next, zoom in until the warning stating to “Zoom in further to generate a functional network for a clicked point” disappears. When that text disappears, the “Calculate an Upstream Network” button will become active. Clicking that button will load the river network into the map. Next, click on a river line (be sure to click within 100m of the river line as it’s represented in the map) and the analysis will automatically start. A status message will appear in the active pane and, when processing is completed the upstream functional network will appear in the map and its length will be displayed in the pane.

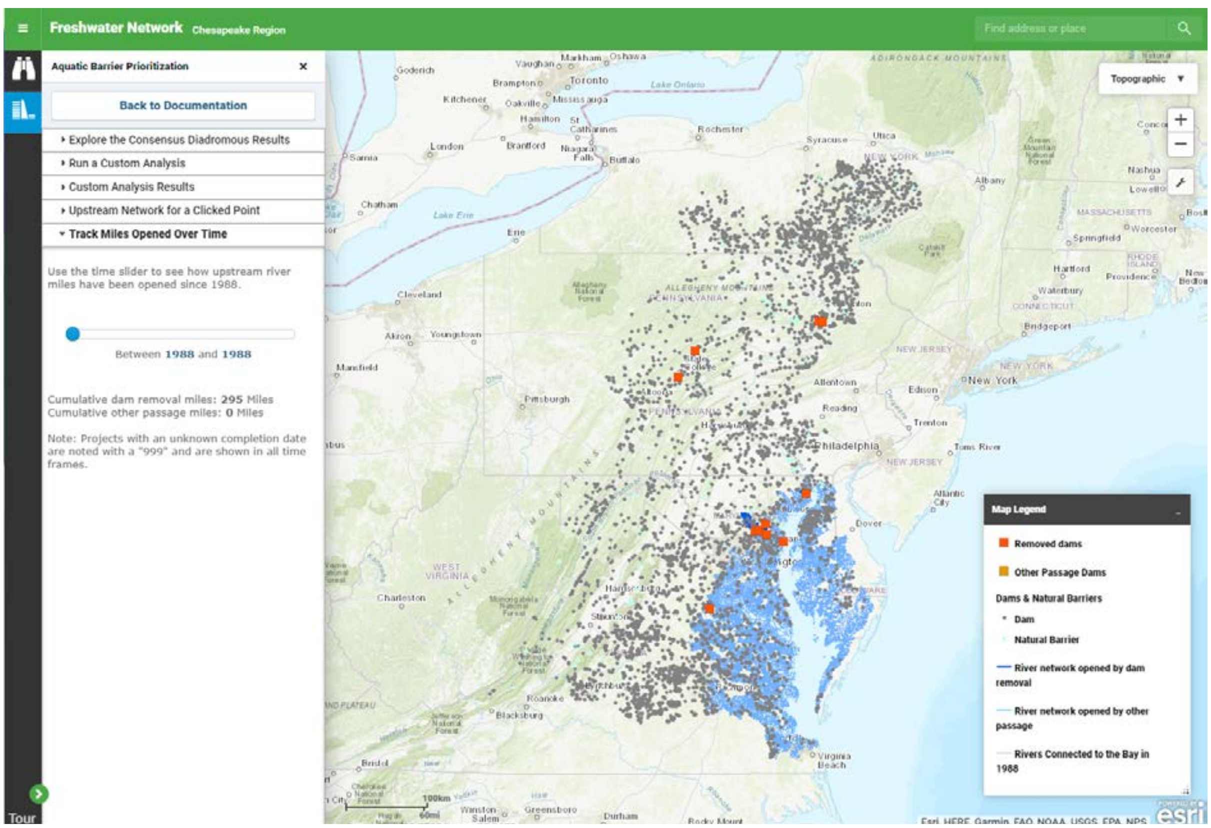
Figure 6-7 An upstream functional river network generated for a point clicked within the map



6.4 Track Miles Opened Over Time

Additional new functionality developed in the 2019 revision of the tool includes the ability to dynamically track upstream miles opened over time. To access this functionality, select the “Track Miles Opened Over Time” pane at the bottom of the left window. This will open the pane, remove other content from the map and load the data to track miles over time. In its initial state, the map will display rivers that were connected to the Chesapeake Bay in 1988. From this point, the time slider can be used to select a range of years within which to display dams that have been removed as well as dams where other fish passage projects have been implemented. In addition to showing the dams that have been removed or had passage projects, the upstream functional networks of these dams will be shown in the map. The pane on the left side of the screen will also show a cumulative total of miles opened by dam removal and by other passage projects. Zooming in to one of these dams on the map will display the dam’s name and the year the passage project was completed. Note that projects for which there is no recorded year are marked with a “999” and are shown at all time steps.

Figure 6-8 Functionality to track upstream miles opened by dam removals and other fish passage projects



7 Dynamic Data Updating

One of the characteristics of aquatic connectivity analyses which utilize metrics based on river networks is their sensitivity to changes or errors in the data. For example, any metric which incorporates upstream functional network (e.g. upstream network length, forest cover in the riparian zone of the upstream network, etc.) will be impacted for a dam if the next upstream dam is removed. This sensitivity, coupled with the potential for data processing to introduce errors (e.g. see the description for on snapping dams in Section 3.3), increases the importance of regular data updates so that the tool is as accurate as possible and reflects data changes due to both on-the-ground actions as well as error fixes.

In previous versions of the tool, edits to the core source datasets (including dams, natural barriers and anadromous fish habitat) were collected over time via email submissions from workgroup members. When a dam was removed, for example, a workgroup member with direct knowledge of it would send an email to The Nature Conservancy with the relevant information such as the dam name, it's ID, and the date of removal. These emails would be collected and retained until time and funds were available to run an update. This generally involved a new grant and time periods of a year or more.

In this 2019 revision of the tool, substantial back-end work was undertaken to streamline and automate the data updating process. This new system allows authorized users to make edits to the core source datasets via a dedicated data editing portal. These edits are downloaded and used to update the tool on a weekly basis. The steps involved in this process are described below, as well as in this online presentation: https://prezi.com/p/on2sawyzplje/chesapeake-fish-passage-auto-updating-process-chart/

7.1 Data editing portal

The core source datasets are hosted on TNC's ArcGIS Online account and accessed via a dedicated web mapping application which is only accessible to authorized users. Edits made in the portal are automatically tracked by user and the date of edit. Further, the authorized data editors have been trained (via workgroup webinars on 10/5/18 and 3/6/19) to always record a comment describing their edits.

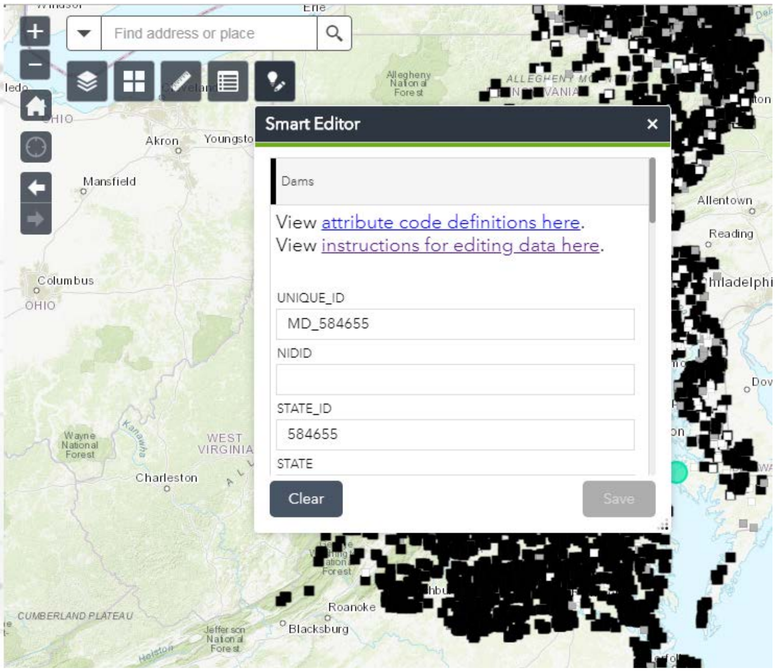


Figure 7-1 Screen capture of the data editing portal

7.2 Download data and check for edits

Every Friday afternoon, the core source datasets, including dams, waterfalls, and anadromous fish habitat presence are downloaded from the data editing portal, which is hosted on TNC's ArcGIS Online account. Additionally, data for dams in Virginia that are also included in the Southeast Aquatic Resource Partnership's (SARP) data editing portal are downloaded from the SARP data portal.

Once downloaded to the local TNC system, the downloaded data are compared to the data that were last used to update the tool. If there have been any changes to any of the core datasets since the last update, the entire analysis is re-run. (Again, due to the "ripple effect" of changes to data in a network environment, one change to any of the core datasets can impact many of the surrounding dams, thus necessitating the analysis be re-run). This comparison is made based on the "last edited date" column, which automatically tracked within ArcGIS Online and Desktop ArcGIS products.

7.3 Archive old data and derived products

If no changes have been made since the last update, processing stops. If any changes have been made, all of the input and derived data from the previous update are given a date stamp and archived. Archived data include the individual core source data layers, the geodatabase with all of the intermediate datasets used to generate metrics, and the geodatabases which underlie the map and geoprocessing services for the tool. Having these archived products makes it possible to easily revert to a previous version, should any errors be accidently introduced.

7.4 Generate metrics

After the source data has been updated in the local TNC GIS environment, all of the metrics that are used in the analysis (see Section 4.1) are regenerated. This step includes recalculation of the functional river networks, local watersheds, and other intermediate datasets in addition to the metrics values calculated for each dam. This process I automated using Python 2.7 and Esri's arcpy Python package , along with other freely available Python packages. Species of Greatest Conservation Need data from the Virginia DIGF WERMS database are also downloaded when updates are run, in order to remain in compliance with the updating requirements of the data sharing agreement.

7.5 Run consensus scenarios

When metrics have been calculated, the consensus prioritization scenarios are run. Using the metric weights and methods described in Section 4, the three consensus prioritization scenarios are run. These scenarios are saved to a file geodatabase and projected for use in the web tool.

7.6 Publish Map & Geoprocessing Services

Using the consensus results and other relevant intermediate data, the map and geoprocessing services that underlie the tool and the custom analysis functionality are republished. Two distinct map services are published. The first one provides map layers for the functionality that falls within the "Explore the Consensus Diadromous Results" pane (see Section 6.1.1) while the second provides the map layers used in the "Track Miles Opened Over Time" pane (see Section 6.4).

Similarly, there are two distinct geoprocessing services that get updated as part of this process. The first provides the custom analysis functionality (see Section 6.2) while the other provides the functionality for the "Click for an Upstream Network" tool (see Section 6.3). In each of these cases, an edit to even a single dam can impact the accuracy of the results. For example, the existing dams are needed to define the upstream functional network for a clicked point. And since it is not possible to know where a user will choose to click-for-an-upstream-network, it is necessary to update the tool with the latest data.

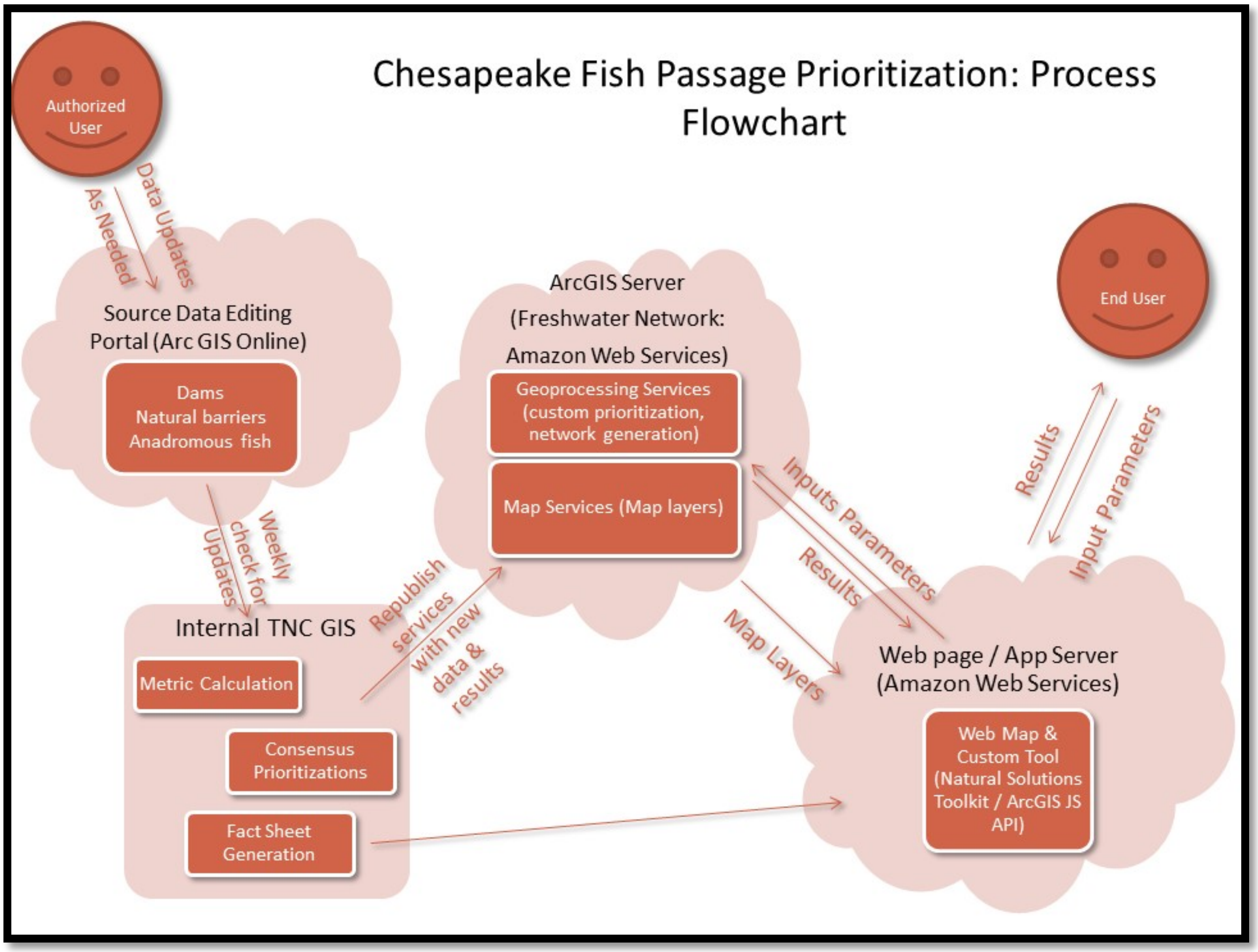
7.7 Generate fact sheets

In addition to updating the map and geoprocessing services, the fact sheets that are produced for each dam must be updated. Again, due to the "ripple effect" of data changes in a network analysis, fact sheets for all dams are regenerated whenever edits are made. For example, if a dam is removed, not only will metric values for many of the remaining dams change, but the prioritized result may as well. During this step new HTML fact sheets are generated, photos are linked in (if available), and the fact sheet is staged for upload.

7.8 Update web application

The final step of the dynamic data updating process is the updating of the web application. This process includes uploading fact sheets and the consensus results that are available for download in the tool (both as a zipped geodatabase and as an Excel spreadsheet). These products are held in an Amazon S3 bucket and linked to from the web application. The web application itself is not altered as part of this process.

7.9 Conceptual flow of data in the automated data editing system



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9 Appendix I: Chesapeake Fish Passage Workgroup

2019 Chesapeake Fish Passage Prioritization Core Group

Name	Affiliation
Mary Andrews	National Oceanic and Atmospheric Administration
Julie Devers	US Fish & Wildlife Service
Ben Lorson	PA Fish & Boat Commission
Jim Thompson	MD Department of Natural Resources
Alan Weaver	VA Dept. of Game and Inland Fisheries
Jessie Thomas-Blate	American RIvers

2013 Chesapeake Fish Passage Prioritization Full Workgroup

Name	Affiliation
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Jose Barrios	US Fish & Wildlife Service
Kathleen Boomer	The Nature Conservancy
Mark Bryer	The Nature Conservancy
Nancy Butowski	MD Department of Natural Resources
Jana Davis	Chesapeake Bay Trust
Michele DePhilip	The Nature Conservancy
Julie Devers	US Fish & Wildlife Service
Judy Dunscomb	The Nature Conservancy
Stephanie Flack	The Nature Conservancy
Greg Garman	Virginia Commonwealth University
Ben Lorson	PA Fish & Boat Commission
Erik Martin	The Nature Conservancy
Serena McClain	American Rivers
Nikki Rovner	The Nature Conservancy
Angela Sowers	US Army Corps of Engineers
Albert Spells	US Fish & Wildlife Service
Scott Stranko	MD Department of Natural Resources
Jim Thompson	MD Department of Natural Resources
Alan Weaver	VA Dept. of Game and Inland Fisheries
Howard Weinberg	Chesapeake Bay Program

10 Appendix II: Input Datasets

Dataset	Source	Description
Dams	Multiple sources including: state agencies, The Nature Conservancy's Northeast Aquatic Connectivity project, and the National Inventory of Dams. Review and edits made by the Chesapeake Fish Passage Prioritization Workgroup. Edits to Virginia dams from SARP data editing portal	This dataset represents dams in the VA, MD, & PA portions of the Chesapeake bay watershed spatially linked to the correct stream flowline in the USGS High Resolution National Hydrography Dataset (High-Res NHD) 1:24,000 stream dataset. Dams that do not fall on mapped streams in the High-Res NHD are not included in the results.
Waterfalls	USGS GNIS database, Chesapeake Fish Passage Prioritization Workgroup.	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.
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. NHDFlowline data were downloaded from the USGS website (http://nhd.usgs.gov/data.html) for the four source subregions (0205, 0206, 0207, 0208) and merged into a single polyline feature class in ArcGIS 10 by Erik Martin at The Nature Conservancy in summer 2011. These data were edited by selecting and removing line segments which form loops or other downstream bifurcations. This editing was done using the Geometric Network & Utility Network Analyst tools in ArcGIS and the Barrier Analysis Tool. Several pre-existing datasets were used to facilitate this process including coverages in Maryland from Pete Steeves (USGS) and Pennsylvania from Scott Hoffman (USGS). These data were dendrites, but based on outdated geometry. They were joined to the current high-res NHD using the REACHCODE attribute. This join

		eliminate approximately 80% of the unwanted segments (braids, loops, downstream bifurcations). Manual editing was used to eliminate the rest. In Virginia, New York and West Virginia, all edits were done manually. Several watersheds (HUC8) in Virginia were edited by Jen Kristolic at the USGS Virginia Water Science center. Once a geometrically correct dendrite was produced, flow direction in the geometric network was set to digitized direction and edits made as needed to ensure proper flow direction. Catchments were then calculated for each line segment (COMID) using a 10m DEM and a Python scripts adapted from the "agree.aml" work done by Pete Steeves and others. The area of each segment was then summed for all upstream segments using the ArcHydro "Accumulate Attributes" tool. This produced the drainage area for each segment which, is subsequently used to calculate the size class for each segment based on ecologically relevant classes established through TNC's Northeast Aquatic Habitat Classification System.
Diadromous fish habitat	Initial data from the Northeast Aquatic Connectivity project was transferred to the project hydrography, with substantial edits and additions made by fisheries biologists in VA, MD, & PA during and following round table meetings to review and compile additional data.	Critical habitats (spawning, nursery or other critical habitats) assigned to reaches of the project hydrography, and those reaches needed to reach the uppermost documented location, for alewife, blueback herring, American shad, hickory shad, Atlantic sturgeon, shortnose sturgeon, striped bass, and American eel. Reaches are coded for either current habitat, potential current habitat, historical habitat, or no documented habitat.
Land Cover	2011 National land Cover Database (NLCD2006)	Land use / land cover data from the NLCD2011. 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.
Impervious Surface	2011 National land Cover Database (NLCD2006)	% Impervious surface data from the NLCD2006. 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..
Chesapeake Bay High Resolution Land Cover	Chesapeake Conservancy	one-meter resolution land cover data for approximately 100,000 square miles of land in and surrounding the Chesapeake Bay watershed
Rare fish, mussels & crayfish. Native fish species richness.	NatureServe HUC8-scale data.	Each dam is assigned the number of rare fish, mussel & crayfish species as well as the number of native fish species in the 8-digit HUC within which the dam is located.
Road stream crossings	North Atlantic Aquatic Connectivity Collaborative	Roads and railroads obtained from Esri's ArcGIS version 9.3 data CDs were intersected with small streams (drainage area <38.61sq mi) as a proxy for culverts locations.
Brook trout catchments	Eastern Brook Trout Joint Venture	Used to indicate whether each dam is located in a catchment that was classified as having an allopatric brook trout population, brook trout sympatric with non-native brown and rainbow trout, non-native trout only, or no trout/unknown by the Eastern Brook Trout Joint Venture (Mark Hudy 2012).
Brook trout catchments	DeWeber and Wagner (2014)	Catchments with predicted brook trout population status

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.
Stream health / water quality	Chesapeake Bay Program Stream Health score "Chessie-BIBI" ; Maryland Biological Stream Survey (MBSS); Virgina's Interactive Stream Assessment Resource (INSTAR)	Each dam was assigned one or more values for stream health based on its location within a watershed. The Chessie-BIBI is designed for use in analyses that cross state lines, while the MBSS and INSTAR data can be used for analyses within those states. Only one stream-health metric is to be used at a time.
Human disturbance	National Fish Habitat Partnership 2010 HCI Scores and Human Disturbance Data (linked to NHDPLUSV1)	Landscape factors representing human disturbances summarized to local and network catchments of river reaches throughout the conterminous U.S.
Species of Greatest Conservation Need	Virginia WERMS Maryland Department of Natural Resources: DNR_NHP_StreamAquatic_EO_tracked Pennsylvania Natural Heritage Program: pnhp_sgcn_srcpoly_2017.shp	Rare fish & mussel element occurances. VA WERMS: Spp_Obs. First accessed Aug 28, 2018. Updated each time the dynamic data updating process runs (as often as weekly, no less than every 6 months)

11 Appendix III: Glossary and Metric Definitions

Chesapeake Fish Passage Prioritization

GLOSSARY
& METRIC DESCRIPTIONS

This glossary was developed to support the interpretation of Chesapeake Fish Passage Prioritization web map & tool
http://maps.freshwaternetwork.org/chesapeake

Tiered Results (5% bins)

- Analysis results grouped into 20 bins where each bin has 5% of the dams in the analysis area.
- These are the results that should be used for dam assessments

Sequential Rank

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

Upstream Barrier Count

- Category: Connectivity Status
- The number of barriers upstream of a given barrier
- Includes natural waterfalls, which are included in network generation
- Does not include barriers excluded from network generation
- Unit: #

Downstream Barrier Count

- Category: Connectivity Status
- 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: #

Number of Hydro Dams on Downstream Flowpath

- Category: Connectivity Status

- Count of hydropower dams on downstream flowpath of a barrier

- Unit: #

Number of Natural Barriers on Downstream Flowpath

- Category: Connectivity Status
- Count of waterfalls on downstream flowpath of a barrier
- Unit: #

Number of Fish Passage Facilities on Downstream Flowpath

- Category: Connectivity Status
- Count of fish passage facilities on downstream flowpath of a barrier
- Unit: #

Upstream Barrier Density

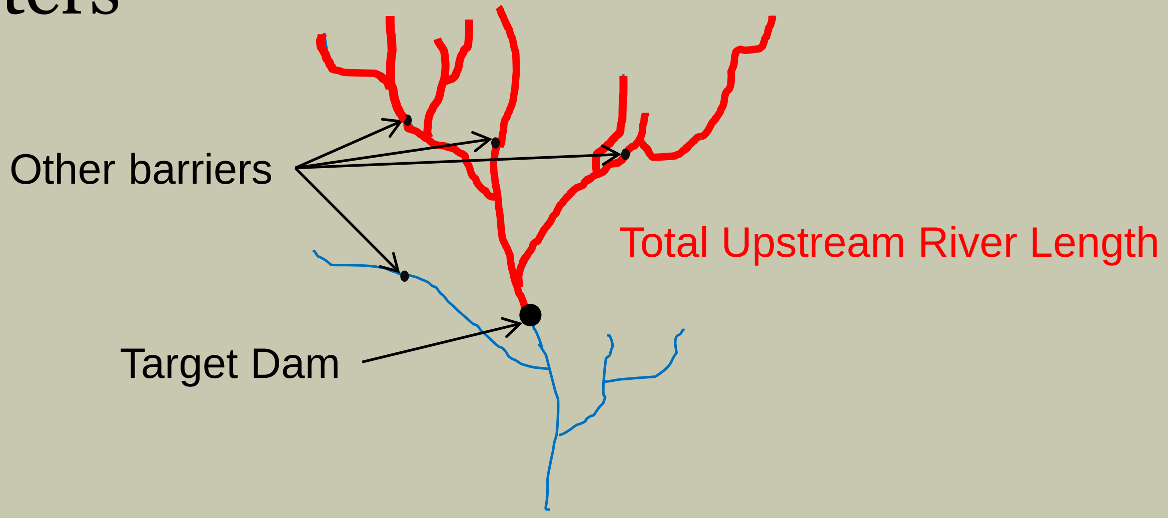
- Category: Connectivity Status
- Upstream Barrier Count divided by the total length of river upstream in meters
- Includes natural waterfalls, which are included in network generation
- Does not include barriers excluded from network generation
- Unit: # / meters

Downstream Barrier Density

- Category: Connectivity Status
- Downstream Barrier Count divided by the Distance to River Mouth in meters
- Includes natural waterfalls, which are included in network generation
- Does not include barriers excluded from network generation
- Unit: # / meters

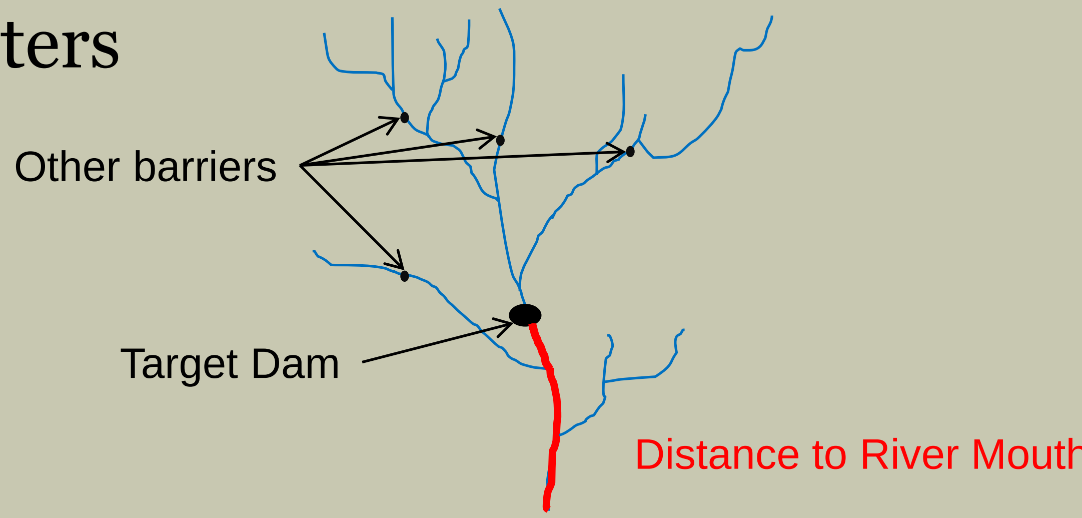
Total Upstream River Length

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



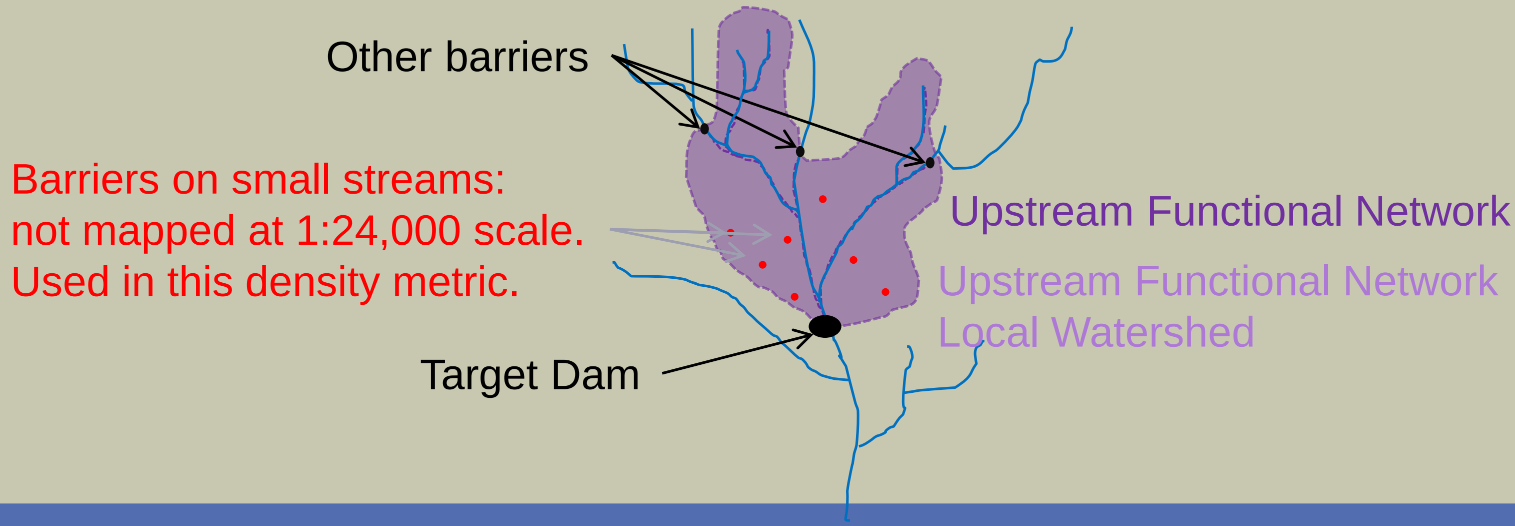
Distance to River Mouth

- Category: Connectivity Status
- Distance from each barrier to the network mouth in meters
- Unit: meters



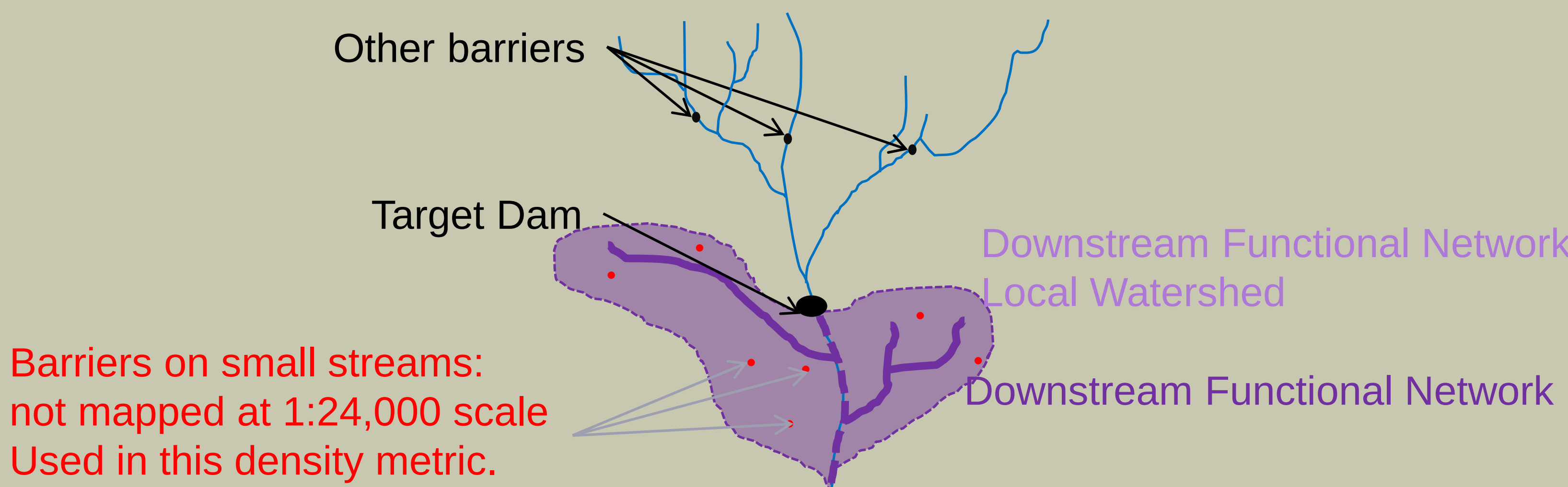
Density of Dams on Small Streams in Upstream Functional Network Local Watershed

- Category: Connectivity Status
- Number of dams on small streams (dams did not snap to analysis hydrography) within the local watershed of the upstream functional network divided by that watershed area
- Unit: # / m²



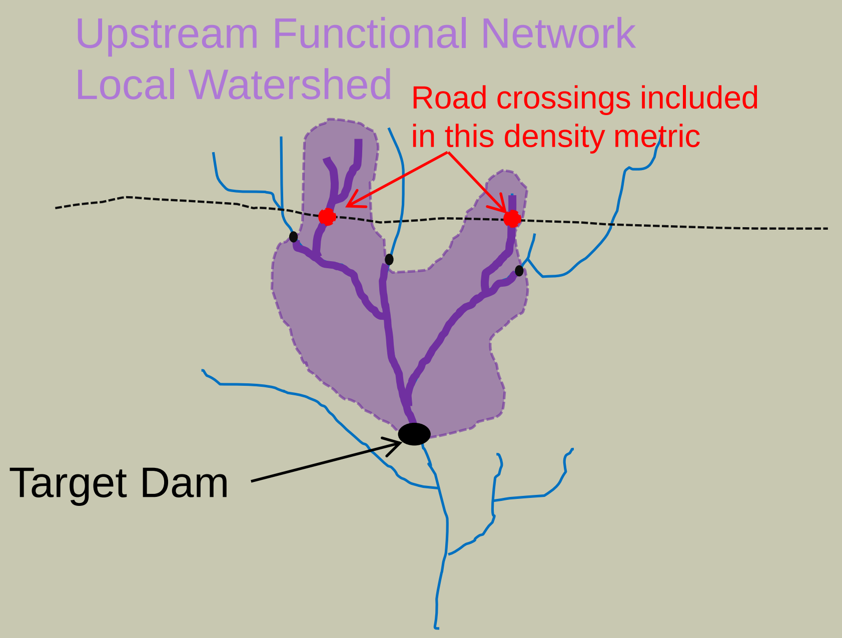
Density of Dams on Small Streams in Downstream Functional Network Local Watershed

- Category: Connectivity Status
- Number of dams on small streams (dams did not snap to analysis hydrography) within local watershed of the downstream functional network divided by that watershed area
- Unit: # / m^2



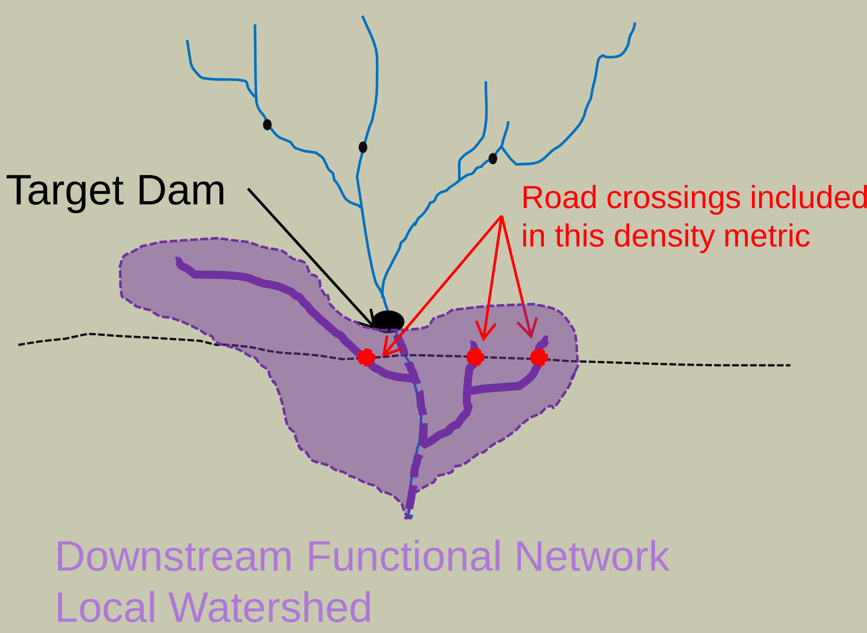
Density of Road & Railroad / Small Stream Crossings in Upstream Functional Network Local Watershed

- Category: Connectivity Status
- Number of road-stream crossings within upstream functional network local watershed divided by that watershed area.
- Road-stream crossing data from North Atlantic Aquatic Connectivity Collaborative
- Unit: # / m²



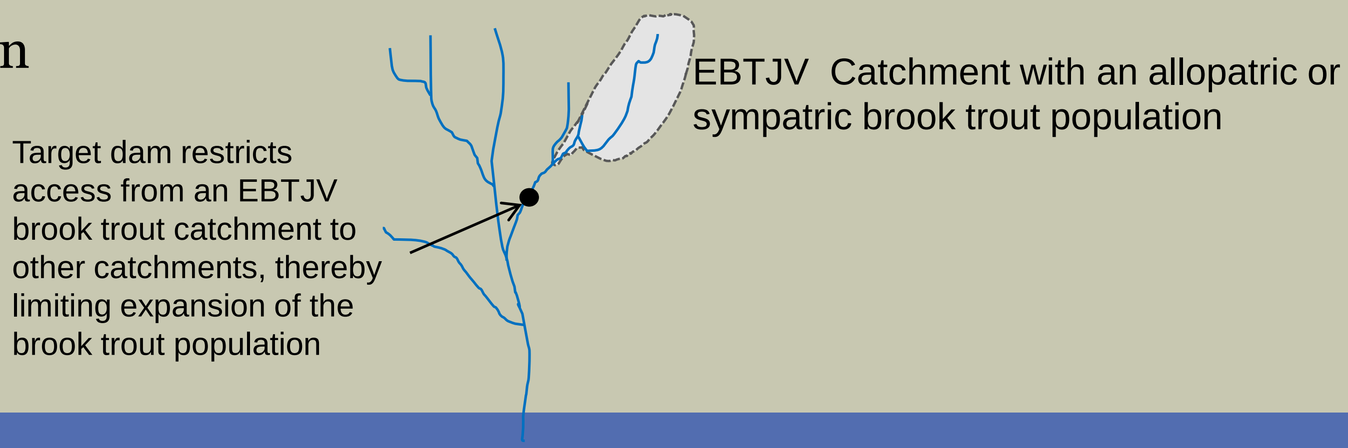
Density of Road & Railroad / Small Stream Crossings in Downstream Functional Network Local Watershed

- Category: Connectivity Status
- Number of road-stream crossings within downstream functional network local watershed divided by that watershed area.
- Road-stream crossing data from North Atlantic Aquatic Connectivity Collaborative
- Unit: # / m²



Barrier to EBTJV Brook Trout Habitat

- Dam where either its Upstream Functional River Network or Downstream Functional River Network intersects an EBTJV catchment (Hudy 2012) with an allopatric brook trout population or brook trout sympatric with brown or rainbow trout *and the other does not*.
- Allopatric and sympatric brook trout catchments includes the following codes: '1.1', '1.1P', '1.2', '1.2P', '1.3', '1.3P', '1.4', '1.4P', '15', '0.5', '1.0', '1.0P', '1P', '1'
- Dams not covered by the extent of the EBTJV 2012 catchment data are not considered as barriers between EBTJV brook trout catchments
- Unit: Boolean

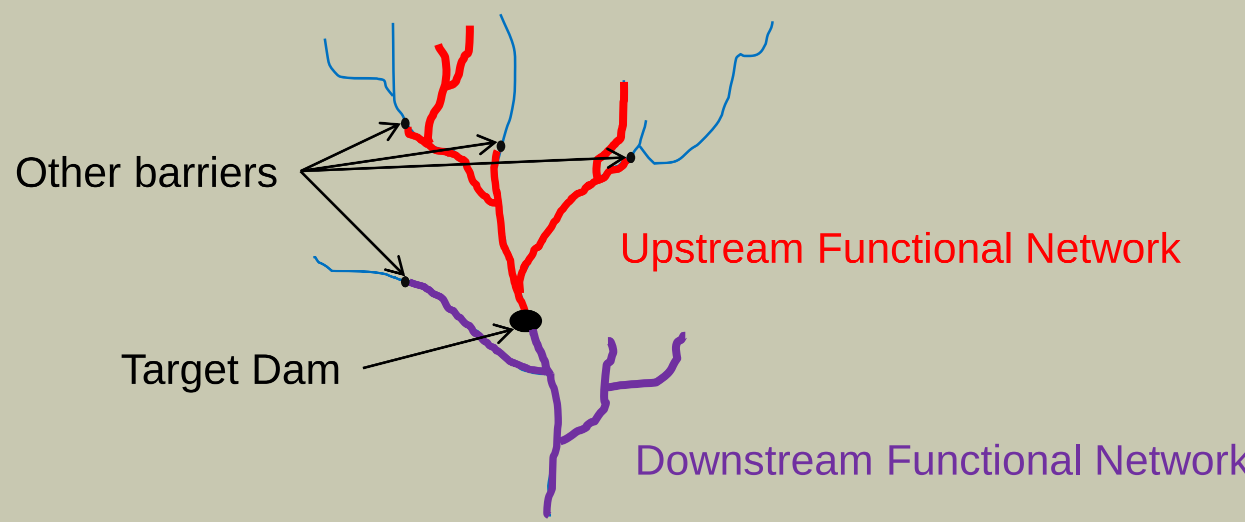


Downstream Functional Network Length

- Category: Connectivity Improvement

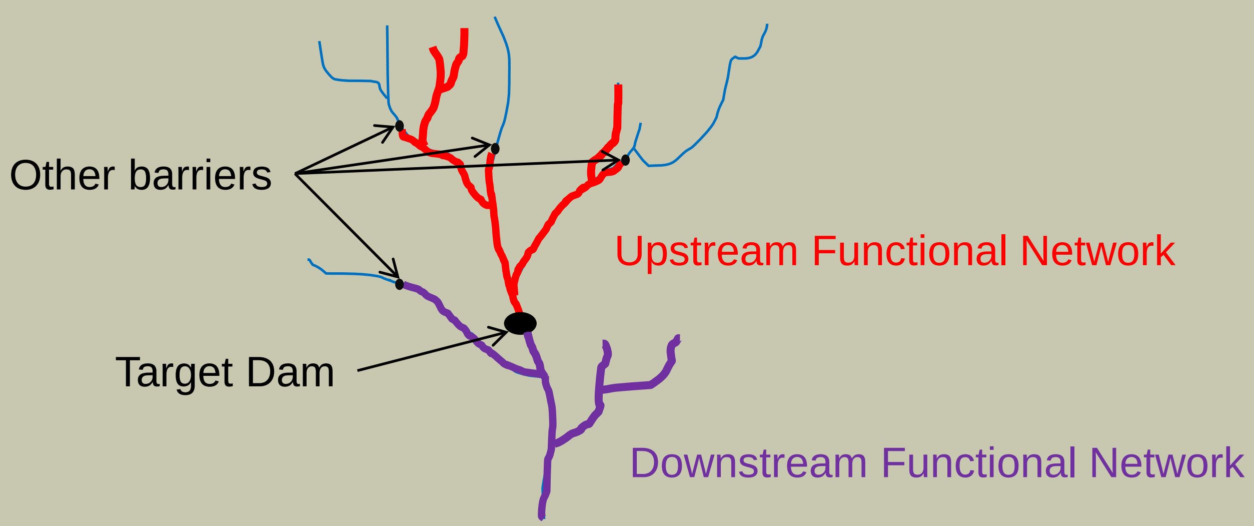
- Length of the functional network downstream of a barrier. The functional network is defined by those sections of river that a fish could theoretically access from any other point within that functional network. Its terminal ends are barriers, headwaters, and/or the river mouth.

- Unit: meters



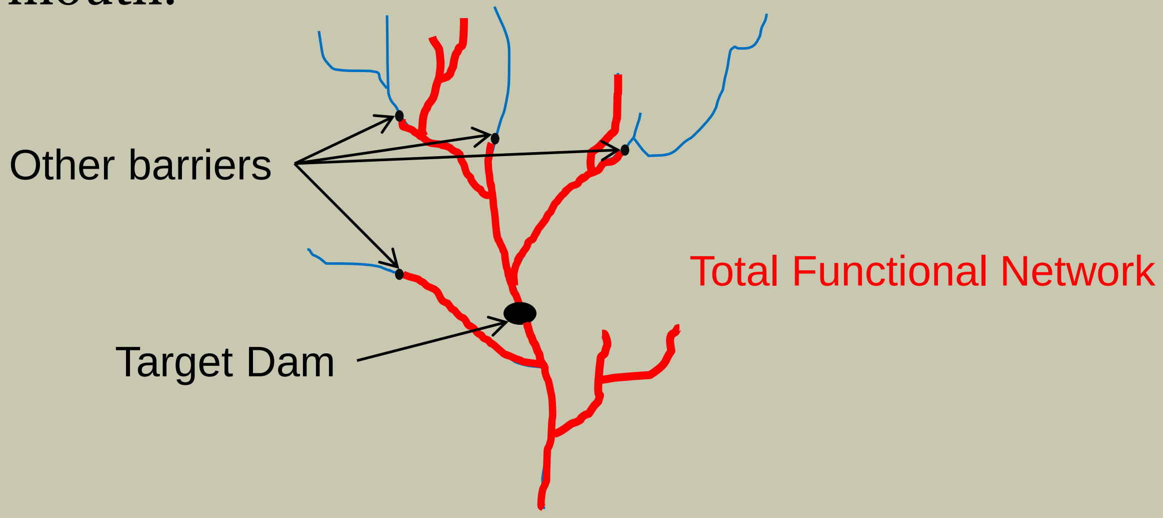
Upstream Functional Network Length

- Category: Connectivity Improvement
- 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



The total length of upstream and downstream functional network

- 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



Absolute Gain

- Category: Connectivity Improvement

- 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

Relative Gain

- Category: Connectivity Improvement
- This metric is Absolute gain divided by the total length of upstream and downstream functional networks.
- Unit: meters

% Impervious Surface in Contributing Watershed

- Category: Watershed & Local Condition
- % Impervious surface in entire upstream (contributing) watershed. Calculated 2011 National Land Cover Database percent developed imperviousness.
- Unit: %

% Natural LC in Contributing Watershed

- Category: Watershed & Local Condition
- % natural landcover in entire upstream watershed. Calculated 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: %

% Forested LC in Contributing Watershed

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

% Impervious Surface in ARA of Upstream Functional Network

- Category: Watershed & Local Condition
- % impervious landcover within Active River Area of the upstream functional river network.
- 2011 National Land Cover Database data
- Unit: %

% Impervious Surface in ARA of Downstream Functional Network

- Category: Watershed & Local Condition
- % impervious landcover within Active River Area of the downstream functional river network.
- 2011 National Land Cover Database data
- Unit: %

% Natural LC in ARA of Upstream Functional Network

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

% Natural LC in ARA of Downstream Functional Network

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

% Forested in ARA of Upstream Functional Network

- Category: Watershed & Local Condition
- % forested landcover within Active River Area of the upstream functional river network.
- 2011 National Land Cover Database data. Includes the following classes: deciduous, evergreen & mixed forest
- Unit: %

% Forested in ARA of Downstream Functional Network

- Category: Watershed & Local Condition
- % forested landcover within Active River Area of the downstream functional river network.
- 2011 National Land Cover Database data. Includes the following classes: deciduous, evergreen & mixed forest
- Unit: %

% Conserved Land within 100m Buffer of Upstream Functional Network

- Category: Watershed & Local Condition

- % of land within 100m buffer of upstream functional network that intersects 2014 secured areas database (TNC)

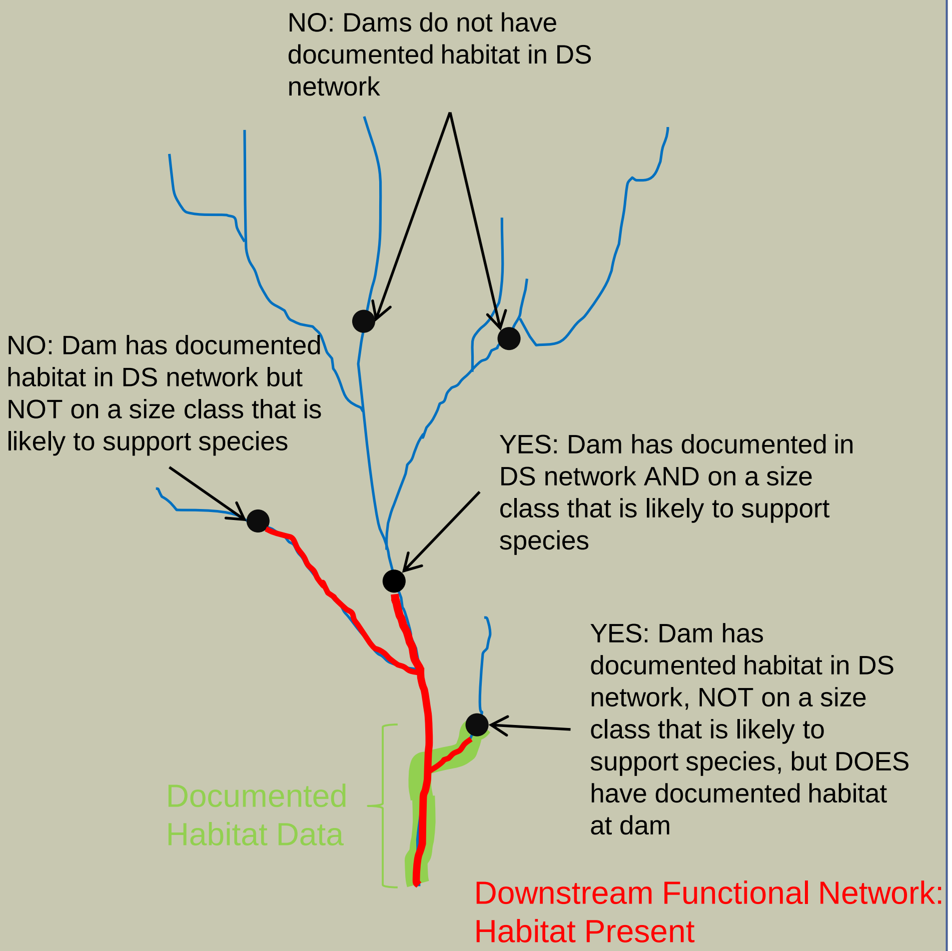
- Unit: %

% Conserved Land within 100m Buffer of Downstream Functional Network

- Category: Watershed & Local Condition
- % of land within 100m buffer of downstream functional network that intersects 2014 secured areas database (TNC)
- Unit: %

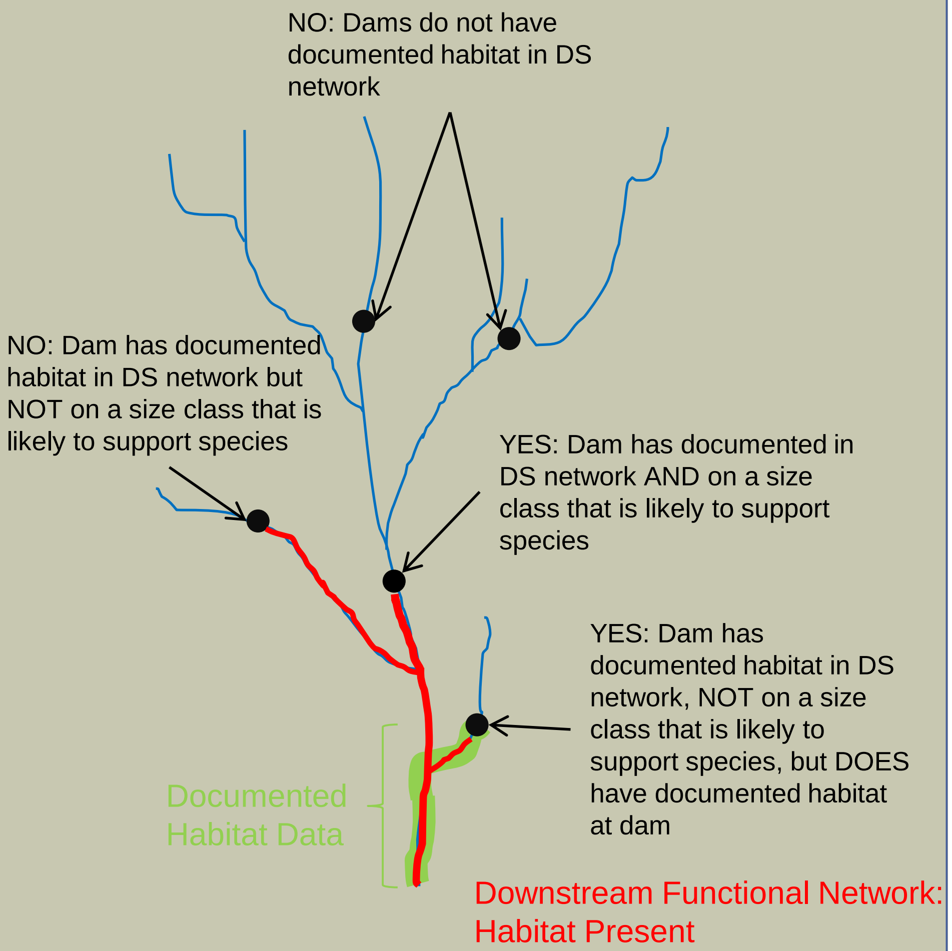
American Shad habitat in Downstream Functional Network

- Category: Ecological
- Presence of American shad downstream of dam. Based on:
  1. Documented habitat in some portion of the dam's downstream functional network
  2. **AND** Dam is on a stream that is likely to support that species based on stream size
     1. Size 2+ Rivers
  3. **OR** There is documented habitat up to a dam on a stream that doesn't meet the above size class rule
  4. **AND** the dam has not been specifically flagged otherwise by Chesapeake Fish Passage Workgroup
- Fish habitat data from multiple sources, reviewed and edited by state fisheries biologists. Each line segment includes its data source.
- Unit: Unitless Classes: "Current", "Potential Current", "Historical"



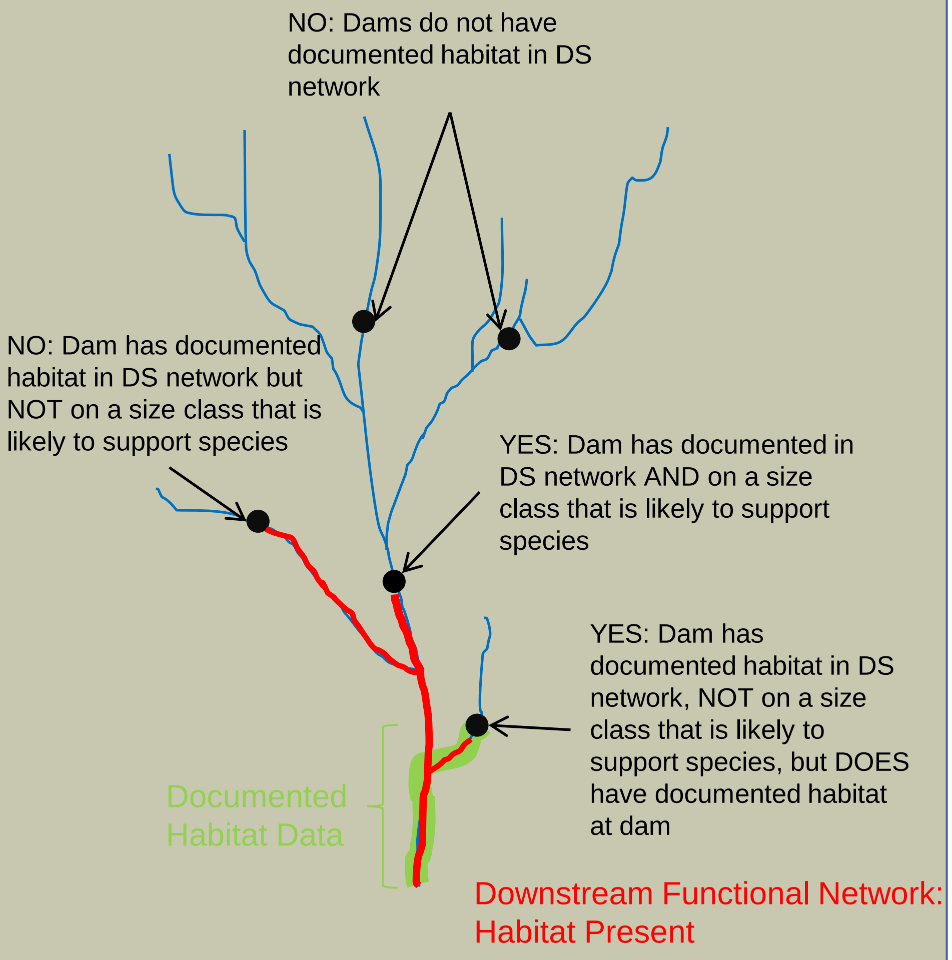
Blueback Herring habitat in Downstream Functional Network

- Category: Ecological
- Presence of blueback herring downstream of dam. Based on:
  1. Documented habitat in some portion of the dam's downstream functional network
  2. **AND** Dam is on a stream that is likely to support that species based on stream size
     1. Size 2+ Rivers & 1a/1b if no gradient >10%
  3. **OR** There is documented habitat up to a dam on a stream that doesn't meet the above size class rule
  4. **AND** the dam has not been specifically flagged otherwise by Chesapeake Fish Passage Workgroup
- Fish habitat data from multiple sources, reviewed and edited by state fisheries biologists. Each line segment includes its data source.
- Unit: Unitless Classes: "Current", "Potential Current", "Historical"



Hickory Shad habitat in Downstream Functional Network

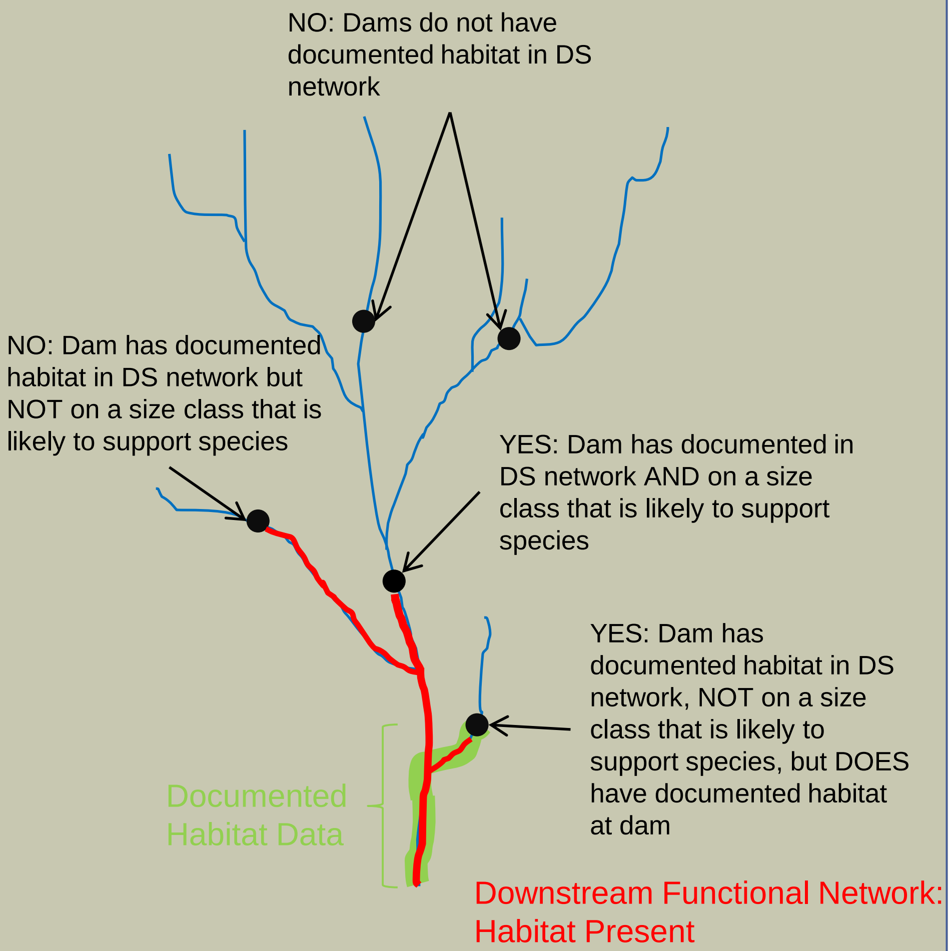
- Category: Ecological
- Presence of Hickory shad downstream of dam. Based on:
    1. Documented habitat in some portion of the dam's downstream functional network
    2. **AND** Dam is on a stream that is likely to support that species based on stream size
        1. Size 2+ Rivers
    3. **OR** There is documented habitat up to a dam on a stream that doesn't meet the above size class rule
    4. **AND** the dam has not been specifically flagged otherwise by Chesapeake Fish Passage Workgroup



- Fish habitat data from multiple sources, reviewed and edited by state fisheries biologists. Each line segment includes its data source.
- Unit: Unitless Classes: "Current", "Potential Current", "Historical"

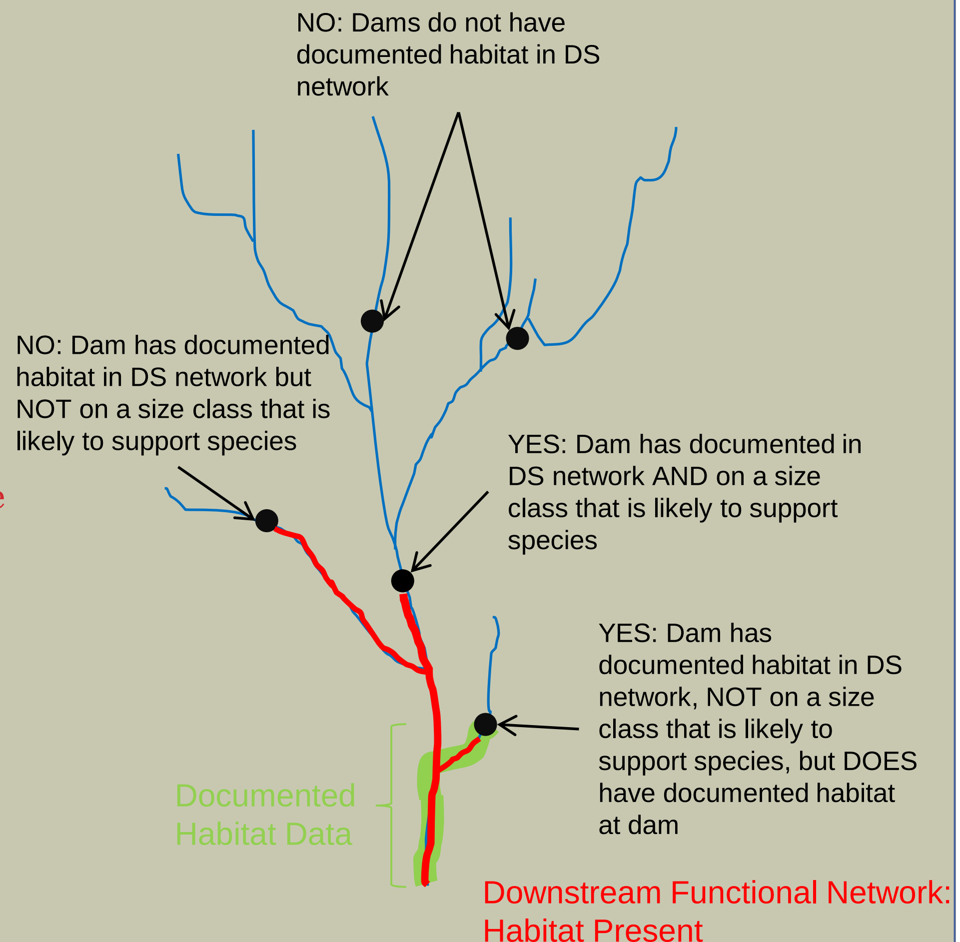
Alewife habitat in Downstream Functional Network

- Category: Ecological
- Presence of alewife downstream of dam. Based on:
  1. Documented habitat in some portion of the dam's downstream functional network
  2. **AND** Dam is on a stream that is likely to support that species based on stream size
     1. Size 2+ Rivers & 1a/1b if no gradient >10%
  3. **OR** There is documented habitat up to a dam on a stream that doesn't meet the above size class rule
  4. **AND** the dam has not been specifically flagged otherwise by Chesapeake Fish Passage Workgroup
- Fish habitat data from multiple sources, reviewed and edited by state fisheries biologists. Each line segment includes its data source.
- Unit: Unitless Classes: "Current", "Potential Current", "Historical"



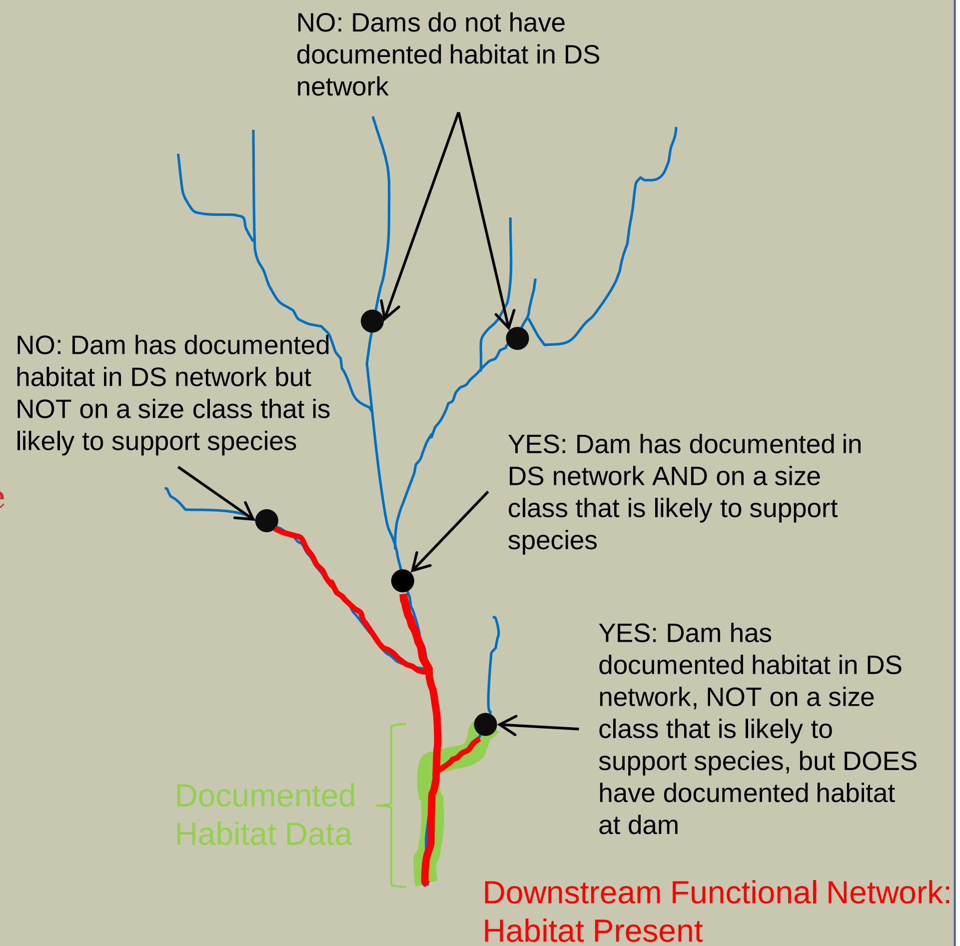
Atlantic Sturgeon habitat in Downstream Functional Network

- Category: Ecological
- Presence of Atlantic sturgeon downstream of dam. Based on:
  1. Documented habitat in some portion of the dam's downstream functional network
  2. **AND** Dam is on a stream that is likely to support that species based on stream size
     1. Size 4+ Rivers
  3. **OR** There is documented habitat up to a dam on a stream that doesn't meet the above size class rule
  4. **AND** the dam has not been specifically flagged otherwise by Chesapeake Fish Passage Workgroup
- Fish habitat data from multiple sources, reviewed and edited by state fisheries biologists. Each line segment includes its data source.
- Unit: Unitless Classes: "Current", "Potential Current", "Historical"



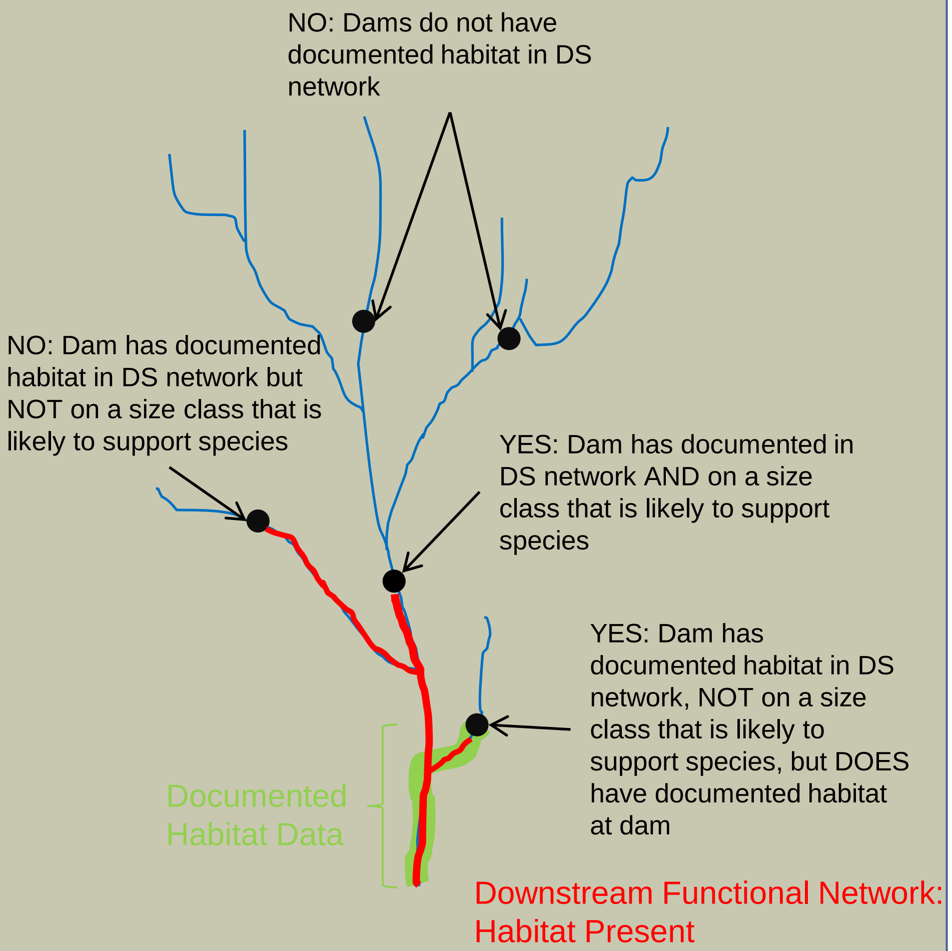
Striped Bass habitat in Downstream Functional Network

- Category: Ecological
- Presence of striped bass downstream of dam. Based on:
  1. Documented habitat in some portion of the dam's downstream functional network
  2. **AND** Dam is on a stream that is likely to support that species based on stream size
     1. Size 3b+ Rivers
  3. **OR** There is documented habitat up to a dam on a stream that doesn't meet the above size class rule
  4. **AND** the dam has not been specifically flagged otherwise by Chesapeake Fish Passage Workgroup
- Fish habitat data from multiple sources, reviewed and edited by state fisheries biologists. Each line segment includes its data source.
- Unit: Unitless Classes: "Current", "Potential Current", "Historical"



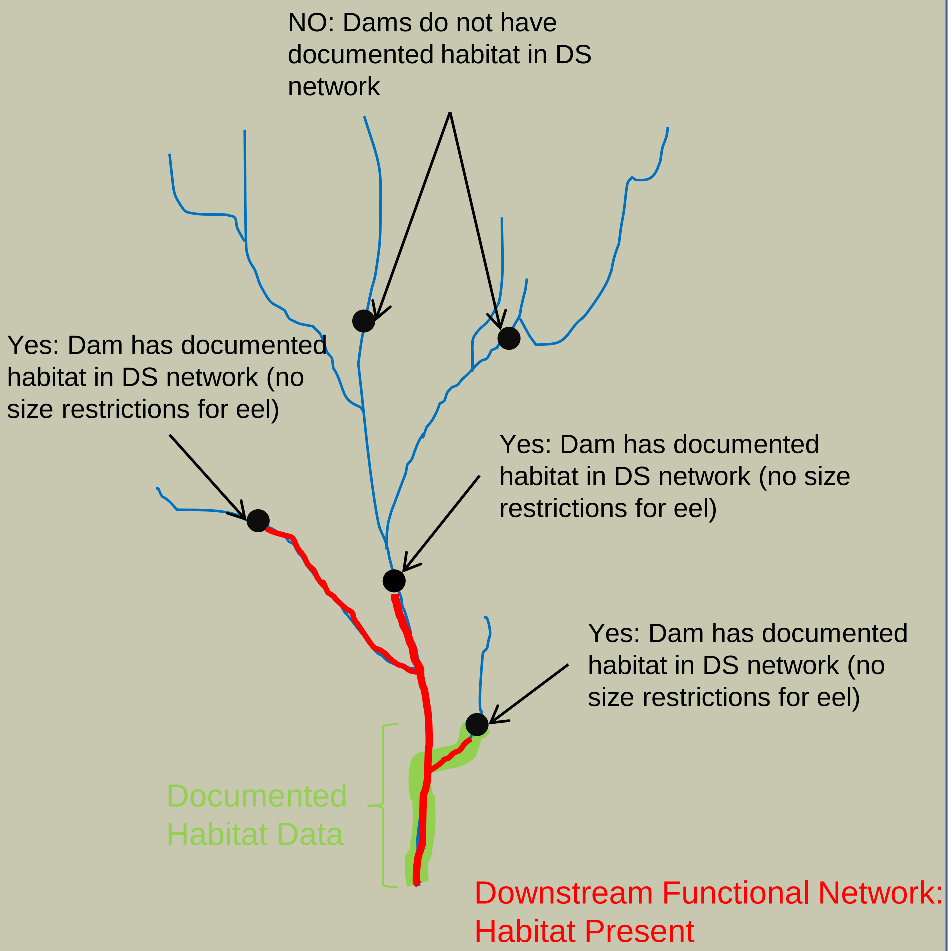
Shortnose Sturgeon habitat in Downstream Functional Network

- Category: Ecological
- Presence of shortnose sturgeon downstream of dam. Based on:
  1. Documented habitat in some portion of the dam's downstream functional network
  2. **AND** Dam is on a stream that is likely to support that species based on stream size
     1. Size 4+ Rivers
  3. **OR** There is documented habitat up to a dam on a stream that doesn't meet the above size class rule
  4. **AND** the dam has not been specifically flagged otherwise by Chesapeake Fish Passage Workgroup
- Fish habitat data from multiple sources, reviewed and edited by state fisheries biologists. Each line segment includes its data source.
- Unit: Unitless Classes: "Current", "Potential Current", "Historical"



American Eel habitat in Downstream Functional Network

- Category: Ecological
- Presence of American eel downstream of dam. Based on:
  1. Documented habitat in some portion of the dam's downstream functional network
  2. No size restrictions on eel
- Fish habitat data from multiple sources, reviewed and edited by state fisheries biologists. Each line segment includes its data source.
- Unit: Unitless Classes: "Current", "Potential Current", "Historical"



Presence of Anadromous Species in Downstream Network

- Category: Ecological
- 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, shortnose sturgeon, Atlantic sturgeon
- Habitat for each species is coded as "Current", "Potential Current" or "Historical"
- If current and historical habitat are documented in the downstream functional network for different species, the current habitat trumps the potential current habitat which in turn trumps the historical habitat. So if alewife habitat is "Current", American shad habitat is "Potential Current" and Atlantic sturgeon are "Historical" the metric will be "Current", indicating that habitat for 1 or more anadromous species is currently documented in the dams downstream network (based on the methods described for each species).
- Does NOT include American eel
- Unit: presence / absence

Number of Diadromous Species

- Category: Ecological

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

- Only "Current" habitat is considered for this metric

- Unit: #

Rare Fish in HUC8

- Category: Ecological
- Count of rare (G1-G3) fish species in the watershed within which the dam is located
- Based on NatureServe watershed (8-digit HUC) data
- Unit: #

Rare Mussels in HUC8

- Category: Ecological

- Count of rare (G1-G3) mussel species in the watershed within which the dam is located

- Based on NatureServe watershed (8-digit HUC) data

- Unit: #

Rare Crayfish in HUC8

- Category: Ecological
- Count of rare (G1-G3) crayfish species in the watershed within which the dam is located
- Based on NatureServe watershed (8-digit HUC) data
- Unit: #

Barrier within EBTJV Catchment with Trout

- 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

Native Fish Species Richness - HUC 8

- Category: Ecological
- Current native fish species richness in the watershed within which the dam is located
- Based on NatureServe watershed (8-digit HUC) data
- Unit: #

CBP Stream Health

- Chesapeake Bay Program stream health score
- Average Benthic Index of Biotic Integrity
- >10,000 sample locations rated as excellent, good, fair, poor, very poor
- Uses HUC10 watersheds where sample density is sufficient, otherwise HUC8 watersheds

MBSS Stream Health- BIBI

- Maryland Biological Stream Survey – benthic macroinvertebrate index of biotic integrity
- HUC10 watersheds rated as good, fair, poor, very poor based on mean of sample data
- Dams are assigned values based on the watershed they are within

MBSS Stream Health- FIBI

- Maryland Biological Stream Survey – fish index of biotic integrity
- HUC10 watersheds rated as good, fair, poor, very poor based on mean of sample data
- Dams are assigned values based on the watershed they are within

MBSS Stream Health- CIBI

- Maryland Biological Stream Survey – combined (average) of benthic macroinvertebrate index of biotic integrity and fish index of biotic integrity

- HUC10 watersheds rated as good, fair, poor, very poor based on mean of sample data

- Dams are assigned values based on the watershed they are within

INSTAR Stream Health - MIBI

- Virginia's Interactive Stream Assessment Resource: modified Index of Biotic Integrity
- 6th order (HUC12) watersheds classified as moderate, high, very high, outstanding
- Dams are assigned values based on the watershed they are within
- Data provided by
  - Virginia Commonwealth University,
  - VA Department of Conservation and Recreation, Division of Natural Heritage

PA Stream Health

- Pennsylvania stream health score, based on benthic index of biotic integrity data obtained from PA DEP.

- Mean IBI calculated for HUC10 watersheds.
  - "small stream" IBI used where drainage <50mi²
  - "large stream" IBI used where drainage >50mi²

- Classed as good (>63), fair (43-63), poor (<43) based on mean IBI score.

- Dams are assigned values based on the watershed they are within

River Size Class

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

1a: Headwaters (<3.861 sq.mi.)

1b: Creeks (>= 3.861<38.61 sq.mi.)

2:   Small River (>=38.61<200 sq. mi.)

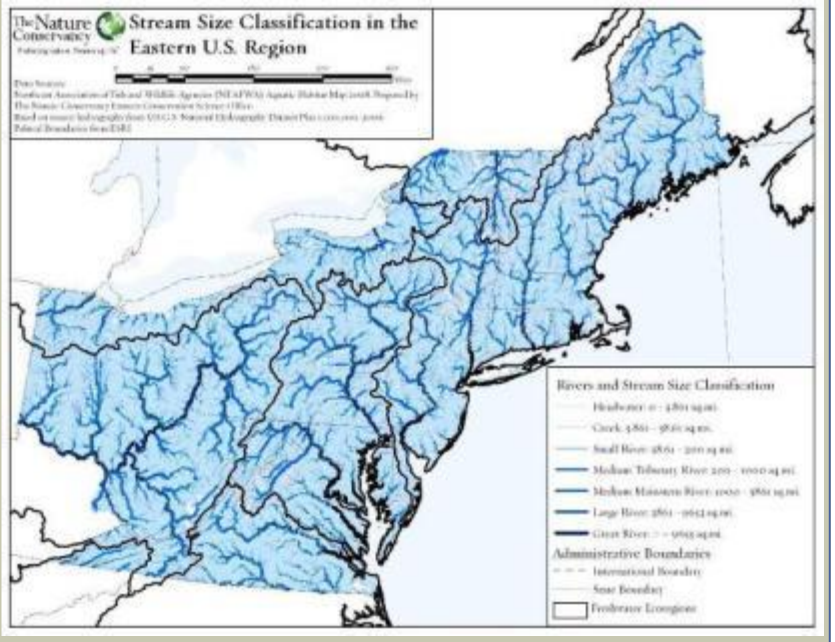
3a: Medium Tributary Rivers (>=200<1000 sq.mi.)

3b: Medium Mainstem Rivers (>=1000<3861 sq.

4:   Large Rivers (>=3861 < 9653 sq.mi.)

5:   Great Rivers (>=9653 sq.mi.)

(measure = upstream drainage area)



Upstream Size Classes Gained by Removal / Bypass

- Category: Size or System Type

- Number of upstream stream size classes gained if dam 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: #

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)

Small Streams Connected Directly to the Bay

- The first dams up from the Bay on small streams (Sizes 1a/1b) within 20km of the Bay (i.e. draining directly to the Bay or near the mouth of a large river).

% Agricultural LC in Contributing Watershed

- Category: Watershed & Local Condition
- % natural landcover in entire upstream watershed. Calculated 2011 National Land Cover Database.
- Agricultural landcover aggregated from the following classes: cultivated crops, pasture
- Unit: %

% Agricultural in ARA of Upstream Functional Network

- Category: Watershed & Local Condition
- % agricultural landcover within Active River Area of the upstream functional river network.
- 2011 National Land Cover Database data. Includes the following classes: cultivated crops, pasture
- Unit: %

% Agricultural LC in ARA of Downstream Functional Network

- Category: Watershed & Local Condition
- % agricultural landcover within Active River Area of the downstream functional river network.
- 2011 National Land Cover Database data. Includes the following classes: cultivated crops, pasture
- Unit: %

% Tree Cover in ARA of Upstream Functional Network

- Category: Watershed & Local Condition
- % tree cover within Active River Area of the upstream functional river network.
- Land cover data from the Chesapeake Bay Conservancy's high resolution (1m) land cover data.
- Unit: %

% Tree cover in ARA of Downstream Functional Network

- Category: Watershed & Local Condition

- % tree cover within Active River Area of the downstream functional river network.

- Land cover data from the Chesapeake Bay Conservancy's high resolution (1m) land cover data.

- Unit: %

% Herbaceous Cover in ARA of Upstream Functional Network

- Category: Watershed & Local Condition
- % Herbaceous cover within Active River Area of the upstream functional river network.
- Land cover data from the Chesapeake Bay Conservancy's high resolution (1m) land cover data.
- Unit: %

% Herbaceous cover in ARA of Downstream Functional Network

- Category: Watershed & Local Condition

- % Herbaceous cover within Active River Area of the downstream functional river network.

- Land cover data from the Chesapeake Bay Conservancy's high resolution (1m) land cover data.

- Unit: %

% Barren Cover in ARA of Upstream Functional Network

- Category: Watershed & Local Condition

- % Barren cover within Active River Area of the upstream functional river network.

- Land cover data from the Chesapeake Bay Conservancy's high resolution (1m) land cover data.

- Unit: %

% Barren cover in ARA of Downstream Functional Network

- Category: Watershed & Local Condition
- % Barren cover within Active River Area of the downstream functional river network.
- Land cover data from the Chesapeake Bay Conservancy's high resolution (1m) land cover data.
- Unit: %

% Road Impervious Surface in ARA of Upstream Functional Network

- Category: Watershed & Local Condition
- % Road Impervious Surface within Active River Area of the upstream functional river network.
- Land cover data from the Chesapeake Bay Conservancy's high resolution (1m) land cover data.
- Unit: %

% Road Impervious Surface in ARA of Downstream Functional Network

- Category: Watershed & Local Condition
- % Road Impervious Surface within Active River Area of the downstream functional river network.
- Land cover data from the Chesapeake Bay Conservancy's high resolution (1m) land cover data.
- Unit: %

% Non-Road Impervious Surface in ARA of Upstream Functional Network

- Category: Watershed & Local Condition
- % Non-Road Impervious Surface within Active River Area of the upstream functional river network.
- Land cover data from the Chesapeake Bay Conservancy's high resolution (1m) land cover data.
- Unit: %

% Non-Road Impervious Surface in ARA of Downstream Functional Network

- Category: Watershed & Local Condition
- % Non-Road Impervious Surface within Active River Area of the downstream functional river network.
- Land cover data from the Chesapeake Bay Conservancy's high resolution (1m) land cover data.
- Unit: %

Dam is on Conserved Land

- Category: Watershed & Local Condition
- Dam location intersects conserved land from 2014 secured areas database (TNC)
- Unit: Boolean

NFHP Risk of Degradation Score

- 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)

Barrier within Modeled Trout Catchment

- 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

- DeWeber, J.T. and Wagner, T., 2015. Predicting brook trout occurrence in stream reaches throughout their native range in the eastern United States. Transactions of the American Fisheries Society, 144(1), pp.11-24. https://doi.org/10.1080/00028487.2014.963256

Barrier blocks EBTJV 2012 Catchments

- 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

Barrier blocks Modeled Trout Catchments

- 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

Presence of rare fish or mussel species in upstream or downstream functional network

- Rare fish or mussel species are found in either the upstream functional network, downstream functional network, or both

- Rare species include those categorized as G1, G2, G3, S1, S2, S3, or state or federally listed

- Data Sources:
  - MD: Data included in this document were provided by the Maryland Department of Natural Resources Monitoring and Non-tidal Assessment Division.
  - PA: Pennsylvania Natural Heritage Program
  - VA: Virginia Department of Game and Inland Fisheries, Wildlife Environmental Review Map Service (WERMS), "SppObs_All" dataset

Presence of globally rare (G1, G2, G3) or federally endangered / threatened fish or mussel species in upstream or downstream functional network

- Globally rare fish or mussel species are found in either the upstream functional network, downstream functional network, or both
- Globally rare species include those categorized as G1, G2, G3, or federally listed
- Data Sources:
  - MD: Data included in this document were provided by the Maryland Department of Natural Resources Monitoring and Non-tidal Assessment Division.
  - PA: Pennsylvania Natural Heritage Program
  - VA: Virginia Department of Game and Inland Fisheries, Wildlife Environmental Review Map Service (WERMS), "SppObs_All" dataset

Presence of rare fish or mussel species in HUC12

- Rare fish or mussel species are found in HUC12 subwatershed in which the barrier is located
- Rare species include those categorized as G1, G2, G3, S1, S2, S3, or state or federally listed
- Data Sources:
  - MD: Data included in this document were provided by the Maryland Department of Natural Resources Monitoring and Non-tidal Assessment Division.
  - PA: Pennsylvania Natural Heritage Program
  - VA: Virginia Department of Game and Inland Fisheries, Wildlife Environmental Review Map Service (WERMS), "SppObs_All" dataset

Presence of globally rare (G1, G2, G3) or federally endangered / threatened fish or mussel species in HUC12

- Globally rare fish or mussel species are found in HUC12 subwatershed in which the barrier is located
- Globally rare species include those categorized as G1, G2, G3, or federally listed
- Data Sources:
  - MD: Data included in this document were provided by the Maryland Department of Natural Resources Monitoring and Non-tidal Assessment Division.
  - PA: Pennsylvania Natural Heritage Program
  - VA: Virginia Department of Game and Inland Fisheries, Wildlife Environmental Review Map Service (WERMS), "SppObs_All" dataset

Upstream Size Classes Gained by Removal / Bypass

- Category: Size or System Type

- Number of upstream stream size classes . 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: #

Miles of Cold Water Habitat in Total Functional Network

- 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

Miles of Cold or Cool Water Habitat in Total Functional Network

- 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