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Identifying Environmental Opportunities outside the Hydropower Project Boundary:

An Updated Methodology of the Basin Scale Opportunity Assessment

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Summary

The Basin Scale Opportunity Assessment (BSOA) initiative, led by the Department of Energy's (DOE) Water Power Program, was designed to establish an integrative approach to assess the potential for combined increases in hydropower energy and improvements in the environment at a basin scale. Methods were developed to isolate mutual benefits to hydropower energy production and environmental protection. To date, the majority of environmental mitigation at hydropower facilities has occurred within the vicinity or project area of hydropower facilities (i.e., direct environmental opportunities). This report summarizes a methodology to identify environmental opportunities independent of a hydropower development and operations (i.e., indirect opportunities), i.e. those that occur outside the project area or not in close proximity to hydropower facilities that may complement increases in energy production. Indirect opportunities include acquisition of conservation land, wetland mitigation, riparian improvements, stream habitat restoration, and removal of non-powered dams. Using geospatial datasets summarizing landscape and stream conditions and the occurrence of high-profile aquatic and terrestrial species of concern, we created a framework to identify indirect opportunities and applied the methodology to the Roanoke Basin (North Carolina and Virginia, USA) as a case study. A scoring system was developed to prioritize indirect opportunities based on landscape/stream condition and the presence of species of concern. In addition, literature reviews and geospatial procedures were used to identify the social emphasis (overall prevalence and spatial variation in prevalence) of various direct and indirect environmental opportunities. The inclusion of indirect opportunities may provide greater potential for environmental mitigation and improvements related to a specific project or hydropower development because indirect environmental opportunities are pervasive and do not rely on direct geographic affiliation with a hydropower facility. The full potential of mutual benefits to hydropower energy production and environmental protection may be underestimated if based solely on potential opportunities near a facility. The methodology presented also has further reaching implications, such as providing environmental stakeholders with mechanisms to prioritize restoration actions within a basin, irrespective of hydropower.

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Acronyms and Abbreviations

303d	303d Impaired Waterbodies Listing
BISON	Biological Information Serving Our Nation
BSOA	basin-scale opportunity assessment
CDRI	Clearinghouse for Dam Removal Information
cfs	cubic (foot) feet per second
DOE	Department of Energy
EO	elemental occurrence
EPA	U.S. Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
FPA	Federal Power Act
GAP	Gap Analysis Program
GIS	geographic information system
HUC	hydrologic unit code
HUC8	8-digit hydrologic unit code
HUC12	12-digit hydrologic unit code
NFHAP	National Fish Habitat Action Plan
NHA	Natural Heritage Area
NHD	National Hydrography Data set
NHAAP	National Hydropower Asset Assessment Program
NLCD	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Association
NPD	non-powered dam
NRI	National Rivers Inventory
NSD	New Stream-reach Development
NWI	National Wetlands Inventory
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
RIBITS	Regulatory In lieu fee and Bank Information Tracking System
TNC	The Nature Conservancy
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
VDCR	Virginia Department of Conservation and Recreation
VWC	Virginia Wetlands Catalog
WSR	Wild and Scenic River

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1.0 Introduction

The Basin Scale Opportunity Assessment (BSOA) initiative, led by the Department of Energy's (DOE) Water Power Program, was designed to establish an integrative approach to assess the potential for combined increases in hydropower energy and improvements in the environment at a basin scale. Through a collaborative effort between Pacific Northwest National Laboratory (PNNL) and Oak Ridge National Laboratory (ORNL), a 10-step methodology was developed to isolate mutual benefits to hydropower energy production and environmental protection. A methodology report (Johnson et al. 2013) was produced as a widely applicable and transferable process for replication in basins across the United States. Of the 10 steps in the methodology report, three are of great importance here and include: 1) identifying hydropower opportunities, 2) identifying opportunities for environmental improvement (e.g. mitigation), and 3) evaluating scenarios in which hydropower and environmental opportunities can mutually benefit. According to Johnson et al. (2013), opportunities are defined as possible actions for hydropower development or environmental improvement. Opportunities to increase conventional hydropower included increasing the capacity at existing dams, powering non-powered dams, or constructing new dams. Environmental opportunities are defined as situations where an existing environmental issue can be improved, either directly or indirectly, as a result of or in conjunction with a hydropower action , such as Federal Energy Regulatory Commission (FERC) relicensing procedures (Johnson et al. 2013). Environmental opportunities independent of a hydropower action (i.e., indirect opportunities), such as land acquisition and wetland rehabilitation, are possible, but were not considered by Johnson et al. (2013) because the focus was primarily concerned with combined hydropower-environmental opportunities, i.e., opportunities for hydropower development that have associated environmental improvements. The report herein updates the existing BSOA methodology as to identify indirect environmental opportunities that complement hydropower opportunities.

1.1 Background

The preliminary BSOA Phase 1 scoping assessment approach, completed in Sept 2013, identified complementary hydropower-environmental opportunities and consisted of five general tasks: 1) contacting key stakeholders, 2) compiling relevant information, 3) identifying hydropower opportunities, 4) identifying environmental issues, and 5) identifying potential complementary hydropower-environmental opportunities (Johnson et al. 2013). Information from the National Hydropower Asset Assessment Program (NHAAP) database was used to identify potential hydropower development opportunities in the basins related to powering Non-powered dams, New Stream Reach Development (NSD), and information for existing hydropower dams (ORNL 2014). Information about key environmental issues that could potentially be improved by hydropower development was identified from publicly-available resources, such as watershed planning documents, environmental impact statements, water-quality certifications, regulatory filings for hydropower projects, and nationally-available environmental data (e.g., EPA 303d listings). The information was placed in geographic context within a Geographic Information System (GIS) database to allow for spatially-driven analyses of hydropower-environmental interactions (Figure 1). The structure of the database was based on a data model that involved core data elements (e.g., spatial representations of hydropower opportunities and environmental opportunities), relationships between data elements, and rules by which interactions between hydropower and environmental issues are explored. Spatial footprints of hydropower opportunities included dams,

reservoirs, and tailwaters, which were included in the model. A central feature of the model was hydrologic catchment polygons (specifically National Hydrography Dataset (NHD) 1:100,000 scale catchments), which served as the common spatial unit for exploring spatial overlap between hydropower and environmental opportunities. To identify complementary hydropower-environmental opportunities, interactions between hydropower opportunities and environmental issues were explored using a consistent, sequential process. A key aspect of the process was development of two sets of criteria for structuring queries of the GIS database that would reveal complementary hydropower-environmental opportunities. The first criteria set applied environmental attributes that may preclude hydropower opportunities (e.g., protected lands, federally listed species, wild and scenic rivers), and the second described potential environmental benefits that may be associated with hydropower. Criteria were kept fairly coarse because of the broad scale of analysis and the intention of providing an initial assessment of potential opportunities. The outcome of the approach was a map and list of complementary hydropower-environmental opportunities for a given basin.

As defined previously, environmental opportunities are defined as situations where an existing environmental issue can be improved, either directly or indirectly, as a result of or in conjunction with a hydropower action (Johnson et al. 2013). Hydropower-environmental opportunities can be classified as direct or indirect depending on whether they improve existing environmental issues that are directly or indirectly related to hydropower development, respectively. In general, combined hydropower-environmental opportunities are typically direct and include improving water quality, hydrology, fisheries, and/or recreation. During the preliminary Phase 1 assessment, only direct hydropower-environmental opportunities were considered (Johnson et al. 2013). In contrast, indirect environmental improvements include wetland mitigation, riparian enhancement, habitat restoration, land acquisition, dam removal, and recreational/cultural enhancement. As an example of a direct opportunity, adding a turbine to a non-powered dam (i.e., a hydropower action) provides an opportunity to improve low dissolved oxygen conditions that may exist downstream. Hence, the physical addition of a turbine may include either engineered aeration structures incorporated into the turbine generator itself, spillage gates, or as infusers at the base of the powerhouse. In general terms, direct environmental opportunities rely on a hydropower action to be realized. In terms of the data model (Figure 1.1), these complementary actions are identified by the intersection of tailwaters and impaired waterbodies with low dissolved oxygen within the same hydrologic catchment (e.g., NHD 1:100,000 catchment). In contrast, wetland restoration (indirect opportunity) can occur miles from a dam and regardless of changes in dam operations or structure.

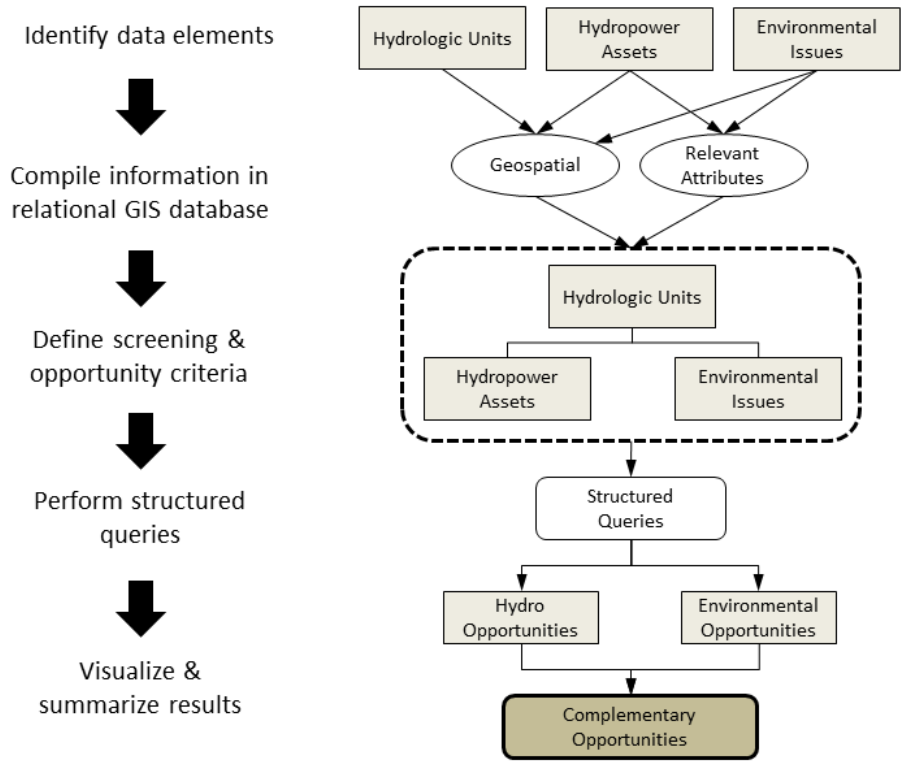

Figure 1.1. BSOA data model and process flow for identifying complementary hydropower-environmental opportunities in Phase 1 Scoping Assessments.

1.2 Indirect Environmental Opportunities

In general, combined hydropower-environmental opportunities typically include improving water quality, hydrology, fisheries, and/or recreation. Hence, mutual benefits are dependent upon the spatial overlap between hydropower opportunities and environmental improvement opportunities. The leading assumption underlying direct opportunities is that environmental benefits must be within, or at least proximate to, the hydropower project boundary. Arguably, the vast majority of environmental improvements related to offsetting hydropower development are direct as considered under typical regulatory pathways, i.e. Federal Energy Regulatory Commission (FERC). In order to mitigate the environmental effects of hydropower development and operation, FERC requires environmental compliance by private owners of hydropower facilities as required by Part I of the Federal Power Act (FPA). Hydropower facilities are licensed (if new construction) or relicensed (if existing) typically under an integrated or traditional licensing procedure, i.e. the most common licensing approaches (FERC 2012b). In these cases, the most common mitigation techniques typically include fish passage, flow and water quality improvement, habitat enhancement, and recreation improvements (FERC 2012a). The environmental issues considered are usually within the vicinity of hydropower facilities because many, if not all, are a direct result of dam construction or operation.

As much, if not more, of the potential for environmental mitigation and improvements within a basin may, in fact, be indirectly related to a specific project or hydropower development, in general. These types of environmental improvements include wetland mitigation, riparian enhancement, habitat restoration, land acquisition, dam removal, and recreational/cultural enhancement. While these potential improvement areas may be located proximate to facilities, many are likely to be many miles away. Hence, the full potential of "win/win" scenarios may be underestimated if based solely on spatial overlap and thus requires prioritizing conservation and sociocultural needs at the scale of the entire basin.

Fortunately, grounds for pursuing environmental opportunities potentially outside the boundaries of a particular project are supported by existing policies, known as Settlement Agreements, also under Part 1 of the FPA (FERC 2006). However, Settlement Agreements are not common in the US having only occurred at less than 10% of power plants and are mostly used at larger facilities (Figure 1.2). Furthermore, FERC requires the following five basic principles for different mitigation measures to be acceptable within settlement agreements: 1) the mitigation must be based on substantial evidence of an environmental need in the record, 2) the mitigation must be enforceable and within the FERC's jurisdiction, 3) a relationship must exist between the measure and the project's environmental effects, 4) required measures should be as specific as possible, and 5) actions should occur as close as possible to the project (FERC 2006). The strict criteria of these requirements will likely limit the type and scope of any indirect environmental opportunities, especially if not directly related to hydropower development or operations. Nonetheless, we include an assessment of indirect opportunities as to inform stakeholders of potential mechanisms of environmental improvements, provide a prioritization of needs in the basin, and evaluate current policies.

1.3 Objectives

The purpose of this report is to provide a methodology for identifying "indirect" environmental opportunities to support mutually beneficial situations of increasing hydropower energy while improving existing environmental conditions within a basin. We developed a framework to rank and prioritize indirect environmental opportunities in order to select the best options for mutually beneficial energy-environmental enhancement. In addition, we questioned how the social emphasis, or social importance, of different mitigation types might influence the relative importance of benefits, especially the social importance of benefits. Hence, we present a literature review approach to quantify the relative social benefits of different mitigation types across basins.

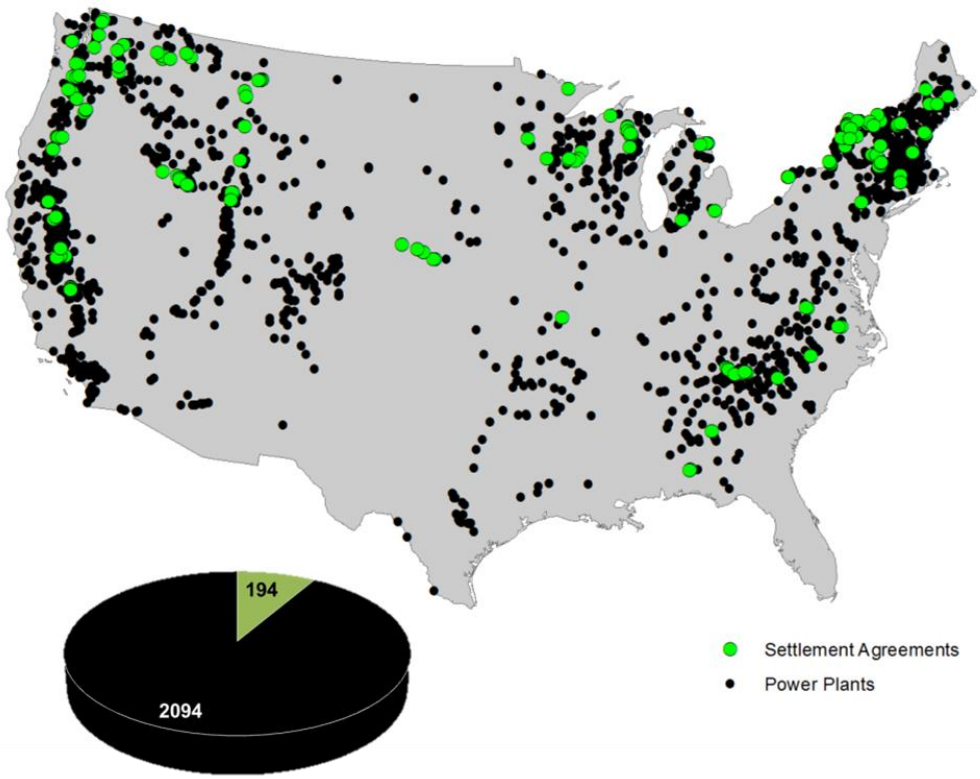

Figure 1.2. Distribution of power plants with and without Settlement Agreements negotiated by the Federal Energy Regulatory Commission

2.0 Methods

We presume that environmental benefits could potentially be provided because of two main factors: 1) increases in energy increase revenue, which increases the affordability of environmental improvements, and/or 2) establishing energy production at a new site (e.g., powering a non-powered dam) triggers the regulatory framework (i.e., FERC) that requires avenues for improvement that would have been otherwise unavailable.

We identified six main types of indirect opportunities that can be prioritized at the scale of an entire basin (Tables 2.1). Typically, opportunities were identified at the spatial resolution of National Hydrography Catchments (NHD). Because an infinite amount of opportunities may exist in the landscape (e.g., >16,000 catchments in the Roanoke Basin), each indirect mitigation type was placed on a relative scale of Benefit Scores, which were additive and dependent upon two elements: 1) SiteScore = the potential of improving the site or catchment and 2) Biodiversity Score = the potential of benefiting a species of concern. Site scores were based upon the current habitat conditions within each NHD catchment whereas Biodiversity scores were based on the presence of potential species of concern. Examples of score calculation are provided later in the document. Species of concern were identified and classified as aquatic, riparian, wetland, upland, or natural heritage terrestrial communities to pertain to different mitigation types (Figure 2.1). Provided these conceptual relationships, Biodiversity Scores for a given mitigation type only considered species of concern supported by habitats associated with that mitigation

(Figure 2.1). For example, riparian improvement was more beneficial if a riparian or aquatic species of concern was potentially present, as opposed to just considering any species of concern.

Several datasets were essential to developing Benefit Scores and included: 1) Elemental occurrences (EO) of species of concern from state-specific Natural Heritage programs or online data repositories (Figure 2.2), 2) National Land Cover Dataset (NLCD), 3) National Fish Habitat Action Plan (NFHAP), 4) GAP analysis protected lands layer, 5) National Wetlands Inventory (NWI), and 6) several other associated datasets (Table 2.2).

Out of these datasets, the EO dataset took the most preparation to transform into a product that informed our analysis. Species of concern for each basin were isolated from state-specific listings and included any species under the following criteria: 1) federal protection (of any kind) under the Endangered Species Act, 2) state listed as protected, and/or 3) recognized as rare and of conservation priority. Given the focus on hydropower development, we also included any diadromous fish species as species of concern. Occurrences of all species found in the basin were obtained from multiple datasets, including national-level surveys, online data repositories, and obtaining state-specific Natural Heritage Program data (Table 2.2).

Occurrences were overlaid with NHD catchments to produce contiguous maps of species richness within different taxonomic groups and/or habitat groups (Figure 2.2). While occurrences were comprehensive, they were not adequate for determining species presence or absence in unsampled locations. Thus, for fish and mussel species, we developed simplified species distribution models that predicted species presence and absence in unsampled NHD catchments (Figure 2.2, bottom panel). Potential presence for a given mussel or fish species in an NHD catchment was based on the combination of 1) the documented presence of the species within the surrounding 12-digit hydrologic unit (HUC12) catchment, and 2) whether flow at the bottom of the NHD catchment exceeded the 25th percentile discharge thresholds of all catchments in which the species had been documented. For species besides fish and invertebrates, we obtained raster maps of modeled species' distributions based on habitat affinities, land cover, and landscape disturbance from the National Gap Analysis Program (USGS 2014).

2.1 Indirect Environmental Opportunity Categories

2.1.1 Wetland Mitigation

Areas that are currently disturbed wetlands or were historically wetlands and converted to other land uses, such as agriculture, are well-suited for wetland restoration and creation because of the complex nature of hydric soils and underlying geomorphic conditions. Because the hydrologic conditions of these locations are difficult to artificially replicate, only existing wetlands or converted wetlands were considered in the analysis. The Virginia Wetlands Catalog (VWC) provided a methodology to prioritize wetlands for restoration/mitigation (Weber and Bulluck 2014). The VWC is a joint project between Virginia Department of Conservation and Recreation (VDCR), Division of Natural Heritage Program, and Virginia Department of Transportation. Wetlands prioritized for restoration in the VWC were graciously provided by VDCR for the Virginia portion of the Roanoke Basin (by Joseph Weber and Jason Bulluck). However, for the remainder of the Roanoke Basin (NC portion) and the Connecticut Basin, we used an approach similar to Weber and Bulluck (2014). Polygons of wetlands were obtained for both basins through the National Wetland Inventory (NWI) mapper (Table 2.2). Natural (as opposed to man-made) wetlands were only considered and ranked if they were ditched or farmed (as opposed to

impounded/leveed), were proximate to conservation lands, occurred in subwatersheds that were highly polluted or contained 303d listed waterbodies, supported species of concern, and were near Regulatory In lieu fee and Bank Information Tracking System (RIBITS) sites (Appendix 1). Datasets for each of the elements used to rank wetlands are provided in Table 3. We determined whether wetlands were artificial and the type of disturbance using the Wetland Classification provided within the NWI. Using the scoring rubric in Appendix 1, we ranked all wetlands across each basin and then summarized average wetland scores within each NHD catchment.

Table 2.1. Types of off-site mitigation, their descriptions, and factors important to determining their benefit.

Mitigation Type	Description	Benefit Score Depends On:
Wetland mitigation	Restore wetlands in areas that were converted to other land uses or were ditched/drainage for agricultural practices.	• Method adapted from Virginia DCR (Weber and Bulluck 2014) • Ditched or farmed Wetlands • Proximity to conservation lands • Impaired waters present • Polluted watershed • Restoration banking program • Wetland, Aquatic, or Riparian Species of Concern
Riparian Improvement	Revegetate areas of riparian loss that maximize existing efforts or areas of greatest need	• Riparian areas with high agriculture or cropland • Connected to high quality habitats • Adjoining protected Lands • Aquatic or Riparian Species of Concern
Instream Habitat restoration	Restore degraded habitats in areas experiencing intense urbanization, road development, and other disturbances.	• Poor local habitat quality • Connected to high quality habitats • Small systems <= 50cfs • Aquatic Species of Concern
Upland Land acquisition	Purchase/conserve/place easements on high quality conservation land	• Near existing protected land, but currently unprotected • Forested or wetland areas • An unprotected natural heritage area of interest • All Species of Concern
Riparian Land acquisition	Purchase/conserve/place easements on high quality riparian land	• Currently unprotected areas joining high quality protected lands • Forested or Wetland • Adjoining a protected river (WSR or NRI) • Riparian or Aquatic Species of Concern
Dam Removal	Remove non-powered dams with low energy potential that free up quality riverine habitats.	• Non-powered dams with little or no energy potential • Length and size of stream miles opened up • Quality of stream habitats open up • Number of diadromous species

Table 2.2. Datasets and sources used to create different indirect mitigation types.

Mitigation Type	Datasets	Website
Wetland Mitigation	National Wetland Inventory	www.fws.gov/wetlands/
	GAP protected Land Status	gapanalysis.usgs.gov/padus/
	Nitrogen or Phosphorus loading	water.usgs.gov/GIS/metadata/usgswrd/XML/nhd_nutrients.xml
	Impaired 303d listed waterbodies	water.epa.gov/scitech/datait/tools/waters/
	Regulatory In lieu fee and Bank Information Tracking System (RIBITS)	geo.usace.army.mil/ribits/index.html
	State Wetland Prioritization	acquired from VA (for VA portion of Roanoke Basin)
Riparian Improvement	National Land Cover Dataset	www.mrlc.gov/
	GAP protected Land Status	gapanalysis.usgs.gov/padus/
Habitat Restoration	National Fish Habitat Action Plan (NFHAP) disturbance index	www.fishhabitat.org/
	NHD Flowline attributes	www.horizon-systems.com/nhdplus/nhdplusv1_home.php
Land Acquisition	National Land Cover Dataset	www.mrlc.gov/
	GAP protected Land Status	gapanalysis.usgs.gov/padus/
	Natural Heritage Areas	acquire from state (purchase may be required)
Riparian Land Acquisition	National Land Cover Dataset	www.mrlc.gov/
	GAP protected Land Status	gapanalysis.usgs.gov/padus/
	Wild and Scenic Rivers	www.rivers.gov/
	National Rivers Inventory	www.nps.gov/ncrc/programs/rtca/nri/index.html
Dam Removal	ORNL NHAAP Resource Assessment	nhaap.ornl.gov/
	NHD Flowlines	www.horizon-systems.com/nhdplus/nhdplusv1_home.php
	National Fish Habitat Action Plan (NFHAP) disturbance index	www.fishhabitat.org/
All Mitigation Types (Species of Concern)	State Natural Heritage Program	acquire from state (purchase may be required)
	Biodiversity Information Serving Our Nation (BISON) Database	bison.usgs.ornl.gov/

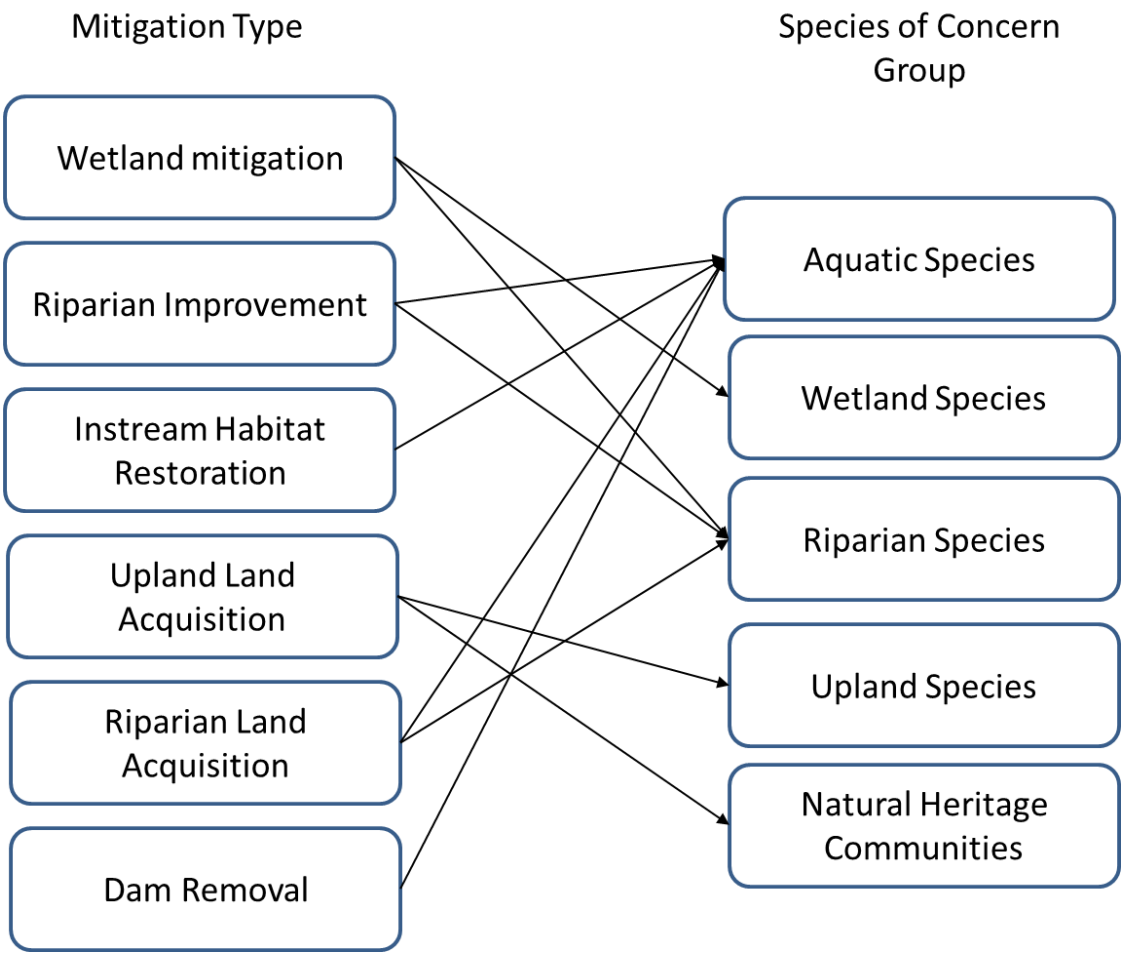

Figure 2.1. Hypothesized linkages between mitigation types and classes of species of concern

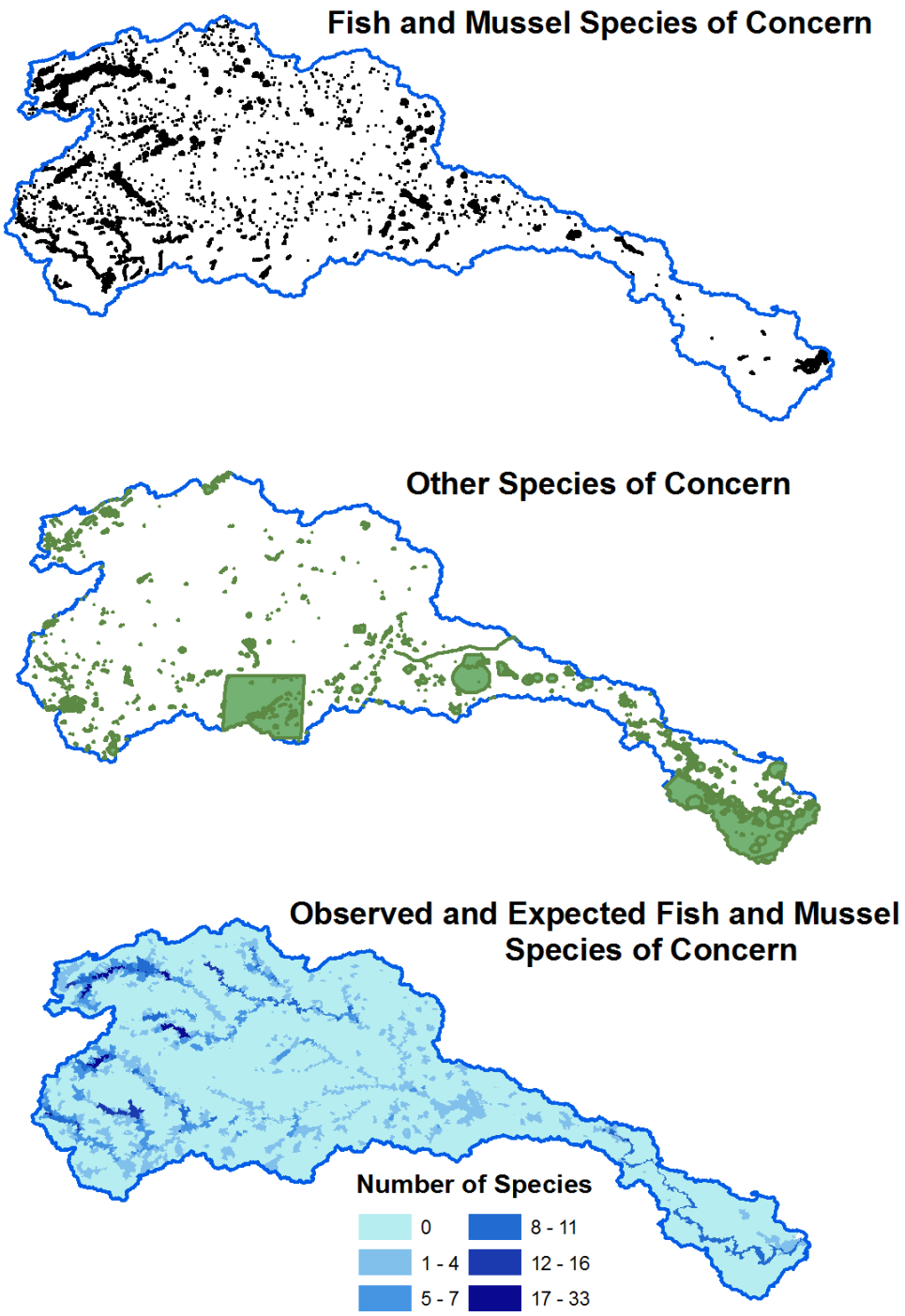

Figure 2.2. Examples of elemental occurrence (EO) datasets used to map locations of species of concern (top and middle). EO datasets were used to map species observations and predict potential locations of occurrence within National Hydrography Dataset catchments (bottom).

2.1.2 Riparian Improvement

Riparian areas, and associated aquatic habitats, experiencing losses in streamside vegetation cover in agricultural areas would benefit from re-vegetation or vegetation enhancement. Revegetation in urbanizing areas was not considered for 2 main reasons: 1) the inability of isolating areas that could realistically support revegetation, and 2) incentive programs such as, Landowner Incentive Program or Conservation Reserve Enhancement Program are only applicable to farm owners, i.e. agricultural lands. Because the width of riparian areas, and associated floodplains, will increase with river size, a variable-width buffer was produced for NHD flowlines based on annual flow (Figure 2.3). The minimum and maximum buffer sizes were set to 100 and 500m, respectively. Annual flow for each NHD flowline was rescaled from 0 to 1 by dividing by the maximum flow value for the entire basin. The ratio was then multiplied by 500 (max buffer) to calculate buffer widths for each flowline, with the smallest buffer being set at 100m. Using the National Land Cover dataset (NLCD), the percentage of areas falling within different land use categories was summarized within each buffer segment.

Segments with high amounts of pasture or crop production land uses were assumed to be more suitable to revegetation. However, riparian improvement should also be dependent upon whether the stream reach connects high quality habitats as opposed to just the immediate condition within the stream reach of interest. We prioritized stream reaches with poor riparian conditions that, if restored, would connect areas of quality habitats to create corridors that enhance migration and connectivity (Figure 2.4). Likewise, we assumed areas adjoining protected lands provide similar benefits. The NHD dataset provides the up-and-downstream connectivity of stream segments through unique identifiers for each stream reach through node-to-node linkage tables. Hence, we summarized the land cover within each stream reach, but also land cover in the immediate up-and-down reaches. Lastly, we summarized the number of observed and potential riparian and aquatic species of concern within each stream segment.

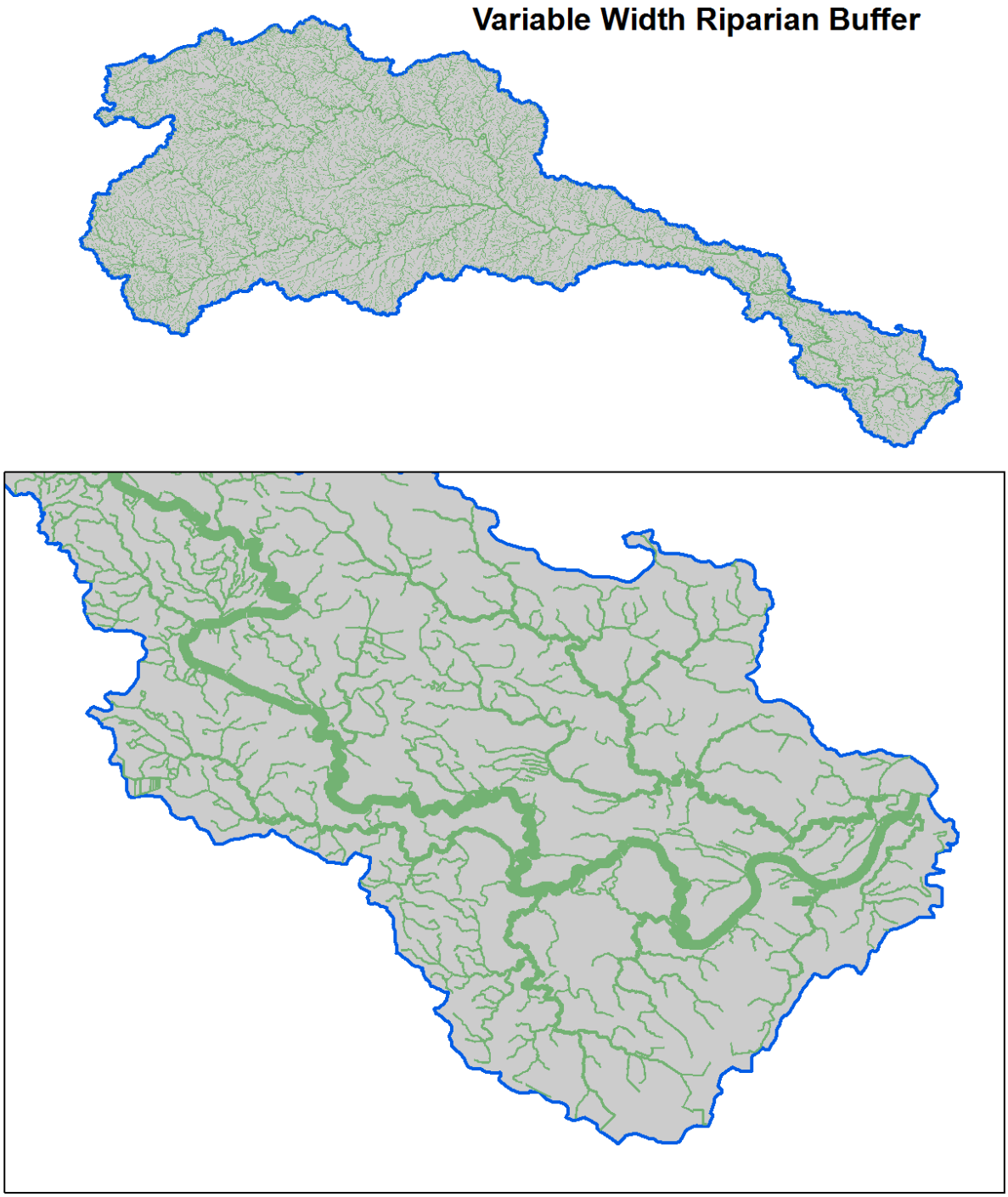

Figure 2.3. Variable-width buffer for each National Hydrography Dataset flowline**.**

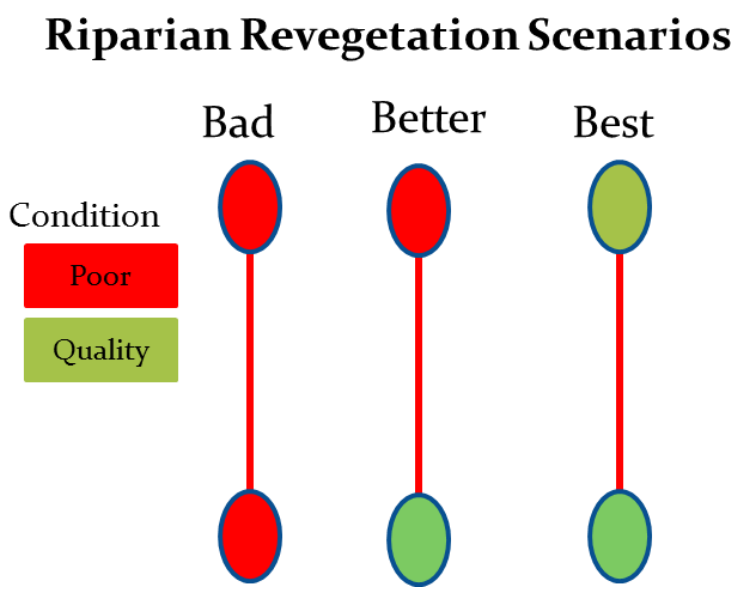

Figure 2.4. Riparian revegetation scenarios in terms of habitat connectivity. The best scenario is when poor conditions are improved that connect quality habitats.

2.1.3 Instream Habitat Restoration

Similar to riparian improvements, habitat restoration should target poor habitats that maximize connectivity while also benefiting aquatic species of concern. Local disturbance indices (LDIST) from the National Fish Habitat Action Plan (NFHAP) provided a suitable surrogate for areas of poor instream habitat conditions (Table 2.2). LDIST is calculated for each NHD segment and takes into account land use, dams, mines, National Pollutant Discharge Elimination Sites, and several other landscape disturbances that influence instream habitats. Using the node-to-node tables, we assessed LDIST for each local NHD segment and the immediate up-and down-stream segment. Because instream habitat restoration is less common in large streams (due to the inability to manipulate substrate, stream banks, and morphology of the stream channel), we used additional site scoring to prioritize stream segments based on stream size using 10 cfs, 20 cfs, and 50 cfs as incremental thresholds. Streams > 50 cfs received low scores. Observed and potential aquatic species of concern were used to prioritize NHD segments.

2.1.4 Upland Land Acquisition

Prioritizing land for conservation purposes is multi-faceted and requires consideration of existing protected lands, habitat quality, areas of natural resource value, and areas supporting of species needing protection. Priority areas for land acquisition should currently be unprotected but near protected lands (as to create corridors and enhance migration), preferably be forested or wetland habitats (at least for Eastern US basins), should not be urbanized areas, and should support species of concern. First, an inverse Euclidean distance raster was created where land conservation values decrease with increasing distance from protected lands (Figure 2.5). Land cover was reclassified into three groups with highest values given to forest and wetland land cover, intermediate values given to agriculture and water, and 0 values given to developed areas. Using map algebra, a composite raster was created as a measure of land acquisition value (Figure 2.5). Average values were summarized within NHD catchments using zonal statistics. Natural heritage areas (NHAs) depict terrestrial communities that are valuable natural resources and support rare communities. Some, not all, NHAs are protected. Hence, protected areas were removed

from NHAs and the area encompassed by NHAs was summarized within each NHD catchment. Land acquisition values, NHA % area, and species of concern within each NHD catchment were then used to prioritize areas for land acquisition.

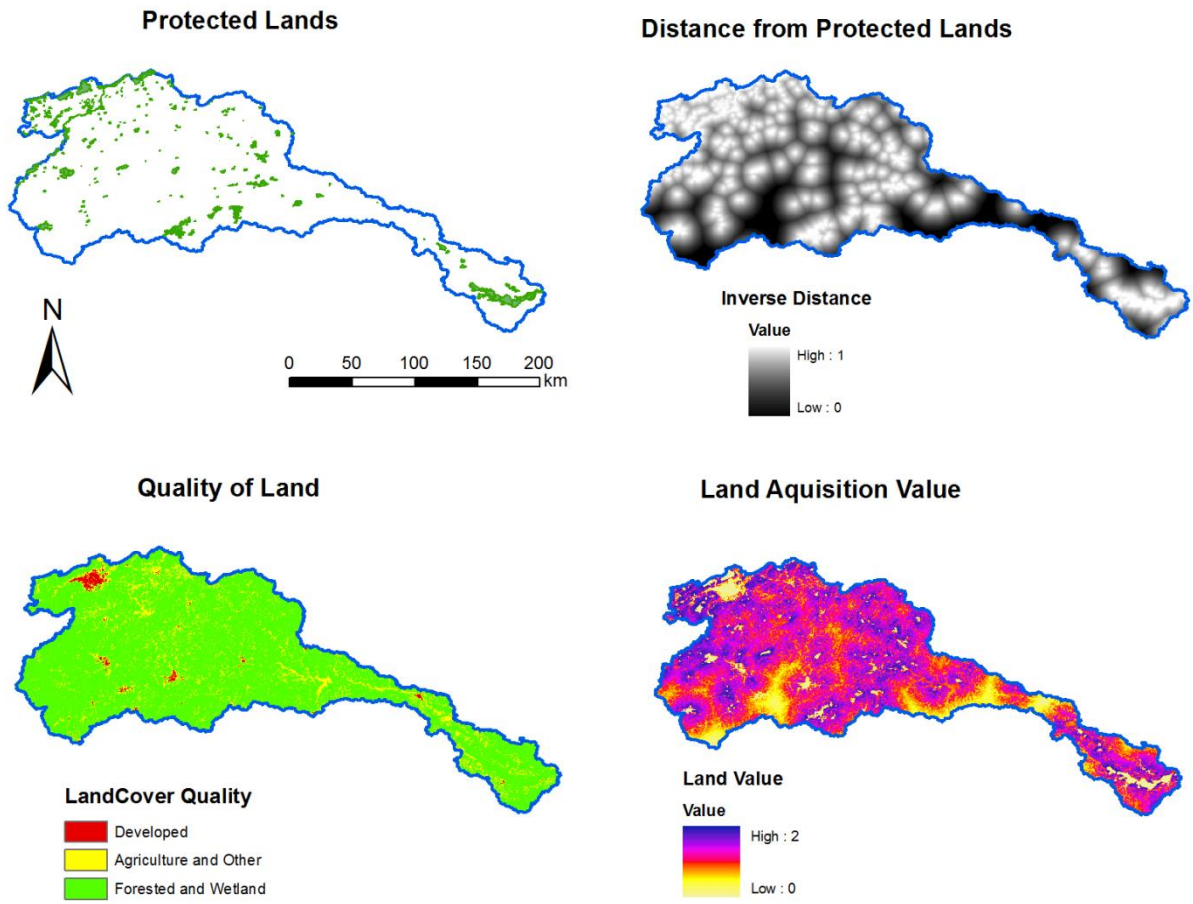

Figure 2.5. Process of creating land acquisition value to support conservation land prioritization.

2.1.5 Riparian Land Acquisition

Prioritizing riparian areas for protection is similar to upland areas except the protected status of up-and down-stream riparian areas is taken into consideration rather than Euclidean distances to protected lands. Using the variable-width buffers, the % coverage of protected lands was summarized for each NHD flowline. Stream reaches with the least amount of riparian protection that could provide connectivity to highly protected stream reaches were considered more beneficial. In addition, stream reaches listed under the Wild and Scenic Rivers Act (WSR) and National Rivers Inventory (NRI) have higher value for riparian land acquisition. Thus, we summarized the % distance of each flowline covered by WSR and NRI streams. We summarized the number of observed and potential riparian or aquatic species of concern within each NHD catchment.

2.1.6 Dam Removal

Dams that are old, dilapidated, and have little energy value should be considered for removal. Only non-powered dams (NPD) were considered for the analysis. Prioritizing dams requires running analyses that assess the functional network of stream mileage opened up once dams are removed. Functional network refers to the mileage of connected streams systems, i.e. stream and tributaries not fragmented by dams (Figure 2.6). In other words, functional networks provide an indication of how much habitat is available to migratory fish if dams are removed (Figure 2.6). Other considerations include the quality of stream habitats accessible after dam removal and the presence of diadromous species. Fortunately, an analysis equivalent to this approach had already been conducted in the Northeastern US (including the Connecticut Basin) by The Nature Conservancy (Martin and Apse 2011). The dataset of dams and scoring rubric was provided by Erik Martin (TNC). Dams and scores were adjusted to suit the needs of our assessment. For the Roanoke, an existing prioritization of dam removal was not available; thus, we calculated the functional network of each NPD as the total distance available upstream to the nearest dam(s). To quantify the quality of habitat of available habitats, we used the NFHAP dataset to calculate the average LDIST score for all NHD segments within each functional network. In addition, the distance of each NPD to the mouth of the basin was also calculated as the relative position of a dam is important to estuarine access. The number of observed and potential fish species of concern and fish diadromous species were used to calculate biodiversity scores with higher weighting for diadromous species.

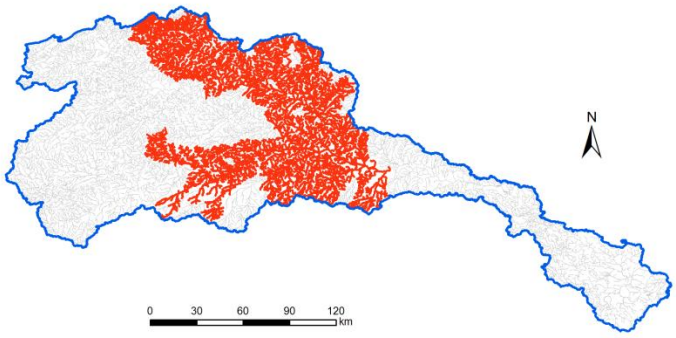

Figure 2.6. Functional network of Kerr Dam (USACE) in Virginia.

2.1.7 Benefit Scoring

Benefit scores for each mitigation type were quantified as the sum of Site Scores and Biodiversity Scores and considered the entire basin. Site Scores and Biodiversity Scores for each mitigation type may be made up of multiple components, each of which is scaled from 0 to 1. All scores are summarized in Table 2.3. As an example, the Benefit Score for riparian land acquisition is provided in equations 1-6.

Eq 2.7.1. $BENEFIT_i = [SITE]_i + [BIOD]_i$

Where *BENEFIT* is the Benefit Score, *Site* is the Site Score, and *BIOD* is the Biodiversity score for the ith NHD stream reach and [ ] indicates that variables are scaled from 0 to 1. SITE and BIOD are further calculated by the following:

Eq 2.7.2. $SITE_i = [PL]_i + [LC]_i$,

Eq 2.7.3. $BIOD_i = [SOC]_i + [PR]_i$,

Where PL is the protected land score, LC is the land cover score, SOC is the species of concern score, and PR is the % of protected rivers within each stream segment. Each component is calculated as:

Eq 2.7.4. $PL_i = (1 - \%protectedland)_i + \frac{(\%protectedland_{up} + \%protectedland_{down})}{2}$, and

Eq2.7.5. $LC_i = 2*(\%forest + \%wetland)_i + \%agric_i - \%devel_i$

Eq 2.7.6. $SOC_i = 2*[\#observedspecies]_i + [\#potentialspecies]_i$

In the case of riparian land acquisition, numbers of species refers to riparian or aquatic species of concern. Benefit Scores, once quantified, were sorted and the highest percentile values (e.g., 90%'tile) were selected for the entire basin (Figure 2.7). The NHD catchments with the top benefit scores were then summarized by 8-digit hydrologic units (e.g., HUC-8).

Table 2.3. Equations for Site Scores and Biodiversity Scores that make up Benefit Scores for different mitigation types. See "Benefit Scoring" section in text.

Mitigation Type	Site Score	Biodiversity Score
Riparian Improvement	$SITE_i = [PL]_i + [LC]_i$ $PL_i=(1-\%protectedland_{loc}) + 1/2*(\%protectedland_{up} + \%protectedland_{down})$ $LC_i = LC_{loc} + 1/2*(LC_{up} + LC_{down})$ $LC_{loc} = 2*(\%agric)_{loc} - \%forest_{loc} - \%wetland_{loc} - \%devel_{loc}$ $LC_{up} = 2*(\%agric)_{up} - \%forest_{up} - \%wetland_{up} - \%devel_{up}$ $LC_{down} = 2*(\%agric)_{down} - \%forest_{down} - \%wetland_{down} - \%devel_{down}$	$BIOD_i = [SOC]_i$ $SOC_i = 2*[\#observedspecies]_i + [\# potential species]_i$ (aquatic and riparian species only)
Habitat Restoration	$SITE_i = [DIST]_i + [FLOW]_i$ $DIST_i=(1-[LDIST]_{loc}) + 1/2*([LDIST]_{up} + [LDIST]_{down})$, where LDIST refers to the NFHAP disturbance index. Recall that 5 is very low disturbance and 1 is very high. $FLOW_i$ = if discharge <= 10cfs, then 1; if discharge > 10 csf and <=20 cfs, then 0.5; if discharge >20 cfs and <=50 cfs, then 0.25; otherwise 0.	$BIOD_i = [SOC]_i$ $SOC_i = 2*[\#observedspecies]_i + [\# potential species]_i$ (aquatic species only)
Land Acquisition	$SITE_i = [PL]_i$ PL is a protected land score derived from geoprocessing; see methods for "Land Acquisition" section.	$BIOD_i = [SOC]_i$ $SOC_i = 2*[\#observedspecies]_i + [\# potential species]_i$ (all species)
Riparian Land Acquisition	$SITE_i = [PL]_i + [LC]_i$ $PL_i=(1-\%protectedland_{loc}) + 1/2*(\%protectedland_{up} + \%protectedland_{down})$ $LC_i = 2*(\%forest + \% wetland)_i + \%agric_i - \%devel_i$	$BIOD_i = [SOC]_i + [PR]_i$ $SOC_i = 2*[\#observedspecies]_i + [\# potential species]_i$ (aquatic and riparian species only) PRi = %length protected river
Dam Removal	$SITEi = 5*[NTWRK]_i + [DIST2MOUTH]_i + [QUALITY]_i$ where NTWRK refers to functional network length, DIST2MOUTH refers to distance to estuary, and quality refers to averaged disturbance (LDIST) scores (from NFHAP) within the functional network	$BIOD_i = [SOC]_i$ $SOC_i = 2*[OBSPEC]_i + [POTSPEC]_i$ $OBSPEC_i = 2*[\#observed\ diadromous\ species]_i + [\#observed\ other\ species\ of\ concern]_i$ $POTSPEC_i = 2*[\#potential\ diadromous\ species]_i + [\#potential\ other\ species\ of\ concern]_i$ (fish and mussel species only)

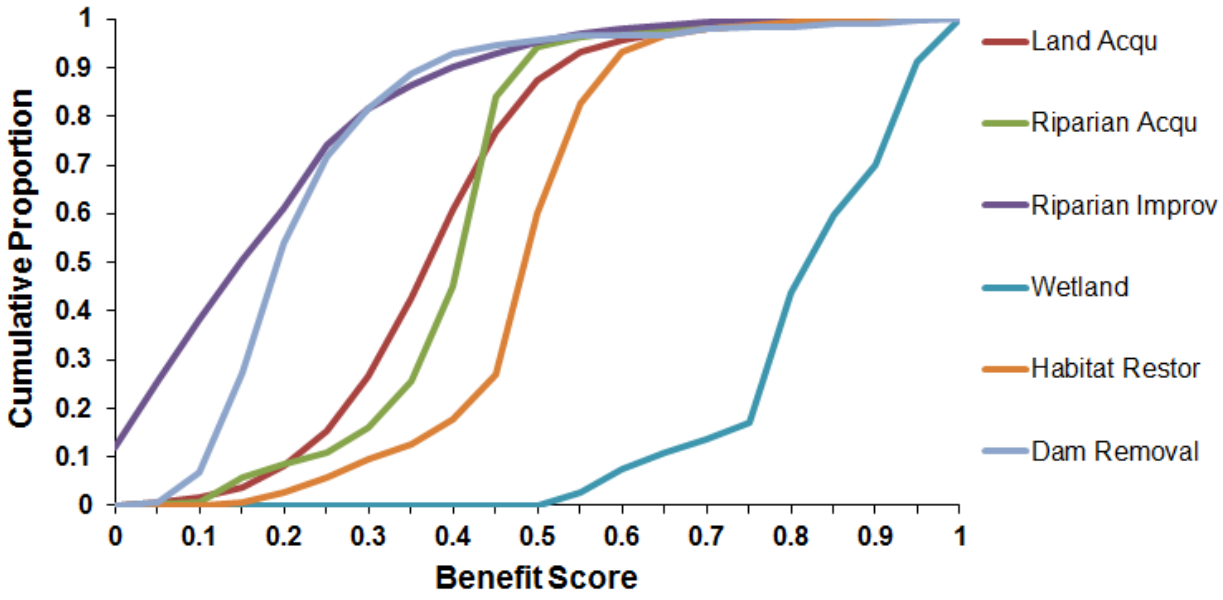

Figure 2.7. Cumulative proportion of Benefits Scores for mitigation types in the Roanoke basin**.**

2.2 Social Emphasis

While Benefit Scores represent an ecological valuation of potential areas for mitigation, they do not take into account social importance or social values. The likelihood of successfully executing an environmental improvement project depends on social acceptance, such as whether communities will accept a given mitigation as compensation for on-site/direct environmental degradation associated with increases in hydropower generation. Social acceptance of mitigation measures depends on many factors, such as the type of mitigation measure, the extent of disturbance that induces a need for compensation, the distance between the area of disturbance and the site of mitigation, and the geographical location of mitigation within a region (e.g., coast versus upland). Determining social acceptance and willingness to accept a measure as compensation is difficult to quantify and would require, in the least, resource-intensive surveys of stakeholder values.

In contrast to measuring social acceptance, social emphasis can be used as a surrogate of the relative social value of different mitigation types. Thus, to reemphasize, we do not propose that we can understand what constitutes acceptable "compensation"; however, we can estimate whether one mitigation type has greater social value than another. Estimating social values are important when comparing potential competing benefits, prioritizing different mitigation types, or calculating potential cumulative benefits.

We can objectively determine social values by assuming that the frequency of documented mitigation types or documented environmental issues is an indication of social values within a region. We used an eco-evidence-based literature review approach to document the frequency of mitigation types and prevalence of studies assessing environmental issues. Eco-evidence approaches, originally developed by epidemiologists in the 1960s, rely on extensive literature review to demonstrate support for hypothesized cause-effect relationships in environmental investigations (Norris et al. 2012). Systematic reviews of literature and associated weighting schemes, based on the strength of each piece of evidence, are used to estimate support for a given cause-effect relationship (Norris et al. 2012). In our case, support is assessed as prevalence of a given action within a geographic area as opposed to hypothetical relationships. The approach we present examines two concepts related to social emphasis. First, we evaluate the overall prevalence of mitigation type and environmental issues within basins using a modified eco-evidence approach based on documentation (literature or web material). Secondly, by extracting geospatial locations from documents, we evaluate spatial variation in social emphasis by mapping the prevalence of mitigation actions or environmental issues in the landscape.

2.2.1 Literature Review

The objective of the literature review was to compile and categorize literature for the purpose of characterizing the relative need/perceived importance of seven types of on- and off-site opportunities for environmental mitigation in the Roanoke basin (Table 2.4). We used a three-tiered approach to compile information that ranged in scientific rigor from peer-reviewed scientific literature to gray literature from government sources to non-peer-reviewed documents and reliable webpages (e.g., .org or .gov). First, we searched ISI Web of Science for peer-reviewed literature using keywords associated with each basin and each type of environmental opportunity (https://apps.webofknowledge.com). For each mitigation type, we began with the most relevant keywords and carried out searches with additional keywords until no new literature documents were identified (Table 2.5). Second, we searched two online databases for gray literature. The Clearinghouse for Dam Removal Information (CDRI) is a database documenting dam

removal projects (http://library.ucr.edu/wrca/collections/cdri/). We searched the CDRI database using the following geographic keywords: “Roanoke River”, “Virginia”, and “North Carolina”. The National Oceanic and Atmospheric Administration (NOAA) maintains a database of georeferenced restoration projects (https://restoration.atlas.noaa.gov). We used the restoration atlas tool provided by NOAA to identify all completed and ongoing restoration projects within each basin. Third, we systematically searched webpages of stakeholders for documentation of environmental mitigation projects. A comprehensive list of stakeholders with known interest in environmental mitigation within each basin was identified in previous steps of the BSOA project (Johnson et al. 2013).

2.2.2 Overall relevance weighting

After compiling all relevant literature, we reviewed and assigned each document to one or more of the seven mitigation types using a systematic classification rubric describing specific types of restoration and research projects (Table 2.4). Next, a weighting system based on the product of three weighting factors was used to characterize the overall relevance of each document (Table 2.6). Weights ranging from 0.14 to 1.00 and were assigned to each document for each of the three weighting factors. First, each document was categorized by the type of research described: a documentation of one or more restoration projects or alternatively an empirical scientific investigation of an environmental response relevant mitigation, but not directly associated with a specific restoration or mitigation project. We reasoned that direct documentation of a restoration project provides stronger evidence (and should be weighted higher) for the need/perceived importance of that mitigation type compared to an empirical scientific investigation that is not directly associated with a restoration or mitigation project. Second, the reliability of each document was categorized based on scientific rigor. Third, we weighted documents by time since completion. We reasoned that the relative need/perceived importance of different types of mitigation may change over time depending on changes in anthropogenic stressors and previously-implemented and successful mitigations.

Table 2.4 Seven types of on- and off-site mitigation opportunity and descriptions of specific types of restoration and research projects falling under each type.

Mitigation type	Restoration examples	Research topics
Direct		
Flow improvement	Flow augmentation; natural flood pulse mimicry	Hydropeaking flow regime; flow regime effects on fish recruitment; flow regime effects on fish spawning; flow regimes as migration cues; floodplain inundation; large wood distribution; riparian vegetation
Fish passage	Culvert modification; fish ladder; trap and transport	Dams as migration barriers; culverts as movement barriers; fish ladder use
Water quality	Tailwater temperature regime; tailwater dissolved oxygen	Non-point source nutrients; non-point source toxins; point source nutrients; point source toxins; sedimentation
Indirect		
Habitat restoration	Bed stabilization; channel form modification	Channel geomorphology; fish habitat; fish recruitment; fish spawning; large wood distribution
Riparian improvement	Debris removal; land acquisition; non-native vegetation removal; native re-vegetation	Recreational use; canopy cover; plant succession
Land acquisition (upland or riparian)	Grassland restoration; prescribed burn; non-native vegetation removal	Bird habitat, implementation of conservation reserve program; plant succession
Wetland mitigation	Non-native vegetation removal; wetland construction	Bird habitat; reptile and amphibian habitat; plant succession
Dam Removal	Decommissioning and removal of dams or other barriers	Dams as migration barriers; culverts as movement barriers

Table 2.5. Keywords used in literature searches for seven mitigation types.

Mitigation type	Geographic keyword	Topic keyword
General	Roanoke River	restoration
Flow improvement	Roanoke River	migration
	Roanoke River	flow regulation
	Roanoke River	flow regime
Habitat restoration	Roanoke River	fish habitat
	Roanoke River	macroinvertebrate habitat
	Roanoke River	crayfish habitat
	Roanoke River	mussel habitat
	Roanoke River	water quality
	Roanoke River	pollution
	Roanoke River	gravel addition
Fish passage/Dam Removal	Roanoke River	dam removal
	Roanoke River	fish passage
Water quality	Roanoke River	water quality
	Roanoke River	pollution
Riparian improvement	Roanoke River	riparian
Land acquisition	Roanoke River	conservation reserve program
	Virginia	conservation reserve program
	North Carolina	conservation reserve program
	Roanoke River	prescribed burn
	Virginia	prescribed burn
	North Carolina	prescribed burn
	Roanoke River	vegetation removal
	Virginia	vegetation removal
	North Carolina	vegetation removal
	Roanoke River	secondary succession
	Virginia	secondary succession
	North Carolina	secondary succession
Wetland mitigation	Roanoke River	wetland

Table 2.6. Weighting system used to characterize overall relevance of each literature document.

Weighting factor	Weighting classification	Score
Research type	Restoration	1.00
	Empirical research	0.50
Scientific rigor	Peer-reviewed journal article	1.00
	Peer-reviewed book chapter	0.66
	Conference proceeding	0.66
	Gov. report / gray literature	0.66
	Stakeholder webpage	0.33
Year completed	2005 – ongoing	1.00
	1995 – 2004	0.86
	1985 – 1994	0.71
	1975 – 1984	0.57
	1965 – 1974	0.43
	1955 – 1964	0.29
	1950 – 1954	0.14
	(min – max)	0.023 – 1.00

2.2.3 Geographic weighting

In addition to the 'overall relevance' weighting scheme, we also weighted restoration projects or restoration-related research based on their location within each basin. This geographic weighting approach is important for identifying spatial variation in the relative need/perceived importance of each mitigation type. For example, fish passage for anadromous species and coastal wetland improvement are more important in the lower basin compared to the upper basin. Locations of projects were identified for each document using geographic coordinates if provided. If coordinates were not provided, site descriptions and/or site maps were used to identify locations. In cases where two or more sites were restored or researched, locations were identified for all sites. For each of the seven mitigation types, a raster dataset was created that contained spatially-continuous (~30 m raster cell resolution) geographic weights. These rasters were developed in ArcMap using a five-step procedure (Figure 2.8). First, the geographic coordinates of each site was displayed in ArcMap (Figure 2.8, 2.9-top) and a separate raster dataset was created showing Euclidean distances from that site to each raster cell. This was repeated for each site. Second, raster cell values were standardized from 0 to 1 and converted distance indices to proximity indices (i.e., higher values for cells nearer to the site). Third, raster cells were multiplied by the documents overall relevance weight. Fourth, all raster datasets were summed to create a single raster dataset containing cell values representing both the overall relevance of the projects as well as their geographic locations. Fifth, the cell values were divided by the number of sites to standardize cell values from 0 to 1. An example of the geographic weighting process is provided in Figure 2.9.

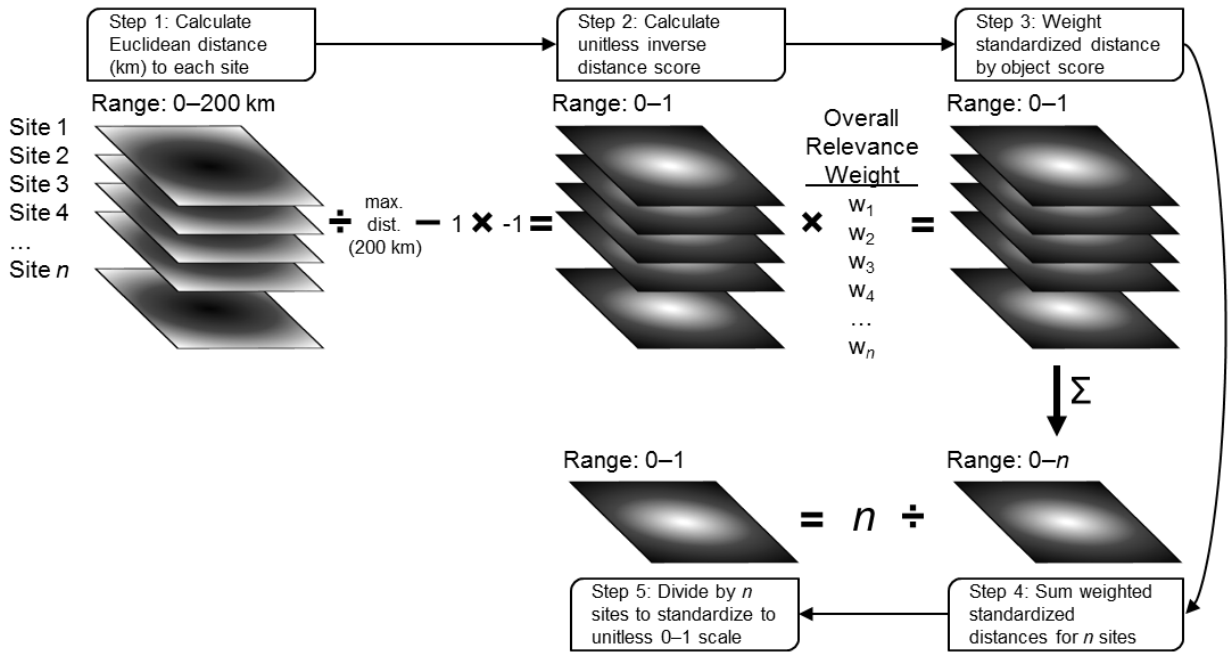

Figure 2.8. Five-step procedure for geographically-weighted mitigation need/perceived importance. This procedure was repeated for each of the seven mitigation types.

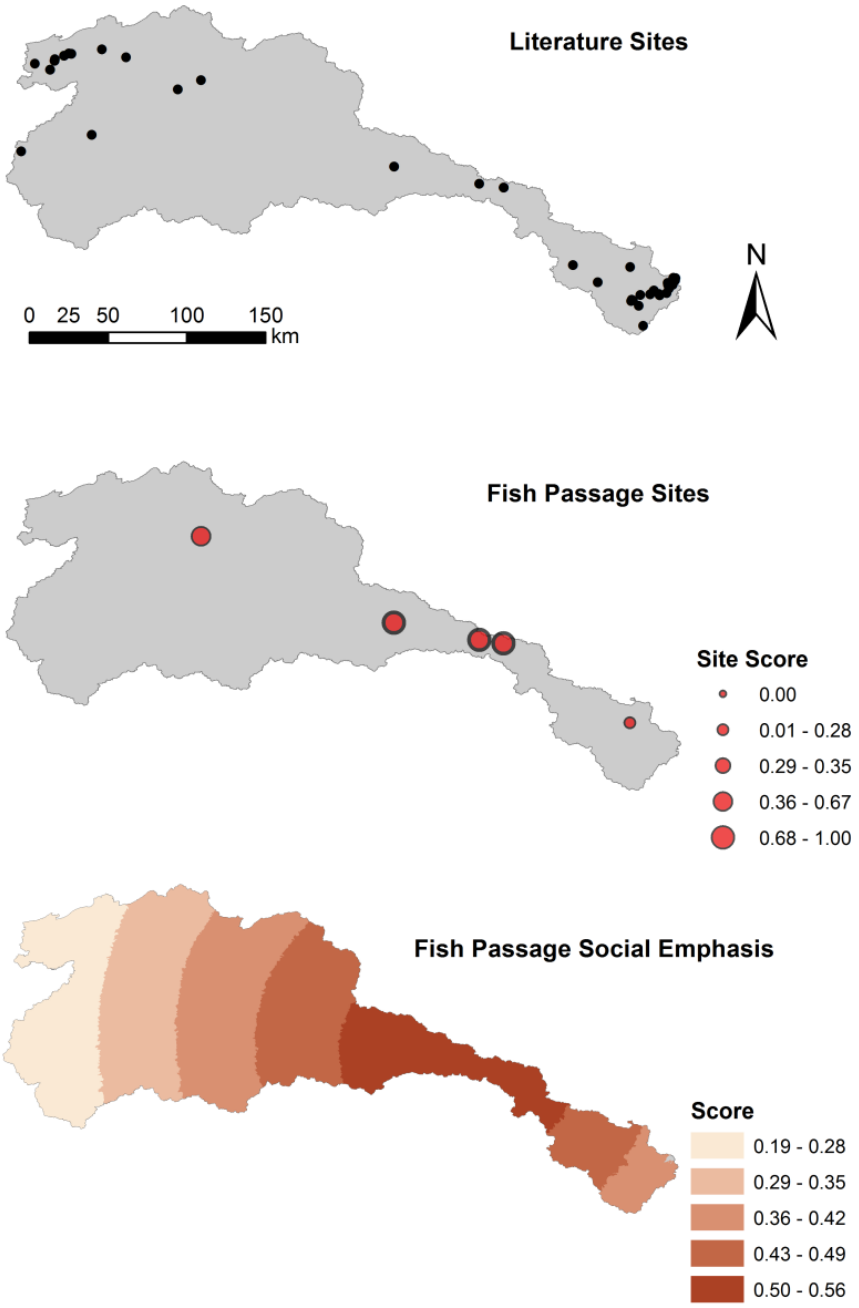

Figure 2.9. Locations of all sites where restoration or research was conducted (top) and only sites where fish passage-related restoration or research was conducted (middle). Note that multiple studies may have been conducted at each site (multiple projects at same location – top panel). The social emphasis score is calculated based on the evidence and density of sites (see Figure 2.8)**.**

2.3 Identifying indirect win-win opportunities

Within the preliminary Phase 1 assessment, a data model was used to identify direct hydropower-environmental opportunities based on spatial overlap, i.e. intersection with the same national hydrography dataset catchment (Figure 1.1). However, the data model can also be used to identify indirect hydropower-environmental opportunities with the condition that hydrologic units are larger than the entire project. According to the Department of Defense, an 8-digit or 6-digit hydrologic unit code is the appropriate size of a mitigation bank service area to offset impacts of any harmful impact or development (DOD-EPA 2008). A larger area ensures that indirect environmental opportunities are selected that maximize ecological and social benefits. Also, indirect hydropower-environmental opportunities can be selected similarly to direct opportunities using a similar structured query to that found in Johnson et al. (2013).

Because indirect opportunities are measured by Benefit Scores and Social emphasis scores, the top 90th percentile scores within each indirect opportunity type can be selected as environmental opportunities. In addition Benefit Scores and Social Emphasis scores can be combined to create cumulative benefits. The geospatial data model can be used to summarize hydropower opportunities and environmental opportunities within HUC-8 watersheds based on various scoring metrics. In this case, hydropower opportunities can be prioritized along with the best indirect environmental opportunities based on the occurrence within the same watershed.

3.0 Conclusions

Herein, we provided a methodology to augment the existing Basin Scale Opportunity Assessment Phase 1 scoping assessment. The inclusion of indirect opportunities expands the scope of the existing BSOA process by considering potential environmental improvements well outside the project boundary but within the immediate basin, thus supporting the ultimate mission of the BSOA. The methodology presented also has further reaching implications, such as 1) providing environmental stakeholders with mechanisms to prioritize restoration actions within a basin, irrespective of hydropower, and 2) an evaluation of current policy limitations (i.e., current limitations in FERC negotiations). The strict criteria of FERC requirements within licensing or settlement agreements may limit the type and scope of any indirect environmental opportunities, especially if not directly related to hydropower development or operations. Obviously, greater potential for environmental mitigation and improvements may be indirectly related to a specific project or hydropower development because indirect environmental opportunities are pervasive and do not rely on direct geographic affiliation with hydropower actions. The full potential of “win/win” scenarios may be underestimated if based solely on spatial overlap and thus requires prioritizing conservation and sociocultural needs at the scale of the entire basin.

4.0. References

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Appendix 1. Wetland restoration scoring rubric taken and modified from Weber and Bulluck (2014). Benefit Scores for wetlands were a sum of all rank scores. Method taken and modified from Weber and Bulluck (2014).

	Rank Scores						
Variables	**1**	**2**	**3**	**4**	**5**	**10**	**Description**
Proximity to Conservation Lands	800-1000 meters	600-800 meters	400-600 meters	200-400 meters	0-200 meters	NA	Weights based on distance to conserved lands with permanent legal protection and managed for animal and plant communities.
Wetland, Riparian, or Aquatic Species of Concern	0 Species	1 Species	2 Species	3 Species	4 or more species	NA	Sites are given biodiversity significance ranks based on the rarity, quality, and number of element occurrences they contain. Values from original data were inverted for weights.
Relatively polluted subwatersheds	above average loads of N, P, and sediments (Low or Low-Moderate category)	moderately high loads of N, P, and sediments (Moderate or Moderate-High category)	highest loads of N, P, and sediments (High category)	X	X	NA	Most polluted subwatersheds in terms of runoff containing nitrogen, phophorous, and sediments.

Ditched or Farmed Wetlands	X	X	X	X	X	Ditched or Farmed	Ditched or Farmed wetlands (i.e. drained) are most likely to be restored as opposed to impounded, diked, leveed, or escavated wetlands
Impaired Waters (303d)	1 303d listing present	2 listings	3 listings	X	X	X	Impaired waters - wetland restoration may improve WQ
RIBITS	X	X	X	X	banked	X	Mitigation and conservation sites contained in the Regulatory In lieu fee and Bank Information Tracking System (RIBITS). Wetlands were ranked whether they occurred 100m from RIBITS location.