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The Integrated Basin-Scale Opportunity Assessment Initiative: Scoping Assessment for the Connecticut River Basin

Final Report

Pacific Northwest National Laboratory
Oak Ridge National Laboratory

October 2014

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The Integrated Basin-Scale Opportunity Assessment Initiative: Scoping Assessment for the Connecticut River Basin

Final Report

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Summary

The Basin-Scale Opportunity Assessment (BSOA) Initiative, led by the U.S. Department of Energy's (DOE's) Water Power Program, established an integrative, three-phase approach for assessing complementary hydropower-environmental opportunities at the scale of a river basin. Under the BSOA Initiative, scoping assessments in a given river basin are intended to provide initial identification, classification, screening, and integration of possible hydropower and environmental opportunities for DOE and basin stakeholders to consider carrying forward as appropriate. Pacific Northwest National Laboratory and Oak Ridge National Laboratory (ORNL) developed a technical approach and methodology for BSOA Phase 1 assessments and performed assessments for the Bighorn, Connecticut, and Roanoke River basins. This report concerns the assessment for the Connecticut River basin.

The scoping assessment for the Connecticut River basin identified *complementary* hydropower-environmental opportunities for powering non-powered dams (NPDs) and new stream-reach developments (NSDs). A complementary hydropower-environmental opportunity was defined as a situation where an existing environmental issue can be improved, either directly or indirectly, in conjunction with a hydropower action. Situations where there may be a direct cause-effect benefit of a hydropower action on an existing environmental issue were assessed at the individual project scale. Opportunities for indirect environmental improvements, for example through compensatory mitigation, were assessed by quantifying hydropower opportunities and environmental issues at the scale of 8-digit hydrologic unit drainages. Hydropower opportunity data were obtained from ORNL's National Hydropower Asset Assessment Program (NHAAP) database, which includes estimates of raw hydropower potential based on hydrologic factors such as annual flow and estimated head.

After screening hydropower opportunities by criteria that would likely preclude development, we identified 66 of 692 NPDs and 27 of 60 NSDs for further analysis of direct and indirect opportunities (Note: NSD sites were not considered in the analysis of direct opportunities). Most (88%) NPD sites were not considered practical opportunities because they had an estimated capacity of less than 0.1 MW. Of the 66 NPD sites, 17 had one or more direct opportunities for environmental improvement within the extent of the project. The estimated capacities of these 17 opportunities ranged from 0.1 to 7.2 MW, representing a total capacity of 20.7 MW. The 27 NSD sites that met our screening criteria represent a total capacity of 46.1 MW. For comparison, a 1 percent increase in existing capacity would provide approximately 22 MW of additional capacity when applied to all 104 existing hydroelectric facilities in the basin.

When assessed at the drainage scale, the potential for powering non-powered dams was highest for the Lower Connecticut (30.1 MW), West Connecticut (9.6 MW), and Middle Connecticut (7.2 MW) drainages. Drainages that exhibited the highest potential for NSDs included the Black-Ottauquechee (11.2 MW), White (8.1 MW), and Deerfield (7.8 MW). Complementary environmental opportunities associated with NPD and NSD sites included opportunities to diminish hydrologic disturbance, enhance flow to mitigate dissolved oxygen and temperature, maintain or improve non-motorized boat recreation, and improve habitat connectivity for diadromous fish.

Based on our experience with the assessment for the Connecticut River basin, we have the following recommendations for future Phase 1 Scoping assessments:

- *Basin Visit* – Include a 2−3 day visit to become familiar with the basin and communicate with key stakeholders about the purpose of the scoping assessment, available data sets, types of results it will produce, and possible follow-on applications. Such a visit would focus the assessment on the types of hydropower opportunities and environmental issues that are most important to those in the basin, as well as expedite data compilation and analysis of direct and indirect opportunities.
- *Data* – Consider using readily available state and local data along with nationally available data sets. Assuming applicable state and local data can be combined in a seamless fashion, such data should enhance the quality of the scoping assessment.
- *Hydropower Opportunities* – Apply data for non-powered water conveyance systems (canals and pipes) and in-stream hydrokinetics as they are available for a given basin. Small hydropower development is growing and will deserve attention in many basins, especially those in the western United States.
- *Environmental Issues* – Consider prioritizing the environmental issues to indicate relative importance of the complementary hydropower-environmental opportunities. Working with key basin stakeholders, as mentioned above, may be an effective mechanism for prioritizing.
- *Stakeholder Interactions and Communications* – Increase interactions and communications with stakeholders over what was realized for the scoping assessment herein. For example, the webinars we conducted to communicate results for the Connecticut assessment were crucial for receiving feedback providing a "reality check" on the preliminary results.
- *Technology Transfer* – Transfer the methodology for Phase 1 scoping assessments via publication of technical reports and/or peer-reviewed journal articles. A peer-reviewed journal article on the methodology for a Phase 1 Scoping Assessment is scheduled to be published in 2014-2015.

Results from a Phase 1 Scoping Assessment could be useful to hydropower developers and regulators alike because they may facilitate identification of opportunities that avoid major regulatory roadblocks and improve environmental stewardship. Hydropower developers could consider complementary hydropower-environmental opportunities as part of proactive steps to identify environmental improvements associated with their development of interest. Likewise, regulators could use information about potential complementary opportunities to advance their missions to protect and enhance natural resources. At a minimum, results of a Phase 1 assessment could inform a framework process for prioritizing hydropower development and potential environmental improvements at the scale of a river basin.

A Phase 1 Scoping Assessment is intended to be the first step in DOE's overall BSOA Initiative process, which includes two subsequent phases: Phase 2 Stakeholder Engagement and Phase 3 Technical Analysis. Ideally, the results of a Phase 1 assessment would be used to quickly the narrow the scope of potential hydropower opportunities in a basin down to a more reasonable number of opportunities for further consideration by stakeholders. Doing so may reduce the amount of time and complications associated with collaborative planning processes involving diverse groups of stakeholders and interests. Through the stakeholder engagement process, the scope of opportunities can be narrowed down further to those that have higher likelihood of going forward. At this point, additional technical analyses may be needed to assess factors such as technical and economic feasibility, environmental impact, and social outcomes. Ultimately, a goal of the Phase 1 process is to reduce the amount of time and resources needed to identify, plan, and assess potential hydropower development opportunities.

Preface

This study was conducted in support of the U.S. Department of Energy (DOE) Water Power Program's Basin-Scale Opportunity Assessment (BSOA) Initiative. The goal of the BSOA Initiative is to develop and implement an integrative approach for the assessment of hydropower and environmental opportunities at a river-basin scale. The BSOA Initiative commenced in fiscal year 2010 (FY10). During FY11-12, research was focused on a pilot study in the Deschutes River basin in central Oregon. Based on that experience, a three-phased, sequential assessment strategy for a given basin was recommended for future work: Phase 1 Scoping Assessment, Phase 2 Stakeholder Engagement, and Phase 3 Technical Analysis. FY13 research objectives concerned development of a technical approach and quantitative, geospatial methodology for Phase 1 Scoping Assessments in two river basins in the contiguous United States: the Connecticut River and Roanoke River basins. The DOE and the U.S. Bureau of Reclamation identified a third basin, the Bighorn River basin, for a Phase 1 Scoping Assessment in FY14. The project objectives for FY14 were to refine the Phase 1 methodology, complete Phase 1 Scoping Assessments for the three aforementioned basins, obtain technical peer review, and conduct outreach regionally and nationally.

BSOA research was realized through collaboration of the Pacific Northwest National Laboratory (PNNL) and Oak Ridge National Laboratory (ORNL), with active participation from DOE. DOE's managers for the project were Hoyt Battey and Thomas Heibel. Simon Geerlofs (PNNL) was the project manager and he worked closely with Brennan Smith (ORNL) as co-laboratory leads to coordinate teams and integrate work between PNNL and ORNL. The PNNL/ORNL team responded to oversight and guidance from the DOE and the BSOA national steering committee, including the federal signatories of the Hydropower Memorandum of Understanding (DOE, Bureau of Reclamation, and U.S. Army Corps of Engineers).

This report documents the final Phase 1 Scoping Assessment for the Connecticut River basin. The preliminary assessment delivered in FY13 was finalized in FY14 after making some modifications and improvements to the methodology and receiving feedback from basin stakeholders. Key changes from the preliminary version include the inclusion of opportunities to improve efficiency at existing hydroelectric facilities and the methodology to assess indirect complementary hydropower-environmental opportunities. The contents of this report are not specifically intended for use in any manner in Federal Energy Regulatory Commission licensing proceedings in the basin.

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For more information about this research, see the BSOA website (www.basin.pnnl.gov) or contact Simon Geerlofs (simon.geerlofs@pnnl.gov; 206-528-3055).

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We thank Hoyt Battey and Thomas Heibel (DOE); members of the BSOA national steering committee, including Linda Church-Ciocci (National Hydropower Association), Julie Keil (Portland General Electric), Jeff Leahy (National Hydropower Association), Kerry McCalman (Bureau of Reclamation [BOR]), Lisa Morales and Kamau Sadiki (U.S. Army Corps of Engineers), Jeff Opperman (The Nature Conservancy [TNC]), Mike Pulskamp (BOR), Richard Roos-Collins (Water and Power Law Group), and John Seebach (Low Impact Hydropower Institute).

For the Connecticut assessment, we also are grateful for assistance from Mike Sale (BCS, Inc.); Melanie Harris, Fritz Rohde, Bill McDavitt, and Sean McDermott (National Marine Fisheries Service); Kurt Imhoff and Chris Vernon (PNNL); Kim Lutz and Chuck Peoples (TNC); John Ragonese (TransCanada); Chris Hatfield and Frank Yelverton (USACE); and Mark Tedesco (U.S. Environmental Protection Agency). We also thank participants in the webinar on February 11, 2014, for the Connecticut assessment, many of whom are listed above, and Melissa Grader and Ken Sprankle (U.S. Fish and Wildlife Service) for their constructive comments.

Acronyms and Abbreviations

BSOA	basin-scale opportunity assessment
cfs	cubic (foot) feet per second
DO	dissolved oxygen
DOE	Department of Energy
DOM	dissolved organic matter
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ft	foot (feet)
FY	fiscal year
GAP	Gap Analysis Program
GIS	geographic information system
HDI	hydrologic disturbance index
HUC	hydrologic unit code
km	kilometer(s)
km^2	square kilometer(s)
MOU	Memorandum of Understanding
MW	megawatt(s)
NABD	National Anthropogenic Barrier Data set
NCAT	Northeast Aquatic Connectivity Tool
NFHAP	National Fish Habitat Action Plan
NHD	National Hydrography Dataset
NHAAP	National Hydropower Asset Assessment Program
NOAA	National Oceanic and Atmospheric Administration
NMFS	National Marine Fisheries Service
NPD	non-powered dam
NSD	New Stream-reach development
NPD	non-powered dams
NWSR	National Wild and Scenic River
ORNL	Oak Ridge National Laboratory
PAD	protected area database
T&E	threatened and endangered
TNC	The Nature Conservancy
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WBD	Watershed Boundary Dataset

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1.0 Introduction

The study reported herein was conducted for the U.S. Department of Energy (DOE) by researchers at the Pacific Northwest National Laboratory (PNNL) and the Oak Ridge National Laboratory (ORNL) in response to the DOE's Basin-Scale Opportunity Assessment (BSOA) Initiative. The PNNL/ORNL team developed an approach and methodology for BSOA Phase 1 Scoping Assessments and applied it to the Connecticut River basin. The purpose of a Phase 1 Scoping Assessment is to identify complementary hydropower-environmental opportunities[1] in a given basin for DOE, basin stakeholders, and others to consider pursuing as appropriate.

1.1 Background

The BSOA Initiative originated as an action item in the 2010 Memorandum of Understanding (MOU) for Hydropower among the DOE (Office of Energy Efficiency and Renewable Energy), Interior (Bureau of Reclamation), and Army (U.S. Army Corps of Engineers [USACE]). The purpose of the Hydropower MOU (DOE et al. 2010) is to "…help meet the Nation's needs for reliable, affordable, and environmentally sustainable hydropower by building a long-term working relationship, prioritizing similar goals, and aligning ongoing and future renewable energy development efforts…" among the three signatory federal agencies. The MOU agencies, while recognizing that hydropower is the largest source of renewable energy in the nation, emphasized that efforts to increase hydropower generation must avoid, mitigate, or improve environmental conditions in our nation's rivers and watersheds. Accordingly, the goal of the BSOA Initiative is to develop and implement an integrative approach for the assessment of hydropower and environmental opportunities at a basin scale.

The BSOA Initiative emphasizes sustainable, low-impact, or small hydropower, and related renewable energies, while simultaneously identifying opportunities for associated environmental improvements in a given basin. By exploring specific pathways through which integrated hydropower and environmental opportunities might be feasible, the BSOA Initiative complements other DOE assessments of hydropower, such as small hydropower (Hall et al. 2006), powering non-powered dams (Hadjerioua et al. 2012), and new stream-reach development (i.e., constructing a new hydropower dam; Kao and Smith 2013). The BSOA Initiative provides a framework with nationally deployable applicability to identify, investigate, synthesize, and visualize "win-win" hydropower and environmental opportunities at the basin scale. By shifting focus from the site to the basin, system-scale opportunities that benefit both hydropower and environmental conditions can be assessed. Expanding the scale of analysis enables identification of commonality among the sometimes disparate goals of regional stakeholders and increases the possibility that development can proceed with fewer conflicts. Federal, state, and local agencies; the hydropower industry; the environmental community; and other stakeholders in a basin could benefit from the identification and development of "win-win" opportunities resulting in the generation of more energy and improvement of environmental conditions. Information from BSOAs is intended to encourage subsequent dialog among regional stakeholders about feasible actions that can be taken at the basin scale to increase hydropower generation, while protecting and improving environmental values, within the context of existing uses.

[1] By definition, a complementary hydropower-environmental opportunity is an opportunity for hydropower development that has possible direct or indirect environmental improvements associated with it.

The MOU agencies established a national steering committee to serve in an advisory capacity to research team members from the PNNL and ORNL during implementation of the BSOA Initiative. The national steering committee consists of representatives of the MOU agencies, the hydropower industry, the environmental community, and other key stakeholders. During fiscal year 2010 (FY10), the national steering committee selected the Deschutes River basin in central Oregon for a pilot study. Since then, researchers have developed a multidisciplinary toolbox to conduct opportunity assessments using geographic information system (GIS) models, hydrology modeling, water management operational modeling, hydropower technology evaluation, data visualization, and stakeholder engagement (Geerlofs et al. 2011; Larson et al. 2014).

Based on experience from the pilot study (Larson et al. 2014), a three-phased, sequential assessment approach for a given basin was identified to improve the cost-effectiveness, research efficiency, and impact of the BSOA Initiative. The phases are as follows:

- Phase 1 Scoping Assessment − rapid (approximately 6 months), initial classification, screening, and identification of potential complementary hydropower-environmental opportunities;
- Phase 2 Stakeholder Engagement − stakeholder-driven opportunity identification, prioritization, and scenario building;
- Phase 3 Technical Analysis − detailed analysis of interactions and tradeoffs between hydropower and environmental opportunities in the context of other water uses.

Progression from one phase to the next requires a conscious go/no go decision on the part of DOE and the national steering committee. Specifically, the intent of a Phase 1 Scoping Assessment for a given basin is to identify the stakeholder and hydrologic context, list and map possible hydropower opportunities and environmental issues in the basin, and perform geospatial analysis to identify potential complementary hydropower-environmental opportunities.

1.2 BSOA and the Connecticut River Basin

During 2013, the BSOA national steering committee selected the Connecticut River basin for a Phase 1 Scoping Assessment because the basin has good potential for hydropower, opportunities to improve habitat connectivity, and challenging environmental issues. The basin is characterized by water-quality and fish passage issues associated with dams that could provide opportunities for environmental improvements. In addition, strong stakeholder and community engagement has resulted in solid foundational science and high data richness. The selection process is described in detail in Section 2.1 of Johnson et al. (2013).

We previously reported preliminary results for the Phase 1 Scoping Assessment for the Connecticut River basin (Johnson et al. 2013). Since then, we conducted limited outreach to stakeholders via webinars[1] and incorporated the feedback we received into this final version. For example, improvements in the methodology involved incorporating indirect or unaffiliated opportunities[2]. We also recast the

[1] February 11, 2014—attendees included J. Ragonese (TransCanada), K. Kennedy (The Nature Conservancy), L. Morales and M. Wilmes (U.S. Army Corps of Engineers), B. McDavit and S. McDermott (NMFS), and others. April 30, 2014—attendees included M. Grader and K. Sprankle (USFWS).

[2] Indirect opportunities are those in the basin but not at a particular hydropower development site.

results to better describe their environmental context, including the potential negative impacts of hydropower development.

1.3 Objective and Report Contents

The objective of the research reported herein was to finalize the Phase 1 Scoping Assessment of complementary hydropower-environmental opportunities for the Connecticut River basin. Methods are described in Section 2.0. The results are contained in Section 3.0. Section 4.0 contains discussion and Section 5.0 lists the references. Appendix A contains a list of sites where we identified complementary hydropower-environmental opportunities for non-powered dams.

2.0 Methods

The PNNL/ORNL team developed a stepwise technical approach to Phase 1 Scoping Assessments.[1] The approach (Figure 2.1) starts with planning/organization and basin selection (Steps 1−2). The core of the assessment process consists of five main steps (Steps 3−7). The major technological advance from this research was new quantitative geospatially driven methods of identifying and assessing complementary hydropower-environmental opportunities (Step 7).[2] The approach closes with limited outreach/feedback followed by finalization (Steps 9−10). This section contains a brief description of the methods for Steps 5−7 of the BSOA Phase 1 Scoping Assessment for the Connecticut River basin; detailed methods for all steps are presented by Johnson et al. (2013) and Larson et al.[3]

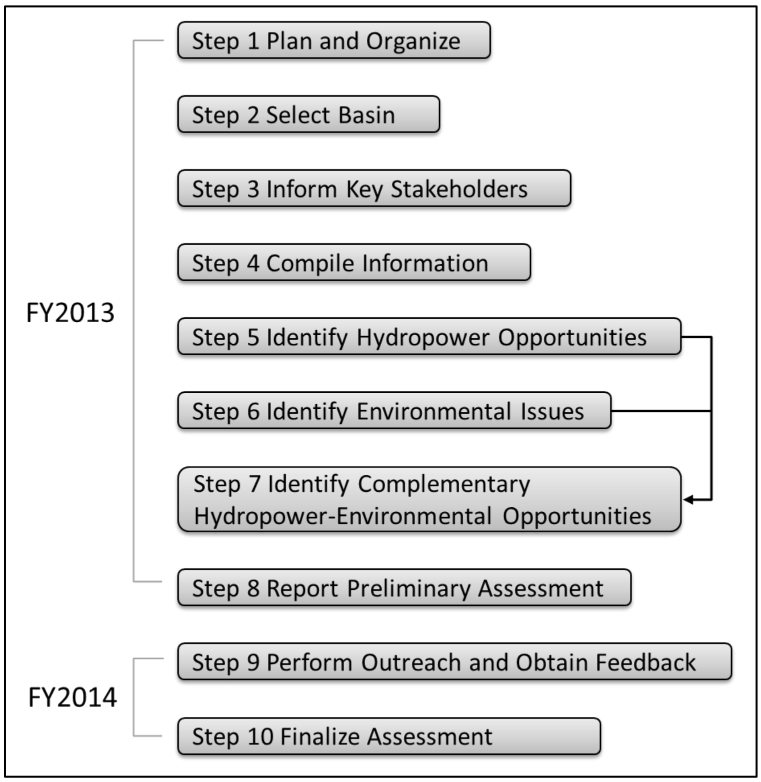

Figure 2.1. Stepwise technical approach for Phase 1 Scoping Assessments for a given basin.

[1] We make a distinction between "approach" and "methodology"—approach means the overall composition and relationships among the steps, whereas methodology refers to data manipulation and analytical procedures specific to a given step in the approach.

[2] By definition, opportunities are possible actions and issues are problems. An environmental "opportunity" is defined as a situation where an existing environmental issue can be alleviated as a result of a hydropower action. Other environmental opportunities independent of a hydropower action, such as ecosystem restoration, water management, and wetland rehabilitation, are possible, but were not considered at this time because the focus was on complementary hydropower-environmental opportunities.

[3] Larson KB, JD Tagestad, RA McManamay, MS Bevelhimer, GE Johnson, CR Derolph, and SH Geerlofs. In Preparation. *A Geospatial Approach for Rapid Assessment of Hydropower and Environmental Opportunities at a Basin Scale*.

2.1 Hydropower Opportunities

Information from the National Hydropower Asset Assessment Program (NHAAP) database was used to identify opportunities for powering non-powered dams and potential new stream-reach development sites in the Connecticut River basin. Non-powered dams (NPDs) were evaluated for the potential to install turbines and generate power. New stream-reach development (NSD) sites were evaluated for their suitability for dam installation within the context of the hydrologic factors such as annual flow, estimated head, and 100-year floodplain boundaries. At existing powered dams, opportunities for possibly increasing capacity include improving the efficiency of operations, increasing head, and replacing existing turbines, such as those with “fish-friendly” turbine designs. Because these types of opportunities are complex and depend on a suite of site-specific factors, we applied a 1 percent increase in capacity at existing powered dams to give an approximation of increased power by modifying existing powered dams. Other hydropower development opportunities, such as powering of non-powered water conveyance systems (canals and pipes) and in-stream hydrokinetics were not included because they apparently are not being pursued at this time in the Connecticut River basin.

For each hydropower opportunity, the upstream and downstream extent of the project was delineated for subsequent analysis of direct complementary hydropower-environmental opportunities (see Section 2.3). Where available, water bodies (i.e., reservoirs/lakes/ponds) from the high-resolution National Hydrography Dataset (NHD) that are greater than 0.1 km^2 and located within 300 ft of the associated project were used to delineate the upstream extent of the project. For projects where NHD water bodies were not available, the NHD flowline segment immediately upstream of the project was used. Conversely, NHD flowline segments extending approximately 10 mi downstream of each project were used to delineate the downstream extent of each project.

Spatial representations of the dams and their associated upstream and downstream extents were loaded into the GIS database supporting the BSOA data model (described below). Descriptive information about each hydropower opportunity was also loaded into the database to allow for hierarchical viewing and analysis of hydropower spatial data.

2.2 Environmental Issues

We identified and mapped environmental issues in the basin that may present challenges for, or potentially be improved by, potential hydropower development. Key environmental issues were ascertained from discussions with stakeholders and publicly available resources such as watershed planning documents, stakeholder reports, environmental impact statements, water-quality certifications, regulatory filings for hydropower projects, and nationally available environmental data (e.g., the U.S. Environmental Protection Agency’s [EPA’s] Clean Water Act 303d list of impaired waters [EPA 2013], National Fish Habitat Assessment [Esselman et al. 2011], and NatureServe). Spatial representations of environmental issues were derived from existing geospatial data or manually georeferenced from information in literature sources and loaded into the BSOA geospatial database (see Step 7; Figure 2.1). In addition, ecological, cultural, or aesthetic issues representing potential public resistance to or negative impact caused by hydropower development were also identified and used to screen hydropower opportunities from the analysis. Geospatial data for environmental issues were compiled from multiple sources, including the NHAAP database, federal and state geospatial clearinghouses, and by georeferencing data from geographic descriptions of environmental issues in the literature.

All geospatial data were input to a GIS and intersected with networked hydrologic catchments, which served as a common map unit for cataloging environmental issues with disparate spatial representations (point, line, or area). The map of environmental issues provided the basis for identification of environmental opportunities based on the interaction of potential hydropower developments and potential management changes. Brief descriptions of the data sets used for the Connecticut assessment are provided in Table 2.1. Categories of environmental data considered in this assessment are described in detail in the ensuing narrative.

Environmental opportunities were defined as environmental issues in the basin that could be mitigated or improved by one or more of the following hydropower actions: 1) directly by adding a turbine to an existing NPD, and 2) indirectly as part of powering an NPD or development of an NSD. We did not associate environmental issues with hydropower opportunities for increasing efficiency at existing facilities due to insufficient information on such opportunities at the time of this assessment.

Table 2.1. Descriptions of data sets used for the Connecticut assessment. Asterisks (*) indicate data that were obtained from the NHAAP database.

Issue Category Sub-Category	Description	Data Set(s)
Fish Interactions		
Barriers	Physical barriers (i.e., dams, weirs, culverts) preventing migratory movements of fish	NCAT Tool (TNC); NABD
Injury/ Entrainment	Injuries or morality resulting from entrainment through dam, turbine strike, and associated hydropower operations	FERC orders; USACE NID; NABD
Water Quality		
Temperature	Abnormal temperatures (too low or too high)	EPA 303d Listed Waterbodies*
Dissolved Gases	Low dissolved oxygen	same
Pollution	High pollution or contaminant levels	same
Turbidity/ Erosion	High erosion and turbidity levels	same
pH/ Acidification	Low pH	same
Bacteria	Elevated pathogen and bacteria concentrations	same
DOM/nutrients	Elevated nutrients and DOM (dissolved organic matter)	same
Salinity	Increased total dissolved solids and salinity	same
Aquatic Habitat Loss/Degradation		
T&E Species Habitat	Areas containing state or federally listed species excluded from critical habitat designations	NatureServe
Critical Habitat	Critical habitat designation areas for federally listed endangered and threatened species	USFWS Critical Habitats*
Sensitive Habitats	Areas designated by federal or state as having high biodiversity or conservation value (e.g., wetlands, diverse habitats)	State-specific conservation data sets
Habitat Condition	Degree of anthropogenic disturbance (e.g., urbanization, upstream dams) in watershed or stream segments	NFHAP*
Hydrology & Hydraulics		
Hydraulic Modification	Degree of hydrologic disturbance of stream flows. Presence of infrastructure, such as canals and penstocks, known to modify natural hydrologic processes.	NHD 1:24,000 scale canals, penstocks, pipelines; USGS stream gages*; NFHAP*

Table 2.1. (contd)

Issue Category Sub-Category	Description	Data Set(s)
Other Water Resource Issues		
Wild and Scenic River	Rivers protected under the Wild and Scenic River Act	Digitized NWSR lines − Rivers.gov*
Protected Areas	Areas owned and protected for conservation, recreation, or aesthetic purposes	PAD US Database*
Recreational Importance	Areas of known recreational value, such as fishing or boating	DeLorme fish and boat access*; American Whitewater Rafting runs*
Aesthetic Preservation	Areas of aesthetic value, such as waterfalls, geologic formations, or landmarks	Waterfall point locations*

FERC = Federal Energy Regulatory Commission; NABD = National Anthropogenic Barrier Dataset; NCAT = Northeast Aquatic Connectivity Tool ; NFHAP = National Fish Habitat Action Plan; NHD = National Hydrography Dataset; NID = National Inventory of Dams; NWSR = National Wild and Scenic River; PAD = protected area database; T&E = threatened and endangered; TNC = The Nature Conservancy; USFWS = U.S. Fish and Wildlife Service; USGS = U.S. Geological Survey

2.2.1 Fish Passage Barriers

Barriers, primarily dams, are obstacles to fish migration that could provide an environmental opportunity if mitigated through barrier removal or creation of fish passage mechanisms. Specific locations where fish passage is considered important for anadromous fish restoration in the basin were derived from The Nature Conservancy's (TNC's) Northeast Aquatic Connectivity Tool (NCAT), which evaluates the potential ecological value of improving fish passage at a particular dam, either through dam removal or improvements to passage facilities (Martin and Apse 2011). Results from the NCAT analysis were grouped into percentile-based tiers. Dams that ranked in the top two tiers (i.e., top 10 percent) were used to represent potential opportunities for improving fish passage in the complementary opportunity assessment because these dams may represent bottlenecks to the restoration of anadromous species. NCAT was completed for the entire Connecticut River basin; we used the data on migratory fish in the Phase 1 Scoping Assessment. Dams intersecting anadromous fish habitats (see Section 2.2.3 Aquatic Habitat Loss/Degradation) were identified as barriers. Note that even if a dam has a fishway for upstream fish passage there is no guarantee of successful passage because the fishways can be inefficient or inoperable. A Phase 1 Scoping Assessment, however, is not capable of a resolution high enough to incorporate this level of detail.

2.2.2 Water Quality

Water-quality issues were considered if they could be mitigated by modifying dam operations by 1) adding a new turbine, intake, or gate, or 2) trapping pollutants, toxics, or contaminants within reservoirs. Spatial information about water-quality issues was obtained from the EPA's Impaired Water Waters Dataset for 303d-listed waters (EPA 2013) and by manually georeferencing information from literature sources. The EPA impaired waters website provided point, line, and polygon coverage of 303d-listed water bodies. All water-quality issues present in a basin may not be captured by 303d listing. Thus, records of water-quality issues mentioned in reports, journals, or websites were georeferenced and included as issues. Water-quality issues that were deemed most relevant for the integrated opportunity assessment included water temperature, low dissolved oxygen (DO), excessive sedimentation, and high turbidity.

2.2.3 Aquatic Habitat Loss/Degradation

Remaining aware of habitat conditions relative to anthropogenic disturbance offers opportunities for habitat restoration or mitigation, as well as consideration of where development should not occur to avoid impacts to sensitive species. Habitat-related factors considered in the scoping assessment of the Connective River basin include:

- *T&E species habitat*: Locations of federally and state-listed endangered and threatened species were obtained from literature or online sources and georeferenced. In addition, state-specific natural heritage data containing locations of federally/state-listed species were compiled and included in analysis. Areas of sensitive habitat may pose constraints on hydropower opportunities.
- *Critical habitats*: Polygon and line representations of T&E species habitats were obtained from the U.S. Fish and Wildlife Service (USFWS). All federally listed species do not have associated Critical Habitat designations. Again, critical habitats may be an indication of negative impact from hydropower.
- *Sensitive habitats*: State department websites provide geographic coverage of various areas considered sensitive to development or of high conservation value. Because of jurisdictional boundaries, these data sets vary from state to state. However, these data were combined to provide consistent seamless coverage for the entire basin. Anadromous fish habitats were created using historic and current fish distributions from NatureServe at the 8-digit hydrologic unit code (HUC) resolution. NHD (1:100,000 scale) stream lines were filtered to only include stream reaches with an average flow ≥20 cfs. NHD stream lines falling within the current distribution of anadromous fish were considered potential habitat.
- *Habitat condition:* Aquatic habitats displaying high levels of anthropogenic disturbance may be an environmental opportunity for habitat restoration or mitigation. The National Fish Habitat Action Plan (NFHAP) developed a disturbance index for each NHD (1:100,000 scale) catchment in the United States. Disturbance indices were accompanied by summarized anthropogenic disturbance information including land use (e.g., urbanization), roads, dams, mines, and point-source pollution sites for each local watershed and the total upstream cumulative watershed.

2.2.4 Hydrologic Disturbance

High levels of hydrologic disturbance may present an environmental opportunity because altered stream flows could be mitigated by hydropower dam operation. Two sources of information were used as surrogates of hydrologic disturbance. First, canals, penstocks, and pipelines were available as line events in the NHD (1:24,000 scale). The presence of this infrastructure suggests changes in natural hydrology. Second, a predictive model of hydrologic disturbance was constructed using discharge from reference-condition and disturbed U.S. Geological Survey (USGS) stream gages. All USGS gages were selected within a 50-km radius around each basin. Hydrologic statistics were calculated that summarized the discharge from each stream gage. All gages were placed in a hydrologic class, i.e., group of streams sharing similar hydrology. Based on class membership, hydrologic statistics from disturbed gages were compared to reference gages to calculate a hydrologic disturbance index (HDI). From McManamay et al.

(2012), “The disturbance index is a composite score for USGS gaged streams based on eight factors for each entire basin: major dam density, change in reservoir storage from 1950 to 2006, freshwater withdrawal, artificial paths (canals, ditches and pipelines), road density, distance to major NPDES (National Pollutant Discharge Elimination System) sites and the fragmentation of undeveloped land." Geospatial information (urbanization, dams, water use) was summarized within NHD stream reaches and was used to develop a statistical model to predict an HDI for every stream reach in the basin.

2.2.5 Other Water Resource Issues

Additional issues related to water resources include Wild and Scenic River designations, protected areas, recreational importance, and waterfalls:

- *Wild and Scenic River* − The greatest protective measure placed on a river is the Wild and Scenic River designation, which specifically prohibits new dam construction. Line coverage of Wild and Scenic Rivers is provided by the National Wild and Scenic Rivers System (www.rivers.gov).
- *Protected Areas* − Protected areas typically represent areas owned and managed for conservation, recreation, and aesthetic purposes. The owner and designation for each parcel, however, will determine the likely positive or negative impact on hydropower opportunities. Locations of protected areas were obtained from the National Gap Analysis Program (GAP) Protected Area Database of the United States (PAD US). PAD US employs a ranking system of protective status, with Status 1 and 2 lands being managed more strictly for conservation purposes than Status 3 and 4 lands managed for variable purposes, including recreation and extractive uses. Status 1 and 2 lands were considered areas where hydropower development of any kind is highly unlikely. [1]
- *Recreational Importance* − Areas known for recreational value may represent public resistance to hydropower development if recreation is compromised by development. However, the absence of recreation or potential for recreational improvement may create an opportunity because hydropower licensing typically involves the creation of public access areas. Boat ramps, fishing access areas, and American Whitewater boating runs were compiled from the NHAAP database. Spatial information about non-motorized boating locations was derived from American Whitewater’s National Whitewater Inventory (http://www.americanwhitewater.org/content/River/view/) and manually georeferenced from literature sources (CRJC 2009).
- *Waterfalls* − Waterfalls represent areas of aesthetic importance that should be considered for preservation in context of any hydropower development. Waterfall locations were compiled from the NHAAP database.

[1] GAP Status 1: An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management. GAP Status 2: An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance. Source: *http://gapanalysis.usgs.gov/*.

2.3 Identifying Complementary Hydropower-Environmental Opportunities

We evaluated potential hydropower opportunities in the context of existing environmental issues to identify where complementary opportunities or potential conflicts might occur. Recall, an environmental “opportunity” was defined as a situation where an existing environmental issue can be alleviated, either directly or indirectly, as a result of or in conjunction with a hydropower action. Other environmental opportunities, such as ecosystem restoration, are possible but are not considered in a Phase 1 Scoping Assessment because of the complexity in scope that is typically involved with such opportunities. Environmental opportunities can result *directly* from a hydropower action, e.g., installing a turbine at an NPD provides opportunity for aerating downstream reaches that have low DO issues; or *indirectly* from a hydropower action, e.g., modifying or removing a nearby dam to improve fish passage and habitat connectivity as part of development elsewhere. Environmental opportunities for dam removal were considered in association with NPD and NSD opportunities (as described in Section 2.2.1). In this section, we explain the data model and geospatial database, and the process for identifying direct and indirect complementary hydropower-environmental opportunities.

2.3.1 Data Model and Geospatial Database

We developed a geospatially driven data model to examine spatially explicit interactions between hydropower opportunities and environmental issues to identify possible complementary hydropower-environmental opportunities (Figure 2.2). The data model enables a rapid, flexible, and robust process for assessing interactions between data elements that are spatially disparate but functionally linked. The BSOA data model involves core *data elements*, *relationships* between data elements, and *rules* by which interactions were explored and opportunities revealed. Core data elements of the BSOA data model include hydropower opportunities, environmental issues, and hydrologic units from the national Watershed Boundary Dataset (WBD) and NHD.[1] Hydrologic units were chosen as the common spatial unit for associating hydropower and environmental data because they are nested within each other, allowing for multi-scale associations to be drawn. For the Connecticut River basin (a 4-digit HUC), this includes 8-, 10- and 12-digit HUCs from the WBD, and hydrologic catchments from NHD, which are the smallest hydrologic units used in the analyses.

Relationships between data elements were realized in a geospatial database, which standardized storage of the elements in a spatial and tabular format and facilitated implementation of the data model. A key function of the geospatial database was to maintain the spatial relationships among the data elements. The geospatial database also maintained non-spatial relationships among data objects and tables containing descriptive attributes for each element that were used to examine interactions in greater detail. By using this type of relational structure, the geospatial database allowed for examining interactions between hydropower opportunities and environmental issues under a variety of scenarios.

[1] For more information about hydrologic units, visit http://nhd.usgs.gov/.

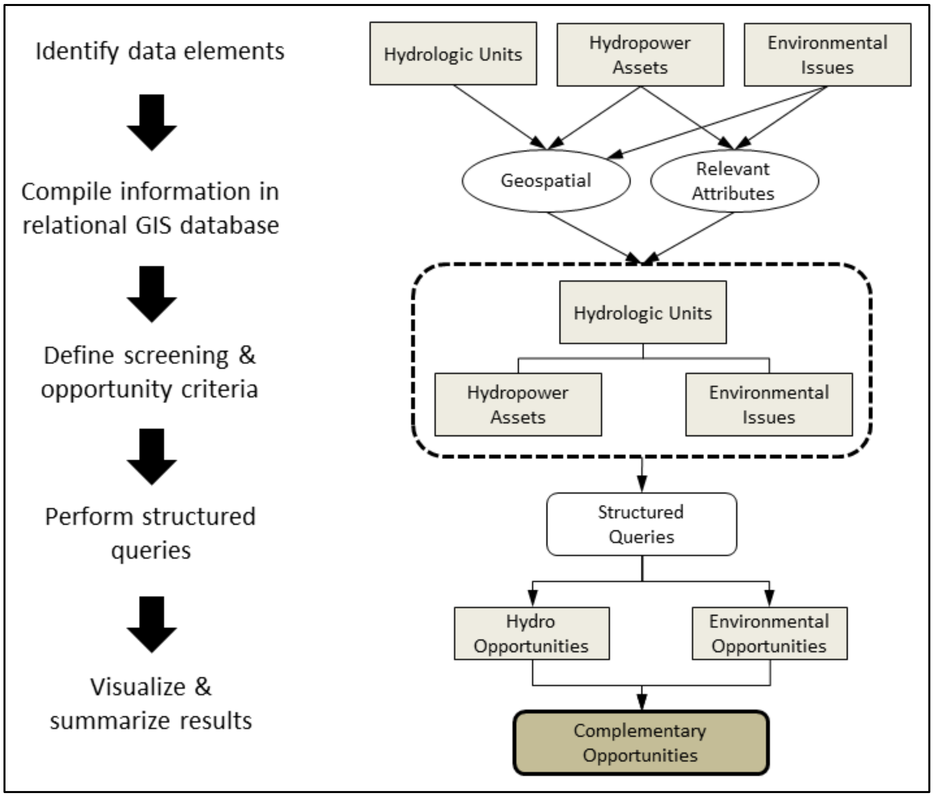

Figure 2.2. BSOA data model and process flow for identifying complementary hydropower-environmental opportunities in Phase 1 Scoping Assessments.

2.3.2 Direct Complementary Hydropower-Environmental Opportunities

In the context of this assessment, *direct* complementary hydropower-environmental opportunities are defined as those in which there is a direct cause-and-effect relationship between a hydropower action and environmental improvement (e.g., construction of a fish ladder, operational changes to improve water quality, meeting environmental flow requirements, or improving recreation) within the upstream and/or downstream extents of a project. Direct opportunities may have indirect effects (e.g., increased productivity of aquatic populations, improved ecosystem processes and services), which we define differently from indirect complementary hydropower-environmental opportunities in this assessment (see Section 2.3.4).

The data model for identifying direct opportunities included six steps aimed at examining relationships between hydropower opportunities and environmental issues within hydrologic catchments (the smallest hydrologic unit in the BSOA data model) that intersect the upstream and downstream extents of a given project. Relationships are defined by two sets of *criteria*: one set that describes conditions that may preclude development and another set that describes positive hydropower-environmental interactions. The criteria are then used to structure queries of the geospatial database to locate and view complementary hydropower-environmental opportunities. The six-step process for identifying direct complementary hydropower-environmental opportunities is as follows:

1. Select a hydropower opportunity type. Hydropower opportunity types considered with respect to direct complementary hydropower-environmental opportunities in the Connecticut River basin were

powering an NPD. Other types of hydropower opportunities that could be included in future assessments are modifying an existing site, powering a water conduit, or developing hydrokinetic energy.

2. List relevant environmental issues that might be affected by the selected hydropower opportunity. This list necessarily should include more than what might be considered opportunities for environmental improvement to create a broad characterization of possible effects from which opportunities can be identified.

3. Identify environmental issue(s) that could be affected in a positive manner if hydropower development was conducted in a particular fashion; an example is the environmental issue of low DO.

4. Describe what and how the environmental improvements could be realized during hydropower development. For example, installing a turbine at an NPD could be done in a way (e.g., with aerating turbines) that increases DO levels in a downstream reach that has low DO issues.

5. Define criteria to identify sites where the selected hydropower opportunity might be realized as well as criteria where the hydropower opportunity may create a mutual environmental opportunity. Step 5 criteria include attributes or issues (environmental and other) that we deemed would almost certainly *preclude* development at a particular location, as follows:

    a. Generating capacity <0.1 MW for NPD

    b. GAP status = 1 or 2[1]

    c. Wild and Scenic River designation

    d. Other Protected Area designation

    e. Presence of threatened/endangered species habitat.[2]

6. Identify data sets needed to analyze spatial interaction between hydropower and environmental opportunities. This includes the locations of projects, environmental issues, hydrologic units, and extent of each project (i.e., upstream and downstream). In the example presented above, the opportunity to improve low DO is downstream of the dam within a 10-mile reach defined as its downstream extent.

The criteria established in Steps 5 and 6 above were used to structure queries of the geospatial database to identify locations where the hydropower opportunities and environmental issues of interest interact. For the purposes of our assessment, we focused on developing criteria that pertain to key environmental issues in the Connecticut River basin (Table 2.2). There is, however, inherent uncertainty about how a given opportunity would be realized. For example, for the opportunities strongly tied to flow management, it is assumed that powering a NPD would provide some mechanism(s) for managing flows to better meet environmental objectives like improving water quality or recreation. Ultimately, the exact mechanism or manner in which a hydropower opportunity addresses a specific environmental issue depends on a suite of factors whose description is beyond the scope of a Phase 1 Scoping Assessment.

[1] Lands classified by the USGS National Gap Analysis Program as having permanent protection from conversion of natural land cover. For more information refer to http://gapanalysis.usgs.gov/

[2] This criterion may not always preclude development in some cases, but was important for consideration for preliminary assessments in the Connecticut River basin.

Table 2.2. Generic structure and example environmental opportunities and associated criteria for classifying interactions between environmental issues and the NPD hydropower opportunity types.

Environmental Criteria	Example Environmental Opportunity
Does not meet EPA criteria for dissolved oxygen (DO).	Aeration from new development/adding a turbine could increase DO in downstream reaches with DO impairment.
Does not meet EPA criteria for sedimentation/siltation or turbidity.	New development/adding turbine could provide better flow management in downstream reaches with excessive sedimentation or turbidity impairments.
Does not meet EPA criteria for temperature.	New development/adding a turbine could provide better flow management in downstream reaches with temperature impairments.
High level of hydrologic disturbance.	New development/adding a turbine could provide better flow management in downstream reaches with high hydrologic disturbance.
Presence of American Whitewater boat runs and “Other” important paddling waters.	Adding a turbine could provide better flow management in existing whitewater/paddling reaches below the dam.
Presence of a dam that is a candidate for improvements or removal for anadromous fish restoration.	Assume improvements to fish passage can be made as part of project development, either through facility modification or dam removal.

2.3.3 Identifying Indirect Complementary Hydropower-Environmental Opportunities

An *indirect* complementary hydropower-environmental opportunity is defined as an opportunity to improve an environmental condition in the basin that is not within the extent of or directly affected by the hydropower project of interest. We define these opportunities differently from indirect effects, such as increased population productivity, species health, and ecosystem services. Examples of indirect opportunities can include direct-effect actions elsewhere in the basin (e.g., installing or improving fish passage at another dam, removing a dam, providing recreational access) as well as compensatory mitigation such as high-quality land acquisition, wetland restoration, and habitat or fisheries enhancement. While some compensatory mitigation projects have been identified in the Connecticut River basin, data on specific projects and locations are not readily available for the entire basin. (Note, ORNL has developed methods to assess potential mitigation opportunities in the Roanoke River basin; for details, see McManamay et al. [2014]) Therefore, we quantified indirect opportunities from the same data on environmental issues used in the analysis of direct opportunities because there are both direct and indirect methods for resolving those issues. As information about compensatory mitigation projects becomes available, it can be added to the Connecticut River database and included in future analyses of indirect opportunities.

Because indirect opportunities are not linked to any one particular hydropower opportunity type or location, we quantified them as independent opportunities so that stakeholders could assess possible combinations of opportunities at multiple scales. We used guidance adopted by the USACE and EPA regarding compensatory mitigation for losses of aquatic resources (73 FR 19594) to choose an appropriate spatial scale for summarizing indirect opportunities.[1] The Rule states that compensatory mitigation should be located within the same watershed as the affected site, and should be located where it is most likely to successfully replace lost functions and services. For the Connecticut River basin assessment, we chose to use 8-digit HUC drainage areas (roughly equivalent to drainages of major tributaries to the Connecticut River) to quantify the number of indirect complementary hydropower-environmental opportunities. This approach could be expanded to multiple scales to allow stakeholders to hierarchically determine which portions of the basin present the most potential for "win-win" hydropower development and environmental improvement scenarios.

The data model for identifying indirect opportunities is similar to that for identifying direct opportunities in that it uses the same core data elements, spatial relationships between data elements and hydrologic units, and criteria that describe conditions that may preclude development. However, the indirect opportunity data model does not include criteria that describe direct hydropower-environmental interactions because each environmental issue is treated as an independent opportunity for improvement. Indirect opportunities are also assessed at a larger scale (8-digit HUC drainage) than direct opportunities (hydrologic catchments within an individual project extent). The following process describes how indirect complementary hydropower-environmental opportunities were identified in this assessment:

1. Select a hydropower opportunity type. Hydropower opportunity types considered with respect to indirect complementary hydropower-environmental opportunities in the Connecticut River basin included powering an NPD, constructing an NSD, and implementing efficiency improvements at existing powered dams. Other types of hydropower opportunities that could be included in future assessments are powering a water conduit or developing hydrokinetic energy.
2. List relevant environmental issues that might be affected by hydropower development. This list necessarily should include more than what might be considered opportunities for environmental improvement to create a broad characterization of possible effects from which opportunities can be identified.
3. Identify environmental issue(s) in the affected watershed that could be addressed to offset the impact of hydropower development; an example is removing a dam in the lower watershed to restore habitat connectivity for migratory fish species.
4. Define criteria to identify sites where the selected hydropower opportunity might be realized (same as Step 5 for identify direct opportunities).
5. Identify data sets needed to spatially analyze interaction between hydropower and environmental opportunities. This includes the locations of projects, environmental issues, and hydrologic units.
6. Catalog environmental issues by hydrologic catchments and quantify the number of affected catchments in each 8-digit HUC drainage in the basin for each issue. Similarly, quantify the number of hydropower opportunities in the watershed that meet criteria in Step 4.

For the purposes of this assessment, we considered the same key environmental issues identified as potential direct opportunities (Table 2.2) as potential indirect opportunities for environmental improvement that may help offset hydropower development. An example may be improving fish passage at a dam through facility modification in conjunction with a hydropower development opportunity at that

[1] For more information about the USACE Final Mitigation Rule see http://www.usace.army.mil/Missions/CivilWorks/RegulatoryProgramandPermits/mitig_info.aspx.

location (i.e., direct complementary opportunity) or as part of a hydropower development elsewhere in the watershed (i.e., indirect complementary opportunity). In either case, there is inherent uncertainty in how an opportunity may be realized because there may be multiple ways to address the issue. However, it is presumed there are more potential mechanisms for indirect opportunities because they are not tied directly to any particular hydropower development action. In the example of improving fish passage at a given dam, dam removal would not be an option if there was interest in hydropower development at that dam, whereas removal could be an option if the hydropower opportunity was elsewhere.

3.0 Results

The Phase 1 Scoping Assessment for the Connecticut River basin entailed identifying hydropower opportunities and environmental issues, then integrating them geospatially to reveal complementary hydropower-environmental opportunities.

3.1 Hydropower Opportunities

We considered the following hydropower opportunities for the Connecticut River basin because relevant data were readily available in the NHAAP database: increasing efficiencies at existing hydropower plants, powering NPDs, and NSDs.

The assessment of potential hydropower capacity that could be obtained by powering NPDs identified 86 of 692 NPDs in the Connecticut River basin that have a potential capacity of ≥0.1 MW each and a combined capacity of 80.7 MW. Of the 86 NPDs with a potential capacity of 0.1 MW or greater, 66 meet the criteria for a potential opportunity and represent a total capacity of 69.5 MW (Figure 3.1).

Through NHAAP a total of 238.8 MW of potential NSD capacity distributed among 60 possible locations was identified in the basin. It is impractical to develop all of these sites, but each site presents a possible opportunity that is evaluated further in this analysis. Of the 60 NSD locations, 27 meet the criteria for a potential opportunity for NSD and represent a total capacity of 46.1 MW (Figure 3.2).

Hydropower production at some of the 104 existing hydropower dams in the basin (representing a total installed capacity of 2,198.5 MW) might be increased by replacing turbine/generator machinery or improving operational efficiency. Improvements at existing hydropower facilities, however, will necessarily be site-specific and dependent on age of the plant, cost-effectiveness of the improvements, any required mitigation, and other factors. As an example for the Connecticut River basin, we applied a modest 1 percent increase in capacity, which would equate to approximately 22 MW of additional generating capacity. Such improvements could be linked with flow enhancements or requirements at existing sites. Minimum flow turbines could be installed where there are none presently or hydropower turbines could be used in lieu of excess spill or to provide flow in bypass reaches. Both could result in greater minimum flows to benefit aquatic resources. More detailed examination of flow enhancement related to turbine or operational improvements at existing facilities would be appropriate during a Phase 3 Technical Analysis.

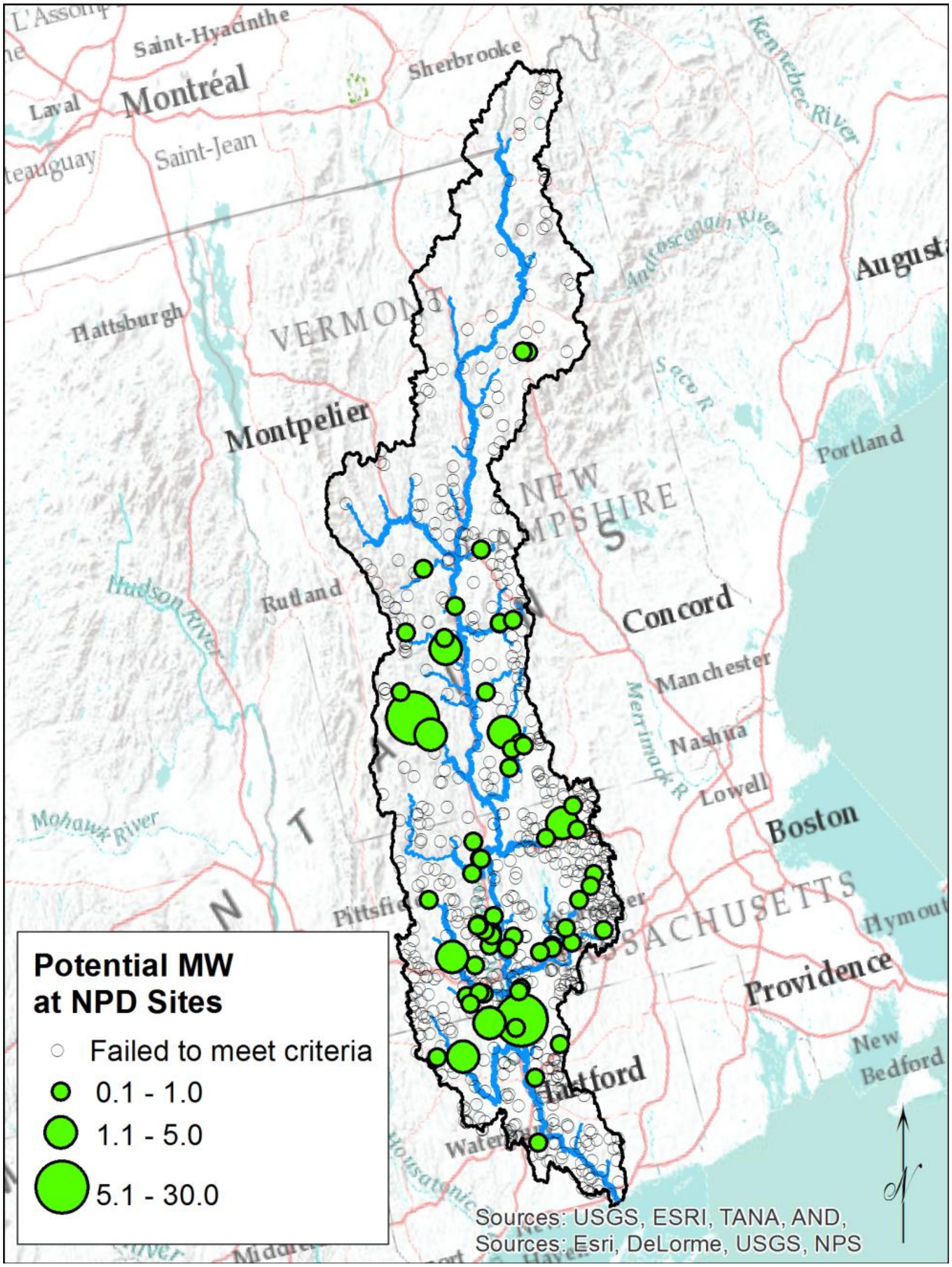

Figure 3.1. Non-powered dam sites in the Connecticut River basin that meet the screening criteria for potential hydropower development opportunities irrespective of environmental improvements (N = 66). Sites that do not meet the criteria are also shown for reference. (Data source: NHAAP)

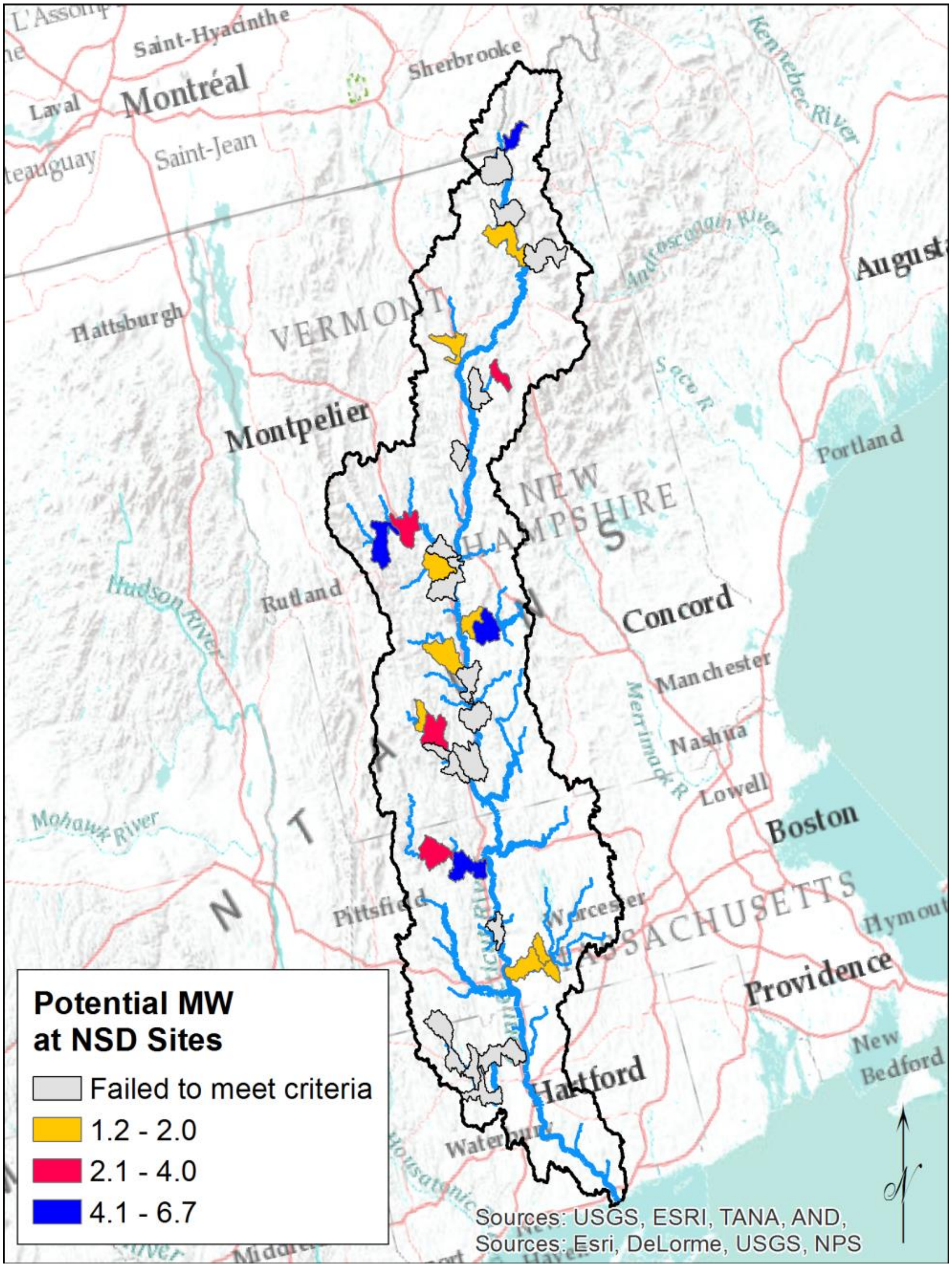

Figure 3.2. New stream-reach development sites in the Connecticut River basin that meet the screening criteria for potential hydropower development opportunities irrespective of environmental improvements (N = 27). Sites that do not meet the criteria are shown for reference. (Data source: NHAAP)

3.2 Environmental Issues

One the most important environmental issues in the Connecticut River basin is barriers to fish movement. The dam at Turners Falls blocked upstream fish passage when it was constructed in 1798. Over the years, numerous dams (over 2,000 across the basin) have blocked or restricted fish passage. Improving fish passage is a priority issue for restoring fish populations such as American shad (*Alosa sapidissima*), American eel (*Anguilla rostrata*), Atlantic salmon (*Salmo salar*), blueback herring (*Alosa aestivalis*), and shortnose sturgeon (*Acipenser brevirostrum*). Figure 3.3 illustrates catchments that contain at least one dam that was ranked by Martin and Apse (2011) as a top two-tier dam (i.e., top 10 percent) with respect to its importance in restoring diadromous fish populations.

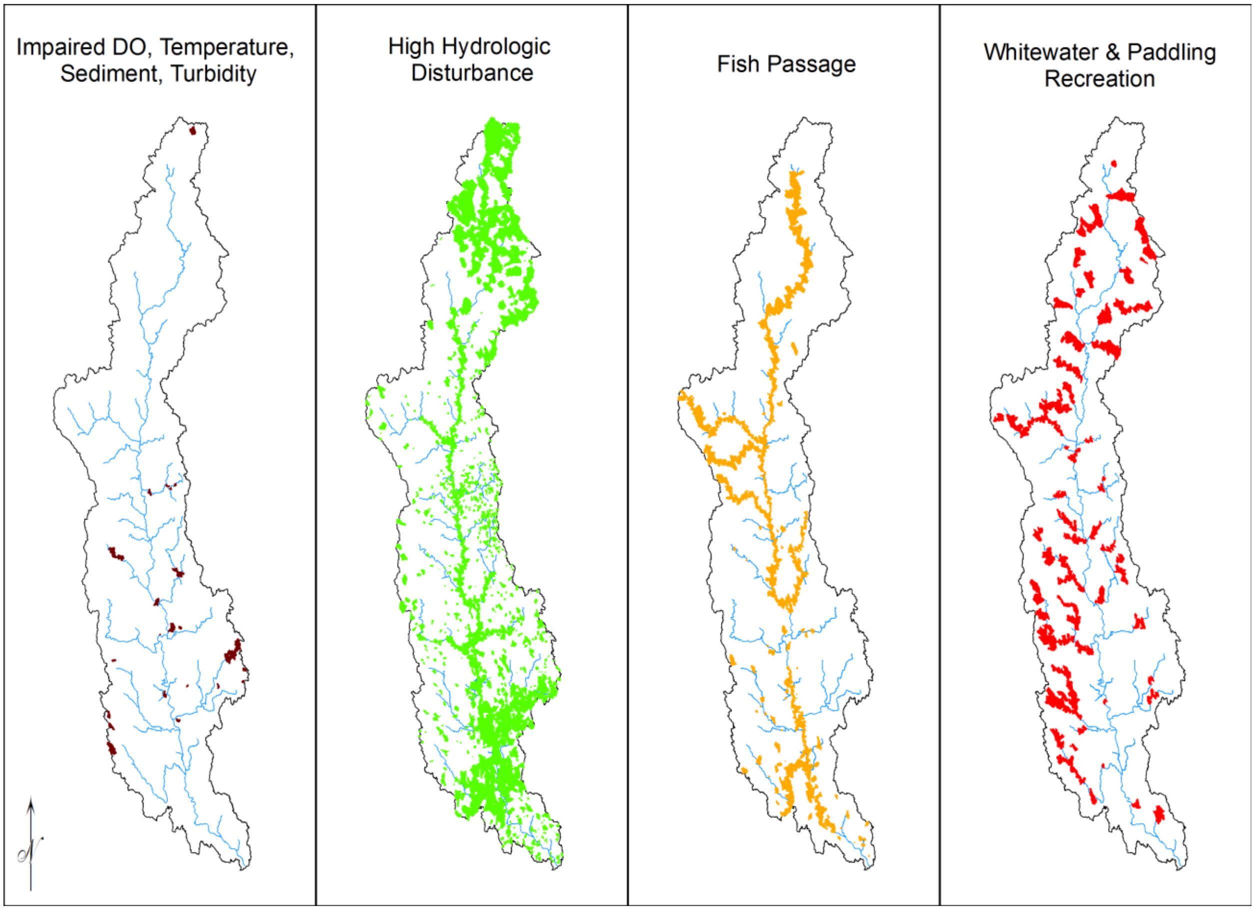

Figure 3.3. Catchments in the Connecticut River basin showing key environmental issues that were examined for potential complementary hydropower-environmental opportunities. Data sources are listed in Table 2.1.

Impaired water quality also emerged in our information assessment (Step 4) as an important environmental issue in the Connecticut River basin (Figure 3.3). Prevalent water-quality issues include bacteria, pollution, water temperature, low DO, sedimentation, and turbidity. Water quality in the Connecticut River basin is affected by many factors, although soil chemistry, water management, land use, and non-point pollution are commonly cited factors.

Dams, especially those operated for flood control, are a primary cause of flow alteration in the Connecticut River basin. Other factors contributing to flow alteration in the basin include withdrawals for water supply, irrigation, land conversion, and snow-making. Flow alteration is thought to be a significant factor affecting the distribution and abundance of the dwarf wedgemussel (*Alasmidonta heterdon*), a federally endangered species found in the basin. Maintaining non-motorized recreational boating opportunities is also a significant issue in the basin. Figure 3.3 illustrates catchments that were classified as having a high level of hydrologic disturbance (HDI $\geq$9) or containing stream reaches that are important non-motorized boat recreation areas.

In summary, there is a diverse and complicated set of environmental issues in the Connecticut River basin that are inextricably linked to past, present, and future hydropower development in the basin. Efforts are under way to address some of these issues and mitigate the negative effects of dams in the Connecticut River basin. For example, blueback herring and alewife (*Alosa pseudoharengus*) are being considered for listing under the Endangered Species Act (ESA), work is under way to restore sea lamprey and American eel populations, and passage solutions are being pursued for shortnose sturgeon downstream of Turner's Falls Dam.[1] Summarizing the extensive effort by federal, state, and local interests and utilities to mitigate the effects of dams is beyond the scope of this assessment. Instead, this assessment focuses on broadly capturing the key types and locations of environmental issues in the basin to gain a rapid understanding of where potential complementary hydropower-environmental opportunities may exist. Although we conducted an extensive literature review and data searches to try to capture the key environmental issues in our analyses, we acknowledge that some issues may not be fully captured in our process because of limited data availability and stakeholder involvement. The environmental issues included in the following analyses are intended to illustrate the process outlined herein of identifying complementary hydropower-environmental opportunities. Thus, the assessment is not intended to identify new environmental issues, but rather to provide additional information to those tasked with addressing them that may be helpful in their planning processes.

3.3 Direct Complementary Hydropower-Environmental Opportunities

We identified complementary hydropower-environmental opportunities for powering NPDs by evaluating spatially explicit, direct interactions between individual hydropower opportunities and environmental issues within the extent of projects (Table 3.1). Specifically, we focused on six types of environmental opportunities associated with powering a non-powered dam:

- *Manage flow to mitigate low DO* – Aeration of water through new turbine(s) could increase DO in downstream reaches with DO impairment.
- *Manage flow to mitigate sedimentation and turbidity* – Adding new turbine(s) could increase water velocities and provide better flow management in downstream reaches with excessive sedimentation or turbidity impairments.
- *Manage flow to mitigate temperature impairment* – Adding new turbine(s) could increase water velocities and provide better flow management in downstream reaches with temperature impairment.
- *Manage flow to mitigate hydrologic disturbance* – Adding new turbine(s) could provide opportunities for improving timing and amount of flow to reduce hydrologic disturbance in downstream reaches.

[1] K. Sprankle, USFWS, personal communication April 30, 2014.

- *Manage flow for existing whitewater/paddling* – Adding new turbine(s) could provide opportunities for improving flow to enhance whitewater or paddling recreation in downstream reaches.
- *Improve fish passage, either through facility modification or dam removal* – Refurbishment of existing downstream and/or upstream fish passage facilities at a dam considered important for diadromous fish restoration could be made as part of installing new turbine(s). We also considered this opportunity in the context of making facility improvements or breaching adjacent dams within the spatial extent of a given NPD opportunity.

Table 3.1. Number and capacity of NPD sites that may have complementary opportunities for environmental improvement in the Connecticut River basin.

Environmental Opportunity	Number	MW
Aeration from new development/adding a turbine could increase DO in downstream reaches with DO impairment.	0	0
New development/adding a turbine could provide better flow management in downstream reaches with sedimentation or turbidity impairments.	0	0
New development/adding a turbine could provide better flow management in downstream reaches with temperature impairment.	2	9.1
New development/adding a turbine could provide better flow management in downstream reaches with high hydrologic disturbance.	7	6.4
Adding a turbine could provide better flow management in existing whitewater/paddling reaches below dam.	8	12.3
Assume improvements in fish passage can be made as part of project development, either through facility modification or dam removal.	11	16.0
Total number and megawatts of sites that have at least one potential environmental opportunity[(a)]	17	20.7

(a) The total number of sites and megawatts is not equal to the sum of the data in the rows above because some hydropower sites have more than one environmental opportunity.

Of the 692 NPD sites evaluated, 66 passed the initial screening criteria, and of these 17 provided at least one of the environmental opportunities above (Table 3.1; Figure 3.4). Complementary opportunities associated with the 17 NPD sites included opportunities to diminish hydrologic disturbance and improve temperature, non-motorized boat recreation, and fish passage. Estimated capacities of these 17 opportunities ranged from 0.1 to 7.2 MW, representing a total capacity of 20.7 MW. Most (88%) NPD sites were not considered practical opportunities because they had an estimated capacity of less than 0.1 MW. However, 284 sites (not mutually exclusive from those with capacities of less than 0.1 MW) were also deemed impractical because they intersected catchments containing protected lands (GAP Status 1 or 2, or Wild and Scenic Rivers) or habitat of the dwarf wedgemussel, an ESA-listed species. Note, however, that this assessment of potential new hydropower capacity is conservative because it does not include other hydropower opportunity types, nor does it include potential system-level benefits. For additional site-specific information about the 17 NPD sites, please refer to Appendix A.

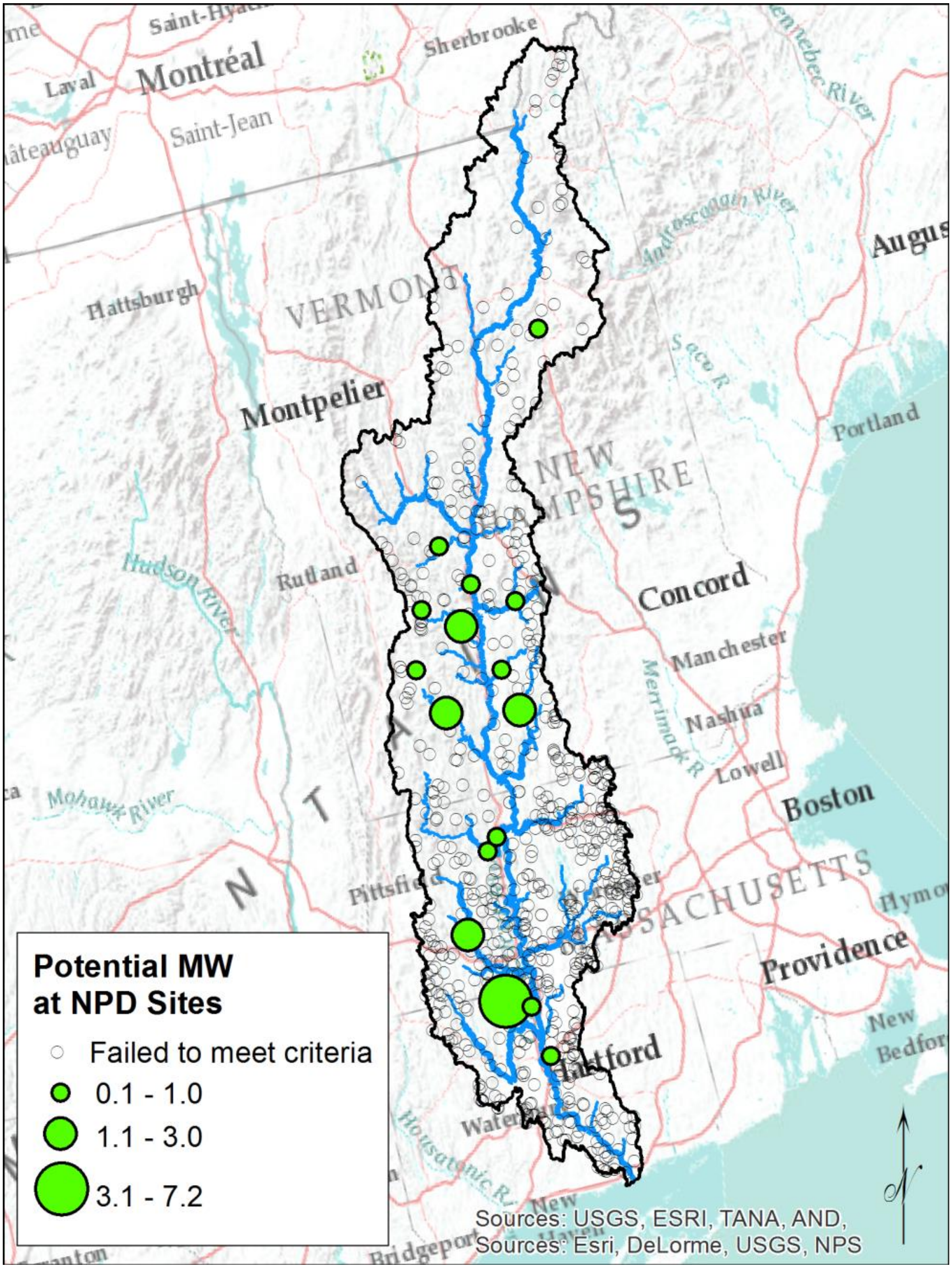

Figure 3.4. Non-powered dam sites in the Connecticut River basin having at least one complementary hydropower-environmental opportunity.

3.4 Indirect Complementary Hydropower-Environmental Opportunities

An *indirect* complementary hydropower-environmental opportunity is defined as an opportunity to improve an environmental condition that is not within the extent of or directly affected by the hydropower project of interest, but is within the same watershed as the affected hydropower site. In this sense, opportunities to improve an environmental condition are not linked to any one particular hydropower type, action, or location, and can be quantified as independent opportunities at multiple scales. We quantified these opportunities at the scale of 8-digit HUC drainages in the Connecticut River basin by summarizing the total number of each hydropower opportunity type (i.e., powering NPDs, efficiency improvements at existing powered dams, and NSDs) and environmental opportunity type within the same drainage. The same screening criteria for analysis of direct complementary opportunities were used to define potentially feasible hydropower opportunities for analysis of indirect opportunities, with the exception of existing powered dams because they are already permitted by the Federal Energy Regulatory Commission. The results of that analysis follow.

Of the 692 NPD sites evaluated, 66 passed the initial screening criteria, representing a potential total of 69.5 MW added capacity in the basin (Table 3.2). Drainages that exhibit the highest potential for powering NPDs include the Lower Connecticut (30.1 MW), West (9.6 MW), and Middle Connecticut (7.2 MW). Of the 60 NSD locations evaluated, 27 passed the screening criteria, representing a total capacity of 46.1 MW (Table 3.2). Drainages that exhibit the highest potential for NSD include the Black-Ottauquechee (11.2 MW), White (8.1 MW), and Deerfield (7.8 MW). It is important to note the estimates of potential hydropower from powering NPDs and NSDs from the NHAAP assessment represent estimates of raw potential and do not reflect true potential for development based on technical or economic feasibility, social desire, environmental impact, or any other extrinsic factor. However, they provide a starting point for discussion of potential opportunities.

Increasing hydropower through efficiency improvements at existing hydroelectric facilities was identified by key stakeholders in the Connecticut River basin as a more realistic opportunity for increasing hydropower. Therefore, we applied a modest 1 percent increase in capacity for all 104 existing facilities in the basin to provide a benchmark for comparison to opportunities for powering NPDs and NSDs. A 1 percent increase in existing capacity would provide an additional 22 MW in capacity in the basin, most (91%) of which can be attributed to facilities in the Middle Connecticut (10.2 MW), Deerfield (6.9 MW), and Waits (3.0 MW) drainages (Table 3.2).

Of the 12,436 hydrologic catchments in the Connecticut River basin, 3,194 (26%) contained at least one of the environmental issues we included for potential indirect hydropower-environmental opportunities (Table 3.3). The most prevalent issue in the basin, in terms of number of affected catchments, was areas indicated to have a high hydrologic disturbance index (see 2.2.4 *Hydrologic Disturbance*). This issue is more common in in the Lower Connecticut, Middle Connecticut, and Black-Ottauquechee drainages and is primarily tied to flow alteration caused by dams, especially those operated for flood control. Other factors contributing to flow alteration in the basin include withdrawals for water supply, irrigation, land conversion, and snow-making. Areas with high hydrologic disturbance were included in the analysis of indirect complementary opportunities because they may represent locations where flow is manually altered and operations could be evaluated for opportunities to improve

Table 3.2. Summary of hydropower opportunities by 8-digit HUC drainage.

8-Digit HUC Name	*Existing Powered Dams*		*Non-Powered Dams*		*New Stream-Reach Developments*		Total No. of Hydropower Opportunities[b]	Total Added Capacity (MW)[c]
	Number	Total Added Capacity (MW)[a]	Number	Total Added Capacity (MW)	Number	Total Added Capacity (MW)		
Black-Ottauquechee	21	0.6	9	4.0	7	11.2	37	15.8
Chicopee	10	0.2	9	4.5	2	2.4	21	7.2
Deerfield	10	6.9	4	1.4	5	7.8	19	16.1
Farmington	3	0.2	2	2.0	0	0.0	5	2.2
Lower Connecticut	0	0.0	7	30.1	0	0.0	7	30.1
Middle Connecticut	14	10.2	18	7.2	0	0.0	32	17.4
Miller	6	0.0	4	2.7	0	0.0	10	2.7
Passumpsic	9	0.1	0	0.0	1	1.2	10	1.2
Upper Connecticut	5	0.0	0	0.0	4	7.4	9	7.4
Upper Connecticut-Mascoma	4	0.4	0	0.0	0	0.0	4	0.4
Waits	13	3.0	2	0.9	2	3.8	17	7.7
West	2	0.0	4	9.6	3	4.2	9	13.8
Westfield	6	0.4	7	7.0	0	0.0	13	7.4
White	1	0.0	0	0.0	3	8.1	4	8.1
Total No. of Opportunities/Capacity	104	22.0	66	69.5	27	46.1	197	137.6

(a) Total added capacity for existing powered dams based on a 1 percent increase through efficiency improvements.
(b) Equal to the sum of the number of powered dams, non-powered dams, and new stream-reach development opportunities for a given drainage.
(c) Equal to the sum of the total added capacities for each hydropower opportunity type for a given drainage.

Table 3.3. Summary of affected catchments classified by environmental issues that represent potential indirect complementary hydropower-environmental opportunities.

8-Digit HUC Name	DO Impairment	Sedimentation/ turbidity	Temperature impairment	High Hydrologic Disturbance	Non-motorized boat recreation	NCAT top 10% dam	Total No. of Affected Catchments[a]
Black-Ottauquechee	8	0	0	367	82	4	437
Chicopee	28	4	0	293	19	0	329
Deerfield	1	0	0	74	132	2	168
Farmington	7	0	0	132	55	16	195
Lower Connecticut	0	0	0	449	12	22	475
Middle Connecticut	5	13	1	370	59	16	445
Miller	1	0	0	63	8	3	72
Passumpsic	0	0	0	19	11	0	28
Upper Connecticut	1	0	0	245	31	0	262
Upper Connecticut-Mascoma	0	0	0	51	47	3	101
Waits	0	0	0	114	58	2	164
West	0	0	14	98	108	7	215
Westfield	4	0	0	60	99	8	164
White	0	0	0	45	109	2	139
Total No. of Affected Catchments	55	17	15	2380	830	85	3194

(a) The total number of affected catchments for individual HUCs is not equal to the sum of the values in the rows because some catchments may have more than one environmental issue.

environmental flows. Altering flow for environmental purposes may have benefits for numerous environmental issues, including conservation of the federally endangered dwarf wedgemussel.

Presence of non-motorized boat recreation was the second-most common issue in the basin. Non-motorized boat recreation is widely distributed throughout the basin, although it is more abundant in the Deerfield, White, and West drainages (Table 3.3). Data obtained for this issue came primarily from American Whitewater's National Whitewater Inventory and additional information obtained from literature. Examples of opportunities to improve boat recreation (motorized and non-motorized) and fishing access indirectly as part of a hydropower project include securing water releases to maintain boatable water, increasing and improving public access, and protecting adjacent lands.

Dams ranked highly by Martin and Apse (2011) with respect to their importance for restoring diadromous fish populations was the third-most common environmental issue, in terms of the number of affected catchments, in the Connecticut River basin (Table 3.3). The presence of highly ranked dams was most common in the Lower Connecticut, Middle Connecticut, and Farmington drainages. These data were included in the analysis of indirect complementary opportunities because they represent focal points for discussion of measures to improve habitat connectivity for diadromous fish that could be included as part of hydropower development elsewhere in the basin. Such measures could include improvement of existing fish passage facilities or removal of retired dams that present barriers to fish migration.

By comparing raw hydropower potential and key environmental issues independently at the 8-digit HUC drainage scale, we can begin to identify where there may be greater potential for indirect complementary hydropower-environmental opportunities in the basin. For example, the Lower Connecticut drainage has the highest raw potential for hydropower in terms of additional capacity (30.1 MW; Table 3.3). However, this additional capacity may be attributed entirely to powering non-powered dams, which is less tractable according to key stakeholders in the basin and therefore may not provide much incentive for environmental improvement elsewhere in the drainage. Furthermore, the Lower Connecticut drainage has the highest number of dams ranked highly by Martin and Apse (2011) with respect to their importance for diadromous fish restoration, which suggests that many NPDs in the drainage may already be problematic for fish. Thus, any potential project in the Lower Connecticut drainage would likely need to consider improving fish passage at existing facilities or removing dams.

Conversely, the Deerfield drainage, which ranked third in terms of total raw hydropower potential (Table 3.3), may have more diverse opportunities for increasing hydropower (10 existing hydroelectric facilities, 4 NPD sites, and 5 NSD sites) and subsequently more avenues for potential indirect environmental improvements. With the exception of non-motorized boat recreation, the Deerfield drainage does not contain a high number of affected catchments with respect to other drainages in the basin and the environmental issues we included in our analysis. However, there may be other types of environmental issues present in the Deerfield drainage that are not represented in our analysis. In addition, the propensity of a given issue or issues does not necessarily correlate with the relative importance of that issue. For example, the Deerfield drainage contains two dams identified by Martin and Apse (2011) as being in the top 10 percent of dams in a 13-state region in the northeastern United States that are ecologically important for diadromous fish restoration.

Examining potential indirect linkages between hydropower and environmental issues can also be performed using map-based data visualization. Figure 3.5 illustrates an example of how tabular information such as that in Table 3.2 and Table 3.3 can be displayed to visualize regional differences in raw hydropower potential and the number of hydrologic catchments affected by at least one environmental issue. Similar map schemas could be used to illustrate more specific comparisons of hydropower opportunities and environmental issues depending on a person's given interest. For example, drainages could be colored by potential capacity increase for one hydropower opportunity type and labeled by number of affected catchments for one particular environmental issue.

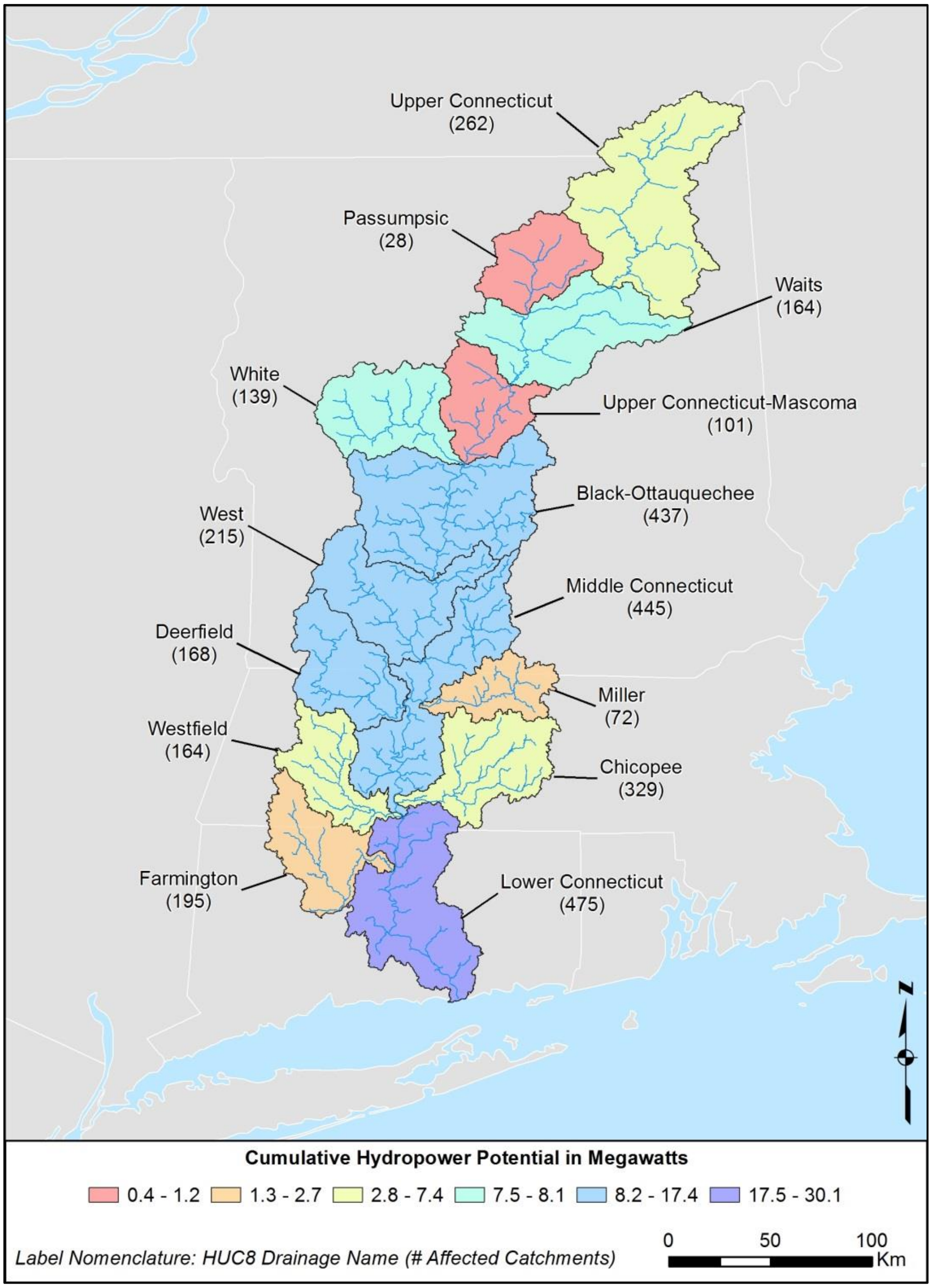

Figure 3.5. Cumulative hydropower potential and number of hydrologic catchments (in parentheses) affected by one or more environmental issues. (NOTE: Cumulative hydropower potential represents potential capacity increases for efficiency improvements at existing facilities, powering non-powered dams, and new stream-reach developments.)

4.0 Discussion

The Phase 1 Scoping Assessment for the Connecticut River basin provides a general, high-level scientific assessment of potential complementary hydropower-environmental opportunities. The assessment is intended to provide information for review by DOE, the national steering committee, and key basin stakeholders about the feasibility of opportunities for hydropower development and associated environmental improvements in the Connecticut River basin. This closing section of the assessment contains discussion of the technical approach and methodologies, including strengths, assumptions, and lessons learned. We also discuss the significance and meaning of the scoping assessment results. Finally, we offer guidance to others considering pursuing the complementary hydropower-environmental opportunities we identified. Note, however, there are no plans at this time for work on a Phase 2 Stakeholder Engagement or a Phase 3 Technical Analysis for the Connecticut River basin.

4.1 Strengths and Assumptions of Phase 1 Approach

The Phase 1 approach is designed for conducting rapid initial assessments of hydropower and associated environmental opportunities at a basin scale. Key strengths of the approach are that it is nationally deployable, relatively quick to implement (6 months or less), and useful for examining and visualizing opportunities under a variety of scenarios. The BSOA data model and geospatial database enable the approach to be implemented for any river basin. The data model and database can be used to standardize identification and visualization of opportunities across basins, but are also flexible enough to allow for customized assessments of opportunities. The database schema and associated GIS tools developed to populate the database can be used to quickly build a BSOA geospatial database for a given basin. Thus, the primary time constraint in future assessments will likely be data acquisition.

The BSOA data model is central to Phase 1 methodology. The data model outlines a process flow, key data elements, relationships between data elements, and criteria for examining interactions among data elements to identify complementary opportunities. A strength of this model is the criteria that define opportunities. Criteria can be objective or subjective, depending on the objectives of the analysis and interests of the stakeholders. However, defining criteria becomes increasingly difficult as relationships among types of hydropower opportunities, environmental issues, and stakeholder interests become more complex. This issue is particularly difficult with respect to defining direct complementary opportunities at the scale of the individual project because potential cause-and-effect mechanisms are needed in the definition. Conversely, criteria may be simplified for identifying indirect complementary opportunities because potential mechanisms for how the opportunity may be realized are not needed. Assuming criteria can be defined, the data model provides a means by which opportunities may be screened quickly in a uniform manner. The criteria presented herein represent an initial consideration of attributes that were deemed relevant for conducting assessments in the Connecticut River basin.

Several key assumptions were made in the Phase 1 development process that are important to discuss. One assumption is that the hydrologic units used in our analyses (8-digit HUC drainages and catchments) are appropriate spatial units for examining relationships (positive or negative) between hydropower opportunities and environmental issues. The purpose of using hydrologic units (or some other spatial polygon) is twofold. First, it resolves an analytical challenge of spatially relating hydropower opportunities and environmental issues that may be spatially disparate but functionally linked. In doing so, it also helps to satisfy a goal of the BSOA Initiative to expand the scale of analysis to identify commonality among the sometimes disparate goals of regional stakeholders. Hydrologic units were chosen for our analyses because they are hydrologically linked, which is important to consider when evaluating relationships between hydropower opportunities and environmental issues. Because they are not uniform in size and shape, there may be some spatial ambiguity when relating hydropower opportunities and environmental issues. However, this issue exists for other spatial polygons as well and is difficult to address because the exact spatial extent of hydropower-environmental interactions is not known. This potential bias was deemed acceptable for the purposes of a high-level, basin-scale assessment.

Related to this is the assumption that the spatial extents of hydropower opportunities used in this assessment are appropriate for identifying interactions with environmental improvements for a given hydropower opportunity. A goal in defining these extents is to choose areas that are hydrologically and ecologically appropriate with respect to the interactions being examined. However, as previously mentioned, this is difficult to do because the exact spatial extent of hydropower-environmental interactions is not known. A second goal is to refine these extents to better represent actual conditions, taking into account factors such as adjacent dams, topography, etc., and thereby improve independence among adjacent hydropower opportunities. This is also difficult to do because of uncertainties and a lack of data about the extent of influence for individual sites. For example, NHD water bodies were not available to represent the upstream extent for some hydropower opportunities in this assessment. However, these opportunities were typically small non-powered dams and presumably have small upstream and downstream extents. In addition, this bias was reduced in the analysis by aggregating hydropower and environmental data to a common spatial scale of hydrologic catchment.

It is important to note that complementary hydropower-environmental opportunities were treated equally, i.e., we did not prioritize or weight opportunities. The reason one opportunity was not considered more important than another at the same location was that we wanted to present the full realm of opportunities in an unbiased manner that hopefully facilitates discussion among stakeholders and helps them identify the opportunities that are most valuable to regional interests. Moreover, the total number of opportunities at one location did not make that location more or less important than another in the scoping assessment process. The Phase 1 methodology is intentionally agnostic to the relative importance of any given opportunity because it is intended to provide a high-level assessment that facilitates more involved stakeholder engagement and in-depth technical analysis.

Another important assumption of the Phase 1 process is that the environmental issues included in the analysis are appropriate for gaining a rapid understanding of where potential complementary hydropower-environmental opportunities may exist. We developed a comprehensive list of common environmental issues that might pertain to hydropower development in the United States. This list was used to help guide the compilation of information about key issues in the Connecticut River basin. During this process, it was discovered that perhaps not all of the issues may be relevant or important for a BSOA. In addition, some issues may not be fully captured in our analyses because of limited data availability or difficulty defining defensible criteria for examining interactions between hydropower and environmental issues. Some data sets, such as the NCAT data set (Martin and Apse 2011) that helped us identify environmental opportunities related to fish passage, have limitations and should be applied carefully. The environmental issues included in this assessment are intended to illustrate the Phase 1 process, which focuses on consideration of existing environmental issues in the context of increasing hydropower.

Because the Phase 1 Scoping Assessment process is heavily dependent on available data and is designed to be a rapid, nationally deployable process, the level of detail is necessarily coarse. A trade-off to this limitation is to be able to obtain meaningful results without having to perform expensive and time-consuming data mining and analysis. Where readily available, basin- or state-specific data should be used to supplement national-scale data and enable investigation of more basin-specific issues. However, use of such data in a multi-state basin like the Connecticut River basin can create difficulties for creating seamless basin-scale data sets due to state-specific differences in data availability, analysis methods, and intended uses. Data selection is an absolutely critical step in the Phase 1 process and should be undertaken with care. Future assessments may benefit from additional time and communication with key stakeholders in the basin to identify appropriate data.

NCAT results were useful because they provided an ecologically appealing and rapid means of conducting an initial screening of opportunities. However, it is important to acknowledge that similar opportunities may exist at other dams despite their NCAT rankings. Additional input from key stakeholders will help to identify other locations in the basin that are of interest for improving fish passage.

4.2 Recommendations for Future Phase 1 Scoping Assessments

Based on our experience with the assessment for the Connecticut River basin, we have the following recommendations for future Phase 1 Scoping Assessments:

- *Basin visit* – Include a 2- to 3-day visit to become familiar with the basin and communicate with key stakeholders about the purpose of the scoping assessment, available data sets, types of results it will produce, and possible follow-on applications. (This assumes the entity performing the scoping assessment is not from the basin.) Such a visit would focus the assessment on the types of hydropower opportunities and environmental issues that are most important to those in the basin, as well as expedite data compilation and analysis of direct and indirect opportunities.
- *Data* – Consider using readily available state and local data along with nationally available data sets. Assuming applicable state and local data can be combined in a seamless fashion, such data should enhance the quality of the scoping assessment.
- *Hydropower Opportunities* – Apply data for non-powered water conveyance systems (canals and pipes) and in-stream hydrokinetics as they are available for a given basin. Small hydropower development is growing and will deserve attention in many basins, especially those in the western United States, which have significant irrigation infrastructure.
- *Environmental Issues* – Consider prioritizing the environmental issues to indicate relative importance of the complementary hydropower-environmental opportunities. Working with key basin stakeholders, as mentioned above, may be an effective mechanism for prioritizing.
- *Stakeholder Interactions and Communications* – Increase interactions and communications with stakeholders about findings related to the scoping assessment described herein. For example, the webinars we conducted to communicate results for the Connecticut assessment were crucial for receiving feedback to provide a "reality check" on the preliminary results.

- *Technology Transfer* – Transfer the methodology for Phase 1 Scoping Assessments via publication of technical reports and/or peer-reviewed journal articles. A peer-reviewed journal article on the methodology for a Phase 1 Scoping Assessment is scheduled to be published in 2014-2015.

4.3 Applying the Results of the Scoping Assessment

Results from a Phase 1 Scoping Assessment could be useful to hydropower developers and regulators alike because they may facilitate identification of opportunities that avoid major regulatory roadblocks and improve environmental stewardship. Hydropower developers could consider complementary hydropower-environmental opportunities as part of proactive steps to identify environmental improvements associated with their development of interest. Likewise, regulators could use information about potential complementary opportunities to advance their missions to protect and enhance natural resources. At a minimum, the results of a Phase 1 assessment could inform a framework process for prioritizing hydropower development and potential environmental improvements at the scale of a river basin.

A Phase 1 Scoping Assessment is intended to be the first step in DOE's overall BSOA Initiative process, which includes two subsequent phases: Phase 2 Stakeholder Engagement and Phase 3 Technical Analysis. Ideally, the results of a Phase 1 assessment would be used to quickly the narrow the scope of potential hydropower opportunities in a basin down to a more reasonable number of opportunities for further consideration by stakeholders. In doing so, it may reduce the amount of time and complications associated with collaborative planning processes involving diverse groups of stakeholders and interests. Through the stakeholder engagement process, the scope of opportunities can be narrowed down further to those that have higher likelihood of going forward. At this point, additional technical analyses may be needed to assess factors such as technical and economic feasibility, environmental impact, and social outcomes. Ultimately, a goal of the Phase 1 process is to reduce the amount of time and resources needed to identify, plan, and assess potential hydropower development opportunities.

5.0 References

73 FR 19594. U.S. Federal Register. Vol. 73 No. 70. *Compensatory Mitigation for Losses of Aquatic Resources*. 10 April 2008.

CRJC (Connecticut River Joint Commissions). 2009. *Connecticut River Recreation Management Plan, Riverwide Overview*. Connecticut River Joint Commissions, Charlestown, NH. Available at: http://www.crjc.org/river-plan/water-resources-management-plan/.

DOE, BOR, and USACE (U.S. Department of Energy, Bureau of Reclamation, and U.S. Army Corps of Engineers). 2010. Memorandum of Understanding for Hydropower. Available from the U.S. Department of Energy, Washington, D.C. Available from http://en.openei.org/wiki/Federal_Memorandum_of_Understanding_for_Hydropower.

EPA (U.S. Environmental Protection Agency). 2013. National Geospatial Datasets. Available at: http://water.epa.gov/scitech/datait/tools/waters/data/downloads.cfm.

Esselman, PC, DM Infante, L Wang, D Wu, AR Cooper, and WW Taylor. 2011. An index of cumulative disturbance to river fish habitats of the conterminous United States from landscape anthropogenic activities. Ecological Restoration 29: 133-151.

Geerlofs S, N Voisin, K Ham, J Tagestad, T Hanrahan, A Coleman, J Saulsbury, A Wolfe, B Hadjerioua, K Stewart. 2011. *The Integrated Basin-Scale Opportunity Assessment Initiative, FY 2011 Year-End Report: Deschutes Basin Preliminary Hydropower and Environmental Opportunity Assessment*." PNNL-20802, final report prepared for the U.S. Department of Energy by Pacific Northwest National Laboratory, Richland, Washington. Available at: www.basin.pnnl.gov.

Hadjerioua B, Y Wei, and S Kao. 2012. *An Assessment of Energy Potential at Non-Powered Dams in the United States*. Final report prepared for the U.S. Department of Energy by Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Hall DG, KS Reeves, J Brizzee, RD Lee, GR Carroll, and GL Sommers. 2006. *Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants*. DOE-ID-11263, final report prepared for the U.S. Department of Energy by Idaho National Laboratory, Idaho Falls, Idaho.

Johnson GE, MS Bevelhimer, KB Larson, JD Tagestad, JW Saulsbury, RA McManamay, CA Duberstein, CR DeRolph, SL Hetrick, BT Smith, and SH Geerlofs. 2013. *The Integrated Basin Scale Opportunity Assessment Initiative: Phase 1 Methodology and Preliminary Scoping Assessments for the Connecticut River and Roanoke River Basins*. PNNL-22807. Annual Report 2013 prepared for the U.S. Department of Energy, Washington, D.C., by the Pacific Northwest National Laboratory, Richland, Washington, and Oak Ridge National Laboratory, Oak Ridge, Tennessee. Available at: www.basin.pnnl.gov.

Kao S and B Smith. 2013. *An Assessment of Energy Potential from New Stream-reach Development in the United States*. ORNL/TM-2012/298, initial report on methodology prepared for the U.S. Department of Energy by Oak Ridge National Laboratory, Oak Ridge, Tennessee. Available from http://nhaap.ornl.gov/content/non-powered-dam-resource-assessment.

Larson KB, SE Niehus, JD Tagestad, KD Ham, SH Geerlofs, and MC Richmond. 2014. The Integrated Basin-Scale Opportunity Assessment Initiative: Pilot Assessment for the Deschutes River Basin. PNNL-23197. Prepared for the U.S. Department of Energy, Washington, D.C., by the Pacific Northwest National Laboratory, Richland, Washington. Available at: www.basin.pnnl.gov.

Martin EH and CD Apse. 2011. *Northeast Aquatic Connectivity: An Assessment of Dams on Northeastern Rivers*. The Nature Conservancy, Eastern Freshwater Program, Brunswick, Maine.

McManamay RA, DJ Orth, CA Dolloff, and EA Frimpong. 2012. A Regional Classification Of Unregulated Stream Flows: Spatial Resolution And Hierarchical Frameworks. *River Research and Applications* 28:1019−1033.

McManamay RA, MJ Troia, CR DeRolph, MS Bevelhimer, MP Schramm, K Larson, J Tagestad, G Johnson, Y Jager. 2014. *Identifying Environmental Opportunities outside the Hydropower Project Boundary: An Updated Methodology of the Basin Scale Opportunity Assessment*. Technical Memorandum prepared for the U.S. Department of Energy by the Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Appendix A

Complementary Hydropower-Environmental Opportunities for Non-Powered Dams

Appendix A

Direct Complementary Hydropower-Environmental Opportunities for Non-Powered Dams

This appendix provides a list (Table A.1) of the direct complementary hydropower-environmental opportunities for non-powered dams that we identified in the Phase 1 Scoping Assessment for the Connecticut River basin.

Table A.1. Non-powered dams where at least one complementary hydropower-environmental opportunity was identified during the Phase 1 Scoping Assessment for the Connecticut River basin. (Note: "X" indicates the presence of a given environmental issue.)

Dam Name[(a)]	Stream/River Name	Temperature Impairment	Non-motorized boat recreation	High Hydrologic Disturbance	NCAT top 10% dam
Ball Mountain Dam	West River	X	X		X
Bethlehem Sewage Lagoon	Ammonoosuc River		X		
Billings Pond	Barnard Brook		X	X	X
Cellu Company Dam	Hockanum River				X
Congamond Lakes\South Dike	Congamond Lakes South Pond			X	
Conway Electric Dam	South River		X	X	
Lake Rescue	Black River				X
Littleville Dam	Middle Branch Westfield River		X	X	X
Municipal Sewage Lagoon 2	Sugar River			X	
North Springfield Dam	Black River				X
Schwartz Pond Dam	Stony Brook			X	X
Surry Mountain Dam	Ashuelot River				X
Townshend Dam	West River	X	X		X
Vilas Pond Dam	Cold River		X		X
Wiley & Russell Dam	Green River			X	
Williams	West River		X		
Windsor Upper	Mill Brook				X

(a) Dam name presented as it appears in the USACE National Inventory of Dams.

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