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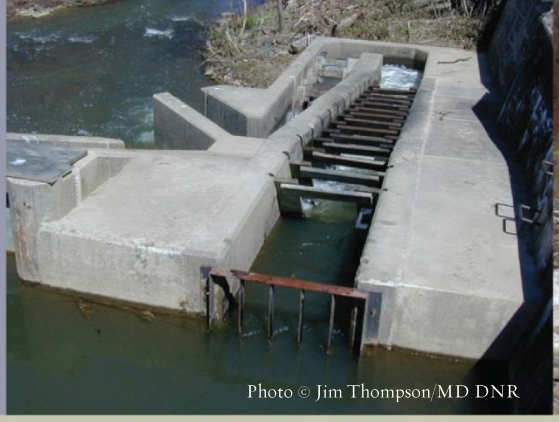

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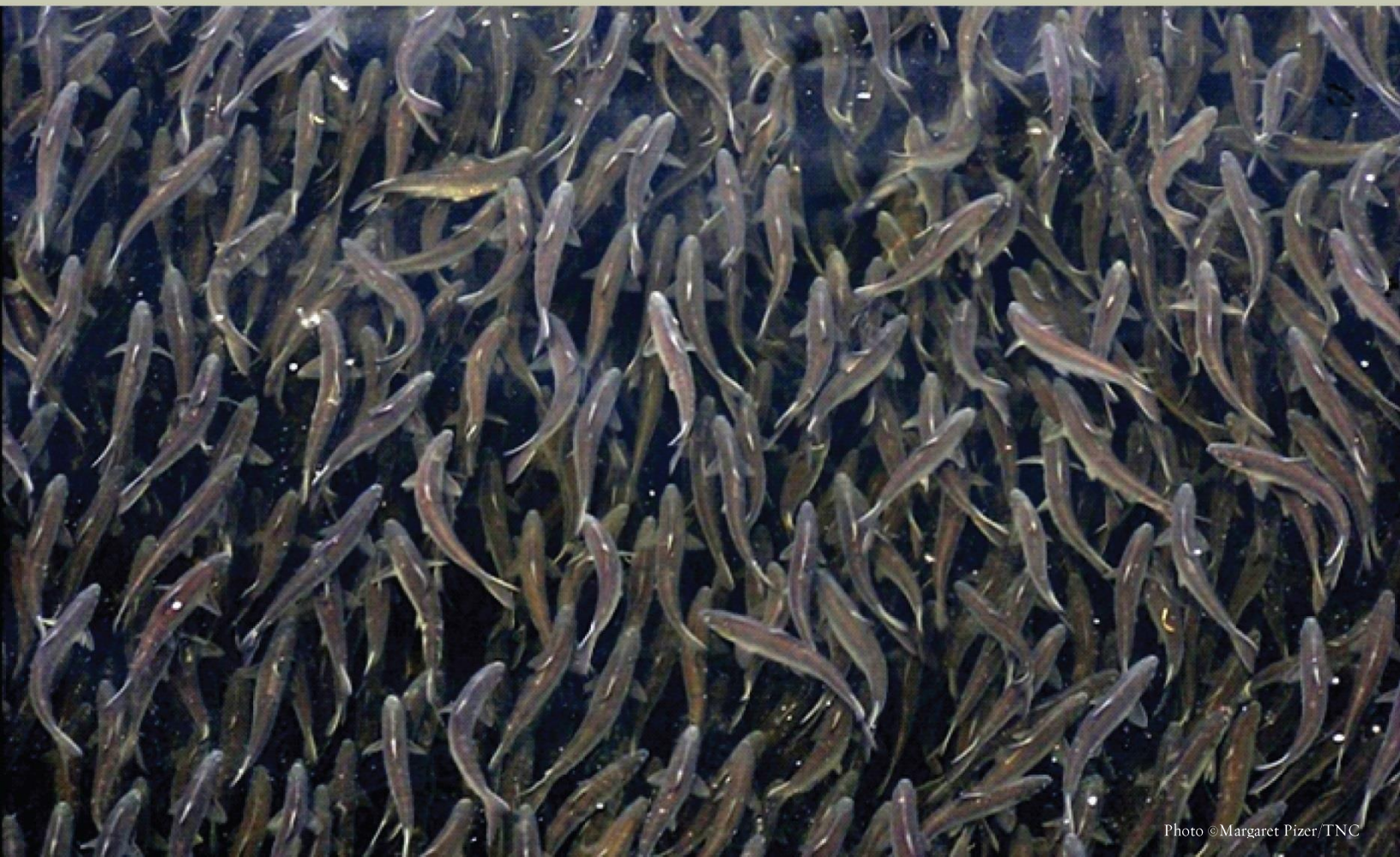
# Chesapeake Fish Passage Prioritization

*An Assessment of Dams in the Chesapeake Bay Watershed*

*7/1/2013*



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# 1 Background, Approach, and Outcomes

## 1.1 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 or zero-emission hydro power, flood control, and irrigation. Many more dams, however, no longer provide the services for which they were designed (e.g. old mill dams) or are inefficient due to age or design. 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 1-1: Bloede Dam, the first barrier to migratory fish on the Patapsco River

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.

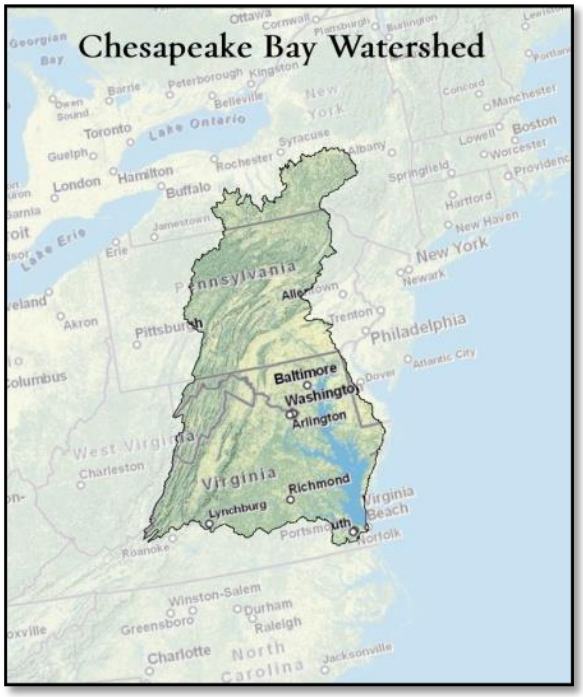
## 1.2 Approach

### 1.2.1 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 1-2: Chesapeake Bay watershed




### 1.2.2 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.

# 2 Data Collection and Preprocessing

Spatial data for the project were gathered from multiple data sources and processed in a Geographic Information System (GIS) to generate descriptive 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 fish, mussel, and crayfish watersheds, fish species richness, and Eastern Brook Trout Joint Venture catchments. A complete list of data used in the project can be found in Appendix II. A further description of the core datasets follows.

## 2.1 Definitions

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

### 2.1.1 Functional River Networks

A 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.

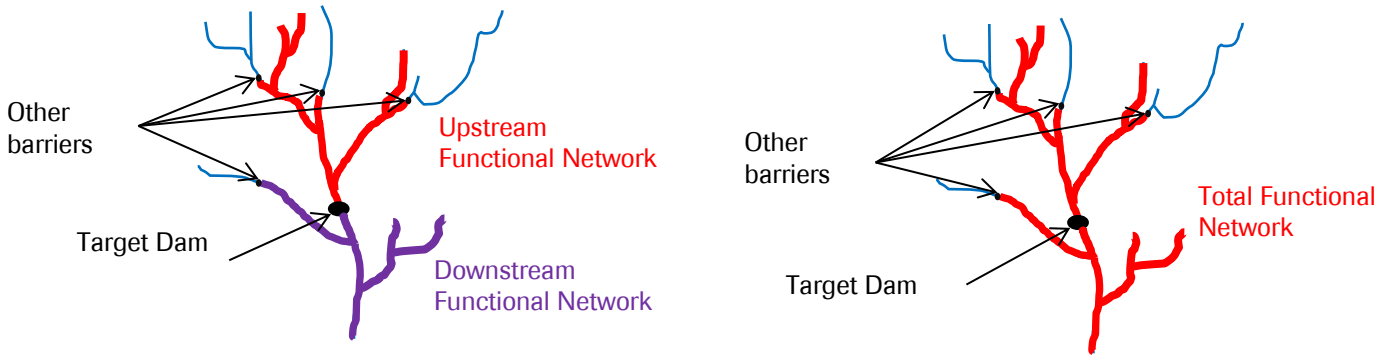



Figure 2-1: Conceptual illustration of functional river networks

## 2.1.2 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.

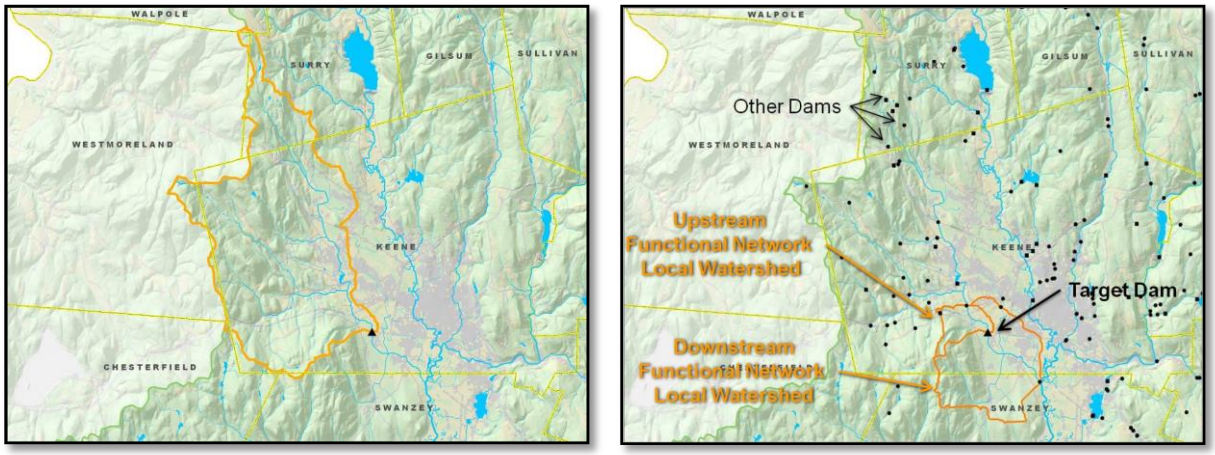



Figure 2-2: The contributing watershed is defined by the total drainage upstream of a target dam. The upstream and downstream functional river network local watersheds are bounded by the watershed for the next dams up and down stream.

## 2.1.3 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).

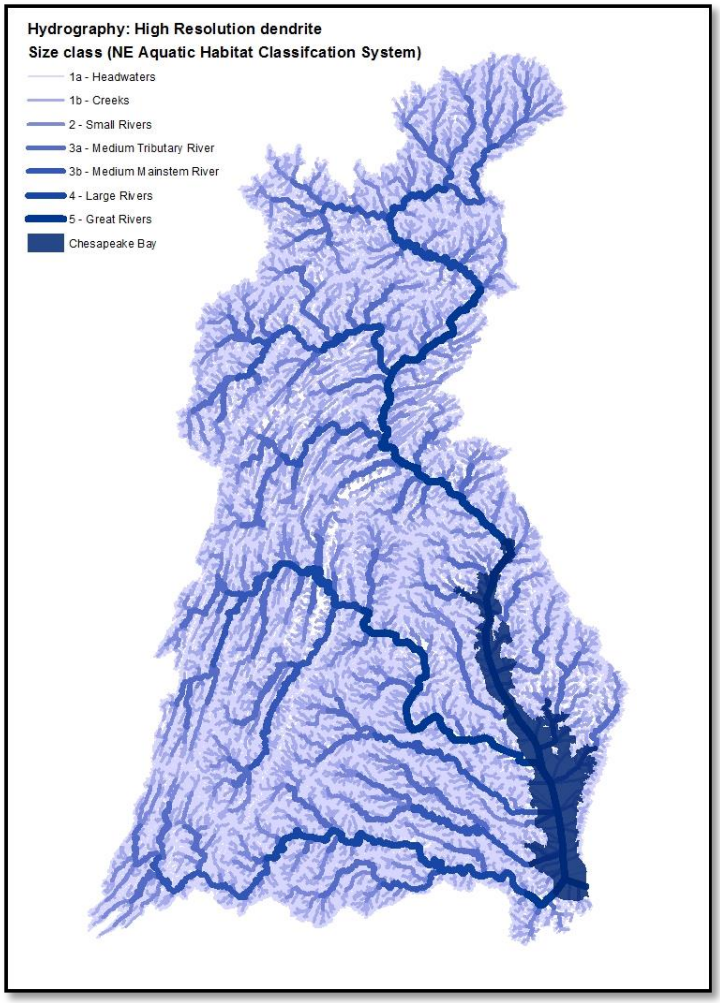



Figure 2-3: Size class definitions and map of rivers by size class in the Chesapeake Bay watershed.

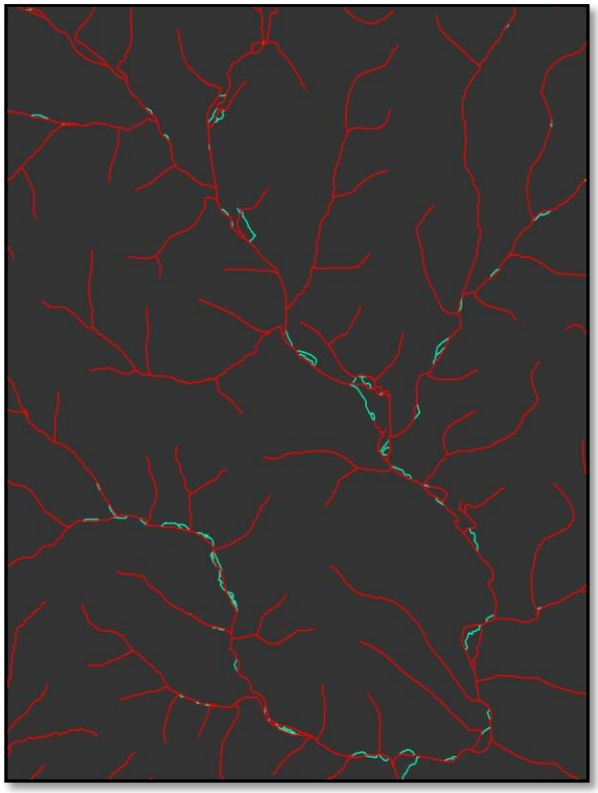
1a) Headwaters (<3.861 $mi^2$)
1b) Creeks (>= 3.861<38.61 $mi^2$)
2) Small River (>=38.61<200 $mi^2$)
3a) Medium Tributary Rivers (>=200<1000 $mi^2$)
3b) Medium Mainstem Rivers (>=1000<3861 $mi^2$)
4) Large Rivers (>=3861 < 9653 $mi^2$)
5) Great Rivers (>=9653 $mi^2$)
(Defining measure = upstream drainage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

## 2.2 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 2-4: 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.

## 2.3 Dams

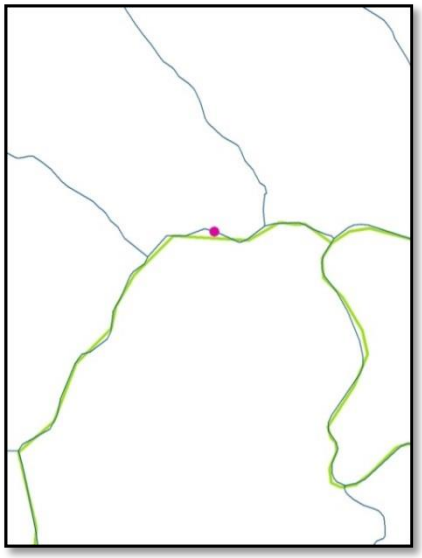
Dam data was obtained primarily from the Northeast Aquatic Connectivity project. Dam data for the Northeast Aquatic Connectivity project was obtained from several sources including state agencies the US Army Corps' National Inventory of Dams (NID), and the USGS Geographic Names Information System (GNIS) 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 2-5: 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 2-6: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.

There were 6,377 dams in the entire database when the analysis was run. This number included duplicates, dams outside the study area which are needed to bound the network analysis but which were not evaluated, dams on small streams which are not mapping in the NHDPlus hydrography, as well as other dams or structures which are not barriers such as breaches, levees, and removed dams. Excluding duplicates and non-barriers there are 5,482 dams in the database. In the end 3,883 of these dams were evaluated in the analysis. This represents 70.8% of the 5,482 dams that are current barriers, with the remaining dams falling on small streams that are not mapped in the project hydrography, or which lie outside the 3-state study area.

Figure 2-7: 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.

## 2.4 Diadromous Fish Habitat

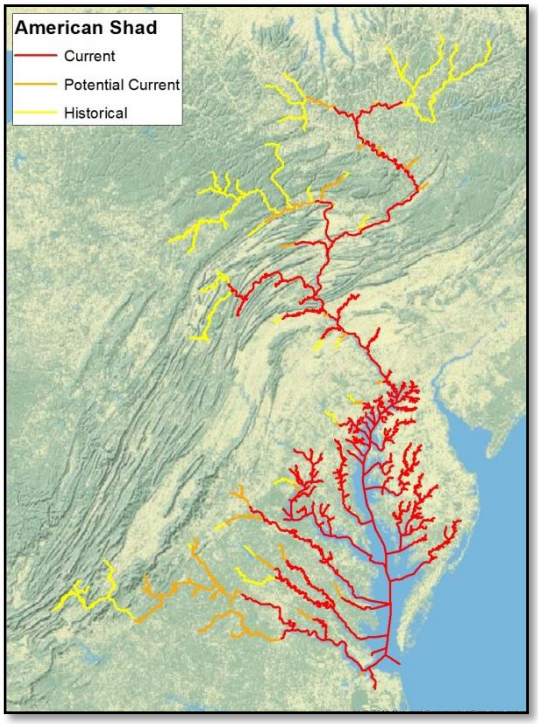
Identifying opportunities to best improve aquatic connectivity for the benefit of diadromous fish populations was one of the key goals of the project. Diadromous fish habitat downstream of a dam was one of the most important factors chosen by the Workgroup for the diadromous fish benefits scenario to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

ecological benefit if removed or mitigated.

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.

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 2-8: 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 in the web map: http://maps.tnc.org/erof_ChesapeakeFPP

## 2.5 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.

# 3 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.

## 3.1 Metric Calculation

A total of 40 metrics were calculated for each dam in the study area using ArcGIS 10.1. Metrics were organized into five categories for convenience: Connectivity Status, Connectivity Improvement, Watershed/Local Condition, Ecological, and Size/System Type. 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.

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

| Metric Category | Metric | Unit | Sort Order |
|---|---|---|---|
| Connectivity Status | # Dams Downstream | # | A |
| | # Fish Passage Facilities Downstream | # | D |
| | Total Upstream River Length | m | D |
| | Upstream Barrier Density | #/m | A |
| | Downstream Barrier Density | #/m | A |
| | Density of Small (Unsnapped) Dams in Upstream Functional Network Local Watershed | #/m² | A |

| | | | |
|---|---|---|---|
| | Density of Small (Unsnapped) Dams in Downstream Functional Network Local Watershed | #/m² | A |
| | Density of Road & RR / Small Stream Crossings in Upstream Functional Network Local Watershed | #/m² | A |
| | Density of Road & RR / Small Stream Crossings in Downstream Functional Network Local Watershed | #/m² | A |
| | Dam is a barrier to brook trout catchments (EBTJV2012) | Boolean | A |
| Connectivity Improvement | Upstream Functional Network Length | m | D |
| | The total length of upstream and downstream functional network | m | D |
| | Absolute Gain | m | D |
| Watershed / Local Condition | % Impervious Surface in Contributing Watershed | % | A |
| | % Natural LC in Contributing Watershed | % | D |
| | % Forested LC in Contributing Watershed | % | D |
| | % Impervious Surface in ARA of Upstream Functional Network | % | A |
| | % Impervious Surface 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 |
| Ecological | # 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 |
| | 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 |
| | Eastern Brook Trout joint Venture 2012 Catchments | unitless class | D |
| | Native fish species richness - HUC 8 | # | D |
| Size / System Type | # Upstream Size Classes >0.5mi gained | # | D |
| | Total Reconnected # stream sizes (upstream + downstream) >0.5 Mile | # | D |
| | Small streams connecting directly to ocean | Boolean | D |

The methods used to calculate all metrics was automated and documented via ArcGIS Model Builder models and custom Python scripts. Contact the author for more information on the methods used to calculate metrics.

## 3.2 Metric Weighting

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 3-2, Table 3-3, and

Table 3-4 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 3-2: Workgroup-Consensus metric weights for the Diadromous Fish Scenario

| Metric Category | Metric | Diadromous Weight |
|---|---|---|
| Connectivity Status | # Dams Downstream | 10 |
| | # Fish Passage Facilities Downstream | 5 |
| | Total Upstream River Length | 10 |
| | Density of Road & Railroad / Small Stream Crossings in Upstream Functional Network Local Watershed | 5 |
| Connectivity Improvement | Upstream Functional Network Length | 10 |
| Watershed / Local Condition | % 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 3-3: Workgroup-Consensus metric weights for the Resident Fish Scenario. These weights were largely retained by the Workgroup from the Northeast Aquatic Connectivity project, with some modifications.

| Metric Category | Metric | Resident Weight |
|---|---|---|
| Connectivity Status | Upstream Barrier Density | 1 |
| | Downstream Barrier Density | 1 |
| | Density of Small (1:24k) Dams in Upstream Functional Network Local Watershed | 3 |
| | Density of Small (1:24k) Dams in Downstream Functional Network Local Watershed | 3 |
| | Density of Road & Railroad / Small Stream Crossings in Upstream Functional Network Local Watershed | 5 |
| | Density of Road & Railroad / Small Stream Crossings in Downstream Functional Network Local Watershed | 5 |
| | Dam is a barrier to brook trout catchments (EBTJV2012) | 2 |
| Connectivity | The total length of upstream and downstream functional network | 10 |

| | | |
|---|---|---|
| Improvement | Absolute Gain | 15 |
| Watershed / Local Condition | % Impervious Surface in Contributing Watershed | 5 |
| | % Natural LC in Contributing Watershed | 5 |
| | % Impervious Surface in ARA of Upstream Functional Network | 2 |
| | % Impervious Surface in ARA of Downstream Functional Network | 2 |
| | % Natural LC in ARA of Upstream Functional Network | 1 |
| | % Natural LC in ARA of Downstream Functional Network | 1 |
| | % Forested LC in ARA of Upstream Functional Network | 2 |
| | % Forested LC in ARA of Downstream Functional Network | 2 |
| | % Conserved Land within 100m Buffer of Upstream Functional Network | 2 |
| | % Conserved Land within 100m Buffer of Downstream Functional Network | 2 |
| | CBP Stream Health | 5 |
| | # of rare (G1-G3) fish species in HUC8 | 3 |
| | # of rare (G1-G3) mussel HUC8 | 3 |
| | # of rare (G1-G3) crayfish HUC8 | 2 |
| | Eastern Brook Trout joint Venture 2012 Catchments | 10 |
| | Native fish species richness - HUC 8 | 3 |
| Size / System Type | Total Reconnected # stream sizes (upstream + downstream) >0.5 Mile | 5 |

Table 3-4: 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 |
|---|---|---|
| Connectivity Status | Density of Small (1:24k) Dams in Upstream Functional Network Local Watershed | 5 |
| | Density of Small (1:24k) Dams in Downstream Functional Network Local Watershed | 3 |
| | Density of Road & Railroad / Small Stream Crossings in Upstream Functional Network Local Watershed | 5 |
| | Density of Road & Railroad / Small Stream Crossings in Downstream Functional Network Local Watershed | 2 |
| | Dam is a barrier to brook trout catchments (EBTJV2012) | 10 |
| Connectivity Improvement | The total length of upstream and downstream functional network | 5 |
| | Absolute Gain | 15 |
| Watershed / Local Condition | % 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 |
| | Eastern Brook Trout joint Venture 2012 Catchments | 25 |

As noted in the caption for Table 3-4 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 5: Web Map and Custom Analysis Tool.

## 3.3 Prioritization

Once metric values were calculated and relative weights assigned to the metrics of interest, metrics were combined through a weighted ranking process to develop a prioritized list for each scenario. The ranking process used involves four steps and simple mathematical operations, as illustrated Figure 3-1.

Figure 3-1: 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 |

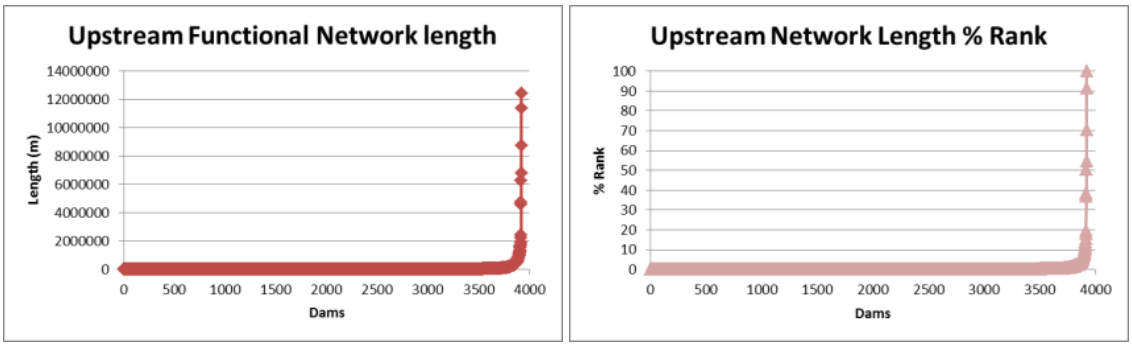
5

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

- Step 1: All values are converted 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 3-2, converting the values to percent ranks perserves the magnitude of difference between dams.

Figure 3-2: 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 3-3: A comparison of metrics with outliers and with a more even distribution.

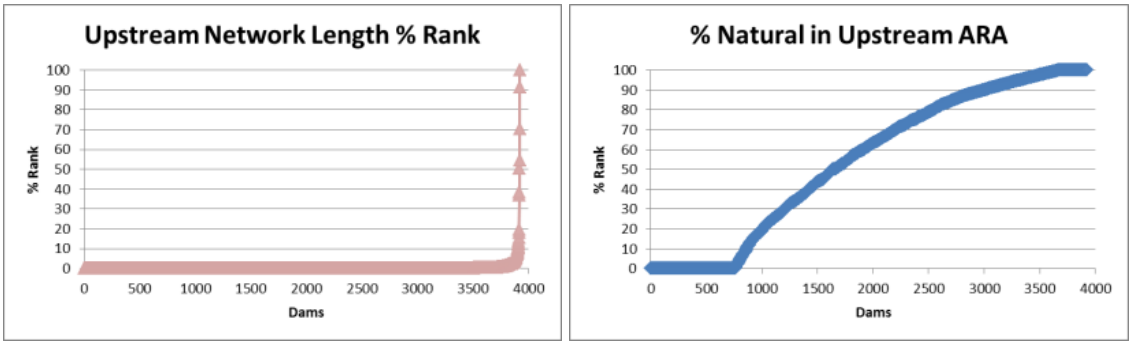
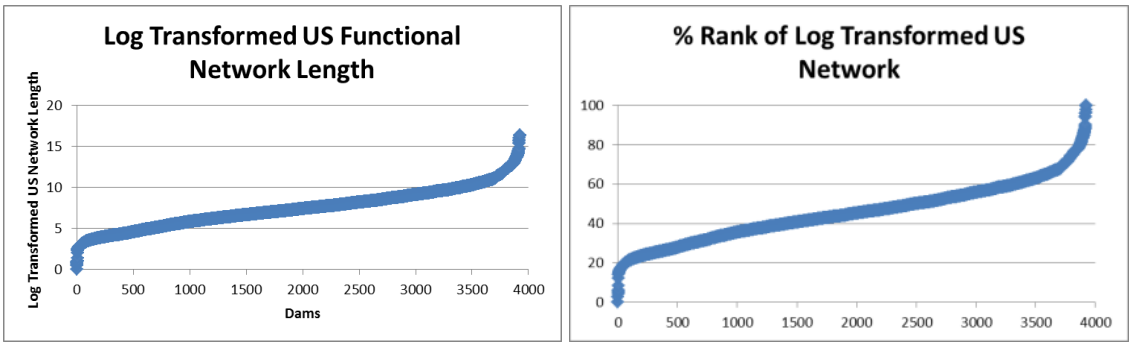



Figure 3-3 compares the distribution of upstream functional network length with percent natural landcover in the Active River Area of each dam's upstream functional network for dams in the study (where natural landcover is an aggregation of National Landcover Database categories, as detailed in Appendix 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 3-4.

Figure 3-4: 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 3-5 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, and Total Length Upstream.

Figure 3-5: 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.

| | Name | Upstream Functional Network Length (m) | % Natural LC in ARA of Upstream Functional Network |
|---|---|---|---|
| Values in real units | 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 |

| | Name | Upstream Functional Network Length (% rank) | % Natural LC in ARA of Upstream Functional Network (% rank) |
|---|---|---|---|
| 1: Percent 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 |

| | Name | Upstream Functional Network Length (weighted rank) Weight=40 | % Natural LC in ARA of Upstream Functional Network (weighted rank) Weight=60 |
|---|---|---|---|
| 2: Weighted Rank | 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 |

| | Name | Summed Ranks |
|---|---|---|
| 3: Summed Rank | 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 |

| | Name | FinalRank |
|---|---|---|
| 4: Final Rank | Dam A | 2 |
| | Dam B | 4 |
| | Dam C | 1 |
| | Dam D | 3 |
| | Dam E | 5 |
| | Dam F | 7 |
| | Dam G | 6 |

| | Name | Upstream Network Length (m) --> *Log Transformed (ln)* | % Natural LC in ARA of Upstream Functional Network |
|---|---|---|---|
| Values in real units | 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 |

| | Name | Upstream Functional Network Length (% rank) | % Natural LC in ARA of Upstream Functional Network (% rank) |
|---|---|---|---|
| 1: Percent 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 |

| | Name | Upstream Functional Network Length (weighted rank) Weight=40 | % Natural LC in ARA of Upstream Functional Network (weighted rank) Weight=60 |
|---|---|---|---|
| 2: Weighted Rank | 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 |

| | Name | Summed Ranks |
|---|---|---|
| 3: Summed Rank | 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 |

| | Name | FinalRank |
|---|---|---|
| 4: Final Rank | Dam A | 1 |
| | Dam B | 3 |
| | Dam C | 2 |
| | Dam D | 6 |
| | Dam E | 5 |
| | Dam F | 7 |
| | Dam G | 4 |

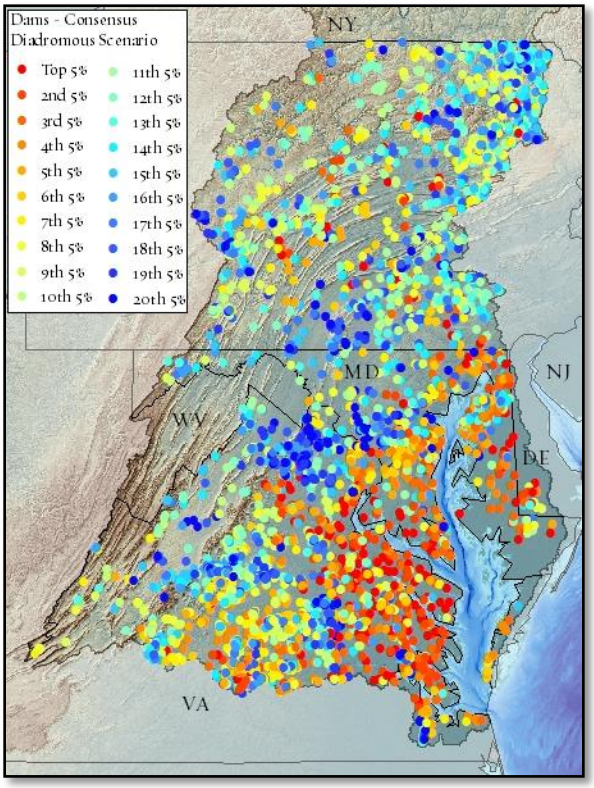
# 4 Results, Uses, & Caveats

## 4.1 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 selecting metrics and applying relative weights (see Section 3.2) from the dams and data compiled for the project (see Section 2). These results can be viewed and downloaded from http://maps.tnc.org/erof_ChesapeakeFPP.

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 functionality and the species passed during various flow conditions, as well as the relative lack of data to describe passage success rates, it was determined that 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 4-1: 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.

### 4.1.1 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

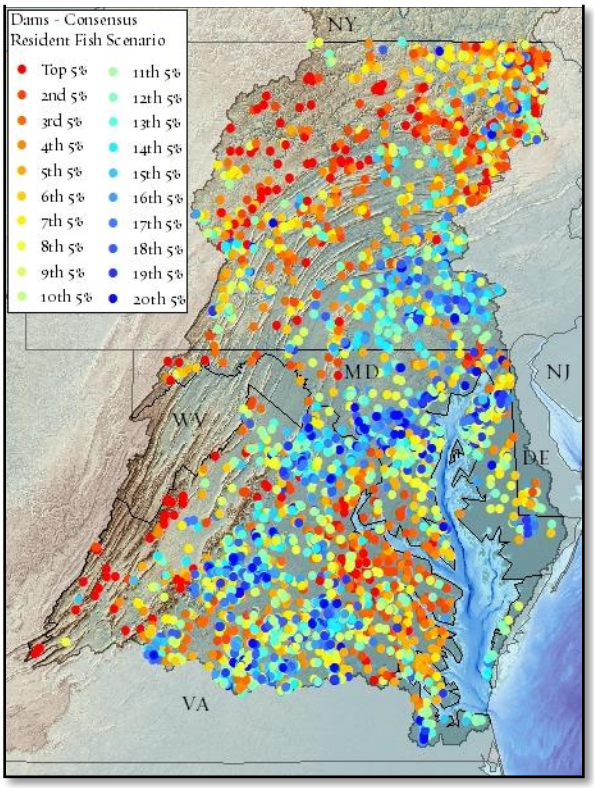
metric weights presented in Table 3-2, and produced the results depicted in Figure 4-1 one would expect in a scenario designed to benefit diadromous fish, the dams in the higher tiers, those whose removal would provide the greatest benefit to diadromous fish, tend to be found closer to the Bay and on 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 194 dams in Tier 1, 31 (16%) have existing fish passage facilities. This represents 60% of the dams in the study that have existing fish passage facilities.

### 4.1.2 Resident Fish Scenario

Using the metrics and metrics weights first selected by the Northeast Aquatic Connectivity Workgroup and modified by the Chesapeake Fish Passage Workgroup (presented in Table 3-3), 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 4-2, these results differ substantially from the Diadromous Fish Scenario result. They are driven by absolute gain (weight=15), total functional network length (weight=10), and suite of land cover condition metrics.

Figure 4-2: Workgroup-consensus Resident Fish Scenario results

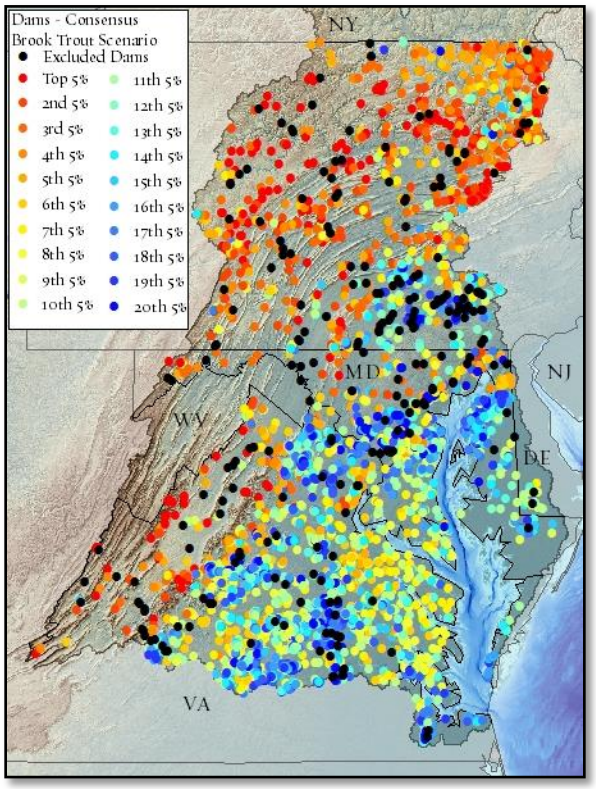



High priorities in this scenario are clustered in areas with a high proportion of natural land cover and long functional networks like the West Branch of the Susquehanna and western Virginia. A cluster of high priority dams is also found in the Rappahannock and Mattaponi drainages where relatively high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

### 4.1.3 Brook Trout Scenario

Beyond the Resident Fish Scenario, which was largely carried over from the Northeast Aquatic Connectivity project, the Workgroup elected to produce a brook trout-specific scenario. This scenario is based on the weights in Table 3-4 and prioritizes dams as presented in **Error! Reference source not found.**. In addition to the weights selected by the Workgroup, this scenario is limited to dams on small streams (those draining <100 square kilometers, sizes 1a and 1b from the Northeast Aquatic Habitat Classification System). Dams on larger rivers were excluded to reflect the fact that brook trout habitat is found primarily on smaller, cold water systems.

Figure 4-3: Workgroup consensus Brook Trout Scenario




This scenario is driven to a large extent by the 2012 Eastern Brook Trout Joint Venture (EBTJV) catchment-scale data (weight=25). Substantial weight is also given to absolute gain, land cover metrics, and whether a dam is a barrier to EBTJV catchments. As can be seen in Figure 4-3, 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.

## 4.2 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.

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

- **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.
- **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 5, 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.

## 4.3 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.

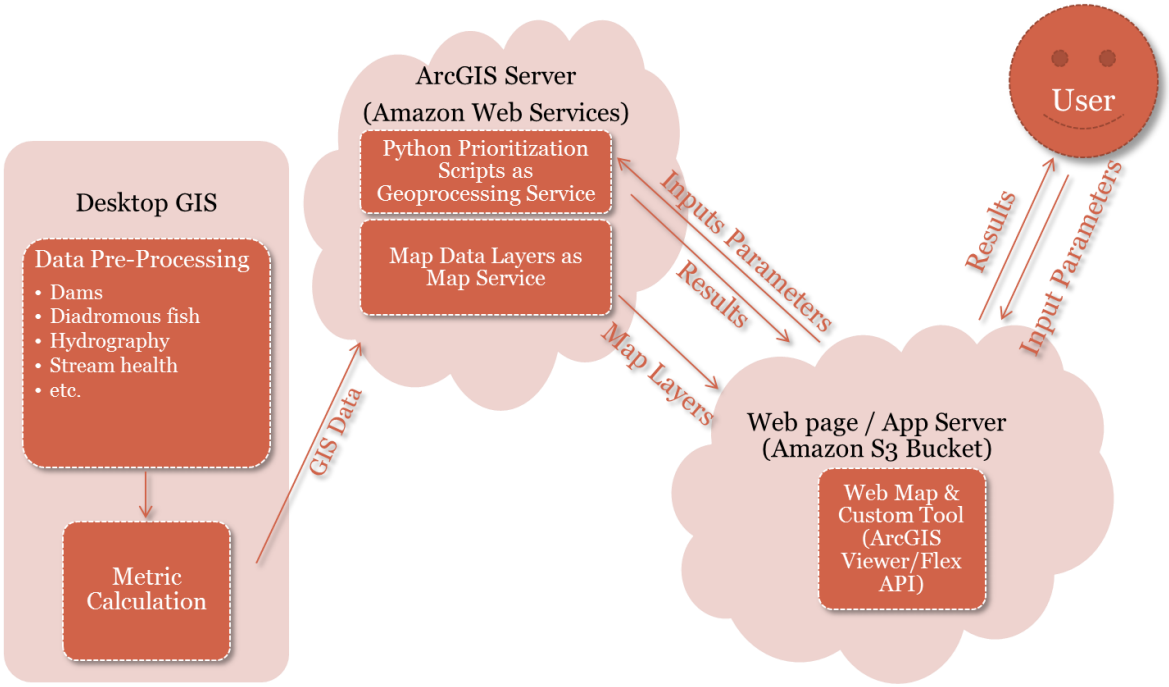
Finally, it is important to note that any aquatic connectivity project will have ecological benefits and if an opportunity arises it should not be rejected solely on the grounds that it does not rank out in one of the upper tiers of this project. Ultimately, whether the benefits provided by a given passage 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.

# 5 Web Map & Custom Analysis Tool

Project results and a tool to run custom user-defined scenarios can be found at http://maps.tnc.org/erof_ChesapeakeFPP. 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 tabular data, search for a dam interactively or by name, 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 the ArcGIS Viewer for Flex (http://resources.arcgis.com/en/communities/flex-viewer) modified using the ArcGIS Flex API (http://resources.arcgis.com/en/communities/flex-api). Likewise, the custom analysis tool is developed using Python geoprocessing scripts and the ArcGIS acrpy module

(http://resources.arcgis.com/en/help/main/10.1/index.html#//000v000000v7000000). These geoprocessing scripts are served to the internet via ArcGIS Server and consumed in the web map via the ArcGIS Viewer platform. Figure 5-1 illustrates the conceptual architecture of the web map & custom analysis tool.

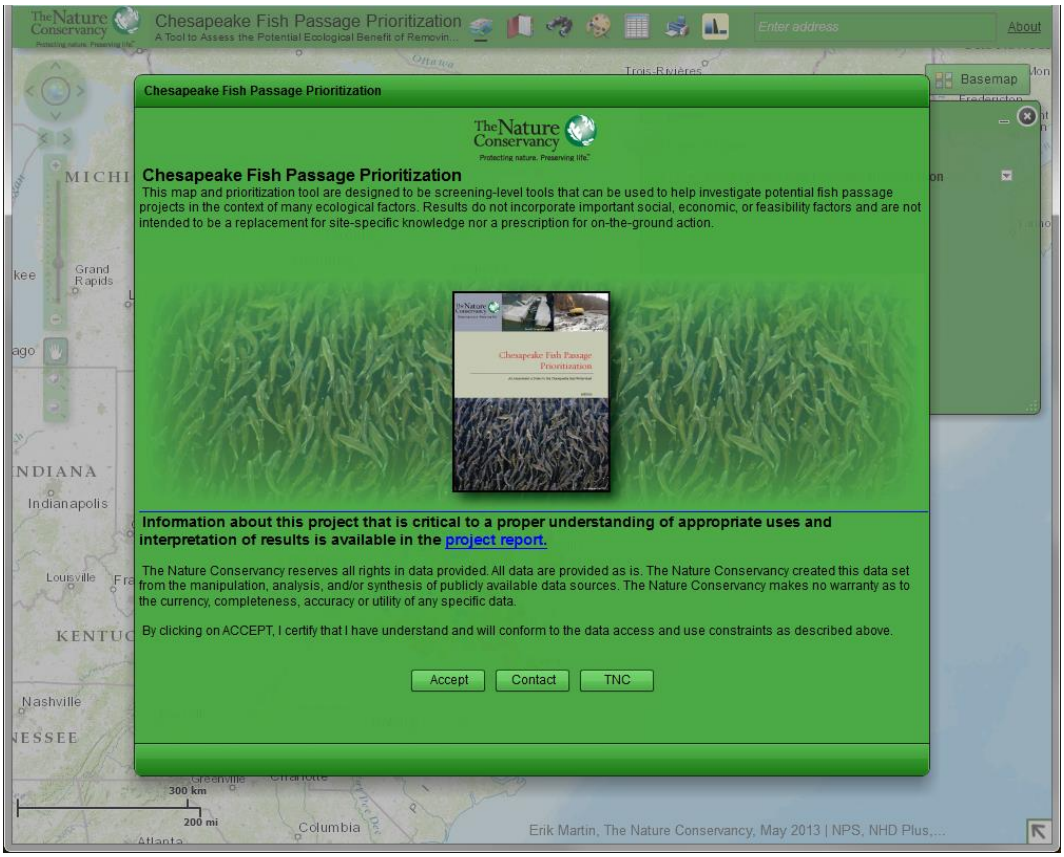
Figure 5-1: Conceptual architecture of web map & custom prioritization tool




## 5.1 Web Map

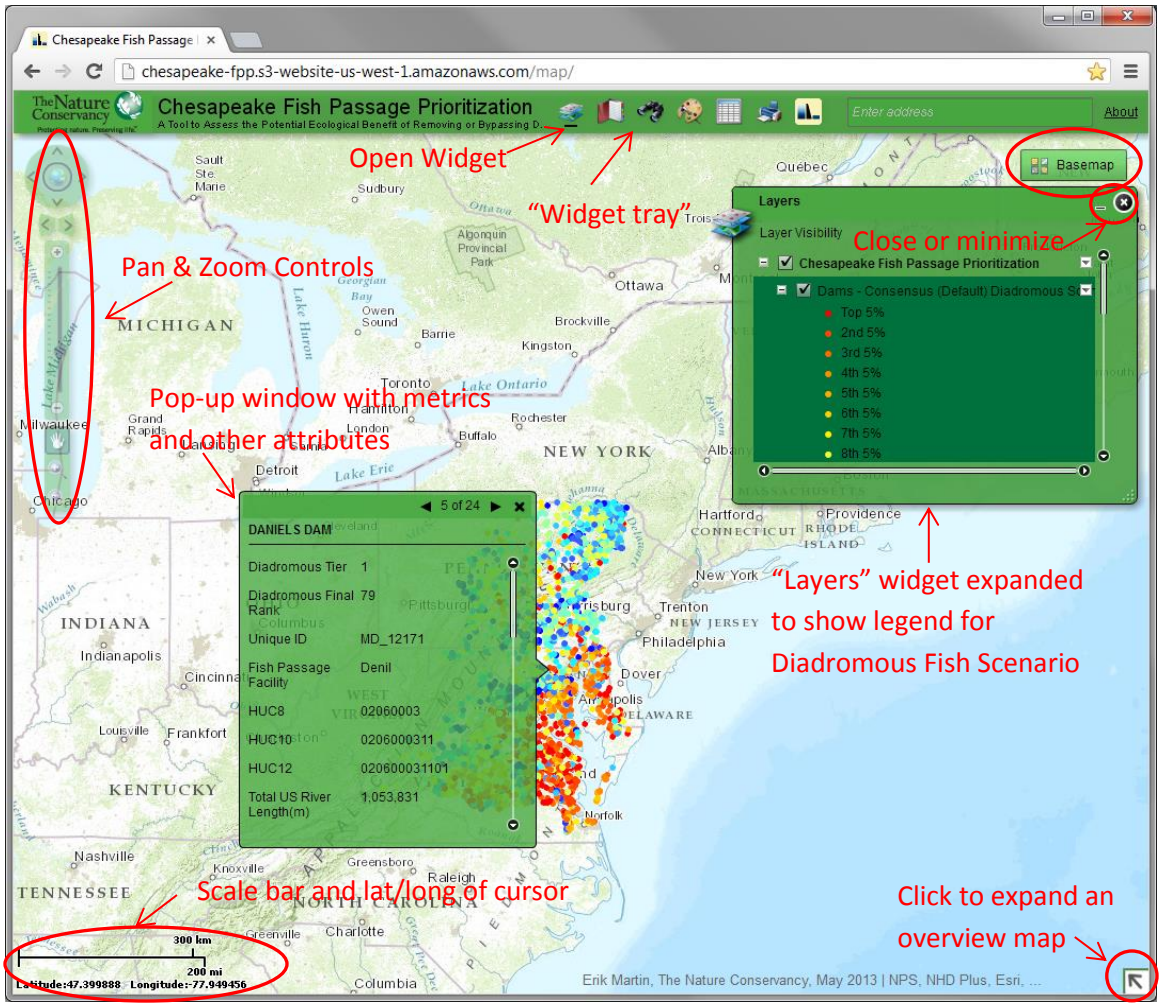
Upon first entering the map, a welcome screen pops up with important information about the project, links to additional information, and use limitations. Three buttons at the bottom of the welcome screen allows users to enter the map by accepting the use constraints ("Accept"), "Contact" the authors via email, and link to The Nature Conservancy's website ("TNC").

Figure 5-2: Web map welcome screen. Click on "Accept" to agree to the use constraints and enter the map.




By default, the map is loaded with the Workgroup-consensus Diadromous Fish Scenario results displayed. Clicking on a dam point brings up attribute information including values for all of the metrics that were used in the diadromous fish scenario. The basic features of the web map are noted in Figure 5-3. At the top of the map window is a tray of “Widgets”. Each widget opens a window that contains some functionality. Widgets can be minimized, closed, expanded and dragged. Detail about the map widgets can be found in Section 5.1.2.

Figure 5-3: Basic features of the web map



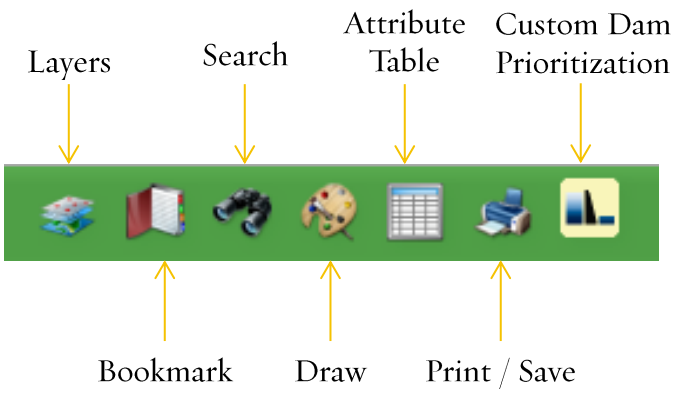

## 5.1.1 Project Data

Several project datasets are available in the map. These can be toggled on and off via the Layers "widget", which is open by default. Expanding the "+" signs in the Layers widget reveals the Legend for each of the layers in the map. The dropdown arrow on the right side of each layer in the Layers widget can be used to zoom to the extent of that layer and to view a description of the layer. In addition to the three Workgroup-consensus scenarios, several supporting datasets are provided. These include diadromous fish habitat compiled for the project (describe in Section 2.4), river hydrography, watershed boundaries, natural land cover & percent impervious surface, non-native fish observations, natural waterfalls, and previously removed dams.

## 5.1.2 Widgets

Several "widgets" are available to help users interact with the map. Widgets are located along the top of the map frame in the widget tray, as illustrated in Figure 5-4. Widgets that are currently opened are indicated by a black line under the widget icon in the widget tray.

Figure 5-4: Widgets in the Widget Tray




### 5.1.2.1 Layers

The Layers widget is open by default when the map loads. Individual layers can be turned on and off by checking or unchecking the box for each layer. If a layer is part of a grouped layer, the box for the group must be checked in order for the layer to be visible in the map. Expanding the check boxes for each layer reveals any nested layers and displays the symbology if there are no nested layers. The drop-down arrow on the right side of each layer name allows users to zoom to the extent of the layer and view a brief description of the layer. These features are illustrated inFigure 5-5.

Figure 5-5: The Layers widget

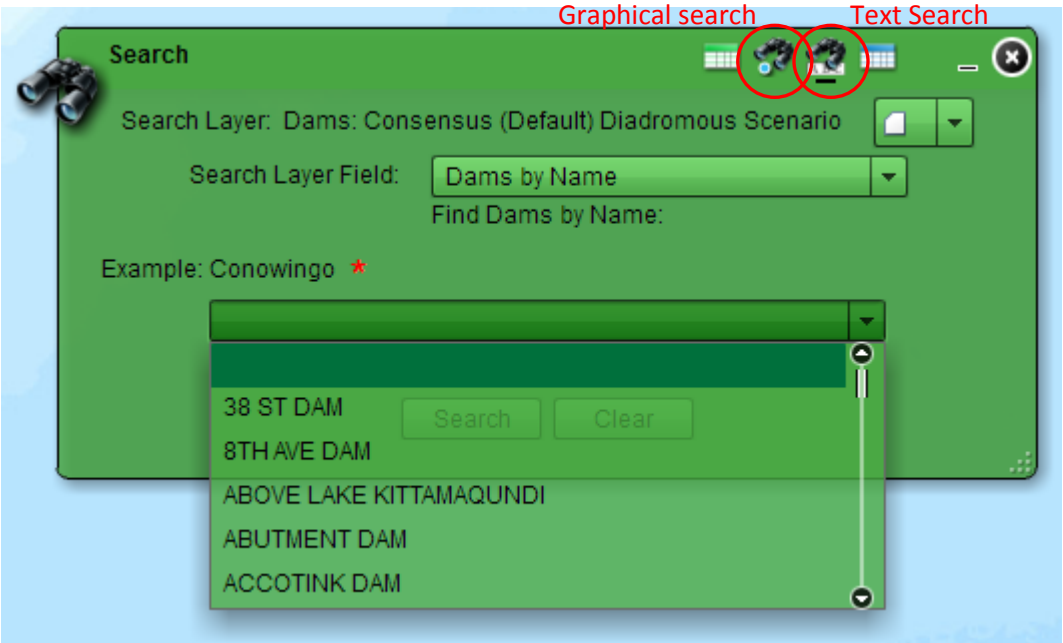
### 5.1.2.2 Bookmark

The Bookmark widget allows users to zoom to predefined map extents including Virginia, Maryland, Pennsylvania and the entire Chesapeake Bay watershed. Users can also define and save the current map extent as bookmarks to easily return to it later. However, these user-defined bookmarks do not persist between sessions.

### 5.1.2.3 Search

The Search widget can be used to locate dams by name, by result Tier, or graphically. To search for a dam by name, simple open the widget and select the dam name of interest from the list that is automatically pre-loaded, as depicted in. This text search option to search by name is enabled by default when the widget is opened.

Figure 5-6: Search widget- find a dam by name.



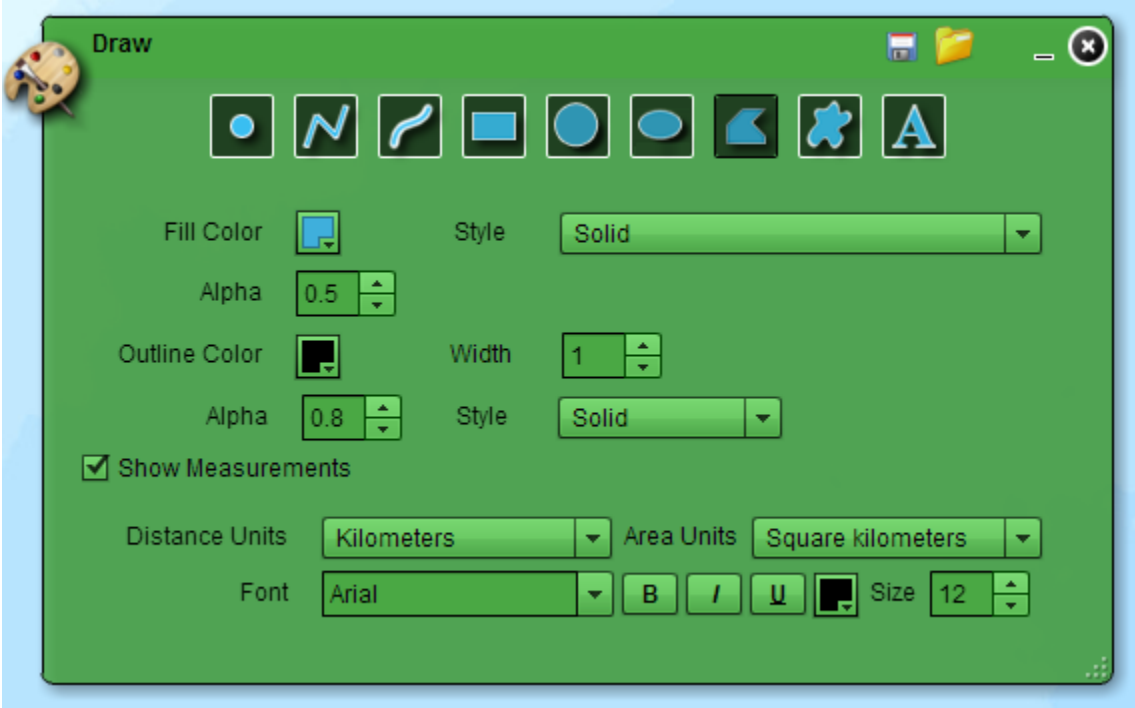

To find dams by result Tier, simply select the "Search Layer Field" dropdown and select "Dams by Diadromous Tier (or Brook Trout Tier or Resident Tier, respectively). Then select the Tier of interest. Selecting "1" would bring up a list of all of the top tier dams for that scenario.

To search for dams graphically, select the "Graphical Search" icon at the top of the widget. Drawing tools can then be used to draw a box around a set of dams, for example, and retrieve a table of attributes for these dams. Additional information about the Search widget can be found at http://www.arcgis.com/home/item.html?id=5d4995ccdb99429185dfd8d8fb2a513e.

### 5.1.2.4 Draw

The Draw widget can be used to annotate a map with text or drawings. Several options are available to customize the look of drawings including fill color, outline color, and transparency (alpha). An option is also available to display measurements for drawings. Preferred units and fonts can be set if measurements are included. Drawings can be saved and shared or re-loaded into another map session. They will also be included if the map is saved (PDF) or printed via the Print widget.

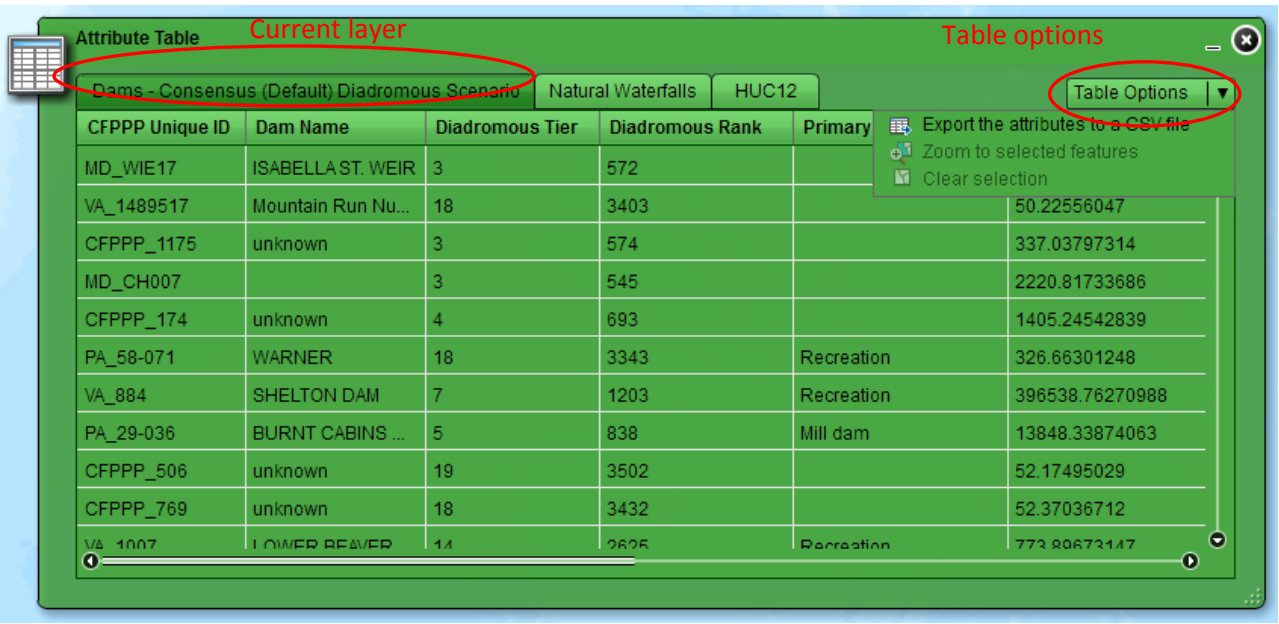
Figure 5-7: The Draw widget




### 5.1.2.5 Attribute Table

The Attribute Table widget provides access to attributes for the map layers. Records can be sorted by and column by clicking on the header of that column. The Attribute table is linked to each feature in the map. Records in the attribute table can be selected and the

Figure 5-8: Attribute Table widget




corresponding features in the map can be zoomed to. Multiple records can be selected by holding down

the Control or Shift keys. Additionally, records can be exported as a CSV text file, via the Table options dropdown. Only attributes for those layers that are visible in the map appear in the attribute table. Further, only those features that are within the current extent of the map appear in the attribute table.

#### 5.1.2.6 Print

The Print widget allows the current map view, formatted as the map window only or to the selected size with border information (legend, scale bar, etc) included. It can be saved as a PDF or image file (JPG, PNG) and saved. The result is opened as a new tab or window in the user's browser, whence it can be saved to the desired location.

#### 5.1.2.7 Custom Dam Prioritization

The Custom Dam Prioritization tool (widget) was developed for the Chesapeake Fish Passage Prioritization project to allow prioritizations based on user-specified metrics weights to be developed. Further explanation of the Custom Dam Prioritization tool is in Section 5.2.

## 5.2 Custom Dam Prioritization Tool

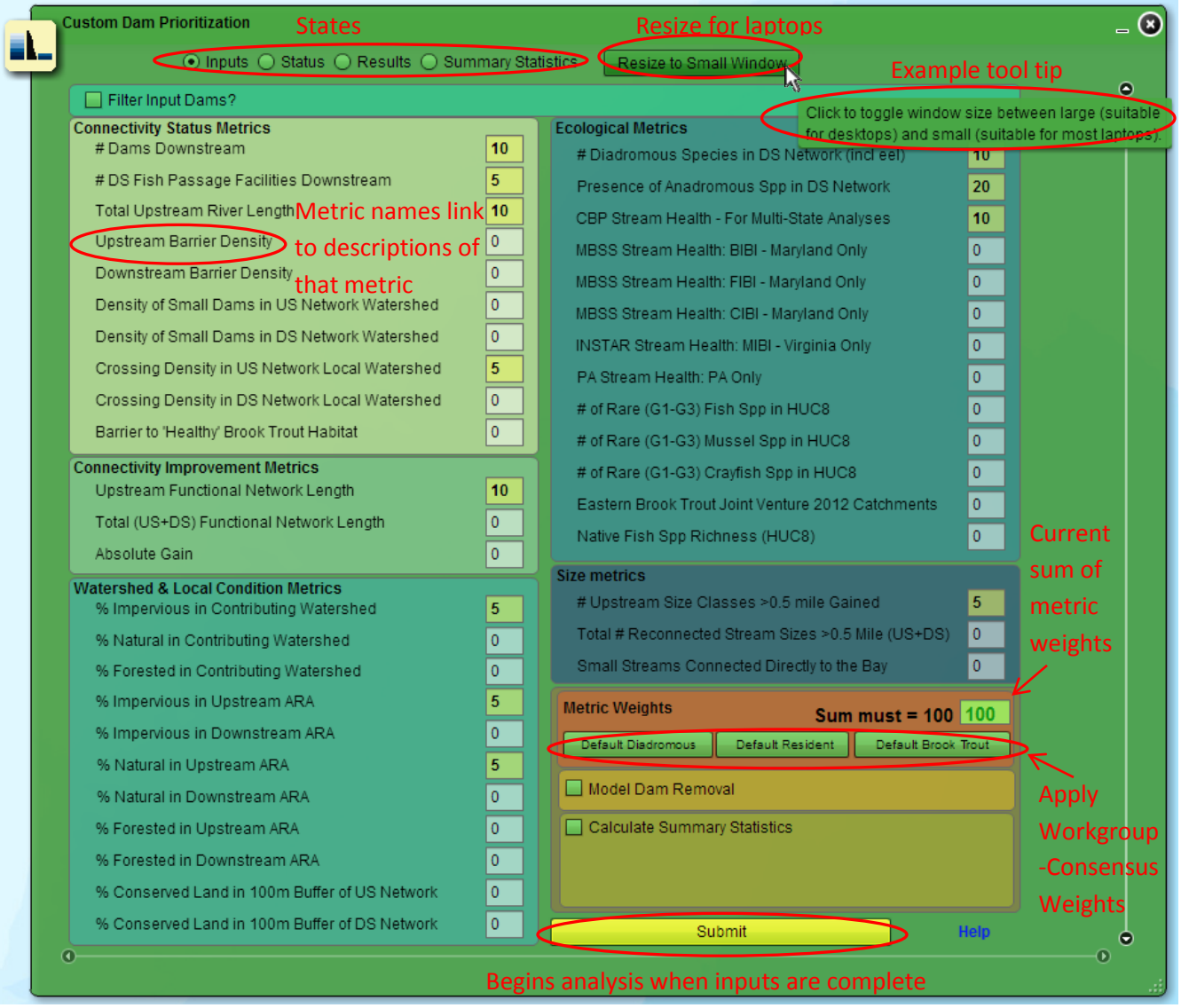
The Custom Dam Prioritization tool (or the "Tool") allows users to modify and build off of the three scenarios developed by the Chesapeake Fish Passage Workgroup (see Section 4.1) by altering metric weights, filtering out the input dams (e.g. by state or watershed), and running "removal scenarios" as if one or more dams had been removed from the network.

The Tool exists in four different states: Inputs, Status, Results, and Summary Statistics. The Inputs state is open by default and is the interface through which the user inputs all desired parameters. When all inputs are entered and processing has begun, the Tool will automatically switch to the Status state to report information on the status of the processing. When it is finished, it will automatically switch to the Results state, which displays a table of Attribute information for the custom prioritization results. Additional information on interacting with the Results is in Section 5.2.5.1. Finally, the Summary Statistics state displays a table of optional summary statistics, if they were calculated (See Section 5.2.3). Although the Tool will automatically switch between states at key times, the user can select a given state at any time by using the radio buttons along the top of the Tool.

Hovering the mouse over most items in the Tool summons tool tips – short descriptions of that button, input, or other feature. The tool tips contain instructions and other useful information. Descriptions of each metric can be found by clicking on the metric name. This will open a link to a PDF file which contains a full glossary of all metrics.

The basic features of the Custom Dam Prioritization tool are illustrated in Figure 5-9.

Figure 5-9: Custom Dam Prioritization Tool layout




## 5.2.1 Applying Custom Weights

As has been described in Section 3.2, 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.

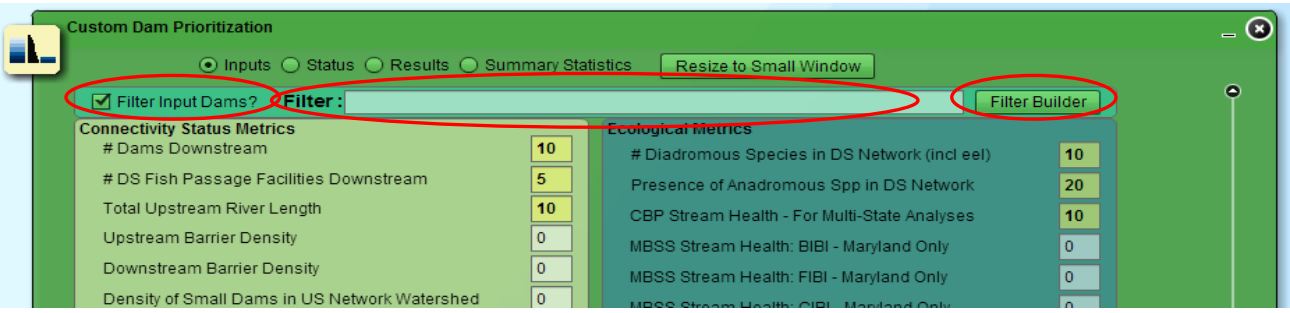
As shown in Figure 5-9, there are buttons to apply the Workgroup-consensus weights. Applying these weights and running a prioritization with no other alterations will produce the same results as what are pre-loaded into map. After a set of Workgroup-consensus weights are applied they can be altered or removed as desired.

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. A warning message will appear if weight it applied to one of these metrics as a reminder to use a filter.

### 5.2.2 Filtering Input Dams

The universe of dams that is input into a given custom scenario can be subset from the entire dataset. The can be done by geography (e.g. to limit an analysis to a given state or watershed) or other attribute (e.g. to exclude hydro dams from an analysis, or only include dams that have American shad in their downstream networks). To apply a filter, first check the "Filter" checkbox in the top left corner of the Tool, as shown in Figure 5-10. This will reveal a text input where an ArcGIS-compliant SQL-based definition query can be applied (e.g. "STATE" = 'VA').

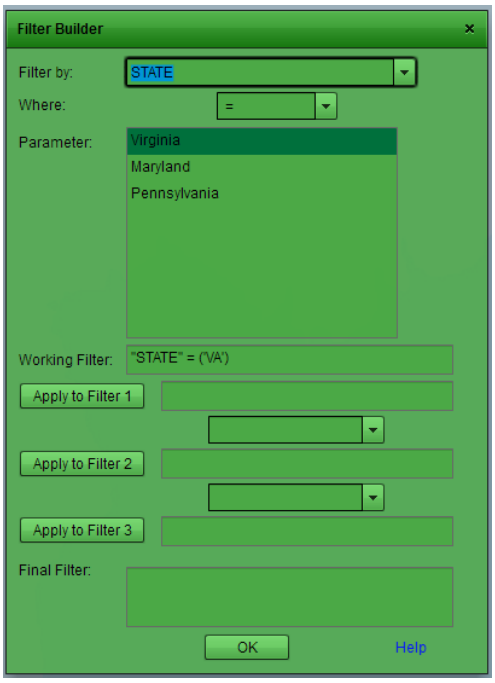
Figure 5-10: The Tool with the option to filter input dams highlighted

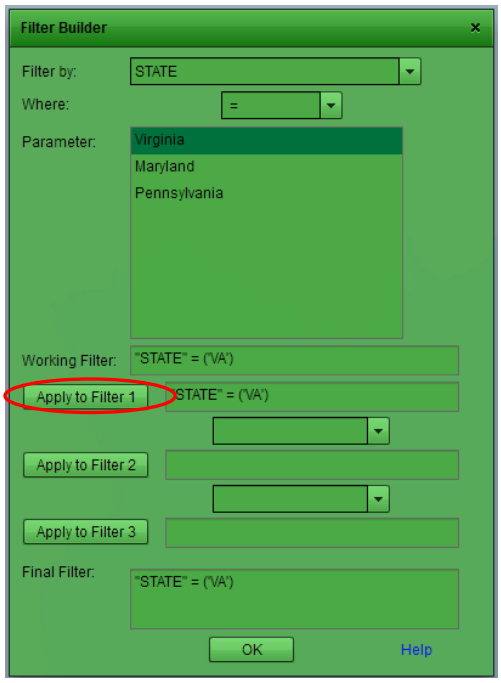



To simplify the application of filters, users can select the "Filter Builder" button. This interactive dialog helps users build filter statements. Plain-English is displayed to the user and the appropriate GIS field names and syntax is automatically applied. The filter builder steps users through building a filter with up to three filtering statements. 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"). Help on using the proper operator (e.g. use "IN" if there are multiple values: "STATE" IN ('VA', 'MD')) can be access via the Help link at the bottom of the Filter Builder.

As the statement is built, the "Working Filter" text box will update using the proper field names and GIS syntax. When the statement is complete, it must then be applied using the "Apply to Filter 1" button in order for it to be used. As illustrated in Figure 5-11, the statement then appears in the "Final Filter" text box at the bottom of the Filter Builder.

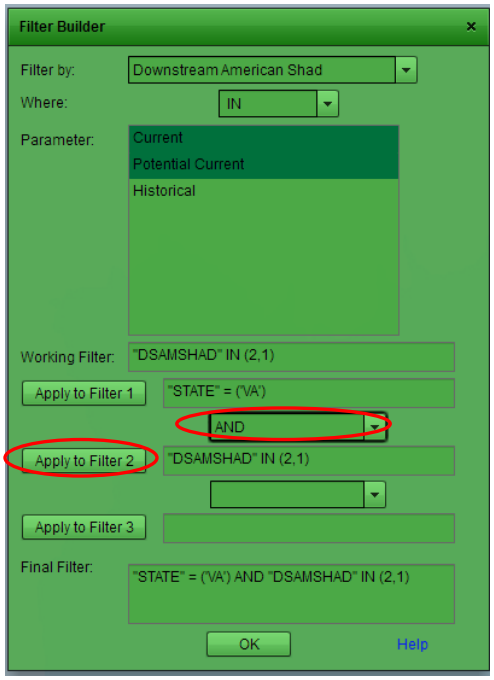
Figure 5-11: Building a filter



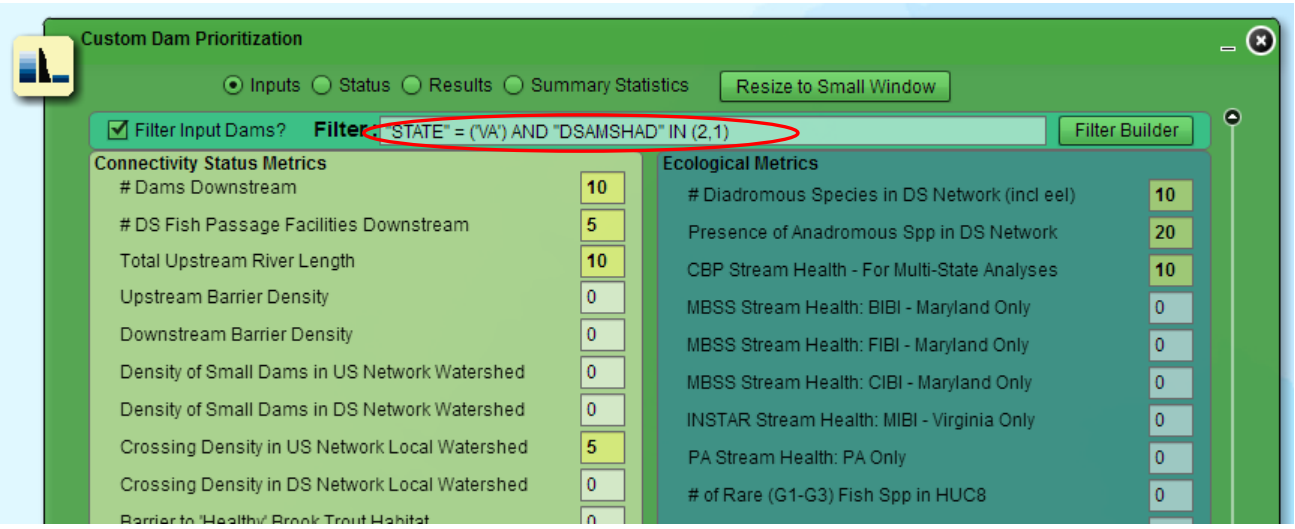

If additional filters are desired, they can be developed by repeating the process. Figure 5-11illustrates adding a filter so that only dams that have documented Current or Potential Current habitat in their downstream functional networks are included in the analysis. Multiple values (Current & Potential Current) can be selected by holding down the Ctrl key and clicking. Another operator is placed between the two filter statements. The example depicted in Figure 5-12 results in the following filter statement : "STATE" = ('VA') AND "DSAMSHAD" IN (2,1) , which restricts the dams in the analysis to dams in Virginia with Current or Potential Current American shad habitat in their downstream functional networks.

Figure 5-12: Adding a second filter using the Filter Builder




Finally, clicking on “OK” in the Filter Builder applies the Final Filter statement to the input filter dialog on the Tool. Note that it is critical to keep the check box check if using a filter. Unchecking it will remove the filter. Likewise, if the box is checked a filter must be applied.

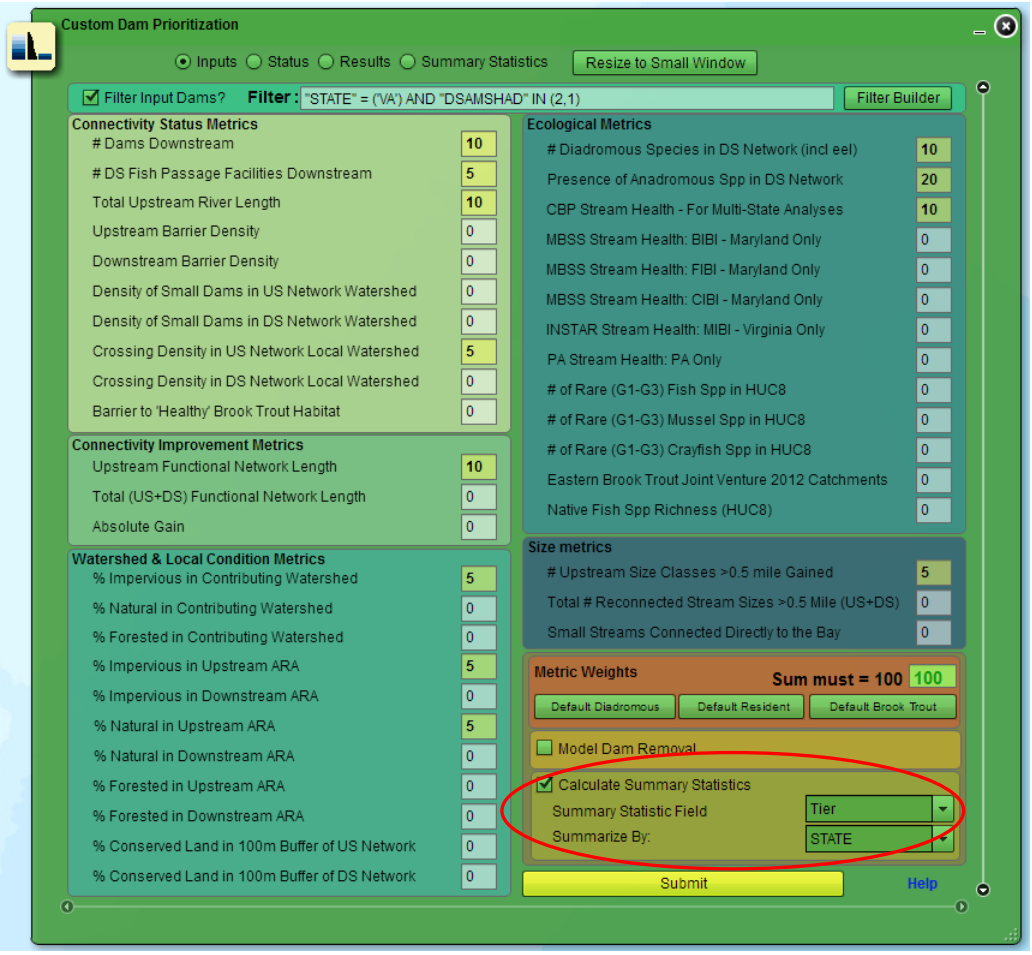
Figure 5-13: Final filter applied from the Filter Builder




### 5.2.3 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, simply check the "Calculate Summary Statistics" box towards the bottom right corner of the Tool. This will reveal options to generate summary statistics for either Tier or the Final Rank (the un-binned sequential results) by either State or Watershed. The output table will enable users to makes statements such as "Watershed X has a mean Tier value of 8 while Watershed Y has a mean Tier value of 5." From this statement we can deduce that Watershed Y has more dams with greater potential to benefit the target of interest, based on the metric weights chosen by the user, than Watershed X.

Figure 5-14: Selecting the option to run summary statistics on custom prioritization results




## 5.2.4 Dam Removal Scenarios

One or more dams can be selected for "removal" when a prioritization is run. This functionality can allow users to model the impact of a proposed project on the remaining dams in the network. Significantly, 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. It also empowers users to run scenarios that exclude dams which are found to be errors in the database, without having to wait for updates to be made to the database.

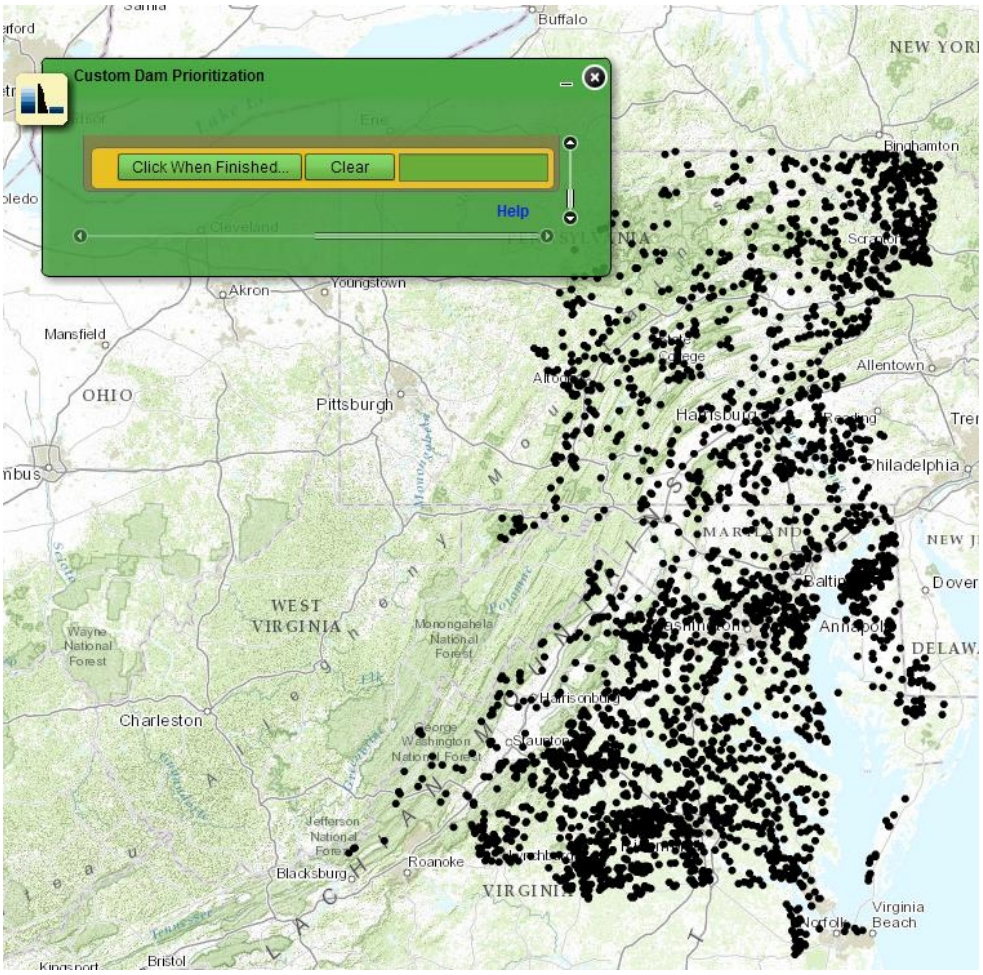
To run a prioritization scenario that includes modeled removals, first check the "Model Dam Removal" check box towards the bottom right corner of the Tool. This reveals a button to "Select Dams" as well as a text input box (Figure 5-15). If you know the UNIQUE_ID for your dams of interest, you can simply 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 an individual dam, or via the Attribute Table widget (Section 5.1.2.5). This can be useful when running the same or similar scenarios multiple times.

Figure 5-15: Selecting the option to model dams for removal

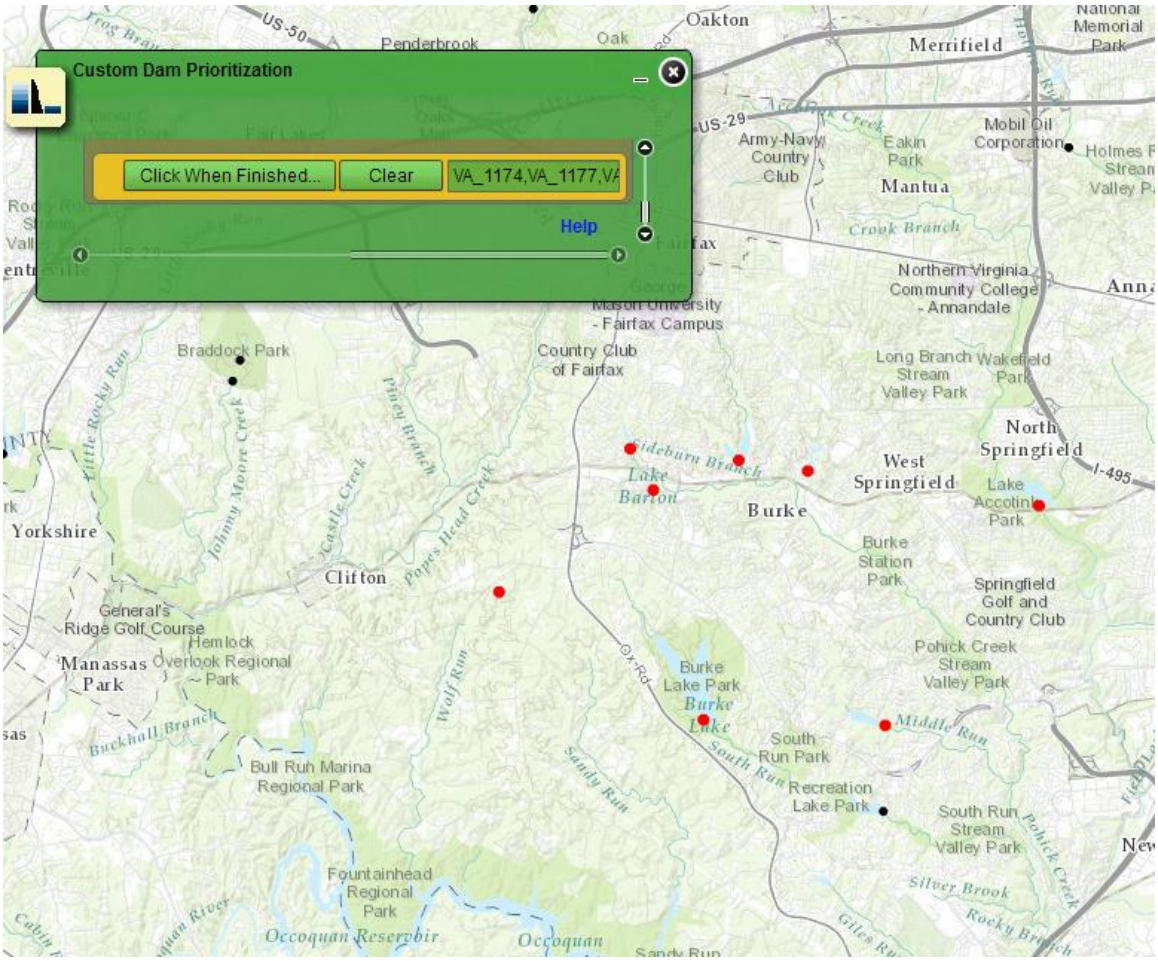
More convenient in many cases will be the option to select dams interactively through the web map. This can be done by clicking on the "Select Dams" button next to the Model Dam Removal check box. Clicking on this button prepares the Tool to interactively select dams for removal. This includes automatically resizing the Tool and moving it to a corner of the map, turning off all map layers, and adding a layer of all dams (symbolized as black points) that is used for selection. This process can take a few moments, and a warning message appears to inform the user as much.

Figure 5-16: Dams ready to be selected for modeled removal




When the warning message is dismissed, users can proceed to select dams for "removal." 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. Currently, users are limited to selecting 10 or fewer dams for removal to keep processing times reasonable. 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.

Figure 5-17: A set of dams (haphazardly selected for demonstration purposes) to be modeled as removed

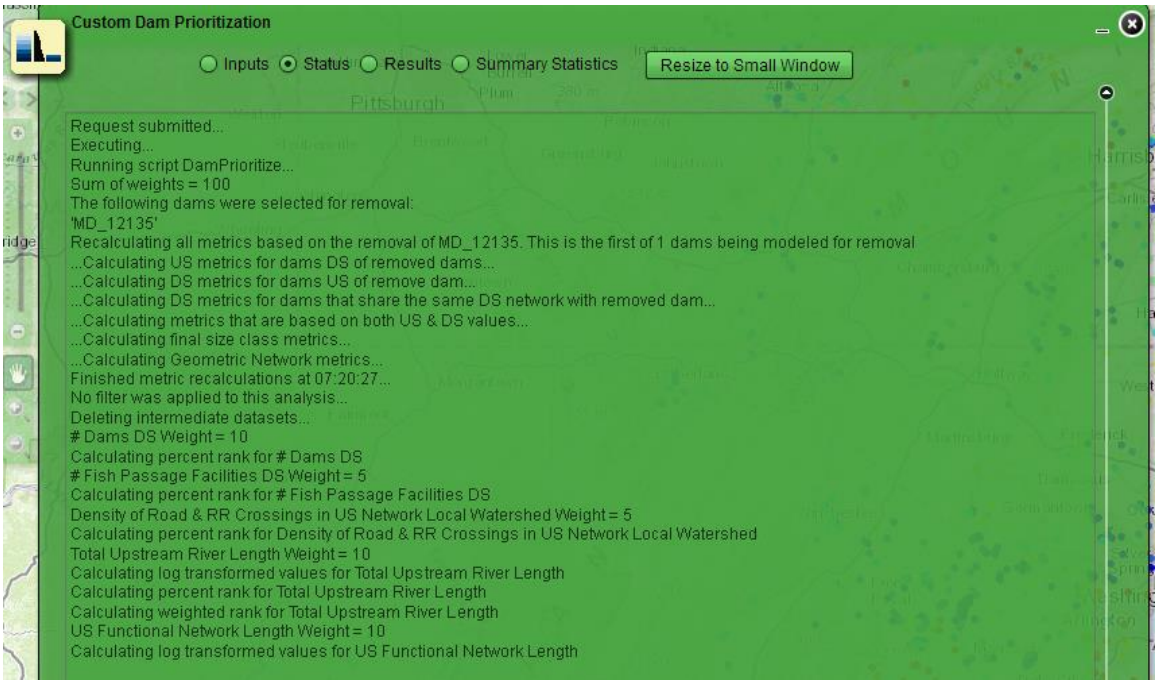



When finished, clicking on the “Click When Finished” button will reformat the UNIQUE_IDs into the proper syntax, remove the selection layer from the map, and turn the other map layers back on. After once metric weights are also applied, the analysis can be started by clicking the “Submit” button. When the prioritization is complete, the values that are displayed in the Results are calculated as if the chosen dams had been removed – this is true of the prioritization outputs (Final Rank and Tier) as well as all of the metric values that were included in the analysis (those whose weight >0).

### 5.2.5 Viewing and Exporting Results

When an analysis is started, the Tool will automatically switch to the “Status” state. This state is used to report the progress of the prioritization. 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 30 seconds & 2 minutes.

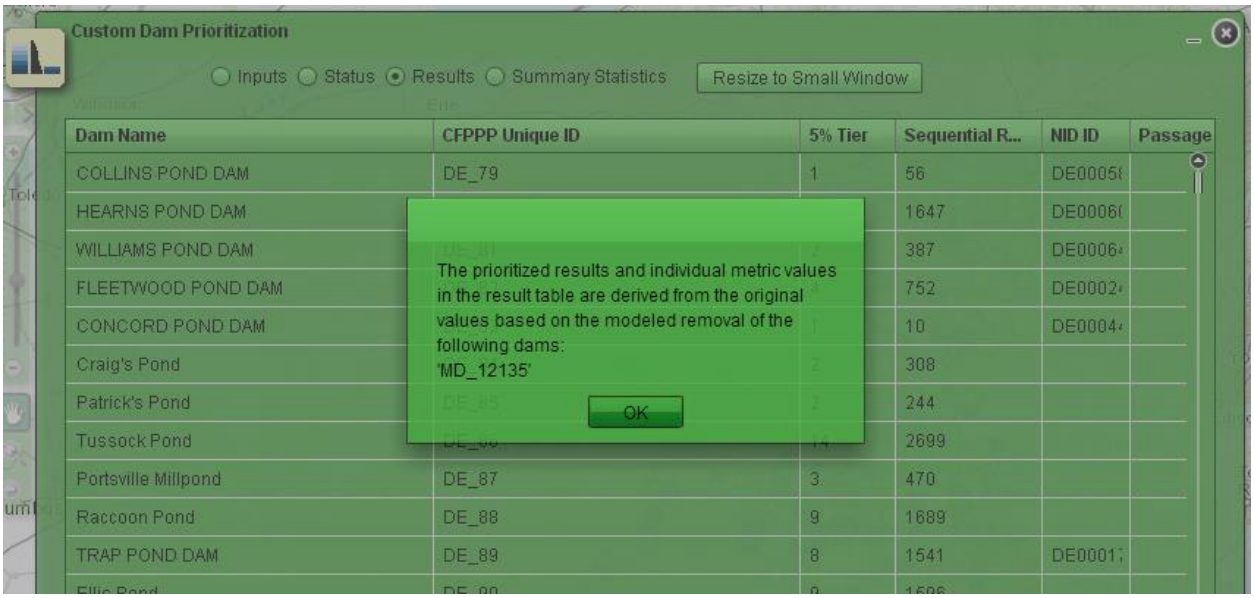
Figure 5-18: The "Status" state of the Tool displaying updates on a current analysis.




### 5.2.5.1 Results

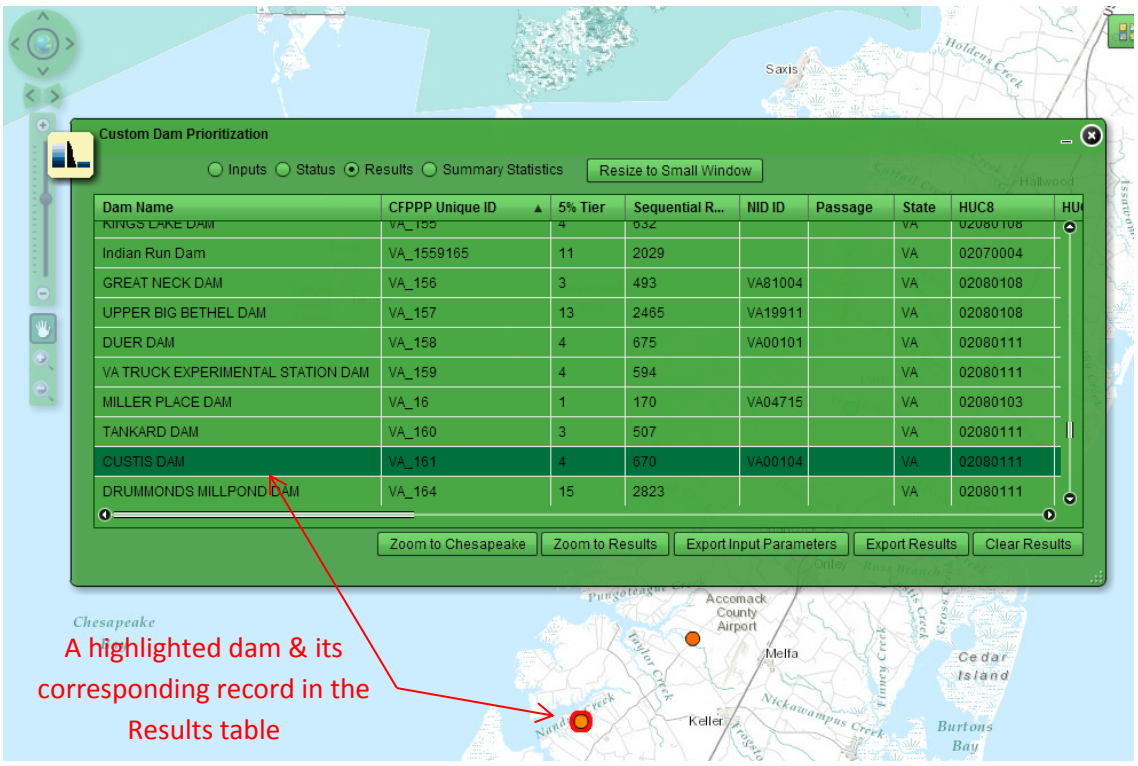
Results are presented in the Results state of the Tool. When an analysis is complete the Tool will automatically switch to this state. If any dams were selected for "removal," a warning message will appear to remind the user that the values presented in the Results are based on the selected dams being removed (Figure 5-19).

Figure 5-19: The Results state with a warning message indicating which dam(s) were selected for removal.



After dismissing this warning, users enter the Results table. Similar to a desktop GIS, records in the Results table are linked to features in the map. Clicking on a record will highlight the dam in the map with a pulsing red halo. Double clicking on the record in the table will zoom to that dam. Likewise, clicking on a dam in the map will highlight and the associated record in the table.

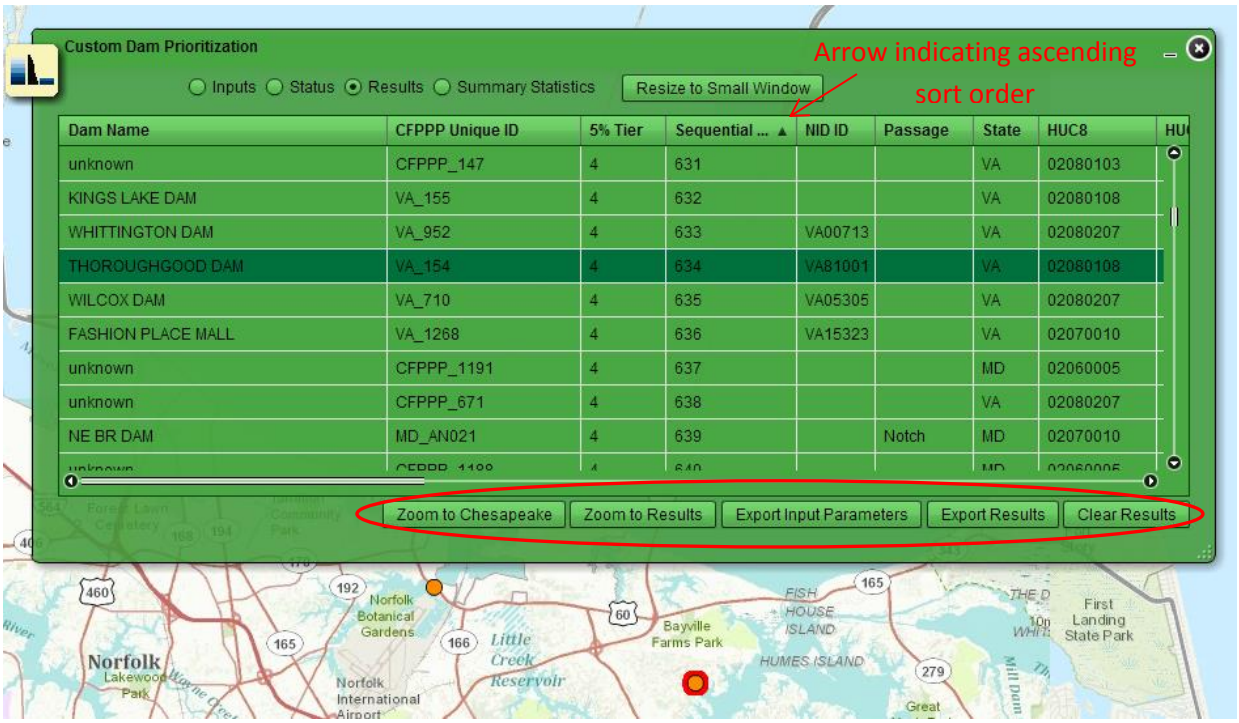
Figure 5-20: A selected record in the Results table and the corresponding feature highlighted in the map.




The 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). However, custom results are larger than and the pre-loaded Workgroup-consensus results and the circle symbols in custom results have a fine black outline. However, it may be desirable to turn off the Workgroup consensus results (using the Layers widget) to avoid confusion.

Any given column in the Results table can be used to sort the table. Note that only those metrics which are used in a given analysis (weight >0) are included in the results table.

Figure 5-21: Sorting on a column in the results and buttons to work with the results.




A series of buttons along the bottom of the Results table allow users to interact with the results. From left to right these buttons zoom to the full extent of the Chesapeake, zoom to the extent of the custom results, export input parameters (metric weights, filter, dams selected for removal) to a text file, export the results table as a Microsoft Excel file, and clear the results (both the table and the features on the map). Note that latitude and longitude, both in NAD83 decimal degrees, are included in the results export. These can be used to plot the dams in a user's desktop GIS. *It is strongly recommended that input parameters always be saved with results, and that the file names be made to correspond to each other*.

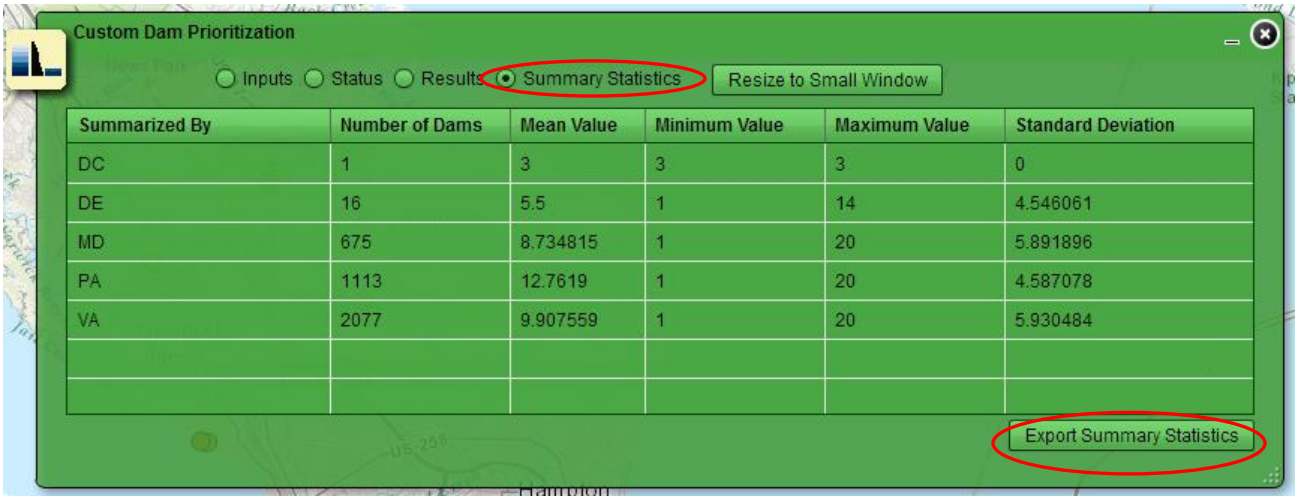
### 5.2.5.2 Summary Statistics

Optionally, summary statistics can be run on custom scenario results. To access the summary statistics table, simple select the Summary Statistics radio button at the top of the Tool (Figure 5-22). Summary statistics can be run on either Tier or Final Result (the un-binned, sequential rank) and by states or watersheds. In the example below, summary statistics are shown by state for Tiers. Thus, all of the states in the analysis has at least one Tier 1 dam, except Washington DC whose sole dam is in Tier 3. Likewise, the three main states in the analysis (VA, MD, PA) all have one or more dams in Tier 20. The mean Tier value is lowest in Maryland, indicating that *on average* dams in Maryland would provide greater ecological benefit, *based on the metrics weights selected in this custom scenario*. However, we can also see that Virginia has far more dams than either Maryland or Pennsylvania, indicating that there are more potential projects to be undertaken.

Similarly to the Results table, the Summary Statistics can be exported as a Microsoft Excel (.xls) file and saved for future reference. Also, as with the results and input parameter exports, it is strongly

recommended that summary statistics exported as an Excel file named to clearly indicate which scenario it is derived from.

Figure 5-22: Summary statistics of custom scenario results




| Summarized By | Number of Dams | Mean Value | Minimum Value | Maximum Value | Standard Deviation |
|---|---|---|---|---|---|
| DC | 1 | 3 | 3 | 3 | 0 |
| DE | 16 | 5.5 | 1 | 14 | 4.546061 |
| MD | 675 | 8.734815 | 1 | 20 | 5.891896 |
| PA | 1113 | 12.7619 | 1 | 20 | 4.587078 |
| VA | 2077 | 9.907559 | 1 | 20 | 5.930484 |
| | | | | | |
| | | | | | |

# 6 References

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# 7 Appendix I: Chesapeake Fish Passage Workgroup

| Name | Affiliation |
|---|---|
| Mary Andrews | National Oceanic and Atmospheric Administration |
| Colin Apse | The Nature Conservancy |
| 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 |

# 8 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. | 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, potetnial current habitat, historical habitat, or no documented habitat. |
| Land Cover | 2006 National land Cover Database (NLCD2006) | Land use / land cover data from the NLCD2006. 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 contrbuting watershed of each dam, as well as within the active river area of the dam's upstream and downstream networks. |
| Impervious Surface | 2006 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 contrbuting watershed of each dam, as well as within the active river area of the dam's upstream and downstream networks.. |
| Rare fish, mussels & crayfish. Native fish species richness. | NatureServeHUC8-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. |

| | | |
|---|---|---|
| Roads and Railroads | Esri version 9.3 data | 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). |
| 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. |

# 9 Appendix III: Glossary and Metric Definitions

The Nature Conservancy
Protecting nature. Preserving life.™

# 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.tnc.org/erof_ChesapeakeFPP

# 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 Waterfalls 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

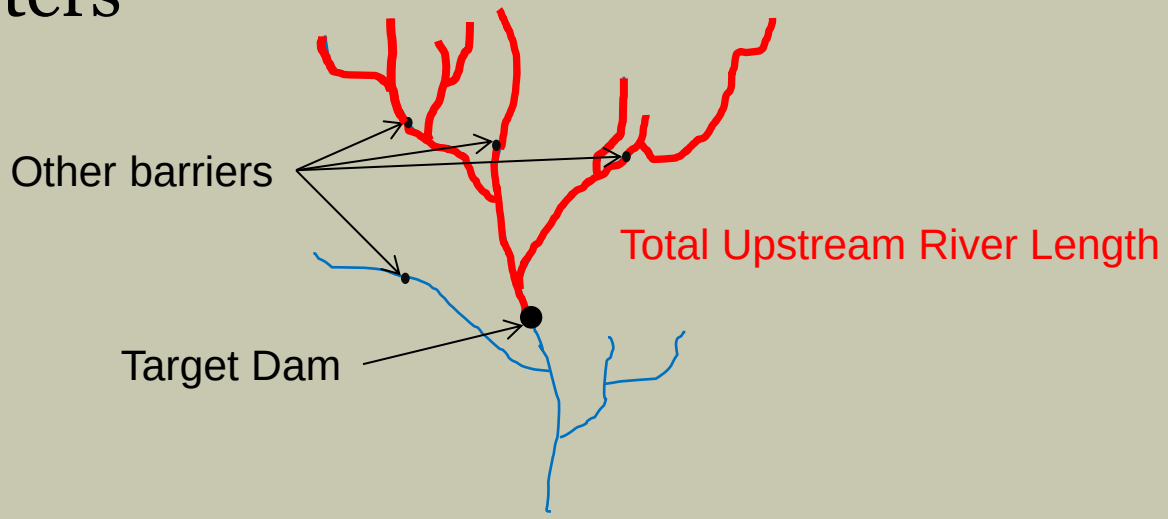


- Category:  Connectivity Status
- Downstream Barrier Count divided by the Distance to River Mouth in meters
- Includes natural waterfalls, which are included in network generation
- Does not include barriers excluded from network generation
- Unit: # / meters

# Total Upstream River Length



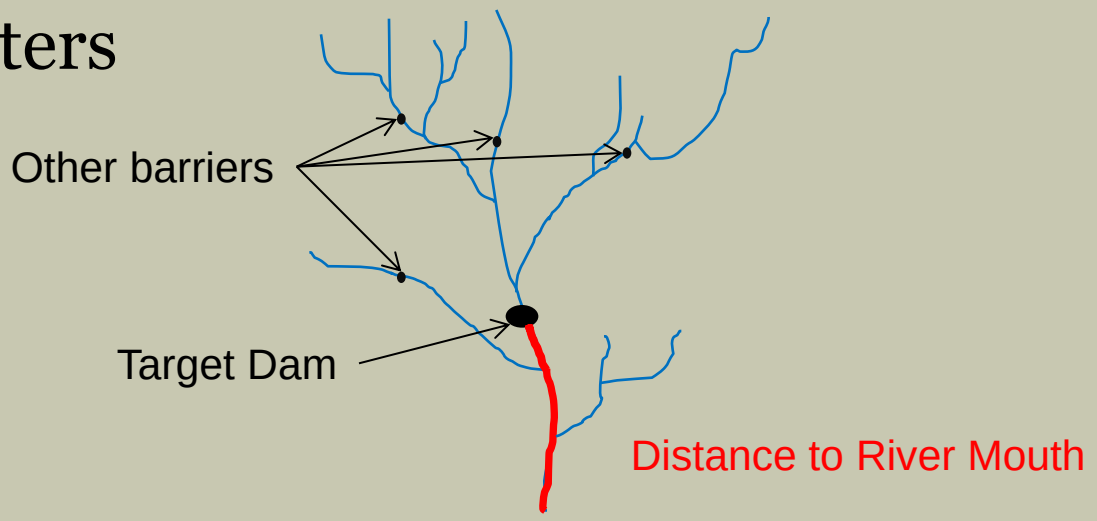
- Category:  Connectivity Status
- Total length of river network upstream of a given barrier, regardless of any upstream barriers.
- Unit: meters



# Distance to River Mouth



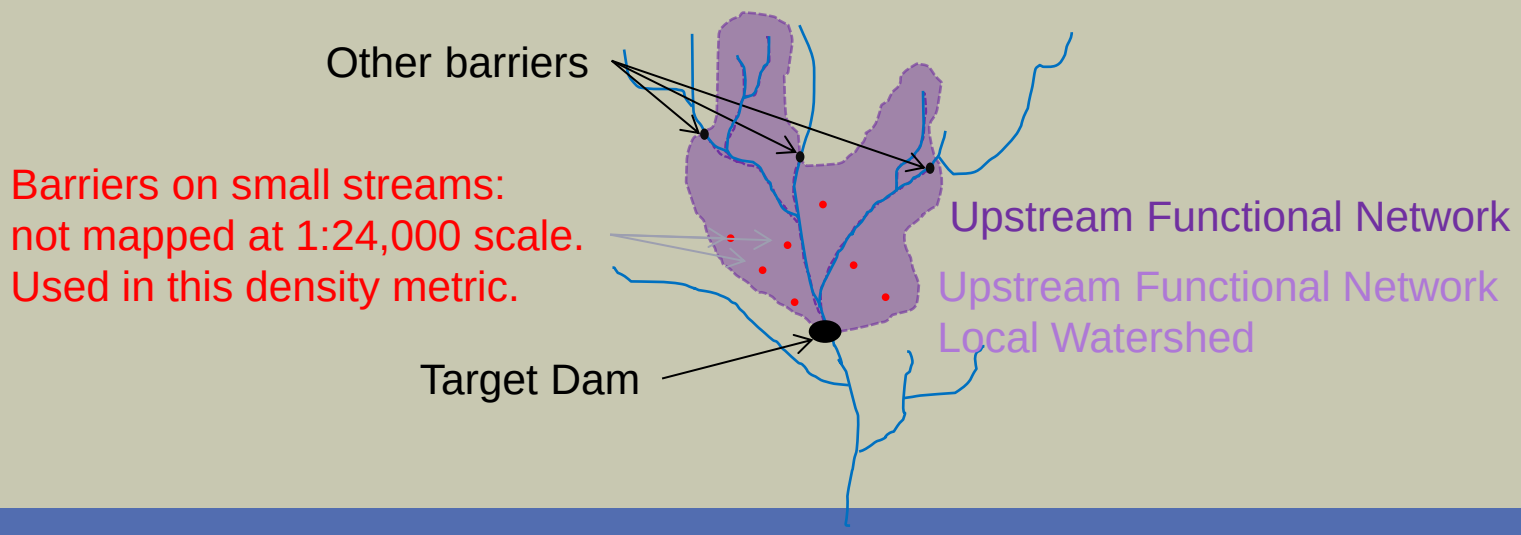
- Category:  Connectivity Status
- Distance from each barrier to the network mouth in meters
- Unit: meters



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



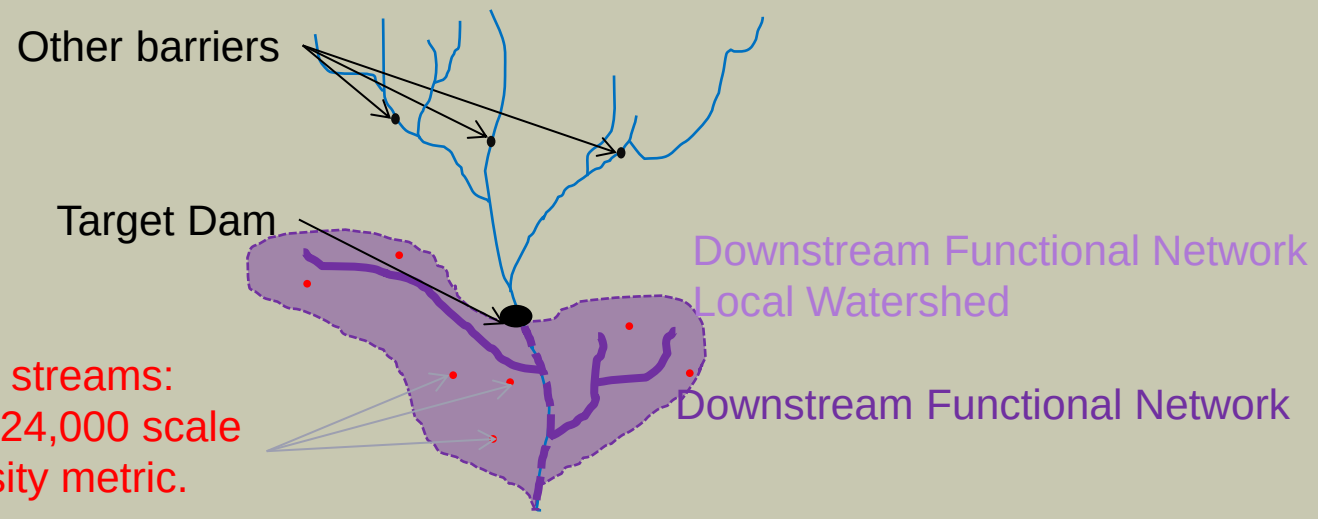
- Category: Connectivity Status
- Number of dams on small streams (dams did not snap to analysis hydrography) within the local watershed of the upstream functional network divided by that watershed area
- Unit: # / m²



# 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: # / m²

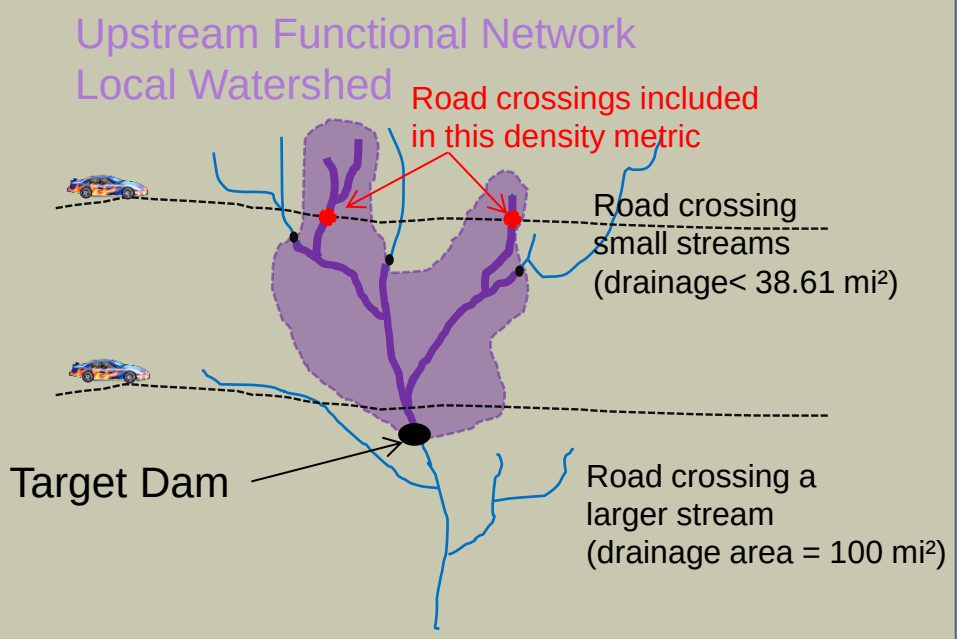



Barriers on small streams:
not mapped at 1:24,000 scale
Used in this density metric.

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



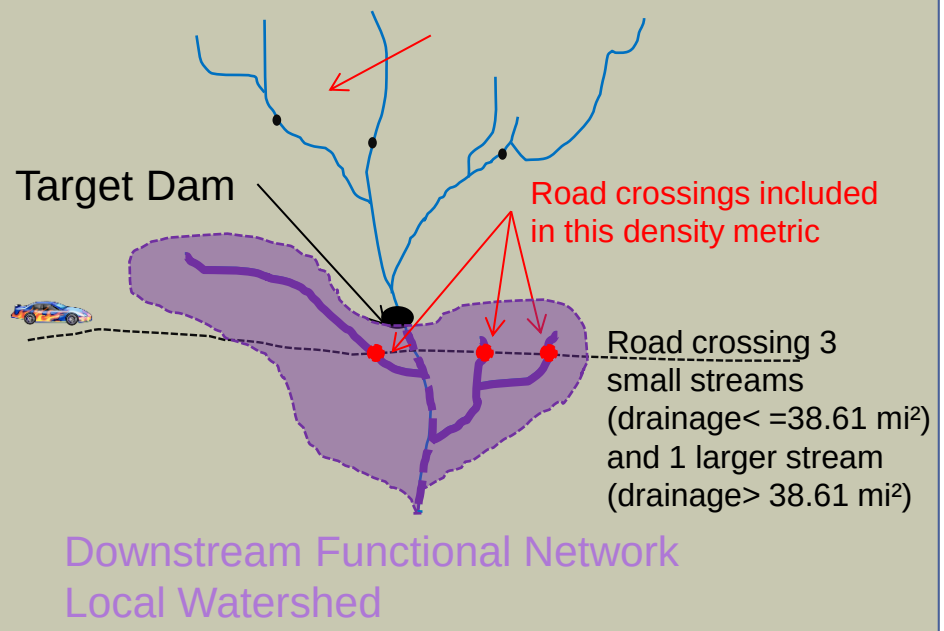
- Category: Connectivity Status
- Number of Road/Railroad and hydrography intersections within upstream functional network local watershed divided by that watershed area. A proxy for culverts.
- Road and RR data from ESRI Streetmap USA
- Only small streams (drainage <= 38.61 mi²) are included. Larger streams more likely to have bridges.
- Unit: # / m²



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



- Category: Connectivity Status
- Number of Road/Railroad and hydrography intersections within downstream functional network local watershed divided by that watershed area. A proxy for culverts.
- Road and RR data from ESRI Streetmap USA
- Only small streams (drainage <= 38.61 mi²) are included. Larger streams more likely to have bridges.
- 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

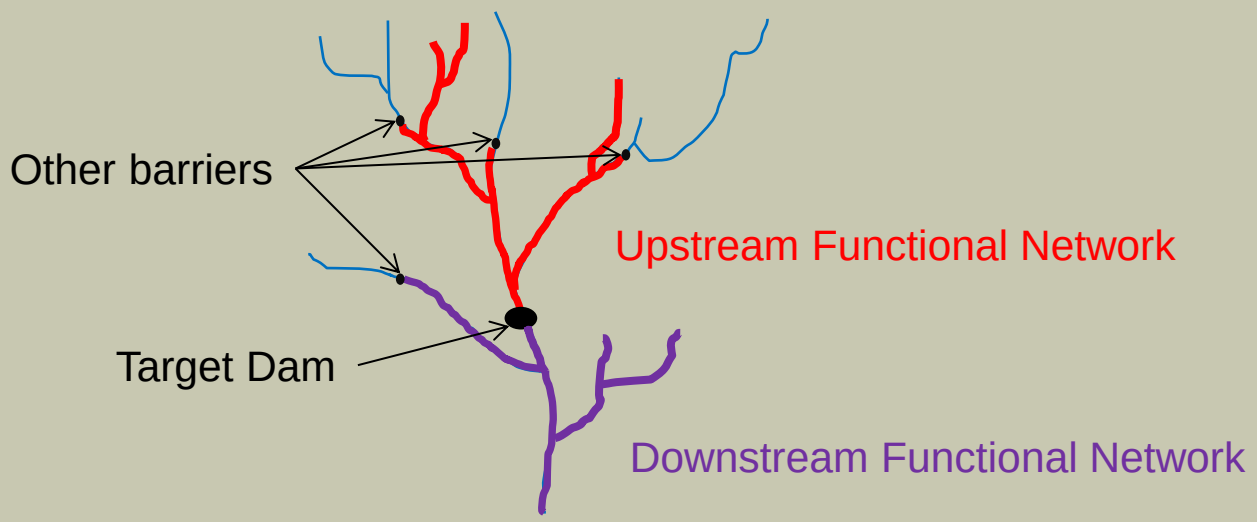
# Downstream Functional Network Length



- 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



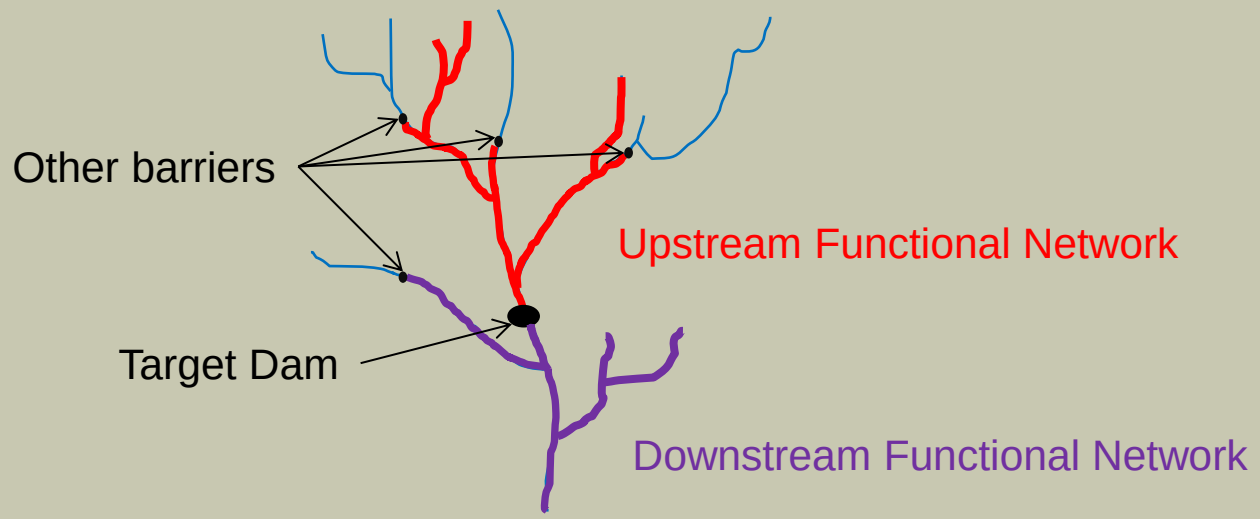
# Upstream Functional Network Length



- 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.

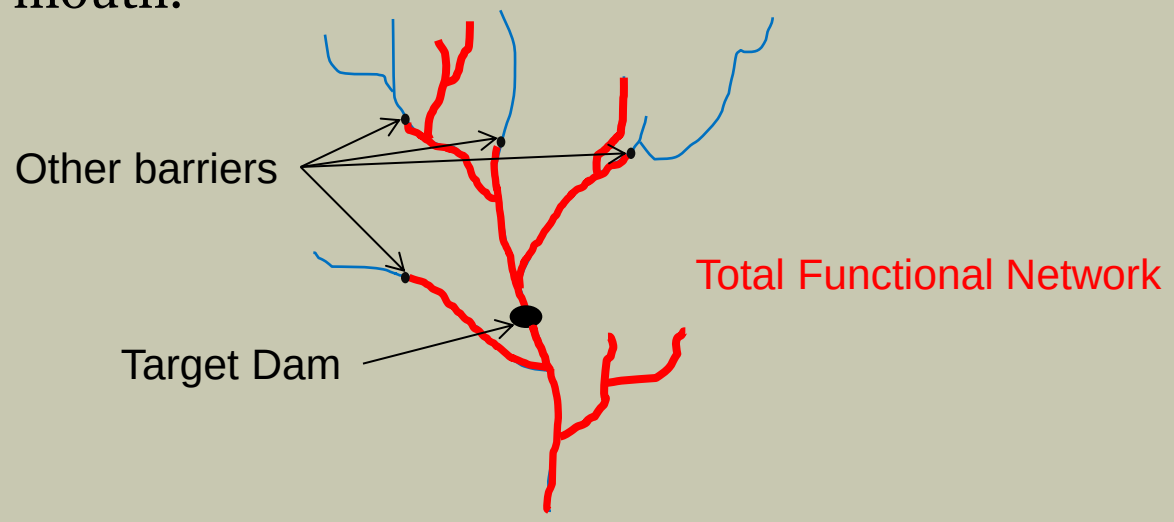
- Unit: meters



# 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 2006 National Landcover Database percent developed imperviousness.
- Unit: %

# % Natural LC in Contributing Watershed



- Category: Watershed & Local Condition
- % natural landcover in entire upstream watershed. Calculated 2006 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 2006 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.
- National Landcover Database 2006 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.
- National Landcover Database 2006 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.
- National Landcover Database 2006 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.
- National Landcover Database 2006 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.
- National Landcover Database 2006 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.
- National Landcover Database 2006 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 2009 secured areas database (TNC)
- Unit: %

# % Conserved Land within 100m Buffer of Downstream Functional Network

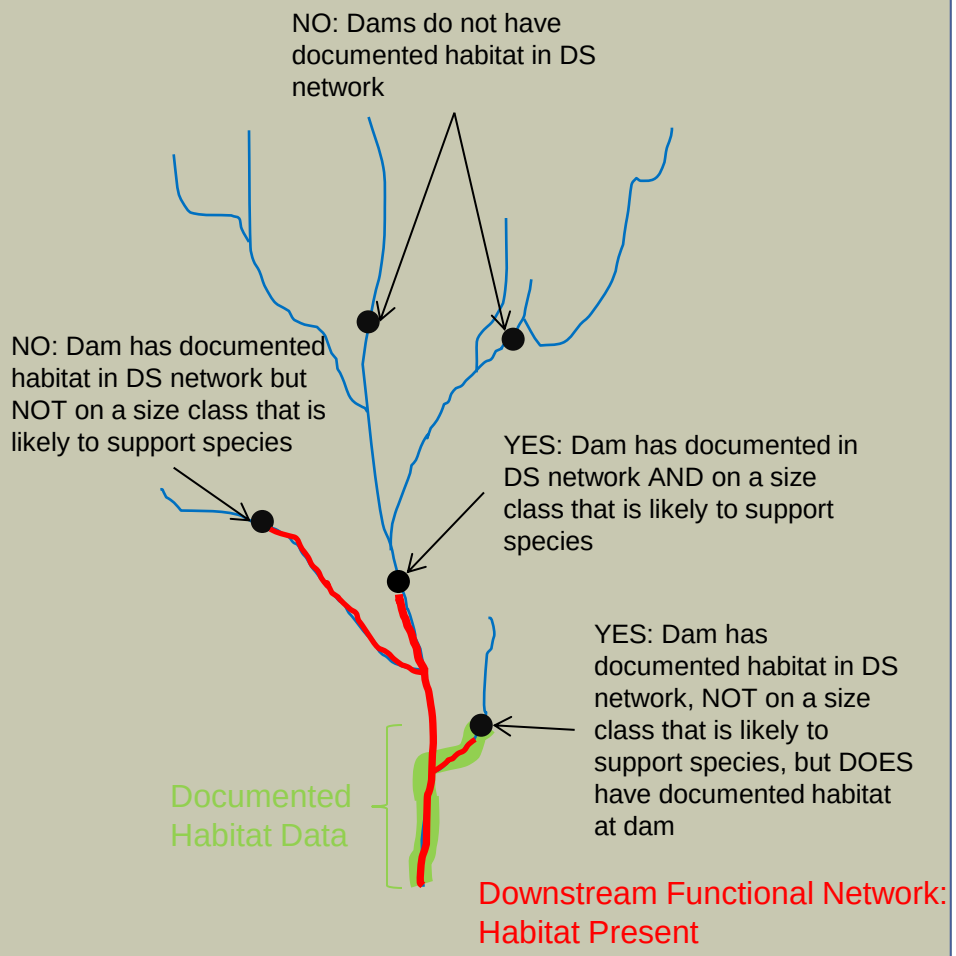


- Category: Watershed & Local Condition
- % of land within 100m buffer of downstream functional network that intersects 2009 secured areas database (TNC)
- Unit: %

# American Shad habitat in Downstream Functional Network



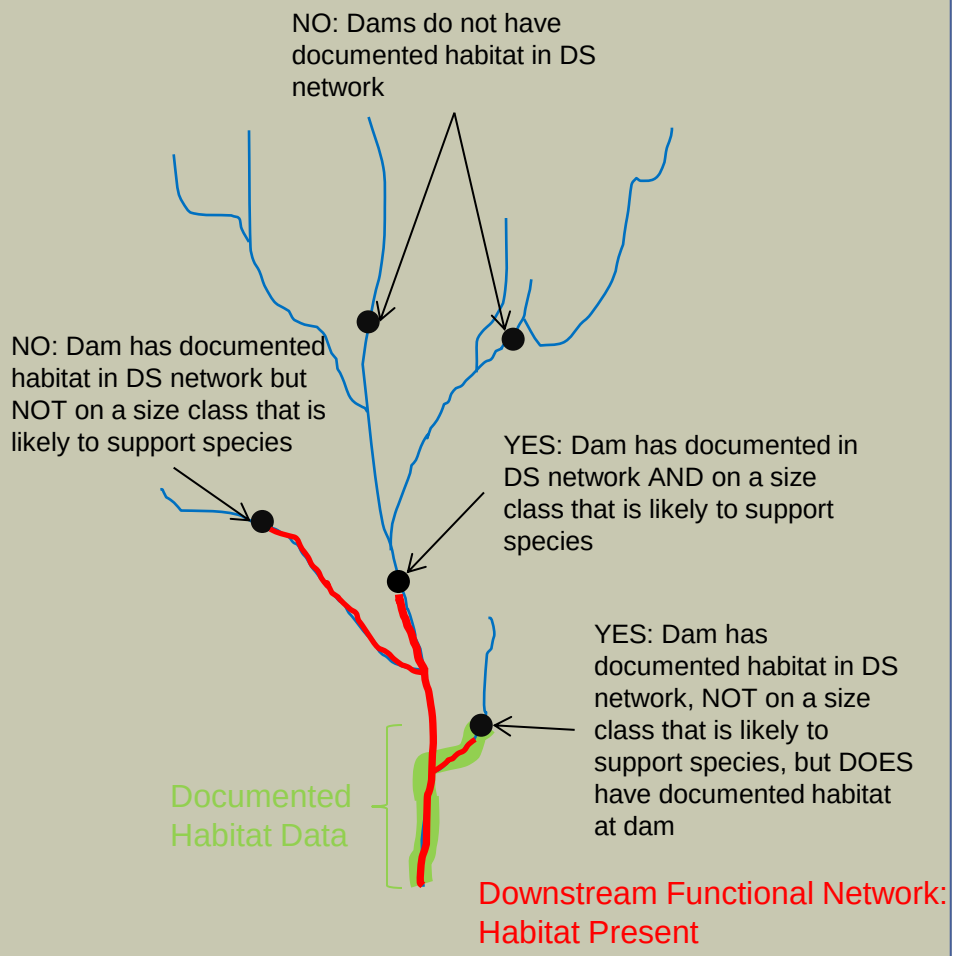
- Category: Ecological
- Presence of American shad downstream of dam. Based on:
  1. Documented habitat in some portion of the dam's downstream functional network
  2. **AND** Dam is on a stream that is likely to support that species based on stream size
     1. Size 2+ Rivers
  3. **OR** There is documented 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



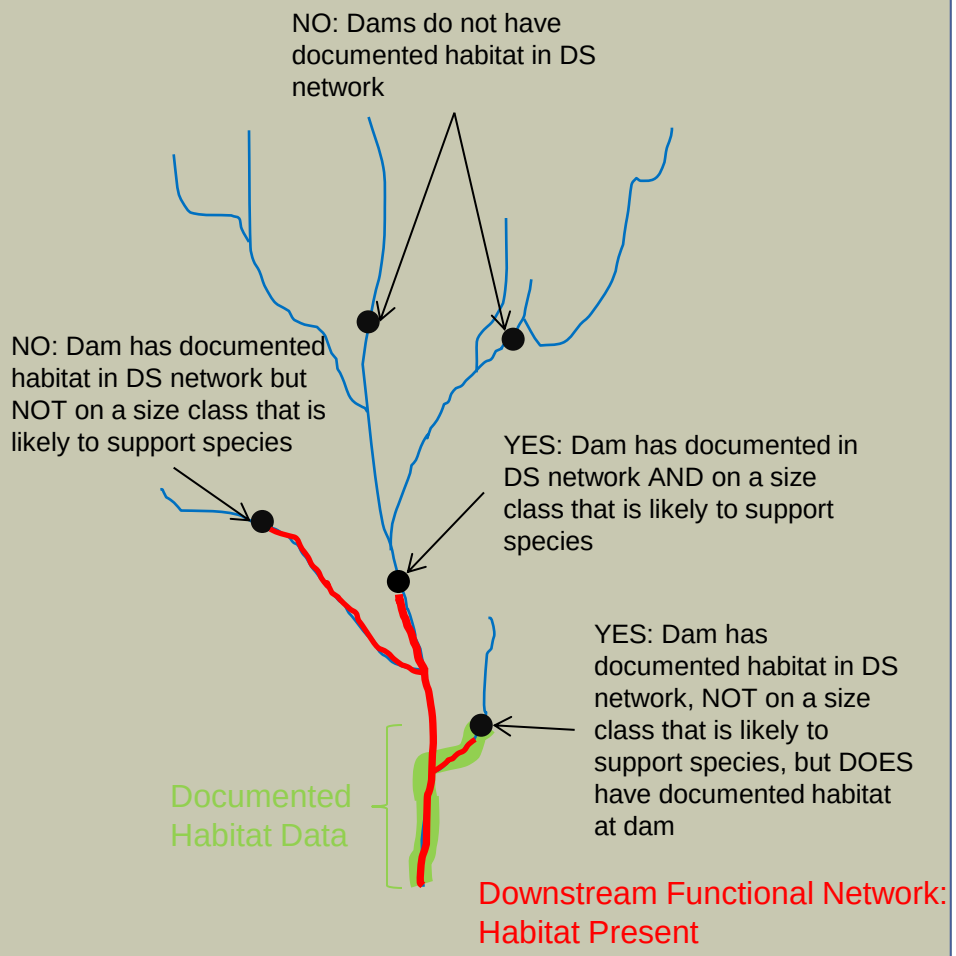
- Category: Ecological
- Presence of blueback herring downstream of dam. Based on:
  1. Documented habitat in some portion of the dam's downstream functional network
  2. **AND** Dam is on a stream that is likely to support that species based on stream size
     1. Size 2+ Rivers & 1a/1b if no gradient >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



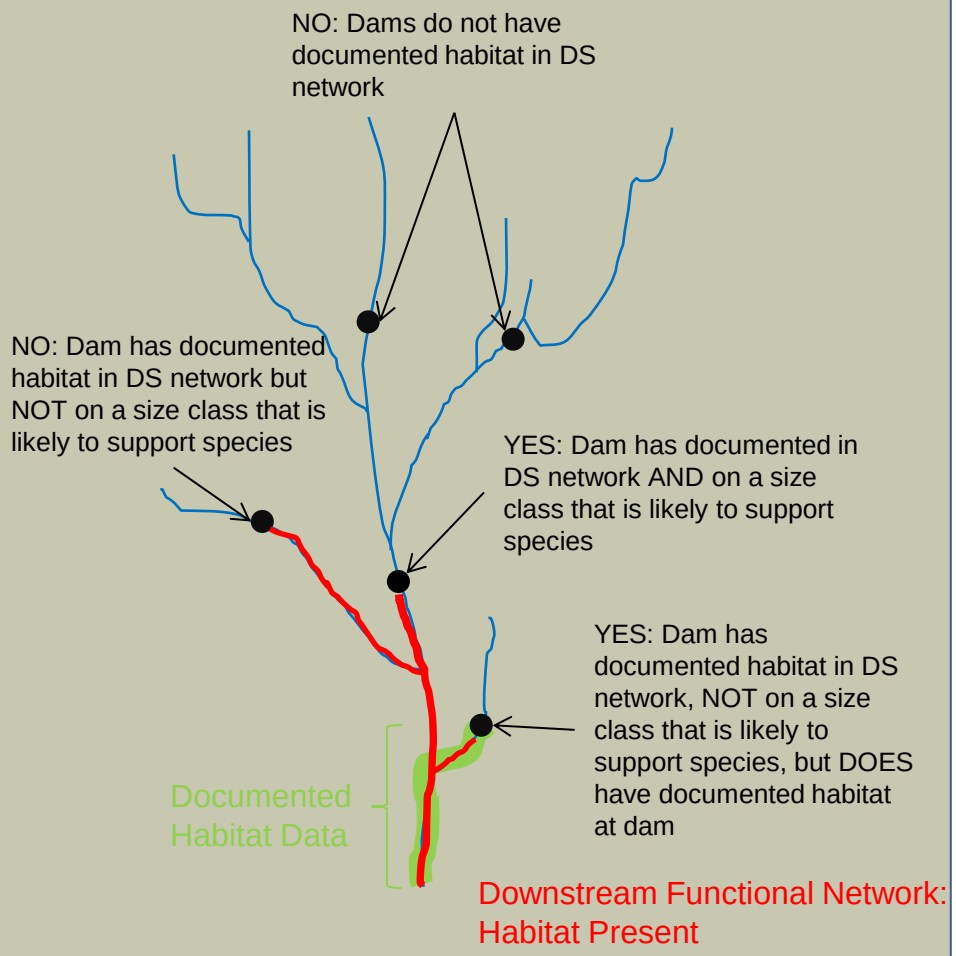
- Category: Ecological
- Presence of Hickory shad downstream of dam. Based on:
  1. Documented habitat in some portion of the dam's downstream functional network
  2. **AND** Dam is on a stream that is likely to support that species based on stream size
     1. Size 2+ Rivers
  3. **OR** There is documented 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



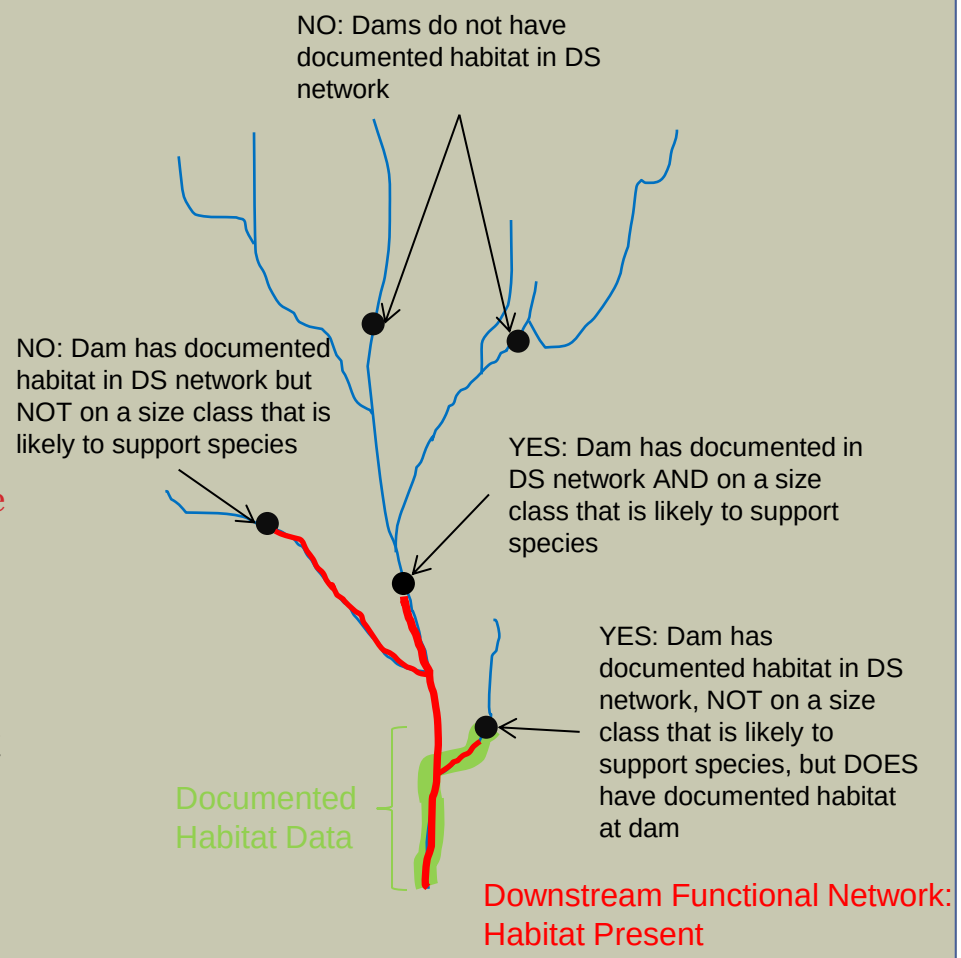
- Category: Ecological
- Presence of alewife downstream of dam. Based on:
  1. Documented habitat in some portion of the dam's downstream functional network
  2. **AND** Dam is on a stream that is likely to support that species based on stream size
     1. Size 2+ Rivers & 1a/1b if no gradient >10%
  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



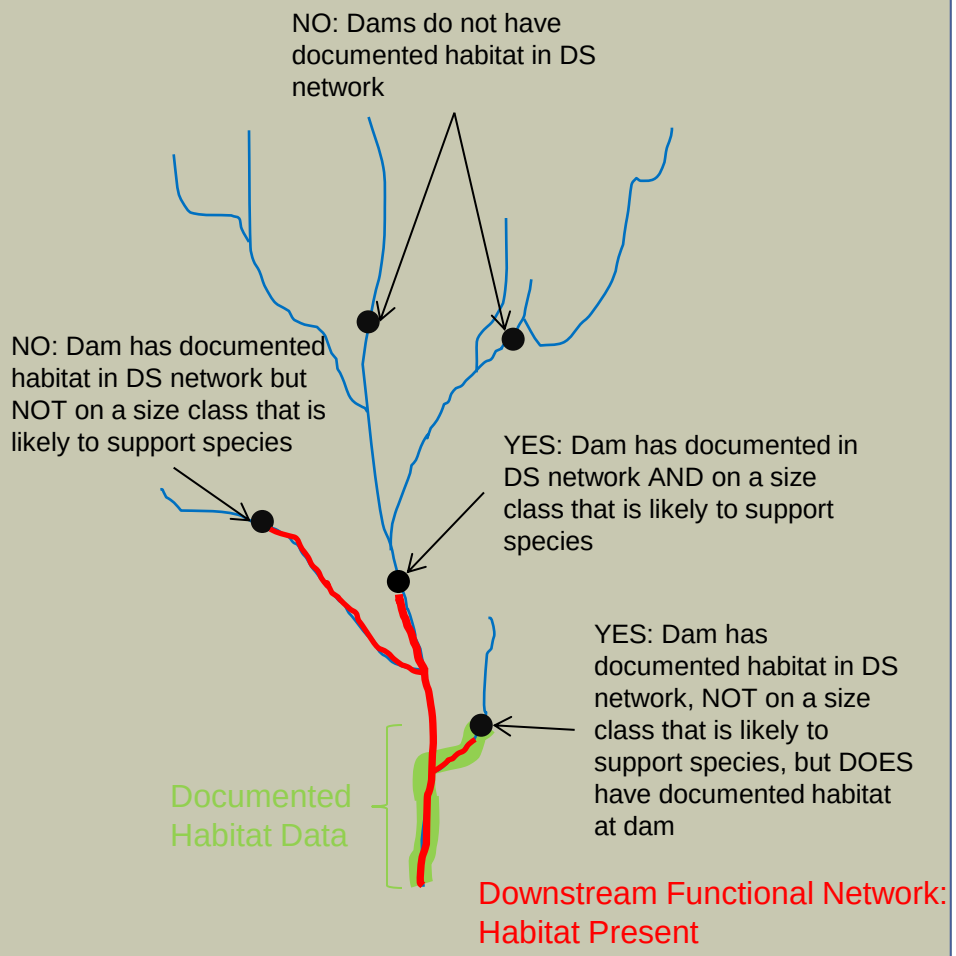
- Category: Ecological
- Presence of Atlantic sturgeon downstream of dam. Based on:
  1. Documented habitat in some portion of the dam's downstream functional network
  2. **AND** Dam is on a stream that is likely to support that species based on stream size
     1. Size 4+ Rivers
  3. **OR** There is 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



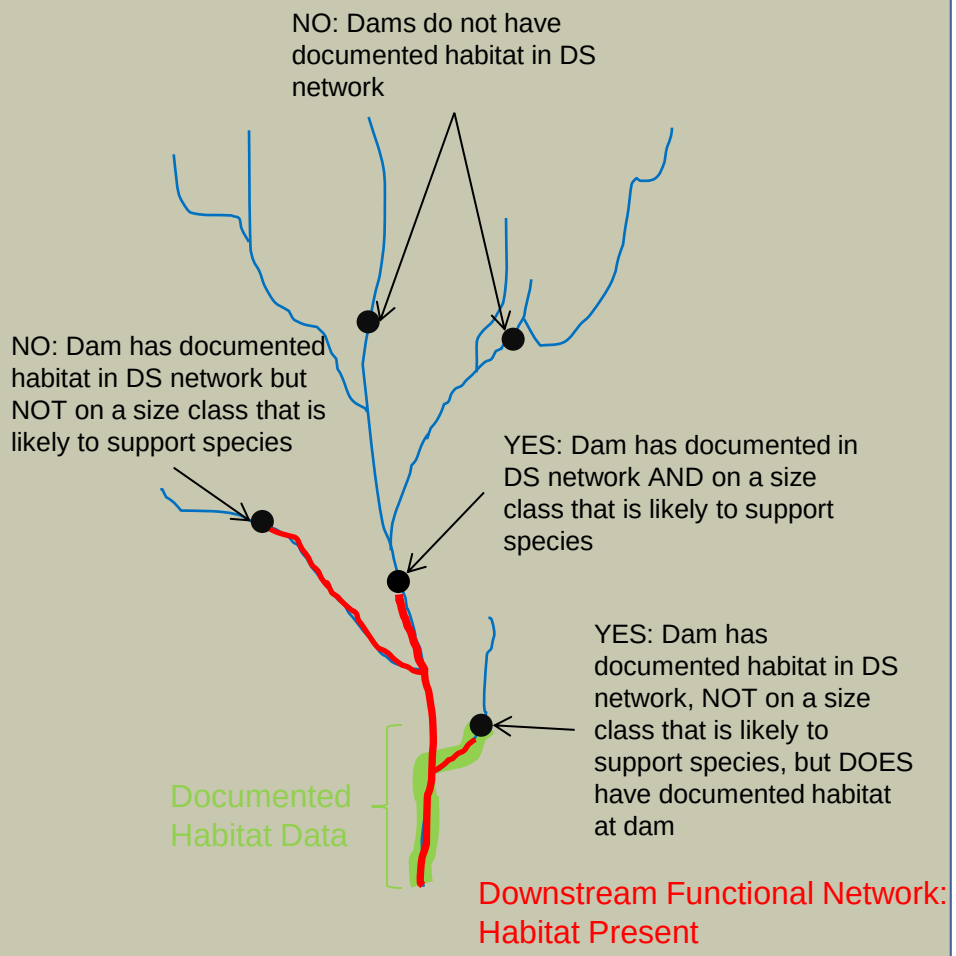
- Category: Ecological
- Presence of striped bass downstream of dam. Based on:
  1. Documented habitat in some portion of the dam's downstream functional network
  2. **AND** Dam is on a stream that is likely to support that species based on stream size
     1. Size 3b+ Rivers
  3. **OR** There is documented 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



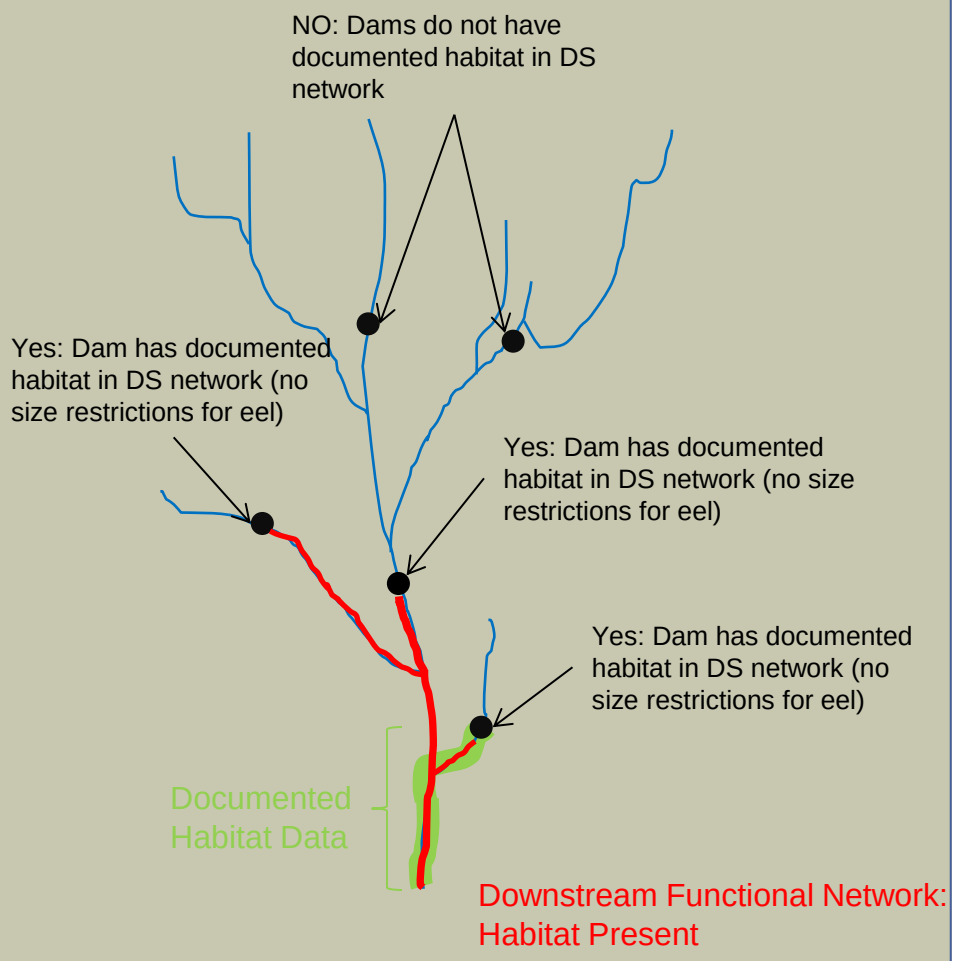
- Category: Ecological
- Presence of shortnose sturgeon downstream of dam. Based on:
  1. Documented habitat in some portion of the dam's downstream functional network
  2. **AND** Dam is on a stream that is likely to support that species based on stream size
     1. Size 4+ Rivers
  3. **OR** There 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: #

# Dam in Eastern Brook Trout Joint Venture Catchment



- Category: Ecological
- Dam within an Eastern Brook Trout Joint Venture (EBTJV) catchment. (Mark Hudy 2012)
- Catchment data were grouped and ranked by the Chesapeake Fish Passage Workgroup as follows:
- Unit: Categorical

| Category (Codes) | Rank |
|---|---|
| **Allopatric brook trout** (1.1, 1.1P, 1.5) | 1 |
| **Sympatric with non-native browns & rainbow** (1.0, 1.0P, 1.2 , 1.2P, 1.3, 1.3P, 1.4, 1.4P, 0.5, '0.5P) | 2 |
| **Non-Natives Only** (0.1, 0.1P, 0.2, 0.2P, 0.3, 0.3P, 0.4, 0.4P) | 3 |
| **No trout / Unknown** (0, 0P, <null>) | 4 |

- Where:
  - Allopatric Brook trout populations = 1.1 and 1.1 P*
  - Sympatric Brook Trout populations = 1.0 and 1.0 P*
    - Sympatric with brown trout = 1.2 and 1.2 P*
    - Sympatric with rainbow trout = 1.3 and 1.3 P*
    - Sympatric with rainbow and brown trout = 1.4 and 1.4 P*
  - No brook trout = 0
  - Unknown = 0 P*
  - Stocked waters = 0.5
  - Stocked on top of wild brook trout = 1.5
  - Exotic cold water trout = 0.1 and 0.1 P*
    - Exotic brown trout = 0.2 and 0.2 P*
    - Exotic rainbow trout = 0.3 and 0.3 P*
    - Exotic rainbow and brown trout = 0.4 and 0.4 P*
  - *P = Predicted, No actual sample in catchment or sample collection greater than 10 years old. Classified based on the classification rule sets.

# 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

VCU
Virginia Commonwealth University

# PA Stream Health

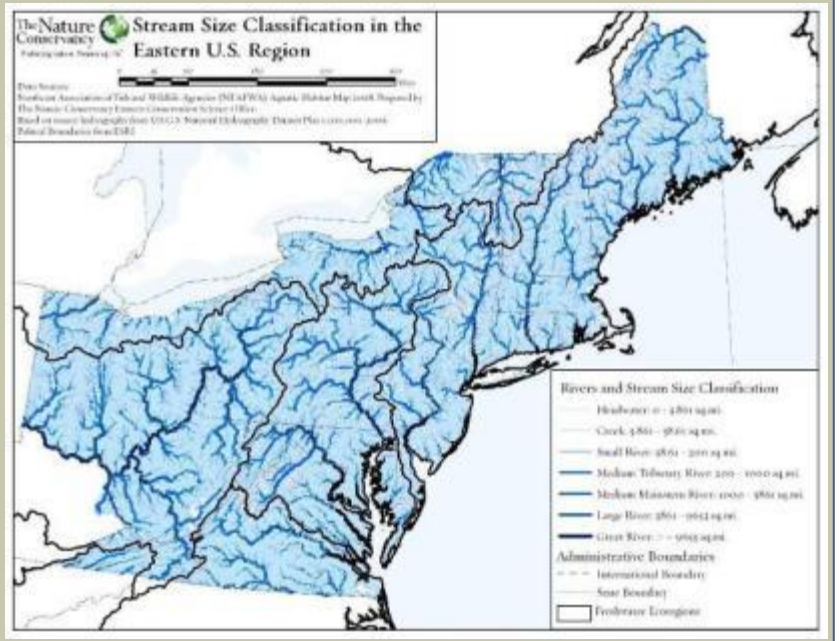


- Pennsylvania stream health score, based on benthic index of biotic integrity data obtained from PA DEP.
- Mean IBI calculated for HUC10 watersheds.
  - "small stream" IBI used where drainage <50mi²
  - "large stream" IBI used where drainage >50mi²
- Classed as good (>63), fair (43-63), poor (<43) based 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).