A GIS Tool Prioritizing Dams for Removal within the State of North Carolina

By:

Kathleen McCole Hoenke

Dr. Mukesh Kumar, Co-Advisor
Dr. Martin Doyle, Co-Advisor
American Rivers, Client

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MP Advisor's signature

ABSTRACT

A GIS tool for prioritizing removal of dams based on ecological and social metrics is presented. The Barrier Prioritization Tool uses a hierarchical decision making framework that entails identification of an objective, criteria of qualities that meet that objective, and measurable indicators to quantify if criteria is met. Here the primary objective is to identify the best dams to remove. Criteria include good habitat connectivity, good water quality connectivity and connectivity of stream miles while avoiding social conflict, improving flow downstream, and improving safety. Sensitivity of rankings to habitat indicators used indicates that indicators of habitat quality overlap. Following the construction of the Barrier Prioritization Tool, three prioritization scenarios are conducted for American Rivers; one prioritization includes social and safety criteria, another includes only ecological criteria, and the third is a prioritization specific to anadromous fish. All three of these prioritization scenarios identify dams within the top 20 ranked dams that are currently classified as pre-identified potential dam-removal projects, indicating that the tool is performing as intended. Dam removal has proven to be an effective mechanism of quickly restoring in-stream habitat for lotic species through connecting fragmented river networks and returning the system to a free flowing state. By aiding in the dam removal project identification process, this tool makes the restoration of streams through dam removal more efficient. In the future, this tool will be used by American Rivers and their colleagues to run other prioritizations of the tool while experimenting with different indicator and criteria weights in order to find more potential projects for removal.

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I: INTRODUCTION

Rivers are important ecosystems for aquatic species as well as local economies. Restoration of degraded river ecosystems can substantially improve their conditions for organisms and humans alike (American Rivers, 2002). Presently, the option of dam removal is considered an effective method for restoring a river by returning it to a more natural state. Generally many dams provide benefits such as flood control, hydropower and water supply. However, after the early settlement of Americans, many Mill Acts were created in order to encourage the development of the milling industry and the economy. Therefore, a large number of dams in North Carolina were constructed to power mills up until the 1700s, and are now outdated and no longer serve their originally intended purpose (Walter and Merritts, 2008). These dams tend to be small, (25 feet high and smaller), though some large dams do exist in the state. Dams can negatively impact river ecosystems, and large dams impact rivers differently than small dams. Small dams degrade lotic habitat quality and fragment the river network, making the survival of lotic species and anadromous more difficult. On the contrary, larger dams tend to alter the flow and sediment transport of the system, and degrade water quality (Bednarek, 2001).

Within the state of North Carolina, river basins are extremely important to the survival and reproduction of anadromous fish, which travel upstream from the ocean to spawn in the spring of every year. Without connected river networks, anadromous fish struggle to gain access to important spawning grounds. However, it has been found that anadromous fish take advantage of upstream spawning habitat restored through dam removal, such as in the case of the removal of Quaker Neck Dam on the Neuse River near Goldsboro, North Carolina (Burdick and Hightower, 2006). Anadromous fish are historically important in North Carolina. Rivers such as the Roanoke are home to anadromous river herring (*Alosa pseudoharengus, Alosa aestivalis*) and American shad (*Alosa sapidissima*), important species to commercial and recreational fisheries all throughout history to present (Watson, 1996). As far back in 1787, citizens of Orangeburg, South Carolina took a stand against the Edisto dam, a dam constructed to power a (Furgason) Sawmill, claiming it deprived them of "the benefits and emoluments of a [shad] fishery [that] their fellow citizens living upon other water courses 200 miles above said dam enjoy with plenty" and highlighted the role of dams in blockage of fish migration (Watson, 1996).

In addition to anadromous fish, North Carolina rivers are also home to an astoundingly diverse assortment of aquatic species. In fact, the Southeast region is home to two thirds of all of the freshwater fish and mussel species in North America, and also has the highest percentage of threatened or endangered freshwater species within the United States (Master et al., 1998). Specific endangered species within North Carolina include the Cape Fear shiner (*Notropis mekistocholas*), a small fish species endemic to the region, and a variety of rare freshwater mussels (NCDENR, 2011). All of these species are directly impacted by changes in connectivity of the river network and fragmentation and transformation of habitat due to the presence of small dams. These small dams both restrict the movement of species and transform the habitat upstream of the dam to a more lentic environment (Hayes et al., 2006). This lentic environment is associated with a lower fish species richness upstream of the dam when compared to downstream, therefore altering the fish community in the upstream reach (Helms et al., 2011).

Larger dams have a greater impact on flow alteration than smaller dams. Diminished flow in river ecosystems was the primary predictor of biological integrity for fish and macroinvertebrate communities in a study by Carlisle et al (2010). Diminished flow directly correlates with an increased impairment of streams. Impairment, a term used to describe a stream that is no longer meeting water quality standards, is caused by decreasing levels of dissolved oxygen, high nutrient levels, and accumulation and suspension of sediments. Impairment is caused by point and non-point source pollution like storm water runoff from urban areas, and is created and/or exacerbated by man-made barriers (dams and culverts) (Carlisle, 2010). Large dams also alter water temperature and dissolved oxygen in river systems in a variety of ways, particularly in large impoundments formed by large dams. First, these dams alter temperature by slowing the flow of water, which sometimes causes temperature stratification. In these instances, the epilimnion (upper) portion of the water will warm, and decrease in density while cool dense water will sink to the hypolimnion (lower portion). This phenomenon creates a stratification of these two layers, and they will mix together less frequently than in a free-flowing system. As microorganisms respire in the hypolimnion, oxygen is depleted but cannot be replenished without mixing, therefore possibly forming dead zones (areas with no dissolved oxygen) in deeper layers (Bednarek, 2001).

In addition to stratification caused by warming, warmer temperatures both within the impoundments may negatively impact fish and other species that are unable to acclimate to these changes (Olden and Naiman, 2009) (Bendarek, 2001). In North Carolina, three large dams have been identified by the NC Division of Water Quality as the direct cause of impairment to the segment of the river upstream through reducing the dissolved oxygen and decreasing the quality of fish and benthic communities. In addition, alteration of the natural river flow by large, particularly hydropower, dams can change the thermal regime of a river, and have negative impacts on species downstream where warm surface waters are released. Removal of the dam has the potential to remedy these issues. Although there are few studies that have examined temperature change as a result of dam removal, a study by Bartholomew et al. modeled the effects of removing a dam on the Klamath River on the West Coast. They discovered that dam removal would restore the timing of the river to its natural 'thermal signature,' making the water resemble ambient temperatures; a positive change for the Chinook salmon in that region (Bartholomew, 2005). Also, if dam removal is not an option, altering the release of water from large dams so that it resembles more of a natural flow regime can be beneficial to species in the watershed (Olden and Naiman, 2009).

Finally, larger dams also alter sediment transport. Flowing systems naturally transport sediment, particularly bed load material, which creates habitat for organisms such as benthic macroinvertebrates and replenishes areas that have eroded downstream. Specific types of sediments are important for certain species during spawning, like salmon. Dams slow this transport, and create a buildup of sediment upstream (Walter and Merritts, 2008). Removing a dam would restore sediment transport, and expose cobble upstream, bringing back natural riffles and pools (American Rivers, 2002).

On the social front, many dams are old and non-functional, creating safety hazards throughout the state. Over 75% of dams in North Carolina are privately owned and many no longer serve a functional purpose. However, private land owners who own the dams are often hesitant to remove these dams because they are unsure of the impacts of removal (positive or negative), and may be unaware of the liability that a hazardous dam can cause (American Rivers, 2002). Working opportunistically, resource managers are sometimes able to locate a dam that would provide high ecological benefit if removed, and is also in poor condition with no functional use. In cases like this, the land owner could be more likely to agree to remove the dam. This opportunistic approach could be supplemented by a systematic prioritization of dams for removal based on ecological, social, and economic criteria (American Rivers, 2002).

Overall, both scientists and environmental managers consider selective dam removal to be an ecologically-effective and in many instances, a cost effective method of restoration (returning the ecosystem to its flowing state), when the appropriate conditions are met (Keller et al., 2011). For instance, removing a dam can improve habitat quality for fishes that do best in lotic environments, as well as the water quality, temperature, and connectivity of the ecosystem. However, several considerations arise when evaluating dam removals, and projects have unique conditions that require a more in depth planning and permitting process. For instance, if a large load of fine sediments has built up behind the dam, this will initially be suspended and can have impacts to the downstream area as it may contribute to a larger total suspended load downstream. Also, if the sediment is toxic and is not dredged and properly disposed of prior to removal, it could be re-suspended and cause hazards to organisms. It is important to consider nutrient dynamics for dam removals in nutrient-sensitive waters. Finally, the existence and potential loss of wetlands in the impoundment behind the dam needs to be considered (Stanley and Doyle, 2003). Although these issues may create short-term impact and therefore necessitate more rigorous planning and preparation prior to removal, dam removal still generally provides an overall benefit to the system in the long term (American Rivers, 2002).

Many entities have sought to create tools or models to assist with identifying high-priority dams for removal. The Nature Conservancy and its partners have recently completed the Northeast Aquatic Connectivity Assessment Project, a project that prioritizes stream segments for restoration, using dam removal as a restoration tool, from Maine to Virginia. This project brings together stakeholders from state governments and non-profits in order to gather the best data available to re-connect river ecosystems within the region (The Nature Conservancy, 2012). Other organizations have conducted prioritization schemes for conservation purposes, such as the South Atlantic Regional Partnership (SARP). SARP hopes to prioritize riverine habitats for conservation throughout the Southeast (Duncan, 2011). In addition, numerous state agencies seek to prioritize watersheds for conservation and restoration. Currently, Pennsylvania is seeking to prioritize watersheds for conservation, using dam location as a metric. Within the state of North Carolina, resource managers have already worked to prioritize small catchments in the Yadkin-Pee Dee River Basin for conservation using GIS (Stober et al. , 2011). This project, while similar to others in the region, is unique in that it specifically prioritizes dams rather than stream segments for removal, and it can be manipulated and run several times by the user, allowing for more flexibility in the project selection process.

II. OBJECTIVE

The primary objective of this project is to create a user friendly GIS based tool for prioritizing dams for removal within the state of North Carolina, using ecological and social metrics. In order to create this tool, an organized barrier dataset was created by combining multiple barrier datasets that currently exist within the state. Using the organized dataset, after the creation of the tool, barriers were ranked by American Rivers using an Objectives Hierarchy, and three barrier prioritization scenarios were conducted.

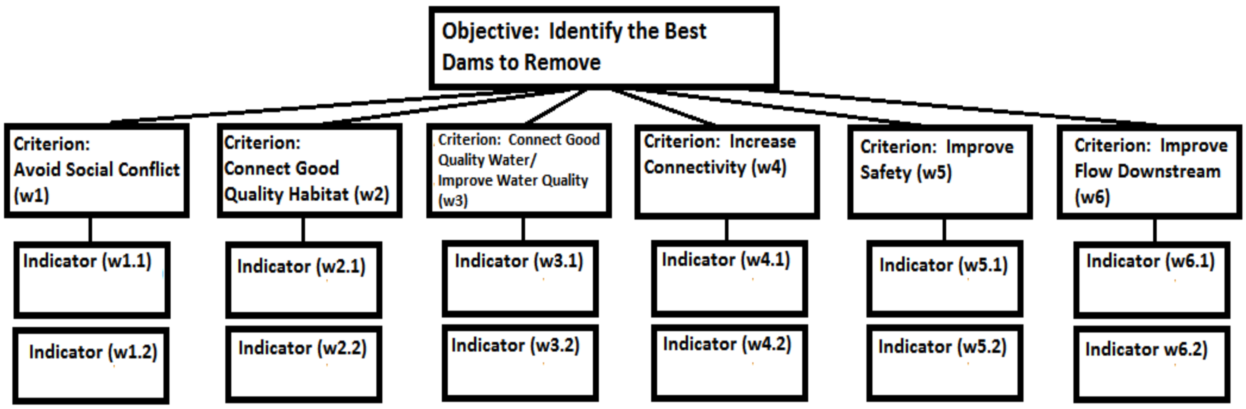
1. An ecologically and socially based barrier prioritization,
2. An ecologically based barrier prioritization, and
3. An anadromous fish based barrier prioritization.

Differences between the three prioritization outputs are compared. Also the sensitivity of the tool to different weighting schemes is evaluated.

III. METHODS: OBJECTIVES HIERARCHY AND RELEVANT DATA

1. *Multi Attribute Utility Theory: Construction of an Objectives Hierarchy*

Figure 17: Framework of an Objectives Hierarchy



Multi attribute Utility Theory is a decision making framework used to prioritize dams for removal each time the Barrier Prioritization Tool is run. Multi attribute Utility Theory (MAUT uses an objectives hierarchy to organize the prioritization. The first step in an objectives hierarchy is the determination of a primary goal, or fundamental objective, to solve a problem. The fundamental objective for this project is to identify the best dams to remove. Following the identification of this primary objective, a set of specific secondary objectives called criteria are identified to determine if the primary objective is being met (Clemen, 1996). The criteria for this project are: Connect high quality habitat, connect areas of high water quality/improve water quality, improve connectivity, improve flow downstream, avoid social conflict, and improve safety (Figure 1).

Finally, within each criterion, measurable indicators in the form of data are selected to determine if each criterion is met. A variety of measurable indicators for each of the criteria within this project are selected based on available data from different agencies within the state of North Carolina, such as the Division of Water Quality, the Natural Heritage Program, and the Division of Marine Fisheries. Due to the differing motivations for prioritization, users can choose different indicators depending on their prioritization objectives, much like a menu. For instance, habitat indicators relating to anadromous fish can be substituted for other habitat indicators when performing an anadromous fish prioritization.

Measurable indicators are given a rank from 0 to 1 based on the level of utility, or satisfaction gained from one additional unit of an indicator, determined by American Rivers. When using an objectives hierarchy, there are different methods of evaluating utility for each indicator through formal solicitation processes (McNutt, 2002). However, given the large number of criteria and the desire to construct a large number of indicators for each criterion that could be substituted by the user, time did not allow for this thorough analysis. Here, the framework allows assignment of indicator ranks by the decision makers and their colleagues. When ranking indicators, American Rivers uses their professional opinion and expertise of identifying important qualities of potential dam removal projects. Indicator utility is then assessed by graphing the change in preference per unit of indicator for those indicators that are not binary.

Next, ranked indicators are then weighted within each criterion and added together (see Figure 1: $w1.1 + w1.2 = 100$, $w2.1 + w2.2 = 100$, or $\sum (wp.n) = 100$), and criteria are weighted and added together in order to produce a final rank (see Figure 1: $w1 + w2 + w3 + w4 + w5 + w6 = 100$). Formal methods of weighting, such as swing weighting are not suitable because the tool is designed to allow users to change these weights depending on alternate prioritization scenarios. For instance, if a user wants to prioritize dams for removal to find a project specifically for ecological reasons and does not consider the social criterion to be important, their weighting scheme would be different than another user who may want to target projects that solely open a large number of upstream miles (connectivity criterion). It is important to note that all indicator weights must add to 100 within a criterion, and all criteria weights must add to 100 for the final rank to be an accurate representation of the prioritization (Clemen, 1996).

Figure 18: Indicator and Criteria Percentages for a Statewide Social Prioritization

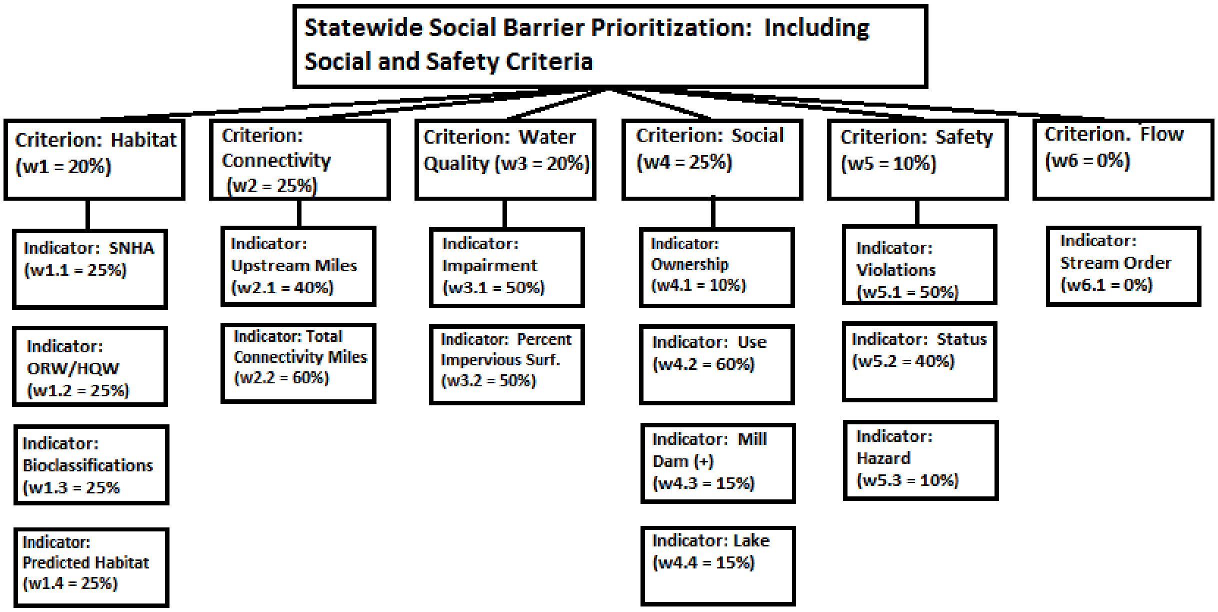
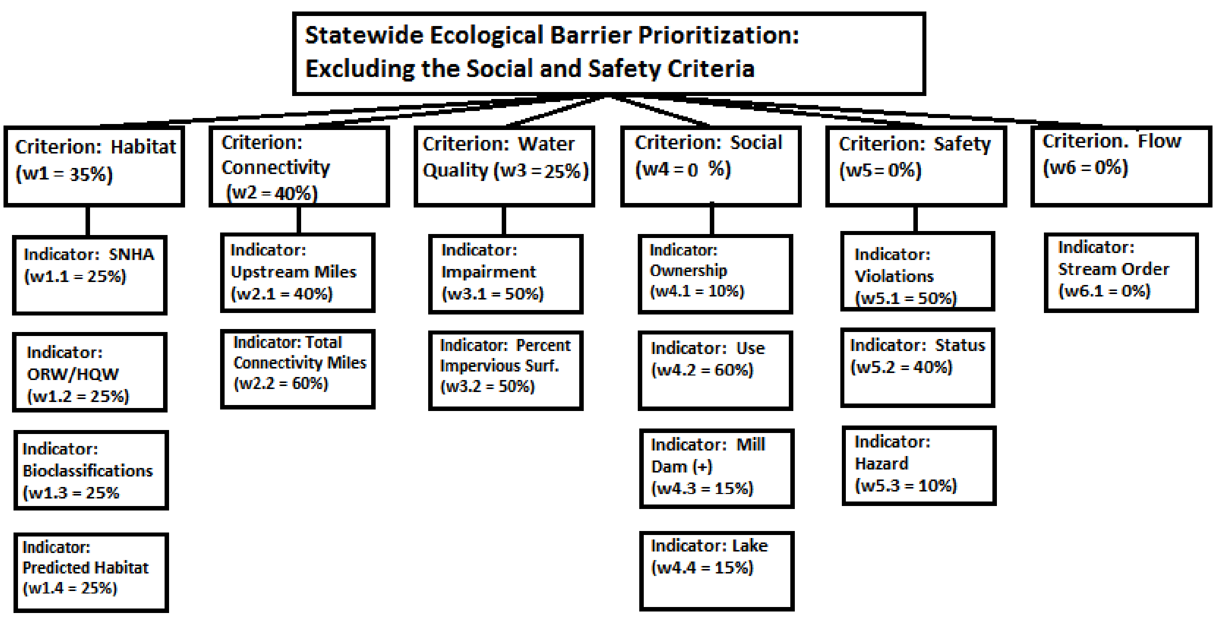


Figure 19: Indicator and Criteria Percentages for a Statewide Ecological Prioritization



Though the tool is designed for users to change weights for both indicators and criteria, within this project three prioritizations are performed:

1. A statewide social prioritization that includes the social and safety criteria,

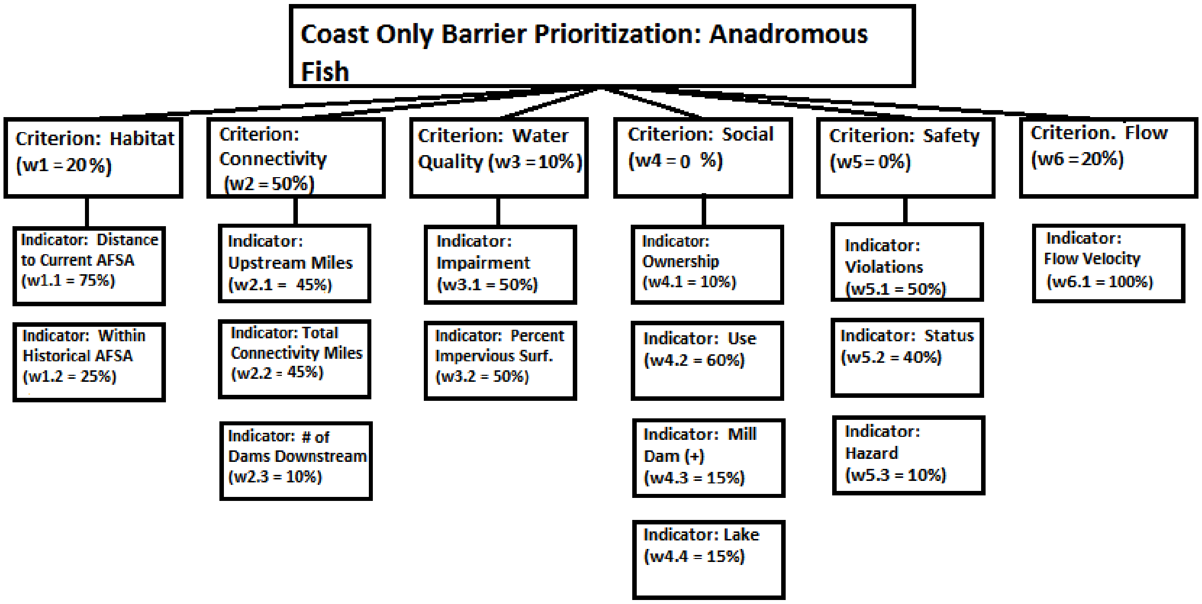
2. A statewide ecological prioritization that excludes the social and safety criteria, and

3. An anadromous fish prioritization.

For both the social and ecological prioritizations, it is assumed that dams on high quality stream segments, such as those on areas of good water quality, as well as good habitat quality (Significant Natural Heritage Areas or SNHAs, areas designated as Outstanding Resource Waters or ORW, as well as High Quality Waters or HQW, and areas designated as having good or excellent fish or benthic communities also known as biological classifications) should be removed in order to connect the best quality streams. Also, the removal of dams that will open the most functional upstream mileage are preferred in order to maximize the benefit of removal. The flow criterion is not used statewide prioritizations, as headwater streams are also assumed to be important due to their influence on downstream habitat and their tendency to support unique species, however this may be used in the future to separate larger projects from smaller ones. (Batt, L. American Rivers., 2011). In reference to habitat quality, there has been controversy surrounding the short term impact of dam removal on certain species of interest, such as mussels, following a removal (Sethi et al., 2004). For instance, some mussel species have been found thriving in larger numbers downstream of some small dams (Singer and Gangloff, 2011). However, it has been documented that mussel species richness decreases within the impoundments of dams (Sickel et al., 2007). Therefore, it is assumed that the overall removal of the dam would allow for the long term benefit of the species when special measures such as pre-removal monitoring and relocating mussels occur on a project by project basis.

For the social prioritization, in reference to social criterion, it is has been easiest in the past for American Rivers to remove dams that are primarily used for recreation or do not have a current use, such as an old mill dam. In addition, dams that repeatedly receive dam safety violations from the State Dam Safety Program tended to be liabilities for private owners, and easier to remove, hence the safety criterion (Objectives hierarchies for the social and ecological prioritizations can be seen in figures 2 and 3).

Figure 20: Selected Indicators, percentages, and Criterion Percentages for an Anadromous Fish Prioritization



For an anadromous fish prioritization, the most influential habitat quality indicators are the distance of the dam from the current anadromous fish spawning areas (AFSA), and whether or not the dam is in a historical AFSA. For connectivity, downstream barriers in addition to total connectivity and upstream mileage are important. Social and safety criteria are not used in this prioritization, because it is assumed that dams with negative social and safety attributes could be overlooked as these dams could potentially be manipulated for the passage of fish if removal is not an option. One example of fish passage is the installation of rock rapids to make it more feasible for fish to swim over the dam. Rock rapids are currently being installed at Lock and Dam #1, a dam on the Cape Fear River (Batt, L. American Rivers., 2011). Flow is also important for spawning of anadromous fish, as they tend to spawn in greater numbers when the flow velocity is of 0.4 meters per second or greater, though this criterion may be manipulated for future prioritizations, as shad have been found at the base of a dam with lower river velocities (Objectives Hierarchy for anadromous fish prioritization can be seen in figure 4). (Hightower et al. , 2011). Finally, in order to effectively use the number of downstream dams as a connectivity indicator, the barrier dataset was limited to dams having one functional mile upstream or greater using Microsoft Access, and the prioritization was limited to the coastal ecoregion using the Barrier Prioritization Tool.

2. *Relevant Datasets*

Information about the North Carolina Barrier Dataset (April 2011)

The first step of the construction of the Barrier Prioritization Tool is to create an organized barrier dataset using the many available barrier datasets within the state. This barrier dataset is a point shapefile that contains both locational and attribute information for dams (no culverts), specifically their location, as well as information regarding their ownership, use, structural dimensions, date of construction, etc.. The dataset consists of dams from the North Carolina Dam Safety Database, the National Inventory of Dams (NID) dataset (1996), the Aquatic Obstruction Inventory (AOI), as well as a shapefile of potential projects identified by American Rivers.

The NC Dam Safety database is the primary database used by managers in North Carolina. This dataset was created by the North Carolina Dam Safety Program, and consists of dams regulated by the program. However, in July 2011, North Carolina House Bill 119 was signed into law, changing the height and impoundment size requirements for regulation of dams by the Program. Prior H.B. 119, the North Carolina Dam Safety Program regulated dams that were 15 feet in height with impoundments of 10 acre feet. As of July 2011, the Program regulates dams of 25 feet in height and with impoundment sizes of 50 acre feet. Therefore, the dataset used in this project includes dams less than 25 feet in height, and it is unclear if future updates (occurring every four years) will continue to include these dams (McIvoy, 2012).

The National Inventory of Dams dataset is a national dataset from the US Army Corps of Engineers, updated every four years. The current NID dataset was last updated in 2010, and was created including dams that meet one of the following criteria:

1. High hazard classification - loss of one human life is likely if the dam fails.
2. Significant hazard classification - possible loss of human life and likely significant property or environmental destruction.
3. Equal or exceed 25 feet in height and exceed 15 acre-feet in storage.
4. Equal or exceed 50 acre-feet storage and exceed 6 feet in height.

However, the NID dataset used for this project is from 1996, as permission requirements make this dataset difficult to obtain. NID datasets prior to 2010 include dams that are greater than or equal to 10 feet in height. However, the 2010 update of this dataset includes dams that are only greater than or equal to 25 feet in height (Association of State Dam Safety Officials, 2010).

Finally, the Aquatic Species Obstruction Inventory, initiated in October of 2006 and released in 2007, was an undertaking by the State of North Carolina (Division of Land and Water Resources) and the US Army Corps of Engineers to identify dams that were not part of the NC Dam Safety database. These include small dams less than 15 feet, and dams that were previously undiscovered. It is unclear if this database will be updated in the future (North Carolina Division of Water Quality, 2007).

These three datasets, in addition to a small dataset of dams located in the field by American Rivers as potential projects that are not found on any of the previous datasets, are combined, and overlapping points are deleted. For overlapping dams, relevant attribute information is retained (for instance, if a dam is both NC dam safety and AOI, it may contain photos from the AOI, and more descriptive information). A Source field is added to the new dataset, to identify the master dataset each dam came from.

Dataset statistics

The AOI has 177 dams. Ninety four of these dams overlap with NC dam safety and 6 of these with NID. Twenty eight dams were removed from the dataset because they were either non-barriers (17 dams) or off stream (meaning that they were not located on a main stream segment) (5 dams). Therefore, a total of 128 dams were removed from the dataset. Once these 128 dams were removed, 49 dams remained that were actually new dams unregulated by NC dam safety. These 49 dams were added to the master dataset, and 11 dams were added from American Rivers' potential project list to total 60 new dams added to the master dataset that were not regulated by NC dam safety or the Corps.

Each dam on the NC dam safety layer has an NID ID. However, the NID dataset has 7 dams that were not on NC dam safety; 6 that were overlapping with AOI, and one that was from the FERC 2010 hydropower list. The NID dataset used was obtained from the Duke library, 1996. While the NID dataset was updated in 2012, gaining permission to obtain this dataset is often difficult, so any additional data from the NID dataset (such as owner type and owner name) may be outdated.

Tables 1 and 2: Owner and Use Type Statistics for Dams in the Organized Barrier Dataset

Owner Type	Number of Dams
Unidentified	291
Federal	46
Local Gov	293
Private	4309
Public Utility	3
State	72
Unknown	17
Utility	78
Total	**5109**

Use	Number of Dams
Recreation/Fishing Only	3253
Primarily Recreation with Secondary Use	449
Water Supply as Only or First Use	129
Hydropower as Only or First Use	76
Other	1202
Total	**5109**

The final barrier dataset for this project has a total of 5109 dams. Of these 5109 dams, the majority are used solely for recreation. Of these dams, many are small dams on small tributaries. Of the dams that are used primarily for recreation, many of these dams may also be secondarily used in other ways, such as water supply, hydropower, etc. Finally, 1202 dams are considered to be used for other purposes, such as flood control, irrigation, etc. In terms of owner type, the majority of dams are privately owned. It is important to note that 291 dams have no owner type listed, and 17 are listed as being unknown.

Indicator data: sources, association to the barrier dataset, and ranking

General:

The 1-100,000 scale National Hydrography Dataset (NHD) plus flow line dataset is used as the primary river dataset in this project (Horizon Systems Corporation, 2011). Hydrologic Unit (HUC) data can be obtained from the US Geological Survey (U.S. Geological Survey, 2011)

Criterion 1: Connect High Quality Habitat

Statewide Habitat Indicator Data

Habitat indicator data consists of Significant Natural Heritage Area (SNHA) polygons from NC DENR Natural Heritage Program, High Quality and Outstanding Resource Waters lines (HQW/ORW) from the Division of Water Quality, Bio classification lines from the Division of Water Quality, and Habitat Predictor lines from a study conducted by Mark Endries at the USFWS. Significant Natural Heritage Areas are areas identified by the state as being important for conservation due to their level of biodiversity. They contain either rare species communities, or special animal habitats. Twenty five percent of natural heritage areas are currently conserved, however the rest are privately owned. SNHAs are updated quarterly, and a new SNHA GIS polygon file is produced (NC DENR Natural Heritage Program, 2011).

ORW and HQW are surface water classifications given by the division of water quality. All waters in North Carolina have some kind of surface water designation. HQW and ORW designations are classified as being areas of high quality waters determined by both biological and physical/chemical characteristics. DWQ operates on a by-basin schedule to update these classifications. The data used in this tool is from January 2011 (NC DENR Division of Water Quality, 2011). Biological classifications are also classifications from the Department of Water Quality, and are labeled as either fish classifications (excellent or good) or benthic classifications (excellent or good). These classifications are a measure of the health of the system, meaning that if the communities of fish and macroinvertebrates are good, than the habitat and water quality of the system is considered to be good as well. These data are from January 2011 and are updated yearly (NC DENR Division of Water Quality, 2011).

Habitat predictor data are from the US Fish and Wildlife Service. USFWS used species locational data from a variety of sources, as well as environmental variable data describing characteristics of the rivers in North Carolina in order to predict other river segments where species may be found, using Maxent (maximum entropy) software. This study attempts to identify gaps in locational data, where sampling did not occur. Maxent software determines the probability that a species would be found in a given area.

USFWS compiled locational data from NC Natural Heritage element occurrence data (where endangered species are known to be located), North Carolina Museum of Natural Sciences Research and Collections Section Dataset, North Carolina Wildlife Resource Commission Priority Species Monitoring Dataset, NCWRC Trout Distribution Dataset, NC DWQ Benthos Macroinvertebrate Assessment data, and NCDWQ Stream Fish Community Assessment Program Data. Environmental variable data consists of attributes such as flow, velocity, and drainage area from the NHD plus dataset, as well as land cover data from the Southeast Gap Analysis Project Land Cover Dataset (Endries, M. USFWS, 2011). All species data are associated with stream segments by USFWS with a 100m search distance from the 1-100,000 scale NHD plus dataset. Maxent models were produced for 226 different aquatic species, and ranked according to its Nature Serve global rank. This rank, or G rank, is a measure of the extinction risk of the species, ranging from G1- high risk, to G5-lower risk. USFWS ranked these habitats from 0 to 256 based on G rank using an exponential scale increasing with extinction risk, and gives these calculation values a value from 1-10 (Endries, M. USFWS, 2011). American Rivers re-ranked this value on a scale from 0-1 for use as a habitat indicator.

Table 3: Derivation of Habitat Predictor Indicator Ranks by USFWS

Global Rank	Classification Value	Classification Sum	Habitat Indicator Rank
No species	0	0	0
G5 Species	1	1	0.1
G4G5 Species	2	2	0.2
G4 Species	4	3-4	0.3
G3G4 Species	8	5-8	0.4
G3 Species	16	9-16	0.5
G2G3 Species	32	17-32	0.6
G2 Species	64	33-64	0.7
G1G2 Species	128	65-128	0.8
G1 Species	256	129-256	0.9
		>257	1

Supplementary data not used in the prioritization include Brook Trout flow lines, NC Natural Heritage Species Occurrences, and WRIT priority watersheds. Brook trout flow lines consist of locational data of brook trout only, both native Southern Appalachian Brook Trout and Eastern Brook Trout. This file is a collaboration between the NC Wildlife Resource Commission and the North Carolina Natural Heritage Program. These data were are used as an indicator because there is some controversy about whether or not dams actually protect native brook trout from contact with stocked species by blocking their migration. Element Occurrence data, though accounted for in the USFWS habitat predictor data, are added to the dataset as informational data so the user could see exactly what endangered species was known to occur in that stream segment, (NC DENR Natural Heritage Program, 2011). These occurrence data are accounted for in the Habitat Predictor data indicator. WRIT priority watersheds are HUC 12 watersheds ranked by the Watershed Restoration and Improvement Team within NC DENR as being of high priority for conservation for a number of state agencies (Clark, P. and Jones, D., 2011). These watersheds might be included as an indicator within the habitat criterion for users who wish to prioritize dams in conjunction with state priorities.

Habitat data shapefiles (SNHA, HQW/ORW lines, and bio classifications) are associated with the dams via a spatial join with a search distance of 300 meters. A distance of 300 meters is used because the join is cross checked by hand, and 300 meters is conservative enough that it does not exclude any dams that should have correctly joined to habitat data and did not. However, all data associated with the dams using the 1-100,000 scale NHD plus, such as the USFWS maxent data are done using a search distance of 100 meters to keep in line with the Nature Conservancy's Northern Aquatic Connectivity Assessment Project (The Nature Conservancy, 2012). All of these indicators can be used in place of one another. For instance, the user may select one of the four indicators to use within the habitat criterion.

Following association of indicator data to dams, indicator rank fields are then added, and ranks are then assigned based on the joined data within Microsoft access. Generally, these indicators are binary, in that if a dam is on an area of high habitat quality, it is given a 1, if not, it is given a 0. However, varying levels of significance are given different ranks, in the case of significant natural heritage areas (i.e.: if the area was of national significance it is given a 1, if regional, a 0.8 and so on. See Appendix A for utility/rankings of indicators).

Anadromous Fish Habitat Indicator Data

Anadromous fish habitat indicators can be substituted for the statewide habitat indicators in order to prioritize specifically for anadromous fish. Anadromous fish spawning area data are obtained from the NC Division of Marine Fisheries (DMF). The Euclidean Distance function in GIS is used to calculate a raster with distances of each dam to the spawning areas (Division of Marine Fisheries, 2011). These distances are joined to the barrier dataset and ranked; the closer the distance of the dam to the anadromous fish spawning area, the higher the rank.

In addition, a historical spawning area map from DMF (titled the Macdonald map from the early 1990's (Division of Marine Fisheries, 2011)) is digitized and made into a shapefile. All HUC 8 units within this shapefile are selected and made the historical spawning region shapefile. All dams within these selected HUC 8s are in turn selected by location. This indicator is a binary indicator, in that if a dam is in the historic region, it is given a 1, if it is not in the historic region, it is given a 0.

Criterion 2: Connect High Quality Waters/Improve Water Quality:

Two indicators were used for this criterion. The first is whether a dam is located on an impaired water body. These data are derived from impairment lines obtained from the NC Division of Water

Quality. Impaired water GIS data are updated frequently by DWQ. Listing a body of water as impaired is a management scheme created by the EPA through the Clean Water Act. Through the Clean Water Act, the EPA gives States the power to manage non-point source pollution in the United States through listing specific bodies of water as impaired if they are no longer meeting a specific use due to poor water quality (waters are listed as impaired for a variety of reasons). If a water body is listed as impaired, a Total Maximum Daily Load, or TMDL, is created. A TMDL is the total maximum daily amount of a pollutant that is permitted to enter a water body (The Environmental Protection Agency, 2012).

The second indicator used for this criterion is the percent impervious surface within each HUC 12. These data are provided by the Nature Conservancy, and are calculated from the National Land Cover Database updated in 2006 (The Environmental Protection Agency, 2007).

The Impairment data shapefile is associated with the dams by hand. Only those stream segments that are impaired for low dissolved oxygen, high chlorophyll a, and high temperatures located upstream of the dams are included. Also, stream segments designated as IRC rating of 4c, meaning the dam is causing water quality impairment, are included (these specific designations are extracted from the original shapefile with a select by attribute function). TNC impervious surface data are provided via an access database, and are linked to the barriers via a HUC 12 code within Microsoft access. Indicator ranks are then assigned based on the joined data within Microsoft access. Generally, if a dam is on an area of impairment, it was given a positive rank, assuming that removing the dam would alleviate some of these issues. If the dam was in an area of low impervious surface, it got a higher rank, assuming that these dams would have fewer complications from removal (such as high sediment loads released from removal in urbanized streams) (Batt, L. American Rivers., 2011).

Criteria 3 and 4: Avoid Social Conflict and Improve Safety

Both Social and safety data criteria indicator data are obtained from the NC Dam Safety officeand the NID datasets. These data are already embedded within each dataset, and therefore rank fields and indicator ranks are created in Microsoft excel. Water supply use data are cross checked by hand with DWQ water supply intake points and water supply watershed polygons. In addition, hydropower data are cross checked by hand with multiple hydropower dam datasets used in the Master's Thesis of Chris Sands, an MS student at UNC Chapel Hill.

Generally, if a dam is used for recreation only, it is given a high rank. If dams are primarily used for hydropower or water supply, they are given the lowest rank, while other uses such as irrigation and flood control fall in the middle. Dams with "mill" in their names were given a binary rank of 1, because mill dams tend to be no longer in use. Dams with "lake" in their names were given a binary rank of 0, because lake dams tend to be in high populated areas and valued aesthetically, making them harder to remove (Batt, L. American Rivers., 2011).

Criterion 5: Improve flow downstream

Flow data in the form of mean annual flow velocity are obtained from the NHD plus dataset. They are associated with the dams using a spatial join and a search distance of 100 meters.

Once spatially joined, this indicator is ranked in Microsoft access. Ranks of 0 are given to dams with flow velocity below 0.4 m/s, and a 1 given to those greater than or equal to 0.4 m/s, which is the critical threshold identified for spawning of American Shad (Saint Johns River Water Management District, 2011) (Hightower et al. , 2011). Once again, this criterion may be altered or excluded in the future depending on the user.

Criterion 6: Improve Connectivity

Connectivity data are created using the BAT (Barrier Assessment Tool) created by the Nature Conservancy. This tool runs using only ARC GIS 9.3 at this point (a more updated version is in the process of being funded for creation). The BAT tool uses the NHD plus flow lines and they need to be void of loops/bifurcations. These bifurcations are removed by hand and by eliminating certain line segments classified in the NHD VAA table as being "2", meaning they are a side of a loop. Perennial streams are also removed to stay consistent with TNC. Along with the river flow line, the BAT tool uses the barrier point file, in this case the organized barrier dataset, and snaps the barriers to the river line file with a specified snapping distance of 100 meters. Connectivity indicators are calculated for all barriers that successfully snap to the network. These are:

1. Total Upstream Mileage: The total number of miles upstream of the dam, up to the end of the stream network. This measure does not stop at the next barrier upstream.

2. Functional Upstream Mileage: The number of miles upstream of a dam to the next upstream barrier.

3. Functional Downstream Mileage: The number of miles downstream to the next dam.

4. Total Upstream and Downstream Functional Connectivity: The number of functional miles upstream and downstream of the dam.

5. Upstream Barriers: Number of barriers upstream of the dam.

6. Downstream Barriers: Number of barriers downstream of the dam.

Within these indicators, three are used for this prioritization: Upstream functional miles, total upstream and downstream connectivity, and number of downstream barriers. Generally, indicator ranks are given as follows: the higher the mileage upstream and total connectivity, the higher the rank, and the lower the number of downstream barriers, the higher the rank for anadromous fish prioritizations (Batt, L. American Rivers., 2011).

IV: METHODOLOGY: THE BARRIER PRIORITIZATION TOOL

The barrier prioritization tool is designed in GIS to utilize indicator fields within the barrier attribute table to create criteria and ranks via weights input by the user. The user is also able to manually select specific indicators to weight within criteria (interface visible in figure 4).

Figure 4: Interface of the Barrier Prioritization Tool

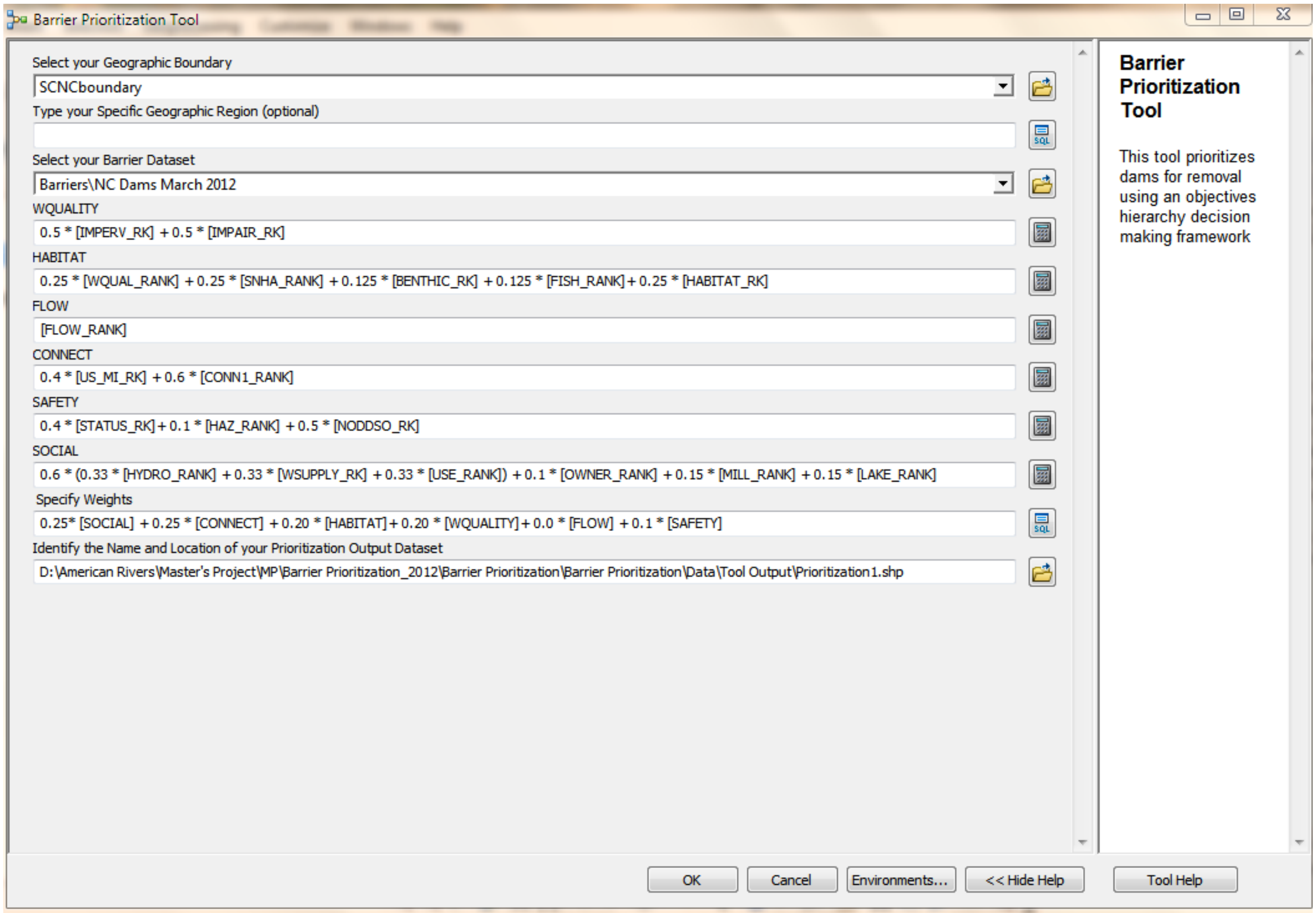
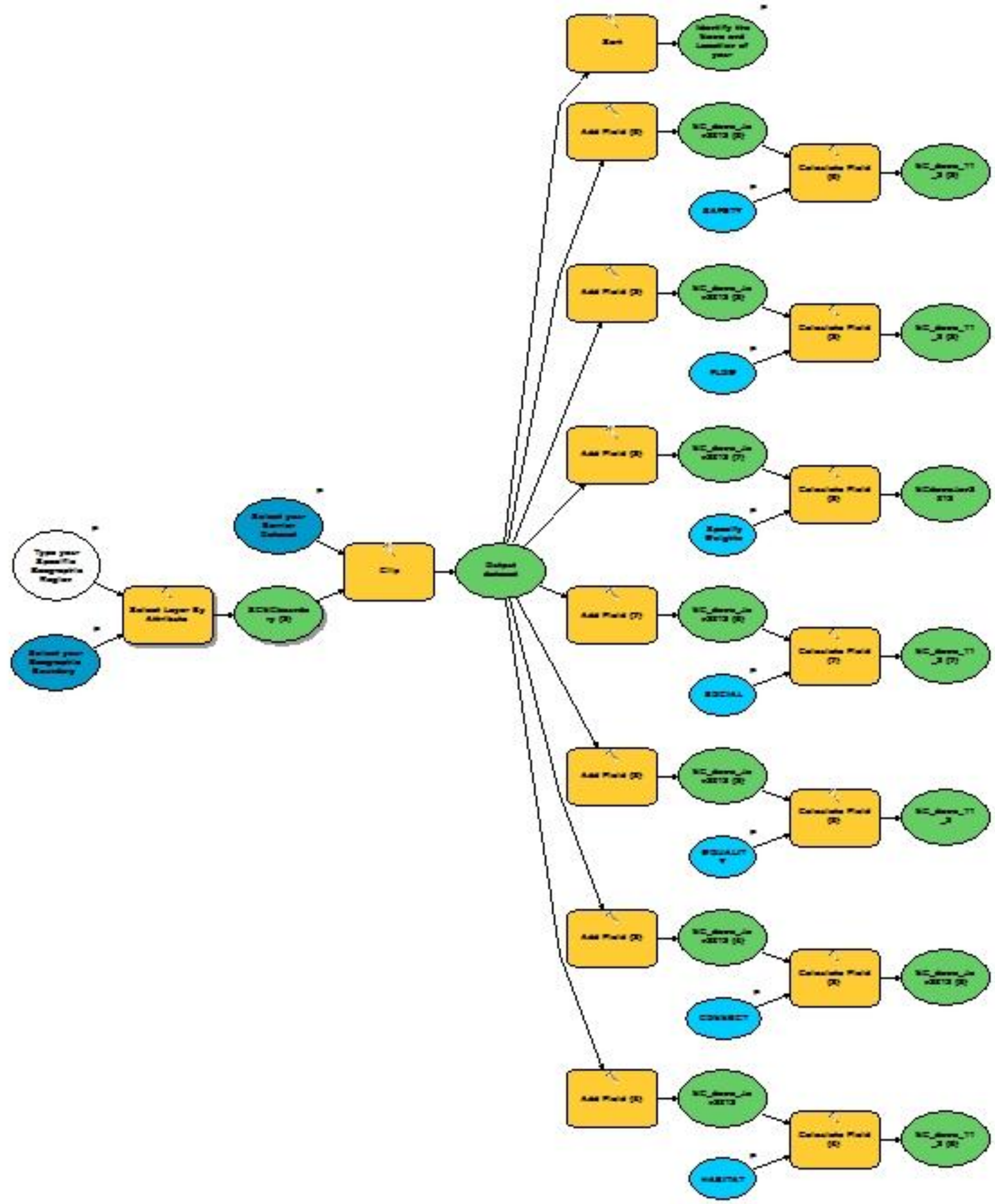


Figure 6: Model View of the Barrier Prioritization Tool in Model Builder, ArcGIS 10



The Barrier Prioritization Tool is designed in model builder in ArcGIS 10, (tool model visible in figure 6). It begins with a select by attribute field so the user can select a geographic boundary if preferred. It then clips the dataset by the boundary, and adds criteria fields as well as a rank field to the new clipped barrier dataset. Each criterion field uses the calculate field tool so that the user can indicators within each criterion, weight them, and weight the criteria within the rank field using a VB script. The default indicators, indicator weights and criterion weights are set to the social prioritization scheme, and the user can change these by simply typing in the fields within the tool's interface (figure 5). Next, the tool calculates the criteria fields and a rank field within the new barrier dataset, and automatically sorts the attribute table from highest to lowest rank, as well as automatically symbolizes the dataset using natural breaks and separating them into twelve classes.

Sensitivity Analyses

An informal sensitivity analysis using the social prioritization is performed for the two connectivity methods (one that includes tributary dams and the other that does not include tributary dams), as well as between the three prioritizations. The motivation behind this analysis is to determine if removing tributary dams would eliminate some of the error associated with the creation of connectivity data using the BAT tool (see connectivity data description in section 4.7) .These prioritizations are performed using the no tributary connectivity method (where dams indicated as being on a tributary are removed) and all tributary method (where no tributary dams are removed). Sensitivity is determined by the number of dams in the top 20 that changed between the two prioritizations (number of new dams added from one prioritization to the other).

Sensitivity of the prioritization to which habitat indicators are used within the habitat criterion is also explored. Overall overlap of habitat indicators is assessed using the Microsoft excel sorting function. Dams that are on significant natural heritage areas are sorted to see how many of them do not exhibit high values of the other three habitat indicators. A sensitivity analysis using the tool is also performed using only the habitat predictor indicator for the habitat criterion, and the number of new dams that appear in the top 20 was recorded as sensitivity.

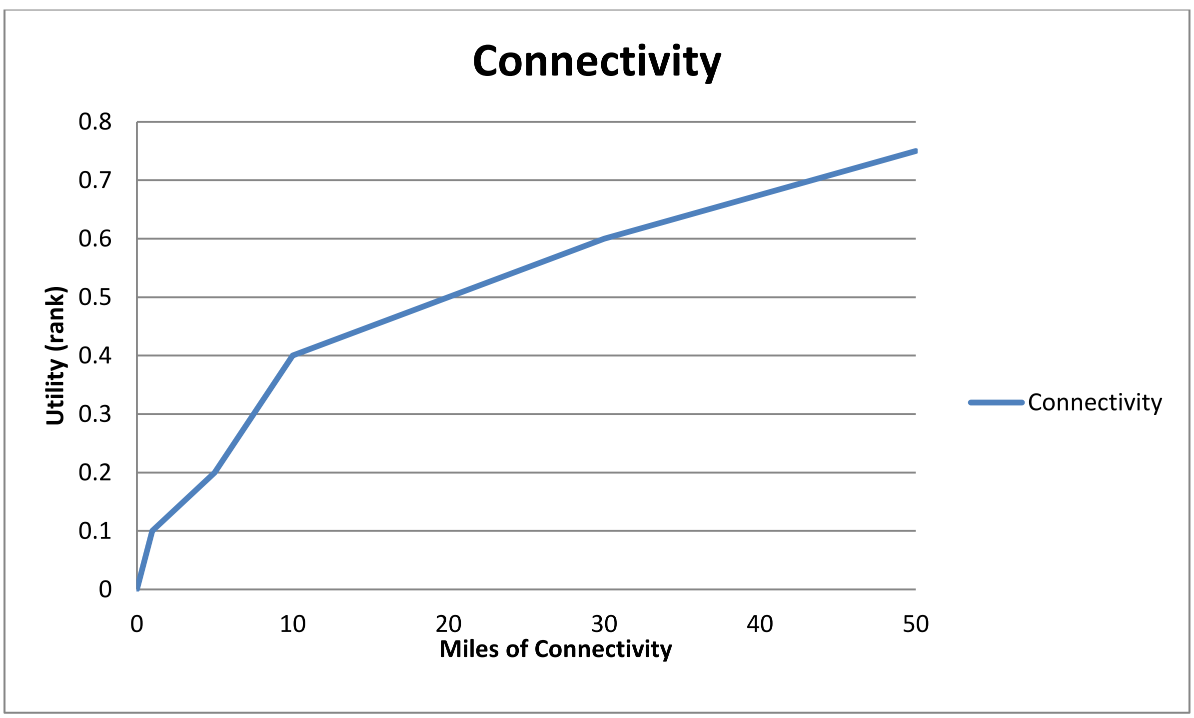
To test the sensitivity of the prioritization to changes in criterion weights, a criterion is increased by 25% of its current weight, and the others are decreased by 6.25% of their current weights in order to keep them equal. Each time a criterion is increased by 25 percent, a prioritization run is performed. . Sensitivity is determined by the percent of new dams that show up in the top 20 ranked dams.

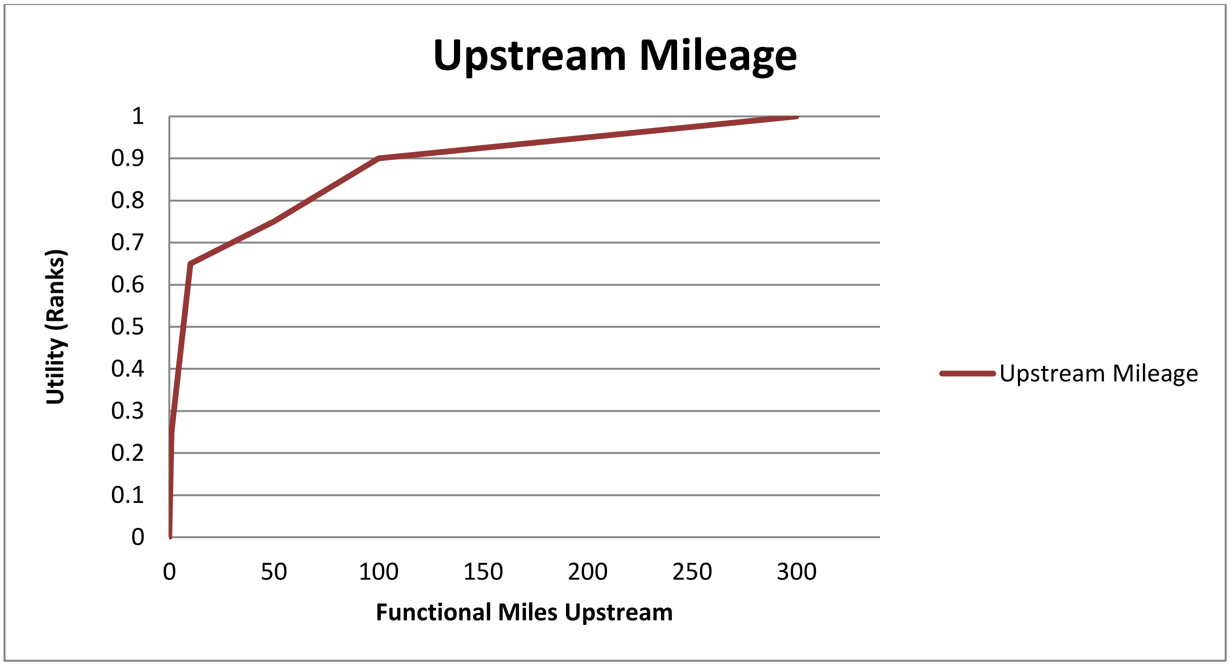
V: RESULTS

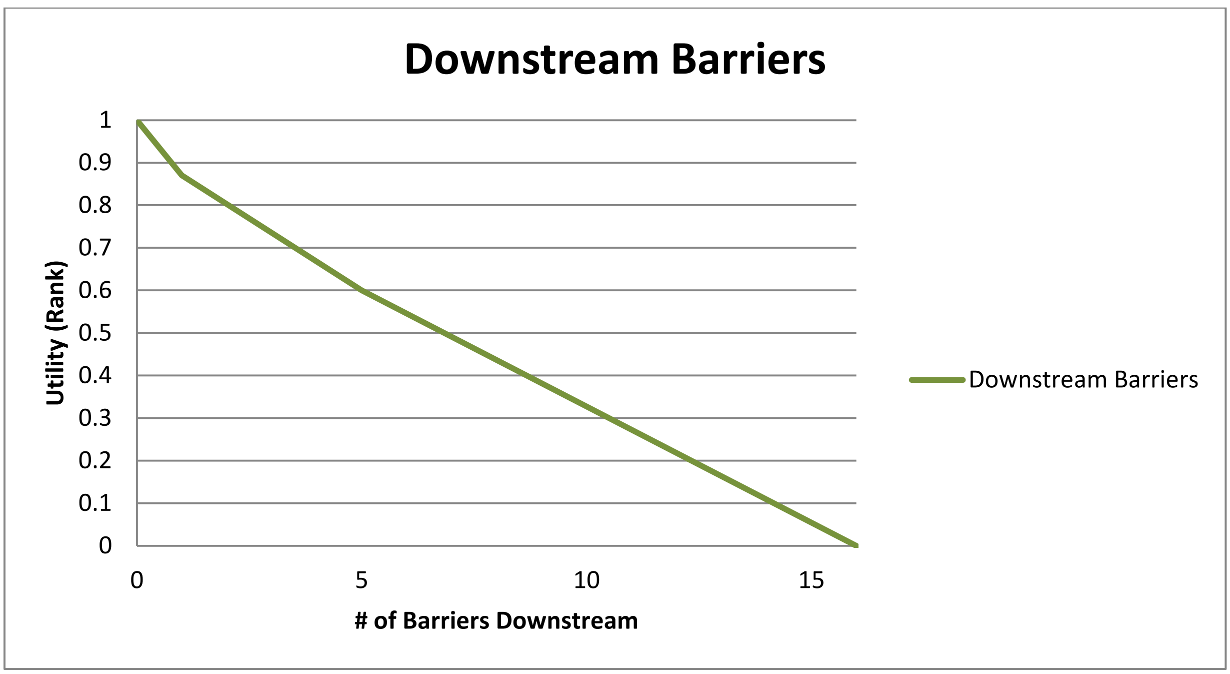
Resulting Utilities of Indicator Ranks

Many of the indicators are binary, meaning if the dam has the particular desired attribute, it was given a 1. If it does not have the attribute it is given a zero. However, there are a few indicators that are measurable, such as the connectivity indicators. These indicators exhibit a non-linear utility, meaning that an increase of one unit of the indicator does not equate an increase of one unit of utility or satisfaction.

Figure 21: a-c. Utilities of Connectivity Indicators



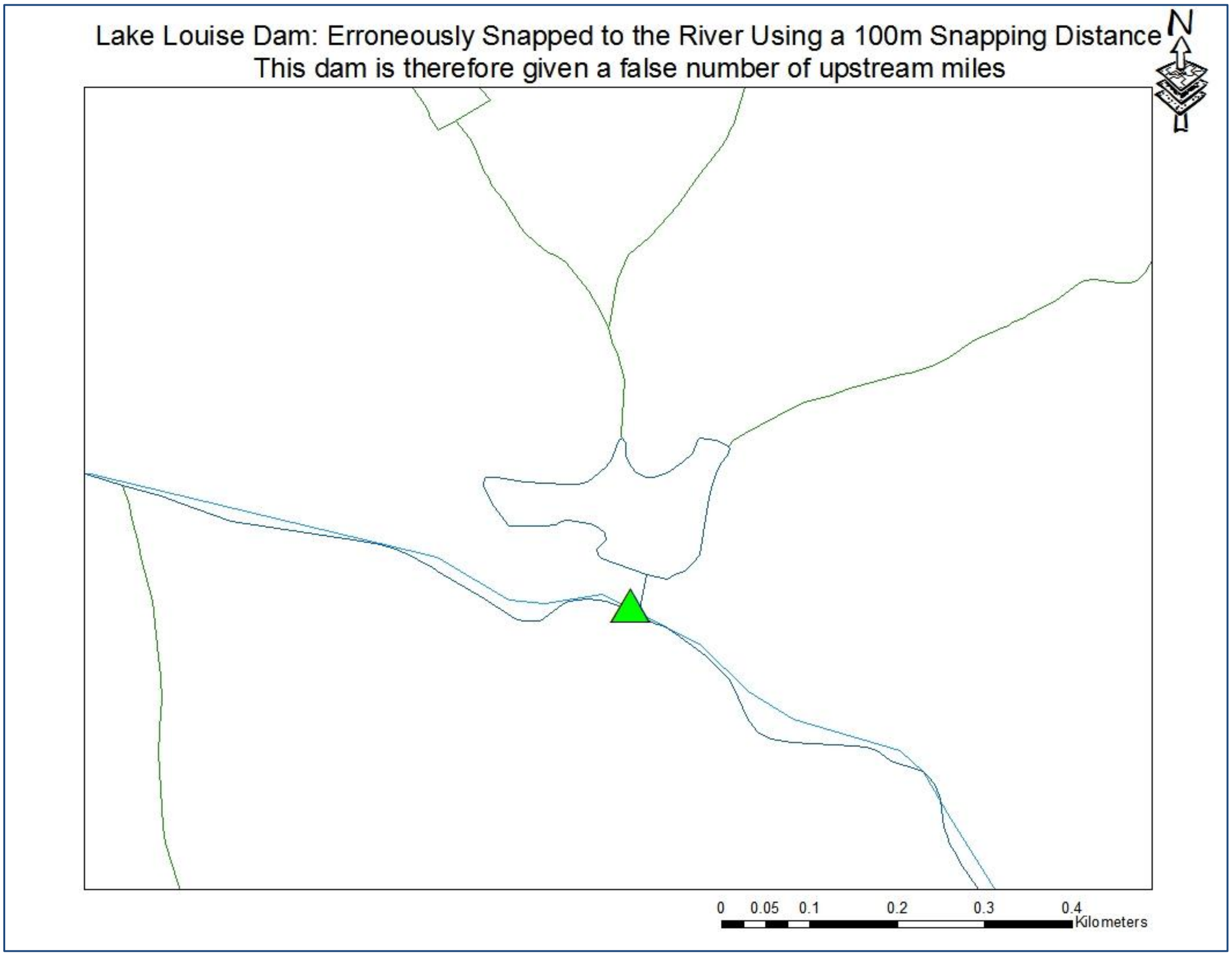




Sensitivity of Prioritization to Connectivity Methods

As seen in the image below, certain dams located on smaller tributaries are erroneously snapped to large rivers and connectivity data is incorrect. In this image, Lake Louise Dam is the dam associated with the impoundment above it. However, the 100m snapping distance snaps this dam to the river below, which gives it 35 functional upstream miles, when it should have less than one mile. This will cause the dam to rank higher in the prioritization than it should.

Figure 22: An Example of Snapping and Search Distance Error; Lake Louise Dam



Due to this error, two runs of the BAT tool occur. The first run excludes dams on tributaries (except for those on large river tributaries like the Haw). A tributary is defined as a river reach that intersected a large named river. Removing these dams is thought to be the lesser of two evils, in that dams such as Lake Louise dam and small farm pond dams would not be added to the BAT analysis, though this is debatable. Dams are identified as being on a tributary if they were on a river with a –Tr in the name. These dams are removed from the dataset prior to analysis with the BAT tool via a Microsoft excel filter. After the BAT tool is run, these dams are placed back into the dataset into Microsoft excel, then the table of dams is uploaded as a shapefile. Of these 5109 dams, 1360 snap to the network. The second run included all tributary dams. Of the 5109 dams, 2396 snap to the NHD plus network. Therefore, 1036 more dams snap when including the tributary dams, almost double the amount of dams than when using the no tributary method. Of the dams using the all tributary method, 1862 dams have 3 or fewer functional upstream mileage, whereas the no tributary method has 912 dams with fewer than 3 upstream miles.

Figure 23: Statewide Differences in Upstream Miles for each Dam Using Two Connectivity Methods

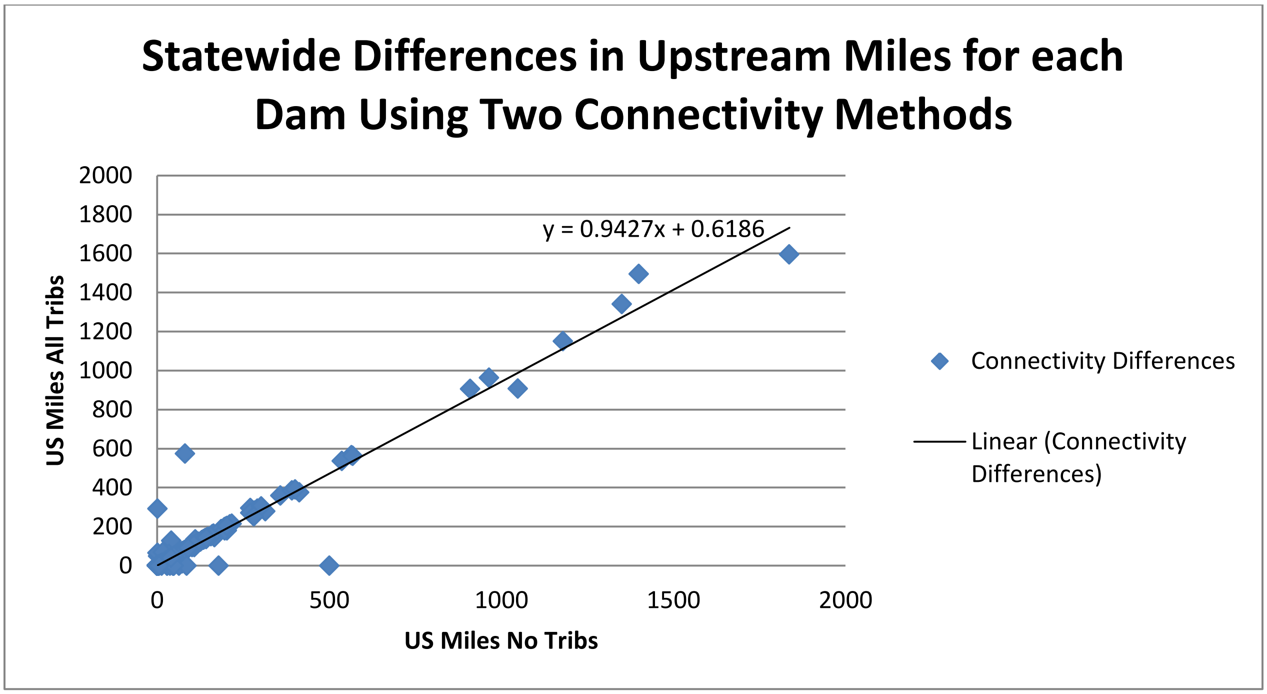


Figure 24: Differences in Upstream Miles for each Dam Using Two Connectivity Methods for the Cape Fear River Basin

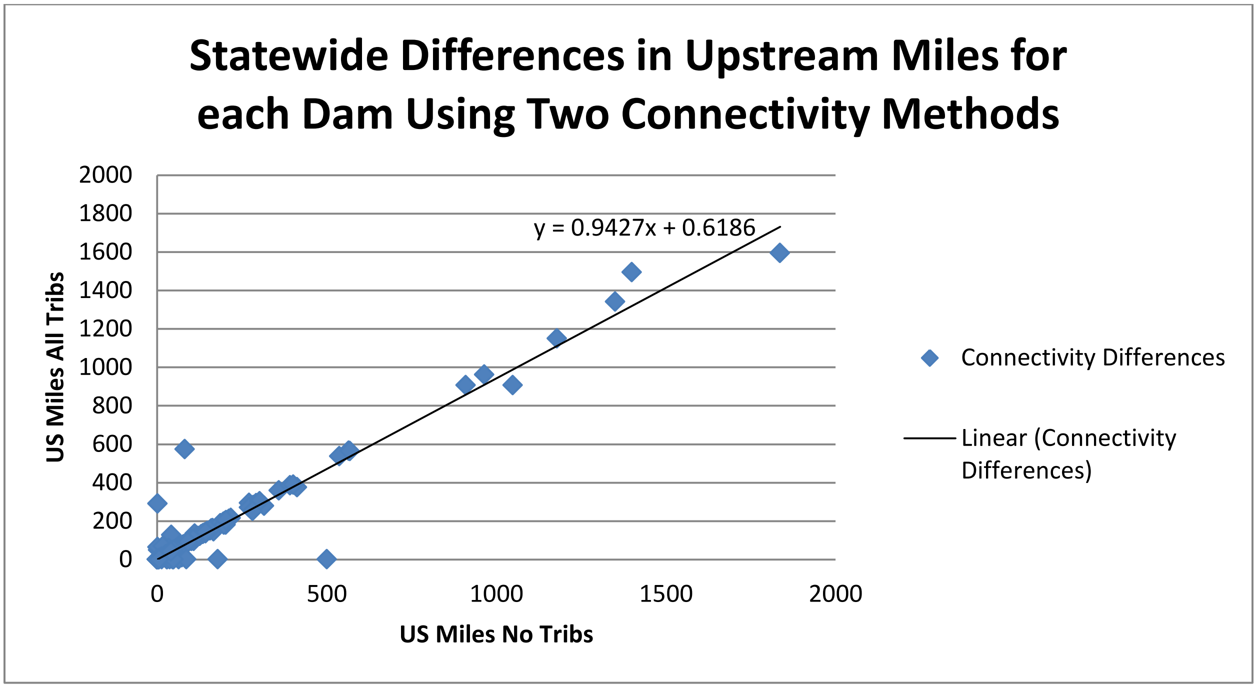
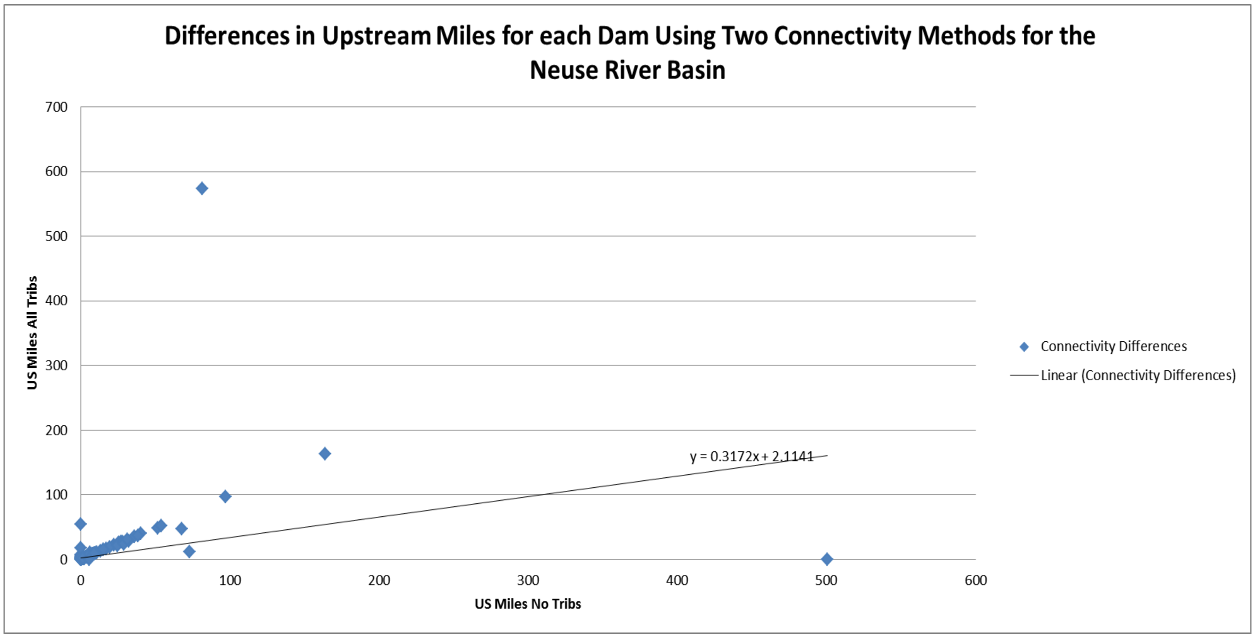


Figure 25: Differences in Upstream Miles for each Dam Using Two Connectivity Methods for the Neuse River Basin



Functional upstream mileage for each dam using the two connectivity methods are plotted against each to compare to the differences between the two connectivity methods. Upstream mileage including tributary dams is plotted on the y axis, and upstream mileage not including tributary dams is plotted on the x axis. A statewide analysis of the methods is also compared to dams in the Neuse basin and the Cape Fear basin. It is clear that while both methods produce relatively similar connectivity measurements for each dam, some basins have more error than others.

Table 4: Sensitivity of the Top 20 Ranked Dams within a Statewide Social Prioritization to Two Connectivity Methods

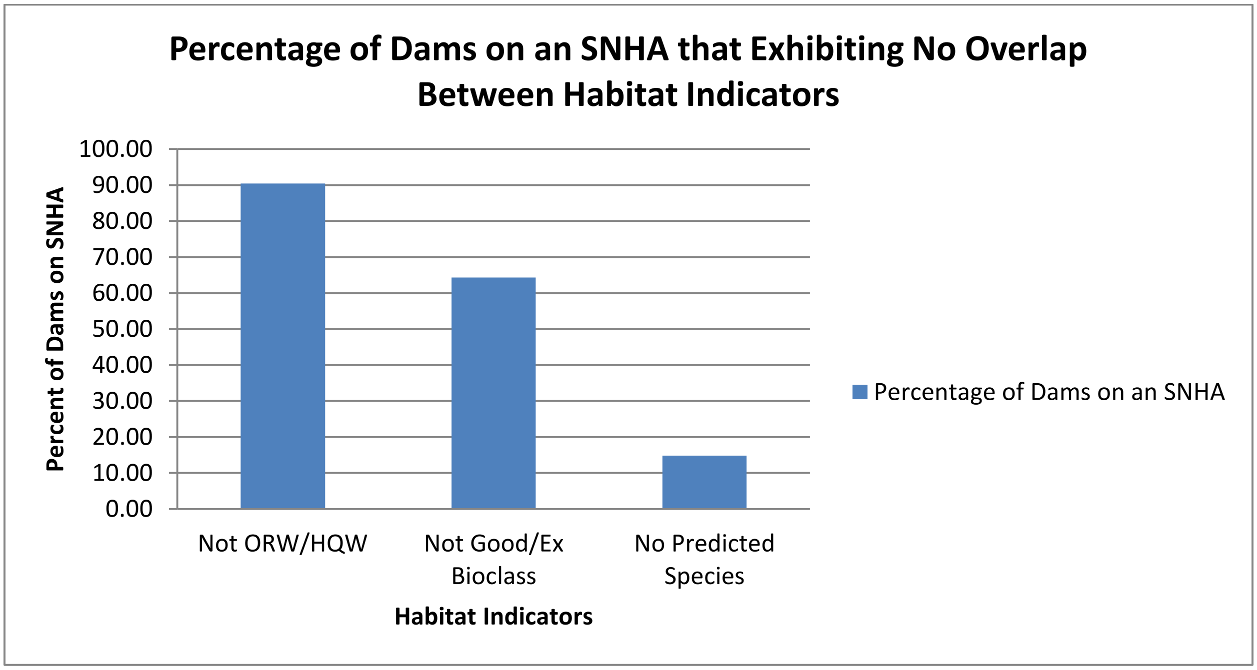
Sensitivity Analysis of Connectivity Methods				
"No Tributary Method"			"All Tributary Method"	
KHID	Rank		KHID	Rank
5167	1		5168	1
13	2		5167	2
25	3		13	3
838	4		25	4
32	5		838	5
3068	6		3068	6
841	7		841	7
27	8		5118	8
3975	9		32	9
5168	10		27	10
3027	11		3975	11
3638	12		3027	12
7	13		7	13
24	14		24	14
4	15		4985	15
5	16		1292	16
3288	17		4	17
4940	18		5	18
5118	19		3638	19
5116	20		3288	20

Two statewide social barrier prioritizations are performed using connectivity indicators of both methods. Of the top 20 ranked dams that are output of the prioritization, 2 new dams appear (10% change) using the all tributary method (highlighted in yellow). Dam 1292 was erroneously snapped to the river network and therefore has larger numbers of connectivity miles than it should. On the contrary, Dam

4985 appeared in the top 20 and has the same number of connectivity miles using both connectivity methods.

Habitat Indicator Overlap: Sensitivity to Changes in Habitat Indicator Selection

Figure 26: Investigating Habitat Indicator Overlap

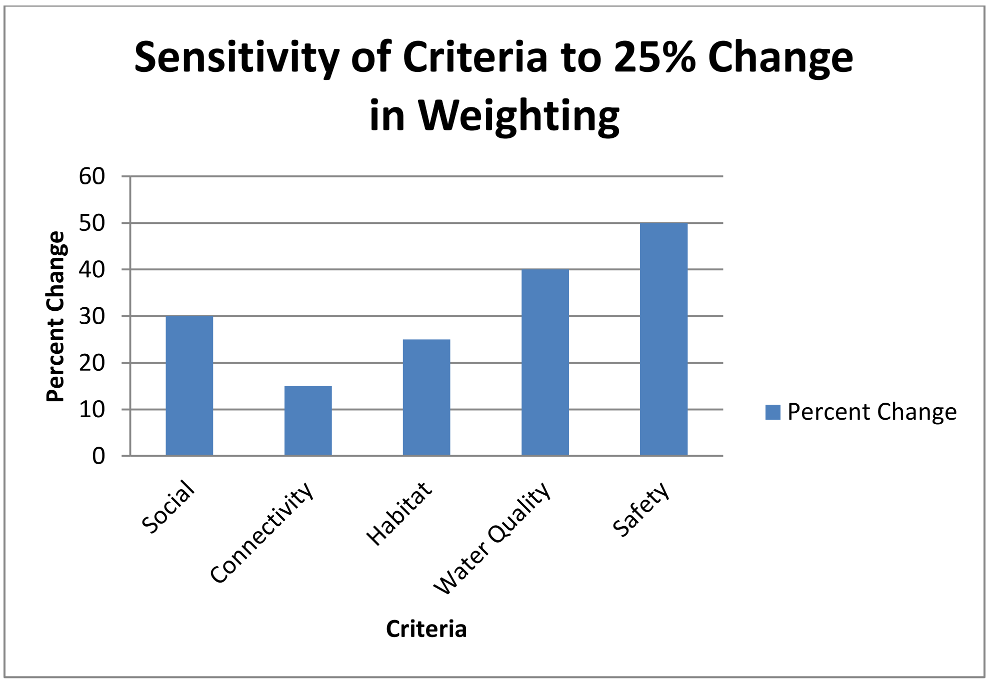


The possibility of overlap between habitat indicators is assessed using the sort function in Microsoft Excel. Those dams that are on Significant Natural Heritage Areas but not having any overlap with the other habitat indicators are noted and show in figure 12. When sorting habitat indicators, of the 115 dams that are on Significant Natural Heritage Areas, 17 of them (15%) are listed as showing no overlap with the habitat predictor data. In other words, only 17 of the dams on significant natural heritage areas did not appear to be on areas predicted as having species of interest. In addition, of the 115 dams on Significant Natural Heritage Areas, 104 of them are not located on rivers classified as being outstanding or high quality waters, and 74 of them are not on rivers classified has having good or excellent fish/benthic biological communities.

Also, one Social Prioritization occurs using only the USFWS species predictor data as the indicator for the habitat criterion, in order to test if habitat indicator overlap causes any changes in the prioritization output. Of the top 20 dams, 5/20 of the dams change from the previous prioritization which uses all four habitat indicators. Therefore, a 10% change occurs. All five of these dams that are added are not on Significant Natural Heritage Areas, and 3 of the 4 do not have any of the other habitat indicators. Therefore, the habitat predictor indicator and the significant natural heritage indicator show the most overlap.

Sensitivity of Criteria to a 25% Change in Weight

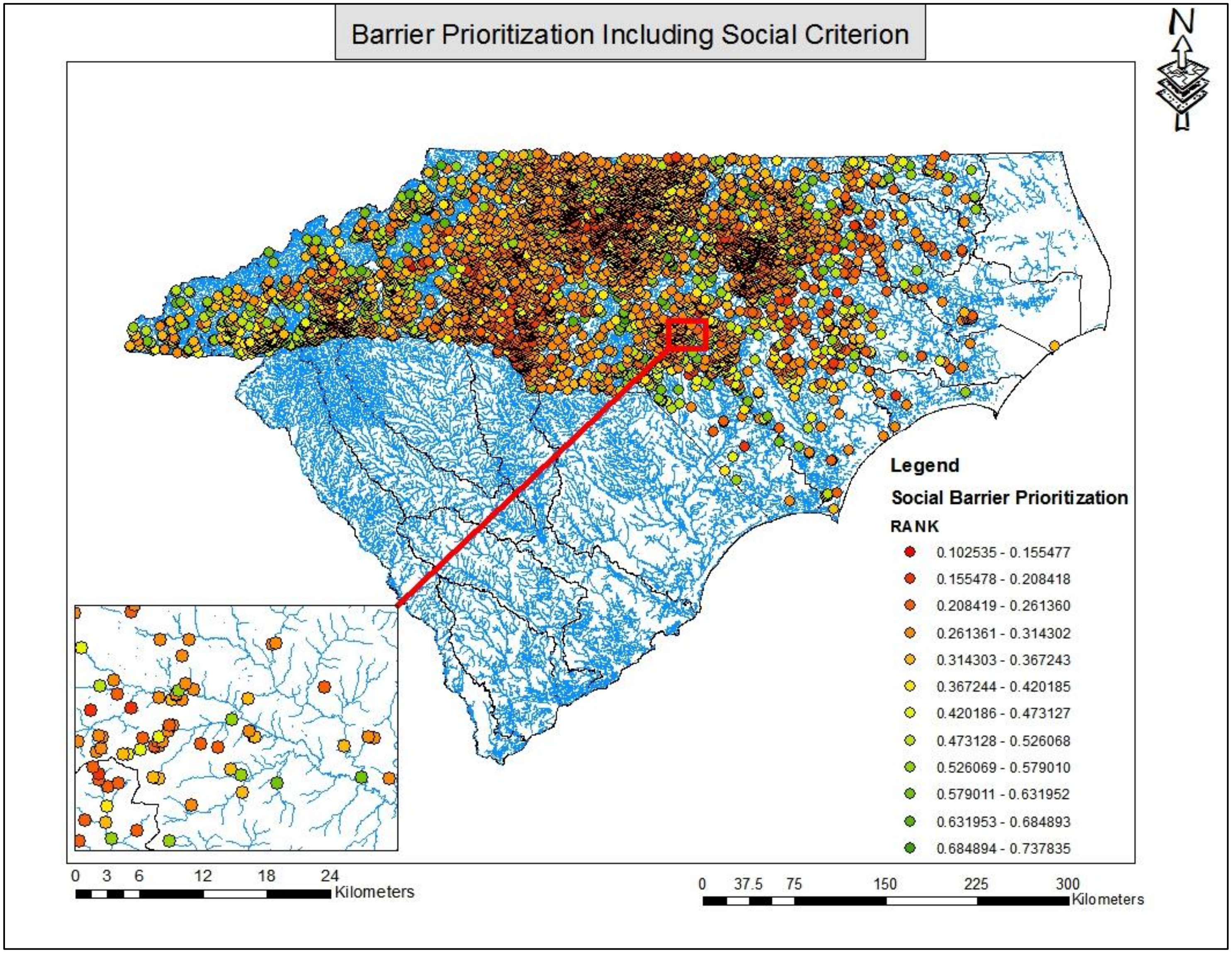
Figure 27: Sensitivity of Criteria to 25% Change in Weight within a Statewide Prioritization Including Social Criterion



To test the sensitivity of the top 20 ranked dams to changes in criteria weights, criteria weights are each changed by 25% to identify the percent change in the top 20, or how many new dams out of the top 20 appear. A 25% change in the weighting of the safety criterion results in the highest change in the overall top 20 ranked dams, whereas a 25% change in the weighting of the connectivity criterion results in the lowest change in the top 20 rank dams.

Final Barrier Prioritization Results

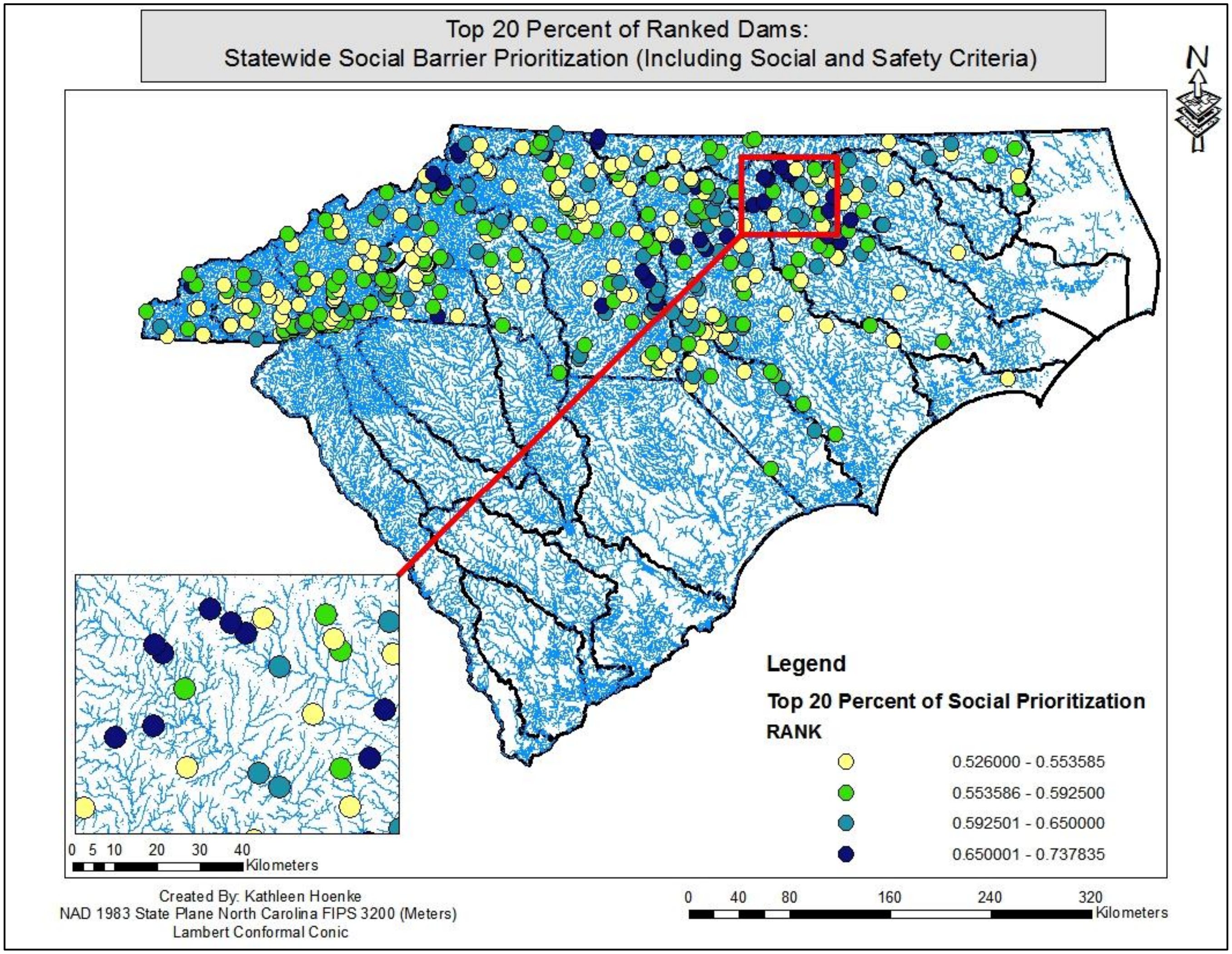
Figure 28: Statewide Barrier Prioritization (Classified with Natural Breaks) Including Social Criterion



The Barrier Prioritization Tool has the ability to allow any user to select specific indicators for each criterion, and specify indicator weights and criteria weights based on their management preferences. It then outputs a new shapefile of dams that are automatically sorted from highest to lowest rank within the attribute table, as well as symbolized by rank using a natural breaks classification scheme so that they may be viewed by the user as seen in figure 14. The user may then zoom in to specific locations on the map to individually explore higher ranking dams, or open the attribute table of the shapefile and individually view the dams from highest to lowest rank.

Figure 14 shows the output of the Barrier Prioritization Tool using a statewide social prioritization scheme, meaning it includes both the social and safety criteria. Out of the approximately 5000 dams, many of the dams rank low in terms of being good dam removal projects, because the majority of dams are small tributary dams used as agricultural ponds and have less than one functional upstream mile of connectivity.

Figure 29 and Table 5: Top 20 Percent of Ranked Dams (Classified with Natural Breaks) and Top 20 Ranked Dams using a Social Prioritization Scheme



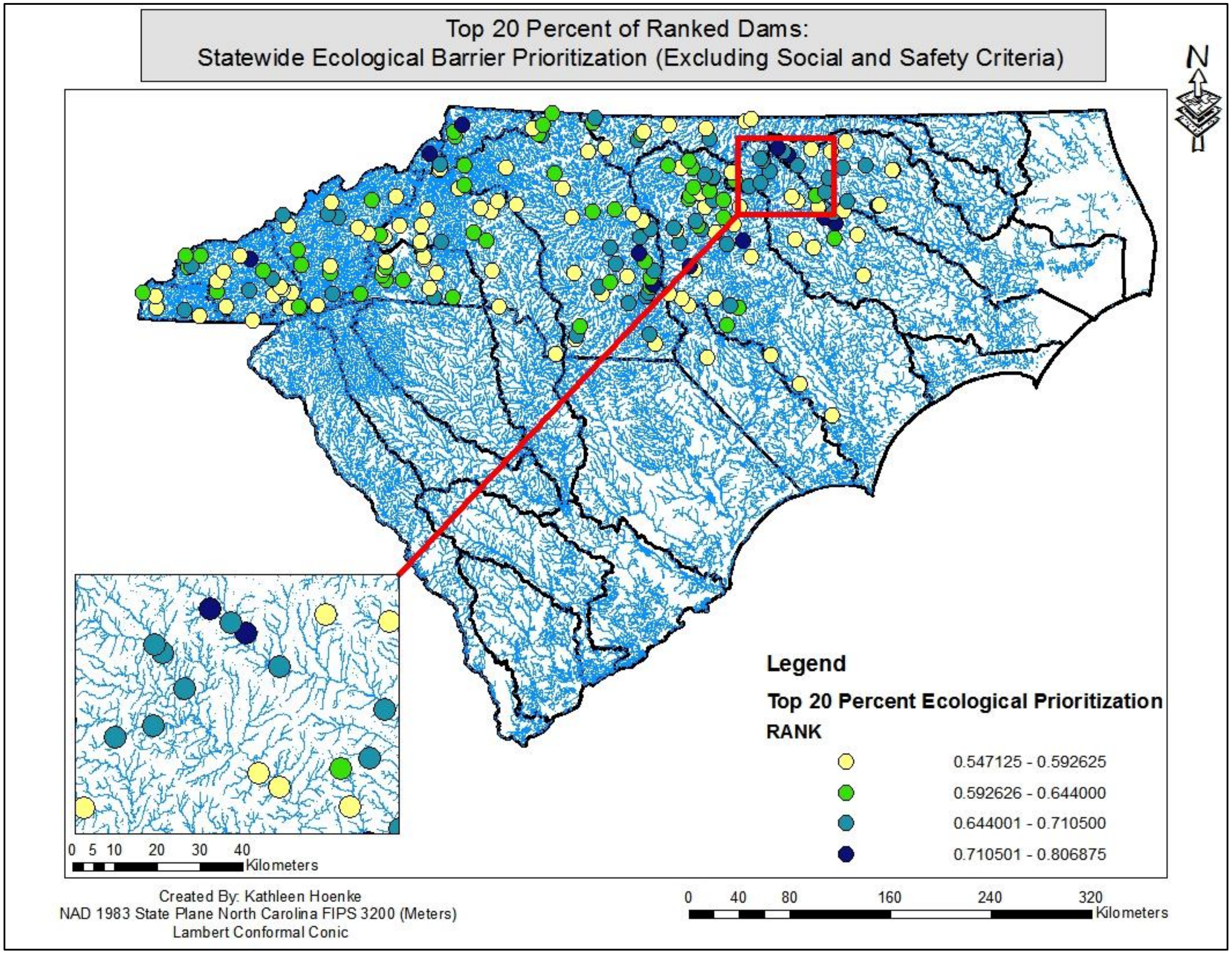
Top 20 Ranked Dams: Social Prioritization		
KHID	**Rank**	**Current Potential Project?**
5167	1	Yes
13	2	Yes
25	3	Yes
838	4	Yes
32	5	No
3068	6	No
841	7	No
27	8	Yes- Unwilling Land Owner
3975	9	No
5168	10	Yes
3027	11	No
3638	12	Removed
7	13	No
24	14	No
4	15	No
5	16	Yes-Unwilling Land Owner
3288	17	No
4940	18	No
5118	19	No
5116	20	No

For this project, three trial statewide prioritizations are conducted using the no tributary connectivity method; a social prioritization which includes both the safety and the social criterion, an ecological prioritization which excludes the safety and social criterion, and an anadromous fish prioritization which excludes dams that have less than one upstream mile. Indicators are selected for each criterion and given a weight out of 100, and criteria are given weights out of 100 by American Rivers (see figures 2, 3 and 4 for selection of indicators and weights for each prioritization).

Figure 15 shows only the top 20 percent ranked dams of the approximately 5000 total dams from the social prioritization, since American Rivers and colleagues will be focusing their attention to these dams to search for potential projects. These dams are classified using natural breaks so that the best dams can be easily seen in the map view.

Within the social prioritization, the top ranked dams are dams that are primarily used for recreation, and are located on streams classified as areas of high habitat quality. Out of the top 20 dams, 15 are considered to be either active or inactive mill dams, 19 are used primarily for recreation, and one is used only for water supply. Of the 19 used for recreation, 12 are used only for recreation, two are used primarily for recreation but also for irrigation, and three are used primarily for recreation but also for water supply. In reference to habitat, 19 are located on Significant Natural Heritage Areas. Of the top 20 dams, seven are pre-defined potential projects (Table 5). In fact, the third ranking dam is in the process of being removed, and a grant for funding for the removal of the fourth was just approved. On the contrary, of these seven projects, two were explored for removal by American Rivers, however in both cases the land owner did not want to remove the dam.

Figure 30 and Table 6: Top 20 Percent of Ranked Dams (Classified with Natural Breaks) and Top 2 Ranked Dams: Statewide Prioritization Using an Ecological Prioritization Scheme

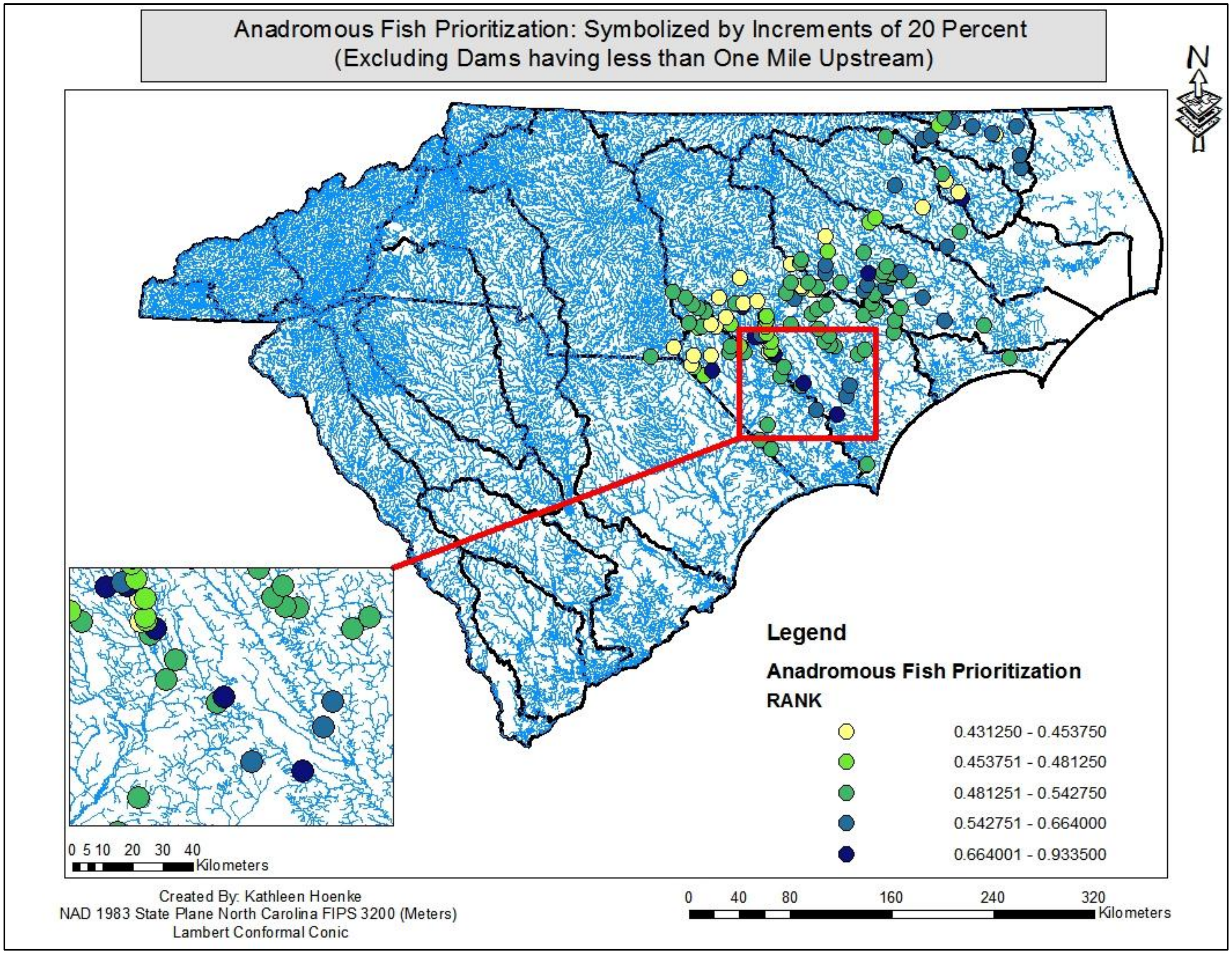


Top 20 Ranked Dams: Ecological Prioritization		
KHID	Rank	Current Potential Project?
13	1	Yes
48	2	No
32	3	No
53	4	No
5167	5	Yes
46	6	No
5096	7	No
3068	8	No
5017	9	No
25	10	Yes
838	11	Yes
5116	12	No
4756	13	No
5168	14	Yes
4	15	No
3975	16	No
3638	17	Removed
34	18	No
3809	19	No
5138	20	No

Within the ecological prioritization (social and safety criteria excluded), the top 20 ranked dams include those that are used primarily for water supply and hydropower but are on the areas of highest habitat quality. For instance, contrary to the social prioritization which has 19 of the top 20 used for recreation, only 12 are used primarily for recreation. Of the 12, nine are used for recreation or fishing only, three are used primarily for recreation but have other uses. However, contrary to the social prioritization which has only one dam with a primary use other than recreation, four out of 20 in the ecological prioritization are used primarily for hydropower, one is used primarily for water supply, and one is used for another unidentified purpose.

Within the ecological prioritization, 6 out of 20 are current projects (table 6). Also, between the ecological and the social prioritization, 11out of 20 are overlapping. Therefore, many of the same dams rank high, though they change order significantly in the top 20 which can be seen in the color change between the two prioritizations in figure 15 versus figure 16.

Figure 31 and Table 7: An Anadromous Fish Prioritization (Classified with Natural Breaks) as well as Top 20 Ranked Dams



Top 20 Ranked Dams: Anadromous Fish Prioritization		
KHID	Rank	Current Potential Project?
5048	1	Yes
5047	2	Yes
3732	3	Yes
4809	4	Yes
839	5	Yes
5017	6	No
5105	7	No
3809	8	No
4749	9	No
5161	10	No
19	11	No
5138	12	No
5116	13	No
5139	14	No
4813	15	No
5032	16	No
5035	17	No
53	18	No
25	19	Yes
3975	20	No

Within the anadromous fish prioritization, top ranked dams are very different from the top ranked dams in the social and ecological prioritizations, in that they are all located on the coast, are all in close proximity to current anadromous fish spawning areas and/or within the historical anadromous fish spawning area, and have high connectivity mileage and a low number of dams downstream. These qualities are prioritized for when using the Barrier Prioritization Tool, by allowing the user to select a geographic area to limit the prioritization to the coast, and select different indicators within the habitat and connectivity criteria that are unique to anadromous fish passage.

More specifically, while the social and ecological prioritizations have many of the same dams within the top 20 ranked dams, the anadromous fish prioritization causes new dams to surface in the top 20, many of which are not on areas of high habitat quality such as Significant Natural Heritage Areas, as habitat indicators used are different for this prioritization scheme. Within this prioritization, 6/20 are pre-defined potential projects (table 7).

VI: DISCUSSION

Comparison of Top 20 Dams Using the Three Prioritization Frameworks

When observing the results of the three prioritizations, roughly 30-35 percent of the top 20 dams in each are pre-identified potential projects, and were selected by American Rivers prior to this tool's creation. Meaning, the tool is performing as intended, successfully identifying dams that American Rivers considers to be good potential removal projects. In fact, American Rivers has used this ranking system in a grant for the removal of dam 25, which ranks third in the social prioritization, mentioning that the dam was ranked high using the prioritization tool and the grant was approved, therefore showing this tool's worth in the dam removal process (table 5 and 6). Pre-identified potential projects also ranked high in the anadromous fish prioritization. Of particular note is the number one ranked dam from this prioritization, dam number 5048 (table 7). This dam is actually Lock and Dam #1, a dam that was pre-identified as being very important for fish passage, however removal is not possible, and a rock rapids fish passage structure is currently being installed.

When comparing social prioritization to the ecological prioritization, the ecological prioritization includes 8 dams that are either hydropower or water supply dams and these are not included in the social prioritization (Table 6). For instance, Jordan Lake and Falls Lake, which are very large dams operated by the US Army Corps of Engineers and depended on for municipal water sources rank high in this prioritization. While these dams may be extremely beneficial to remove for ecological reasons, the chances of removing them are slim. However, when observing the top 20% of dams in the ecological prioritization, there is a chance that some of these dams could be altered to accommodate for specific species, which is why this ecological prioritization is important. This is also true of the anadromous fish prioritization, which also does not include the social or safety criteria. Many of these dams are large and their primary uses are not recreation (such as Roanoke Rapids Lake Dam, Falls Lake Dam, etc. See Table 7). However, a fish ladder or rock rapids could be installed on these dams if the owner is unwilling to remove the dam, making the use indicator less relevant (Batt, L. American Rivers., 2011).

There are some instances where dams appear in the top 20 ranked dams for both the social and ecological prioritization. In fact, 6/20 dams overlap between the social and ecological prioritizations (tables 5 and 6). There are two scenarios where this overlap can occur. First, a dam that has a use other than recreation can rank high in both the ecological prioritization and the social prioritization, such as the Tar River Dam. This dam is used as water supply, but recreation is listed as its first use, and it ranks very high in the habitat criterion, therefore making it continuously appear in both top 20 lists. This issue could be remedied to an extent by weighting the social criterion higher in the social prioritization, or manually editing those dams that have recreation as its primary use, but in reality is primarily used for hydropower or water supply. Second, other dams that appear in both the social and ecological prioritizations are those dams that have extremely high habitat quality but also exhibit the best social safety attributes. An example of this is Lassiter Mill Dam. This dam is located on a Significant Natural Heritage Area, also has been classified as having an excellent benthic community at the dam, has a high number of upstream miles, and also is considered a millpond with its only use being recreation, if any at all. In fact, Lassiter Mill Dam is unique in that it is present in the top 20 ranked dams of all three prioritizations, is a pre-identified potential project and is currently in the process of being removed. Dams like Lassiter Mill Dam that rank high on both the social and ecological prioritization should be given particular attention, as they are most likely the most ideal projects.

One issue presents itself within the social prioritization, which is land owner willingness. Within this prioritization, two of the top 20 dams are current projects, but the landowner is unwilling to remove the dam (Table 5). This fact underscores the underlying issue with the Barrier Prioritization Tool. No matter how this tool is used, there is no guarantee that a willing land owner will be present. There is no way for the data used in the tool to reflect land owner opinion, unless each land owner of every dam is surveyed. Therefore, the purpose of this tool is to serve as a first step for filtering the roughly 5000 dams in order to make the identification of potential projects easier. It does not mean the projects that rank high necessarily should or will be removed. Following use of the tool, project partners and managers should further investigate potential projects for the standpoint of viability (if the dam being used, and if that use be replaced), landowner willingness, and other critical factors. This secondary investigation will determine the final priority of projects.

Sensitivity Analyses

When criteria weightings are changed (individually increased by 25%), there are differences in the top 20 dams that are output in the prioritization (Figure 13). However, no matter which criterion is changed by 25%, approximately 5 of these dams consistently remain in the top 20, meaning that they rank high in all criteria no matter what the criteria is weighted. These dams also tend to be current potential projects, which is intuitive and another indicator that the tool is clearly successfully separating out dams according to the values of American Rivers.

Also, as expected, when one criterion was increased by 25%, dams tended to drop out of the prioritization that lacked qualities of that specific criterion. For example, when social was increased by

25%, dams that were primarily hydropower and water supply dropped out of the top 20. When habitat was increased by 25%, all dams in the top 20 were on a significant natural heritage area. Therefore, the prioritization is sensitive to changes in criteria weights.

The sensitivity of criteria, more specifically the ability of a certain number of dams to remain in the top 20 regardless of changing criteria weights, indicates that ecological criteria such as water quality, habitat, and even connectivity are linked and paint a picture of how urbanization can impact riverine habitats. For instance, dams that are on significant natural heritage areas, or areas where specific species of interest exist tend to be in areas with low impervious surface. They also tend to have higher connectivity. This idea is intuitive, because if a dam has low impervious surface in its watershed, then the water quality is likely to be better, and therefore more species are likely to thrive. Also, areas of low impervious surface mean that the area is more rural or more forested. These land uses/land covers are associated with mill dams, since they were built for the purpose of aiding the agriculture and forestry industries. These mill dams also tend to have higher connectivity than other dams located in urban centers, because higher concentrations of dams tend to be located in cities, fragmenting the connectivity of the river there. Evidence of these connections is shown in the sensitivity analysis in the number of dams in the top 20 that consistently show up regardless of percent change. In addition, safety is the criterion with the most sensitivity to percent change. These dams tend to be high hazard and have dam safety violations. High hazard dams tend to be very large dams or small dams in urban areas that would pose a danger to life or property if they were to fail. Many water supply or hydropower are high hazard dams, linking them more closely with social indicators.

These connections show how tightly woven the issues of urbanization are to water and habitat quality. The more the population increases, the higher the percent of impervious surface will be in watersheds; the higher this impervious surface, the lower the water quality. The more populations increase, the higher the need for electricity and water, and perhaps the more hydropower and water supply dams built, resulting in fewer opportunities for river restoration through dam removal.

These connections also highlight the use of this tool by future users. For instance, since safety is the most sensitive criterion, if a user increases the weight of safety (which ranks dams as high if they are high hazard) they may also output more dams that have higher impervious surface, if there is indeed a connection between urban dams and safety hazards.

Indicator Limitations

General:

Indicators were ranked according to American Rivers. Most of these indicators that were continuous (not binary) tended to exhibit a non-linear utility curve (Fig 7 a-c), meaning that the amount of satisfaction gained by the decision maker from each unit increase of an indicator was not linear. However, utility was not assessed using a formal utility elicitation process, meaning that the changes in rank do not correspond to exact points of when American Rivers is indifferent to indicator changes. Ideally, for continuous data, a Certainty Equivalent Elicitation Approach would be used, where American Rivers would determine at what measurement of the indicator an inflection point of utility exists. For indicators that exhibit a constructed scale, for example significant natural heritage areas, where there are only four possible options (the dam is on a national area, state area, etc.), a Probability Equivalent Elicitation Approach would be used (Clemen, 1996). Because neither of these elicitation approaches are used it could be argued that the ranks for each indicator were selected arbitrarily. However, given the high percentage of dams within the top 20 from prioritizations that were already pre-identified as active or potential projects, it can also be argued that American Rivers successfully ranked indicators to accurately portray how they value attributes of good dam removal projects .

All data associated with the barriers via a spatial join had error in the search distance used. Because dam GPS location error is not uniform (i.e.: all dam locations are not exactly on the stream segment, and the error in distance from the stream is not the same for all dams) there is potential for some dams to have indicator data associated with them that should not be, and vice versa. This includes flow indicators such as stream order and flow. As described with connectivity data below, the only way to fix this error is to manually assess each dam by hand and snap it to the river network.

Also, indicator data that were associated with the attribute tables of the dam such as use information, owner information, etc, may be outdated or incorrect. Some of this error was corrected by comparing the organized dataset with more recent data such as FERC hydropower data to update the hydropower use designation from the NC dam safety office; however use and ownership can change in the four years between when the NC dam safety dataset is updated.

Therefore, when projects are selected for exploration after a prioritization, the user should manually look at the dams in GIS individually to make sure the habitat data associated with it are correct, as well as the upstream mileage. Also, the user should look at the various individual indicators to make sure they understand the full picture of the dam being explored (some dams with extremely good habitat and water quality, as well as connectivity may come up high even if they are not used for recreation, and even when the social criterion is weighted high).

Finally, this tool uses the NHD Plus river flow line dataset at a scale of 1-100,000. Some have argued that this dataset is too coarse to visibly determine if dams are on small streams of interest. However, the NHD Plus has an enormous amount of data associated with it, such as flow velocity, elevation, and slope, which were useful in the prioritization process. Therefore the benefits of using the NHD plus dataset outweighed the costs associated with the coarse scale.

Habitat and Water Quality Data

Habitat and water quality criteria indicator data were associated with the dams using a spatial join. Therefore, the quality of habitat and water quality within a certain distance upstream of the dam is unknown. This limits the analysis, because just beyond this distance there could be a significant natural heritage area, a certain endangered species, or an area of impairment. Therefore, in the future, a method of accounting for these indicators within a certain distance upstream and downstream is necessary, perhaps through using ArcGIS network Analysis.

Also, habitat criteria indicator data such as significant natural heritage areas may be linked to habitat predictor data, making habitat data redundant. For instance, areas that are considered to be significant by the NC Natural Heritage Program may be designated a significant natural heritage because of the presence of endangered species, and therefore this indicator is not independent of the habitat predictor indicator. On the contrary, there is not a complete overlap between the datasets, so if only one indicator is used in the habitat criterion, a potentially significant dam could be missed. Overlap also seems to be an issue with the outstanding/high quality water designation and the significant natural heritage area. However, given the results of the sensitivity analyses to using only the habitat predictor indicator, it seems as though while there is overlap, there are some unique/non-overlapping habitat qualities brought to the table when using all four indicators (Fig 12). For instance, of the 115 dams on a significant natural heritage area, 14 percent of them have no species listed as the habitat predictor indicator, and upwards of 90 percent of them do not have any presence of high quality water or bio classifications.

In the prioritization when using only the habitat predictor indicator, 5 new dams are added to the top 20 due to a high score for the habitat predictor indicator however they do not exhibit qualities of any of the other three indicators. The presence of these 5 new dams could suggest that they have somewhat of a lower habitat quality than those dams exhibiting both high predictor scores and are also on Significant Natural Heritage Areas, on streams classified as ORW, etc. However, The 15 dams that remain in the top 20 that score high for the habitat predictor data as for the other 3 habitat indicators, suggests there is some overlap between these indicators though the cause of this overlap is hard to identify and therefore cannot be removed from the prioritization when using all indicators. Therefore, if a user chooses only one indicator, he/she may miss dams that have other habitat qualities, on the contrary if he/she chooses all four, dams that have only one indicator may be missed. If anything, a user may be able to successfully use ORW/HQW, bio classifications, and either habitat predictor data or significant natural heritage areas due to the high percentage of overlap between these two indicators, though there are still some dams left out if he/she uses one or the other.

One interesting thought is that the appearance of this overlap could be more of an issue of causality than data dependence. For instance, an area designated as an outstanding resource water would mean that the water of exceptionally good quality, and an indicator of habitat quality. However, the good water quality makes an area more hospitable to organisms, so the designation of the significant natural heritage area due to its uniqueness in species could be to an extent caused by the good conditions of the stream.

The state's methodologies of collecting habitat data and classifying rivers should be further explored for the user to decide which indicators are most appropriate to choose for the qualities they wish to fulfill within the habitat quality criterion.

Connectivity

The Barrier Analysis tool uses a 100 meter snapping distance to snap dams to the stream shapefile. However, dam coordinate locations do not place them directly on the river network. Some dams are off by as many as 300 meters when they should be snapped to the river, and others are off by 50 meters but they should not be snapped to the stream because they are a small farm pond dams located on small tributaries nearby. Therefore, using a snapping distance of 100 meters causes error where some dams snap that should not be snapped, and some are not snapped that should, as seen with Lake Louise Dam (Fig 8).

However, for this project, a 100 meter snapping distance was used in order to follow the lead of the Nature Conservancy's Northeast Barrier Assessment Project. TNC went through a variety of checks to fix these errors for the northern study. However, given the amount of time to fix these issues and the limitations for this project, these checks were not performed for this project. Therefore, in order to eliminate some error, two sets of connectivity were generated:

1. Connectivity data was calculated after removing dams on small tributaries from the calculation.
2. Connectivity data was calculated using all dams.

Both of these methods cause error in the dataset, whether it be that dams are not accounted for, or dams are present that should not be, therefore neither one of these methods are 100% correct, however, given the difference in the amount of dams that snap to the network using the two methods, the question is whether or not a large percentage of these additional 1036 dams are actually potential projects with high upstream functional mileage that were erroneously excluded from the prioritization using the no tributary methodology, and whether or not these additional dams are worth the error of falsely snapping dams to the network. At first glance, using the all tributary method, 1862 dams have only 3 or fewer functional upstream mileage, whereas the no tributary method has 912 dams with fewer than 3 upstream miles. Therefore, this suggests that the majority of dams added to the prioritization through using the all tributary method are small dams with low connectivity, which would not be weighted high in the prioritization, and adding them does not make much of a (beneficial) difference.

When observing this phenomenon more closely through graphing, the statewide differences in upstream mileage between the two methods produce a slope of 0.94, meaning the majority of dams had similar upstream mileage using the two methods. However, it is clear that some dams have a larger number of upstream miles using one method compared to the other. When comparing dams in the Cape Fear river basin to the Neuse River Basin, differences are apparent between basins. The Neuse river basin has some more obvious differences in upstream miles between methods; however both methods produce a higher number of upstream mileages than when compared to the other, so it is difficult to distinguish which method is better (Figs 9, 10, 11).

On the contrary, when comparing the two connectivity methods within the social statewide barrier prioritization, of the 20% that changed order significantly, while they did change order, they stayed in the top 20. These dams changed order because including all tributaries reduces the number of functional upstream mileage for some dams, therefore moving them down in the prioritization. However, of the top 20, two new dams appeared. One of these dams (KHID 1292) is ranked number 16 of 20 (Table 3), and is showing 170 upstream functional upstream mileage of connectivity. Upon further inspection, this dam actually is a very small tributary dam that should have less than one upstream mile of connectivity. This error occurred because the tributary is less than 100 meters from the main river. This is a serious error because this dam would be targeted for exploration for removal, when in reality it is not an acceptable candidate.

On the contrary, another dam (KHID 4985) appeared in the prioritization using the all tributary method. This dam has the same number of connectivity miles using both methods, however it moved into the top 20 because other dams had reduced upstream mileage using this method, and therefore moved down in the prioritization. This dam is an acceptable candidate for exploration; however it begs the question of whether some dams moved down in the prioritization due to lower mileage produced by small tributary dams falsely snapping to the river network (Table 3).

Therefore, when choosing between these two connectivity methods, the method excluding tributaries should be used in order to eliminate the possible error of very small dams being prioritized high. The benefit of adding dams with low connectivity does not outweigh the cost. However, because this method excludes potential projects on tributary dams and some users may value headwater streams, the best solution to this issue is to hand check dams with large differences in functional upstream mileage to see if they should indeed be snapped to the river network, and then manually editing these errors in the dataset, which was the methodology used by The Nature Conservancy in the Northeast Aquatic Connectivity Assessment Project. However, the Nature Conservancy North Carolina Chapter is currently funding the effort of snapping each of the 5000 dams to its appropriate stream, and connectivity errors will be corrected and incorporated into connectivity indicators by the end of May 2012.

Another error unrelated to snapping surrounds the calculation of downstream dams, an important indicator for anadromous fish spawning. Since all intermittent streams were removed from the stream shapefile prior to using the BAT tool, some very small dams were shown having only a small stream segment above the dam, with the downstream stream segment being non-existent (because the downstream segment was intermittent and taken out). Therefore, the downstream barrier count as well as the distance to mouth and number of downstream miles showed a false reading of zero. To eliminate these issues, barriers with functional upstream mileage of one mile or less are be taken out of the dataset when using these indicators within anadromous fish prioritization.

Finally, the number of downstream barriers was calculated to the end of the stream network, or the downstream most node. In the western and southern side of the state where another state is the downstream most node the distance to the mouth and the downstream barrier count is not calculated to the ocean. This issue can be remedied by prioritizing within specific geographic areas (i.e.: coast only) within the Barrier Prioritization Tool.

Once again, the ideal situation is to individually sort through these 5109 dams and manually correct errors by snapping each dam to its appropriate river, a task which is currently underway through funding from the Nature Conservancy in Durham, North Carolina.

Tool Limitations

At the present moment, the Barrier Prioritization Tool successfully performs the objectives hierarchy and ranks dams when weights are provided by the user. However, this tool is not "Bomb Proof," meaning that if a user provides percentages that do not add to 100%, the tool will still run and produce fundamentally inaccurate results. In addition, because the user can select indicators from a menu for each criterion, it is possible for a user to incorrectly choose an indicator for the wrong criterion, such as choosing the same indicator twice in different criteria or placing indicators within the criteria weighting field and therefore ranking dams based on indicators that are not independent of one another (for instance, instead of weighting the habitat criterion and then the water quality criterion which are composed of indicators, the user bases a final rank on weighting two habitat indicators differently). This can also produce inaccurate results by overweighting specific aspects of the tool, and a drop down window to restrict what indicators can be used would be beneficial. However, it is realistic that the user may actually only be concerned with two indicators of the same criterion for management or funding purposes, so the tool was specifically made to be flexible in this way.

Finally, difficulties arise when new barriers are added in the future, or indicator data is updated. The Barrier Prioritization Tool does not have a method of automatically updating data within the barrier dataset, nor adding new barriers to the dataset. This must be done in Microsoft Access or Microsoft Excel, by manually adding dams and manually updating the indicator data associated with these dams, especially for indicator data that was spatially joined to the dams. While a second tool is in development that allows input of the barrier dataset and then automatically spatially joins updated data, this tool does not automatically update indicator data that is embedded in the attribute table (such as use and safety indicators). This second tool should be developed so that the Barrier Prioritization Tool remains relevant in the future.

Future Utilization of the Barrier Prioritization Tool

American Rivers, working jointly with the North Carolina Aquatic Connectivity Team, will remove points representing current potential projects from the barrier dataset, and run a series of prioritizations using different indicators and different weightings for indicators and criteria in order to produce identify a number of potential dam removal projects for endorsement.

The Barrier Prioritization Tool has an enormous amount of potential for future use. If used correctly, it has the capability of sorting through large number of barriers so that the user can more efficiently identify potential dam removal projects. However, in the future, a more accurate association of indicator data to the barrier dataset is important. For instance, it would be very helpful to prioritize dams based on the ecological indicators present within the upstream and downstream drainage areas, rather than just at the location of that dam. This can be completed by re-associating the ecological indicator data using ArcGIS Network Analysis. In addition, an undertaking to fix connectivity errors is necessary. The connectivity issue is currently being addressed by manually editing the connectivity data, snapping each dam to its appropriate river in order to make this tool the best it can be. It would also be helpful to improve the process whereby indicator rank values were determined. This could be done by constructing a formal interview process to elicit utility values of each indicator, and comparing the output prioritization with the new rankings to see if the top dams change.

As expected, more accurate indicator data is always beneficial, and these indicators should be updated as it becomes available. This includes data availability for South Carolina. At the present time, ecological indicator data for South Carolina is lacking. It would be useful for the North Carolina prioritization to include dams within basins that connect in South Carolina, for a more accurate picture of habitat connectivity and potential projects. Therefore, South Carolina dams and data should be further explored in order to expand the usage of this tool.

Aside from improving the accuracy of indicator data and including South Carolina dams, it is important that the existence of this tool be communicated to other partners within the State of North Carolina. While the Aquatic Connectivity Team will endorse this tool and utilize its output, there are other agencies that could benefit from it. For instance, local governments may be interested in applying this tool to their counties to fulfill specific grants. Wake County has already expressed interest in the tool through a colleague within NC ACT; however providing presentations of this tool to local governments would prevent others from unknowingly re-creating a similar tool, and allow them to benefit from its creation. Also, organizations such as the Northeastern Brook Trout Joint Venture should be collaborated with for future use of this tool. For instance, while brook trout data is included in available indicators, there is some controversy surrounding how it should be used to evaluate dam removal priorities. Some dams block stocked trout from reaching native trout populations, which can help preserve the integrity of native population in the short term. However, long-term management solutions must be considered. Collaborating with the Venture would allow for this tool to be expanded to consider these concerns.

Finally, this tool has the potential to be used in other states, especially those that are geographically similar to North Carolina. The Barrier Prioritization Tool prioritizes dams using an input table of barriers with indicator rank fields embedded. Theoretically, if managers of a different state defined criteria and indicators for dam removal specifically to that state and associated them with dams within a point shapefile, the tool could prioritize dams within that state. However, obtaining a thorough barrier dataset for another state, as well as accurate indicator data, is challenging. Additionally, states that vary topographically such as those on the west coast could be problematic when using this tool for a statewide prioritization, because river processes could vary greatly between basins. However limited use of the tool in these regions could be possible such as prioritizing dams at the basin level.

VI. CONCLUSION

The Barrier Prioritization Tool presents a great opportunity to efficiently locate potential dam removal projects for further exploration. While dam removal can be a controversial topic, this tool offers enough indicator options within it so that users may choose the indicators they feel best represent the criteria they wish to be met for a potential project. The Barrier Prioritization Tool has proven its ability to successfully select projects through the large number of dams that show up in the top 20 that were already removal projects prior to this tool's creation.

Using GIS as a method to prioritize projects is useful and is beneficial if used correctly. However, it is important to keep in mind that a prioritization using GIS is only as accurate as the data and methodology that is used within it, and the professional judgment of resource managers is crucial to the successful use of this tool. It is necessary that this tool be updated with the best and most updated available data, and that methodologies of associating this data with the barrier dataset are improved, such as connectivity data methodology, and assessment of indicators within each dam's entire upstream and downstream drainage area, rather than just at the dam. With these improvements, this tool has the potential to make river restoration through the implementation of dam removal projects more efficient and effective.

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APPENDIX A: INDICATOR DATA SOURCES AND RANKING TABLE

Barrier Prioritization Indicator Ranks and Criteria						
Criteria	Source	Data Form		Indicator	Units	Rank
Connectivity "CONNECTIVITY "	TNC BAT Erik Martin	Barrier Analysis Tool; 100m snapping distance. Ranks via American Rivers	BAT connectivity	Connectivity mi		
					50-5753	1
					30 to 50	0.75
					10 to 30	0.6
					5 to 10	0.4
					1 to 5	0.2
					0 to 1	0.1
					0	0
				Upstream Mi	>100	1
					100 to 50	0.9
					10 to 50	0.75
					10 to 1	0.65
					1 to 0	0.25
					0	0
				Barriers Downstream	5 to 16	0
					1 to 5	0.6
					0 to 1	0.87
					0	1
Habitat Quality "HABITAT"	NC Heritage data aquatic SNHAs only. Contact: Allison Weakley.NC. Cons. Planning Tool	Polygon data; spatially joined to dams 300m distance. Ranks via NC conservation planning tool	SNHA	Nat/state significance	yes/no	1
				Regional Significance	yes/no	0.87
				Local Significance	yes/no	0.73
				none	yes/no	0.33
				Millpond/pond	yes/no	0

	USFWS Maxent Data Mark Endries	Line data spatially joined to dams 100m distance. Pre-ranked, scale changed from 0-10 to 0 to 1		G1 + species		1
				G1 species		0.9
				G1G2 Species		0.8
				G2 Species		0.7
				G2G3 Species		0.6
				G3 Species		0.5
				G3G4 Species		0.4
				G4 Species		0.3
				G4G5 Species		0.2
				G5 species		0.1
				No species present		0
	NC Heritage data. Contact: Allison Weakley.NC. Cons. Planning Tool	Line data; spatially joined to dams 300m distance. Ranks via NC conservation planning tool	Benthic	Benthic Excellent	yes/no	1
				Benthic Good	yes/no	0.5
				none of the above		0
			Fish	Fish Excellent	yes/no	1
				Fish Good	yes/no	0.5
				none of the above	yes/no	0
	DWQ, NC planning tool	Line data; spatially joined to dams 300m distance. Ranks via NC conservation planning tool	DWQ	Outstanding Res. Waters	yes/no	1
		0		High Quality Waters	yes/no	0.8
				none of the above	yes/no	0
Water Quality "WQUALITY"	DWQ	Line data; spatially joined to dams 300m distance. Ranks via American Rivers	Impaired: DO/ temp/chlorophyll a upstream and	IRC 4c: Impaired because of dam	yes/no	1
				Impaired IRC: 5 upstream only	yes/no	1

			downstream	Impaired IRC: 5	yes/no	0.7
				Not yet impaired, labeled potential standards violation	yes/no	0.5
				no impairment	yes/no	0
	TNC Impervious Surface in a HUC 12 data	Microsoft Access Data by Huc 12; microsoft access append query by Huc 12 name. Ranks by American Rivers	% impervious surface in the barrier's huc 12	>20% (Impaired)		0
				11%-20% (Impacted)		0.33
				6%-10% (somewhat impacted)		0.67
				<5% (healthy)	`	1
"FLOW"	NHDplus line data VAA table	Joined to NHDplus line dataset; spatially joined to dams via 100m distance. Rankings via American Rivers			7	1
					6	1
					5	1
					4	0.9
					3	0.75
					2	0.55
					1	0.25
					0	0
	NHDplus line data VAA table	Joined to NHDplus line dataset; spatially joined to dams via 100m distance. Rankings via American Rivers		>0.4 m/2		1
				<0.4m/s		0
Avoid Social Conflict "SOCIAL"	Martin Doyle; NC Dam Safety	in attribute table; Microsoft Access Sorting. Rankings via American Rivers	Hydropower	2010 FERC list (encompasses all H)	yes/no	0
				not hyopower	yes/no	1
	Cam McNutt; Ncdam safety	in attribute table; Microsoft Access	Water Supply	S; within area of intake;	yes/no	0

		Sorting. Rankings via American Rivers		impoundment present		
				S; within area of intake; run of river	yes/no	0.5
				S is only use	yes/no	0.6
				S is first use	yes/no	0.7
				Not water supply	yes/no	1
	Ncdam safety; AOI	in attribute table; Microsoft Access Sorting. Rankings via American Rivers	Other Uses			
				Use = R, RF, F, FR only	yes/no	1
				Use= R or F first	yes/no	0.67
				Use =I only	yes/no	0.07
				Use = I first	yes/no	0.13
				Use = C	yes/no	0
				Use = C first	yes/no	0.2
				none of the above	yes/no	0.33
	NC dam safety; AOI	in attribute table; Microsoft Access Sorting. Rankings via American Rivers	Mill Pond	Mill in name; AOI mill in comments	yes/no	1
				no Mill in name	yes/no	0
	Ncdam safety; AOI	in attribute table; Microsoft Access Sorting. Rankings via American Rivers	Ownership	Gov't: Fed, local, state	yes/no	1
				Private	yes/no	0
			Lake	name contains 'Lake'	yes/no	0
				name does not contain 'lake'	yes/no	1
Eliminate Safety Hazards "SAFETY"	Ncdam safety	in attribute table; Microsoft Access Sorting. Rankings via American Rivers	NC dam safety violations	Both		1
				DSO 2010	yes/no	0.9
				NOD 2010	yes/no	0.5
				None of the above	yes/no	0
			Hazard	High/Significant	yes/no	1
				Intermediate	yes/no	0.6
				Low	yes/no	0
				blank	yes/no	0
			Status	Impounding	yes/no	1

				Breached/Drained	yes/no	0
Species Specific Benefits	DMF	DMF polygon data. Euclidean distance from dams to polygons performed, distances joined to dams. Ranks via American Rivers	Distance to current AFSA (mi)		0	1
					0 to 1	0.9
					1 to 5	0.8
					5 to 20	0.65
					20 to 50	0.5
					50-308	0
	Mark Cantral Macdonald map	Polygon; digitized from McDonald Map, spatially joined to barriers. Rankings via NC Conservation Planning tool	AFSA	Within historic region	yes/no	1
	Jake Rash, Allison Weakley	Line; Analyzed by hand. Rankings via NC conservation planning tool and American Rivers. Data may not be a good representation of dam removal, as discussed in workshp	Brook Trout	App Brook trout only immediately in watershed	yes/no	1
				App Brook trout only further up in watershed	yes/no	0.8
				Bkt only in watershed	yes/no	0.7
				none of above		0

APPENDIX B: BARRIER PRIORITIZATION TOOL USER MANUAL

Barrier Prioritization Tool User Manual
Creator: Kathleen M. Hoenke
Master of Environmental Management Master's Project May 2012
Duke University Nicholas School of the Environment
Funded by: American Rivers and the Stanback Internship Program at Duke University

Introduction: This tool was created for the use of American Rivers and their colleagues, to better filter through barrier (dam) datasets with the purpose of finding the best potential dam removal projects based on ecological and social metrics. Thus, dams are prioritized as being better to remove if they rank high in six criteria: Increase in connectivity; increase in habitat quality, increase in water quality, minimize social conflict, increase in flow, and decrease safety risks. These are assumptions of what will occur if the dam is removed, and are based on social and safety data from dam safety offices of NC and SC, as well as the USACE, water quality and habitat data from NC DENR and SC DHEC, flow data from the NHDplus dataset, and connectivity data calculated using the Barrier Assessment Tool created by the Nature Conservancy (using the NHD plus).

The steps of this project were as follows:
1) Create an organized barrier dataset
2) Calculate connectivity data for each barrier
3) Join habitat and water quality data to the dataset
4) Create rank fields for each data metric
5) Create a tool to prioritize the barriers through the use of an Objectives Heirarchy prioritization scheme

<u>Barrier Prioritization Tool</u>

Description: This tool uses the most updated barrier dataset complete with metric data rankings fields and prioritizes them via adding criteria fields (that combine certain metric ranking fields: see each criteria in the Ranks and methodology document in the docs folder) and a rank field which weights each criteria field.

Tool Steps:
1) **Select your geographic area by using the dropdown window and specifying your geographic area shapefile or by navigating to it using the yellow folder button (i.e.: SCboundary**). The default is already set to NCboundary.
2) **Specify your specific geographic area by typing in the VB script code**. Ie: if you wish to prioritize dams only in the Neuse River Basin, type: BASIN = 'NEUSE'
3) **Select your barrier dataset that you wish to prioritize, using the drop down window or the navigate button (same as the method in step 1).** Note: This barrier dataset MUST have the appropriate indicator ranking fields already within it, use the provided barrier dataset in the default, or the dataset including dams with only 1 upstream mile + for anadromous fish prioritization.
4) **Specify the indicators and weights you wish to use for each criterion. Type the field name of the indicator and its weight into the criterion field** (i.e.: 0.25*[SNHA_RANK] + 0.25*[HABITAT_RK]). These percentages must add to 100 within each criterion.

5) **Specify the weights of each criterion in the prioritization scheme. You can change these in the expression window, by typing the decimal percentage as in step 4**. (Ie: 0.3 * [SOCIAL] means that the social criterion, which consists of the social indicators, ownership, use, millpond, etc. has a weight of 30 percent). All percentages must add up to 100.
6) **Specify your output location of the prioritized barrier dataset. The default is set to the Tool Output folder.** Change the name of the new dataset accordingly.
7) Click ok.
8) Once the tool has run, your barrier dataset that is in the table of contents window of the Map document will have already updated with six criteria fields (SOCIAL, CONNECTIVITY, HABITAT, SAFETY, FLOW, and WQUALITY) as well as a RANK field. Dams are automatically sorted from highest to lowest rank. Dams are also symbolized using a natural breaks classification, classified into 12 classes. To change the symbology of your barriers via their rank by right clicking the dataset →clicking properties→Symbology tab→ quantities→ Select Rank in the Value drop down window→graduated colors. If you wish to see which barrier has the highest value for a particular criteria, say HABTIAT, double click that column header. However this will not maintain the descending order of the RANK field.

9) A dbf table was created with your prioritization in the tool output folder, named after your prioritization. You can now open this table in Microsoft Excel or Access, by opening either program, selecting file→ open. Make sure that you click all file types in the scroll window of the program when searching for the table. It will be a .dbf table. You can now edit this table and re-save in the new format.