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The Nature Conservancy & Northeast Association of Fish and Wildlife Agencies

Northeast Aquatic Connectivity

An Assessment of Dams on Northeastern Rivers

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1.1 Background and Approach

The 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 freshwater spawning habitats from the sea and prevent brook trout populations from reaching thermal refuges. The Northeastern U.S. (the New England and Mid-Atlantic states) has the highest density of dams and road crossings in the country, with an average of 7 dams and 106 road-stream crossings per 100 miles of river (Anderson and Olivero Sheldon 2011).

Throughout the Northeast, hundreds of dams have been removed and hundreds of culverts have been replaced or retrofitted over the last two decades in projects where ecological restoration was a goal. 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. In order to complete an assessment at the regional scale, the Northeast Association of Fish and Wildlife Agencies (NEAFWA) awarded the Nature Conservancy (TNC) a 2007 Regional Conservation Needs (RCN) Grant. This RCN grant was designed to have TNC support state resource agencies in the Northeast U.S. (fish and wildlife, marine fisheries, dam safety, etc.) in efforts to strategically reconnect fragmented river, stream, coastal, reservoir, lake and estuarine habitat by removing or bypassing key barriers to fish passage. The primary ecological goal of mitigating fish passage barriers is to enhance populations of fish including anadromous fish, coldwater species, and other species of greatest conservation need (SGCN).

From its first meeting in December 2008, the Northeast Aquatic Connectivity Project (NAC) was organized around a Northeast Connectivity Workgroup which met virtually through web conferences throughout the almost three year project term. The Workgroup included state resource agency personnel from throughout the NEAFWA states (ME, NH, VT, MA, RI, CT, NY, NJ, PA, MD, DC, DE, VA, WV), as well as Canadian provincial, federal, non-profit, academic and private consulting participants. Strategic decisions were made by consensus of the Workgroup while most of the data development and analysis was completed by the NAC Leadership Team at The Nature Conservancy.

Phase 1 of Northeast Aquatic Connectivity Project involved creation of the Workgroup, agreement on a project methodology, and gathering the best available information about current methods of barrier assessment and prioritization. This Phase was carried out through a series of monthly conference calls involving presentations from Workgroup members or other outside experts. The overarching goal of Phase 1 was to examine the state-of-the-art in barrier assessment and categorize and narrow the assessment attributes that would be eventually incorporated into the Northeast Connectivity Assessment Tool.

Phase 2 of the project focused on the difficult task of determining what metrics should be used for barrier assessment throughout the NEAFWA states, given data limitations and the limits of GIS technology. In the end, a total of 72 metric from five metric categories -- Connectivity Status, Connectivity Improvement, Watershed and Local Condition, Ecological, and Size/System Type -- were selected and used in the analysis. These metrics were calculated in a GIS and used to assess each dam for its potential benefit to anadromous and resident fish if removed or bypassed.

1.2 Data

Four datasets: dams, natural waterfalls, anadromous fish habitat, and the NHDPlus form the core of the Northeast Aquatic Connectivity project (NAC). Dams were the primary unit of analysis in the NAC project. Attributes were calculated in a GIS for each dam in the analysis and the relative ecological benefit of removing or mitigating each dam was assessed using these attributes. Natural waterfalls were included as barriers to fish passage in the analysis, but they were not evaluated for their potential ecological benefit if removed. Anadromous fish habitat data were compiled and improved for this project, and provided the basis for one of the most important attributes by which dams were evaluated in the anadromous fish benefit scenario. Finally, the 1:100,000 scale NHDPlus hydrography and its associated attributes formed the foundation for the stream network calculations and many of the watershed metrics as well.

Data were compiled from numerous sources including federal, state, regional, and local sources and merged into unified, normalized datasets for the study area. All data were then aligned to the NHDPlus hydrography. Each of the core datasets was then iteratively reviewed and error checked by the NAC Leadership team and Workgroup participants from each of the states. It is the belief of the project team that the dam dataset in particular is the first comprehensive, error checked dam dataset in the region. In addition to these datasets, numerous other datasets were used to calculate summary information for each of the dams (e.g. land cover, conservation land, and roads & railroads).

1.3 Methods and Software

Workgroup members developed metric weighting schemes for two aquatic habitat restoration scenarios, one which is designed to assess the likely benefits to anadromous fish and the other the likely benefits to resident fish. When evaluating dams for a given scenario (anadromous fish, resident fish, or custom designed), not all of the 72 metrics are of equal importance. For example, one might reasonably expect that the number of connected river miles upstream of a dam is of greater importance than the number of rare crayfish species when evaluating dams with respect to anadromous fish. Likewise, when evaluating dams with respect to connectivity for resident fish, the total amount of reconnected network might be considered of greater importance than the presence of anadromous fish habitat.

For each scenario, relative weights were chosen for each metric (total weight for all metrics =100). Weights were chosen by the Workgroup through a collaborative process during project conference calls and revised several times in light of draft results.

1.3.1 Barrier Analysis Tool

Two software products have come out of the NAC. The Barrier Analysis Tool (BAT) is an ArcGIS 9.3 plug-in that facilitates several of the network calculations that were performed for the NAC project. Development of the BAT was jointly funded by NEAFWA through the Northeast Aquatic Connectivity project and The Nature Conservancy's Latin America program and is freely available to interested parties via the project website or by contacting the authors.

1.3.2 Northeast Aquatic Connectivity Tool

The Northeast Aquatic Connectivity Tool (NCAT) was developed to execute the weighted ranking process, to allow users to re-rank dams at multiple spatial scales (e.g. region, state, watershed), to exclude dams that don't meet specific criteria (e.g. exclude hydro power dams from the results), and to modify the metric weights to develop new scenarios (e.g. species-specific weighting scenario). The NCAT is an Excel 2007 tool that comes pre-loaded with an all input data. A user simply enters the desired scale of their analysis and selects relative weights that are appropriate for their given scenario for their metrics of interest. The weights that were chosen by the Workgroup for the anadromous fish benefits scenario and the resident fish benefits scenario are included in the NCAT as a reference for the user.

1.4 Assessment Results

The results cover the 13 state NEAFWA region and permit assessment of opportunities for strategic reconnection of aquatic habitats at multiple scales. There are many ways to report and use the results from the two default weighting scenarios, and one of the strengths of the project is the flexibility in filtering and sorting of data to allow for different types of questions to be answered.

One of the striking findings is that when states are compared each one stands out depending on how the comparison is made and on what questions are asked of the model. This emphasizes that there is not a single "priority" that comes out of the Northeast Aquatic Connectivity Project, but rather a whole set of relative values that can be used to inform decision-making at the appropriate scale for the question being asked. The scenario results provide an initial road-map for aquatic restoration across the Northeast that should ***be supplemented by local knowledge of ecological, social, and economic conditions*** when involved in restoration planning or resource allocation.

Although the results can be viewed as a sequential list of dams, the precision with which GIS can calculate metrics is not necessarily indicative of differences in ecological benefit. In order to accurately represent that assessment results, and provide for ease of interpretation, the almost 14,000 dams in the NCAT results were grouped into 5% tiers for reporting. However, it should be noted that it is necessary to "draw a line in the sand" between dams to create these tiers and dams that are near the tier divisions may be very similar to each other.

The results and data presented in this report are based on the best available region-wide data and methods as of the writing of the report in August 2011. By design, this analysis only examines ecological criteria-- it does not incorporate the myriad social, political, economic and feasibility factors which are *critical to evaluate before determining a course of action on any dam mitigation project. Additionally, given the regional nature of the analysis, in many cases data that represent the lowest common denominator across the region were used so that fair comparisons could be made across political jurisdictions.*

Furthermore, these results represent a snapshot in time and will change as conditions on the ground change and the data which represent these conditions is improved in accuracy and resolution. Although a timeframe and funding source has yet to be determined, it is the intention of the authors to make efforts to update the underlying data and analysis over time. As such, the most current data should be always obtained from the NEAFWA website (rcngrants.org) prior to using these results in a decision-making process.

The preceding disclaimers reinforce a simple truth: these results should be used with caution and examined in the context of other relevant information. They are a screening-level tool and are not a replacement for site-specific knowledge.

1.4.1 Anadromous Fish Benefits Weight Scenario

The results for the anadromous fish benefits scenario exhibit an intuitive pattern of relatively high rankings for dams along the coastal zone and up major rivers. This pattern is largely driven by the anadromous fish habitat data, which was the metric to which the Workgroup assigned the most weight. It also exemplifies the extent to which the analysis results are dependent on the input data. This is a significant fact in light of the various sources from which data were obtained. For example, the number of dams in the top tier (top 5%) is dominated by Maine. Although it can be argued that Maine has many of the best anadromous fish runs and habitat quality in the east, it is also true that the anadromous fish data used in the analysis were more comprehensive in Maine due to the work done by Houston et al (2007).

Maine also has most dams in the top two tiers (top 10%), followed closely by Virginia, and Massachusetts. Measured as a percent of dams in the state, Maine, Delaware, and Virginia have the most dams in the top tier of results.

1.4.2 Resident Fish Benefits Weight Scenario

The results for the resident fish benefits scenario in the Northeast present a very different picture than that for anadromous fish. Relatively high ranks for resident fish restoration opportunities occur along the Appalachian chain, the Adirondacks and the Maine North Woods, as might be expected due to their status as brook trout strongholds with coldwater habitat. The results also point toward strong ecological potential in Northwest Pennsylvania and much of Eastern and Southern Virginia, which reflects long connected river network length as well as species richness and rarity. Overall, the resident fish scenario provides insights distinct from the anadromous fish scenario which can be useful for managers interested in conservation of native fish assemblages in the Northeast.

By absolute number, New York, Maine, Pennsylvania, and Virginia have the most dams in the top tier of results in the resident fish benefits scenario. Expressed as a percentage of dams within each state, Maine and Virginia are joined by West Virginia as having the most dams in both the top tier and the top 10%.

1.4.3 Basin Summaries

In addition to informing decisions at the state level, results can be examined at the watershed scale to advance aquatic connectivity restoration across political jurisdictions. A handful of metrics, meant to be a rough representation of the full suite of metrics that are used in the two scenarios, can be used to discern patterns between and within the basins. In general moving south along the Atlantic coast basins from the Penobscot River basin in the north, natural land cover quantity is seen to decline and impervious surface is seen to increase down to southern New England and the Hudson basin. Continuing further south away from the New York metropolitan area to the James River basin, impervious surfaces decline although much of the natural land cover is replaced with a higher percentage of agricultural land. The length of connected networks is also seen to decline from the Penobscot to the Connecticut and Hudson basins then increase modestly moving further south. Healthy brook trout populations, based on Eastern Brook Trout Joint Venture data, become less frequent moving south, a trend that is closely mirrored by the drop in the number of cold water stream miles in each network. In contrast, fish species richness and the numbers of rare fish, mussel, and crayfish are seen to steadily increase moving south.

Results for major interior basins, from the Richelieu in the north to the Kanawha in the south, highlight many areas for potential restoration efforts for resident fish assemblages. In general, these interior basins tend to have long functional river networks, especially total functional river networks (upstream + downstream), which were determined by the Workgroup to be of greater importance for resident fish than upstream functional river networks. These long networks are a reflection of the lower density of dams on the rivers. Landcover across these interior basins is relatively natural compared to the Atlantic coast basins which are host to more major urban centers.

Overall, the results show the basins in Maine, particularly the Penobscot and Kennebec basins, and the Chesapeake Bay region to be particularly ripe for restoration efforts to benefit anadromous fish. These areas have documented anadromous fish habitat and relatively long connected river networks which represent opportunity in light of dam removal. Basins with high potential for resident fish restoration opportunities tend to have rural interiors where land cover is in a more natural state and barrier densities are lower, resulting in longer connected networks. Virtually all of the basins along the Atlantic coast and in the interior of the region have portions which fit this description. Furthermore, it is critical to emphasize that *all* basins provide opportunities for aquatic connectivity restoration within them.

1.5 Utility of NAC Results to State Resource Agencies

The Northeast Aquatic Connectivity project (NAC) was designed to assist resource agencies in the Northeastern U.S. in efforts to strategically reconnect fragmented river, stream, coastal, reservoir, lake and estuarine habitats by targeting removal or bypass of key barriers to fish passage. From 2008 to

2011, this broad goal has driven innovative work by a representative group of state, federal, NGO, academic and private professionals dedicated to improving resource quality throughout the Northeast.

In order to understand how the Northeast Aquatic Connectivity project will likely be useful to state agencies in their efforts to restore fish passage and aquatic habitat, Workgroup members were asked to provide the project leadership team feedback directly. This feedback can be grouped into eight overarching categories: acquisition of project funding, development of basin plans or watershed management projects, focusing restoration work, support advocacy for removal / improved passage, communications, as a database of indicators and measures, ensuring resident species are addressed, and support for state administrative actions.

1.5.1 Project Limitations

Given the ambitious scope of the Northeast Aquatic Connectivity project, the quality of many existing state databases, and the lack of relevant regional databases, there are expected limitations associated with the NCAT tool and its default results. Workgroup members were polled on limitations of the results and desired future improvements. These comments can be grouped into the following overarching categories: quality of data, regional scale, scale of hydrography, lack of feasibility "filter", lack of culvert barrier information, and potential over-reliance on results by funders. Overall, state agency staff clearly recognize the limitations associated with the Northeast Aquatic Connectivity project products and understand that the completion of this NEAFWA-funded project should not be the end of the process.

Finally, the Workgroup and the TNC project leadership team believe strongly that *the NCAT outputs should not be used as the only basis for assessing the value of a potential project, but be used as one line of evidence to be examined and supplemented with local ecological, opportunity, and feasibility information*.

1.5.2 Strategic Investment Recommendations for Northeast Connectivity Restoration

The TNC Project leadership team believes that one important role that NEAFWA (or another multi-state body) can play going forward is to ensure that the Northeast Connectivity Assessment Tool (NCAT) and associated analysis tools (e.g. the Barrier Analysis Tool) are available online. More difficult will be maintaining the momentum of the network and the desire to have a database and decision support system that can be updated and upgraded over time. We suggest that to accomplish these goals, the Northeast Aquatic Connectivity Workgroup should continue to virtually meet on an annual basis to review and discuss:

1. Use of, and complications with the use of, the NCAT and associated products at the state, basin or multi-state scales
2. Updates that have been made to state or other relevant databases

3. New decision support systems and assessment methodologies that have been developed in the region
4. Assess potential collaborations with federal and other multi-state institutions, including those outside the Northeast region
5. Recommendations for revision of the Northeast Aquatic Connectivity databases
6. Recommendations for revision of NCAT methodology
7. Recommendations for addition to the Northeast Aquatic Connectivity databases

Any recommendations made by the Workgroup, if it does continue, would require an implementing body to follow through on some or all of these recommendations. It is unclear who the implementer would be at this stage, though various federal or regional agencies could fulfill the role and it need not be only one agency or institution that is involved.

There are also agencies and institutions outside of the thirteen state Northeast region that are very interested in participating in a future phase of the Northeast Aquatic Connectivity project. In particular, early phases of the project included strong participation from Canadian provincial agencies. An expansion of this work into Canadian provinces would be welcomed by these resource agencies. Additionally, staff and contractors of the Southeast Aquatic Resources Partnership (SARP) have expressed significant interest in developing a Southeast Aquatic Connectivity project and are currently assessing data limitations to undertaking such a project. This demonstrated interest from beyond the Northeast region provides an opportunity not just to leverage the success of the Northeast Aquatic Connectivity Project, but to find resources to accomplish these recommendations and future Workgroup goals.

Beyond these more process-based recommendations, it is clearly important to focus on ensuring that fish passage restoration project selection is influenced by the results of the NAC project and that biological outcomes "in-the-water" allow for adaptive management of the NCAT approach. Primary funders such as NOAA and USFWS need to both understand the value of NCAT outputs and its limitations. Although certain NOAA and USFWS offices have already shown their interest and understanding of the approach, TNC's project leadership team should be available to make sure that all key funding agency program staff are briefed on NCAT results and have their questions answered on its potential use. We would also recommend that one to two years after funding agencies begin using these results, NEAFWA leadership and/or the Northeast Aquatic Connectivity Workgroup (if it continues) complete a review of how NCAT information is being used and what might be improved about tool, underlying data, or use of the data.

1.6 Conclusion

As documented in the following report, the Northeast Aquatic Connectivity project (NAC) has resulted in a set of valuable outcomes that will assist resource agencies in the Northeastern U.S. in efforts to strategically reconnect fragmented aquatic habitats by targeting removal or bypass of key barriers to fish passage.

Overall, there is clear momentum behind the products and approach of the Northeast Aquatic Connectivity Workgroup, and many people are motivated to both use the initial products and to make sure that the tool and its underlying data improve over time. It should be noted, however, that this is just one of a number of tools available to certain states to assess connectivity restoration opportunities. Although the NCAT results break new ground in terms of the regional scale and consensus approach, it may be more appropriate in some cases to use other state or basin approaches that are more catered to local data and circumstances. It is also critical that the results of NCAT not been seen by the public as a list of targets for removal, given that many of these dams are private property and some are seen as valuable community or state assets. Finally, the NCAT results only take into account ecological information at the regional scale and do not incorporate local field information or feasibility. *Thus, it is important that users build on NCAT results with site-specific information*.

Several federal and multi-state agencies have shown either great interest or funding commitment to using and building upon the Northeast Aquatic Connectivity Project. This is an affirmation of NEAFWA's investment but also presents a challenge given the geographic scope and institutional complications associated with maintaining and updating a database and decision support tool. Regardless of future direction, the NAC project and its products have significantly advanced the dialogue on strategically advancing connectivity restoration at the regional and basin scale.

2 Background, Approach, and Outcomes

2.1 Background

The anthropogenic fragmentation of river habitats through dams and poorly designed culverts is one of the primary threats to aquatic species in the United States (Collier et al. 1997, Graf 1999). The impact of fragmentation on aquatic species generally involves loss of access to quality habitat for one or more life stages of a species. For example, dams and impassable culverts limit the ability of anadromous fish species to reach preferred spawning habitats and prevent brook trout populations from reaching thermal refuges. The Northeastern U.S. (the New England and Mid-Atlantic states) has the highest density of dams and road crossings in the country, with an average of 7 dams and 106 road-stream crossings per 100 miles of river (Anderson and Olivero Sheldon 2011).

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 all still create barriers to passage. The states of the Northeast have begun to make good progress towards reconnecting habitats through dam removal as well as culvert replacements and retrofits. In addition, fish ladders have long been used to provide fish passage in situations where dam removal is not a feasible option. Throughout the Northeast, hundreds of dams have been removed and hundreds of culverts have been replaced or retrofitted over the last two decades in projects where ecological restoration was a goal. 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.

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. This assessment can be done at a range of scales, with the appropriate scale dependent on restoration goals. In order to complete an assessment at the regional scale, the Northeast Association of Fish and Wildlife Agencies (NEAFWA) awarded the Nature Conservancy (TNC) a 2007 Regional Conservation Needs (RCN) Grant. This RCN grant was designed to have TNC support state resource agencies in the Northeast U.S. (fish and wildlife, marine fisheries, dam safety, etc.) in efforts to strategically reconnect fragmented river, stream, coastal, reservoir, lake and estuarine habitat by removing or bypassing key barriers to fish passage. The primary ecological goal of mitigating fish passage barriers is to enhance populations of fish including anadromous fish, coldwater species, and other species of greatest conservation need (SGCN).

2.2 Project Approach

From its first meeting in December 2008, the Northeast Aquatic Connectivity Project (NAC) was organized around a Northeast Connectivity Workgroup which met virtually through web conferences throughout the almost three year project term. The Workgroup included state resource agency personnel from throughout the NEAFWA states (Figure 1), as well as federal, Canadian provincial, non-profit, academic and private consulting participants. This collaborative workgroup approach built upon TNC's successful experience working with a state agency team to complete the Northeastern Habitat Classification and Mapping Project, also funded by NEAFWA. For the NAC, state resource agency participants were nominated by their agency and an attempt was made to have representation from state resource agency staff working on inland fisheries issues and anadromous fisheries restoration, although often these are different state agencies. A list of the well over forty participants in the NAC Workgroup can be found in Table 1-1 at the end of this report as well as in the Appendix.

Figure 2-1: NEAFWA states

The Workgroup agreed to work collaboratively to develop region-wide protocols, tools, and new datasets useful to state agency staff in their work on barrier mitigation. A shared scope of work was defined to reflect these goals. Although all decisions were made by consensus of the Workgroup, most of the data development and analysis was completed by the NAC Leadership Team. This team was made up of staff from The Nature Conservancy's Eastern U.S. Conservation Program, who worked in between calls to accomplish agreed-upon tasks for distribution via email and presentation at subsequent calls.   The team was lead by Colin Apse throughout the project term and included various TNC staff members over time to take advantage of a diverse set of capacities. These staff are listed in Table 1-1 and in the report Appendix.

Before the project commenced, the scope of work focused the project on collecting existing spatial data and defining consensus techniques for relative ranking of barriers for purposes of fisheries restoration projects. The project was designed to result in a set of products that are useful for state fish and wildlife agency staff in a variety of data availability circumstances. The scope focused on assessment using spatial data that exists or is easily gathered, and is fairly consistent across the region.

2.3 Workgroup Discussions and Outcomes: Phase 1

Phase 1 of Northeast Aquatic Connectivity project involved creation of the Workgroup, agreement on a project methodology, and gathering the best available information about current methods of barrier assessment and prioritization. The December 2008 Workgroup conference call served as an orientation to the project and the start of our consensus-based approach to accomplishing the scope of work. As a consequence of this call, the Workgroup agreed that it was necessary to get a better understanding of the range of data availability and assessment techniques that existed at the time. Over the next 18 months, the Workgroup examined and evaluated existing state, federal, and NGO approaches to barrier assessment and prioritization through WebEx presentations by experts in the field. These presentations were followed by Workgroup discussions and synthesis by the NAC leadership team. The overarching goal of Phase 1 was to examine the state-of-the-art in barrier assessment and categorize and narrow the assessment attributes that would be eventually incorporated into the Northeast Connectivity Assessment Tool. These presentations and discussions also had the unintended benefit of creating an Eastern U.S. network of professionals that were engaged in barrier assessment and mitigation. The value of this networking is hard to estimate, but overall progress in the field was on display at the 2011 National Conference on Engineering and Ecohydrology for Fish Passage (see http://cee.umass.edu/fishpassage/conference2011). This conference included a well attended presentation by the NAC leadership team on the NE Aquatic Connectivity Project.

During Phase 1, the WebEx presentations to the Workgroup included the following (with lead presenter noted):

1. *Optimizing Fish Passage Barrier Removals in Maine,* Jed Wright, USFWS
2. *Maryland Barrier Prioritization Approach*, Jim Thompson, Maryland DNR
3. *National Fish Passage Decision Support System*, Jose Barrios, USFWS
4. *An Ecological Framework for Prioritizing Dams the Lake Michigan Basin of Wisconsin*, Helen Sarakinos, River Alliance of Wisconsin
5. *Pine-Popple Watershed Culvert Prioritization for Fish Passage*, Matt Diebel, University Wisconsin
6. *Conservation Assessment & Prioritization System (CAPS*), Scott Jackson, University of Massachusetts
7. *Functional Linkage of Watersheds & Streams (FLoWS)*: Watershed Hydrology Metrics for Aquatic Resources, John Norman, Colorado State University
8. *Dendritic Connectivity Index (DCI) and Applications*, David Cote and Dan Kehler, Parks Canada
9. *Population Persistence of Brook Trout: Models & Forecasts*, Ben Letcher, USGS

10. *Modeling of Road-Stream Crossing Barriers in the Connecticut Basin*, Ethan Plunkett, University of Massachusetts
11. *Genetic characterization of brook trout (Salvelinus fontinalis) populations in Nash Stream, New Hampshire*, Meredith Bartron, USFWS
12. *Evaluating Fragmentation in the Connecticut River Basin*, Arlene Olivero Sheldon, TNC
13. *Massachusetts Restoration Potential Model*, Chris Leuchtenburg, MA Riverways

Many of these presentations can be found at the project website:

http://conserveonline.org/workspaces/neconnectivity/documents/presentations

Review of methodologies that could not be presented was completed by the NAC leadership team and summarized in between Workgroup calls. The presentations also included approaches that were reliant on more detailed site-specific data. This was done with an understanding that the NE Aquatic Connectivity Project would not be reconciling on-the-ground barrier data collection methodologies which differ, or are lacking, in states across the region due to project scale and scope.

The Workgroup also reviewed various datasets and metric calculation approaches via presentations, discussion, and readings. These included information about Eastern Brook Trout Joint Venture data (presented by Nat Gillespie, Trout Unlimited) and the Northeast Aquatic Habitat Classification System (presented by Arlene Olivero Sheldon, The Nature Conservancy). As a result, at the end of the first phase of the project—approximately March 2009—the Workgroup had agreed upon these eight initial ranking categories for use in assessment of barriers across the NEAFWA region:

- Connectivity Status
- Connectivity Improvement (Potential for Enhancement)
- Anadromous Fish Presence or Benefits
- Rare Species Presence or Benefits
- Resident Fish Integrity or Benefits
- Watershed and Local Habitat Condition
- Freshwater System Size or Type
- Conservation Status

Based on what was learned in Phase 1 of the project, a matrix was created to demonstrate what barrier metrics were being used by existing approaches to barrier assessment. In Table 1 below, seven state/basin approaches and their metrics are sorted into ranking categories for display and comparison. These results served as critical foundation for the discussions in Phase 2 of the project.

Table 2-1: Barrier Metrics Used in Existing State and Basin Assessment Approaches.

Ranking Categories	Barrier Metrics	MD[1]	MA[2]	ME[3]	RI[4]	NH[5]	WI[6]	CT River[7]
Connectivity Status	Presence of existing fish passage					x		

	structure							
	Density of dams in watershed						x	
	Number of dams downstream to the ocean		x					x
	Barrier at head of tide/first blockage on river	x	x					
	Total stream length upstream (for anadromous)			x				x
Connectivity Improvement	Absolute gain (minimum of upstream and downstream network size for resident species)							x
	Length of stream centerline in dam subwatershed (upstream mainstem and tributaries to next dam)		x					
	Channel order gained						x	
	Relative Gain (absolute gain/total length of up and down network for resident species						x	x
Anadromous Fish Presence or Benefits	Fishery resource value (as judged by USFWS, NOAA, and/or state)	x				x		
	American Eel Habitat (local judgment)	x						
	Upstream Salmon Habitat (modeled)			x				
	Pond area for Alewife spawning			x				
	Anadromous species present at site (salmon, shad, herring)				x			
	Anadromous fish presence: overlap with NatureServe HUC8 anadromous fish distribution							x
Rare Species Presence or Benefits	Fishery resource value (as judged by USFWS, NOAA, and/or state)	x						
	Priority biodiversity in dam subwatershed (e.g., Living Waters in MA)		x					
	State listed species likely to benefit					x	x	
	Presence of rare/threatened freshwater species in upstream and/or downstream subwatershed network							x
Resident Fish Integrity/Assemblage	Fish IBI score	x						
	Sportfish presence						x	

	Overlap of Eastern Brook Trout Joint Venture HUC11 dataset							x
Watershed Condition/Water Quality	Percent impervious surface upstream	x			x			
	Road density in dam subwatershed		x					
	303d listed waterbody				x		x	
Freshwater System Size or Type	Stream order at dam	x						
	Presence of coldwater stream in dam subwatershed		x					
	Number of NEAFWA stream habitat types in the upstream and/or downstream network							x
	Dam is located on headwater						x	
	Presence of NEAFWA stream habitat types of interest in the upstream and/or downstream network							x
Conservation Status	Federal or State river designation (e.g., wild and scenic, exceptional resource waters)					x	x	
	Public land associated with dam				x			

1. Maryland Ecological Value Criteria (MD Department of Natural Resources Fish Passage Program). 2. Massachusetts Restoration Potential Model (MA Riverways Program). 3. Optimizing Fish Passage Barrier Removals in Maine (USFWS Gulf of Maine Coastal Program). 4. Anadromous Fish Run Site Selection Tool (Rhode Island habitat Restoration). 5. Procedure to Assist in the Prioritization of Dam Removal Projects (NH Dept. of Environmental Services) 6. Small Dam Removal GIS (River Alliance of Wisconsin). 7. Evaluating Fragmentation in the Connecticut River Basin (TNC)

2.4 Workgroup Discussions and Outcomes: Phase 2

Phase 2 of the project focused on the difficult task of determining what metrics should be used for barrier assessment throughout the NEAFWA states, given data limitations and the limits of GIS technology. Excellent state or watershed specific datasets that would have been ideal to employ, such as culvert barrier assessments, exist in some areas but since the project is region-wide only data that covered the entire NEAFWA region was used for this project. To determine which region-wide connectivity metrics were to be used, a multi-stage process was employed by the Workgroup. The first stage involved a discussion of each ranking category and associated metrics, based on a presentation from the NAC leadership team, and a determination of whether each metric should be included in the analysis. A spreadsheet was maintained that tracked Workgroup discussions. Five questions generally guided the discussion of whether metrics should be included:

1. What is the ecological relevance to anadromous fish life cycles?
2. What is the ecological relevance to resident fish life cycles?
3. Is the metric unique or non-redundant?
4. Is the metric feasible to calculate region-wide?
5. Is the metric understandable by the non-specialist?

Once all eight original ranking categories had been covered and the metrics had been narrowed down, the NAC Leadership Team focused its efforts on calculating as many metrics as possible for demonstration to the Workgroup. Calculation of this draft set of Northeast Aquatic Connectivity metrics required compilation of state and federal data as well as review of data accuracy by state and federal experts. Data fields of primary importance were the location and size of dams, the location and size of waterfalls, and the extent of current anadromous fish habitat. The effort required by the NAC Leadership Team and the Workgroup for this stage of work was immense, and continued in some states until one month before the expiration of the project term. A description of this effort can be found in Section 3 of this report.

In addition, one of the early products of the Northeast Aquatic Connectivity project was developed in order to permit calculation of metrics related to connectivity status and improvement. The Barrier Analysis Tool (BAT) was developed by Duncan Hornby of the University of Southampton's GeoData Institute under contract with The Nature Conservancy using funding from the project and TNC's Latin American Program. The BAT benefited from careful review by the NAC Leadership Team and Workgroup, resulting in a final GIS-based program in August 2010. Details on the BAT are included in Section 4 of the report.

The final portion of Phase 2 of the project included the presentation of metric calculation results and determination of default assessment weights for two agreed upon ranking scenarios: 1) anadromous fish benefits; and 2) resident fish benefits. The Workgroup agreed that two scenarios were required, due to the radically different habitat and life cycle requirements of these two assemblages. A narrowed set of assessment metrics were defined by the Workgroup based on initial output of the modeling effort. This included a set of five ranking categories encompassing 33 metrics. Proposed scenario-specific weightings for these metrics, and associated rationales, were presented to the Workgroup by the NAC Leadership Team for discussion. Weighting discussions were completed in an iterative fashion with the Workgoup based on the expert opinion of members who were able to analyze the impacts of different weighting scenarios after receiving draft results.

The process of defining default weights was advanced significantly by use of a pilot area, the Connecticut River Basin, in which early results were shown to a broad group of stakeholders organized by The Nature Conservancy and USFWS for their comments and proposed revisions. As a result of Connecticut Basin stakeholder as well as Workgroup discussions, not all metrics were used in default weighting and different set of metrics are used for each scenario. Final metrics, categories and weights are shown in Figure 2-2.

Figure 2-2: Anadromous fish scenario and resident fish scenario metric weights chosen by NE Aquatic Connectivity Workgroup.

Metric	Anadromous	Resident
Downstream Impassable Dam Count	15	0
Upstream Dam Density	3	1
Downstream Dam Density	0	1
Distance to River Mouth from Dam	7	0
Upstream River Length	3	0
Density of Small (1:24k) Dams in Upstream Functional Network Local Watershed	5	3
Density of Small (1:24k) Dams in Downstream Functional Network Local Watershed	0	3
Density of Road & Railroad / Small Stream Crossings in Upstream Functional Network Local V	3	5
Density of Road & Railroad / Small Stream Crossings in Downstream Functional Network Loca	0	5
Number of Hydro Dams on Downstream Flowpath	5	0
Connectivity Status Subtotal	**41**	**18**
Upstream Functional Network Size	15	0
The total length of upstream and downstream functional network	0	20
Absolute Gain	2	10
Connectivity Improvement Subtotal	**17**	**30**
% Impervious Surface in Contributing Watershed	3	5
% Natural LC in Contributing Watershed	0	5
% Impervious Surface in ARA of Upstream Functional Network	2	2
% Impervious Surface in ARA of Downstream Functional Network	0	2
% Natural LC in ARA of Upstream Functional Network	5	2
% Natural LC in ARA of Downstream Functional Network	0	2
% Conserved Land within 100m Buffer of Upstream Functional Network	0	2
% Conserved Land within 100m Buffer of Downstream Functional Network	0	2
Watershed and Local Condition Metric Subtotal	**10**	**22**
Presence of anadromous species Current & Historic (binary, yes/no)	20	0
Number of anadromous species present downstream	5	0
Current # of rare (G1-G3) fish species in HUC8 (Max #)	0	3
Current # of rare (G1-G3) mussel HUC8 (@ dam)	0	3
Current # of rare (G1-G3) crayfish HUC8 (@ dam)	0	1
Current "Healthy" Eastern Brook Trout in HUC8 (@ dam) (EBTJV dataset)	0	8
Current Native fish species richness - HUC 8 (@ dam)	0	3
Ecological Metric Subtotal	**25**	**18**
River Size Class	5	0
Number of new upstream size classes >0.5 miles gained by removal	2	0
Miles of Cold Water Habitat (any stream size)	0	7
Total Reconnected # stream sizes (upstream + downstream) >0.5 Mile	0	5
Size Metric Subtotal	**7**	**12**
Sum of Weights (MUST =100)	**100**	**100**

The project was completed in August 2011 the same way in which it started, as a consensus approach to the difficult question of how to assess the relative value of barriers for removal or mitigation in order to benefit fish communities throughout the Northeast. Workgroup participants generally judged the default output of the Northeast Connectivity Tool NCAT to be 80% - 90% accurate in reflecting their understanding of the relative ecological benefit that could result from mitigation of barriers in the geographic area they knew best. This was considered by the Workgroup to be adequate to meet project goals, but all agreed that the NCAT and its default outputs should be seen as a starting point rather than a conclusion. There was consensus that when assessing the relative value of different barrier mitigation projects, local expertise will continue to be indispensible. This expertise is required to bring in relevant ecological information (e.g. presence of invasive species) and to assess the political and economic feasibility of any barrier mitigation project. Furthermore, this project uncovered significant data gaps both within states and across the region that should be addressed in future iterations. Nonetheless, the Northeast Aquatic Connectivity project described in this report can be seen as a major contribution to the art and science of barrier assessment, and should provide a valuable resource for state agencies to use in strategically connecting aquatic habitat throughout the Northeastern U.S. region.

3 Data Collection, Data Preprocessing, and Data Gaps

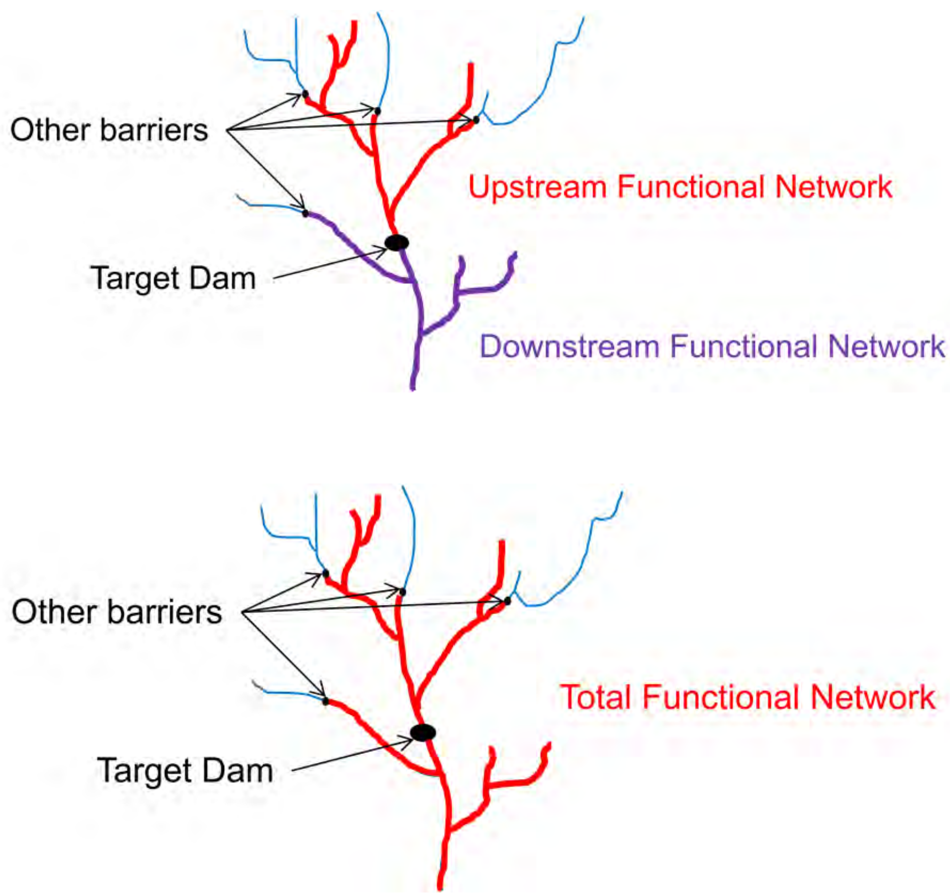
3.1 Definitions

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

3.1.1 Functional River Networks

A dam's functional river network, also referred to as its connected river network or simply its network, is defined by those stream reaches that are accessible to a hypothetical fish within that network. A given target dam's functional river network is bounded by other dams, headwaters, or the river mouth, as is illustrated in Figure 3-1. A dam's total functional river network is simply the combination of its upstream and downstream functional river networks. The total functional network represents the total distance a fish could theoretically swim within if that particular dam was removed.

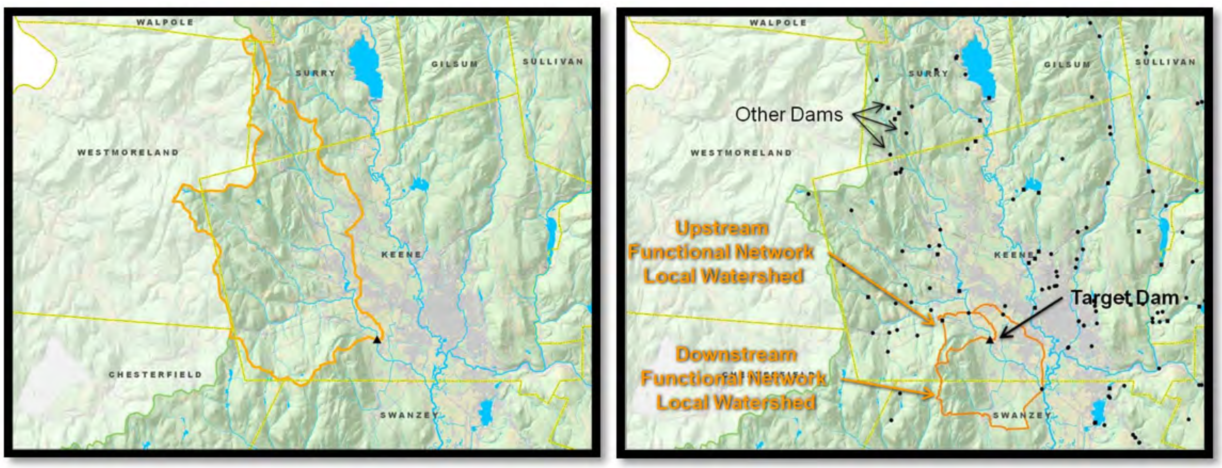
Figure 3-1: Conceptual illustration of functional river networks



3.1.2 Watersheds

For any given dam, metrics involving three different watersheds are used in the analysis. The contributing watershed, or total upstream watershed, is defined by the total upstream drainage area above the target dam. Several metrics are also calculated within the local watershed of target dam's upstream and downstream functional river networks. These local watersheds are bounded by the watersheds for the next upstream and downstream functional river networks, as illustrated in Figure 3-2.

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



3.2 Core data sets

Four datasets: dams, natural waterfalls, anadromous fish habitat, and the NHDPlus form the core of the Northeast Aquatic Connectivity project (NAC). Dams were the primary unit of analysis in the NAC project. Attributes were calculated in a GIS for each dam in the analysis and the relative ecological benefit of removing or bypassing each dam was assessed using these attributes. Natural waterfalls were included as barriers to fish passage in the analysis, but they were not evaluated for their potential ecological benefit if removed. Anadromous fish habitat data were compiled and improved for this project, and provided the basis for one of the most important attributes by which dams were evaluated. Finally, the 1:100,000 scale NHDPlus hydrography and its associated attributes formed the foundation for the stream network calculations and many of the watershed metrics as well.

3.2.1 Dams

Dams act as barriers to the movement of fish and other aquatic organisms. The NAC project seeks to rank dams based on their potential ecological benefit if removed or mitigated for fish passage. At the outset of this project, no regional dam dataset existed that included the thousands of smaller dams which are not accounted for in the U.S. Army Corps of Engineers' (USACE) National Inventory of Dams (NID). These smaller dams can be just as detrimental connectivity for aquatic organisms as larger dams, and are far more numerous, thus their inclusion in the analysis was crucial.

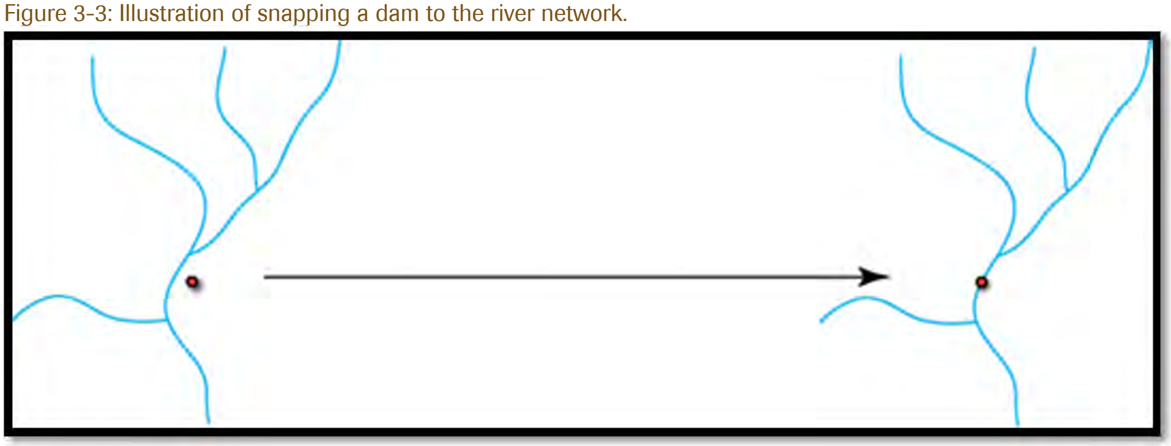
3.2.1.1 Data Collection

Dam data was obtained from several sources. Primary among them were the respective state agencies from each of the participating states. Additional dams were obtained from the NID, and the U.S. Geological Survey's (USGS) Geographic Names Information System (GNIS) database. A complete list of dam data sources by state can be found in the report Appendix. Datasets varied considerably from state to state with respect to spatial accuracy, available attributes, and data format. In a few cases, culvert location data were available for portions of states. However, because this data was very inconsistent across the region with respect both to culvert presence as well as passability, only dams were included in the analysis. If culverts had been included for some areas, the relative ranks of dams in those areas would have been affected. For example, if two watersheds with a similar number of dams were being compared but data for one of the watersheds included culverts, that watershed would appear much more fragmented, and hence the potential ecological gain from removing or remediating any given dam would be diminished and its rank reduced. Due to the wide variation in spatial data accuracy and the repercussive effect of data errors in a network analysis, considerable effort was put into the review and refinement of the dam datasets.

3.2.1.2 Dam Data Preprocessing

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 NHDPlus 1:100,000 scale hydrography. (Additional information on the NHDPlus is provided below.) Snapping in this case involved moving all dam points within 100m of the hydrography onto the hydrography, as illustrated in Figure 3-3.

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



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 3-3 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", less than 100m might prevent this from happening, but in other cases dams that do belong on the hydrography might be missed. Thus, the project team selected a 100m snapping tolerance as a middle-of-the-road value, and followed this process up with an extensive error checking procedure.

The post-snapping error checking process involved four phases: 1) prioritizing dams using an automated flagging process which produced a priority rank of 1-9 for each dam, 2) manually reviewing the high priority dams in-house at TNC, 3) sending the TNC-reviewed dams to state contacts for additional review and 4) incorporating the state-reviewed dams back into the master dataset. Details on the error flagging methodology can be found in the report Appendix 3.

In practice, due to the vast number of dams and the realities of staff time constraints, dams with priority values 1-4 were considered for manual review. In some cases, only dams with priorities 1-3 were able to be reviewed. Manual review involved comparing dams to several available data sources including 1:24,000 scale USGS topographical maps, aerial photography, web maps (e.g. Google maps), or internet searches for individual dams, until a determination could be made with respect to the dam's location. Any edits that were made by TNC during the manual review process were noted in the attribute table of the dam database. When TNC staff had completed initial review of the data, each state's data was sent back to the appropriate state participant for additional review. State participants were first asked to help make determinations where TNC staff were unable to discern where a given dam should be located. As time allowed, they were also encouraged to provide additional review of the high priority dams.

After state review, the dam datasets from all states were merged and further reviewed by TNC staff on an as-needed or case-by-case basis. For example, when the datasets from multiple states were combined duplicates often arose where dams fell on rivers which form state borders (e.g. the Connecticut River). Additionally, as the project progressed and draft results were produced, additional edits were made to the dam data based on input from state participants.

There were 32,433 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. A total of 27,837 valid dams were included in the database. In the end 13,835 of these dams were evaluated in the analysis. This represents 49.7% of the 27,837 dams that are current barriers in the study area, with the remaining dams falling on small streams that are not mapped in the NHDPlus hydrography.

3.2.2 Waterfalls

Waterfalls can act as natural barriers to fish migration. In the NAC project which, among other things, seeks to rank dams based on the potential ecological benefit of a dam's removal or mitigation, this can be significant where dams are located above natural waterfalls which may never pass anadromous fish.

3.2.2.1 Data Collection

The primary data source for waterfalls was the USGS GNIS database, which includes named features from 1:24,000 scale topographic maps. A handful of additional waterfall data were provided for the state of Connecticut by CT Department of Environmental Protection/Inland Fisheries Division staff who requested the data be included in the analysis. Additional waterfalls were available for portions of Pennsylvania and New York, at much higher densities than were available in the GNIS database. These waterfalls were not included in the final analysis, due to the difference in waterfall densities and the corresponding effect it would have on relative ranking of dams in these regions, similar to the effect the inclusion of culverts would have had on the analysis in the analysis (Section 3.2.1.1).

3.2.2.2 Data Preprocessing

Waterfall data were subjected to a similar review process as dams were. Waterfalls were snapped to the NHDPlus hydrography using a 100m snap tolerance and the results reviewed by TNC staff and state participants. However, because the GNIS database does not contain many of the attributes that were used to prioritize dams for review (e.g. waterbody name, height, etc), no prioritization effort was undertaken for the waterfall data. Nevertheless, the relatively small number of waterfall points in the region (618), allowed for the manual review of all waterfalls.

Snapped waterfall locations were compared by TNC staff to 1:24,000 scale topographic maps, aerial photographs, and other references including web maps (e.g. Google Maps) and internet searches. Waterfalls whose locations could not be confirmed were flagged. The data were then sent to state participants for review with the request that review begin with these flagged waterfalls. State-reviewed datasets were merged by TNC staff into a regional dataset for use in the analysis.

3.2.3 Anadromous Fish Habitat

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

3.2.3.1 Data Collection

Anadromous fish current habitat data were obtained from the Atlantic States Marine Fisheries Commission (ASMFC) database for American shad, hickory shad, blueback herring, alewife, striped bass, and Atlantic sturgeon (ASMFC 2004). Additional data for these species and for Atlantic salmon were obtained for Maine from work performed by Houston et al (2007), New Hampshire’s Great Bay watershed (Odell et al 2006), and the Connecticut River basin (Zimmerman et al, unpublished).

American eel were also considered for inclusion in the analysis. However, the lack of good distribution data for eel, as well as the feeling that the other anadromous species would adequately represent the ecological needs of eel, led to the decision to exclude American eel from the analysis.

3.2.3.2 Data Preprocessing

Anadromous fish data were transferred from the geometry used in the ASMFC data to the 1:100,000 scale NHDPlus hydrography. Each reach was assigned as code of 0 – 2 where:

1 = reach contains current freshwater habitat (spawning, overwintering)
0 = reach does not contain current freshwater habitat (spawning, overwintering)
2 = historical / reach contains likely restoration potential habitat

Availability of historical / restoration potential habitat data were generally much more limited than current habitat data were. In the ASMFC data, only streams in Connecticut had any historical habitat reaches. Additional historical data were available in the anadromous fish data from Maine (Houston et al 2007) and New Hampshire (Odell et al 2006). In the cases of both Maine and New Hampshire, additional presence values were consolidated into current habitat and historical / potential restoration habitat. In Maine, "historical" & "historical assumed" were both classes as "historical" and "current" & "current assumed" were both classed as "current". "Uncertain" reaches, were not considered for either current or historical habitat. In New Hampshire's Great Bay, similar classes were used as in Maine, except the qualifier was named "uncertain" rather than "assumed". Thus, "current" & "current uncertain" were both classed as "current" and "historical" & "historical uncertain" were both classed as "historical".

The project team debated whether the historical data, which is regionally very incomplete, should be used in the analysis. As described above, culvert data were not used in the analysis due to inconsistent coverage and the effect that this would have on the relative ranking of dams across the region. However, some team members believed that it was important to use the best available anadromous fish habitat data to represent their jurisdictions and if historical data were available, they should be used. In the end, historical data were used in the analysis, as described further in Section 4.2.4, but an option to use only current data is made available for use in the Northeast Connectivity Assessment Tool (NCAT).

After all the anadromous fish data were merged and normalized, data were reviewed in the context of the dam dataset. This was done to maximize topological accuracy where fish habitat was intended to stop at a given dam. In the GIS, if a line representing fish habitat extended beyond the terminal dam, even by a small amount, upstream dams could be improperly coded as having fish habitat within their downstream network. In cases where it was unclear whether the fish habitat data were intended to terminate at a given dam, the data were left unaltered. This review process was a manual effort, undertaken by a trained fisheries biologist volunteering with TNC.

3.2.4 NHDPlus

The 1:100,000 scale NHDPlus formed the foundation for much of the worked performed in this analysis. The other core datasets were all edited to conform to the geometry of the NHDPlus hydrography. It was used for all network calculations (e.g. number of stream miles upstream of a given dam) and several of the reach-based attributes of the NHDPlus were used to evaluate dams on a given reach (e.g. % impervious surface in the upstream watershed of a reach). Additional information on the NHDPlus can be found at http://www.horizon-systems.com/nhdplus/.

3.2.4.1 Data Preprocessing

In order to perform the types of network analyses that were run in this project, the hydrology had to be represented as a single-flowline dendritic network. Like the branches of a tree, the streams in a dendritic network merge together moving towards the base of the network. There are no loops or divergences in downstream flow in a dendritic network.

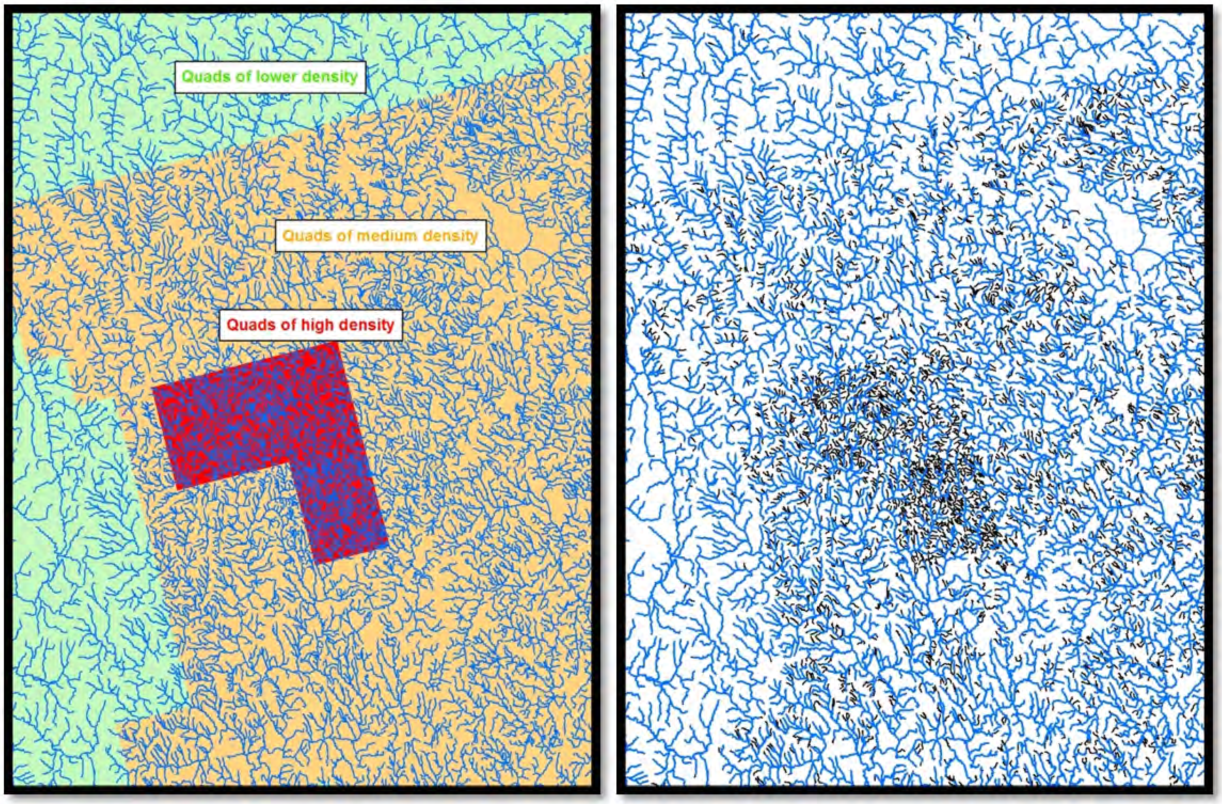
The attributes of the NHDPlus greatly facilitate the work required to arrive at a dendritic network. Each stream reach can be linked to a “Divergence” field which stores values to indicate whether that reach is part of a divergence (i.e. braid), and if so whether it is the main path or a minor path. This attribute can accordingly be used to select out the main stems of braided rivers or other downstream flow path bifurcations.

When the edited dendrite was run through the Barrier Analysis Tool (BAT, described further in Section 4.1) additional bifurcations were identified and addressed through manual editing. In some cases, these bifurcations were the effect of loops resulting from errors in the NHDPlus. For example, some streams erroneously crossed ridgelines thereby connecting two watersheds and creating a loop. In other cases, non-natural features, like canals, cut across the landscape creating loops each time they crossed a pair of streams on the same “branch” of the network. In either case the solution involved editing the network to break loops. This process was informed by the 1:24,000 scale topographical maps, elevation-derived flow direction data, and the NHDPlus hydrologic sequence attribute which lists the upstream and downstream segments for each given segment. Editing continued until the final product was accepted by the BAT with no errors.

Finally, the density of small headwater streams is not consistent in the NHDPlus. These smallest streams are denser in some areas corresponding to certain USGS topographic quadrangles (Figure 3-4) and less dense in other areas. This uneven density can be traced back to the source USGS topographical maps from which the NHD data were digitized. The inclusion of inconsistently dense streams would have ramifications on dam rankings. For example, if smaller streams were included in some quads, the length of the functional network above or below dams in these quads would be artificially high and not comparable to lengths in neighboring quads where no very small stream miles were included in the mapped hydrography. Additionally, if smaller streams were included in some quads, more dams would be included in the analysis (i.e. more dams would “snap” to the hydrography). To address this inequality, the TNC project team selected several size thresholds and examined the effect of removing streams smaller than each size threshold on stream density from quad to quad. A watershed size threshold of 1 mile^2 was selected based on this review and the expert opinion of Workgroup members. Streams whose watersheds were below this threshold were removed from the analysis to create a more consistent and comparable stream hydrology network across the analysis region.

Figure 3-4: Example of varying density of streams in the NHDPlus.

a) Uneven headwater stream density in the NHDPlus b) hydrography (in blue) after streams with watersheds <1 mi^2 (in black) are removed



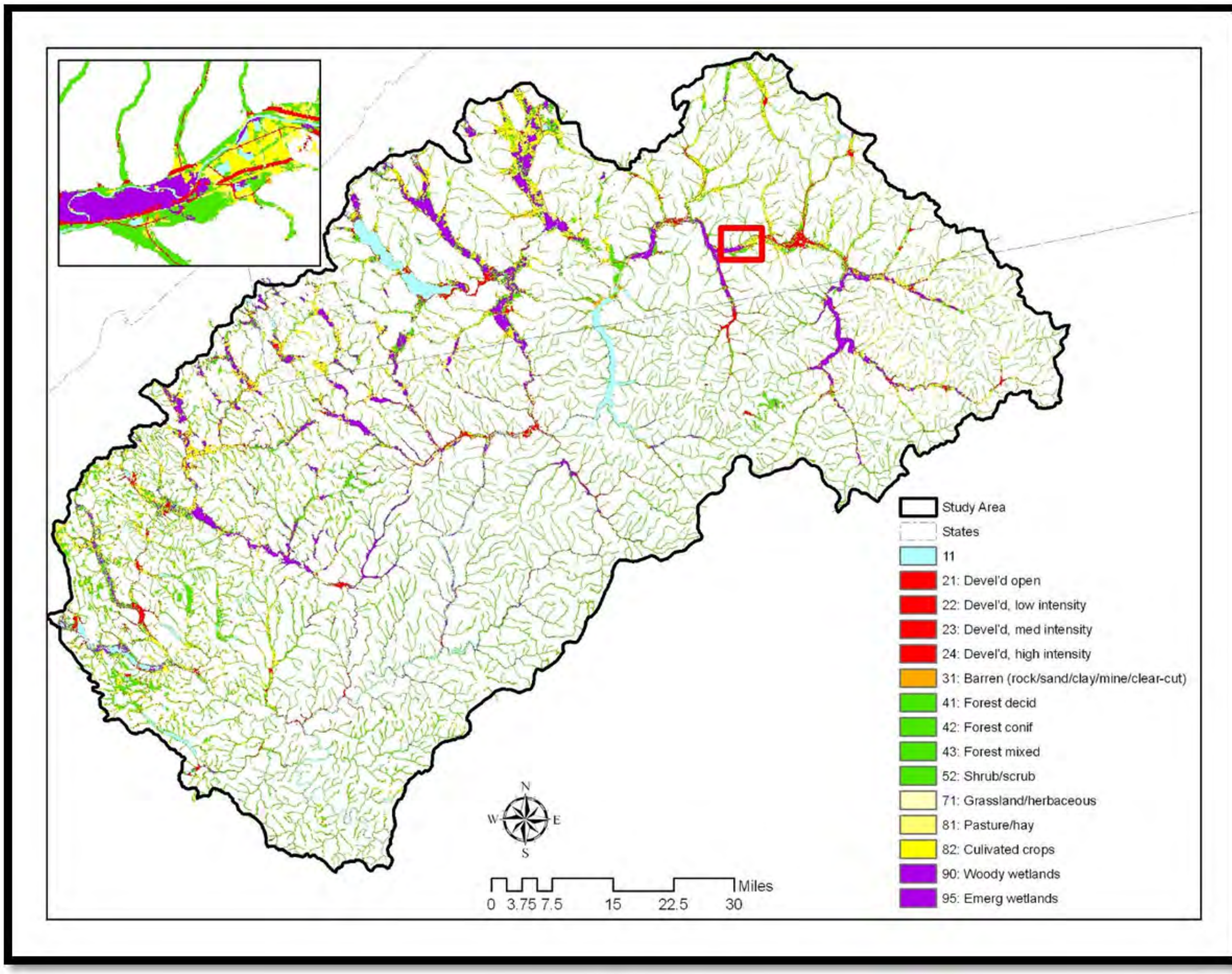
3.3 Additional Datasets

Several additional datasets were used to describe the ecological condition of the streams, watersheds, and land immediately surrounding a dam and its upstream and downstream connected networks. Dams whose removal or mitigation could improve access to streams and watersheds that are in better ecological condition were ranked higher than those dams in more degraded areas.

3.3.1 Active River Area

The Active River Area (ARA) is a spatially explicit framework for modeling rivers and their dynamic interaction with the land through which they flow (Smith et al 2008). Distinct portions of the ARA include the meander belt, riparian wetlands, floodplains, terraces, material contribution areas. The ARA is different from, but was calibrated to and compared against the FEMA 100-year floodplain. The NAC project used the ARA as a unit within which various landcover metrics, such as impervious surface, were summarized. Figure 3-5 depicts an example of a landcover summary within the active river area of a watershed.

Figure 3-5: Example of landcover analysis within the active river area of a watershed.



3.3.2 National Land Cover Database

The 2006 National Land Cover Database (NLCD 2006) was used to assess land cover condition within the Active River Area and 100m buffer of each dam's upstream and downstream connected networks. Landcover data were grouped into two classes: natural and agricultural. Natural landcover was defined by the following NLCD values: deciduous, evergreen, and mixed forest, scrub/shrub, grassland, barren land, open water, and woody & emergent wetlands. Agricultural landcover was defined by pasture/hay and cultivated crops. Developed lands were accounted for using the NLCD impervious surface data.

3.3.3 TNC secured lands

The Nature Conservancy's secured lands dataset identifies those parcels that have permanent protection from development. The presence of secured lands adjacent to streams has implications over time for both water quality and the ability of a river to maintain its natural processes (Abell et al 2007). For each dam in the analysis, the percent of secured land within a 100m buffer of its upstream and downstream connected networks was calculated. Additionally, dams which were situated on secured lands were attributed with this information.

3.3.4 Northeastern Aquatic Habitat Classification System

Data from the Northeastern Aquatic Habitat Classification System (Olivero and Anderson 2008) were used in several aspects of the analysis as proxies for aquatic habitat diversity and quality. Like the Northeast Aquatic Connectivity project, the NEAHCS project used the NHDPlus as its base hydrologic network. Therefore, all of the attributes calculated during the NEAHCS project could be easily used to assess dams and their upstream and downstream connected networks. Variables that were used in the analysis included size (calculated as a function of upstream watershed size) and modeled expected natural water temperature class. As is described in additional detail in Section 4.2, several metrics were calculated from this data including the number of size classes & miles of each size class in each dam's upstream and downstream connected networks, as well as the miles of cold & cool transitional water in each dam's networks.

3.3.5 Eastern Brook Trout Joint Venture (EBTJV)

Eastern Brook Trout Joint Venture (Hudy and Thieling 2006) data at the subwatershed (HUC 10) scale were used to identify those subwatersheds with the greatest likelihood of "healthy" brook trout populations present. The "healthy" population classification was grouped from several classes in the EBTJV data. Where available, survey data in the "intact", "qualitative intact", and "reduced" categories were considered healthy (Gallagher, personal communication). Where no survey data were available, data that were modeled in the "predicted intact" and "predicted reduced" categories as part of the EBTJV project were used (Thieling 2006). Several models were developed by Thieling (2006) using watershed and subwatershed metrics in a GIS to predict brook trout population status. These metrics include percentage of forested land, combined sulfate and nitrate deposition, percentage of mixed forest in the water corridor, percentage of agriculture, road density, and latitude. The most model with the most predictive success, model run 3, was used in this analysis where survey data were not available.

3.3.6 Nature Serve

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

3.3.7 ESRI - Roads & Railroads

Each time a stream crosses a road or railroad an opportunity for reduced fish passage is presented. The density of these crossings was calculated for each dam's local watershed. Although not every crossing can be considered a barrier to fish passage, it is likely that a watershed with a higher density of crossings would have reduced connectivity relative to a watershed with fewer crossings. Using the assumption that larger streams would require a road or railroad bridge (and thus be less likely to present barriers to fish passage than culverts), only road/railroad crossings with smaller streams (creeks and headwaters, <38.6 mile^2 drainage) were included in this portion of the analysis.

3.4 Data Gaps

3.4.1 Non-Atlantic coast drainages

Many of the metrics which were calculated for this analysis take advantage of a dam's location within its overall hydrologic network. For example, the "distance to river mouth metric" evaluates the distance in river miles to the mouth of the river (ocean) as represented in the NHDPlus hydrography. Similarly, the "number of downstream dams" metric and the "number of downstream waterfalls" metrics evaluate the number of these features between each given dam and the river mouth.

Dams on rivers which flow outside the study area, i.e. those streams which are not part of Atlantic Coast drainages, have incomplete downstream data. For those watersheds which are part of the Ohio/Mississippi drainage, efforts were made to include downstream networks down to the first NID dam. Additional NHDPlus hydrography data from the surrounding states (Ohio, Kentucky, Tennessee and North Carolina) were collected and edited to produce single-flowline networks, thus extending the dendritic network into these states beyond the study area. Metrics for dams whose downstream networks extend into these states and which evaluate the dam's downstream connected network or downstream connected network watershed are accurate, save for the lack of data on non-NID dams and the potential impact of these dams. However, metrics which incorporate distance to river mouth or the number of features downstream of a dam (e.g. waterfalls/hydro dams) underestimate the true length of the distance to river mouth and/or the number of features on the river. Dams in these drainages have been qualified in the results as non-Atlantic coast drainages.

Similarly, dams on rivers which drain to the St. Lawrence River have incomplete downstream data. However, in these cases, no data on hydrography or dams from Canada were included. Dams from the portions of northern New York, Vermont, and Maine which are affected are qualified in the results.

3.4.2 Fish Passage Facilities

Information on fish passage facilities was inconsistent across the region and within states. Originally, the project team hoped to collect information on fish passage facilities and run sizes for many dams in the region. It quickly became clear, however, that this information was rarely comprehensive in the state dam datasets. To address this problem, fish passage information was recorded and compiled into the project database where available. Rather than attempting to make judgments on the passability of any given dam for any given species under any given set of conditions, the presence of fish passage facilities at a dam is simply presented as a qualifier with the project results. This allows an end-user to exclude dams with passage from a particular management analysis, if desired. Where state biologists supplied additional, more detailed, information this was recorded in the "Comments" field in the database.

3.4.3 Culverts

Culverts at stream and road/railroad crossings can reduce or prohibit the passage of fish and other aquatic organisms due to water velocity, insufficient water depth, elevated outlets, and debris accumulation (Larinier 2002). To ideally represent aquatic connectivity, data on culvert locations and data describing passability would be available across the region. The current state of the data is far from this ideal, with location data available for certain watersheds in some states and survey data for a smaller subset of these. Although the project team explored using modeling techniques to estimate the probability of fish passage at culverts (Plunket 2009), it was determined that insufficient data were available to include culverts as barriers in the analysis. An alternative measure, the density of road/stream crossings in the local watershed of each dam, was used as a surrogate for evaluating the impacts of culverts.

3.4.4 Overall data quality

As described above, data for this analysis were collected from many different sources. Each dataset came with its own spatial and attribute error, error which in most cases had not been quantified nor was easily quantifiable, particularly with respect to dam data. Due to the network-based nature of this analysis, one error in a dam dataset has a ripple effect across other dams in the same network. For example, if a dam which has been removed and is no longer a barrier to fish passage remains in the database, the length of connected network for each dam upstream and downstream of it will be impacted.

As was described in Section 3.2, substantial effort was put into error-checking and refining the dam data, as well as the other core datasets in the analysis. However, it is expected that errors remain in each dataset. Additionally, as time passes and conditions on the ground change due to dam removals, breaches, or new dam construction, the dam data will become increasingly outdated. Therefore, it is best to think of the data and this analysis as a snapshot in time which will require regular updates to stay current. See Section 6 for recommendations for some options on how to address these regular updates.

4 Methods and Software Developed

4.1 Barrier Analysis Tool

The Barrier Analysis Tool (BAT) is an ArcGIS 9.3 plug-in that facilitates several of the network calculations that were performed for the NAC project. Development of the BAT was jointly funded by NEAFWA through the Northeast Aquatic Connectivity project and The Nature Conservancy's Latin America program and developed by Duncan Hornby at the University of Southampton's GeoData Institute. Using dendritic hydrography data and barrier point data, the BAT calculates functional river networks, counts the upstream and downstream barriers, the total length of all upstream networks, and the distance to river mouth. Additional metrics, such as density of downstream barriers, can be derived from these base metrics. Analyses can also be run on non-barrier point data (e.g. count of downstream macroinvertebrate sample sites, accumulation of upstream storage values, etc). The BAT is freely available to interested parties via the project website or via the authors.

4.2 Metric Calculation

A total of 72 metrics were calculated for each dam in the analysis. The metrics are grouped into five categories: Connectivity Status, Connectivity Improvement, Watershed and Local Condition, Ecological Metrics, and Size/System Type Metrics. A complete list of metrics, a brief explanation of each one, and the methods used to calculate the metric is presented in Table 4-1, at the end of this document.

4.2.1 Connectivity Status

Connectivity status metrics evaluate the current state of fragmentation in each dam's surrounding river network. Dams in the analysis are evaluated based on the premise that a dam in a less fragmented network would produce a greater ecological benefit if it were removed or remediated than a dam which is located in a more fragmented network. Connectivity status metrics include counts and densities of dams on the 1:100,000 scale NHDPlus hydrography. Additionally, the densities of dams on small streams (not in the NHDPlus) and road/stream & railroad/stream crossings within the upstream and downstream functional network local watersheds are included.

4.2.2 Connectivity Improvement

Connectivity improvement metrics assess each dam for the beneficial impact its removal would have on network connectivity. Each of the five metrics in this category deal with the length of the functional river network, either upstream, downstream, total, or measurements of network gain. In each case, the more network length gained by a dam's removal, the greater the dam's potential ecological benefit is considered to be.

4.2.3 Watershed and Local Condition

Watershed and local condition metrics evaluate the ecological condition of a given dam's contributing watershed, within its upstream and downstream functional river network local watersheds, within the Active River Area of its upstream and downstream functional river networks and within a 100m buffer of its upstream and downstream functional river networks. Dams whose watershed and local conditions are in better condition (i.e. less impervious surface, more natural land cover) are considered to have a greater potential ecological benefit if removed. This is due to the well established relationship between land cover characteristics and fish assemblages (e.g. Wang et al 2000, Scott et al 1986, Weaver and Garman 1994).

4.2.4 Ecological

Ecological metrics representing both anadromous and resident fish were assessed within each dam's functional networks or watersheds. Anadromous fish habitat data, one of the core datasets of the project, were summarized within the downstream functional network of each dam. If fish habitat data were located within a dam's downstream functional network, the assumption was made that the dam's removal would increase upstream access for those species. Two metrics were derived from the current habitat and historical/restoration potential habitat for each of the seven species examined in the analysis: the "presence of any one of the seven species in a dam's downstream functional network" and "number of species present in the downstream functional network". For the "presence of any one species" metric, current habitat was taken preferentially over historical habitat (i.e. if current habitat was documented for species A and historical habitat was documented for species B, the network was considered to have current habitat.) Only current habitat data were examined for the "number of species present" metric.

Data of ecological interest for resident fish were all available at the subwatershed (HUC8) scale. These data include the presence of rare fish, mussel, or crayfish, fish species richness from NatureServe, and "healthy" brook trout populations from the Eastern Brook Trout Joint Venture. In each of these cases, dams were assigned values for these metrics based on the subwatershed within which the dam is situated.

4.2.5 Size

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 class, based on the catchment drainage size thresholds developed for the NAHCS (Olivero and Anderson 2008), were summarized within each dam's upstream and total (upstream + downstream) functional river networks as a proxy for habitat diversity within each network. Metrics calculated include the number of miles in each size class in each network, the number of size classes within each network, and the number of new size classes gained in the upstream network (i.e. the number of size classes which are not represented in the downstream network).

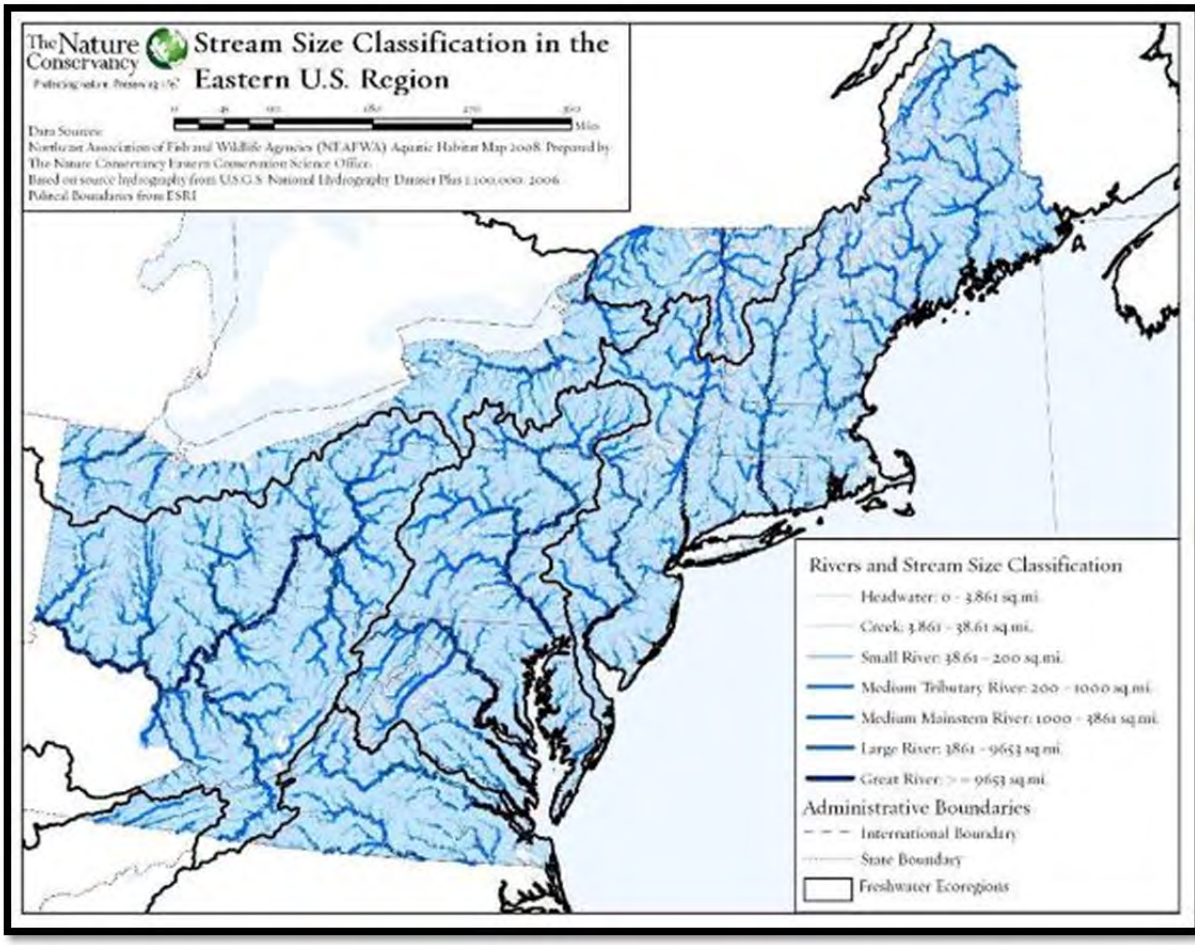


Figure 4-1: Size class definitions and map of rivers by size class in the study area.

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)

4.3 Metric Weighting

When evaluating dams for a given scenario (e.g. anadromous fish, resident fish, etc), not all of the 72 metrics are of equal importance. (In fact, many of the metrics are duplicative to give end users of the NCAT a suite of options when running custom analyses -- see following section for additional detail on the NCAT). For example, one might reasonably expect that the number of connected river miles upstream of a dam is of greater importance than the number of rare crayfish when evaluating dams for anadromous fish. Likewise, when evaluating dams with respect to connectivity for resident fish, the total amount of reconnected network might be considered of greater importance than the presence of current anadromous fish habitat.

Northeast Aquatic Connectivity Workgroup members developed weighting schemes for both anadromous fish and resident fish scenarios. For each scenario, relative weights were chosen for each metric where the total for all metric weights equals 100. Initial weights were chosen through a collaborative process during project conference calls. Weights were further revised several times in light of draft results. The final weights used in the development of the tiered results are presented in Figure 2-2.

4.4 Northeast Aquatic Connectivity Tool (NCAT)

4.4.1 Purpose and design of the NCAT

The Northeast Aquatic Connectivity Tool (NCAT) was developed for the Northeast Aquatic Connectivity project. The NCAT allows users to re-rank dams at multiple spatial scales (e.g. region, state, watershed), to exclude dams that don't meet specific criteria (e.g. exclude hydro power dams from the results), and to modify the metric weights to develop new scenarios (e.g. species-specific weighting scenario).

The NCAT is an Excel 2007 tool that comes pre-loaded with an input data table where each row represents one dam in the analysis and each column represents one metric that was calculated for each dam. The user interface of the NCAT utilizes two separate worksheets: a table of metric weights and a table of results. The table of metric weights comes preloaded with the anadromous fish weights chosen by the project team, but these can be edited by the user. The results are displayed alphabetically within 5% tiers, although these can be sorted by the user using standard Excel tools. A detailed guide to using the NCAT is presented in Appendix 2.

4.4.2 Mechanics of the NCAT

The NCAT uses a simple weighted ranking process to order dams in the analysis. This process allows each dam to be evaluated based on the metrics that were calculated in GIS, weighted per the relative weights chosen by the Workgroup or using custom, user-defined custom weights. This methodology was designed to be simple and transparent, while incorporating the flexibility that was desired by the project team. An example of the process steps, which utilizes a *hypothetical* example of four dams being evaluated based on two metrics, is presented in Figure 4-2. The NCAT processes each of these steps on a separate worksheet in the workbook, passing the results from each step to the next.

Figure 4-2: 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	3	4
Dam B	2	2
Dam C	1	3
Dam D	4	1

2

Dam Name	US Functional Network Length (% rank)	DS Functional Network Length (% rank)
Dam A	75	100
Dam B	50	50
Dam C	25	75
Dam D	100	25

3

Dam Name	US Functional Network Length	DS Functional Network Length
Dam A	75 * 0.75	100 * 0.25
Dam B	50 * 0.75	50 * 0.25
Dam C	25 * 0.75	75 * 0.25
Dam D	100 * 0.75	25 * 0.25

4

US Functional Network Length (weighted rank)	DS Functional Network Length (weighted rank)
56.25	25
37.5	12.5
18.75	18.75
75	6.25

Summed Ranks
81.25
50
37.5
81.25

5

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

6

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

- Step 1: Rank all dams in the area of interest for each metric
    - All dams in the study area are sequentially ranked for all attributes. If the user has selected a scale other than the entire region (e.g. state, watershed) only dams at that scale are ranked. Depending on the metric, it will either be sorted so that large values are ecologically beneficial (as is depicted in this example with functional river network length) or so that small numbers are ecologically beneficial (as is the case with the "number of downstream dams" metric). The list of metrics in Table 4-1 indicates whether a given metric is sorted in ascending or descending order.
- Step 2: Convert all ranks to a percent scale
    - Ranks are converted to a percent scale. This is necessary for "apples-to-apples" comparisons when metric values are not continuous variables.
- Step 3: Multiply the percent rank by the chosen metric weight
    - In this hypothetical example, assume upstream functional network length weight = 75 and downstream functional network length weight = 25.
- Step 4: 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 5: Rank the summed ranks
    - The summed ranks are, in turn, ranked
- Step 6: Sort and display the results
    - The final ranks are sorted for presentation. In the regional analysis results, dams are grouped and displayed alphabetically within tiers which each contain 5% of the total dams.

5 Assessment Results

The results that come out of the Northeast Connectivity Assessment Tool (NCAT) cover the 13 state NEAFWA region and permit assessment of opportunities for strategic reconnection of aquatic habitats at multiple scales. Seventy-two ecologically-relevant metrics are calculated for almost 14,000 dams across the region, allowing for customized assessment of ecological return on investment for restoration projects. A subset of metrics was weighted by the Workgroup for use in two default assessment scenarios—one for anadromous fish benefits and the other for resident fish benefits. This section of the report describes the assessment results based on these default weights and scenarios.

There are many ways to report and use these default results, and one of the strengths of the project is the flexibility in filtering and sorting of data to allow for different types of questions to be answered. Here we provide summaries of: 1) the anadromous fish benefits scenario by state; 2) the resident fish benefits scenario by state; 3) major North Atlantic coast basin results; and 4) major interior basin results for resident fish. One of the striking conclusions of these summaries is how the relative standing of a state or portion of basin varies significantly based on what questions are asked of the model. This again emphasizes that there is not a single “priority” that comes out of the Northeast Aquatic Connectivity Project, but rather a whole set of relative values that can be used to inform decision-making at the appropriate scale.

Although the results can be viewed as a sequential list of dams, the precision with which GIS can calculate metrics is not necessarily indicative of ecological benefit differences. In order to accurately represent the assessment results, and provide for ease of interpretation, the almost 14,000 dams in the NCAT results were grouped into tiers, each consisting of 5% of the total dams, for reporting. This was done to emphasize the fact that the precision with which data is calculated in a GIS is not necessarily indicative of a difference in ecological benefit. That is, we do not argue that a dam with 21.2 km of upstream functional network is necessarily better than dam with 21.1 km of upstream functional network. Grouping dams into tiers also acts to diminish the perceived impact of errors which are present in the input data, as discussed in Section 3. However, it should also be noted that it is necessary to "draw a line in the sand" between dams to create these tiers and dams that are near the tier divisions may be very similar to each other.

The results and data presented in this report are based on the best available region-wide data and methods as of the writing of the report in August 2011. By design, this analysis only examines ecological criteria-- it does not incorporate the myriad social, political, economic and feasibility factors which are critical to evaluate before determining a course of action on any dam mitigation project. Additionally, given the regional nature of the analysis, in many cases data that represent the lowest common denominator across the region were used so that fair comparisons could be made across political jurisdictions.

Furthermore, these results represent a snapshot in time and will change as conditions on the ground change and the data which represent these conditions is improved in accuracy and resolution. Although a timeframe and funding source has yet to be determined, it is the intention of the authors to make *efforts to update the underlying data and analysis over time. As such, the most current data should be always obtained from the NEAFWA website (rcngrants.org) prior to using these results in a decision-making process.*

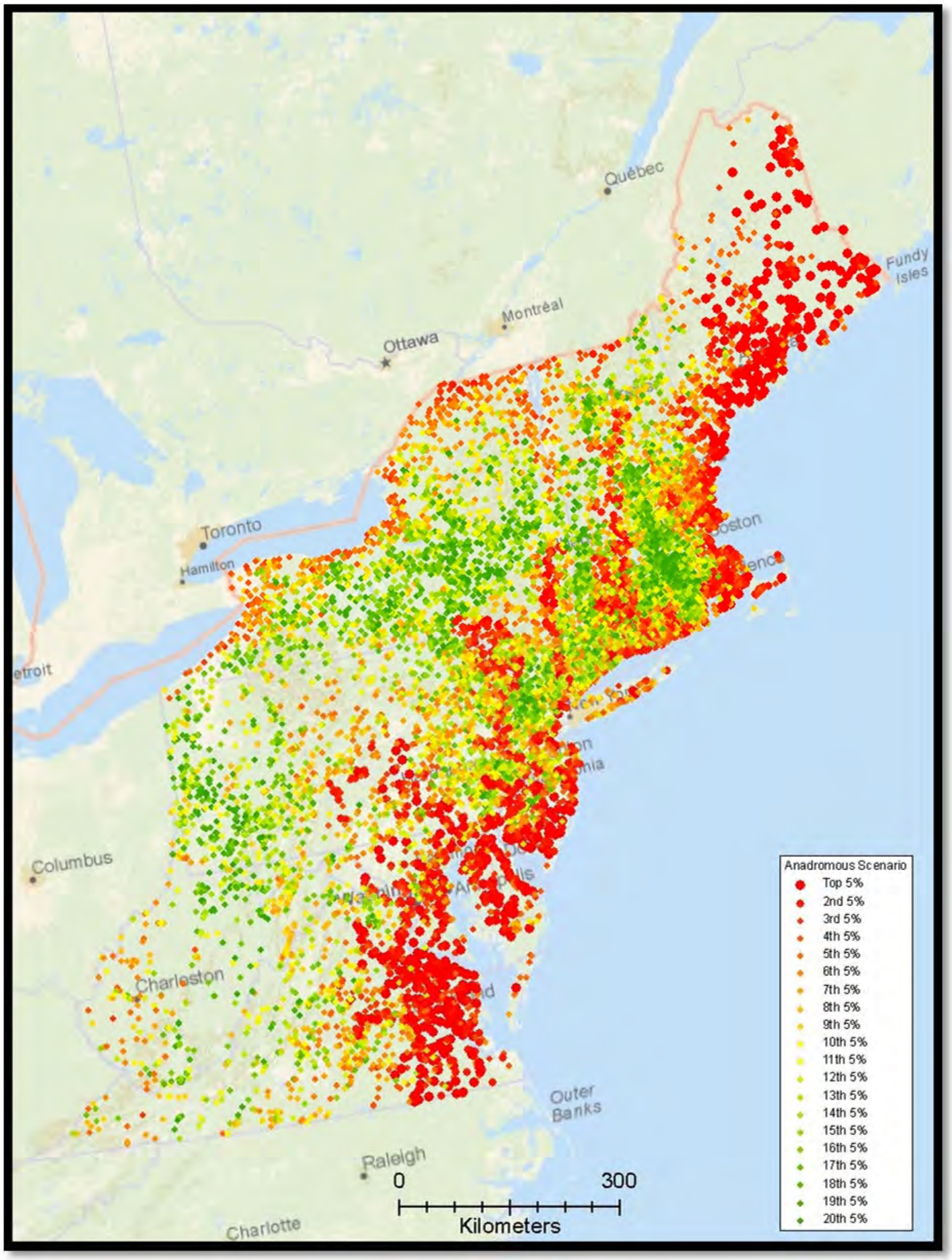
The preceding disclaimers reinforce a simple truth: these results should be used with caution and examined in the context of other relevant information. They are a screening-level tool and are not a replacement for site-specific knowledge.

5.1 Anadromous Fish Benefits Scenario Results by State

5.1.1 Results overview

The results for the anadromous fish benefits scenario demonstrate an intuitive pattern of relative high rankings for dams along the coastal zone and up major rivers. There are a few exceptions, including sites along the St. Lawrence River and in inland Maine locations. The analysis highlights dams that act as bottlenecks to the restoration of anadromous species. This fish passage analysis does not take into account feasibility of removal or mitigation, which require site-specific. Overall, the scenario results provide an initial road-map for anadromous fish restoration across the Northeast to be supplemented by local knowledge of ecological and social conditions.

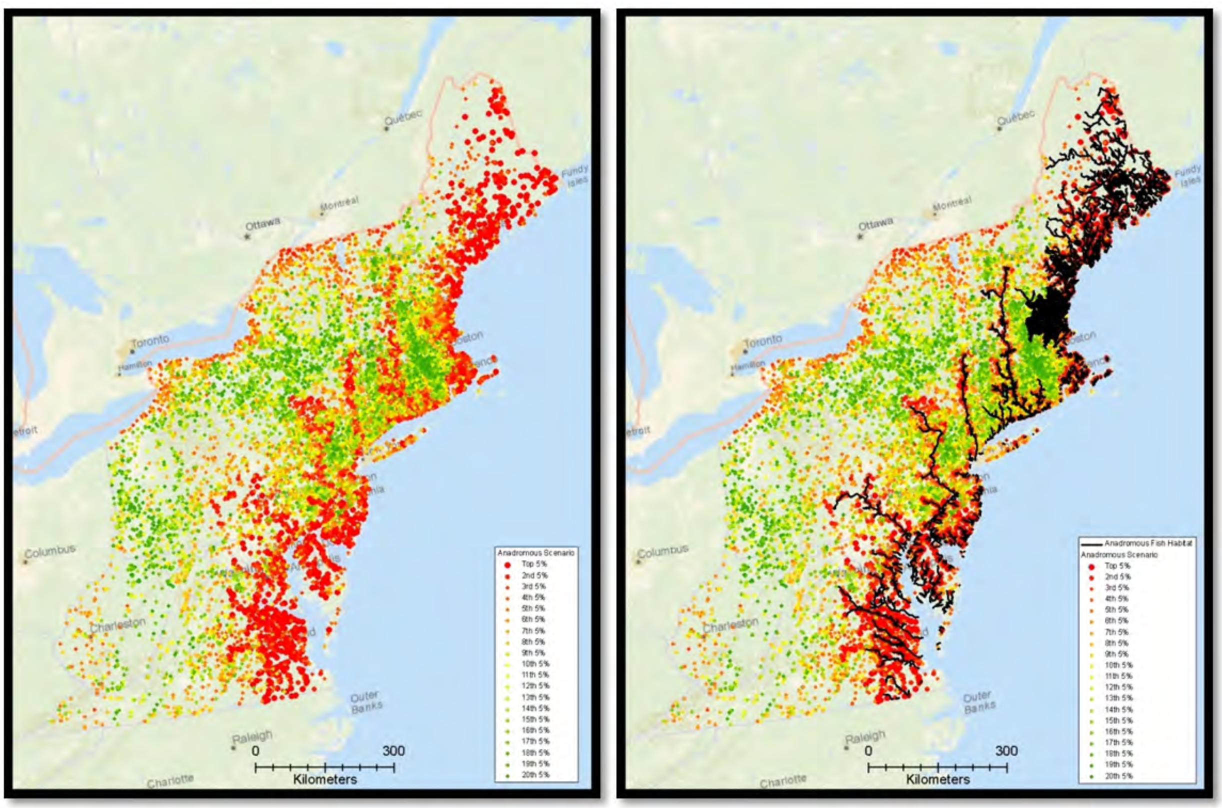
Figure 5-1: Anadromous fish benefits scenario results.



5.1.2 Key metrics

The anadromous fish benefits scenario is largely driven by three metrics which account for half of the total relative weight of the 16 metrics used in this scenario (Figure 2-2). These three metrics are the presence of anadromous fish habitat in a dam's downstream functional river network, the length of functional river network upstream of a dam, and the number of impassable dams below a given dam (where passable dams are crossed by anadromous fish habitat data). Other metrics which received a relative weight of five or higher include 1) distance from the dam to the river mouth, 2) density of dams on small streams (not snapped to the NHDPlus hydrography) in the upstream functional network local watershed 3) number of hydro dams on the downstream flowpath, 4) percent of natural landcover[1] in the Active River Area of the upstream functional river network, and 5) river size class. The high weight of the anadromous fish habitat data is an especially strong factor driving the anadromous scenario results. Its influence can be seen when the anadromous fish habitat data are overlaid with the anadromous results, as is illustrated in Figure 5-2. All of the dams in the top 5% had anadromous fish habitat in their downstream networks. Of the 1,385 dams in the top two tiers (top 10%), only six did not have anadromous fish habitat in their downstream networks. These dams rose into the top 10% based on the values of their other metrics. It is also possible, therefore, for dams in locations that never had anadromous fish present to rank high in the anadromous benefits scenario. To address this potentially confounding issue, a flag is provided in the results to indicate dams in HUC8 watersheds which had no historical records of the anadromous fish in this analysis. This flag is based on NatureServe data that was compiled by the TNC Leadership team and reviewed by biologists from each of the states, and can be used to exclude these dams from the results, if desired.

Figure 5-2: Anadromous fish benefits scenario results key metric maps.



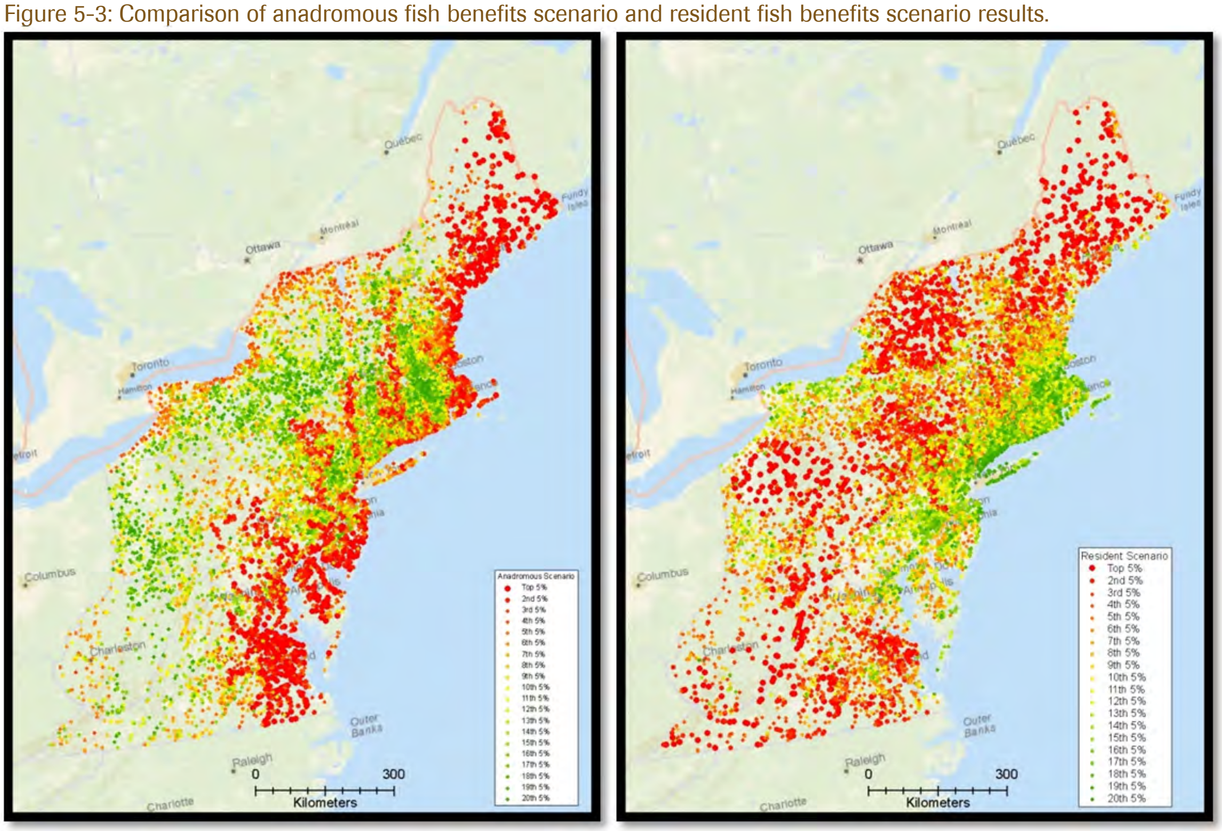
A similar pattern can be seen in the other highly weighted metrics. The mean length of functional upstream networks for dams in the top 10% was 41 km and the median length was 8.6 km. This contrasts with a mean of 19 km and a median of 2.7 km for all dams in the analysis. Likewise, of the 1,385 dams in the top 10% only 45 have an "impassable" dam downstream.

[1] See Table 4-1 for a detailed list of the NLCD classes which were grouped into the "natural" category

These results reflect the input of the Workgroup members, who logically judged the presence of anadromous fish habitat downstream of a dam is very important when evaluating that dam for the potential benefit to anadromous fish species. It also exemplifies the extent to which the analysis results are dependent on the input data. This is a significant fact in light of the various sources from which data were obtained. For example, the number of dams in the top 5% is dominated by Maine (216 out of 692). Although it could be argued that Maine has many of the best anadromous fish runs and habitat quality in the east, it is also true that the anadromous fish data used in the analysis were more comprehensive in Maine due to the work done by Houston et al (2007). Additionally, the spatial extent of the anadromous fish data in Maine is largely driven by Atlantic salmon which are able to penetrate further inland due to their strong swimming and leaping abilities. Thus, their range, both current and historical, overlaps with more dams than other species such as alewife, which are not able to penetrate as far inland.

A visual comparison of the anadromous fish benefits scenario and the resident fish benefits scenario (Figure 5-3) reinforces that the results are driven by the weights which were chosen by the project Workgroup.

Figure 5-3: Comparison of anadromous fish benefits scenario and resident fish benefits scenario results.



5.1.3 Anadromous Results by State

Maine also has most dams in the top 10% (303 out of 1,385), followed closely by Virginia at 255, and Massachusetts at 161. Table 5-1 and Figure 5-4 illustrate the number of dams per state in each result tier.

Table 5-1: Number of dams per state in each tier of results in the anadromous fish benefits scenario.

Anadromous Result Tier	CT	DE	MA	MD	ME	NH	NJ	NY	PA	RI	VA	VT	WV
Top 5%	21	26	55	67	216	9	71	23	28	8	168	0	0
2nd 5%	67	13	106	76	87	28	75	64	66	10	87	13	1
3rd 5%	116	5	121	68	58	31	58	100	53	9	55	18	1
4th 5%	114	9	84	42	68	49	38	135	60	11	57	21	4
5th 5%	73	15	42	23	64	52	48	166	67	13	80	36	13
6th 5%	68	6	42	28	32	61	49	176	106	11	62	25	26
7th 5%	73	3	54	21	24	71	37	172	103	17	66	29	24
8th 5%	72	2	43	13	18	61	47	168	130	17	64	28	31
9th 5%	91	6	47	18	13	63	49	188	118	14	44	26	16
10th 5%	89	3	55	23	12	73	47	167	114	18	38	25	28
11th 5%	99	3	49	24	8	65	40	176	119	22	44	20	24
12th 5%	93	1	57	16	4	68	32	190	118	28	37	26	24
13th 5%	106	3	75	12	6	55	43	187	107	29	37	17	15
14th 5%	112	0	66	16	2	46	54	197	105	23	31	20	23
15th 5%	111	0	73	10	2	62	49	192	106	18	30	18	22
16th 5%	96	0	95	14	4	48	44	192	86	42	30	18	25
17th 5%	88	0	92	7	1	63	48	208	100	23	21	25	15
18th 5%	107	0	102	8	2	56	57	173	96	39	15	25	13
19th 5%	78	0	116	1	2	53	44	204	97	22	14	36	25
20th 5%	30	0	147	3	2	57	53	205	82	33	5	26	28
Total Dams (#)	1704	95	1521	490	625	1071	983	3283	1861	407	985	452	358

Figure 5-4: Number of dams per state in each tier of results in the anadromous fish benefits scenario.

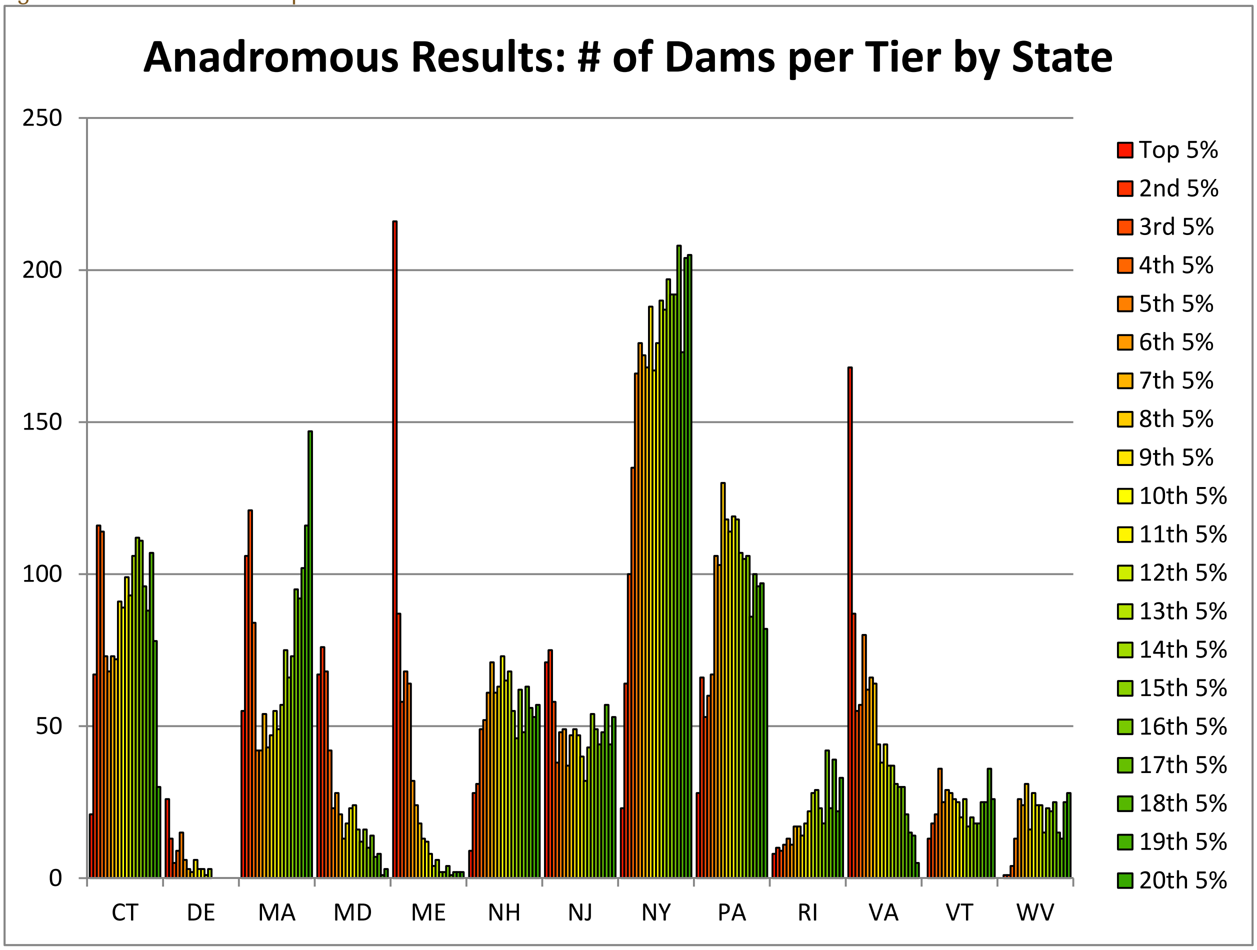


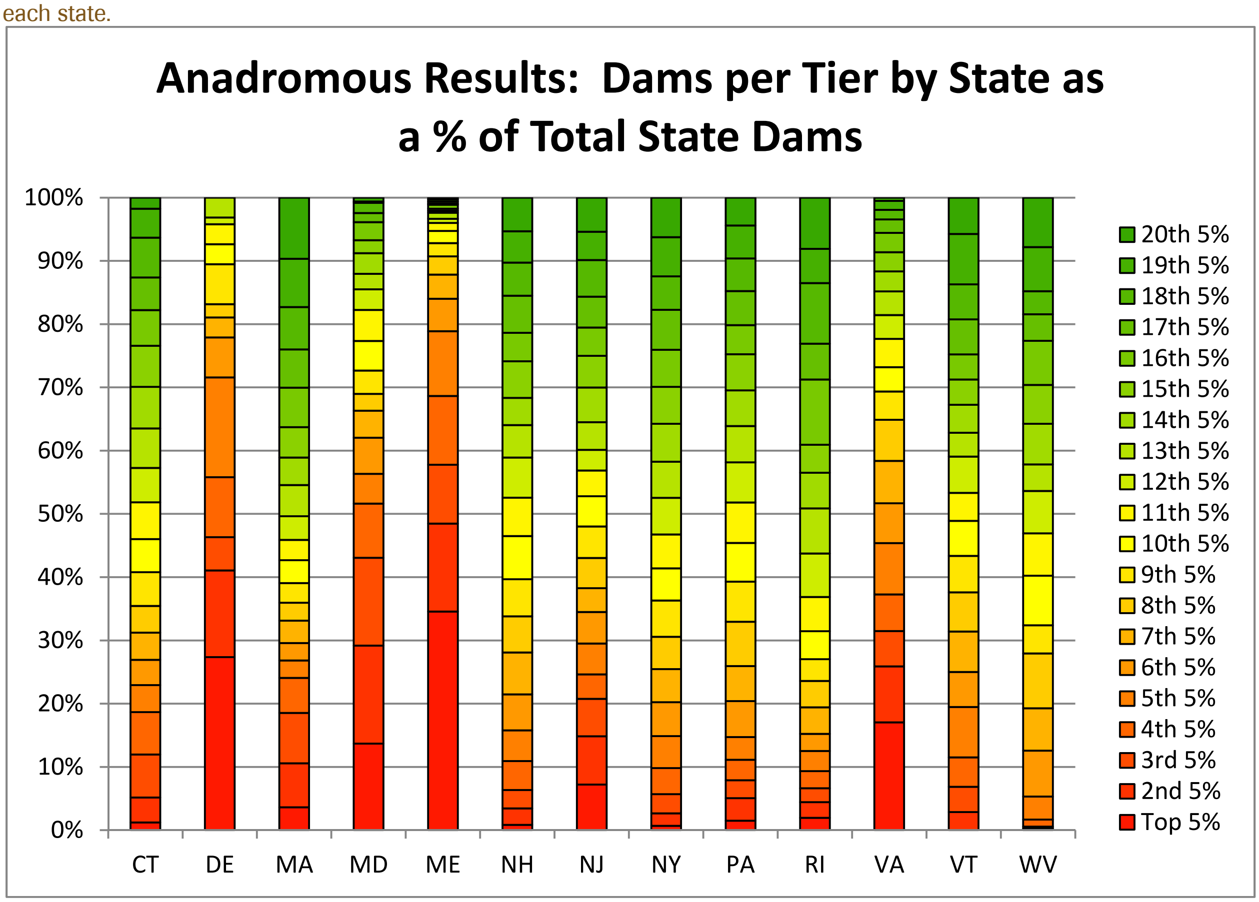
Table 5-2 and Figure 5-5 below depict the number of dams in each tier for each state expressed as a percent (normalized by the total number of dams in each state). Measured this way, Maine, Delaware and Virginia have the most dams in the top tier (top 5% of dams in the region).

Table 5-2: Number of dams per state in each tier of the anadromous fish benefits scenario as a percent of total dams in each state.

Anadromous Result Tier	CT	DE	MA	MD	ME	NH	NJ	NY	PA	RI	VA	VT	WV
Top 5%	1.2	27.4	3.6	13.7	34.6	0.8	7.2	0.7	1.5	2.0	17.1	0.0	0.0
2nd 5%	3.9	13.7	7.0	15.5	13.9	2.6	7.6	1.9	3.5	2.5	8.8	2.9	0.3
3rd 5%	6.8	5.3	8.0	13.9	9.3	2.9	5.9	3.0	2.8	2.2	5.6	4.0	0.3
4th 5%	6.7	9.5	5.5	8.6	10.9	4.6	3.9	4.1	3.2	2.7	5.8	4.6	1.1
5th 5%	4.3	15.8	2.8	4.7	10.2	4.9	4.9	5.1	3.6	3.2	8.1	8.0	3.6
6th 5%	4.0	6.3	2.8	5.7	5.1	5.7	5.0	5.4	5.7	2.7	6.3	5.5	7.3
7th 5%	4.3	3.2	3.6	4.3	3.8	6.6	3.8	5.2	5.5	4.2	6.7	6.4	6.7

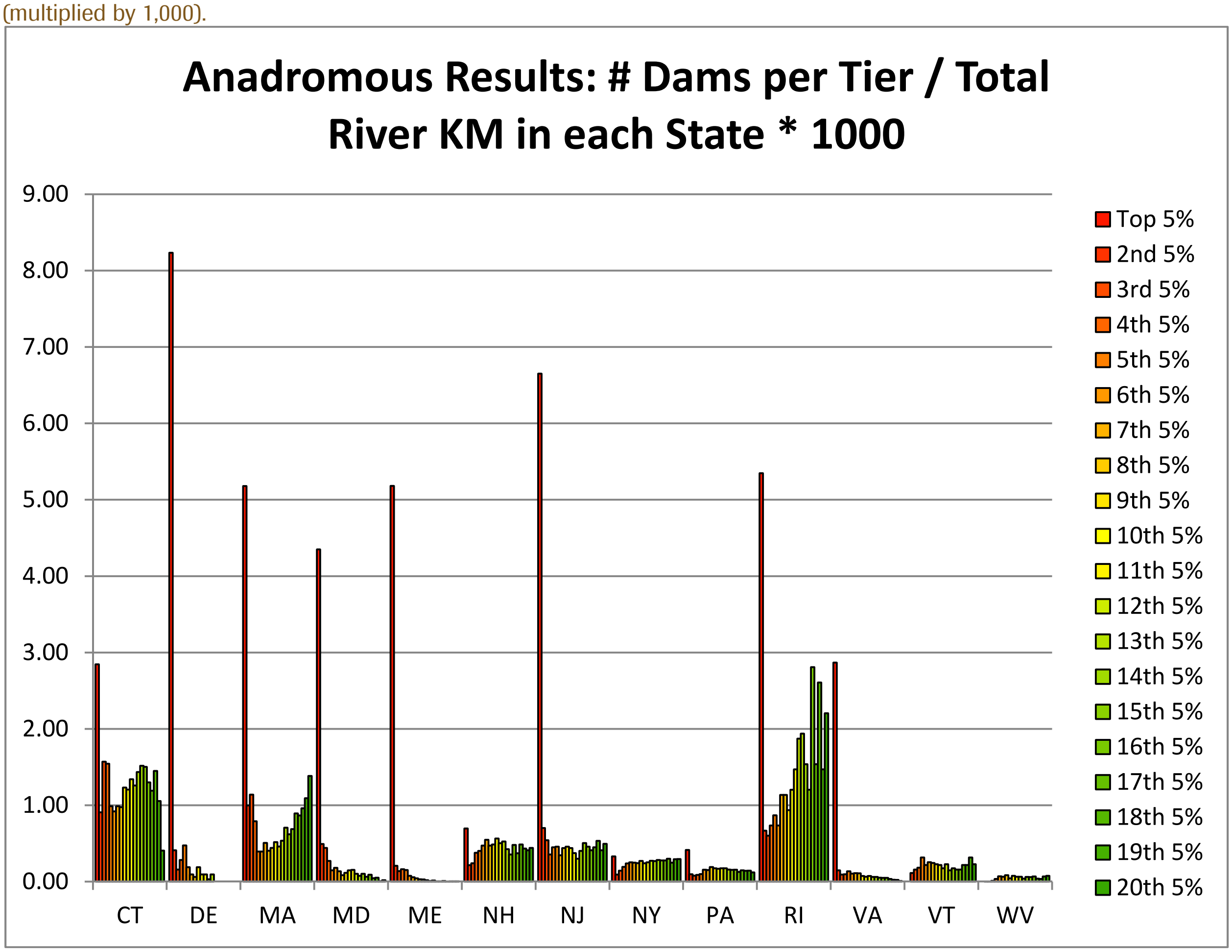
8th 5%	4.2	2.1	2.8	2.7	2.9	5.7	4.8	5.1	7.0	4.2	6.5	6.2	8.7
9th 5%	5.3	6.3	3.1	3.7	2.1	5.9	5.0	5.7	6.3	3.4	4.5	5.8	4.5
10th 5%	5.2	3.2	3.6	4.7	1.9	6.8	4.8	5.1	6.1	4.4	3.9	5.5	7.8
11th 5%	5.8	3.2	3.2	4.9	1.3	6.1	4.1	5.4	6.4	5.4	4.5	4.4	6.7
12th 5%	5.5	1.1	3.7	3.3	0.6	6.3	3.3	5.8	6.3	6.9	3.8	5.8	6.7
13th 5%	6.2	3.2	4.9	2.4	1.0	5.1	4.4	5.7	5.7	7.1	3.8	3.8	4.2
14th 5%	6.6	0.0	4.3	3.3	0.3	4.3	5.5	6.0	5.6	5.7	3.1	4.4	6.4
15th 5%	6.5	0.0	4.8	2.0	0.3	5.8	5.0	5.8	5.7	4.4	3.0	4.0	6.1
16th 5%	5.6	0.0	6.2	2.9	0.6	4.5	4.5	5.8	4.6	10.3	3.0	4.0	7.0
17th 5%	5.2	0.0	6.0	1.4	0.2	5.9	4.9	6.3	5.4	5.7	2.1	5.5	4.2
18th 5%	6.3	0.0	6.7	1.6	0.3	5.2	5.8	5.3	5.2	9.6	1.5	5.5	3.6
19th 5%	4.6	0.0	7.6	0.2	0.3	4.9	4.5	6.2	5.2	5.4	1.4	8.0	7.0
20th 5%	1.8	0.0	9.7	0.6	0.3	5.3	5.4	6.2	4.4	8.1	0.5	5.8	7.8
Total Dams (%)	100	100	100	100	100	100	100	100	100	100	100	100	100

Figure 5-5: Number of dams per state in each tier of the anadromous fish benefits scenario as a percent of total dams in each state.



When normalized by the length of total river kilometers in each state (count of dams in each tier / kilometers of river in the state based on the NHDPlus-derived hydrography that was used in the analysis * 1000), however, a different picture emerges. By this measurement, Delaware and New Jersey have the most dams in the top tier relative to the amount of river in each respective state, with Rhode Island, Maine, Massachusetts, and Maryland following closely behind (Figure 5-6). The high ratio of coastline to area and the corresponding opportunities for anadromous fish habitat that each of these states contains could explain these results.

Figure 5-6: Number of dams in each tier of the anadromous fish benefits scenario by the total length of river in each state (multiplied by 1,000).

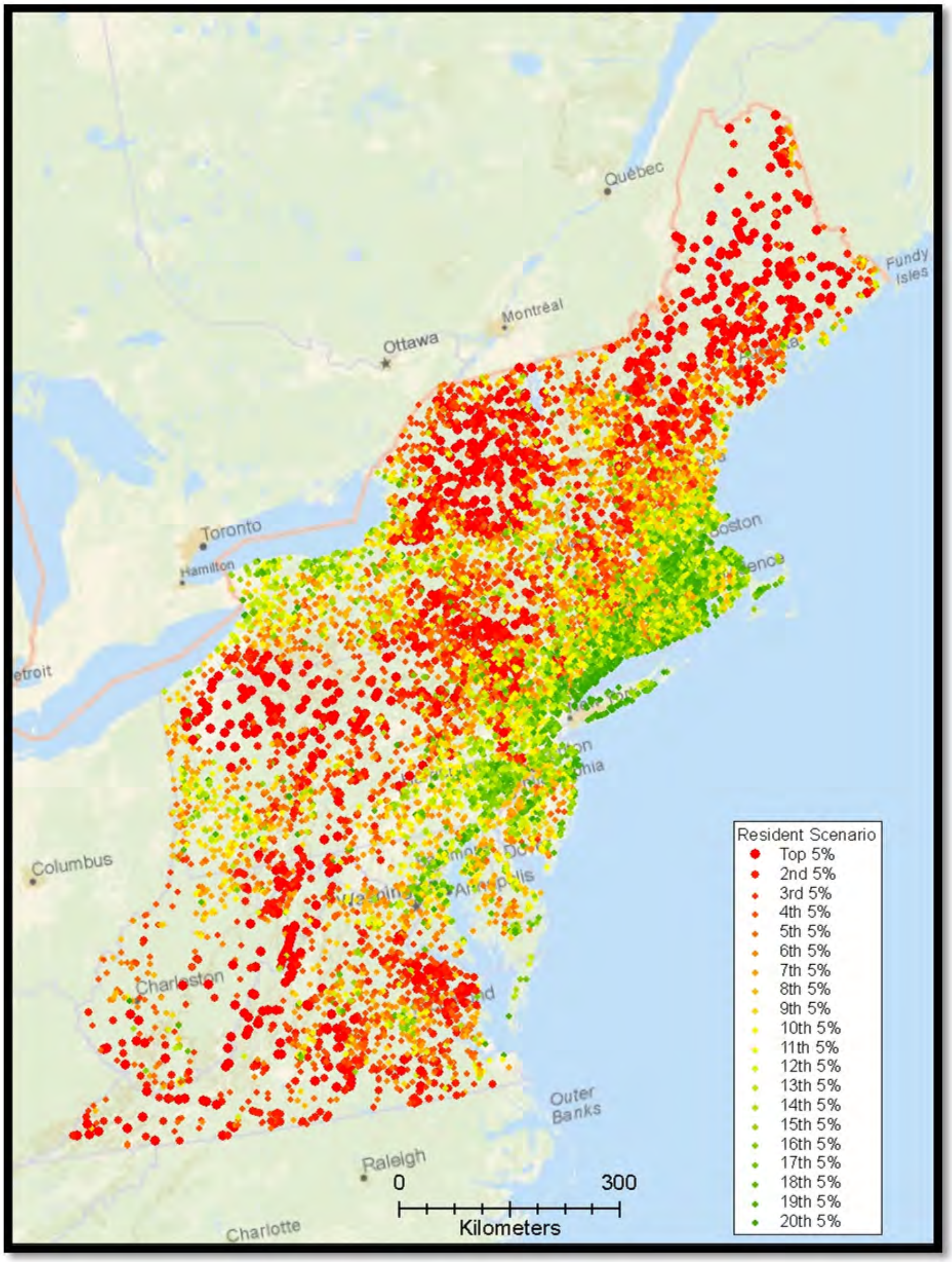


5.2 Resident Fish Benefits Scenario Results by State

5.2.1 Results overview

The results for the resident fish benefits scenario in the Northeast present a very different picture than that for anadromous fish. The resident fish scenario takes into account land cover characteristics as well as both the presence of healthy brook trout populations and watersheds of high species richness and rarity. The pattern of relatively high rankings for resident fish restoration opportunities occurs along the Appalachian chain the Adirondacks and the Maine North Woods, as expected due to their status as brook trout strongholds with coldwater habitat. The results also point toward strong ecological potential in Northwest Pennsylvania and much of Eastern and Southern Virginia, which reflects network length as well as species richness and rarity. Overall, the resident fish scenario provides insights distinct from those for anadromous fish which can be useful for managers interested in conservation of native fish assemblages in the Northeast.

Figure 5-7: Resident fish benefits scenario results.



5.2.2 Key metrics

As shown in Figure 2, the biggest single metric driving the resident fish weight scenario result is the total length of reconnected functional network (upstream + downstream). However, as can be seen in the six maps in Figure 5-8, there is not a single metric which can easily be seen to drive the results as much as anadromous fish habitat does for the anadromous benefits scenario. The following metrics are assigned a weight of five or greater in the resident fish benefits scenario: 1) density of road and railroad/stream crossings in the upstream and 2) downstream functional network local watersheds, 3) total functional network length, 4) absolute network length gain, 5) % impervious surface in the contributing watershed,

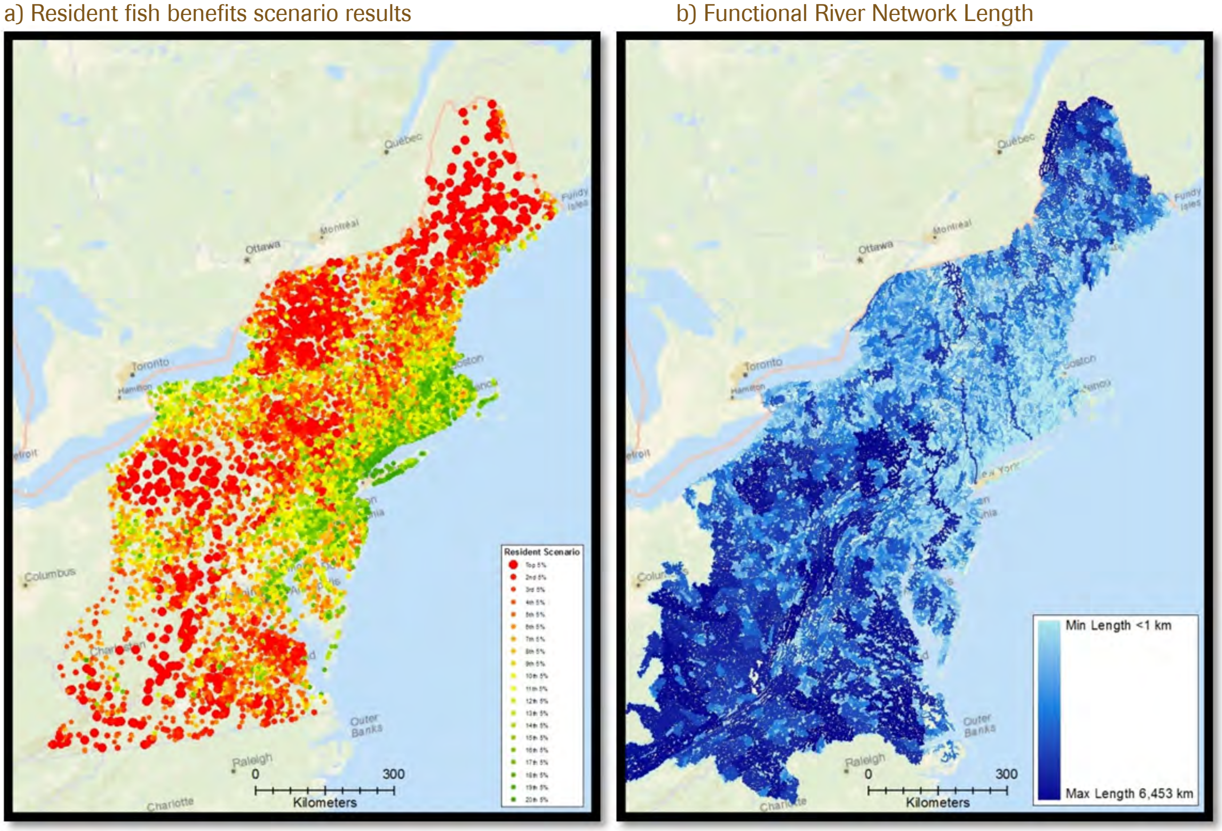
6) % natural landcover in the contributing watershed 7) current "healthy" eastern brook trout in subwatershed, 8) miles of cold water habitat, and 9) total reconnected number of stream sizes. Western Pennsylvania, which has a cluster of top tier dams, is in an area of large connected networks and high fish richness and rarity. The Adirondack region of New York on the other hand, does not have particularly large networks or fish rarity or richness but does have some of the highest percentages of natural landcover in their contributing watersheds, low impervious surface, significant coldwater habitat, and dams in watersheds with "healthy" brook trout populations.

Working back through the metrics by weight, it is possible to deduce what factors are driving the rank of any given dam. Furthermore, as is elaborated on further in Section 5.3, when comparisons are made across different geographies, the resident fish scenario results can be seen to be driven by the suite of landcover characteristics and network length.

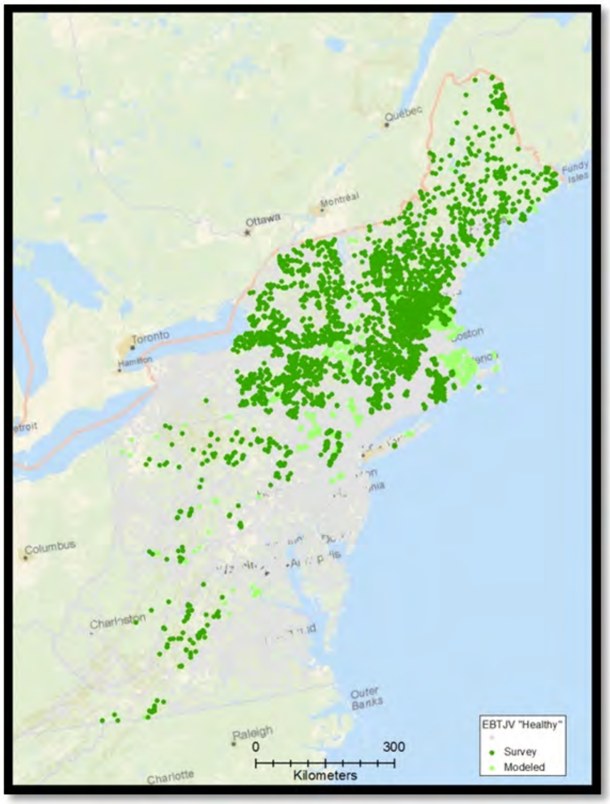
Figure 5-8: Resident fish benefits scenario key metric maps

a) Resident fish benefits scenario results

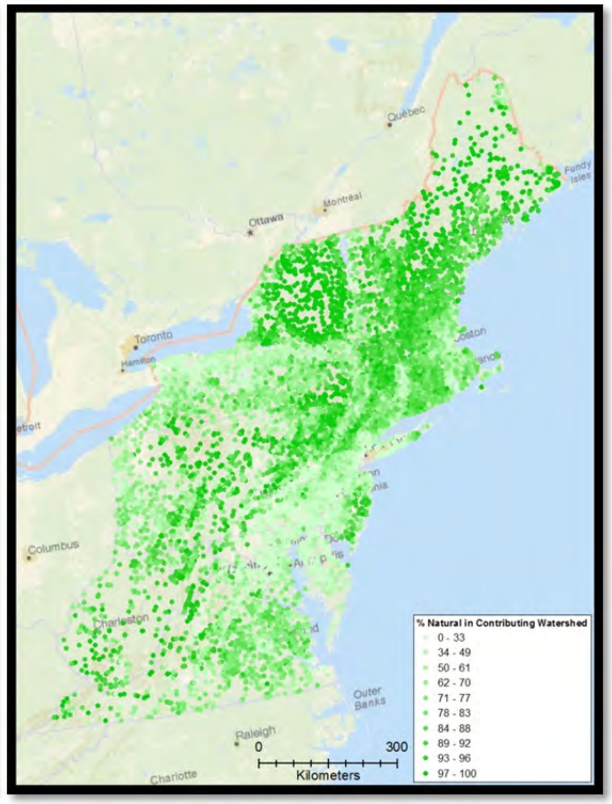
b) Functional River Network Length



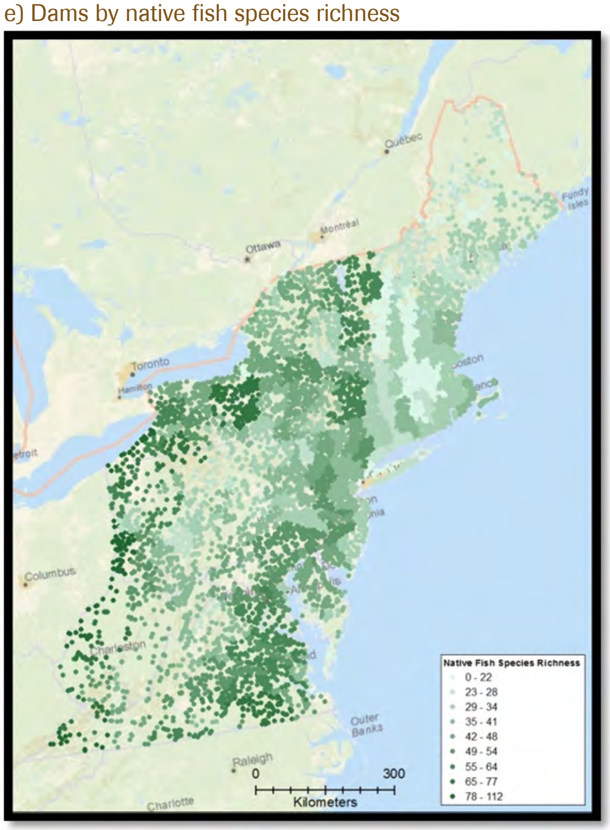
C) Dams in EBTJV - "Healthy" watersheds



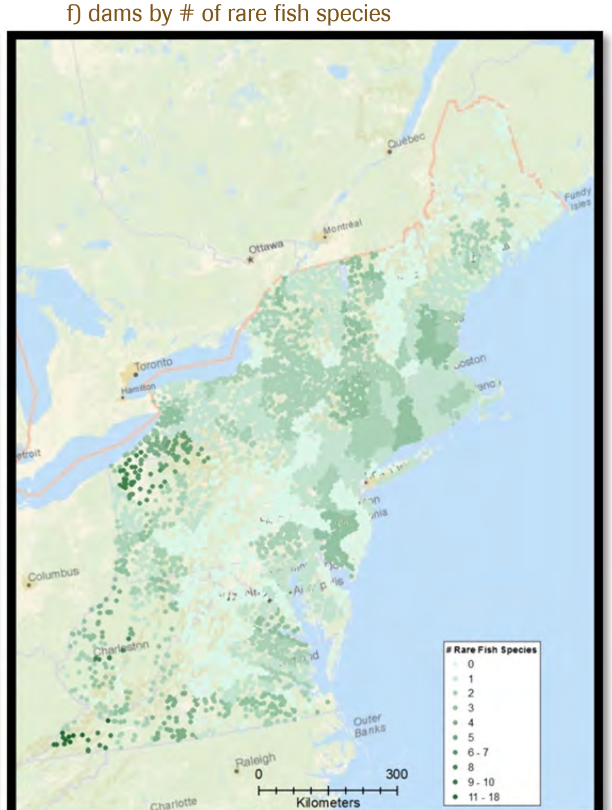
d) dams by upstream % natural landcover



e) Dams by native fish species richness



f) dams by # of rare fish species



It is also important to note that for some metrics there can be many ties between dams. For example, there are six metrics from the "Connectivity Status Category" that are used in the resident benefits scenario. These are the upstream and downstream densities of dams on the hydrography, dams on small streams that were not used in the primary analysis, and road/railroad crossings. For each of these metrics, it is possible to have the ideal, from an ecological perspective, value of zero. There are 44 dams across the region which do, in fact, have values of zero for each of these metrics and which, therefore, are tied in the "Connectivity Status" category.

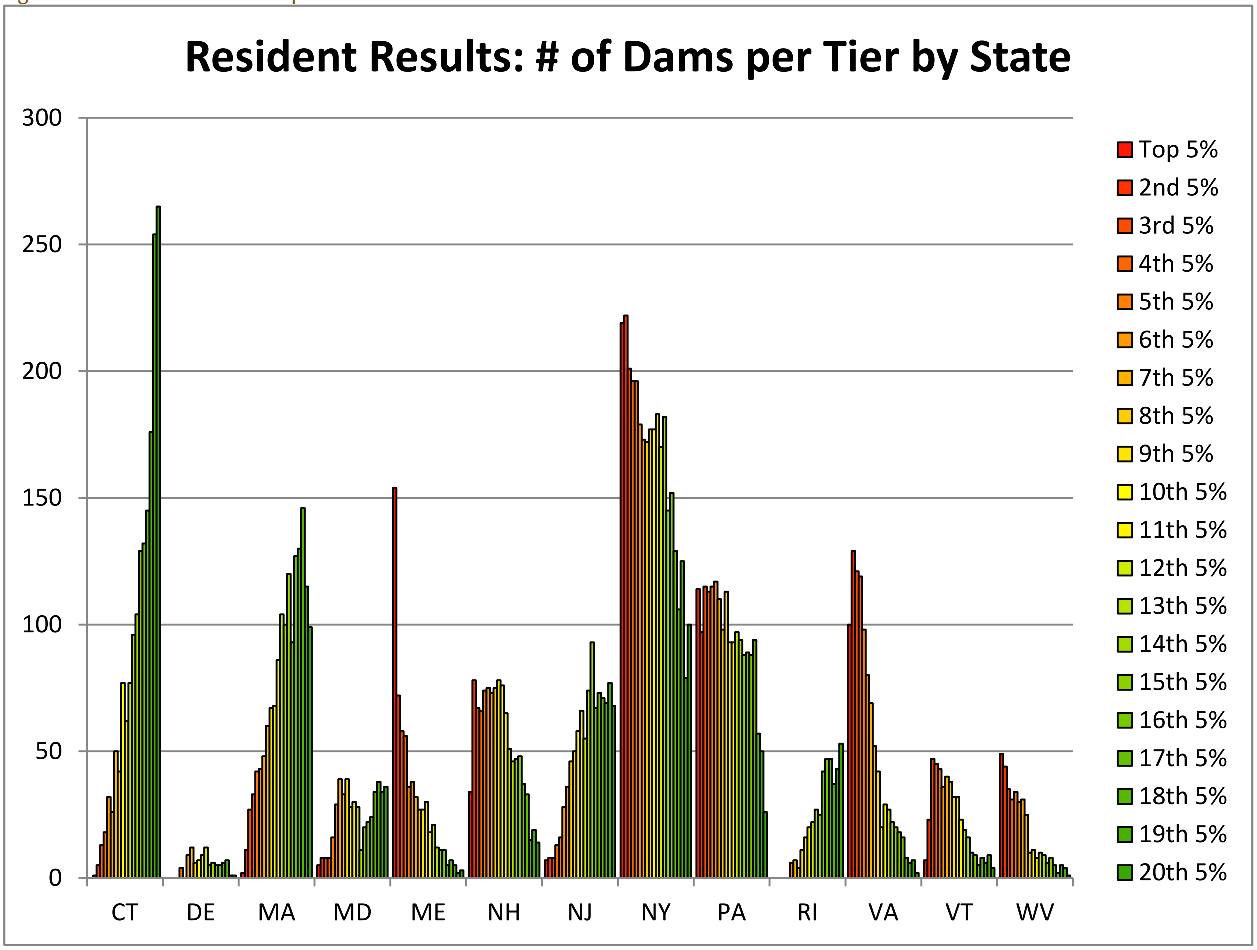
5.2.3 Resident results by state

By absolute number, New York, Maine, Pennsylvania and Virginia have the most dams in the top tier of the resident fish benefits scenario.

Table 5-3: Number of dams per state in each tier of results in the resident fish benefits scenario.

Resident Result Tier	CT	DE	MA	MD	ME	NH	NJ	NY	PA	RI	VA	VT	WV
Top 5%	0	0	2	5	154	34	7	219	114	0	100	7	49
2nd 5%	1	0	11	8	72	78	8	222	97	0	129	23	44
3rd 5%	5	0	27	8	58	67	8	201	115	0	121	47	35
4th 5%	13	0	33	8	56	66	13	196	113	0	119	45	31
5th 5%	18	4	42	16	36	74	16	196	115	0	98	43	34
6th 5%	32	0	43	29	38	75	28	179	117	6	80	36	30
7th 5%	26	9	48	39	32	73	36	173	110	7	69	40	31
8th 5%	50	12	60	33	27	75	46	172	98	4	52	38	25
9th 5%	42	6	67	39	27	78	50	177	113	11	42	32	10
10th 5%	77	7	68	28	30	76	58	177	93	16	20	32	11
11th 5%	62	9	86	30	18	65	66	183	93	20	29	23	8
12th 5%	77	12	104	28	21	51	55	170	97	22	27	19	10
13th 5%	96	5	100	11	12	46	74	182	94	27	22	16	9
14th 5%	104	6	120	20	11	47	93	145	88	25	20	10	6
15th 5%	129	5	93	22	11	48	67	152	89	42	18	9	8
16th 5%	132	5	127	24	5	37	73	129	88	47	16	5	5
17th 5%	145	6	130	34	7	33	71	106	94	47	8	8	2
18th 5%	176	7	146	38	5	15	69	125	57	37	6	6	5
19th 5%	254	1	115	34	2	19	77	79	50	43	7	9	4
20th 5%	265	1	99	36	3	14	68	100	26	53	2	4	1
Total Dams (#)	1704	95	1521	490	625	1071	983	3283	1861	407	985	452	358

Figure 5-9: Number of dams per state in each tier of results in the anadromous fish benefits scenario



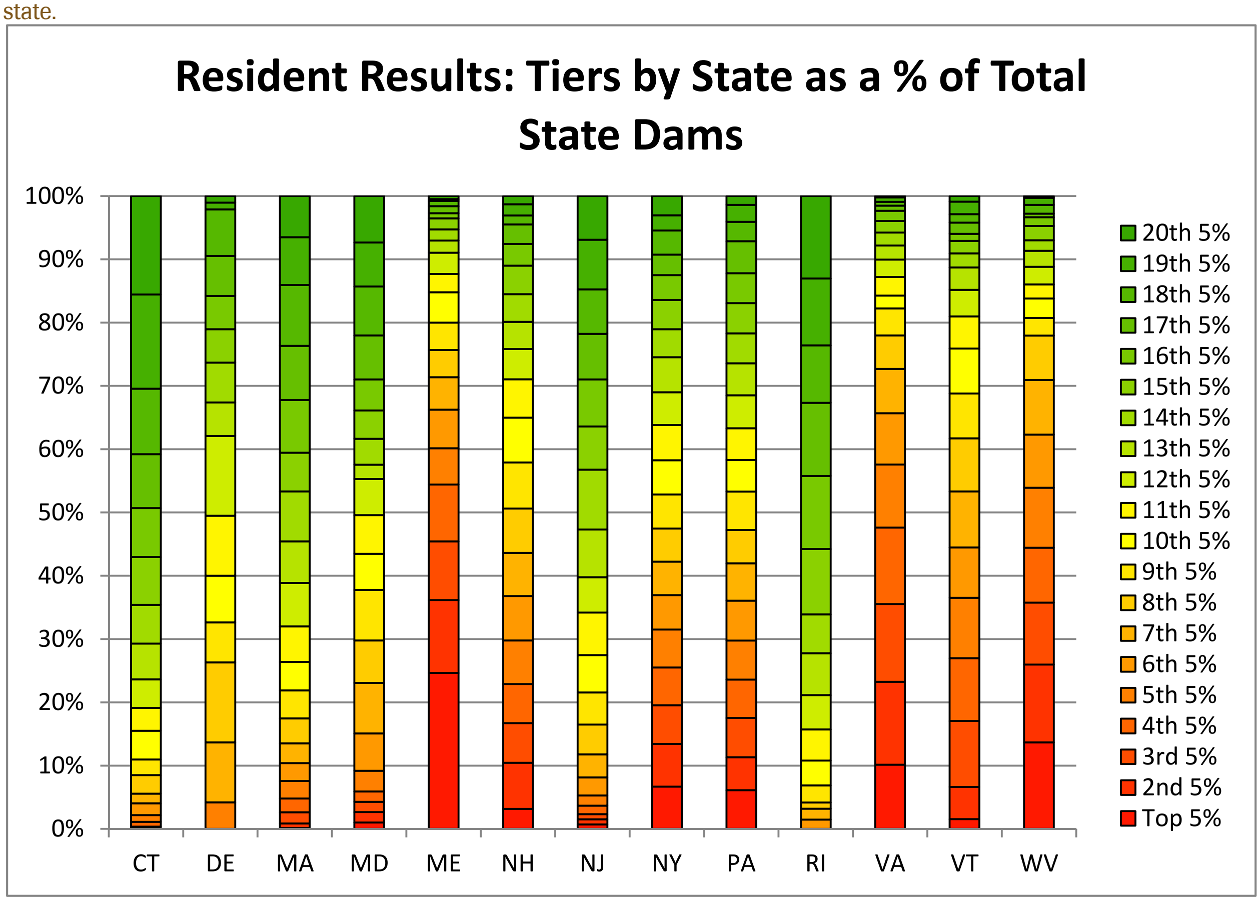
Expressed as a percent of dams within each state, Maine and Virginia are joined by West Virginia as having the most dams in both the top tier and the top 10% (the top two tiers). Interestingly, New York and Pennsylvania both exhibit a surprisingly even distribution of dams within each tier, perhaps the result of the wide diversity of high-quality rivers & natural lands and urban & agricultural areas.

Table 5-4: Number of dams per state in each tier of the anadromous fish benefits scenario as a percent of total dams in each state.

Resident Result Tier	CT	DE	MA	MD	ME	NH	NJ	NY	PA	RI	VA	VT	WV
Top 5%	0.0	0.0	0.1	1.0	24.6	3.2	0.7	6.7	6.1	0.0	10.2	1.5	13.7
2nd 5%	0.1	0.0	0.7	1.6	11.5	7.3	0.8	6.8	5.2	0.0	13.1	5.1	12.3
3rd 5%	0.3	0.0	1.8	1.6	9.3	6.3	0.8	6.1	6.2	0.0	12.3	10.4	9.8
4th 5%	0.8	0.0	2.2	1.6	9.0	6.2	1.3	6.0	6.1	0.0	12.1	10.0	8.7
5th 5%	1.1	4.2	2.8	3.3	5.8	6.9	1.6	6.0	6.2	0.0	9.9	9.5	9.5
6th 5%	1.9	0.0	2.8	5.9	6.1	7.0	2.8	5.5	6.3	1.5	8.1	8.0	8.4
7th 5%	1.5	9.5	3.2	8.0	5.1	6.8	3.7	5.3	5.9	1.7	7.0	8.8	8.7
8th 5%	2.9	12.6	3.9	6.7	4.3	7.0	4.7	5.2	5.3	1.0	5.3	8.4	7.0
9th 5%	2.5	6.3	4.4	8.0	4.3	7.3	5.1	5.4	6.1	2.7	4.3	7.1	2.8

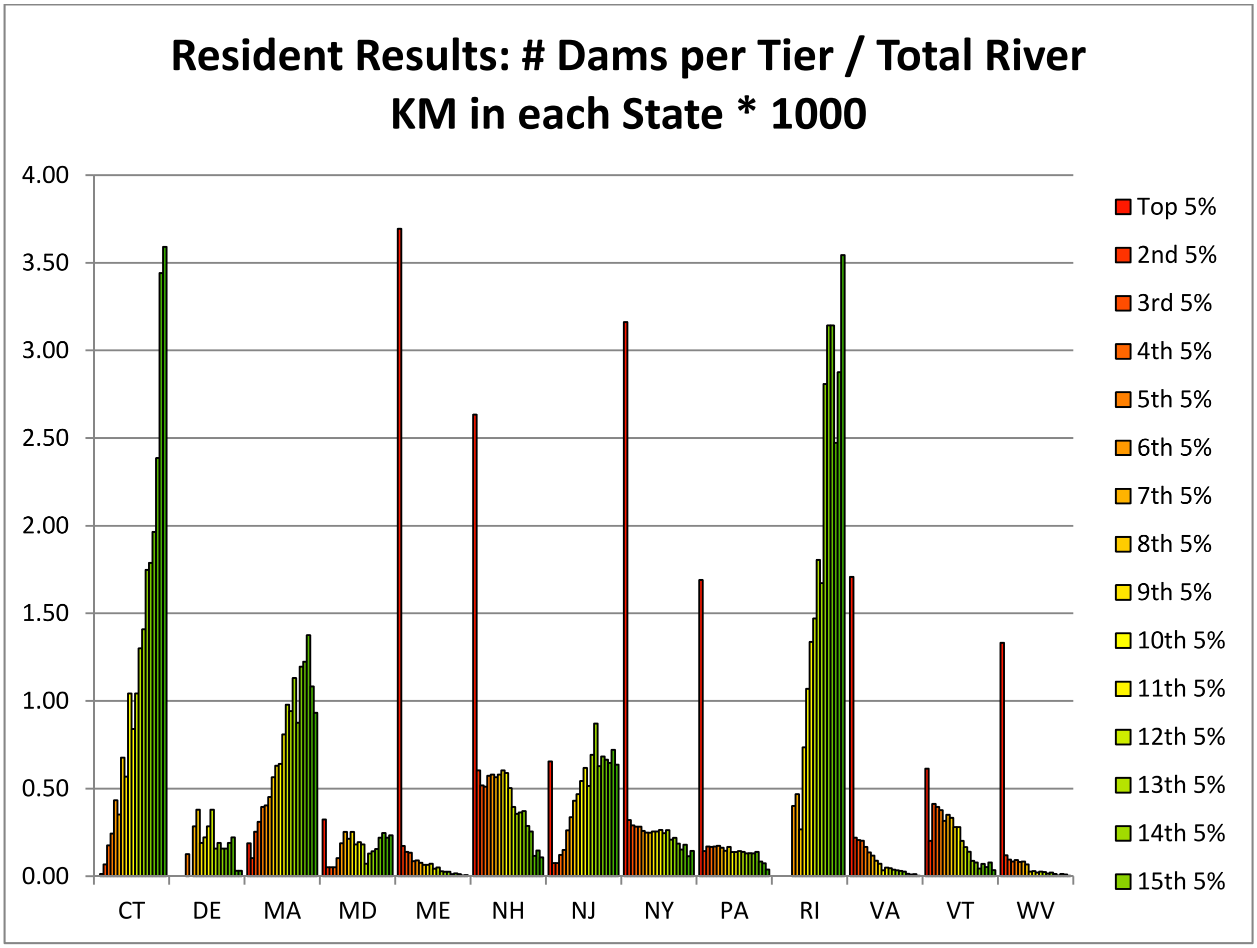
10th 5%	4.5	7.4	4.5	5.7	4.8	7.1	5.9	5.4	5.0	3.9	2.0	7.1	3.1
11th 5%	3.6	9.5	5.7	6.1	2.9	6.1	6.7	5.6	5.0	4.9	2.9	5.1	2.2
12th 5%	4.5	12.6	6.8	5.7	3.4	4.8	5.6	5.2	5.2	5.4	2.7	4.2	2.8
13th 5%	5.6	5.3	6.6	2.2	1.9	4.3	7.5	5.5	5.1	6.6	2.2	3.5	2.5
14th 5%	6.1	6.3	7.9	4.1	1.8	4.4	9.5	4.4	4.7	6.1	2.0	2.2	1.7
15th 5%	7.6	5.3	6.1	4.5	1.8	4.5	6.8	4.6	4.8	10.3	1.8	2.0	2.2
16th 5%	7.7	5.3	8.3	4.9	0.8	3.5	7.4	3.9	4.7	11.5	1.6	1.1	1.4
17th 5%	8.5	6.3	8.5	6.9	1.1	3.1	7.2	3.2	5.1	11.5	0.8	1.8	0.6
18th 5%	10.3	7.4	9.6	7.8	0.8	1.4	7.0	3.8	3.1	9.1	0.6	1.3	1.4
19th 5%	14.9	1.1	7.6	6.9	0.3	1.8	7.8	2.4	2.7	10.6	0.7	2.0	1.1
20th 5%	15.6	1.1	6.5	7.3	0.5	1.3	6.9	3.0	1.4	13.0	0.2	0.9	0.3
Total Dams (%)	100	100	100	100	100	100	100	100	100	100	100	100	100

Figure 5-10: Number of dams per state in each tier of the resident fish benefits scenario as a percent of total dams in each state.



When the resident scenario results are normalized by the total length of rivers within each state, Maine, New York, Pennsylvania, Virginia, and West Virginia are again prominent in the top tier. New Hampshire, as well, appears near the top of these results.

Figure 5-11: Number of dams in each tier of the resident fish benefits scenario by the total length of river in each state (multiplied by 1,000).



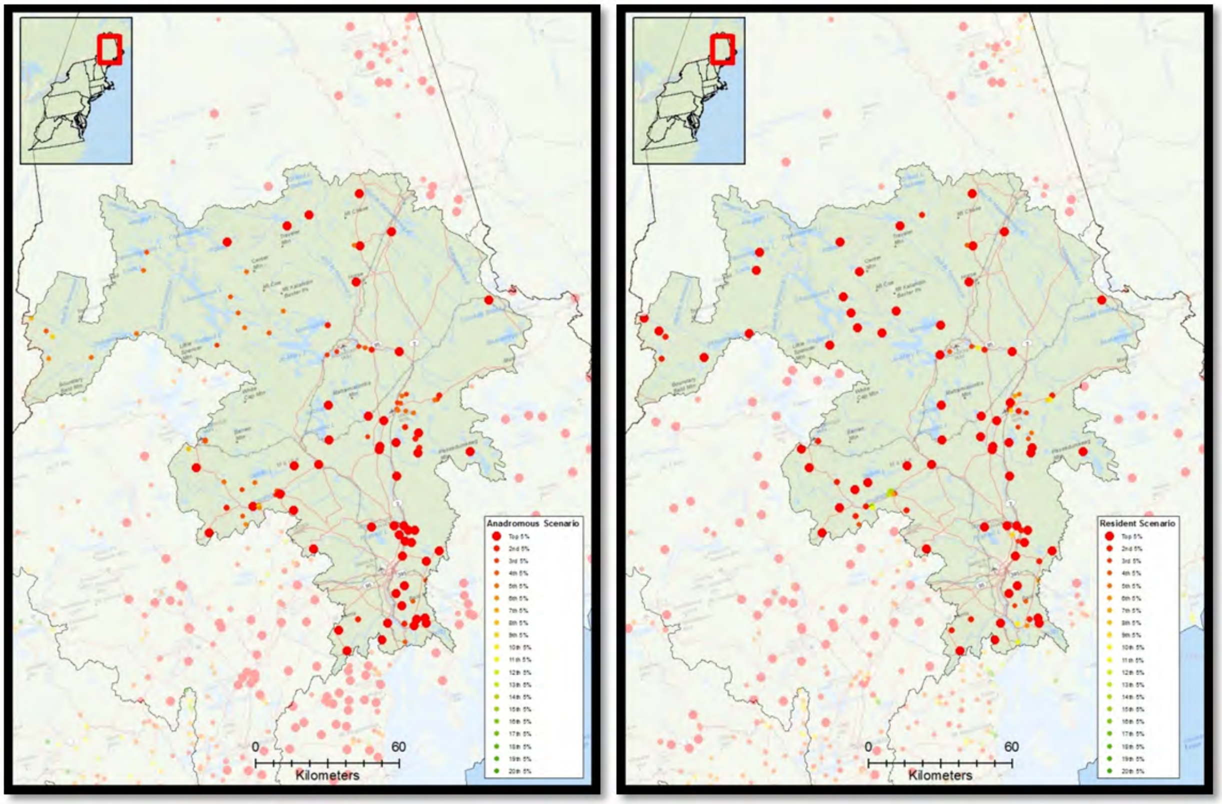
5.3 Major Atlantic Coast Basin Summaries

In addition to being interpreted and informing decisions at the state level, results can be examined at the watershed scale to advance aquatic connectivity restoration across political jurisdictions. The following section briefly describes the results summarized by the major basins of the Atlantic coast. A handful of metrics, meant to be a rough representation of the full suite of metrics that are used in the two scenarios (Figure 2), are reviewed in more detail to discern patterns between and within the basins.

5.3.1 Penobscot River (HUC 0102)

The Penobscot River watershed appears ripe for fish passage projects, based on the results from this analysis. Of the 107 dams in the basin that were included in the analysis 50 -- almost 50% -- were in the regional top tier of the anadromous results. A full 60 were within the top 10% of the anadromous results. A total of 58 of the 107 dams were in the top tier of the resident results (37 of the dams scored in the top tier in both scenarios).

Figure 5-12: Anadromous and resident benefit scenario results: Penobscot River basin

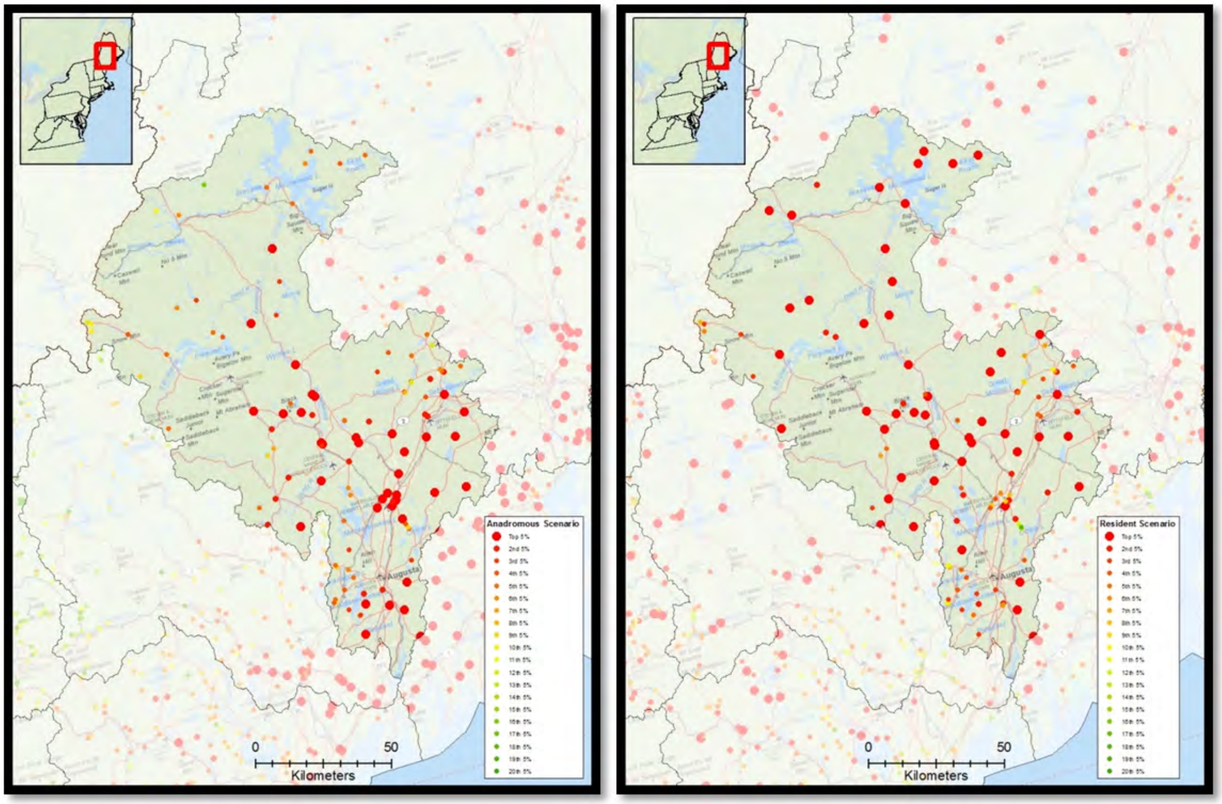


The high standing of dams in the Penobscot watershed is evidence of several factors: the quantity of natural landcover, the relatively low density of 107 dams on over 11,000 km of rivers (1 dam / 103 km) which translates to large connected networks, the presence of several runs of anadromous fish species and "healthy" brook trout populations. Of the 107 dams in the Penobscot River watershed, 92 had ≥90% natural landcover in their contributing watersheds (median 97%). This compares to a regional median value of 77% natural landcover in contributing watersheds. Correspondingly, 84 of the 107 dams had <1% impervious surface (median 0.33%). Similarly, the length of upstream functional networks was relatively long in the Penobscot watershed, ranging up to 822km with a median of 14 km and a mean of 69 km. This compares to regional median and mean values of 2.7 km and 19 km, respectively. The total functional river network lengths ranged up to 1,304 km with a median of 181 km compared to regional median of 31 km. Finally, 68 of the 107 dams have current habitat documented in their downstream functional networks for at least one of the seven anadromous fish species examined in the analysis. An additional 27 dams have historical presence documented. Likewise, 98 of the 107 dams fall in subwatersheds with healthy brook trout populations. All of these numbers point to the high quality of the lands and waterways of the watershed.

5.3.2 Kennebec River (HUC 0103)

The Kennebec River watershed in Maine exhibits many of the same characteristics of the Penobscot River watershed: a high percentage of natural landcover, long river networks, and abundant documented fish habitat. There are 116 dams in the watershed that are included in the analysis. These fall on 7,082 km of river for a density of 1 dam / 61 km of river. For the anadromous fish scenario, 36 of these are in the top tier regionally, and 52 are in the top 10%, while 49 are in the top resident tier and 64 in the top resident 10%. (Twenty-two of the dams appear in the top tier for both scenarios).

Figure 5-13: Anadromous and resident benefit scenario results: Kennebec River basin

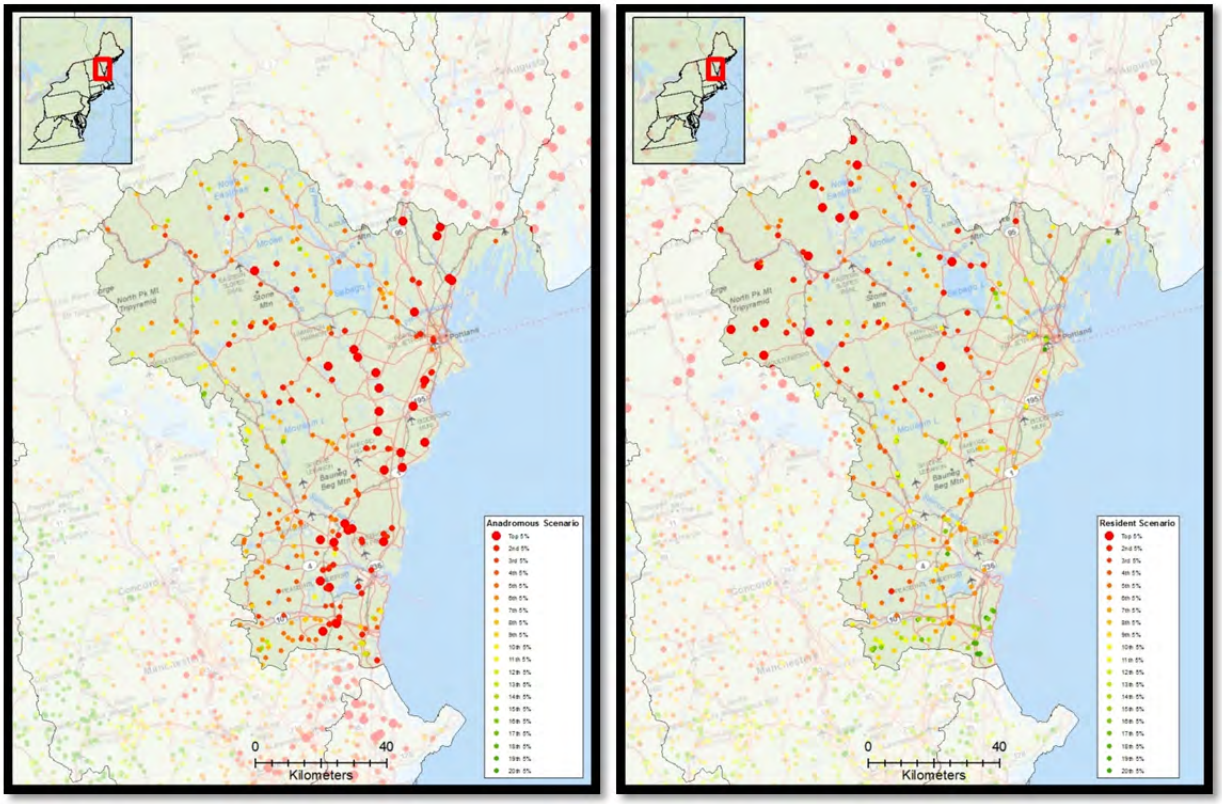


As with the Penobscot, landcover quality, functional network length, and fish habitat are the factors driving the results. Natural landcover in each dam's contributing watershed accounts for ≥90% of the total landcover for 65 of the 116 dams in the Kennebec watershed, (median = 91% natural). Percent impervious surface in each dam's contributing watershed is generally very low, with a median value of 0.65%. Upstream functional network lengths, while not as large as in the Penobscot, are still above the regional averages, ranging up to 617 km with a median of 12 km and a mean of 47 km. Finally, 59 of the dams have current anadromous fish habitat documented in their downstream functional networks and an additional 25 have historical habitat. All but 25 of the dams are in subwatersheds with healthy brook trout populations.

5.3.3 Saco River & South Coastal Maine (HUC 0106)

A total of 307 dams in the Saco River basin were assessed in the analysis. Of these, 31 were in the regional top tier of the anadromous benefits scenario and 72 were in the top 10%, while 14 were in the regional top tier and 40 were in the top 10% for the resident weight scenario.

Figure 5-14: Anadromous and resident benefit scenario results: Saco River basin & South Coastal Maine

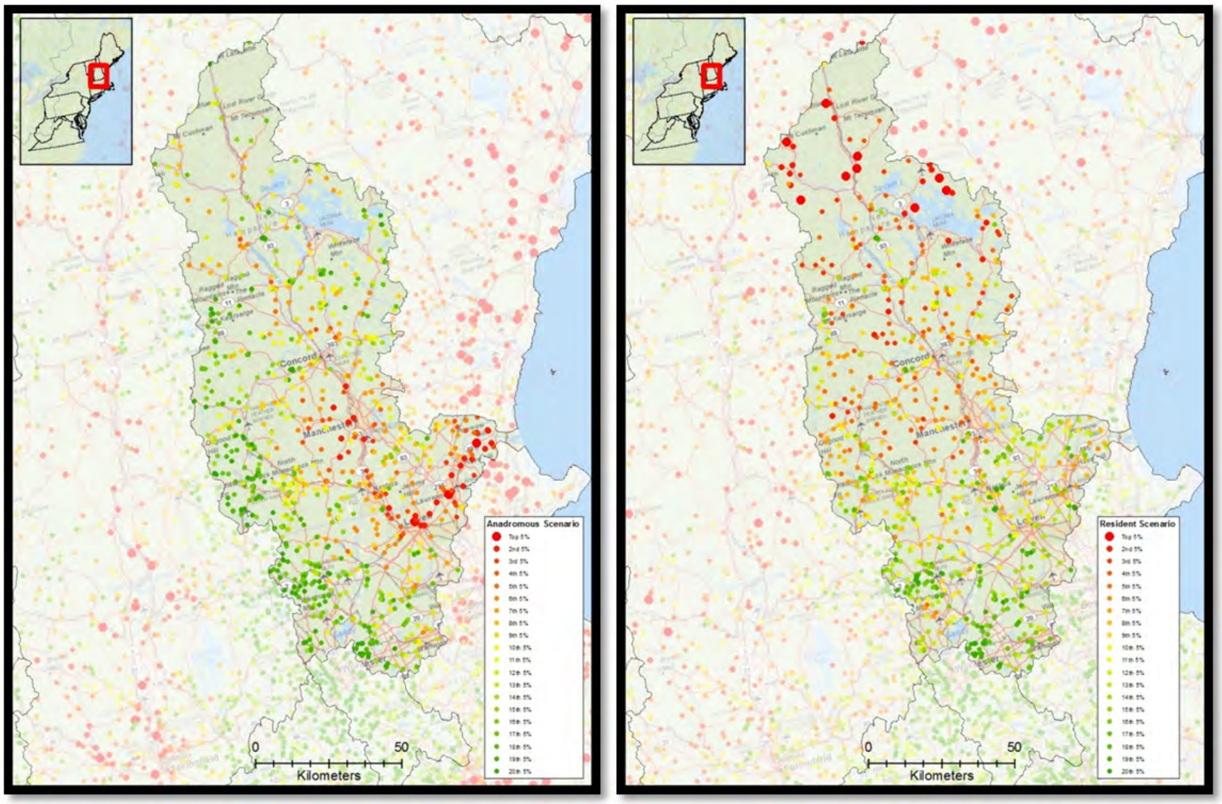


The effects of the more urbanized landscape of southern Maine and the northern Boston suburbs begin to emerge in the Saco River basin. Of the 307 dams, 128 have contributing watersheds with ≥90% natural landcover, (median value of 89% natural). Correspondingly, the values for percent impervious surface in each dam's contributing watershed are generally higher than what was seen in the more rural Penobscot and Kennebec watersheds, with a median value of 1.1 % impervious surface. The density of dams is also greater in the Saco river watershed with 307 dams on 6,140 km of river, for a density of one dam for every 20 km of river. This contrasts to densities of 1 dam per 103 km and 61 km in the Penobscot and Kennebec basins, respectively. As a result the averages for functional network length are also lower in the Saco. The longest upstream functional network for dams in the Saco basin is 340 km with a median value of 4.2 km and a mean of 15.5 km. Current anadromous fish habitat for one or more of the seven species in the analysis was recorded in the downstream functional networks of 107 of the dams in the basin. An additional 147 had historical anadromous fish habitat documented in the downstream networks. Finally, 225 of the dams are situated within subwatersheds with healthy brook trout populations.

5.3.4 Merrimack River (HUC 0107)

The trend seen in the Saco River basin of the increasing effects of urbanization is seen to continue in the Merrimack River basin. There were 847 dams in the basin that were used in the analysis. These dams fall on 7,291 km of river for a density of 1 dam per 8.6 km. Three of these dams are in the top tier regionally, for the anadromous benefits scenario, and a total of 27 are in the top 10%. Nine dams are in the top tier for the resident fish scenario and 27 are in the top 10%.

Figure 5-15: Anadromous and resident benefit scenario results: Merrimack River basin



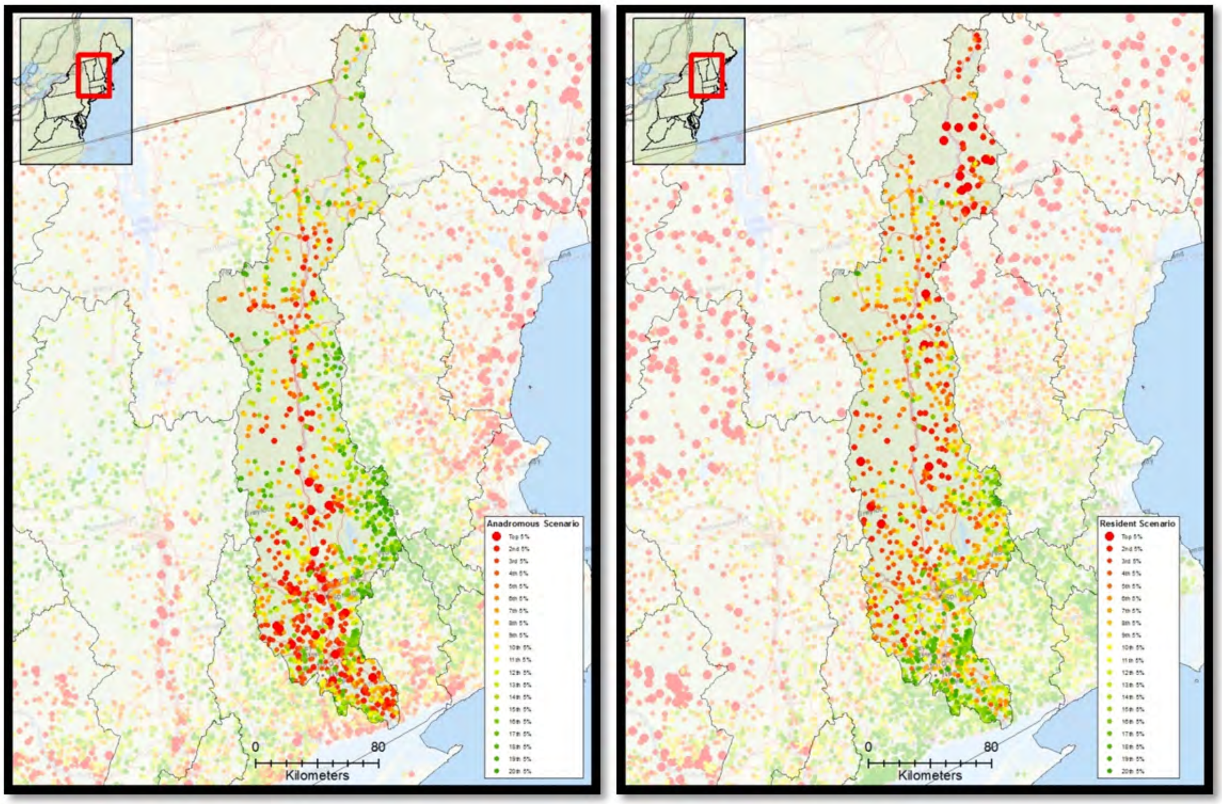
The higher density of dams is followed, in step, with reduced natural landcover, increased impervious surface, and shorter functional river networks. The median value for natural landcover in each dam's contributing watershed is 85% -- a continued reduction relative to the more northerly basins. Impervious surface values are increased as well, with a median value of impervious surface within contributing watersheds of 1.5%. Upstream functional network lengths are also shorter than in the more northerly basins: the longest network is 280 km and the median length is 2.2 km. Forty-nine of the 847 dams have current anadromous fish habitat presence documented in their downstream networks and an additional 358 have historical anadromous fish habitat documented. A total of 584 dams fall in subwatersheds with healthy brook trout populations.

5.3.5 Connecticut River (HUC 0108)

A total of 1422 dams from the basin were evaluated in the analysis. These dams fall on 15,298 km of river, for a density of one dam for every 11 km of river. As can be seen in Figure 5-16, the distribution of dams is not uniform; the southern, more urbanized, portions of the basin have more dams than the more rural northern portions of the basin. The trend of increased urbanization is seen in the southern portion of the Connecticut River basin. Sixty-five percent of the dams in the basin (931 out of 1422) fall within Massachusetts and Connecticut, with the remainder, 491, in Vermont and New Hampshire. This translates to densities of one dam per 6.6 km of river in Massachusetts and Connecticut (6158 km of river) and one dam per 19 km of river in Vermont and New Hampshire (9140 km of river).

Basin-wide looking at the anadromous fish weight scenario results, 22 dams fall in the top tier regionally, and a total of 88 fall in the top 10% regionally. Seventeen dams are in the top tier regionally for the resident fish scenario and 74 are in the top 10%.

Figure 5-16: Anadromous and resident benefit scenario results: Connecticut River basin.

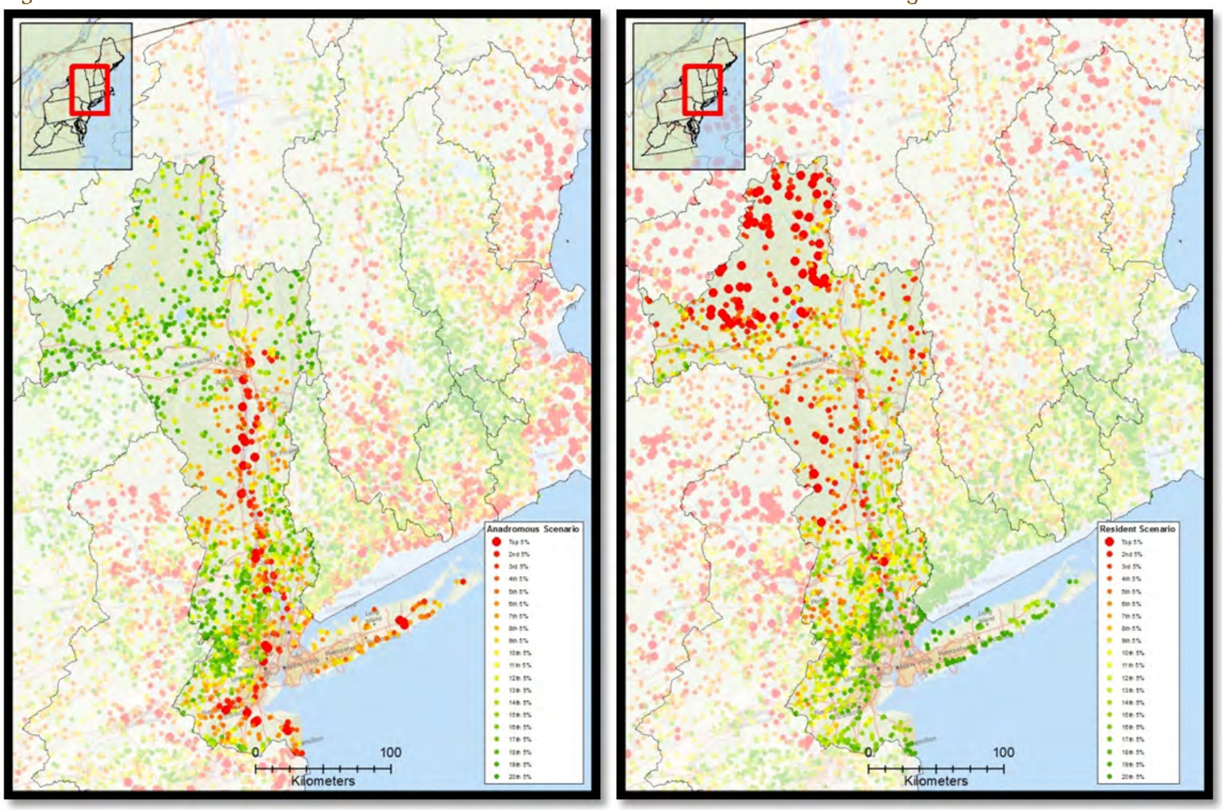


Also basin-wide, dams in the Connecticut have a median of 87% natural landcover in their contributing watersheds, 0.87% impervious surface, and a median upstream functional network length of 1.8 km. Again, however, a distinction can be drawn between the two southern states with a median of 85% natural landcover and 1.3% impervious surface and the two northern states with a median of 91% natural landcover and 0.5% impervious surface. Likewise, the two northern states have longer upstream functional networks (maximum = 685 km; median = 2.8 km) than the two southern states (maximum = 298 km; median = 1.6 km). These distinctions can be readily seen in the resident scenario results (Figure 5-16) where most of the dams in the higher tiers fall in the northern portions of the basin. In the anadromous fish scenario, however, the presence of anadromous fish, which is clearly tied to access to Long Island Sound in the south, overwhelms the network and landcover differences between the two halves of the basin. In Massachusetts and Connecticut, 260 of the 934 dams have documented current anadromous fish habitat in their downstream functional networks, while only 82 of 491 dams in New Hampshire and Vermont do.

5.3.6 Hudson River & Long Island (HUC 0202 & 0203)

The Hudson River Basin (including both the Upper Hudson (HUC 0202) and the Lower Hudson / Long Island (HUC 0203)) has a total of 1,726 dams spread out over 22,711 km of river for a density of one dam for every 13 km of river. A total of 74 dams fall in the top 10% of the anadromous scenario results regionally, while 26 of these are in the top tier. In the resident scenario, 64 dams are in the top tier regionally, and 113 are in the top 10%.

Figure 5-17: Anadromous and resident benefit scenario results: Hudson River basin & Long Island.



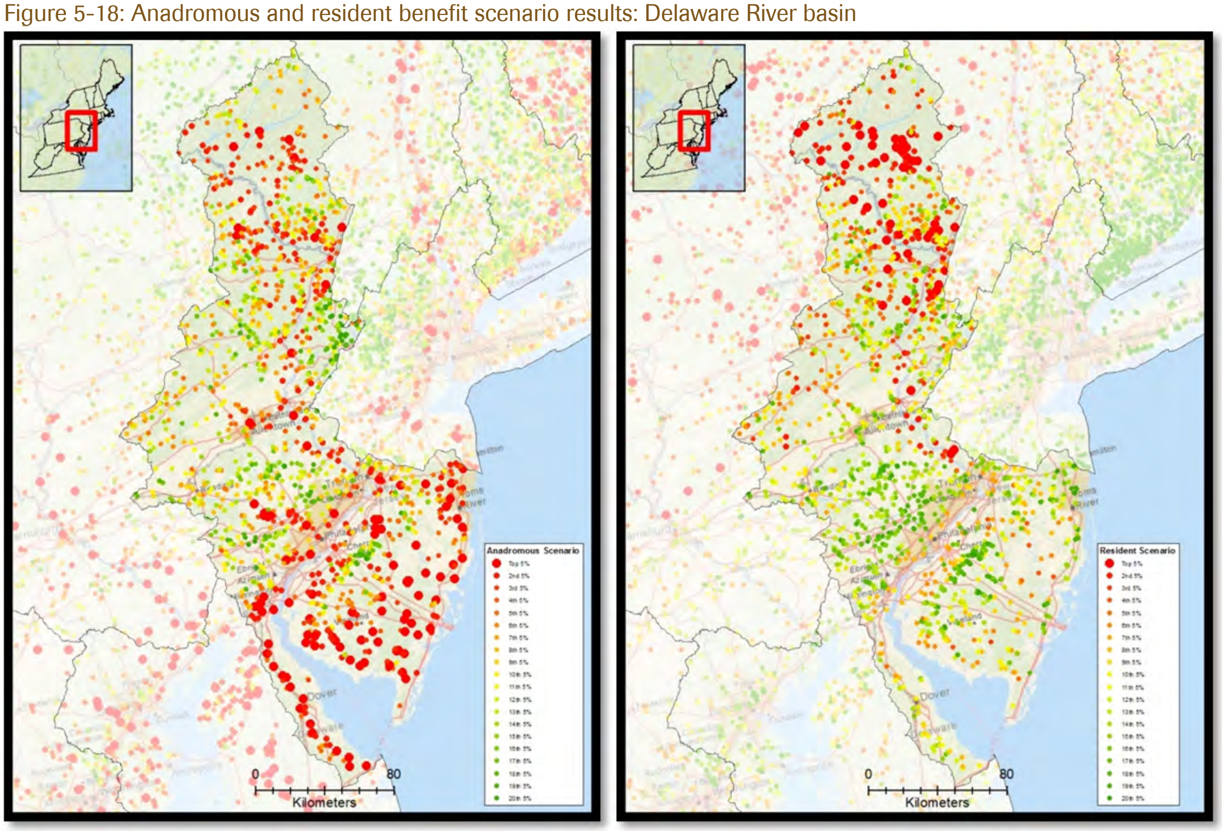
As might be expected, considering the Hudson basin includes the New York metropolitan area as well as the agricultural lands of the Hudson valley, natural landcover is substantially reduced relative to the more northern basins. The median value for natural lands in each dam's contributing watershed is 73% and the median impervious surface value is 1.2%. The longest upstream functional river network is 873 km and the median length is 2.8 km. A total of 142 of the dams have documented anadromous fish habitat in their downstream networks and 549 are in subwatersheds with "healthy" brook trout populations.

Similar to the Connecticut River basin, the network and landcover characteristics are notably different in the more rural north and the more urban south. The median upstream functional network length in the Upper Hudson watershed, for example is 3.5 km while natural landcover and impervious surface medians are 80% and 0.6%, respectively. This compares to median values of 2.2 km, 56% natural landcover, and 5.2% impervious surface in the Lower Hudson/Long Island. Also similar to the Connecticut River basin, the impact of these characteristics can be readily seen in the resident fish scenario results where dams in the top tiers are clustered in the Upper Hudson (and especially in the Adirondacks), while the Lower Hudson is relatively bereft of dams in the upper tiers. Finally, the anadromous fish data again overrides these land cover characteristics in the south, as it was designed to do via the high weight that it was assigned by the Workgroup. Dams in the upper tiers for this scenario are restricted to the immediate vicinity of the Hudson (likely a function of the geomorphology of the river valley) and on Long Island.

5.3.7 Delaware River & New Jersey coastal (HUC 0204)

The analysis evaluated 1,547 dams on 20,320 km of river in the Delaware River basin. This corresponds to a density of one dam for every 13 km of river. Of these dams, 100 were in the top tier regionally in the anadromous fish scenario results and a total of 236 were in the top 10%. The top tier of resident scenario results included 51 dams from this basin, while 113 dams from this basin appear in the top 10% of dams regionally.

Figure 5-18: Anadromous and resident benefit scenario results: Delaware River basin



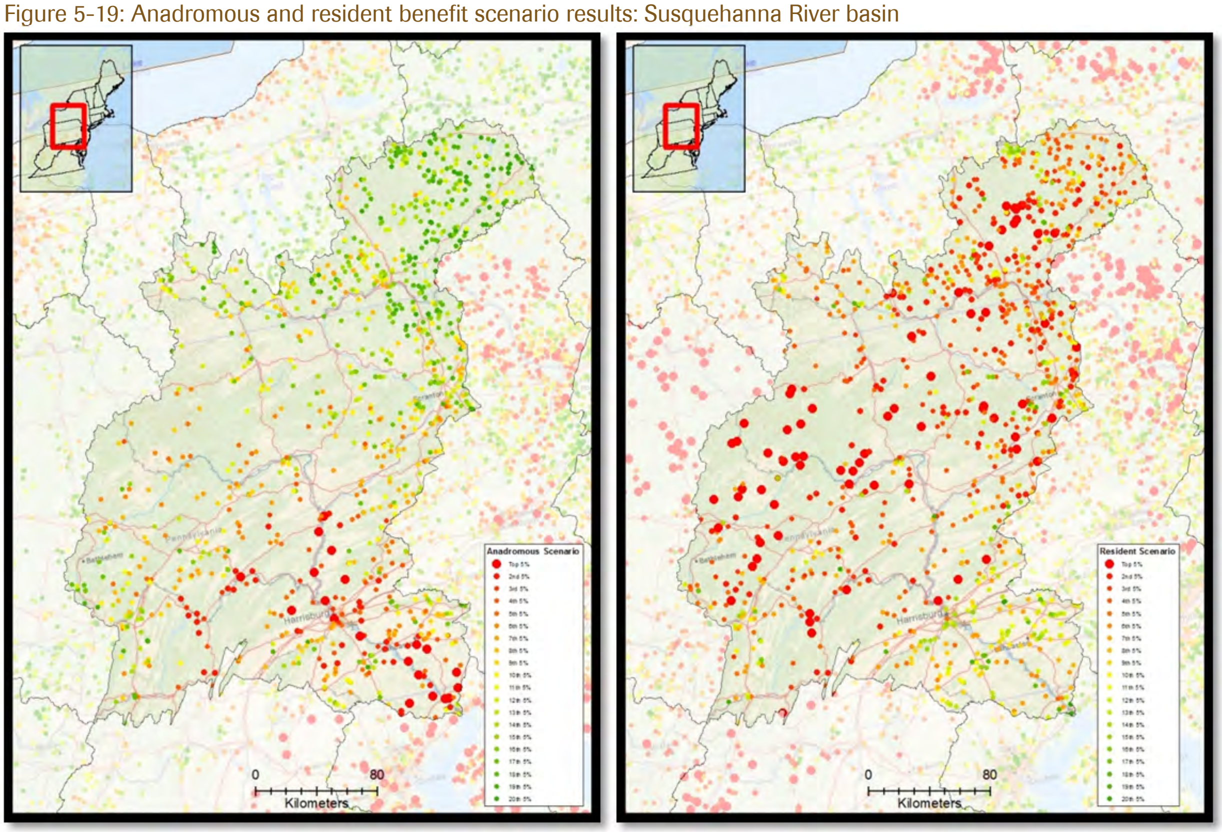
Encompassing several metropolitan areas, including Philadelphia, natural landcover in each dam's contributing watershed is reduced relative to the more northern basins with a median of 65% natural. The median impervious surface is 1.3%.   The upstream functional river length ranges up to 547 km and the median value is 2.8 km. Current anadromous fish habitat is documented in the downstream functional networks of 407 of the dams. A relatively modest 153 of the dams fall in subwatersheds with healthy brook trout populations. The relative paucity of dams in healthy brook trout subwatersheds may be related to water temperatures -- 638 of the dams have no cold water habitat in their total (upstream + downstream) functional networks. In the Penobscot, by contrast, all but two of the dams have some cold water habitat in their total functional networks. On the other hand, mean native fish species richness is 41 in the Delaware, versus 27 in the Penobscot.

Similar patterns can be seen between the Delaware River basin and the Connecticut and Hudson River basins. Notably, there is a dichotomy between the more urban areas in the south (Philadelphia, Wilmington & Dover) and the more rural areas in the north (Catskill Mountains of New York). The resident results reflect this fairly clearly while, again, the anadromous scenario results are dominated by the anadromous fish habitat data.

5.3.8 Susquehanna River (HUC 0205)

The Susquehanna River basin encompassed 1,053 dams on 40,876 km of river in this analysis, for a density of one dam for every 39 km of river. The top tier of regional anadromous scenario results included 20 dams from the Susquehanna and the top 10% included a total of 53. The resident fish scenario results included 68 dams in the top tier and 166 dams in the top 10% of dams across the region.

Figure 5-19: Anadromous and resident benefit scenario results: Susquehanna River basin



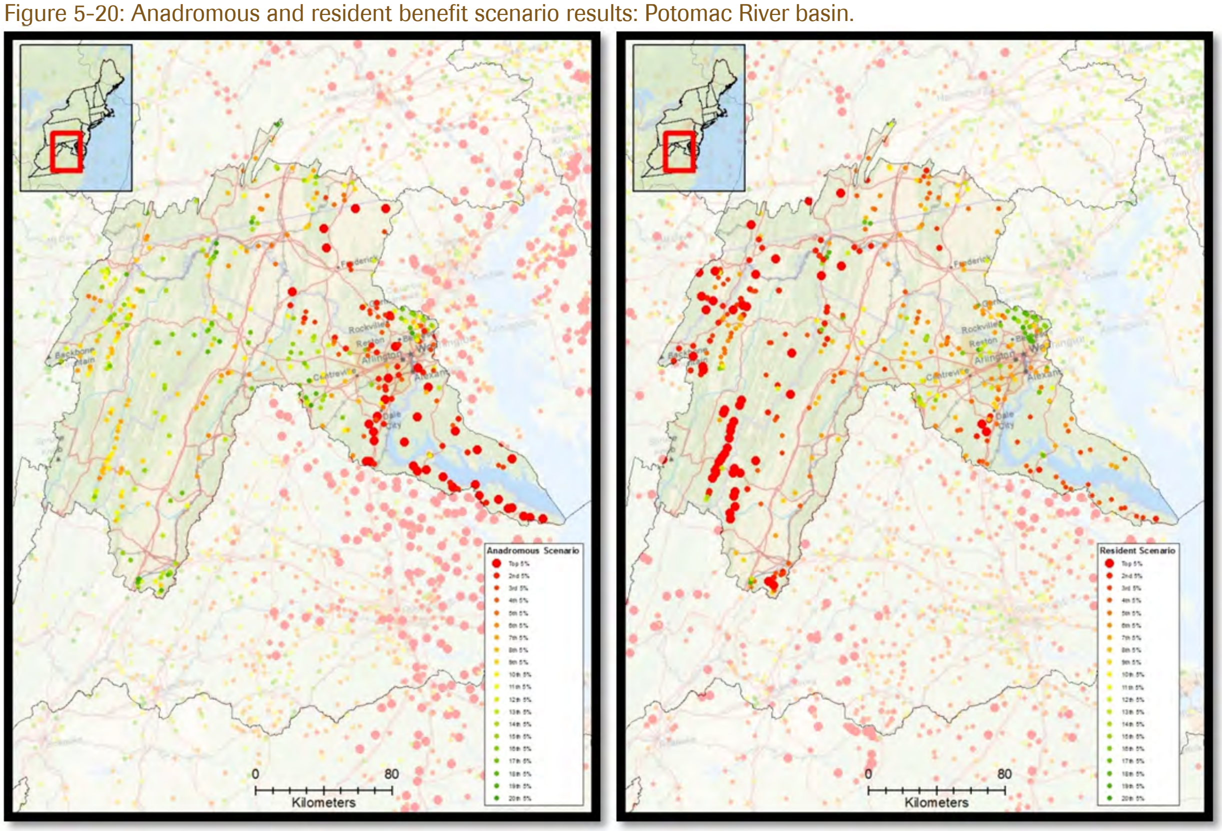
Natural landcover accounts for a median of 69% of each dam's contributing watersheds while impervious surface values have a relatively low median of 0.4% of contributing watersheds. These two numbers hint at the relatively large percent of agricultural landcover within the basin: the dams have a median of 24% agricultural land in their contributing watersheds. Functional network lengths range up to an impressive 6,452 km but have a more modest median value of 3.4 km. Current anadromous fish habitat is documented in the downstream networks of 101 of the dams in the basin, while 325 of the dams are in subwatersheds with healthy brook trout populations. Like the Delaware basin, fish species richness is higher than in the more northern basins, with a mean richness of 39 species.

Unlike most of the other basins, the division in the Susquehanna is not on a purely north-south axis. Rather, most of the dams from the top tier of the resident fish scenario fall in the middle of the basin in the watershed of the West Branch Susquehanna. As can be seen in Figure 5-19 above, this is related, at least in part, to the lower density of dams and corresponding greater network lengths in this part of the basin.

5.3.9 Potomac River (HUC 0207)

A total of 432 dams on 21,125 km of river in the Potomac basin are assessed in the analysis for a density of one dam for every 49 km of river. Of these dams, 35 fall in the top tier regionally for the anadromous fish scenario and a total of 63 are in the top 10%. Fifty-one dams are in the regional top tier in the resident fish scenario and 95 are in the top 10%.

Figure 5-20: Anadromous and resident benefit scenario results: Potomac River basin.



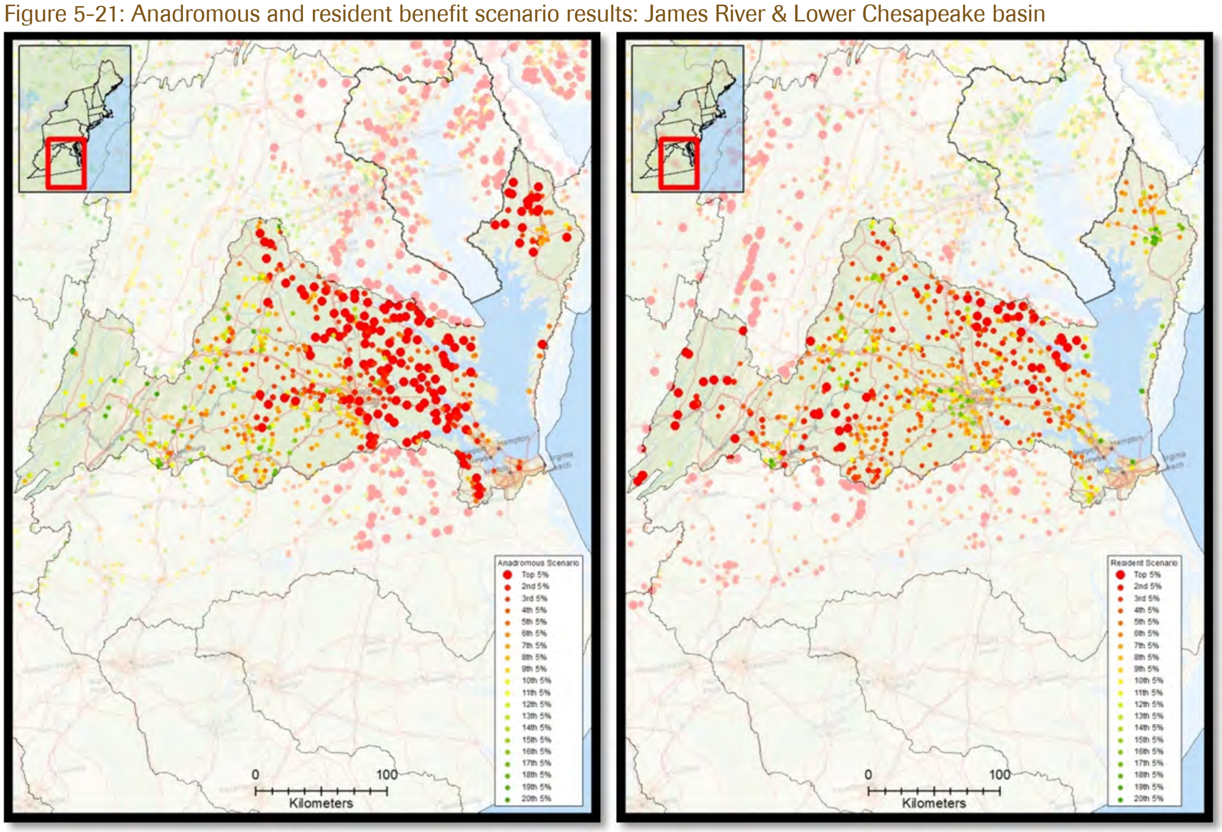
Landcover in the Potomac exhibits many of the same characteristics as the other mid-Atlantic basins do. Natural landcover is relatively low compared to the more northern basins -- the median value in contributing watersheds of dams in the basin is 66% natural. However, impervious surface percentages are also relatively low across the basin with a median of 0.6%. The difference is made up by agriculture, which accounts for a median of 15% of the total landcover in contributing watersheds. Upstream functional network lengths are also similar to the Susquehanna. The maximum length is quite impressive at 4,772 km, but the median length is a more reserved 3.5 km. Almost a quarter of the dams in the basin, 103 out of 432, have current anadromous fish habitat documented in their downstream networks. And while only 45 dams are in subwatersheds with healthy brook trout populations, the mean native fish species richness in subwatersheds within the basin is an impressive 46.

As can be seen in the results in Figure 5-20, dams in the higher tiers are generally located in the more rural western portion of the basin while dams in the higher tiers of the anadromous scenario are closer to the Chesapeake Bay and the anadromous fish that inhabit it. It is notable, however, that several dams in the higher tiers of the resident scenario are clustered lower down in the basin near the Bay. Although many of these dams have very high native fish species richness (up to 62 species), this is nonetheless largely driven by the total functional network length. Total functional network length, which is the sum of both the upstream and downstream networks, is large for those dams that abut the Potomac where it is a large, open arm of the Bay. This is because the downstream network includes the length of the arm as well as all the tributaries up to their first dam.

5.3.10 James & Lower Chesapeake (HUC 0208)

The James and lower Chesapeake basin included 630 dams in this analysis spread across 27,042 km of river. These figures yield a density of one dam for every 43 km of river. In the anadromous fish scenario, 134 of these dams are in the regional top tier and 198 are in the top 10%. In the resident scenario, 46 dams are in the regional top tier and 108 are in the top 10%. Twenty-one of these dams appear in the top tier of both the anadromous and the resident scenarios.

Figure 5-21: Anadromous and resident benefit scenario results: James River & Lower Chesapeake basin



Continuing the pattern seen in the other mid-Atlantic basins, natural landcover accounts for a median of 71% of each dam's contributing watersheds, while impervious surface accounts for a median of 0.4% and agriculture 22%. Likewise, upstream functional river lengths range up to an impressive 2,233 km but have a more reserved median of 4.1 km. Current anadromous fish habitat was documented in the downstream functional networks of 266 of the dams. The mean native fish species richness by subwatersheds was a whopping 50, though only 36 dams were situated in subwatersheds with healthy brook trout populations.

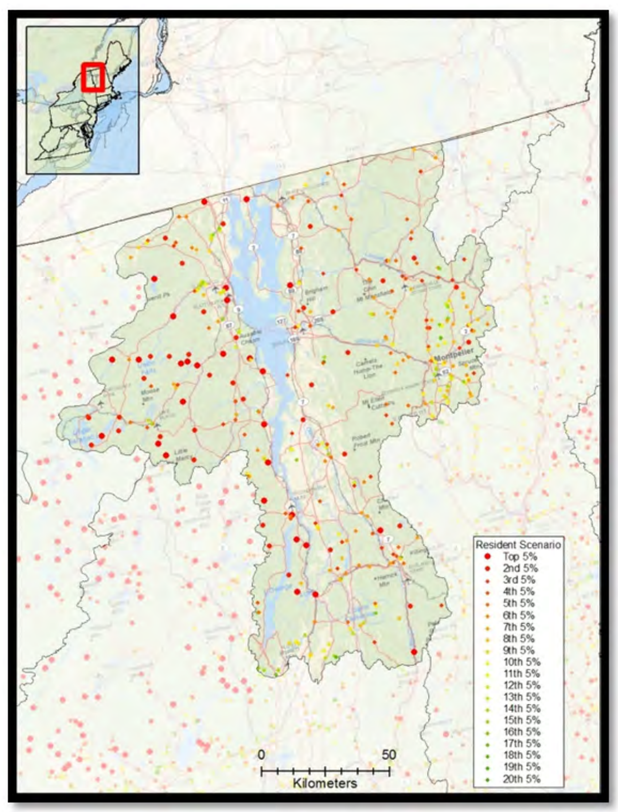
The anadromous scenario results are very clearly driven by the anadromous fish habitat associated with the Chesapeake Bay and its tributaries. The resident scenario results are, interestingly, split between the western portion of the basin where landcover characteristics are of high quality, and the eastern portion of the basin where longer total functional networks are formed where large rivers meet the Bay (as described under the Potomac basin section).

5.4 Major Interior Basin Summaries

Similar basin summaries can be made for major non-Atlantic Coast basins in the study area, especially with respect to resident fish. Although there are noteworthy data gaps for these basins, particularly with respect to metrics which assess the number of downstream features of each dam (other dams, waterfalls, etc) as described in Section 3.4, valid comparisons can be made between these basins for the metrics which are most highly weighted in the resident fish benefits scenario.

Relative to the Atlantic coast basins, these interior basins are characterized relatively natural landcover, lower dam densities, and longer functional river networks. The total functional river network lengths, in particular, tend to be quite long compared to the upstream functional river network lengths, especially for the Kanawha and Monongahela basins. This indicates that many dams are located near headwaters above which there is little mapped stream network. The proliferance of coal-related dams in this region, which are often located near mountain headwaters, could explain this finding.

Figure 5-22: Resident fish benefit scenario results: Richelieu basin



5.4.1 Richelieu (HUC 0201)

There are 363 dams spread across 7,939 km of river in the Richelieu basin that were assessed in this analysis. This corresponds to a density of 1 dam for every 22 km of river. Of these dams, 29 are in the top tier for the resident fish benefits scenario while a total of 65 are in the top 10%.

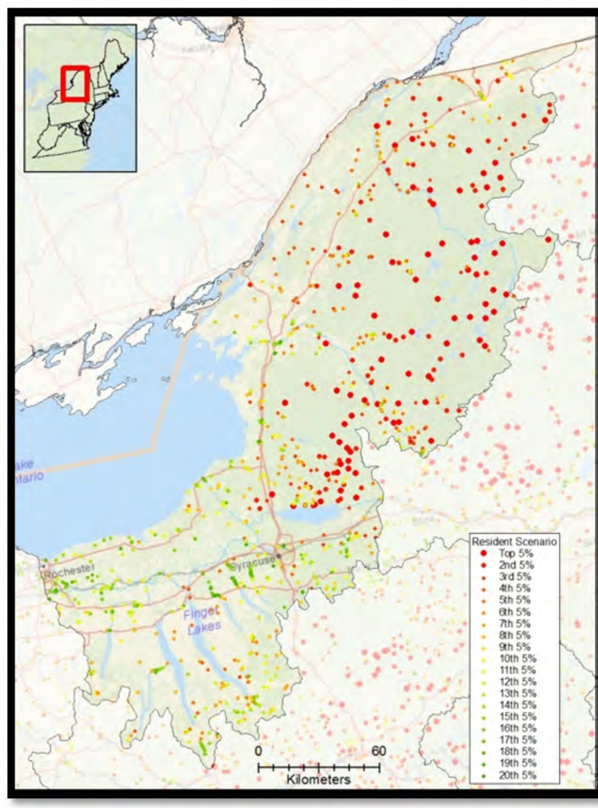
Landcover in the contributing watersheds of dams in the Richelieu basin is comparable to that of the neighboring Connecticut River basin, with median values of 88% natural and 0.52% impervious surface. The median upstream functional network length is approximately twice as long in the Richelieu basin (3.9 km) than in the Connecticut basin (1.8 km), however. This is a function of the density of dams which in the Richelieu is half of the Connecticut (1 dam / 22 km river vs. 1 dam / 11 km of river.) The median length of the total functional river network (upstream + downstream), which was determined by the Workgroup to be a more pertinent metric than upstream functional network for resident fish assemblages, is 39 km in the Richelieu basin.

There are 201 dams in subwatersheds with "healthy" Eastern brook trout populations, and dams have a relatively high mean value of 81 km of cold water in their total functional networks. Mean fish species richness is 55 for dams in the Richelieu basin.

5.4.2 Lake Ontario (HUC 0414 & 0415)

A total of 893 dams in the Lake Ontario basin were assessed in this analysis. These dams are situated on 23,590 km of river, for a density of 1 dam for every 26 km of river. Of these dams, 75 are in the top tier for the resident fish benefits scenario and 137 are in the top 10%.

Figure 5-23: Resident fish benefit scenario results: Lake Ontario basin



Contributing watersheds of dams in the lake Ontario basin have median landcover of 76% natural, but a median impervious surface value of 0.29%. Similar to the mid-Atlantic basins described above, the difference is made up by a relatively high proportion of agricultural lands: a median of 18%. The median upstream functional river network length is 4.9 km, while the median total upstream functional network length is 37 km.

A notable difference can be seen when the two HUCs in this basin are compared. Southeastern Lake Ontario (HUC 0414) which is host to the major urban centers of Syracuse and Rochester, has more dams (547) than Northeastern Lake Ontario-Lake Ontario-St. Lawrence (HUC 0415, 346 dams) and far fewer of these dams are in the top tier (19 vs. 56). This dissimilarity can be seen to be driven by the land cover and network characteristics.

Dams in Northeastern Lake Ontario, which includes much of the western Adirondacks, have a median 98% natural landcover in their contributing watersheds and a median impervious surface of 0.08%. Network lengths are also relatively long; the median upstream functional river network is 6.9 km and the median total functional river network is 64 km. These values are all superior to Southeastern Lake Ontario, when it comes to aquatic restoration for resident fish.

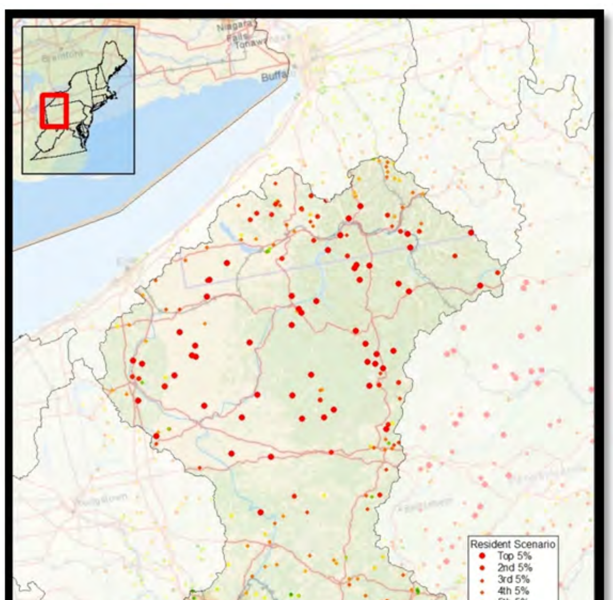
Landcover in the Southeastern Lake Ontario basin is far less natural than in its counterpart basin: 54% natural and 0.48% impervious respectively. The difference is made up by agricultural lands which account for a median of 37% of the dam's contributing watersheds compared to just 1.0% agriculture in the Northeastern Lake Ontario basin. Network lengths are also shorter with median values of 4.0 km and 26 km for upstream functional river network and total functional river network, respectively.

Basin-wide, 369 dams are in subwatersheds with healthy brook trout populations and there is 63 km of cold water stream in their total functional networks, on average. The mean native fish species richness is 50. As one would expect given the landcover and network characteristic, these figures clearly diverge when the two subbasins are examined. Southeastern Lake Ontario has 201 out of 547 dams (38%) in "healthy" brook trout subwatersheds while Northeastern Lake Ontario has 162 out of 346 (47%). Similarly, there is more cold water habitat in the Northeast subbasin (mean 72 km) compared to the Southeast subbasin (mean 56 km). Interestingly, the native fish species richness is greater for dams in the Southeast (mean 57) vs. the Northeast (mean 37). The pattern of more cold water habitat and healthy brook trout populations in the mountainous Northeastern subbasin and greater native fish species richness in the more temperate lowland Southeast parallels the pattern that is seen on a macro scale across the region from Maine to Virginia.

5.4.3 Allegheny (HUC 0501)

There is a relatively low density of dams in the Allegheny basin: 301 dams across 17,171 km of river, for a density of 1 dam for every 57 km of river. This is one of the lowest dam densities in the region and is comparable to the Kennebec River basin in Maine (1 dam / 61 km of river). This low density is reflected in the median upstream functional river network length of 4.3 km (comparable to the Saco River basin in Maine) and especially in the median total network length of 335 km. Of the 301 dams, 53 are in the top tier of the resident fish benefits scenario and a total of 85 are in the top 10%.

Figure 5-24: Resident fish benefit scenario results: Allegheny basin



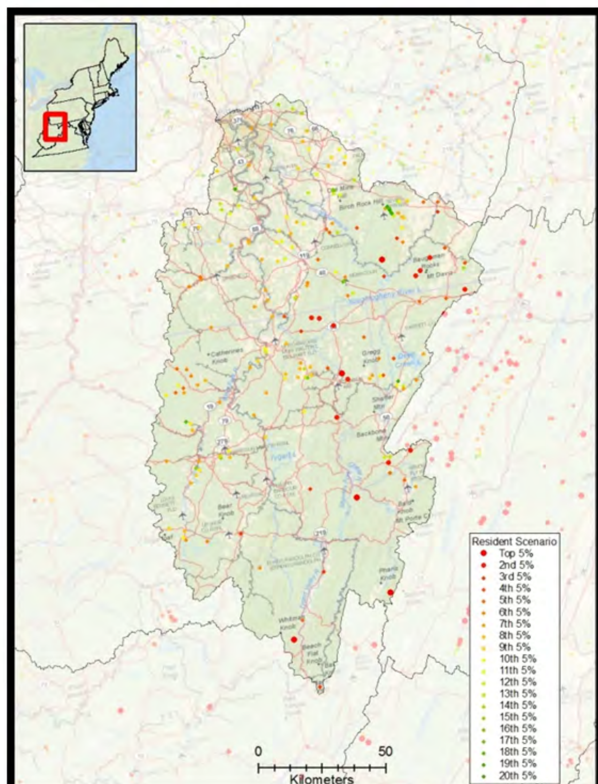
The median values of natural landcover and impervious surface in the contributing watersheds of dams in the basin are 76% and 0.46%, respectively. As with the Lake Ontario basin and the other mid-Atlantic basins described above, there is a relatively high proportion of agricultural land in the contributing watersheds for dams in the basin: the median is 17%.

The more southern location of the Allegheny basin is evident when the resident fish scenario ecological metrics are examined. Only 23 of the 301 dams are in subwatersheds with "healthy" brook trout populations but mean fish species richness is a respectable 51. Interestingly, however, the mean miles of cold water habitat in dams' total functional river networks is very high at 369 km. In part, this is driven by some outlier dams (the median is a more expected, though still high, 69 km). Much of the basin is also mountainous and elevation is a driving factor in the modeled cold water habitat data (Olivero and Anderson 2008). It is also largely a function of the long network lengths which allow for the aggregation of many cold tributary streams within a functional network, resulting in more miles of cold water within each network.

5.4.4 Monongahela (HUC 0502)

There are 202 dams in the Monongahela basin that were assessed in this analysis. These dams are spread across 11,439 km of river for a density of 1 dam for every 57 km of river. Of these dams, five are in the top tier and 15 are in the top 10% of resident fish benefit scenario results.

Figure 5-25: Resident benefit scenario results: Monongahela basin



Landcover in the contributing watersheds of dams in the Monongahela basin is relatively natural, with a median value of 79% natural and median impervious surface value of 0.76%. Although the longest upstream functional river network is 1,562 km, the median is a more modest 2.5 km. The low density of dams is better reflected in the median total functional network length with is a much more substantial 317 km. The large difference between the median upstream functional network length and median total functional network length indicates that many of the dams are situated near headwaters above which there is little mapped stream length.

Only nine dams in the Monongahela basin are in subwatersheds with "healthy" brook trout populations and cold water habitats represent just 31 km of each dam's total functional river network, on average. Mean native fish species richness in the basin is on par for its latitude on the east coast at 46 species.

5.4.5 Kanawha (HUC 0505)

There are 104 dams in the Kanawha basin that were assessed in this analysis. Seventeen of which are in the top tier for resident fish and an additional 12 round out the top 10%. These dams are situated on 16,532 km of river in Virginia and West Virginia (an additional 1,286 km of river are located in the North Carolina portion of this basin, which was not assessed in this analysis) for a density of one dam for every 159 km of river. This represents the lowest density of dams in the study area, a fact which can be seen in the median length of the total functional river network length which is an impressive 762 km. The upstream functional river network length is a much more modest 2.8 km. The difference between the two again reflects that many dams are located near headwaters -- a fact is especially true of the many coal mining related dams in this part of the region.

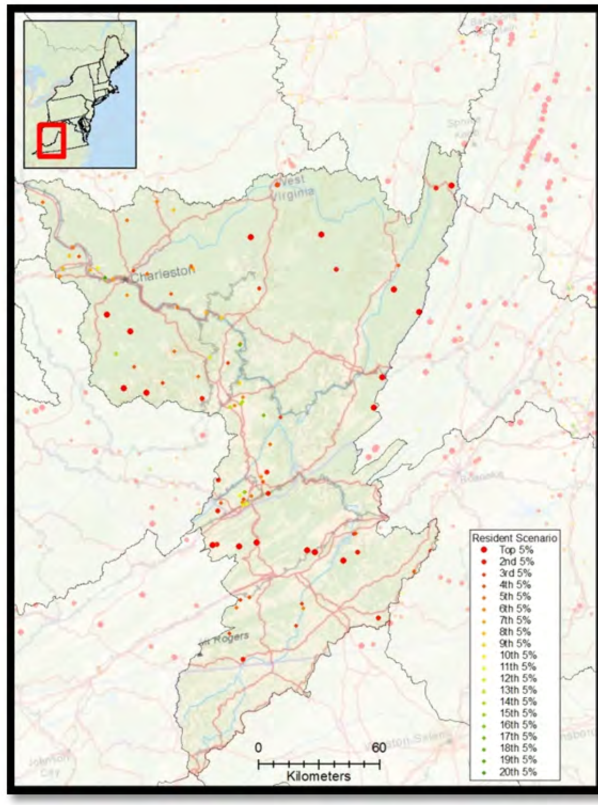


Figure 5-26: Resident fish benefit scenario results: Kanawha basin

Landcover in the basin is in a relatively natural state compared to many of the other basin in the region. The median value for dams' contributing watersheds is 86% natural and just 0.55% impervious surface.

Indicative of its southerly location, only five dams in the basin are in subwatersheds with "healthy" brook trout populations. There is 93 km of cold water habitat in each dams' functional river network, on average, again this is as much a function of long network length as it is an abundance of cold water habitat. Mean native fish species richness is similar to other basins in the immediate vicinity at 50.

6 Northeast Aquatic Connectivity Strategy

6.1 Utility of NAC Results to State Resource Agencies

The Northeast Aquatic Connectivity project (NAC) was designed to assist resource agencies in the Northeastern U.S. in efforts to strategically reconnect fragmented river, stream, coastal, reservoir, lake and estuarine habitats by targeting removal or bypass of key barriers to fish passage. From 2008 to 2011, this broad goal has driven innovative work by a representative group of state, federal, NGO, academic and private professionals dedicated to improving resource quality throughout the Northeast. This section of the report discusses how state, federal and non-profit agencies plan to use the results of the project, including but not limited to the Northeast Connectivity Assessment Tool (NCAT). This section also details some of the limitations of the project and provides recommendations on how to address these limitations through future work.

In order to understand how the Northeast Aquatic Connectivity Project will likely be useful to state agencies in their efforts to restore fish passage and aquatic habitat, Workgroup members were asked to provide the project leadership team feedback directly. This feedback is summarized and paraphrased below in categories of response with the state source noted.

Acquisition of Project Funding

- For removal of dams that are highly ranked, this regional analysis will support efforts to fund those projects. (VT)
- The NCAT is a regional prioritization tool that will allow us to demonstrate the broad scale significance of proposed projects when applying for funding. (VA)
- NAC results will help show granting agencies, other State/Federal government agencies, NGO's and the public how a particular project fits in with the "bigger picture" and help bolster support for high-profile projects. (MD)
- Saying that a project "will open X miles of stream/river to fish passage and ranks in the top 5% of dam removal projects in a state by NEAFWA's Northeast Aquatic Connectivity Project" will sound much better than simply stating that a project "will open X miles of stream/river to fish passage". (PA)
- NCAT results will be useful in acquiring funding for all projects—demonstrating that a project falls within the top 5% priority within the Northeast Region is a persuasive fact. (CT)
- Having a well vetted priority list will make priority projects more competitive for grant funding and for attractive to foundations and donors seeking to maximize their impact per dollar. (American Rivers-TNC CT Basin)

Development of Basin Plans or Watershed Management Projects

- The most beneficial use of the results is likely to be in the development of watershed plans that we are required develop under state law. The results will inform decisions about priority projects for our restoration efforts in Vermont. (VT)
- The NCAT is a useful collection of fish movement barrier information that can be looked at on the watershed scale. Anyone working on regional and/or basin plans can get a sense of the current status of stream connectivity within the area of focus. Plans may start to include not only stream restoration opportunities, but also fish passage needs and the ecological importance of removing

artificial barriers to fish and other aquatic populations. The NCAT highlights just how many barriers there are and should help shape future plans within individual watersheds and basins. (VA)

- The NCAT will provide additional data that can be evaluated when considering specific projects or larger, watershed scale efforts. (VT)
- As we develop management plans for specific rivers/watersheds we will be able to add a fish passage component to those management plans. The NCAT could be utilized to sort projects specific to that watershed and could serve as a starting point to prioritize fish passage projects for that management plan. (PA)
- This is a solid, science-based way to prioritize our actions relative to reducing in-stream barriers and reconnecting aquatic habitats. NHFGD anticipates that the results of this work will help the Department and its partners develop Regional and Watershed Plans. (NH)
- WV TNC, WVDEP and EPA are collaborating on developing a watershed assessment pilot on 5 WV HUCs and the connectivity data set will have direct applicability in their watershed characterizations. The assessments will identify restoration needs and opportunities and, eventually be used to develop watershed plans. (WV)

Focusing Restoration Work

- Having an analysis of the entire state can help identify watersheds or subwatersheds where states might realize the greatest connectivity improvements for a given investment, thereby supporting a focus on particular areas. (VT)
- NCAT can be used as a tool to inform, focus and support aquatic connectivity work. It will be of most value if applied in a practical manner across the state and applied on an as needed basis. NCAT can serve as a tool that could provide a uniform method of analyzing the geospatial impact of barriers. (NY)
- This tool will greatly aid in focusing work on projects with the greatest ecological and cost-effective potential. MD DNR and likely others had envisioned this as a rough tool for assessing fish passage projects and turned it into a well-polished, standardized, user defined, GIS based "mega-tool". The number of user-defined variables, the amount of detail, and the outputs are far greater than anything expected. (MD)
- We have initiated a long-term statewide project to identify "conservation focus areas**".** To qualify for inclusion the site must meet one or both of the following criteria—(1) exceptional sites because of rare species, communities or outstanding provision of ecological services/function and/or (2) threats or impediments to biodiversity. The connectivity data set qualifies for the 2^{nd} criterion and will be incorporated in our models (WV).

Support advocacy for removal / improved passage

- The results provide a means to illustrate, on a variety of scales (local, statewide, regional) the degree of fragmentation that has occurred, and the opportunities for restoration of river and stream continuity. (VT)
- Our state has already referred to the results to impress upon local residents the importance of the project proposed for their community. This seemed to have notable impact. (CT)
- The NCAT will be a good starting point to find out where a particular dam of current interest fits into the larger scope of a region, basin or watershed. The significance of a single barrier comes to light because of the way the NCAT is constructed. (VA)

Communications

- Outputs can serve as information for communication with the public on the general value of fish passage projects. (Multiple states)
- Within the model, we have access to data on connectivity, ecosystem health and watershed conditions. We will use this information to help develop funding proposals and answer questions on the project benefits from partners and the public. (American Rivers-TNC CT Basin)
- The tool has allowed us to merge data across state borders and create a prioritized list for dam removal in the Connecticut River Watershed. We are already using it to develop a shared list of prioritized dam removal sites in the watershed. In so doing, we are strengthening connections and engaging natural resources managers across our four states in ways that we had not previously (American Rivers-TNC CT Basin)

As a Database of Indicators and Measures

- NCAT results will be useful as a database of key measures and indicators associated with existing or future projects. Examples include: 1) length of upstream connected stream network; 2) the presence of a coldwater stream in the upstream connected stream network; and 3) the number of dams downstream to the ocean. (MA)

Ensuring Resident Species are Addressed

- Focusing work for reconnecting habitat for non-anadromous ("resident") species—identifying projects that would provide most bang-for-buck. (CT)

Support for State Administrative Actions

- Given statutory authority to order fish passage projects as a condition to a dam repair permit, these data will help support these administrative actions (CT)

Overall, feedback from the expected end users indicates that the project, its results and associated tools will do well to advance strategic connectivity restoration at multiples scales throughout the region. It is worthwhile to note, however, that in this feedback no clear future role is defined for the Northeast Association of Fish and Wildlife Agencies or other regional body in advancing connectivity restoration at the regional scale. Regional efforts across and within the Northeast region are being catalyzed by some federal and multi-state efforts as described below in Section 7.3. Recommendations for NEAFWA and other institutions roles can be found in Section 7.4.

6.2 Project Limitation and Desired Future Improvements

Given the ambitious scope of the Northeast Aquatic Connectivity Project, the quality of many existing state databases, and the general lack of relevant regional databases, limitations associated with the NCAT tool and its default results were to be expected. As with the discussion of the utility of NAC project outputs, Workgroup members were polled on limitations and desired future improvements. The result of this input is summarized and paraphrased below, grouped by category of input.

6.2.1 Limitations

Quality of Data

- Everyone involved with this project has acknowledged that the quality of the data is highly variable with respect to accuracy and completeness. It is also important to recognize that the dataset does not capture all natural and constructed barriers, which could affect the actual benefits of removing a particular dam. (VT)
- Lack of complete inventories of dams and waterfalls as well as the lack of complete anadromous fish distribution data. These issues just need to be acknowledged upfront so that the NCAT is not expected to do more than it is intended to do. (VA)

Regional Scale

- The NCAT will be of most benefit when effectively tailored for local conditions and metric weighting. Connectivity projects in NY are largely pursued on a smaller scale and in smaller watersheds such that tailor suited analyses would be of more value. (NY)

Scale of Hydrography

- Future iterations of the model would hopefully be at a finer scale so as to include more of the dams in the watershed. (American Rivers-TNC CT Basin)
- The most striking difference between the NCAT and the Massachusetts Restoration Potential Model (RPM) is the use of 1:100,000 hydro data by the former and 1:24,000 hydro data by the latter. As a consequence, the RPM analyzes 2,640 dams in Massachusetts, but the NCAT only includes 1,523. Although some of this difference is due to farm pond dams that aren't on any stream, many of the excluded dams are on small, headwaters streams. The 3rd version of the RPM will increase the priority of dams on headwaters streams to reflect the importance and vulnerability of these systems, so their exclusion in the NCAT is unfortunate. (MA)

Lack of Culvert Barrier Information

- There is great interest in how the NAC project tools could be used to assess barriers other than dams/natural structures, particularly culverts. (NY)

Potential Over-reliance on Results by Funders and Decision-Makers

- NCAT results could hinder the ability of certain States to obtain grant funding from sources that accept applications on a large scale. Granting agencies with this new tool will be able to compare not only projects in one State, but among many States or even an entire region and choose the best projects to apply funds too. This may be good for dam removal in general, but could stifle progress in some states. (MD)
- A barrier that is not ranked very high overall in the region or in a given state may not receive removal and/or passage funding because of its rank, but it may be a very good project in its own right. Funding agencies want to see that a barrier has been put through a prioritization exercise but there are not yet clear, consistent benchmarks on just how high a project needs to rank to be considered for funding or denied automatically. The NCAT can be used to generate lists of potential projects but opportunity often arises and the necessary ingredients gel for a project. Thus, the NCAT ranking should not be the only tool used to determine a proposed project's fate. (VA)
- The model needs to be used as a tool in how we prioritize dam removal, but not as a final decision maker. The NCAT is unable to prioritize dams in a series. The constraints to this are understandable,

but it highlights why natural resource managers and funders need continue to evaluate projects in a big picture context. (American Rivers-TNC CT Basin)

In addition to the data gaps described in Section 3.4, a number of other limitations can be attributed to inadequate regional databases for species of conditions of interest. The following are issues that the Workgroup discussed but could not address due to data or computing limitations:

Impact of aquatic invasive species: Although there was a clear Workgroup recognition that dam removal can, in certain situations, increase the risk to ecosystem health by providing improved pathways for aquatic invasive species, the lack of comprehensive data on invasive species locations prevented this issue from being addressed within the model.

Size of anadromous run: Beyond assessing the extent of current anadromous fish, the Workgroup was interested in using a rating of the size of run for each species of interest. This data does not exist at the regional scale or within most states, and the project budget did not permit the collection of this data through interviews with professionals in each state.

Effectiveness of fish passage: Fish passage facilities vary in the effectiveness in passing target species under various conditions. Ideally, the NCAT assessment would take into account this variation and incorporate it into a passability rating. This data does not exist, although USGS-Conte Lab is investing in the creation of such a dataset which could be incorporated into future NCAT versions.

Historic or likely habitat value: Fish habitat value differs along the longitudinal path of a river or stream, and in some cases that fish habitat value has been modeled (e.g. USFWS work on the Penobscot River). A modeling or expert opinion of fish habitat value was not available throughout the region. Historic habitat information for anadromous species was also not available regionally.

Other anadromous species: The NCAT analysis incorporates data on the current extent of available habitat for seven species for which regional data was available from the ASMFC and USFWS. Workgroup members agreed that future iterations should at the very least include American eel and shortnose sturgeon in the analyses.

Dam mitigation scenario development: The current approach does not allow assessments of the overall ecological benefits of different combinations of multiple dams that might be mitigated.

Species-specific analysis: The current approach allows for assessment of ecological benefits only for broad groups of species. The results would likely be somewhat different if assessments were done for single species. For example, salmon restoration planning would likely not highly value dams that can be leapt by salmon but not by other species.

Incorporation of integrated indices: The Workgroup discussed incorporating a metric that provided an integrative measure of passability, network length, upstream/downstream passage, and fish life history. One example, developed by a Workgroup member, is the Dendritic Connectivity Index. Unfortunately this index was not able to be calculated for the NEAFWA region due to the size of the dataset.

In addition to these technical limitations, there is also a major limitation associated with any restoration prioritization: the ***assessment of feasibility***. The feasibility that fish passage, whether dam removal or one of many types of fish passage facility, can be created at any specific location varies with a range of social, economic, and political factors. These factors cannot be effectively placed in a database, are changing over time, and will always require human judgment to be incorporated into assessment or project planning. Before NCAT outputs are used in a manner that significantly impacts resource distribution, they should be subject to a feasibility assessment at the appropriate scale and level of detail to fit the question being asked.

6.2.2 Future Improvements

Updates to Datasets & Analyses

- A mechanism to incorporate data updates (additions, removal, or modifications) will be important so that the quality of the resulting analysis improves over time. It is important to make the database a living database and be able to complete custom analyses. (VT, PA, NY, NH, USFWS)
- Funding positions to collect the updated data is a problem throughout the Northeast but only with better input data will the NCAT improve (VA)

Adaptive Management of Tool

- As the states begin to use the tool in the “real world” improvement ideas will be formulated. Hopefully, there will be funding available to implement the improvement ideas. (VA)

Overall, state agency staff clearly recognize the limitations associated with the Northeast Aquatic Connectivity project products and that the completion of this NEAFWA-funded project should not be the end of the process. As discussed previously in this report, working at the Northeast scale with existing data imposed many “lowest common denominator” limitations on the project. These included: 1) the inability to incorporate culvert barrier information; 2) inaccuracies in dam, waterfall, and anadromous habitat extent datasets; and 3) the lack of information to evaluate feasibility of dam mitigation. In addition, in order to complete the GIS analyses desired by the TNC project team and Workgroup, the project used 1:100,000 scale hydrography, which led to a loss of approximately half of the dams in the compiled database from the analyses. If the 1:24,000 scale hydrography were used, this number would be expected to increase to approximately 80% of dams in the database, based on tests run in the Chesapeake Bay watershed. Although many of the barriers not included in the analyses are farm ponds or on very small streams, there are also barriers that are not included in the outputs of the NCAT whose removal would benefit resident fish.

In order to address Workgroup feedback during the project term, the Northeast Connectivity Assessment Tool was designed to be used at a range of scales and includes default metric weights chosen by the Workgroup that can be modified by the user. This will allow useful custom analyses to be run, but these analyses can only be executed using the existing region-wide connectivity dataset. The goal of a “living dataset” and a decision support tool based on “real world” improvement ideas, are extremely worthy suggestions outside the scope of the Northeast Aquatic Connectivity Project. State agency recommendations for future improvement such as these inform our own recommendations, which are described in Section 6.4.

Finally, the *Workgroup and the TNC project leadership team strongly believe that the NCAT outputs should not be used as the only basis for assessing the value of a potential project, but be used as one line of evidence to be examined and supplemented with local ecological, opportunity, and feasibility information*. Other lines of evidence may include additional state or basin-specific assessment approaches (Table 2-1 presents several that currently exist), site-specific data, and expert knowledge. NCAT results can be thought of as a "screening level" assessment based on scientific principles and best available data. In addition, given that many dams that are assessed by NCAT are private property or are playing a role in a community, the outputs should be used carefully so they are not misinterpreted as a "target list" for actions that may be undesirable to an owner or a local community.

6.3 Project Leverage and Utility to Federally Funded & Regional Conservation Efforts

The clear enthusiasm for this project, its approach, and initial results were demonstrated by seven regional/national initiatives that have committed to reviewing the results of the project to inform their own efforts. The following is a subset of the feedback received by the TNC project leadership team during the term of the project:

Atlantic States Marine Fisheries Commission - Fish Passage Working Group

- Sees NAC work as high priority and is waiting for NAC products, will review, and likely build upon the results
- Wants to expand results down coast to NC, SC, GA, FL
- Is taking lead on developing a fish passage facility & effectiveness database that could be incorporated into future revisions (Alex Haro, USGS)

Connecticut River Atlantic Salmon Commission (CRASC) - Technical Committee

- Committee had been tasked with developing a system for ranking/scoring fish passage needs in the Connecticut River Basin
- Committee will suggest that CRASC should consider adopting the NCAT approach

U.S. Fish and Wildlife Service- National Fish Passage Program

- Is using elements of the Northeast Aquatic Connectivity project and the Northeast Connectivity Assessment Tool to inform revision of the National Fish Passage Decision Support System

U.S. Army Corps of Engineers

- The Workgroup representative from USACE indicated that the NCAT will be helpful to the Corps in that it will help focus attention on project sites. In addition, the database will assist the Corps in evaluating potential projects sites and their ecological value. This will be important in justifying projects during the funding allocation process.
- The Corps representative suggested that NAC products be posted on the Corps Environmental Gateway Fish Passage web page which is currently under development.

Chesapeake Bay Fish Passage Workgroup

- In 2010, NOAA funded TNC to use its expertise in landscape ecology, connectivity restoration, and GIS data analysis to advance the efforts of the Chesapeake Bay Fish Passage Workgroup in developing a watershed-wide prioritization procedure for Virginia and Maryland. Additional funding was received in 2011 from USFWS to include data acquisition and analysis in Pennsylvania.
- This procedure will build on work done in the Northeast at a finer spatial scale, incorporate more local ecological information, and produce an interactive decision support tool that will be relatively easy to use and update.

The Nature Conservancy

- The NCAT results will be incorporated into an analysis of freshwater ecosystem resilience to climate change. The locations of dams and the lengths of functional networks will critical to this analysis and may be used as a unit of analysis for the resilience work.

Trout Unlimited

- Trout Unlimited (TU) is working with the National Fish and Wildlife Foundation to identify fish passage priorities for a NFWF River Herring Keystone Initiative and will use dam rankings to inform prioritization. Dam rankings will be integrated into TU's Conservation Success Index for Atlantic Salmon
- TU will integrate dam rankings into a threat assessment used to identify key anadromous fish communities for protection and restoration from Maine to Virginia.

6.4 Strategic Investment Recommendations for Northeast Connectivity Restoration

Based on state agency feedback outlined in Section 6.1, it is clear that investing in the Northeast Aquatic Connectivity Project (NAC) was a strategic decision by the Northeast Association of Fish and Wildlife Agencies. The project created a regional network of professionals, advanced efforts towards unified and improved datasets, and resulted in a set of tools that can be customized to the scale or emphases of the user. The momentum associated with NAC looks unlikely to halt at the end of the NEAFWA-funded project given the actions and interest outlined in Section 6.3, yet nonetheless there is potential gap in multi-state action on this critical resource management topic.

The TNC Project leadership team believes that one important role that NEAFWA (or another multi-state body) can play going forward is to ensure that the Northeast Connectivity Assessment Tool (NCAT) and associated analysis tools (e.g. the Barrier Analysis Tool-BAT) are available online. This is likely possible through the RCN website, where other NEAFWA products are accessible. More difficult will be maintaining the momentum of the network and the desire to have a database and decision support system that can be updated and upgraded over time. We suggest that to accomplish these goals, the Northeast Aquatic Connectivity Workgroup should continue to virtually meet on an annual basis to review and discuss:

1. Use of, and complications with the use of, the NCAT and associated products at the state, basin or multi-state scales
2. Updates that have been made to state or other relevant databases
3. New decision support systems and assessment methodologies that have been developed in the region (e.g. future Chesapeake Connectivity Tool)
4. Assess potential collaborations with federal and other multi-state institutions, including those outside the Northeast region
5. Recommendations for revision of the Northeast Aquatic Connectivity databases (e.g. new dam removals, impassable waterfall locations, anadromous fish habitat extent)
6. Recommendations for revision NCAT methodology (e.g. default weights)
7. Recommendations for addition to the Northeast Aquatic Connectivity databases (e.g. culvert assessment data, anadromous or resident habitat information, regional ecological databases)

Of course, any recommendations made by the Workgroup, if it continues, would require an implementing body to follow through on some or all of these recommendations. It is unclear who the implementer would be at this stage, although various options exist and it need not be only one institution that is involved. The following federal and inter-state organizations could support some, or all, of this implementation role:

- Northeast Association of Fish and Wildlife Agencies (e.g., funding, coordination, web posting of tools and data)
- Atlantic States Marine Fisheries Commission (e.g., improvement of anadromous fish habitat database, funding)
- U.S. Fish and Wildlife Service – National Fish Passage Decision Support System (e.g., responsibility for database updates, incorporation of new ideas into FPDSS)
- U.S. Fish and Wildlife Service – Landscape Conservation Cooperatives (e.g. funding, data development in North Atlantic LCC)
- U.S. Geological Survey- Conte Anadromous Fish Laboratory (e.g., creation of fish passage facilities database)
- National Oceanic and Atmospheric Administration (e.g. funding, anadromous fish data development)

In addition, there are non-governmental, private, and academic institutions that could also play an implementation role. These organizations would likely need some funding support, and include but not limited to:

- The Nature Conservancy
- Trout Unlimited

- American Rivers
- The University of Massachusetts-Amherst
- Virginia Commonwealth University

Although many potential variables would be at play in any effort to update and rerun this analysis to incorporate Workgroup recommendations, some rough estimates can be made for planning purposes of an implementing body. The following assumes Workgroup members from the participating states would provide data edits (to dams, waterfalls, and/or anadromous fish data) and TNC would perform the update using the same methodology. First, data edits would be incorporated into the master project database. The amount of time required to do this would vary depending on the quantity and type of data edits received. For example removing a dam from the database is faster than adding a new dam, snapping it to the hydrography, and verifying the results. That said, 5 – 10 days of GIS Analyst labor should be to sufficient to incorporate changes that had been accumulated by the states over the course of a year or two. Re-calculating the metrics for dams would take approximately 3 days of labor. Finally, additional time should be budgeted to review the results with Workgroup members, particularly if changes were also made to metric weights. In sum, TNC would expect it to take approximately 15 days of labor to run an annual or bi-annual update to this analysis. Changes to the methodology would likely increase this estimate, depending on the specific changes at hand.

There are also agencies and institutions outside of the thirteen state Northeast region that are very interested in participating in a future phase of the Northeast Aquatic Connectivity project. In particular, early phases of the project included strong participation from Canadian provincial agencies. Specifically, resource agency staff from Quebec, New Brunswick, Nova Scotia, and Newfoundland contributed to the scoping and methodology undertaken in the NAC project (see Workgroup list in Table 1-1 and Appendix 1). This high level of participation was despite the fact that funds were not available to complete any analyses in these provinces. An expansion of this work into Canadian provinces would be welcomed by these resource agencies. In addition, the TNC project leadership team has had multiple conversations with staff and contractors of the Southeast Aquatic Resources Partnership (SARP), who have shown significant interest in developing a Southeast Aquatic Connectivity project and are wrestling with many of the same, or more difficult, data limitations than were experienced in the NAC project. This demonstrated interest from beyond the Northeast region provides an opportunity not just to leverage the success of the Northeast Aquatic Connectivity project, but to find resources to accomplish these recommendations and future Workgroup goals.

Beyond these more process-based recommendations, it is clearly important to focus on ensuring that fish passage restoration project selection is influenced by the results of the NAC project and that biological outcomes “in-the-water” allow for adaptive management of the NCAT approach. Primary funders such as NOAA and USFWS need to both understand the value of NCAT outputs and its limitations. Although certain NOAA and USFWS offices have already shown their interest and understanding of the approach, TNC’s project leadership team should be available to make sure that all key funding agency program staff are briefed on NCAT results and have their questions answered on its potential use. We would also recommend that one to two years after funding agencies begin using these results, NEAFWA leadership and/or the Northeast Aquatic Connectivity Workgroup (if it continues) complete a review of how NCAT information is being used and what might be improved about tool, underlying data, or use of the data. Taking an adaptive management approach in the use of NCAT would likely help to counteract the valid concern that some state agency staff have about sole reliance on NCAT results to the exclusion of local data and knowledge on ecological conditions, opportunity and feasibility.

7 Conclusion

As documented in the previous six sections, the Northeast Aquatic Connectivity Project (NAC) has resulted in a set of valuable outcomes that will assist resource agencies in the Northeastern U.S. in efforts to strategically reconnect fragmented aquatic habitats by targeting removal or bypass of key barriers to fish passage. Among its accomplishments, the project:

- created a regional network of professionals engaged in aquatic organism passage and assessment of potential ecological benefits associated with barrier mitigation;
- produced the first unified, error-checked database of dams, impassable waterfalls, and anadromous fish habitat across the thirteen state Northeast region that was critical to the NAC but which also has potential benefits for a range of Northeastern management and conservation initiatives;
- provided state agencies and partners a basis to move from opportunistic project selection to a more "ecological-benefits" approach to dam removal and fish passage improvement;
- developed a tool that allows managers to re-rank dams at multiple scales (state, HUC, etc) or using attribute filters (river size class, dam type, etc) and to examine 72 ecologically-relevant metrics linked to dam locations; and
- delivered an extensive set of outputs on the relative ecological benefits to anadromous and resident fish from barrier mitigation that can be used to inform river restoration decision-making at the dam or river network scale.

Major insights from the output of the Northeast Connectivity Assessment Tool using default weightings include:

- All thirteen NEAFWA states have one or more dams in the top 10% tier in the anadromous fish benefits scenario.
- All but one of the NEAFWA states have one or more dams in the top 10% tier in the resident fish benefits scenario
- Which states have the most potential for ecological benefits from dam mitigation varies based on how you look at the question, for example:
  - For the anadromous scenario, Maine and Virginia have the most dams in the top assessment tier, although Massachusetts, New Jersey and Delaware have the most dams in the top tier when state river length is taken into account.
  - For the resident scenario, New York, Virginia, Maine and Pennsylvania have the most dams in the top tier, but when state river length is taken into account West Virginia also rises to the top
- All major North Atlantic Coast basins have dams that are relatively highly ranked in terms of potential ecological benefit for resident and anadromous fish, although the location of these top tier dams within the basin varies based on scenario and the geography of the basin itself.
- The default results of the NCAT should be able to provide an ecologically-based lens to inform restoration decision-making in all NEAFWA states given the breadth and depth of opportunities.

State agency-identified uses for the products of the Northeast Aquatic Connectivity Project include acquisition of project funding, development of basin/watershed management plans, focusing restoration work, supporting advocacy, communications, measures, and support for state administrative action. The outputs of the Northeast Connectivity Assessment Tool (NCAT) also have some weaknesses, including some incomplete or poor quality data inputs, the scale of hydrography and analysis, the lack of a “feasibility filter”, and the absence of regional culvert assessment information. In addition, if NCAT results are used uncritically there is the potential for funders or other decision-makers to ignore the need to incorporate feasibility and other site-specific information into restoration planning.

Overall, there is clear momentum behind the products and approach of the Northeast Aquatic Connectivity Workgroup, and many are motivated not only to use the initial products but to make sure that the tool and its underlying data improve over time. Federal and multi-state agencies such as Atlantic States Marine Fisheries Commission, U.S. Fish and Wildlife Service, the National Oceanic and Atmospheric Administration, the U.S Army Corps of Engineers and the Connecticut River Atlantic Salmon Commission have all shown either great interest or funding commitment to using and building upon the Northeast Aquatic Connectivity project. This is an affirmation of NEAFWA’s investment but also presents a challenge given the geographic scope and institutional complications associated with maintaining and updating a database and decision support tool. Regardless of future direction, the NAC project and its products have significantly advanced the dialogue on strategically advancing connectivity restoration at the regional and basin scale.

Perhaps the most appropriate way to end a report on a project this collaborative is with a quote from a Maryland Department of Natural Resources staff member that participated through the entire project. The “team should be commended for bringing together a broad group of people and keeping them focused on this project for an extended period of time. The results show the benefits of this input and your ability to synthesize it in a reasonable way."

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Table 1-1: List of Workgroup Participants

Representation	Name	Organization
CT	Steve Gephard	CT Department of Energy & Env. Protection
CT	Neal Hagstrom	CT Department of Energy & Env. Protection
CT	Peter Aarested	CT Department of Energy & Env. Protection
CT	Shelley Green	The Nature Conservancy
CT,MA,VT,NH	Amy Singler	American Rivers
CT,MA,VT,NH	Kim Lutz	The Nature Conservancy
DE	Matt Fisher	Delaware Division of Fish and Wildlife
MA	Alicia Norris	MA Dept. of Fish and Wildlife
MA	Christopher Leuchtenburg	MA Dept. of Fish and Game, Riverways Program
MA	Beth Lambert	MA Dept. of Fish and Game, Riverways Program
MA	Alison Bowden	The Nature Conservancy
MA	Scott Jackson	UMASS Extension
MD	Jim Thompson	Maryland DNR
MD	Nancy Butowski	Maryland DNR
ME	Merry Gallagher	Inland Fish's & Wildl. - EBTJV
ME	Josh Royte	The Nature Conservancy
NB	Kathryn Ann Collet	New Brunswick Natural Resources Dept
NH	John Magee	NH Fish and Game
NH	Cheri Patterson	NH Fish and Game
NH	Kevin Sullivan	NH Fish and Game
NH	Doug Bechtel	The Nature Conservancy
NJ	Lisa Barno	NJ Department of Environmental Protection
NJ	Christopher Smith	NJ Department of Environmental Protection
NJ	Ellen Creveling	The Nature Conservancy
NOAA	Matt Collins	NOAA Restoration Center
NOAA	Mary Andrews	NOAA
NY	Doug Sheppard	NY Department of Environmental Conservation
NY	Josh Thiel	NY Department of Environmental Conservation
NY	George Schuler	The Nature Conservancy
NY	Craig Cheeseman	The Nature Conservancy
PA	Scott Carney	PA Fish and Boat Commission
PA	Ben Lorsen	PA Fish and Boat Commission
PA	Michele DePhilip	The Nature Conservancy
PA	Su Fanok	The Nature Conservancy
QC	Suzanne Lepage	Ministère des Ressources naturelles et de la Faune
QC	Jolyane Roberge	Ministère des Ressources naturelles et de la Faune
QC	Sylvain Roy	Ministère des Ressources naturelles et de la Faune
QC	Ariane Masse	Ministère des Ressources naturelles et de la Faune
NL	Dr. Dave Cote	Terra Nova National Park
NS	Dan Kehler	Parks Canada, Atlantic Service Center
Regional	Erik Martin	The Nature Conservancy
Regional	Colin Apse	The Nature Conservancy
Regional	Mark P. Smith	The Nature Conservancy
Regional	Arlene Olivero	The Nature Conservancy
Regional	Mark Anderson	The Nature Conservancy

Regional	Nat Gillespie	Trout Unlimited/USFS
Regional	Carolyn Hall	Trout Unlimited
Regional	Dan Dauwalter	Trout Unlimited
RI	Christine Dudley	Rhode Island Division Fish and Wildlife
Southeast	Duncan Elkins	UGA/SARP
Southeast	Mary Davis	SIFN
USFS-TNC	Mark Fedora	USFS-TNC
USFWS	Jose Barrios	USFWS Fish Passage Program
USFWS	Jed Wright	USFWS Gulf of Maine
USFWS	Alex Abbott	USFWS Gulf of Maine
USFWS	Martha Naley	USFWS
USFWS	Ray Li	USFWS
USGS	Alex Haro	USGS Conte Lab
VA	Alan Weaver	Virginia Dept. of Game & Inland Fisheries
VT	Rod Wentworth	VT Agency of Natural Resources
VT	Brian Fitzgerald	VT Agency of Natural Resources
VT	Len Gerardi	VT Fish and Wildlife Department
VT	Rich Kirn	VT Fish and Wildlife Department
VT	Roy Schiff	Milone & MacBroom
WV	David Thorne	WV Division of Natural Resources
WV	Dan Cincotta	WV Division of Natural Resources
WV	Walt Kordek	WV Division of Natural Resources
WV	Jim Hedrick	WV Division of Natural Resources
WV	Ruth Thornton	The Nature Conservancy

Table 4-1: List and description of metrics calculated for dams

The following table lists all metrics that were calculated for dams in the Northeast Aquatic Connectivity project. Subsets of these metrics were used in the anadromous fish benefits scenario and resident fish benefits scenario, as presented in Figure 2-2. All of these metrics are available for use in custom weight scenarios using the NCAT. For ranking purposes the "Sort Order" indicates whether large values are considered desirable or not. For example, large values are desirable when evaluating the length of a dam's upstream connected network because more habitat would be available to fish if that dam were removed. Conversely, small values are desirable when evaluating the number of hydropower dams downstream of a given dam. Up arrows indicate the metric is ranked in ascending order (i.e. small values are desirable). Down arrows indicate the metric is ranked in descending order (i.e. larger values are desirable.)

Connectivity Status Metrics

Metric	Sort Order	Definition	Notes
Upstream Dam Count	↑	The number of dams upstream of a given dam	Calculated in GIS using BAT
Downstream Dam Count	↑	The number of dams downstream of a given dam	Calculated in GIS using BAT
Downstream Impassable Dam Count	↑	The number of "impassable" dams downstream of a given dam. Impassable dams defined by overlay of state-reviewed anadromous fish data.	Calculated in GIS using BAT
Upstream Dam Density	↑	Upstream Dam Count divided by the total length of river upstream	Calculated in GIS using BAT
Downstream Dam Density	↑	Downstream Dam Count divided by the distance to river mouth	Calculated in GIS using BAT
Distance to River Mouth from Dam	↑	Distance from each dam to the river mouth (ocean)	Calculated in GIS using BAT
Upstream River Length	↓	Total length of river upstream of a dam. The total network available, ignoring all upstream dams	Calculated in GIS using BAT
Density of Small (1:24k) Dams in Upstream Functional Network Local Watershed	↑	Number of dams on small streams (dams did not snap to 1:100k NHDPlus) within the local watershed of the upstream functional network divided by the watershed area	Calculated using Model Builder in ArcGIS

Density of Small (1:24k) Dams in Downstream Functional Network Local Watershed	↑	Number of dams on small streams (dams did not snap to 1:100k NHDPlus) within the local watershed of the downstream functional network divided by the watershed area	Calculated using Model Builder in ArcGIS
Density of Road & Railroad / Small Stream Crossings in Upstream Functional Network Local Watershed	↑	Number of Road/Railroad and hydrography intersections within upstream functional network local watershed divided by watershed area	Calculated using Model Builder in ArcGIS Only small streams (<= Creeks) included. Larger streams more likely to have bridges
Density of Road & Railroad / Small Stream Crossings in Downstream Functional Network Local Watershed	↑	Number of Road/Railroad and hydrography intersections within downstream functional network local watershed divided by watershed area	Calculated using Model Builder in ArcGIS Only small streams (<= Creeks) included. Larger streams more likely to have bridges
Number of Hydro Dams on Downstream Flowpath	↑	Count of hydropower dams on downstream flowpath of a given dam	Calculated in GIS using BAT "Point Accumulate"
Number of Waterfalls on Downstream Flowpath	↑	Count of waterfalls on downstream flowpath of a given dam	Calculated in GIS using BAT "Point Accumulate"

Connectivity Improvement Metrics

Metric	Sort Order	Definition	Notes
Downstream Functional Network Size	↓	Length of the functional network downstream of a dam. 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.	Calculated in GIS using BAT
Upstream Functional Network Size	↓	Length of the functional network upstream of a dam. 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.	Calculated in GIS using BAT

The total length of upstream and downstream functional network	↓	Summed length of the upstream and downstream functional networks of a dam. 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.	Calculated in GIS using BAT
Absolute Gain	↓	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.	Calculated in GIS using BAT
Relative Gain	↓	This metric is Absolute gain divided by the total connected length	Calculated in GIS using BAT

Watershed and Local Condition Metrics

Metric	Sort Order	Definition	Notes
% Impervious Surface in Contributing Watershed	↑	% Impervious surface in entire upstream watershed. Calculated from NFHAP Human Disturbance data linked to the stream segment (COMID) on which the dam falls	Calculated in GIS using ArcGIS Model Builder.
% Natural LC in Contributing Watershed	↓	% natural landcover in entire upstream watershed. Calculated from NHDPlus VAA data (NLCD2001) linked to the stream segment (COMID) on which the dam falls. Where "natural" = Open water, perennial ice/snow, barren land, unconsolidated shore, deciduous forest, evergreen forest, mixed forest, scrub/shrub, grasslands, woody wetlands, emergent herbaceous wetlands	Calculated in GIS using NHDPlus landcover accumulation data
% Agricultural LC in Contributing Watershed	↑	% agricultural landcover in entire upstream watershed. Calculated from NHDPlus VAA data (NLCD2001) linked to the stream segment (COMID) on which the dam falls. Where "Agriculture" = pasture/hay	Calculated in GIS using NHDPlus landcover accumulation data

		and cultivated crops.	
% Impervious Surface in 100m Buffer of Upstream Functional Network	↑	% Impervious surface within 100m buffer of the upstream functional river network. Based on NLCD 2006.	Calculated using Model Builder in ArcGIS
% Impervious Surface in 100m Buffer of Downstream Functional Network	↑	% Impervious surface within 100m buffer of the downstream functional river network. Based on NLCD 2006.	Calculated using Model Builder in ArcGIS
% Natural LC in 100m Buffer of Upstream Functional Network	↓	% natural landcover within 100m buffer of the upstream functional river network. Based on NLCD 2006 where "natural" = Open water, perennial ice/snow, barren land, unconsolidated shore, deciduous forest, evergreen forest, mixed forest, scrub/shrub, grasslands, woody wetlands, emergent herbaceous wetlands	Calculated using Model Builder in ArcGIS
% Natural LC in 100m Buffer of Downstream Functional Network	↓	% natural landcover within 100m buffer of the downstream functional river network. Based on NLCD 2006 where "natural" = Open water, perennial ice/snow, barren land, unconsolidated shore, deciduous forest, evergreen forest, mixed forest, scrub/shrub, grasslands, woody wetlands, emergent herbaceous wetlands	Calculated using Model Builder in ArcGIS
% Agriculture in 100m Buffer of Upstream Functional Network	↑	% agricultural landcover within 100m buffer of the upstream functional river network. Based on NLCD 2006 where "Agriculture" = pasture/hay and cultivated crops.	Calculated using Model Builder in ArcGIS
% Agriculture in 100m Buffer of Downstream Functional Network	↑	% agricultural landcover within 100m buffer of the downstream functional river network. Based on NLCD 2006 where "Agriculture" = pasture/hay and cultivated crops.	Calculated using Model Builder in ArcGIS
% Impervious Surface in ARA of Upstream Functional Network	↑	% impervious landcover within Active River Area of the upstream functional river network. Based on NLCD 2006.	Calculated using Model Builder in ArcGIS
% Impervious Surface in ARA of Downstream Functional Network	↑	% impervious landcover within Active River Area of the downstream functional river network. Based on NLCD 2006.	Calculated using Model Builder in ArcGIS
% Natural LC in ARA of Upstream Functional Network	↓	% natural landcover within Active River Area of the upstream functional river network. Based on NLCD 2006	Calculated using Model Builder in ArcGIS

		where "natural" = Open water, perennial ice/snow, barren land, unconsolidated shore, deciduous forest, evergreen forest, mixed forest, scrub/shrub, grasslands, woody wetlands, emergent herbaceous wetlands	
% Natural LC in ARA of Downstream Functional Network	↓	% natural landcover within Active River Area of the downstream functional river network. Based on NLCD 2006 where "natural" = Open water, perennial ice/snow, barren land, unconsolidated shore, deciduous forest, evergreen forest, mixed forest, scrub/shrub, grasslands, woody wetlands, emergent herbaceous wetlands	Calculated using Model Builder in ArcGIS
% Agriculture in ARA of Upstream Functional Network	↑	% agricultural landcover within Active River Area of the upstream functional river network. Based on NLCD 2006 where "Agriculture" = pasture/hay and cultivated crops.	Calculated using Model Builder in ArcGIS
% Agriculture in ARA of Downstream Functional Network	↑	% agricultural landcover within Active River Area of the downstream functional river network. Based on NLCD 2006 where "Agriculture" = pasture/hay and cultivated crops.	Calculated using Model Builder in ArcGIS
Dam falls on Conserved Land	↓	Dam intersects 2009 secured area database (TNC)	Calculated using Model Builder in ArcGIS
% Conserved Land within 100m Buffer of Upstream Functional Network	↓	% of land within 100m buffer of upstream functional network that intersects 2009 secured areas database (TNC)	Calculated using Model Builder in ArcGIS
% Conserved Land within 100m Buffer of Downstream Functional Network	↓	% of land within 100m buffer of downstream functional network that intersects 2009 secured areas database (TNC)	Calculated using Model Builder in ArcGIS

Ecological Metrics

Metric	Sort Order	Definition	Notes
American Shad habitat in Downstream Functional Network	↓	Presence of American shad in some portion of downstream functional network. Based on state reviewed / amended ASMFC 2006 data.	Calculated using Model Builder in ArcGIS

Blueback herring habitat in Downstream Functional Network	↓	Presence of blueback herring in some portion of downstream functional network. Based on state reviewed / amended ASMFC 2006 data.	Calculated using Model Builder in ArcGIS
Hickory shad habitat in Downstream Functional Network	↓	Presence of hickory shad in some portion of downstream functional network. Based on state reviewed / amended ASMFC 2006 data.	Calculated using Model Builder in ArcGIS
Alewife habitat in Downstream Functional Network	↓	Presence of alewife in some portion of downstream functional network. Based on state reviewed / amended ASMFC 2006 data.	Calculated using Model Builder in ArcGIS
Atlantic sturgeon habitat in Downstream Functional Network	↓	Presence of Atlantic sturgeon in some portion of downstream functional network. Based on state reviewed / amended ASMFC 2006 data.	Calculated using Model Builder in ArcGIS
Striped bass habitat in Downstream Functional Network	↓	Presence of striped bass in some portion of downstream functional network. Based on state reviewed / amended ASMFC 2006 data.	Calculated using Model Builder in ArcGIS
Atlantic salmon habitat in Downstream Functional Network	↓	Presence of Atlantic salmon in some portion of downstream functional network. Based on state reviewed / amended ASMFC 2006 data.	Calculated using Model Builder in ArcGIS
Presence of anadromous species Current & Historic (binary, yes/no)	↓	Presence of any one of the 7 anadromous fish species in some portion of downstream functional network. Based on state reviewed / amended ASMFC 2006 data.	Calculated using Model Builder in ArcGIS
Presence of anadromous species Current Only (binary, yes/no)	↓	Presence of any one of the 7 anadromous fish species in some portion of downstream functional network, current data only (excluding historical/restoration potential). Based on state reviewed / amended ASMFC 2006 data.	Calculated using Model Builder in ArcGIS
Number of anadromous species present downstream	↓	Number of anadromous species present in some portion of downstream functional network. Current data only. Based on state reviewed / amended ASMFC 2006 data.	Calculated using Model Builder in ArcGIS
Current # of rare (G1-G3) fish species in HUC8 (@ dam)	↓	Current # of rare (G1-G3) fish, species in HUC8 that dam is within. Based on NatureServe data.	Calculated using Model Builder in ArcGIS
Current # of rare (G1-G3) mussel	↓	Current # of rare (G1-G3) mussel,	Calculated using Model

HUC8 (@ dam)		species in HUC8 that dam is within. Based on NatureServe data.	Builder in ArcGIS
Current # of rare (G1-G3) crayfish HUC8 (@ dam)	↓	Current # of rare (G1-G3) crayfish, species in HUC8 that dam is within. Based on NatureServe data.	Calculated using Model Builder in ArcGIS
Current "Healthy" Eastern Brook Trout in upstream functional network (EBTJV dataset)	↓	Dam falls in HUC8 with "healthy" eastern brook trout population. Based on EBTJV survey and modeled data.	Calculated using Model Builder in ArcGIS
Current Native fish species richness - HUC 8 (@ dam)	↓	Current # of fish species in HUC8 that dam is within. Based on NatureServe data.	Calculated using Model Builder in ArcGIS

Size Metrics

Metric	Sort Order	Definition	Notes
River Size Class	↓	River size class, based on upstream drainage area. Based on NEAHCS NHDPlus data	Calculated using Model Builder in ArcGIS
Number of new upstream size classes >0.5 miles gained by removal	↓	Number of stream sizes gained if dam were to be removed. Stream segments must be >0.5 miles to be considered a gain. Based on NEAHCS NHDPlus data	Calculated using Model Builder in ArcGIS, summarized in Excel
Gain in Stream Size Relative to Total Length of Reconnected Functional Network	↓	Gain in Stream Size Relative to Total Length of Reconnected Network: miles new size classes / total miles. Based on NEAHCS NHDPlus data	Calculated using Model Builder in ArcGIS, summarized in Excel
Miles Gained of Cold Water Habitat (any stream size)	↓	Total recombined miles of cold water habitat. Based on NEAHCS NHDPlus data.	Calculated using Model Builder in ArcGIS
Miles Gained of Cold & Transitional Cool Habitat (any stream size)	↓	Total recombined miles of cold / cool transitional water habitat. Based on NEAHCS NHDPlus data.	Calculated using Model Builder in ArcGIS
Upstream network # of stream sizes >0.5 Mile	↓	Number of unique stream size classes in upstream functional network, where segments are >0.5 miles	Calculated using Model Builder in ArcGIS, summarized in Excel
Upstream Network Miles in Headwaters	↓	Number of miles of headwater (size1a) in a dam's upstream functional network, where headwaters <3.861 sq. mi drainage	Calculated using Model Builder in ArcGIS
Upstream Network Miles in Creeks	↓	Number of miles of creeks (size1b) in a dam's upstream functional network, where creeks	Calculated using Model Builder in ArcGIS

		>=3.861<38.61 sq. mi. drainage	
Upstream Network Miles in Small Rivers	↓	Number of miles of small rivers (size2) in a dam's upstream functional network, where small river >=38.61<200 sq. mi. drainage	Calculated using Model Builder in ArcGIS
Upstream Network Miles in Medium Tributary Rivers	↓	Number of miles of medium tributary rivers (size3a) in a dam's upstream functional network, where medium tributary rivers >=200<1000 sq. mi. drainage	Calculated using Model Builder in ArcGIS
Upstream Network Miles in Medium Mainstem Rivers	↓	Number of miles of medium mainstem rivers (size3b) in a dam's upstream functional network, where medium mainstem rivers >=1000<3861 sq. mi. drainage	Calculated using Model Builder in ArcGIS
Upstream Network Miles in Large Rivers	↓	Number of miles of large rivers (size4) in a dam's upstream functional network, where large rivers >=3861 < 9653 sq. mi. drainage	Calculated using Model Builder in ArcGIS
Upstream Network Miles in Great Rivers	↓	Number of miles of great rivers (size5) in a dam's upstream functional network, where great rivers >=9653 sq. mi. drainage	Calculated using Model Builder in ArcGIS
Total Reconnected # stream sizes (upstream + downstream) >0.5 Mile	↓	Miles of headwaters (size 1a) in recombined (upstream + downstream) functional networks where headwaters <3.861 sq. mi drainage	Calculated using Model Builder in ArcGIS, summarized in Excel
Total Reconnected Network Miles in Headwaters	↓	Miles of headwaters (size 1a) in recombined (upstream + downstream) functional networks where headwaters <3.861 sq. mi drainage	Calculated using Model Builder in ArcGIS, summarized in Excel
Total Reconnected Network Miles in Creeks	↓	Miles of creeks (size 1b) in recombined (upstream + downstream) functional networks, where creeks >=3.861<38.61 sq. mi. drainage	Calculated using Model Builder in ArcGIS, summarized in Excel
Total Reconnected Network Miles in Small Rivers	↓	Miles of small rivers (size 2) in recombined (upstream + downstream) functional network, where small river >=38.61<200 sq. mi. drainage	Calculated using Model Builder in ArcGIS, summarized in Excel
Total Reconnected Network Miles in Medium Tributary Rivers	↓	Miles of medium tributary river (size3a) in recombined (upstream +	Calculated using Model Builder in ArcGIS,

		downstream) functional network, where medium tributary rivers >=200<1000 sq. mi. drainage	summarized in Excel
Total Reconnected Network Miles in Medium Mainstem Rivers	↓	Miles of medium mainstem rivers (size 3b) in recombined (upstream + downstream) functional network, where medium mainstem rivers >=1000<3861 sq. mi. drainage	Calculated using Model Builder in ArcGIS, summarized in Excel
Total Reconnected Network Miles in Large Rivers	↓	Miles of large rivers (size 4) in recombined (upstream + downstream) functional network, where large rivers >=3861 < 9653 sq. mi. drainage	Calculated using Model Builder in ArcGIS, summarized in Excel
Total Reconnected Network Miles in Great Rivers	↓	Miles of great rivers (size 5) in recombined (upstream + downstream) functional network, where great rivers >=9653 sq. mi. drainage	Calculated using Model Builder in ArcGIS, summarized in Excel