An Assessment of Energy Potential from New Stream-reach Development in the United States

INITIAL REPORT ON METHODOLOGY

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Submitted by

Shih-Chieh Kao, Ph.D.
Primary Investigator
ORNL Water Power Program

Brennan Smith, Ph.D., P.E.
Program Manager
Oak Ridge National Laboratory

OAK RIDGE NATIONAL LABORATORY
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Boualem Hadjerioua, Shih-Chieh Kao*, Ryan A. McManamay, MD Fayzul K. Pasha, Dilruba Yeasmin, Abdoul A. Oubeidillah, Nicole M. Samu, Kevin M. Stewart, Mark S. Bevelhimer, Shelaine L. Hetrick, Yaxing Wei, and Brennan T. Smith

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Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6283
managed by
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*Corresponding Author:
Shih-Chieh Kao
Oak Ridge National Laboratory
PO Box 2008
1 Bethel Valley Road
Oak Ridge, TN 37831-6038
Email: kaos@ornl.gov
Phone: 865-576-1259

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ABSTRACT

This methodology report addresses the datasets, assumptions, processing, and analyses (hereafter collectively termed methodology) necessary to produce assessments of national, regional, and state potential for hydropower development in heretofore undeveloped stream reaches with a nominal potential capacity greater than 1 megawatt. This methodology considers "new stream-reach development" as a hydropower resource class distinct from other hydropower resource classes identified by the Department of Energy (DOE) Water Power Program. The proposed methodology will ideally result in estimates of installed capacity and average annual energy generation for the identified stream reaches, and can also estimate inundated areas, reservoir volumes, and approximate hydraulic heads for hypothetical development locations in those areas. The methodology was designed to accommodate the whole of over 3 million U.S. streams to identify opportunities for new hydropower development. Within the limitations of finite resources, this wide spatial scope demands an approximate methodology that (a) resolves aggregate potential within hydrologic regions and electric power systems and (b) enables the modeling of regional and national scenarios of existing and new electric power generation technology deployment through the development of hydropower capacity cost versus supply curves. This methodology does not produce estimates of capacity, production, cost, or impacts of sufficient accuracy to determine absolute economic feasibility or to justify financial investments in individual site development. It does, however, allow for the identification of stream reaches of high energy intensity, and classification of new potential areas for hydropower development using a range of technical, socio-economic, and environmental characteristics. The products of this effort will differ from previous assessments of new hydropower development opportunities, which used fixed sets of assumptions to determine the overall potential for likely future hydropower development. The goal of this project is to produce datasets and tools that allow for multiple analyses to be conducted by different organizations and individuals using a wide variety of development scenarios and assumptions.

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- Norman Bishop, Knight Piesold
- Linda Church-Ciocci, NHA
- Dave Culligan, HDR | DTA
- Don Erpenbeck, MWH
- John Gasper, Argonne National Laboratory
- Ron Grady, HDR
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- Maria I. Martinez Gonzalez
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- Clement O. Oigbokie II
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EXECUTIVE SUMMARY

This methodology report addresses the datasets, assumptions, processing, and analyses necessary to produce assessments of national, regional, and state potential for hydropower development in heretofore undeveloped stream reaches with a nominal potential capacity greater than 1 megawatt (MW). This methodology considers "new stream-reach development" (NSD) as a hydropower resource class distinct from other hydropower resource classes identified by the Department of Energy (DOE) Water Power Program[1]. The proposed methodology will ideally result in estimates of installed capacity and average annual energy generation for the identified stream reaches, and can also estimate inundated areas, reservoir volumes, and approximate hydraulic heads for hypothetical development locations in those areas. The methodology was designed to accommodate the whole of over 3 million U.S. streams to identify opportunities for new hydropower development. Within the limitations of finite resources, this wide spatial scope demands an approximate methodology that (a) resolves aggregate potential within hydrologic regions and electric power systems and (b) enables the modeling of regional and national scenarios of existing and new electric power generation technology deployment through the development of hydropower capacity cost versus supply curves. This methodology does not produce estimates of capacity, production, cost, or impacts of sufficient accuracy to determine absolute economic feasibility or to justify financial investments in individual site development. It does, however, allow for the identification of stream reaches of high energy intensity, and classification of new potential areas for hydropower development using a range of technical, socio-economic, and environmental characteristics. The products of this effort will differ from previous assessments of new hydropower development opportunities, which used fixed sets of assumptions to determine the overall potential for likely future hydropower development. The goal of this project is to produce datasets and tools that allow for multiple analyses to be conducted by different organizations and individuals using a wide variety of development scenarios and assumptions.

This refined assessment utilizes a comprehensive set of recent U.S. geographic, topographic, hydrologic, hydropower, environmental, and socio-political datasets, including the Natural Resources Conservation Service (NRCS) Watershed Boundary Dataset (WBD), Environmental Protection Agency/U.S. Geological Survey (EPA/USGS) National Hydrography Dataset Plus (NHDPlus), U.S. Army Corps of Engineers (USACE) National Inventory of Dams (NID), USGS National Elevation Dataset (NED), USGS National Water Information System (NWIS), USGS

[1] The DOE Water Power Program classifies hydropower potential into multiple resource classes. These are (1) upgrades to existing facilities, (2) expansion of existing facilities, (3) powering of non-powered dams, (4) development of new "heretofore undeveloped" stream reaches, and (5) energy recovery in constructed waterways. Although it does not yield a net production of energy, pumped-storage hydropower is recognized as a valuable resource for grid flexibility and energy storage.

WaterWatch Runoff Dataset, DOE/Oak Ridge National Laboratory (ORNL) National Hydropower Asset Assessment Program (NHAAP) Dataset, Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS), U.S. Fish and Wildlife Service (USFWS) Federally Listed Endangered Species, USFWS Critical Habitats, USGS Gap Analysis Program (GAP) Conservation Lands, and USGS Water Use Dataset. The methodology for assembling and processing data contains three main components: (1) Identification of areas of energy intensity (higher values for the product of hydraulic head, streamflow, and slope), (2) topographical analysis of opportunity areas to estimate inundated surface area and reservoir storage, and (3) environmental attribution to spatially join various pieces of information related to the natural ecological systems, social and cultural settings, policies, management, and legal constraints. A generalized flowchart is shown in Figure ES-1.

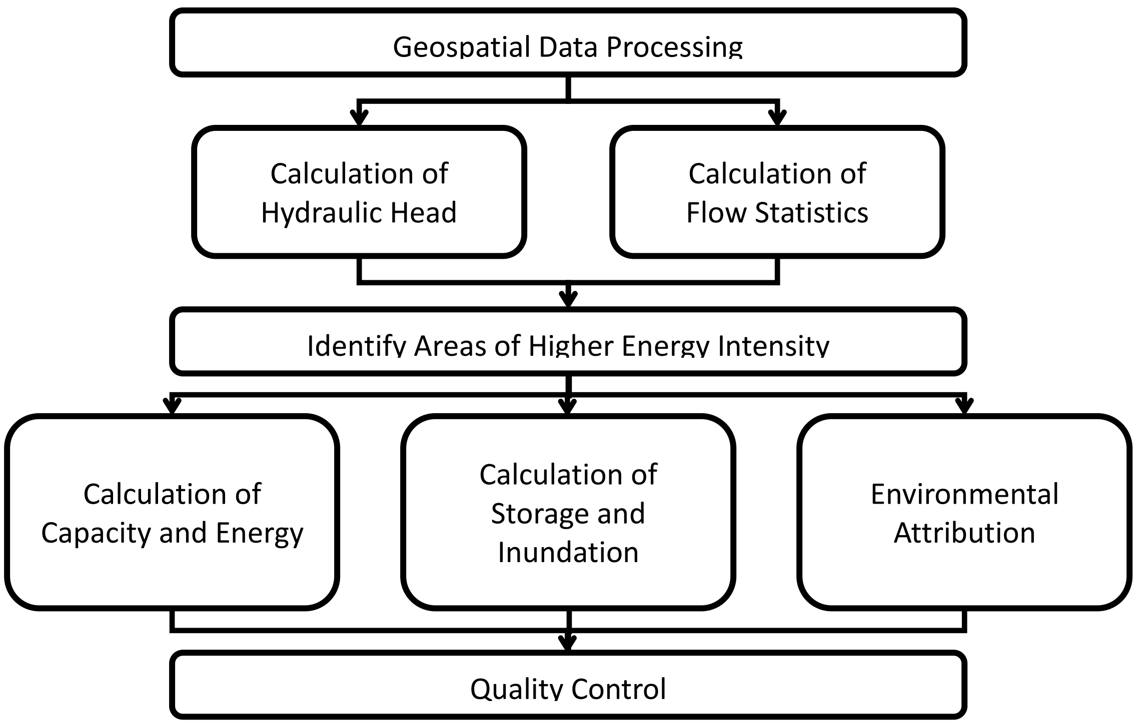

Figure ES-1 General Steps of the NSD Methodology

In FY2012, the methodology was reviewed and revised based on the comments gathered from two peer review workshops (December 2011 for resource characterization and June 2012 for environmental attribution). The USGS HUC04 Subregion is selected as the fundamental geospatial unit used for hydrologic and statistical modeling and parameter estimation, identification of locations for hydropower development, and analyses of energy potential. The identified locations are aggregated into reaches. These reaches are then attributed with various environmental characteristics to support future analyses. Starting from the two pilot Alabama-Coosa-Tallapoosa (ACT) and Apalachicola-Chattahoochee-Flint (ACF) Subregions, the assessment was applied in one fourth of the U.S. HUC04 Subregions in FY2012 and will be continued for the rest of U.S. Subregions in FY2013.

All results will be organized in a comprehensive dataset for the DOE Water Power Program to support further research activities. Nevertheless, given the sensitivity of the results (to avoid possible misunderstanding and misusage of the research outcomes based on the peer review workshop suggestions), the stream-reach characteristics will be further aggregated into HUC08 Subbasins or HUC10 Watersheds for public release. The publically accessible results and underlying data will be distributed through the DOE/ORNL NHAAP Public Portal (http://nhaap.ornl.gov/). Results will be displayed by color-coding HUC10 Watersheds based on the potential for new hydropower development, along with histograms/frequency charts displaying the distribution of generation or capacity in conjunction with certain attributed characteristics (an example is shown in Figure ES-2). The preliminary ACT-ACF study identified more than 90 potential stream reaches for development, with a total of approximately 420 megawatt (MW) installed capacity and 2.68 terawatt-hour (TWh) of hydro-electric generation. In FY2013, results for each hydrologic region will be continuously released with information compiled for other parts of the country.

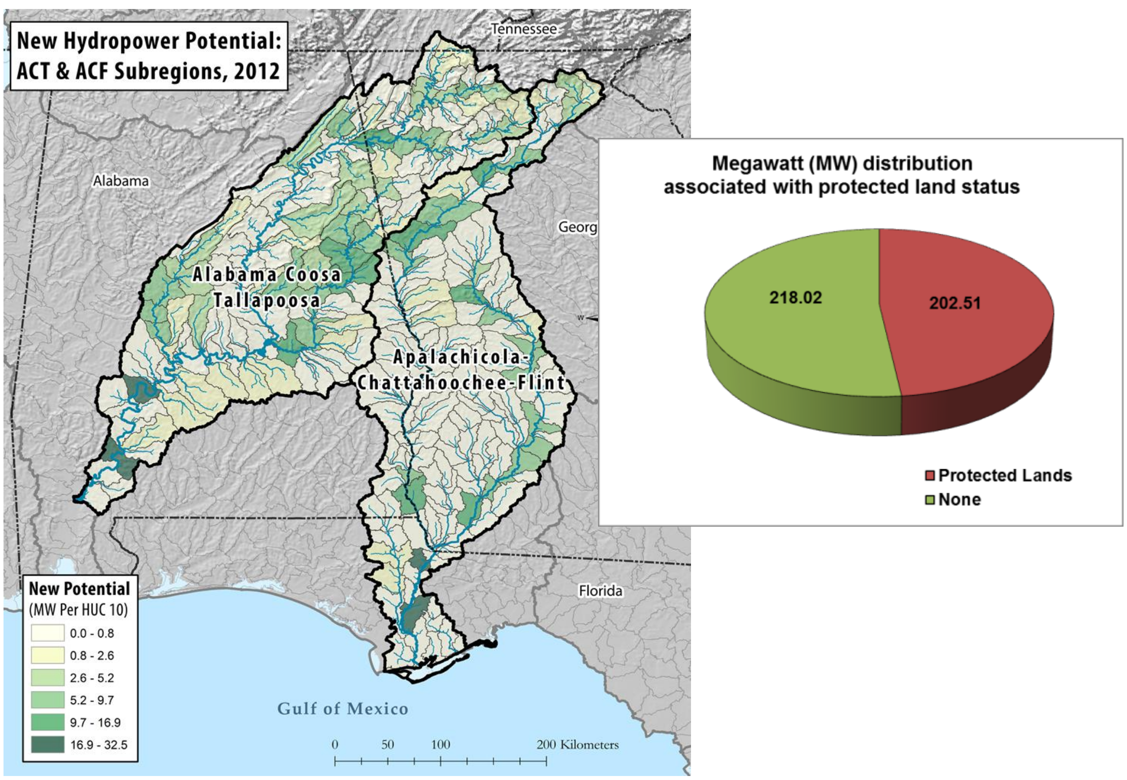

Figure ES-2 Map of the total hydropower install capacity (MW) per reach within the Apalachicola-Chattahoochee-Flint (ACF) and Alabama-Coosa-Tallapoosa (ACT) Subregions (left panel), and the total ACT-ACF capacity associated with projected land status (right panel).

LIST OF ABBREVIATED TERMS

ACF	Apalachicola-Chattahoochee-Flint Subregion (HUC 0313)
ACT	Alabama-Coosa-Tallapoosa Subregion (HUC 0315)
COMID	NHDPlus Object Identifier
DOE	Department of Energy
DOI	U.S. Department of the Interior
EDNA	Elevation Derivatives for National Applications
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
GAP	Gap Analysis Program
GIS	Geospatial Information System
HPRA	FERC Hydropower Resource Assessment Database
HUC	Hydrologic Unit Code
HUC02	Hydrologic Region
HUC04	Hydrologic Subregion
HUC06	Hydrologic Basin
HUC08	Hydrologic Subbasin

HUC10	Hydrologic Watershed
HUC12	Hydrologic Subwatershed
INL	Idaho National Laboratory
IUCN	International Union for the Conservation of Nature
LCOE	Levelized Cost-of-Energy
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NED	National Elevation Dataset
NFHAP	National Fish Habitat Action Plan
NHD	National Hydrography Dataset
NHDPlus	National Hydrography Dataset Plus
NHS	National Hydroelectric Power Resources Study by USACE
NID	National Inventory of Dams
NLCD	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Administration
NPD	Non-Powered Dam
NSD	New Stream-Reach Development
NSDP	New Stream-Reach Development Population
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
ORNL	Oak Ridge National Laboratory
PAD-US	Protected Area Database for the United States

Reclamation	U.S. Bureau of Reclamation
RMSE	Root Mean Square Error
SSP	Stream Segment Population
TIGER	Topologically Integrated Geographic Encoding and Referencing
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WaterWatch	USGS WaterWatch Program
WBD	Watershed Boundary Dataset

LIST OF VARIABLES

A_{NSD}	Inundated Surface Area (acre)
c	Unit Conversion Factor, $(0.3048)^4$
E	Hydro-electric Energy (Watt * hour)
E_{NSD}	The Potential Hydro-electric Energy at a NSD Site (Watt * hour)
GW	Gigawatt (10^9 Watts)
H	Hydraulic Head (ft)
H_{ref}	Reference height (ft) Calculated from FEMA 100-year Flood Elevation
HQS	The Product of H_{ref}, Q_{30} and S_0
MW	Megawatt (10^6 Watts)
MWh	Megawatt hour (10^6 Watts * hour)
P	Hydro-electric Power (Watt)
P_{design}	Design Hydropower Capacity (Watt)
P_{NSD}	The Potential Hydropower Capacity at a NSD Site (Watt)
Q	Flow (ft^3/s)
Q_{30}	The 30% Exceedance Quantile from Daily Flow-duration Curve
Q_{max}	Plant Hydraulic Capacity (ft^3/s)
$Q_{NHDPlus}$	Annual Mean Flow (ft^3/s) Provided by NHDPlus
Q_{tur}	Turbine hydraulic capacity (ft^3/s)
S_0	The Average Channel Slope
T_{NSD}	Residence Time (day)
T_{opr}	Design Daily Operation Time (hour)

TWh	Terawatt hour (10^{12} Watts * hours)
V_{NSD}	Reservoir Storage (acre * ft)
η	Generating Efficiency
γ	Specific Weight of Water, 9800 N/m^3

1. INTRODUCTION

With the rapid development of multiple national geospatial datasets on topography, hydrology, and environmental characteristics in the recent decade, new opportunity arises for the refinement of hydropower resource potential from undeveloped stream-reaches. This methodology report addresses the datasets, assumptions, processing, and analyses (hereafter collectively termed methodology) necessary to produce assessments of national, regional, and state potential for hydropower development in heretofore undeveloped stream reaches with a nominal potential capacity greater than 1 megawatt (MW). This methodology considers "new stream-reach development" (NSD) as a hydropower resource class distinct from other hydropower resource classes identified by the Department of Energy (DOE) Water Power Program[2]. The proposed methodology will ideally result in estimates of installed capacity and average annual energy generation for the identified stream reaches, and can also estimate inundated areas, reservoir volumes, and approximate hydraulic heads for hypothetical development locations in those areas. The methodology was designed to accommodate the whole of over 3 million U.S. streams to identify opportunities for new hydropower development. Within the limitations of finite resources, this wide spatial scope demands an approximate methodology that (a) resolves aggregate potential within hydrologic regions and electric power systems and (b) enables the modeling of regional and national scenarios of existing and new electric power generation technology deployment through the development of hydropower capacity cost versus supply curves. This methodology does not produce estimates of capacity, production, cost, or impacts of sufficient accuracy to determine absolute economic feasibility or to justify financial investments in individual site development. It does, however, allow for the identification of stream reaches of high energy intensity, and classification of new potential areas for hydropower development using a range of technical, socio-economic, and environmental characteristics. The products of this effort will differ from previous assessments of new hydropower development opportunities, which used fixed sets of assumptions to determine the overall potential for likely future hydropower development. The goal of this project is to produce datasets and tools that allow for multiple analyses to be conducted by different organizations and individuals using a wide variety of development scenarios and assumptions.

The methodology incorporates, by reference, the hydrologic unit code (HUC) hierarchy of Region (HUC02), Subregion (HUC04), Basin (HUC06), Subbasins (HUC08), Watersheds (HUC10), and Subwatersheds (HUC12). This hierarchy was originally specified in the U.S.

[2] The DOE Water Power Program classifies hydropower potential into multiple resource classes. These are (1) upgrades to existing facilities, (2) expansion of existing facilities, (3) powering of non-powered dams, (4) development at new "heretofore undeveloped" stream-reaches, and (5) energy recovery in constructed waterways. Although it does not yield a net production of energy, pumped-storage hydropower is recognized as a valuable resource for grid flexibility and energy storage.

Geological Survey (USGS) Water Supply Paper 2294 (Seaber et al., 1987) and refined and expanded in the Watershed Boundary Dataset (WBD) (USGS and USDA-NRCS, 2009). Within the NSD methodology, Subregion is selected as the fundamental hydrologic unit for modeling, parameter estimation, and analyses of energy potential. There are Subregions that exhibit extraordinary spatial heterogeneity, requiring additional resolution of modeling at the level of hydrologic Basins. These Subregions may also require more algorithmic complexity to yield results with accuracy comparable to that of more homogeneous Subregions. In such cases, the additional modeling and algorithmic complexity will be provided in the Subregion-specific reports documenting the results obtained in each Subregion.

This report provides the proposed baseline NSD methodology to be applied to all regions in the conterminous U.S. (lower 48 States). Several previous U.S. hydropower resource assessments are reviewed in Section 2. The methodology of new hydropower resource evaluation is introduced in Section 3. Section 4 explains how the environmental attributes are summarized and used to refine the estimates of power potential developed in Section 3. The initial findings of two pilot Alabama-Coosa-Tallapoosa (ACT) and Apalachicola-Chattahoochee-Flint (ACF) Subregions are reported in Appendix A. Given the data limitation and different energy need, the proposed methodology may not be directly suitable for Alaska and Hawaii. The assessment team will consult with the local power authority to identify a most appropriate approach to conduct and report potential new hydropower resource in Alaska and Hawaii.

2. BACKGROUND

Multiple national and regional assessments of hydropower potential have been conducted using different data sources and methodologies for five hydropower resource classes: (1) upgrades to existing facilities, (2) expansion of existing facilities, (3) powering of non-powered dams (NPD), (4) development at undeveloped stream-reaches, and (5) energy recovery in constructed waterways. Although it does not yield a net production of energy, pumped-storage hydropower is recognized as a valuable resource for grid flexibility and energy storage. Some of the previous assessments are described briefly here.

The Water Resources Development Act of 1976 authorized the National Hydroelectric Power Resources Study (NHS), led by the U.S. Army Corps of Engineers (USACE) Institute for Water Resources, to evaluate the potential for additional hydroelectric power and to prepare a plan for future development of sites under the jurisdiction of USACE. The NHS team published a 23-volume report (USACE, 1983) that identified 1,948 potential sites covering the first four major hydropower resource classes across the U.S. The NHS study started with over 50,000 existing dams and 10,000 undeveloped sites in the initial inventory provided jointly by the USACE dam safety personnel, state engineers, Federal Energy Regulatory Commission (FERC), previous water resource studies, and waterpower surveys conducted by the USGS. All sites were screened and analyzed through a four-stage process with different levels of data requirement and emphasis (i.e., physical potential, economic feasibility, and environmental-social acceptability). It was concluded that 46 gigawatts (GW) of capacity and 124 terawatt hour (TWh) per year of energy may be available from the 1,948 candidate sites, in which 27 GW of capacity and 76 TWh per year of energy were from 541 undeveloped sites. All of the undeveloped sites evaluated in NHS were those previously studied and proposed by other entities.

Conner et al. (1998) performed a state-by-state evaluation of hydropower potential and associated environmental feasibility covering the first four major hydropower resource classes. They examined all potential sites included in the FERC Hydropower Resource Assessment (HPRA) database, which was mainly composed of the FERC preliminary permit information. Some other locations suggested by the state agencies were also evaluated. In addition to the HPRA information (e.g., head, streamflow, proposed capacity and generation), Conner et al. developed a Hydropower Evaluation Software that allowed users to assign environmental attributes to calculate a development suitability factor for each site. They concluded that 30 GW of capacity may be available from 5,677 sites across the U.S., in which 8.5 GW was from 2,761 undeveloped sites.

Focusing on undeveloped sites, Hall et al. (2004) performed a national-scale hydropower resource assessment using the USGS Elevation Derivatives for National Applications (EDNA) dataset. EDNA is a hydrological-conditioned multilayer dataset with synthetic rivers derived from the National Elevation Dataset (NED). For each EDNA stream segment (averaged 2 miles in length), the elevation drop was used as the hydraulic head. The annual streamflow was then estimated through regional regression formulae to compute theoretical hydropower capacity. Utilizing a damless, diversionary development model, Hall et al. suggested that there could be 170 GW of hydropower capacity available from undeveloped sites across the U.S. The work was recently extended in the Pacific Northwest Region, Hydrologic Region 17, using the EDNA data set to identify sites using a new impoundment development model (Hall et al., 2012).

Section 1834 of the Energy Policy Act of 2005 authorized multiple federal agencies within the U.S. Department of the Interior (DOI), DOE, and USACE to investigate hydropower development opportunities at federal facilities. These agencies examined 871 existing facilities to quantify the hydropower potential available at existing federal infrastructure (DOI et al., 2007). The observed maximum streamflow and head were utilized to calculate the maximum power that each site may provide. They suggested that 1.2 GW may be available from NPD development and another 1.3 GW may be available from capacity expansion at existing hydropower plants. Undeveloped sites were not examined in this study.

Following DOI et al. (2007), the U.S. Bureau of Reclamation (Reclamation, 2011) conducted an in-depth study focusing on 530 Reclamation NPDs. For each site, the observed head and flow were collected to estimate the potential capacity, generation, cost-benefit, turbine type, and other relevant information that is useful for hydropower developers. The 30% daily streamflow exceedance quantile was used as a standard for turbine selection. A total of 270 MW of capacity and 1.2 TWh per year of energy were identified from 191 potential Reclamation NPDs.

ORNL, with the support from Idaho National Laboratory (INL), conducted a national-scale NPD assessment (Hadjerioua et al., 2012) for over 54,000 NPDs documented in the USACE National Inventory of Dams (NID). The head and flow were estimated from the NID attributes and the National Hydrography Dataset Plus (NHDPlus). A national total of 12 GW was identified, with over 90% of this capacity concentrated at the top 600 NPDs. Most of the NPD potential was predicted to be located at facilities in USACE navigation locks and dams system. Powering these locks and dams may produce lesser concern for competing water usage and could potentially be developed with less regulatory concern and stakeholder intervention.

3. NEW HYDROPOWER RESOURCES

3.1. Data Sources

Hydropower potential assessment requires several types of data, including watershed boundaries, river geometry, topography, and water availability. These data enable the estimation of the two most important variables for hydropower generation—gross hydraulic head (height difference between upstream pool and tailwater elevation) and the design flow at a location under consideration. Head and flow can be augmented with data and computations to estimate additional parameters, such as storage volume, inundated area, and other NSD attributes. Prospective areas for hydropower development can be selected by these and other parameters according to multiple objectives, including acquisition cost, levelized cost-of-energy (LCOE), environmental impact, or socio-economic impact. While the proposed NSD methodology presented herein includes the preliminary objective of maximizing generating capacity per unit of inundated surface area, the scope of the data collection effort is designed to support characterization of sites based upon multiple objectives in future development scenarios. Table 3-1 summarizes the major physical data types and sources used in this assessment. All environmental-related data and the attribution efforts are discussed in Section 4.

3.1.1. Watershed Boundary Dataset

Watersheds (drainage basins or hydrologic units) define the aerial extent of surface water draining through a common outlet. The intent of defining hydrologic units is to establish a drainage boundary framework, accounting for all land and surface areas. The WBD (USGS and USDA-NRCS, 2009) defines six levels of hydrologic units, labeled by different digits of HUC: Region (2-digit HUC or HUC02), Subregion (4-digit HUC or HUC04), Basin (6-digit HUC or HUC06), Subbasin (8-digit HUC or HUC08), Watershed (10-digit HUC or HUC10), and Subwatershed (12-digit HUC or HUC12). After evaluating several choices of spatial breakdown for analysis (e.g., State, HUC02, or HUC04), it was decided to select the Subregion hierarchy, given the appropriate size and hydrologic homogeneity. The NSD assessment will be conducted by Subregion for over two hundred HUC04 Subregions in the U.S. Preliminary assessments have been completed for the Alabama-Coosa-Tallapoosa (ACT, HUC 0315) and Apalachicola-Chattahoochee-Flint (ACF, HUC 0313) Subregions, and then extended to other hydrologic Regions. Some Subregions that are considered possessing limited hydropower potential (e.g., flat coastal regions with limited head or dry deserts lacking flow) will be omitted for detailed investigation.

Table 3-1 Summary of Data used in the NSD Assessment

Data Type	Data Source	Note
Watershed Boundary	• Watershed Boundary Dataset (WBD), NRCS	NSD assessment will be conducted in HUC04 hierarchy
River Geometry, Existing Water Bodies	• National Hydrography Dataset Plus (NHDPlus), EPA/USGS	NSD assessment is based on NHDPlus version 1
Existing Dams	• National Inventory of Dams (NID), USACE	New inundation should not overlap with existing dams
Topography	• National Elevation Dataset (NED), USGS	1/3 arc-second (about 10-meter) resolution is used
Flow Estimates	• National Water Information System (NWIS), USGS • National Hydrography Dataset Plus (NHDPlus), EPA/USGS • WaterWatch Runoff, USGS	Design flow is estimated from selected NWIS gauges and then extended to the NHDPlus flowlines. Monthly flow time-series is synthesized from the WaterWatch runoff.
Flood Zone	• Flood Insurance Study (FIS), FEMA, http://www.msc.fema.gov/	100-year flood lines are used to derive the reference height

3.1.2. National Hydrography Dataset and National Hydrography Dataset Plus

The NHD is a comprehensive set of digital spatial data representing the surface water of the U.S. using common features such as lakes, ponds, streams, rivers, canals, and oceans. Based on the medium resolution NHD (1:100,000-scale), the U.S. Environmental Protection Agency (EPA) Office of Water, assisted by the U.S. Geological Survey (USGS), has supported the development of NHDPlus to enhance the EPA WATERS application (EPA and USGS, 2010). By integrating a variety of datasets, including the NED, the National Land Cover Dataset (NLCD), and the WBD, NHDPlus adds a variety of useful attributes to NHD features. These attributes include cumulative drainage area, upstream/downstream flowline (surface water elevation), channel slope (surface water elevation drop divided by river length), estimated annual mean flow and mean velocity for each flowline in the stream network. NHDPlus currently covers the entire conterminous U.S.

Based on the comprehensive set of flowlines included in the NHDPlus, the goal of this NSD assessment is to evaluate the hydropower potential of each NHDPlus flowline and identify areas that are potentially suitable for future hydropower development. In addition to flowlines, the geospatial polygons of existing waterbodies (e.g., lakes) are utilized to eliminate some inappropriate flowlines (i.e., artificial flowlines that were created across waterbodies to connect upstream and downstream streams for computational reasons). The slope of each NHDPlus flowline is also used to identify the potentially suitable location for new hydro development, since rivers and streams with relatively higher slopes are typically associated with smaller inundated surface areas and may have higher energy density (more discussion in Section 3.2). Although NHDPlus captures most of the river geometry precisely (visually compared to the satellite image), a few of the highly curved river segments may still be over-simplified in NHDPlus due to the limited 1:100,000 medium resolutions. Therefore, some inconsistencies may occur, especially for those locations with a large difference between NHDPlus and NED elevations. This data limitation cannot be fully handled within the present effort, and can potentially be resolved from the NHDPlus side (e.g., upgrading to the use of higher 1:24,000 resolution).

Quality control will be performed to ensure the reasonableness of the final results. The current NSD assessment is based on NHDPlus version 1.

3.1.3. National Elevation Dataset

The NED (Gesch et al., 2002) is the primary elevation data product of the USGS. The NED is a seamless dataset with the best available raster elevation data of the U.S. All NED data are on the public domain. The NED is derived from diverse data sources that are processed to a common coordinate system and unit of vertical measure. NED data are distributed in geographic coordinates in units of decimal degrees, and conform to the North American Datum of 1983 (NAD83). All elevation values are in meters and, over the conterminous United States, are referenced to the North American Vertical Datum of 1988 (NAVD88). The vertical reference may vary in other areas. NED data are available nationally (except for Alaska) at resolutions of 1 arc-second (about 30 meters) and 1/3 arc-second (about 10 meters), and in limited areas at 1/9 arc-second (about 3 meters). The overall root mean square error (RMSE) of the absolute vertical accuracy of NED is reported to be around 2.44 meters (Maune, 2007).

In the NSD assessment, the 10-meter resolution NED is adopted consistently for the entire conterminous U.S. The main usage of NED is to label the elevation of Federal Emergency Management Agency (FEMA) 100-year flood lines (if elevation has not been provided by FEMA), to delineate the boundaries of the inundated surface area, and to estimate the potential reservoir storage. Although 10-meter resolution may still be insufficient to characterize some delicate surface topographical variation, it provides better accuracy than the commonly used 30-meter resolution NED. For the existing river segments and waterbodies, NED elevation refers to the water surface elevation instead of bed elevation, which is a great advantage since the interest of this project is to estimate the added inundation resulting from new hydro construction as compared to the current condition. There could be some inconsistencies between the 10-meter NED and NHDPlus flowline elevation, since the default NHDPlus elevation was originally derived from the 30-meter NED. However, it is not appropriate to fully update the default NHDPlus elevation by the 10-meter NED because it will break most of the derived NHDPlus features. Fortunately, elevations of both NED and NHDPlus flowlines are largely consistent for the identified areas with new hydropower development potential and, hence, it should not affect the accuracy of the overall assessment.

3.1.4. Federal Emergency Management Agency Flood Zones

FEMA is an agency of the U.S. Department of Homeland Security. FEMA's major responsibility is to coordinate the response to a disaster that has occurred in the United States overwhelms the resources of local and state authorities. For potential flood events, FEMA published the Flood Insurance Study (FIS), which contains information regarding flooding in a community and was developed in conjunction with the Flood Insurance Rate Map (FIRM). The FIS, also known as a flood elevation study, frequently contains a narrative of the flood history of a community and discusses the engineering methods used to develop the FIRMs. The study also contains flood profiles for studied flooding sources and can be used to determine base flood elevations for some areas. FEMA provides flood hazard maps for different flood events (e.g., 100-year and 500-year) across the country, for which a 100-year flood event is defined as a 1 percent chance of being equaled or exceeded in any given year. This data can be obtained in the geospatial information system (GIS) format from the FEMA Map Service Center (https://msc.fema.gov/).

In the NSD assessment, the elevation difference between the NHDPlus flowline and the closest 100-year FEMA flood line is chosen as the reference height to evaluate the hydraulic head. This approach is meant to provide a consistent basis to guide the national NSD evaluation, so that the potential hydrologic implications can be cross-examined through independent FEMA studies. More details are discussed in Section 3.2.3.

3.1.5. National Inventory of Dams

The NID, maintained by the USACE, is a comprehensive inventory of U.S. dams representative of various sizes. The goal of the NID is to include all dams in the U.S. that meet at least one of the following criteria: (1) High hazard classification – loss of one human life is likely if the dam fails, (2) Significant hazard classification – possible loss of human life and likely significant property or environmental destruction, (3) Equals or exceeds 25 feet in height and exceeds 15 acre-feet in storage, and (4) Equals or exceeds 6 feet in height and exceeds 50 acre-feet in storage. Congress first authorized the USACE to inventory dams in the U.S. with the National Dam Inspection Act (Public Law 92-367) of 1972. The latest version of NID 2010 (http://www.nid.usace.army.mil) contains 84,134 dams, together with information such as their purpose, location, river name, drainage area, dam height, dam storage, ownership, and primary usage. In the NSD assessment, the existing NID dams are treated as upstream boundaries during site selection. More details are discussed in Section 3.2.5.

3.1.6. National Water Information System

The NSD assessment uses daily stream gage observations from the USGS NWIS as a basis for estimating powerhouse design flows at potential sites. The NWIS provides daily flow observations from more than 22,000 gage stations throughout the U.S. Given that most of the U.S. streams are ungauged (i.e., the large information gap between 22,000 NWIS stations and 3 million NHDPlus flowlines), a suitable method will be used to estimate flow at ungauged locations based on the nearby NWIS observation. More details are discussed in Section 3.2.4.

3.1.7. WaterWatch Runoff

In addition to NWIS, the USGS WaterWatch unit runoff (Brakebill et al., 2011) is used in this assessment to synthesize monthly flow time series at ungauged locations. Derived from NWIS gauge observation, WaterWatch runoff is the assimilated time series of flow per unit area calculated for each conterminous HUC08 Subbasin. Runoff has a similar unit to precipitation (depth/time). By multiplying WaterWater runoff with the upstream drainage area, the monthly time series of streamflow can be synthesized. The synthesized streamflow time series can be used to estimate the energy production at potential NSD sites, especially at various ungauged locations. More details are discussed in Section 3.2.4.

3.2. Methodology

3.2.1. Energy Production Model

Consistent with previous studies (DOI et al., 2007; Reclamation, 2011), the following power equation is utilized to estimate the hydropower P (Watt) that may be produced with net hydraulic head H (ft) and flow Q (ft^3/s):

$$P = \eta * \gamma * H * Q * c \qquad \text{(Eq. 3.1).}$$

In Eq. 3.1, η is the generating efficiency, $\gamma = 9800\ N/m^3$ is the specific weight of water and $c = (0.3048)^4$ is the unit conversion factor. If both H(t) and Q(t) are expressed as functions of time and $\eta(H,Q)$ is a function of H and Q, then the total hydroelectricity energy E (Watt * hour) generated from hour t_1 to hour t_2 can be computed by:

$$E = \int_{t_1}^{t_2} P dt = c * \gamma \int_{t_1}^{t_2} \eta(H(t), Q(t)) * H(t) * Q(t) dt \quad \text{(Eq. 3.2).}$$

Although the total hydroelectricity energy E can be estimated precisely from Eq. 3.2, it requires detailed data inputs and may not be feasible for the national-scale NSD study. Proper simplification is hence adopted. For the purpose of hydropower resource assessment, the future hydropower plant operation is usually considered to be around the optimal operating point and therefore η can be reasonably assumed to be a constant 0.85 (e.g., USACE, 1983). Similarly, since the target is smaller hydropower sites, and it implies limited reservoir storage, the constant head assumption can be applied to estimate the hydropower P and hydroelectricity energy E.

During the design of hydroelectric projects, the selection of plant hydraulic capacity Q_{max} is made by experienced hydropower design engineers with reference to the site-specific hydrology, available technology, and financial constraints. Streamflow variations can be large in magnitude, such that judgment is required to determine a suitable design value. An excessive Q_{max} may result in over-design and over-investment (i.e., generating faculties will be idled most of the time due to insufficient water supply), while an inadequate Q_{max} may result in a waste of resources (a large amount of water cannot be converted to hydroelectricity and needs to be spilled directly).

When detailed flow records are available, the flow-duration curve can be derived to support decision making. An example of a flow-duration curve is shown in Figure 3-1, using the USGS NWIS Gauge 02337000 daily streamflow from 1971-2008. On the left panel, the time series of daily observation is shown. By sorting all flow observations and computing their percentage exceedance, the flow-duration curve can be built (right panel). For instance, the 30% exceedance quantile Q_{30} is found to be 327 cfs at this site, and it indicates that statistically there is a 30% chance that daily flow may exceed this 327 cfs threshold.

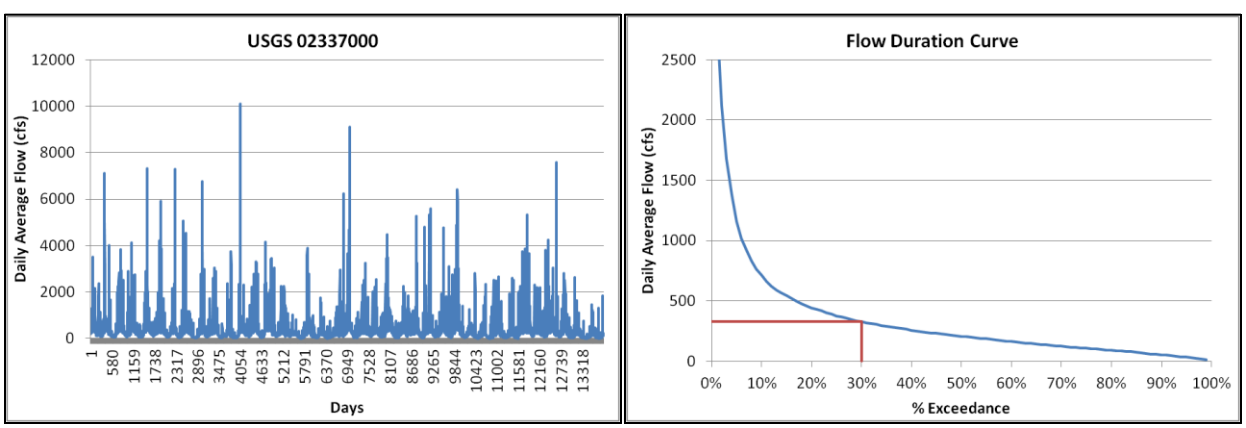

Figure 3-1 Example of a Flow-Duration Curve

Although there is no precise answer regarding what threshold should be used for hydropower resource assessment, Q_{30}, derived from the daily flow-duration curve, is generally regarded as an industry standard that would result in an estimate in the range of the optimal install capacity per dollar of capital investment (Section 3.1, Reclamation, 2011). As stated by Reclamation (2011), a lower exceedance level can be used, such as Q_{20}, which would typically result in a higher installed capacity for the site. However, Reclamation (2011) also cautioned that it may cause incremental costs to increase faster than incremental energy generated. Therefore, the NSD assessment will be based on Q_{30} for consistency with Reclamation (2011).

The plant hydraulic capacity (Q_{max}) defined herein does not necessarily equal the sum of hydraulic capacity of all generating turbines ($Q_{tur,all}$) because the role of reservoir storage and the mode of operation must be considered. If Q_{max}=Q_{30} is chosen from the daily flow-duration curve, the targeted maximum volume that a hydropower plant can handle within a full day equals T_{day} * Q_{30} (hour * ft^3/s) with T_{day} = 24 hour. Combined with the constant head assumption, the corresponding maximum daily generation $E_{max,day}$ (Watt * hour) can be simplified as:

$$E_{max,day} = c * \gamma * \eta * \mathrm{H} * \mathrm{Q}_{30} * \mathrm{T}_{\mathrm{day}} \qquad \text{(Eq. 3.3).}$$

Therefore, in order to harvest this targeted maximum daily energy, one may install turbines with total hydraulic capacity $Q_{tur,all}$ = Q_{30}. In other words, having the hydropower plant running 24 hours to get the total energy $E_{max,day}$. However, sometimes it may be more beneficial to install larger turbines to reach higher power output in shorter periods of demand. In practice, hydropower is typically used more during daytime (peak hours) than nighttime (off-peak hours) due to its ability to quickly respond to power demands. In this fashion, it provides high flexibility for the integration with other sources of energy (e.g., nuclear, coal-burning, natural gas power plants, and variable renewables). If a design daily operation time T_{opr} (hour) is considered, the design hydropower capacity P_{design} (Watt) can be estimated by:

$$P_{design} = G_{max,day} \,/\, \mathrm{T}_{\mathrm{opr}} \qquad \text{(Eq. 3.4).}$$

Equations 3.3 and 3.4 can be further revised to be:

$$P_{design} = c * \gamma * \eta * \mathrm{H} * \left(\mathrm{Q}_{30} * \frac{\mathrm{T}_{\mathrm{day}}}{\mathrm{T}_{\mathrm{opr}}}\right) = c * \gamma * \eta * \mathrm{H} * Q_{tur,all} \qquad \text{(Eq. 3.5),}$$

$$Q_{tur,all} = \mathrm{Q}_{30} * \frac{\mathrm{T}_{\mathrm{day}}}{\mathrm{T}_{\mathrm{opr}}} \qquad \text{(Eq. 3.6).}$$

Therefore, $Q_{tur,all}$ will be the required total turbine capacity (cfs) to harvest the targeted maximum daily generation $E_{max,day}$ within the desired daily operation time T_{opr} with power output P_{design}.

Since it is very challenging to pre-assume a possible T_{opr} for the developer, in this study T_{opr} = 24 hours is used as a likely value for small run-of-river plants with limited storage. Hence, the total hydraulic turbine capacity $Q_{tur,all}$ (cfs) will be determined by Q_{30} estimated from the daily flow-duration curve, and the potential NSD capacity P_{NSD} (Watt) can be computed from the following simplified equation:

$$P_{NSD} = c * \gamma * \eta * H_{ref} * Q_{30} \qquad \text{(Eq. 3.7),}$$

in which H_{ref} represents the reference height derived from the NHDPlus flowline elevation to the FEMA 100-year flood elevation (discussed in Section 3.2.3). While Eq. 3.7 provides a straightforward way to estimate the potential capacity, the true challenge lies in how to estimate the parameters (H_{ref} and Q_{30}) for a large number of NSD sites with limited direct observation. The main focus of this study is to estimate these two main controlling variables for streams across the entire country. Additionally, although the NSD results will be reported based on the T_{opr} = 24 hours assumption, the user may adjust the results themselves based on other T_{opr} corresponding to a greater value placed on production during peak demand periods.

Although Eq. 3.7 can be utilized to estimate NSD resources for smaller hydropower sites (i.e., when T_{opr} is assumed continuously running for 24 hours), this simplified equation may result in under-estimation of installed capacity for hydropower sites with larger storage. For instance, if a hydropower plant is designed to provide power outputs only during daytime (T_{opr} = 12 hours) and has sufficient storage for operational flexibility, then the same amount of water can be utilized in a shorter period with double-installed capacity (from Eq. 3.6). Although not directly comparable, the ratio T_{24hr}/T_{opr} is conceptually similar to the inverse of capacity factor, which is defined as the (actual annual generation in MWh) / [(installed capacity in MW) * (365 days) * (24 hrs)]. For most of the larger hydropower plants (greater than 30MW) in the U.S., the capacity factors are around 0.4 to 0.6, suggesting that many units are not constantly operating. Under such circumstances, the targeted maximum daily generation $E_{max,day}$ should be used for consideration since it is controlled by natural water availability and can be more objective.

The simplified equations (Eqs. 3.3–3.7) should only be used in the context of regional and watershed scale hydropower resource assessment. When considering the detailed design of individual dams and plants, all major factors (η, H, and Q in Eq. 3.2) should be treated as time-varying variables for a complete multi-year numerical simulation. Further influenced by the local power marketing (peak and off-peak energy values), integration with other sources of energy supply (nuclear, coal) and required environmental minimum flow operations, the best investment choice can vary case-by-case and cannot be generalized. Therefore, it is again emphasized that this research is meant to provide a general estimation from the regional resource assessment point of view.

3.2.2. General Procedures of the NSD Assessment

The general procedures of this NSD assessment are described below, with an overall flowchart shown in Figure 3-2. Several major steps will be discussed in detail in the remaining sections of this chapter. Major assumptions are summarized in Table 3-2.

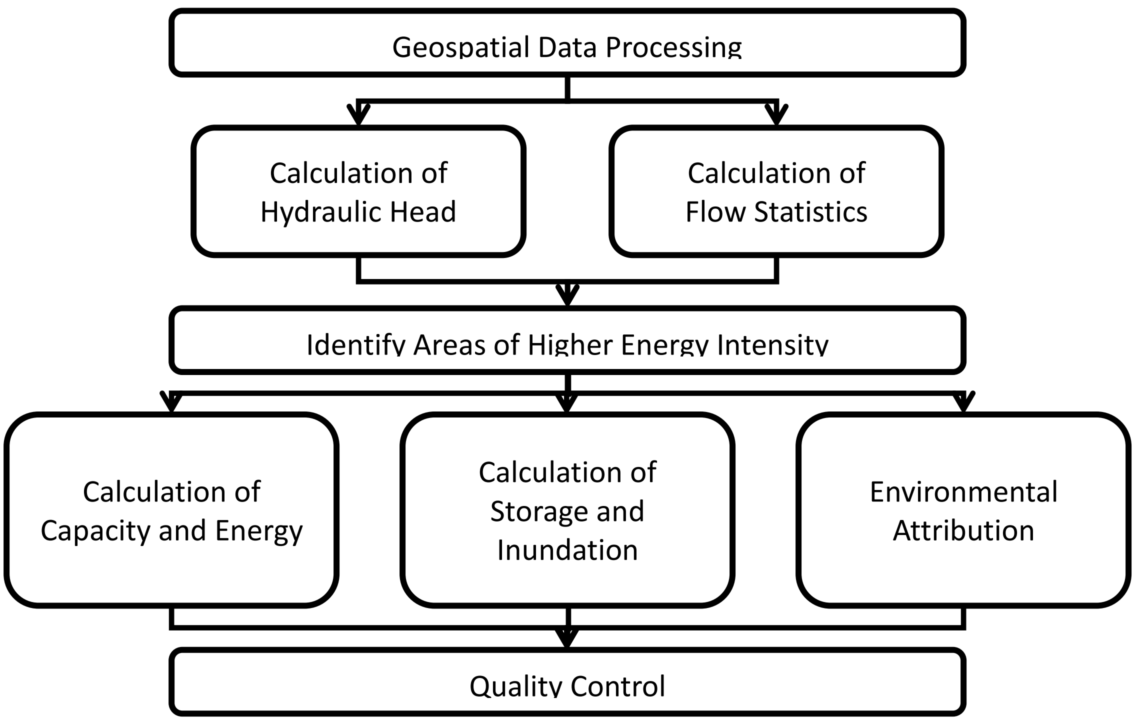

Figure 3-2 General Steps of the NSD Methodology

1. **Preliminary Selection of Stream Segment Population (SSP).** There are around 3 million raw NHDPlus flowlines in the conterminous U.S. (i.e., geospatial lines with unique NHDPlus COMID identifier). For simplification, a preliminary selection of NHDPlus flowlines is performed to eliminate smaller stream segments. Since the focus is on potential run-of-river projects, it is decided to exclude any NHDPlus flowlines with estimated annual mean flow $Q_{NHDPlus}$ less than 35 cfs, in which the excluded flowlines will need at least 400 ft head for 1 MW hydropower potential. Around 2.7 million (90%) smaller segments are eliminated and the remaining 300,000 (10%) NHDPlus flowlines are included in the SSP collection for further assessment. Any flowlines that overlapped with existing water bodies are also removed, since the water may have been regulated by existing dams (no longer a new hydro site consideration).

Table 3-2 Summary of Major NSD Assumptions

Steps	Major Assumptions
1. Preliminary Selection of Stream Segments	• Any NHDPlus flowlines with estimated annual mean flow $Q_{NHDPlus}$ less than 35 cfs are excluded without further analysis.
2. Discretization of NHDPlus Flowlines	• The NHDPlus flowlines can be reasonably discretized into 150-meter long sub-segments to better identify the potential NSD sites. • The elevation of each NHDPlus sub-segment can be linearly interpolated from the starting and ending elevations of the original NHDPlus flowline (i.e., no abrupt slope change).
3. Calculation of Reference Height (H_{ref})	• It is assumed that the new hydro sites will not inundate additional area other than the current 100-year flood zone and, hence, the hydraulic head can be estimated by H_{ref}.
4. Estimation of Plant Hydraulic Capacity (Q_{30})	• It is assumed that a linear relationship exists between the USGS NWIS Q_{30} and the NHDPlus $Q_{NHDPlus}$ so that a conversion ratio can be suggested from historic records to estimate Q_{30} by $Q_{NHDPlus}$. • NWIS gauges with Q_{30} less than 35 cfs are excluded. • Gauges must have complete daily observation from 1989–2008.
5. Site Identification	• The HQS value (product of H_{ref} * Q_{30} * S_0) can be used to select potential NSD locations. • Higher slope (S_0) may result in smaller inundation. • Focus on the dam-toe powerhouse development model. • Sites P_{NSD} less than 1MW are not selected in this study.
6. Estimation of Storage (V_{NSD}) and Delineation of Inundated Surface Area (A_{NSD})	• The 10-meter resolution NED can be utilized to estimate the inundated area A_{NSD} and reservoir storage V_{NSD}. • The residence time T_{NSD} can be estimated by reservoir storage V_{NSD} and annual mean flow $Q_{NHDPlus}$.
7. Estimation of Install Capacity (P_{NSD}) and Hydroelectricity Energy (E_{NSD})	• The reference height H_{ref} can be utilized to estimate the installed capacity P_{NSD}. • Run-of-river assumption (i.e., limited storage). • The energy E_{NSD} can be estimated from monthly streamflow time-series synthesized from the USGS WaterWatch runoff.

2. **Discretization of NHDPlus Flowlines.** Given that the NHDPlus flowlines vary in length (less than a mile to several miles), the methodology discretizes all NHDPlus flowlines in the SSP into 150-meter long sub-segments to better identify the potential NSD sites. For each sub-segment, the elevation is linearly interpolated from the starting and ending elevations of the original NHDPlus flowline, assuming no abrupt slope change in-between. An illustration is shown in Figure 3-3. The interpolated elevation may be inconsistent with the corresponding 10-meter NED, mainly because the original NHDPlus elevation was derived from the 30-meter NED. Nevertheless, the interpolation approach is still preferred along the NHDPlus line, rather than reference to the 10-meter NED, so that the interpolated elevation

will be more consistent with other NHDPlus derived characteristics (e.g., drainage area). A quality control step will be included to filter out those sites with larger inconsistencies in elevation between NHDPlus and NED. Based on the current results and experience, elevations from different datasets are mostly consistent at the identified NSD sites and are not a source of significant uncertainty.

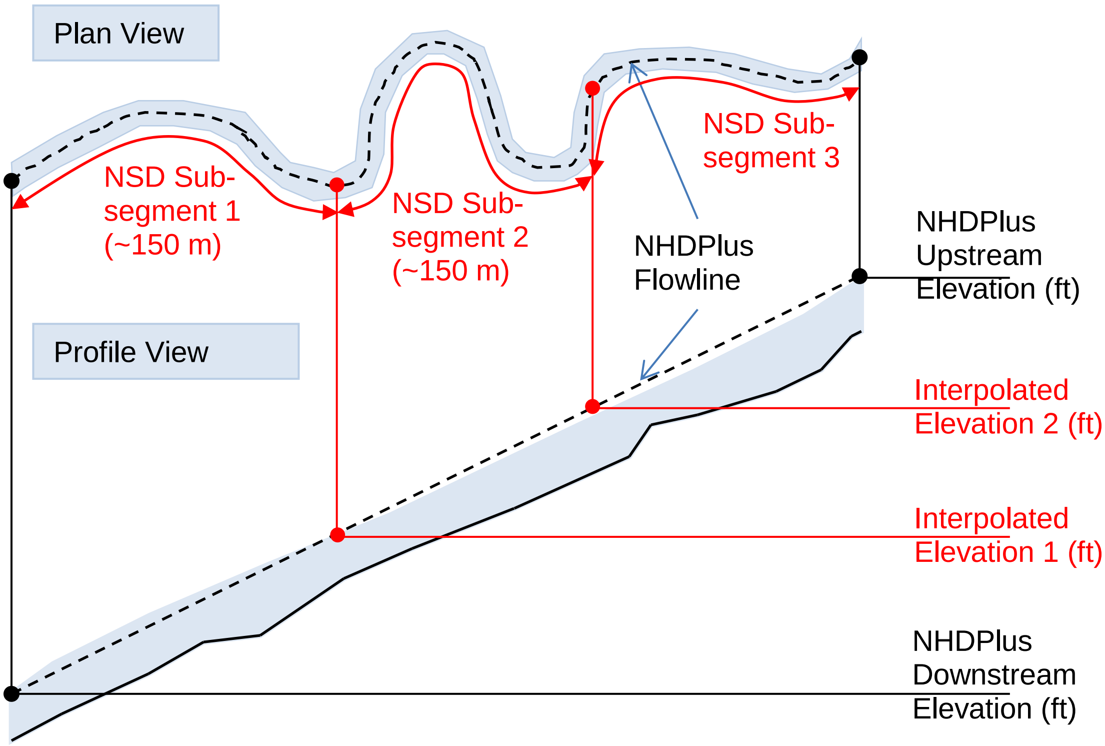

Figure 3-3 Illustration of NHDPlus Flowline Discretization

3. **Calculation of Reference Height (H_{ref}).** A reference height, H_{ref}, defined as the height from a discretized sub-segment to the nearest FEMA 100-year flood line, is used to calculate the potential hydropower at a NSD site. In other words, it is assumed that the new hydro sites will not inundate additional area other than the current 100-year flood zone. For each discretized NHDPlus sub-segment, a cross-sectional profile is drawn perpendicular to the sub-segment. The end points of a cross-sectional profile are defined when the cross section line touches the FEMA 100-year flood lines. Elevation of these end points are then looked up from the 10-meter NED and used to calculate H_{ref}. If the FEMA 100-year flood lines are missing excessively for too many locations, the median H_{ref} from all other identified sub-segments in the same HUC04 Subregion is used instead. More details of H_{ref} are discussed in Section 3.2.3.

4. **Calculation of Plant Hydraulic Capacity (Q_{30}).** For each Subregion, all USGS NWIS gauge stations with complete recent 20-year (1989–2008) daily observations are identified.

The 30 percent daily exceedance flow (Q_{30}) is then computed at each gauge station from the 1989–2008 observation. Consistent with Step 1, gauges with Q_{30} less than 35 cfs are excluded for further comparison. At the same location as the USGS gauge station, the corresponding NHDPlus annual mean flow $Q_{NHDPlus}$ is also identified for comparison. Given that a strong linear relationship is typical between Q_{30} and $Q_{NHDPlus}$, a conversion ratio can be estimated to calculate Q_{30} based on $Q_{NHDPlus}$, so that the plant hydraulic capacity can be estimated at each NHDPlus sub-segment. The $Q_{NHDPlus}$ is readily available within the NHDPlus dataset, so the conversion ratio provides a straightforward way to approximate Q_{30} from available resources. The conversion ratio is expected to be estimated, Subregion by Subregion, based on the local NWIS stations so that the local hydrologic variation can be properly incorporated. More details of Q_{30} are discussed in Section 3.2.4.1.

5. **Hydropower Location Identification.** Within each HUC04 Subregion, the NSD assessment identifies potential locations for hydropower development in the order of decreasing HQS, a product of H_{ref}, Q, and average channel slope S_0 (elevation drop divided by the river length). As discussed in Section 3.2.1, the product of H_{ref} and Q_{30} is proportional to power, implying that higher dam height may result in larger power output. However, raising the dam height usually comes with a trade-off of increasing inundation and may potentially result in greater impacts. Therefore, the channel slope, $S_{0,}$ is included in the optimization since higher S_0 usually implies a smaller inundated area (an example is shown in Figure 3-10). We note that although it is also possible to estimate the inundated area and volume directly (discussed in Section 3.2.6), such computation is too expensive at the site selection level and, hence, S_0 is still preferred as a surrogate of inundation. Following the decreasing order of HQS, NHDPlus sub-segments are identified and transferred from SSP to the new stream-reach development population (NSDP). All sub-segments that will be inundated by the identified NSDP will be removed from SSP before the next iteration. The process will be repeated until all potential sites with 1 MW minimum raw potential have been identified and included in the NSDP. More details of site identification are discussed in Section 3.2.5.

6. **Calculation of Storage (V_{NSD}) and Delineation of Inundated Surface Area (A_{NSD}).** Once a potential site and a targeted dam height (H_{ref}) have been suggested, it is of interest to identify those upstream regions that may be inundated due to the new hydro development. By estimating the flow direction of each 10-meter NED grid based on elevation, the inundated surface area (A_{NSD}) upstream of a new hydro site is delineated and outputted as GIS shapefiles for further geospatial analysis. The total reservoir storage (V_{NSD}) and residence time (T_{NSD}) are also estimated based on the inundated surface area and the estimated annual mean flow $Q_{NHDPlus}$. Given that this process is fairly computationally intensive, a customized computational program has been developed to facilitate a great

number of potential NSD sites. Since the NSD focus is on smaller hydro sites, the existing 30-meter resolution flow duration grids from NHDPlus dataset are insufficient and must be re-estimated (based on the 10-meter resolution NED). More details of delineation of inundated surface area are discussed in Section 3.2.6.

7. **Calculation of Hydropower Capacity (P_{NSD}) and Hydroelectricity Energy (E_{NSD}).** As discussed in Section 3.2.1, after the reference height (H_{ref}) and plant hydraulic capacity (Q_{30}) are estimated, Eq. 3.7 is utilized to estimate the hydropower capacity (P_{NSD}). Based on P_{NSD} and a streamflow time series, the energy production or generation (E_{NSD}) can be calculated. Since the daily or sub-daily resolution streamflow time series are unavailable at most of the ungauged locations, the monthly streamflow time series synthesized from the USGS WaterWatch runoff are used in this NSD assessment as an alternative to calculate E_{NSD}. Within each month, the part of streamflow higher than Q_{30} is considered spilled and not used for hydropower generation. By summing all monthly energy from January 1989 to December 2008, and dividing by 20 years, the potential mean annual energy production E_{NSD} is estimated. The E_{NSD} will serve as the baseline estimate of energy, and can be improved in the future studies by increasing the resolution and accuracy of the synthesized streamflow time series. More details regarding the calculation of monthly streamflow time series and E_{NSD} are discussed in Section 3.2.4.2. Further discussion about the penstock alternative is provided in Section 3.2.7.

8. **Turbine Selection and Preliminary Cost Estimate.** The preliminary turbine selection will be based on H_{ref}, Q_{30}, and the turbine selection matrix (Figure 3-4) provided by Reclamation (2011). Since most of the potential sites are low-head (due to the H_{ref} assumption), both Kaplan and low-head turbines will be likely choices. The possible turbine choices will be included in the attribute table of the identified NSD sites. In addition, the empirical cost equations used by Reclamation (2011), which were derived originally by Hall et al. (2003), will be utilized as the baseline cost estimates. These cost equations will provide preliminary cost estimates of the NSD development, with cost index adjustment to the 2011 currency value. Although it may be desirable to update the empirical cost equations based on more current hydro development statistics, this effort is not within the scope of this initial NSD assessment. When more recent cost equations have become available to the research team, the NSD cost estimates will be updated accordingly.

9. **Quality Control.** Given that several different datasets are jointly analyzed in the NSD assessment, data mismatch can occasionally occur. For instance, the NHDPlus elevation is based on the 30-meter resolution NED and it can be inconsistent with the 10-meter NED that was used to derive the inundation polygons. As a result, quality control through manual

checking is required to ensure the accuracy of the national estimates. Given the high geospatial variability, the quality control steps will be adjusted in different HUC04 Subregions.

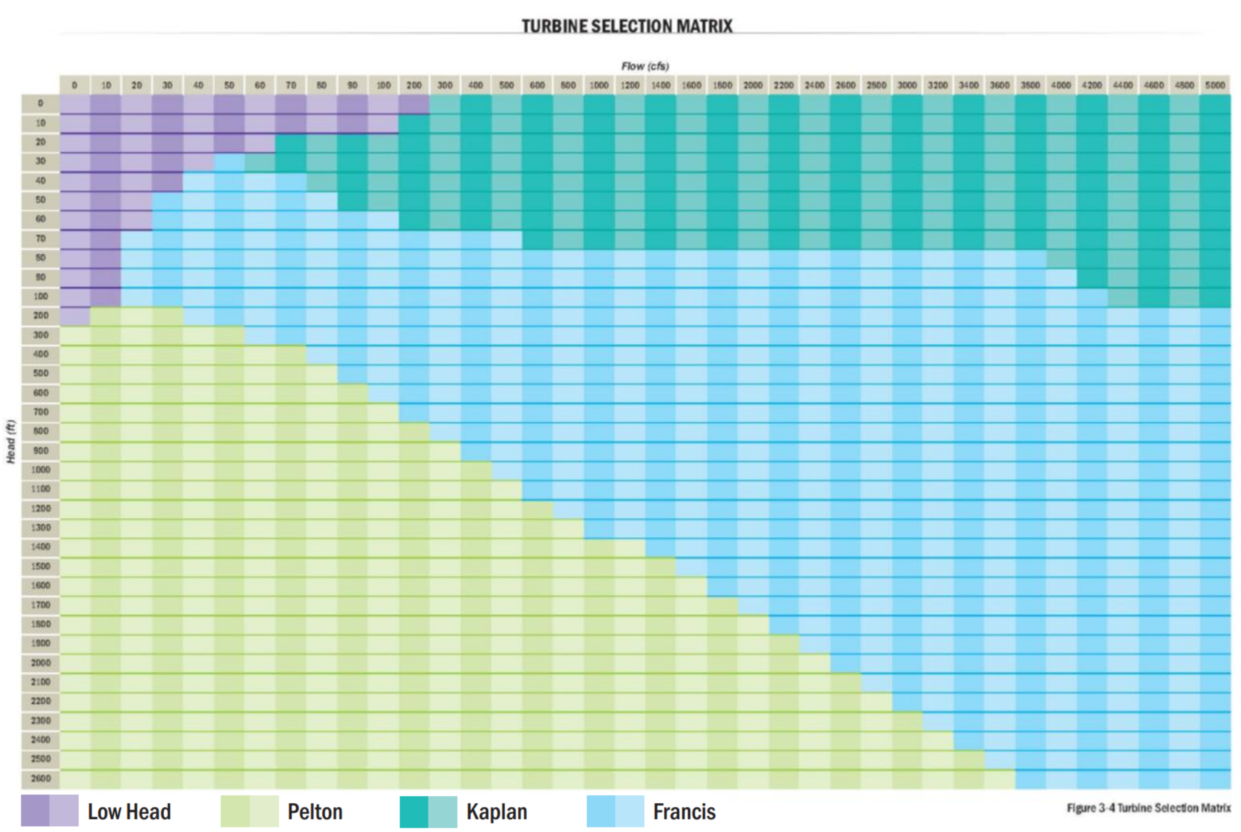

Figure 3-4 Turbine Selection Matrix (Figure 3-4, Reclamation, 2011)

3.2.3. Calculation of Head

To provide a consistent and independent reference for the evaluation of potential areas for new hydropower development across the nation, it was decided to incorporate the existing knowledge of the FEMA FIS flood elevations in this NSD assessment. As a federal regulatory agency, FEMA provides different corrective and preventive measures to reduce flood damage. One such measure is to prepare flood hazard maps for different flood events (e.g., 100-year and 500-year) across the country. The flood elevation lines for the base flood (100-year event) are defined as a 1 percent chance of being equaled or exceeded in any given year. Similarly, a more extreme 500-year flood is defined as 0.2 percent chance. All FEMA flood lines are available in GIS format. A typical example is shown in Figure 3-5.

The use of FEMA boundaries may provide a nationally consistent estimate of head to guide the preliminary selection of potential NSD sites. The usage of a 100-year flood reference height can also simplify the computation of site identification, so that the NSD assessment can be achieved at the national scale. A reference height, H_{ref}, defined as the height from a discretized sub-segment to the nearest pre-development 100-year flood line, is used to calculate the potential hydropower at a NSD site. This assumption will make the new inundation to be constrained within the pre-development FEMA FIS 100-year flood zones.

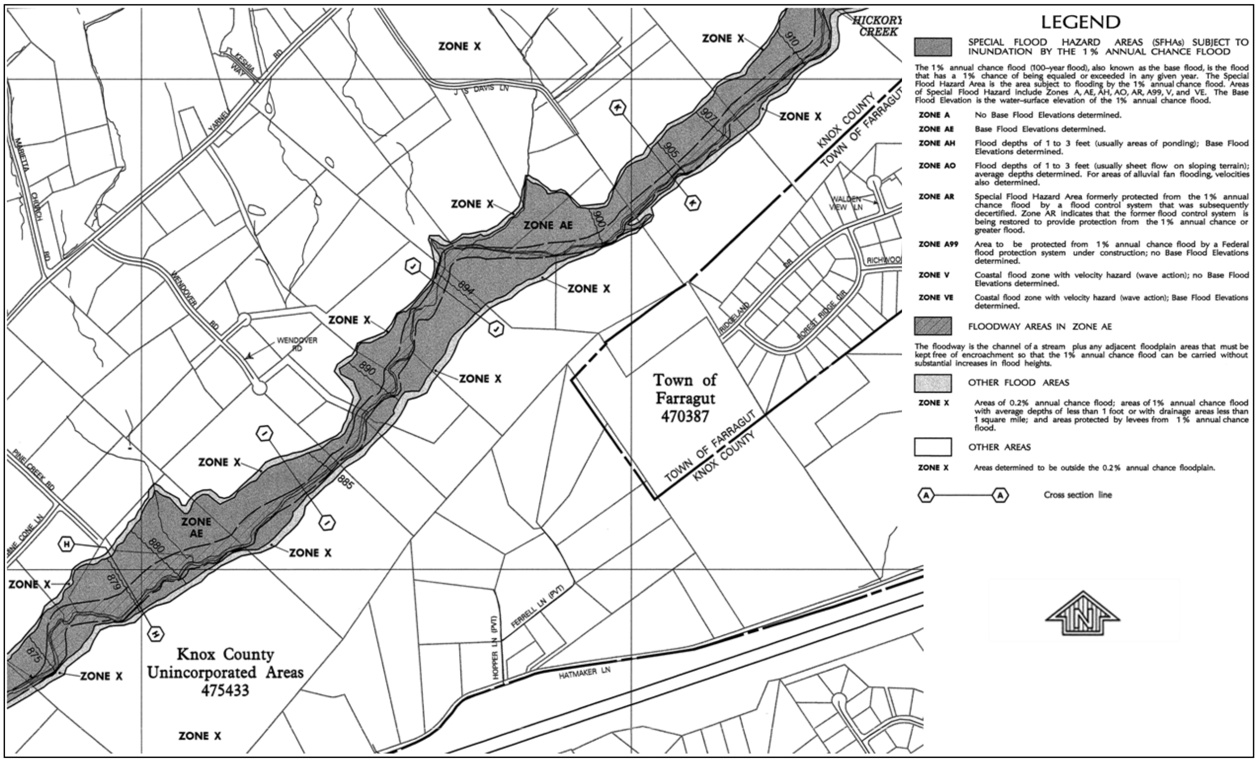

Figure 3-5 Example of FEMA Flood Zones

Although the purpose of FEMA FIS is unrelated to hydropower, the existing flood zones may provide valuable insights to infer the selection of future NSD sites. To be more specific, due to the higher insurance rate and other regulatory consideration, there are usually fewer existing residencies or civil structures in the FEMA 100-year flood zones (i.e., relatively empty) and, hence, the FEMA 100-year flood line can be regarded as an invisible boundary of the existing civil development. In other words, if the NSD inundation is limited to the regions within FEMA 100-year flood zones, there is more likely a chance that the new hydro development will affect fewer existing structures and could potentially be less costly.

However, it should be clarified that this approach does not imply that the FEMA flood zones will remain unchanged after a new hydro dam is placed. Whenever there is a new obstruction across a river, there is the potential for an increase in the flood elevations upstream, and a new FIS and flood zone delineation may be one of the requirements of new hydropower development, depending on the details associated with any particular project's design and operation. Also, it is important to note that H_{ref} is not necessarily the most profitable or environmentally feasible dam height. It is possible that the final design head can be either higher or lower than the reference height, depending on the results of site-specific engineering design and economic/environmental evaluation. After a particular river-reach is chosen for serious consideration of new hydropower development, detailed analysis would need to be conducted to refine the design dam height and assess all economic and environmental issues.

Intensive GIS processing is required to obtain the flood elevation from the FEMA 100-year flood lines. For each of the discredited NHDPlus flowline sub-segment, a cross-sectional profile is drawn perpendicular to the sub-segment (an illustration is provided in Figure 3-11). The end points of each cross section are defined when the cross section line touches the surrounding FEMA 100-year flood lines (with a maximum search length of 150-meter) to estimate H_{ref}. If the elevation is not provided directly on the FEMA flood lines, it is looked up from the 10-meter NED. If the FEMA flood line is missing and interpolation is possible then interpolation has been made between the upstream and downstream 100-year water surface elevations. The elevations may occasionally be inconsistent among NHDPlus, various FEMA FIS and 10-meter NED, and this disagreement may generate bumps and spikes in the water surface elevation. To avoid these sudden bumps and spikes, H_{ref}, calculated at several neighboring NHDPlus sub-segments, may need to be averaged for smoothing. To further address these potential issues, a quality control step will be included to filter out those sites with larger inconsistent elevations among different datasets. Nevertheless, based on the current results and experience, elevations from different datasets are mostly consistent at the identified NSD sites and, hence, it is not considered as a major issue.

Since FEMA FIS is not always available, especially in rural areas associated with minimal development, alternatives must be sought to estimate a comparable H_{ref}. For each HUC04 Subregion, all H_{ref} from NHDPlus sub-segments with valid FEMA information are collected to calculate a medium H_{ref}. When the FEMA information is unavailable and cannot be reasonably interpolated from upstream and downstream H_{ref}, the median HUC04 H_{ref} is used for the calculation of power and energy. Therefore, the purpose of this alternative is merely to provide a comparable reference height, H_{ref}, for NSD siting purposes. Under no condition should this H_{ref} be used to infer the possible 100-year flood zone or be compared to the existing FEMA studies. The characterization of official regulatory flood zones can only be conducted by FEMA or other authorized entities.

3.2.4. Calculation of Flow

3.2.4.1. Calculation of Q_{30}

As discussed in Section 3.2.1, the plant hydraulic capacity, Q_{30}, identified from the daily flow-duration curve represents a general industry-held standard, which most likely results in an estimate in the range of the optimally installed capacity per dollar of capital investment (Reclamation, 2011). The flow-duration curve should be based on at least 20 years of observation so that the wet, dry and normal hydrological years can be well represented. However, while Q_{30} is desired, gauge observation is not always available (or sufficient) in many locations. Most of the NSD sites are either ungauged, or gauged with limited observation. Therefore, alternatives must be sought to estimate Q_{30} for a great number of NHDPlus flowlines.

For each Subregion, all USGS NWIS gauge stations with complete recent 20-year (1989–2008) daily observations are identified. At each gauge station, the 1989 – 2008 observation is then used to derive the flow-duration curve to estimate Q_{30}. The flow observations other than 1989 – 2008 are intentionally omitted so that the Q_{30} estimates among various NWIS gauges will be under the same large-scale meteorological variability. At the same location as the USGS gauge station, the corresponding NHDPlus $Q_{NHDPlus}$ is identified for comparison. A GIS algorithm is designed to automatically link the NWIS gauge station to NHDPlus flowlines according to the following steps: (1) identification of the nearby NHDPlus flowlines based on the NWIS gauge coordinates, (2) comparison of the drainage areas between NHDPlus and NWIS to avoid mismatch, and (3) quality control to ensure the match is done correctly.

Based on current experience, a linear relationship is typically evident between Q_{30} and $Q_{NHDPlus}$. To be consistent with the preliminary selection of SSP, gauges with Q_{30} less than 35 cfs are excluded for further analysis. An example is shown in Figure 3-6, using a total of 77 USGS NWIS gauge stations (37 in HUC0313-ACF and 40 in HUC0315-ACT, all with complete observations from 1989 – 2008). Given the strong relationship between Q_{30} and $Q_{NHDPlus}$, a conversion ratio can be suggested to estimate Q_{30} based on $Q_{NHDPlus}$, so that the plant hydraulic capacity can be estimated at each discretized NHDPlus sub-segment. Although the statistical relationship can be developed in a variety of different ways, such an approach is considered to be the most convenient for the hydropower industry since NHDPlus results can be easily retrieved. By computing the $Q_{30}/Q_{NHDPlus}$ at each station, the results are again illustrated in Figure 3-7. A ratio of 79% is hence suggested in ACF and 89% in ACT (i.e., $Q_{30} = 0.79 * Q_{NHDPlus}$ in ACF and $Q_{30} = 0.89 * Q_{NHDPlus}$ in ACT). The conversion ratio is expected to be estimated for each HUC04 Subregion based on the local NWIS stations so that the local hydrologic variation can be properly incorporated. However, if there are very few suitable NWIS gauges in one HUC04, multiple nearby HUC04s may be combined to provide a ratio jointly.

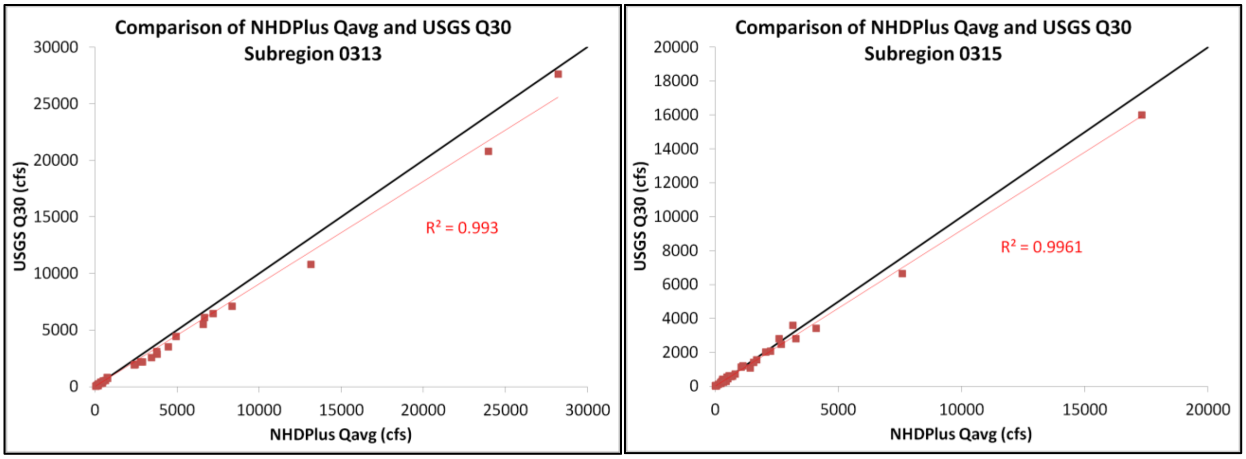

Figure 3-6 Relationship between $Q_{NHDPlus}$ and Q_{30} (ACT-ACF Subregions)

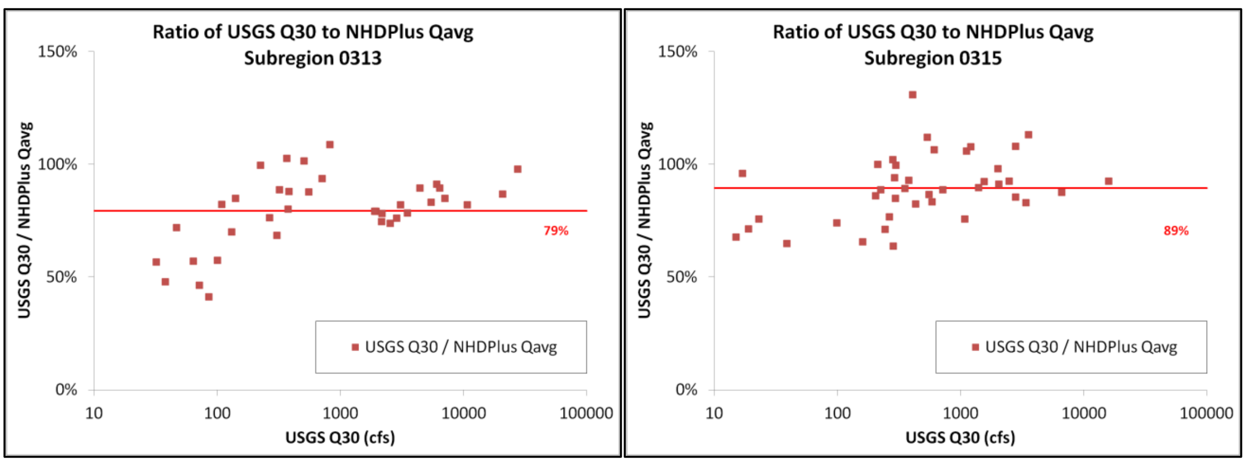

Figure 3-7 Illustration of the $Q_{30}/Q_{NHDPlus}$ Ratio

Although this approach can be applied consistently for all NSD sites, there are several possible sources of uncertainties, including the accuracy of $Q_{NHDPlus}$, availability and representation of the USGS NWIS gauges, and the reasonableness of a constant ratio model. Therefore, actual observations should be considered after the most potential NSD sites are chosen for further engineering consideration. The NSD assessment is targeted to conduct only a large–scale screening, which may assist the developer with considerations of suitable sites for clean and renewable hydropower development. It is important to note that, for any chosen site, detailed engineering design is still needed and is the sole responsibility of the private developer and investor.

3.2.4.2. Synthesization of Monthly Flow Time Series

In addition to NWIS, the USGS WaterWatch unit runoff (Brakebill et al., 2011) is used to synthesize monthly flow time series for the calculation of potential hydroelectricity energy (E_{NSD}) at ungauged location. Derived from NWIS gauge observation, WaterWatch runoff is the assimilated time series of flow per unit area calculated for each conterminous HUC08 Subbasin (an enhanced version of the traditional unit runoff maps). Runoff has a similar unit to precipitation (depth/time). Unlike gauge observation that reports streamflow discharge at a specific river location, runoff represents the streamflow availability for a region. Following the definition given by USGS WaterWatch, runoff is estimated by dividing the observed streamflow discharge by its corresponding drainage area. When computing runoff for watersheds of interest, all stream gauges that are located within its drainage basin are examined and the proper weighting factors are determined to compute a combined runoff. Given the abundant streamflow observations in the U.S. (over 22,000 gages), runoff can now be reasonably computed in the form of time series. The WaterWatch runoff is available in terms of monthly time series from 1901 until present, for each HUC08 Subbasin. An example is illustrated in Figure 3-8, in which the 1971-2008 monthly time series of WaterWatch runoff of the 28 HUC08s in ACT-ACF are shown.

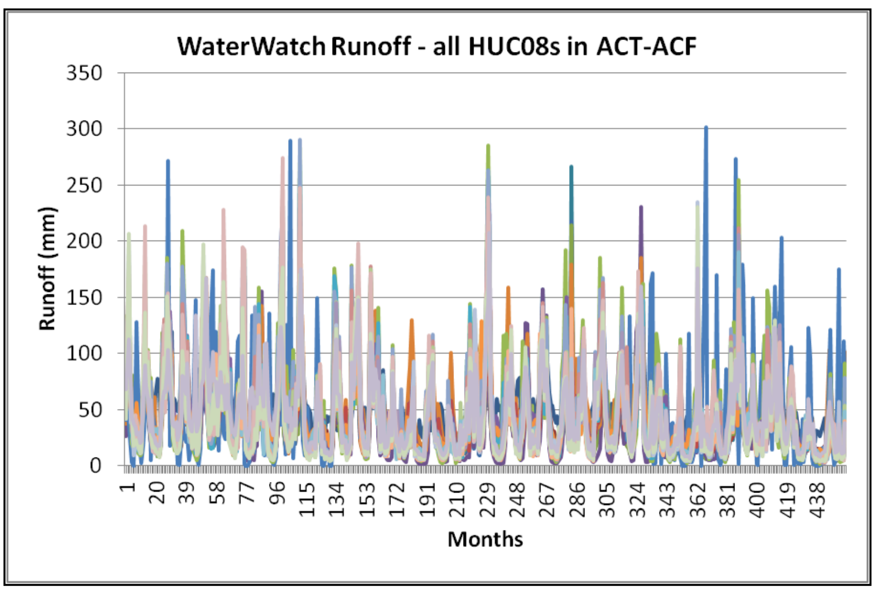

Figure 3-8 Illustration of the 1971-2008 WaterWatch Runoff Monthly Time Series

Since WaterWatch runoff represents flow per unit area, it can be utilized to synthesize monthly flow time series by multiplying runoff with the contributing drainage areas. For instance, if flowline X has a total drainage area (A_{total}), and there are three HUC08s contributing to X, including two complete upstream HUC08s, HUC_1 with area A_1 runoff R_1 and HUC_2 with area A_2

runoff R_2, and a local HUC_3 with area $A_3 = A_{total} - A_1 - A_2$ runoff R_3, the flow can be estimated by $A_1*R_1+A_2*R_2+A_3*R_3$. To automatically synthesize flow, each NHDPlus flowline is classified into different categories, HUC08 by HUC08. For instance, flowlines in HUC 03130008 can be classified into five different categories (Table 3-3). Category 1 represents the local streams, i.e., streams not contributed by any upstream HUC08. In 03130008, Category 3 streams covered flow from 03130005, 03130006, 03130007, 03130009, combined with Category 4 with flow from 03130010, results in Category 5 flow.

In each HUC08, Category 1 is the simplest case since the flow can be synthesized by multiplying the cumulative drainage area (a provided NHDPlus flowline attribute) directly with the corresponding WaterWatch Runoff. For Categories 2 and beyond, the cumulative drainage area of NHDPlus flowline is subtracted by all upstream HUC08s to identify the contributing drainage area from local HUC08. The areas are then multiplied by different corresponding WaterWatch Runoff to estimate flow. The travel time may need to be considered for streams with numerous upstream HUC08s (e.g., lower Mississippi River in HUC Region 08), but should not be an issue for a smaller Subregion like ACT-ACF. Although there are a large number of NHDPlus flowlines, the category assignment can be done relatively easy through the manipulation of cumulative drainage. For instance, the drainage areas of Category 1 flow will always be less than the minimum cumulative drainage areas from other categories.

Table 3-3 Example of Flowline Categories for WaterWatch Flow Synthesization

HUC 03130008	
Categories	**Upstream HUC08s**
1	None (local HUC08 rivers)
2	03130005, 03130006, 03130007
3	03130005, 03130006, 03130007, 03130009
4	03130010
5	03130005, 03130006, 03130007, 03130009, 03130010

In Figure 3-9, a comparison between NWIS gage 02337000 and the corresponding NHDPlus flowline (COMID: 3286256) is shown. This gage is randomly selected from ACT-ACF for verification. The 1989-2008 NWIS monthly observation is shown in black, while the synthesized WaterWatch streamflow time series is shown in blue. The red dash line shows Q_{30} derived from the NWIS gage 02337000 daily flow duration curve. Although there are some mismatch between the synthesized and observed flow, WaterWatch can satisfactorily capture the monthly fluctuation and magnitude of the observed flow. It is not a surprise, since WaterWatch runoff is derived from the local NWIS gage observation in the first place and, hence, such good performance can also be expected in other parts of the country. Given that the WaterWatch runoff has been provided for all HUC08 Subbasins in the conterminous U.S., this approach can be applied consistently for various ungauged locations.

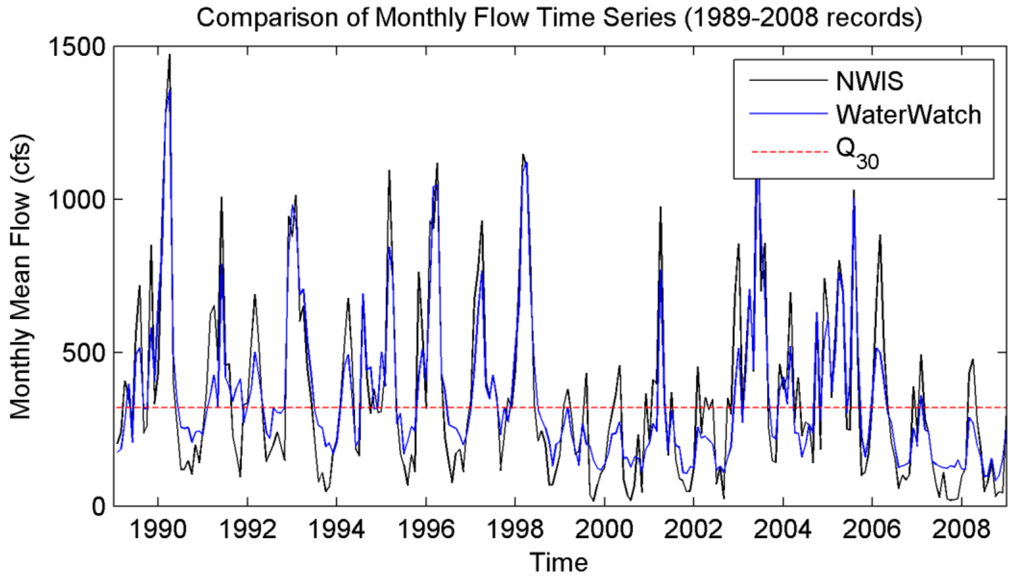

Figure 3-9 Comparison between NWIS and WaterWatch Monthly Flow Time Series

Although ideally, the hydroelectric energy should be calculated from fine resolution streamflow observation (i.e., hourly or sub-hourly), such information cannot be obtained consistently at ungauged locations. Therefore, the WaterWatch synthesized monthly time series is used as an alternative in the NSD assessment. In month m, let $Q_{WW,m}$ (cfs) be the synthesized WaterWatch streamflow and T_m (hour) be the total number of hours, extending from Eq. 3.7, Eq. 3.8 can be used as a simplification to calculate the potential energy production, $E_{NSD,m}$ (Watt * hour / month).

$$E_{NSD,m} = \begin{cases} c * \gamma * \eta * H_{ref} * (Q_{30} * T_m), & Q_{WW,m} > Q_{30} \\ c * \gamma * \eta * H_{ref} * (Q_{WW,m} * T_m), & 0 \leq Q_{WW,m} \leq Q_{30} \end{cases} \quad \text{(Eq. 3.8).}$$

By summing all $E_{NSD,m}$ from January 1989 to December 2008 and dividing by 20 years, the potential mean annual energy production, E_{NSD} (Watt * hour / year), can be estimated. The E_{NSD} will serve as the baseline estimate of energy, and can be improved in the future studies by increasing the resolution and accuracy of the streamflow time series.

3.2.5. Hydropower Location Identification

The discretized NHDPlus sub-segments are considered as possible locations for new hydropower development. To further identify areas of high energy intensity for evaluation, a search tool has been developed to optimize the choice. The objective is to search for stream-reaches that might be worthy of further consideration and which may result in smaller impacts to the local environment if developed. To generalize the concept into a quantifiable matrix useful for a search on the national level, it is suggested that a minimization of the inundation area created by NSD is appropriate since increased inundated areas tend to increase both the financial and environmental thresholds for new construction. Therefore, an objective variable, HQS, is defined as the product of H_{ref}, Q_{30} and channel slope (S_0). As discussed in Section 3.2.1, the product of H_{ref} and Q_{30} is proportional to power and energy so that the larger value is more desirable. Although the process is targeted to minimize inundation area, it is fairly computationally expensive to perform the complete topographical evaluation to delineate the estimated inundation for each location (will discuss in Section 3.2.6) and, hence, a simplification is made to maximize the channel slope (S_0) instead. This is based on the fact that higher channel slope has smaller inundation length. An example is shown in Figure 3-10. Starting from the NHDPlus flowline 6499098 in HUC 03150104 and moving upstream, the relationship between the cumulative river length (upstream), average slope (elevation difference divided by river length), and inundated surface area (calculated in Section 3.2.6) are compared. It is clear that the average slope is generally negatively correlated to inundation and, hence, the HQS objective can provide suitable simplification. Given that the inundation is more difficult to calculate, the full topographical assessment will be performed only on the selected NSD sites.

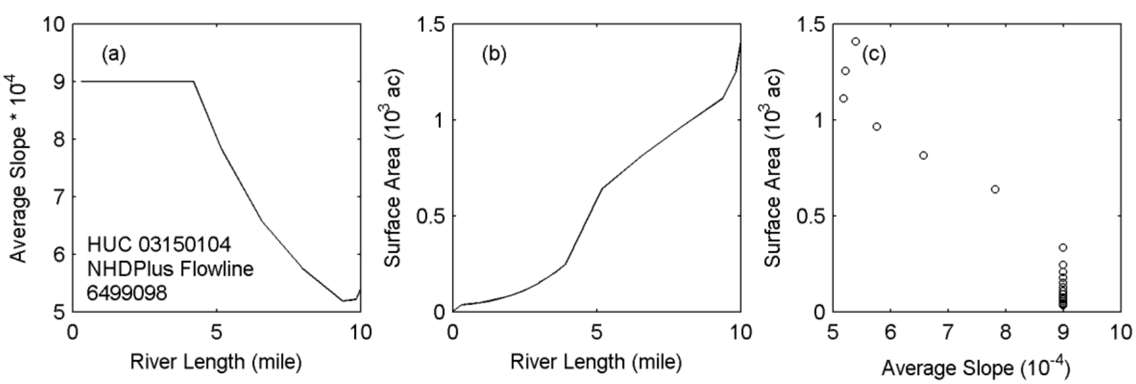

Figure 3-10 Relationship between River Length, Average Channel Slope and Surface Area

A search tool has been developed for site identification in C/C++ programming language and consists of the following steps. The search is design to identify potential NSD sites using the dam-toe powerhouse development model (i.e., all available head are provided by impoundment with no penstock extension). The penstock alternatives will be discussed separately in Section 3.2.7.

1. **Calculation of Virtual Reservoir Characteristics.** For each potential NSD site, the tailwater elevation (i.e., pre-development channel surface elevation) is approximated by the discretized NHDPlus flowline sub-segment elevations. Based on the reference head (H_{ref})

discussed in Section 3.3, the upper pool elevation is computed by adding H_{ref} on the tailwater elevation. The future powerhouse location is assumed to be immediately downstream of the dam, meaning that all head is provided by impoundment with no penstock extension. By tracing upstream along the stream network, the location where the upper pool intersects with the NHDPlus flowline is then identified to calculate the reservoir length and average channel slope (S_0). The calculation is performed for all potential NSD sites included in the SSP.

2. **Adjustment of Hydraulic Head.** If the upper pool intersects with any existing lakes and water bodies, the design hydraulic head needs to be lowered to ensure that the backwater of the NSD will not impact the existing dams. A buffer zone is set so that the upper NSD pool will not be closely adjacent to existing dams or water bodies. The virtual reservoir characteristics are updated (Step 1) for all NSD sites with adjusted H_{ref}. Furthermore, considering the state of technology of low-head hydropower generation, a minimum of 5 ft is required as the hydraulic head. The choice of a lower limit is supported by the statistics of existing hydropower dams, in which over 95% of the hydropower dams are greater than 5 ft. This additional condition is necessary, or otherwise multiple false sites may be identified along major rivers with extremely large discharges (e.g., Mississippi River). Any potential NSD sites with adjusted $H_{ref} < 5$ft are dropped out from the SSP without further analysis.

3. **Hydropower Location Identification.** The objective HQS is calculated for all potential NSD sites in the SSP. The NSD site with the highest HQS is then considered as the most suitable site. Given the usage of the conversion ratio to estimate Q_{30} based on $Q_{NHDPlus}$ (discussed in Section 3.2.4), the $Q_{NHDPlus}$ can also be used directly for site identification so it is more flexible in conducting the NSD assessment in parallel tasks. The identified location is then moved from SSP to the NSDP. All sub-segments that will be inundated by the identified NSDP will be removed from the SSP. Steps 1 and 2 will then be repeated until all potential sites with minimum 1 MW P_{NSD} are identified and included in the NSDP.

The output from the search tool is a complete list of potential NSD areas for new hydropower development. An illustration of schematic is shown in Figure 3-11. While the HQS is utilized in this study to identify NSD sites, there could be other suitable objective functions with different focuses (e.g., minimizing cross-sectional area or construction cost) and hydro types (e.g., run-of-river, storage, or pumped-storage). An extended research topic may be scoped in the future to identify the best merit matrix for the purpose of NSD evaluation with enhanced spatial accuracy.

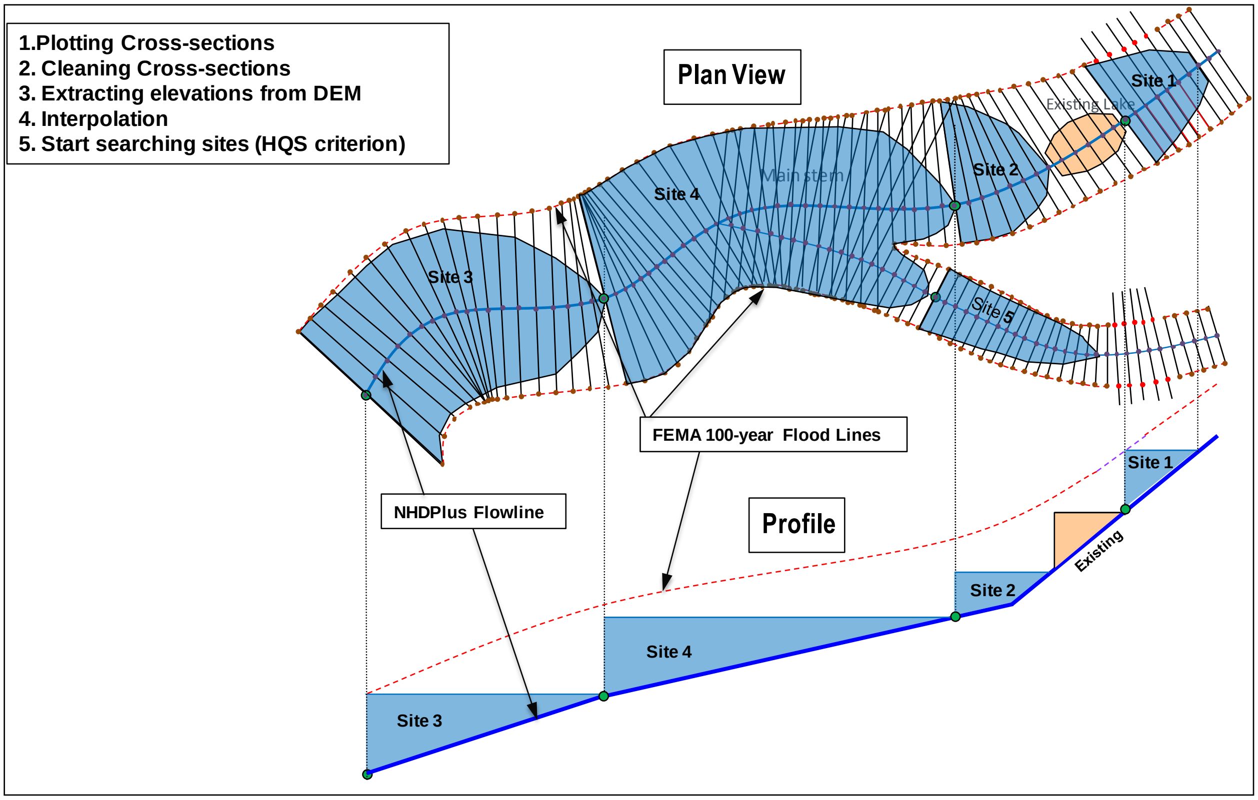

Figure 3-11 Illustration of Site Identification

3.2.6. Calculation of Storage and Inundated Surface Area

Once a potential site and a targeted dam height (H_{ref}) have been suggested, it is used to delineate those upstream regions that may be inundated due to the construction of new hydropower projects. By overlaying the possible inundated area with existing land use, ownership, properties, residency, vegetation and fish population (through the environmental attribution effort), the environmental feasibility and cost benefit can then be evaluated. The total reservoir storage and residence time (storage divided by mean annual flow) can also be estimated based on the inundated surface area. Both storage and residence time are essential site characteristics used to understand how flexible a hydropower plant may operate under natural hydrologic variability. For instance, if two NSD sites have the same storage, the one with shorter residence time (e.g., hours) will be easier to drain compared to the one with higher residence time (e.g., days). The residence time may hint at the potential for a NSD site to provide ancillary services and flexibility to the electric grid. Residence time can also provide some relative indication of possible future water quality issues.

Although the inundated surface area can be delineated directly from contour lines from topography maps, such a procedure is usually time-consuming and cannot be automated. Given the need to evaluate the large amount of river nation-wide, a Matlab-based inundation delineator has been developed for this assessment. Taking the 10-meter NED and NHDPlus flowlines as major inputs, this delineator can be used to identify inundated surface area corresponding to given coordinates and hydraulic height (H_{ref}), and output regions as ESRI ArcGIS Polygon Shapefiles with several computed attributes including inundated surface area (A_{NSD}), reservoir storage (V_{NSD}) and residence time (T_{NSD}). This Matlab-based inundation delineator can perform more efficiently than the common GIS software packages and can better facilitate the NSD assessment need. This section describes the major steps behind this topographical assessment.

3.2.6.1.Data Preprocessing

Instead of delineating inundated areas from contour lines on topography maps, the high-resolution digital elevation dataset is used to provide consistent national elevation data. Given that the 10-meter NED can be obtained consistently throughout the conterminous U.S., it is chosen in the current development. We note that the 3-meter NED is also available, but only for limited areas and, hence, is not preferred due to the emphasis of national consistency. The 10-meter resolution NED provided by the USGS is organized as multiples 1° by 1° tiles, for which there are more than 900 over the conterminous U.S., with total data storage greater than 300 GB (binary raster format). The tiles are further converted to NetCDF formats following the same tiling structure for computational need.

The existing river geometries and annual mean flow estimate are taken from the NHDPlus flowlines, in which only those flowlines with annual mean flow, $Q_{NHDPlus}$, greater than 35 cfs are considered. To increase the computational efficiency, the NHDPlus flowlines are also converted to the same format as NED. Although it significantly raises data storage, it is considered as a necessary trade-off to increase the computational efficiency.

3.2.6.2.Identification of Flow Direction and Upstream Region

By comparing the grid elevation to the eight neighboring cells (N, NE, E, SE, S, SW, W, and NW), the flow direction can be estimated at each grid. To avoid the influence of local depression, the standard “fill sink” procedure is performed prior to the estimation of flow duration grids (i.e., raising the elevation at local depression until all grid-based flow can move outward). All upstream grids corresponding to the NSD site can then be identified. All of these functions are available in standard GIS software (e.g., ESRI ArcGIS), but are usually not computationally efficient and hard to customize. Therefore, they are not considered to be feasible for use for the national-scale NSD study.

Theoretically, after simulating how surface water may flow along each grid cell, the river channel can be determined from NED and it should match with the known channel geometries (for instance, NHDPlus flowlines). Nevertheless, given the uncertainty of digital elevation and inconsistency between NED and NHDPlus, the pure NED-derived river segments may be different, especially at flat regions. To avoid this issue, the "burn in" process is followed, as used in the NHDPlus development, to ensure that the NED-derived flowlines will be consistent with NHDPlus. The idea of river "burn in" is to lower the NED elevation largely at the location of known NHDPlus flowlines, so that the NED-derived flowlines will follow exactly with NHDPlus. This "burn in" process does not affect the validity of the estimates since, after deriving the flow duration grids, the original elevation is then recovered to compute other desired site characteristics (e.g., storage).

3.2.6.3.Delineation of Inundated Surface Area

The concept of delineation of inundated surface area is shown in Figure 3-12. The NSD elevation is treated as the bottom elevation (z_0) of the new reservoir. By assigning a virtual dam height (H_{ref}), all upstream grids with elevation (z) less than z_0+H_{ref} are labeled as regions that may be inundated due to the new dam construction. The total surface area of all labeled grid cells is then computed as A_{NSD} (acre). Given the influence of local depression, some isolated upstream smaller regions may also be found during this procedure. Because of the need to quantify the possible inundation due to new dam construction, only those inundated grids connected to the potential NSD site are considered. The results are output as GIS shapefiles (illustrated in Figure 3-13), so that they can be easily utilized by the following environmental attribution effort.

In the current assessment, upstream grids were labeled as being lower than z_0+H_{ref}. However, due to the backwater effect (i.e., the gradual varied flow assumption), the upstream river profiles will be further pushed up and may result in larger inundation. An in-depth hydraulic computation can be conducted to characterize the backlogged river profile, but the procedure is very costly for multiple sites and may not be beneficial for a national-scale assessment of new hydropower opportunities. When focusing on fewer sites, the delineator can be customized to incorporate some standard hydraulic tools (e.g., HEC-RAS) to delineate the inundated surface area more precisely.

3.2.6.4.Estimation of Reservoir Storage and Residence Time

Similar to the calculation of A_{NSD}, the reservoir storage (V_{NSD}) of potential new hydro sites can be estimated by summing the total volume of inundation of all labeled upstream regions. From

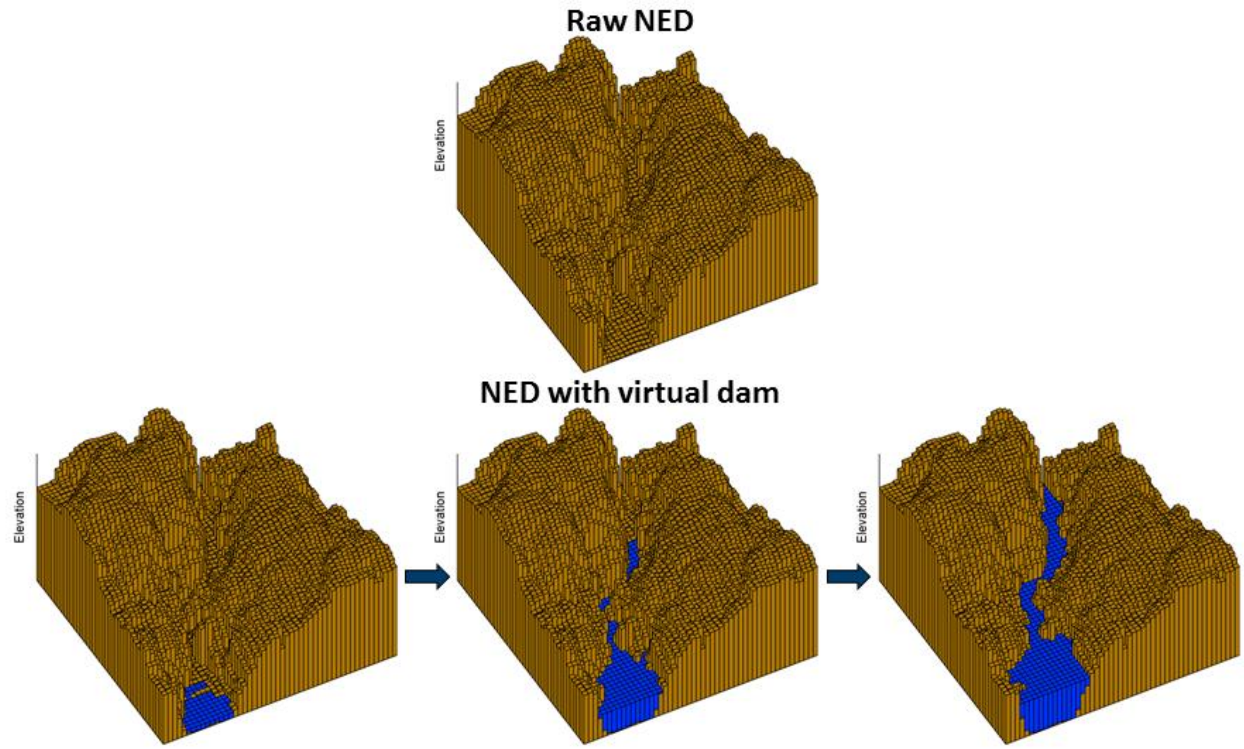

Figure 3-12 Illustration of Delineation of Inundated Surface Area

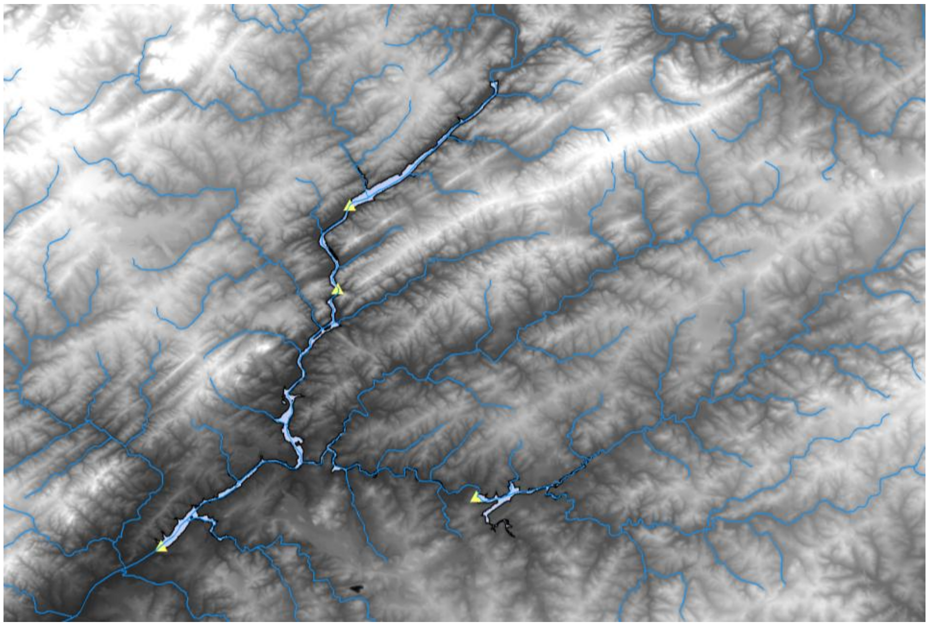

Figure 3-13 Example of the shapefile with computed inundation polygons.

V_{NSD} (acre * ft) and the mean annual flow, $Q_{NHDPlus}$, (cfs), the residence time, T_{NSD}, (day) is estimated by:

$$T_{NSD} = \mathrm{d} * V_{NSD}/Q_{NHDPlus} \quad \text{(Eq. 3.9)},$$

in which d = 0.504 is the unit conversion factor. The residence time (T_{NSD}) can offer an intuitive interpretation of the possible future operation. For instance, if T_{NSD} equals 1 day, it means that it may take approximately one day to fully deplete the storage for hydropower generation (with the assumptions of no inflow and constant mean natural outflow [$Q_{NHDPlus}$]). As stated, given the usage of H_{ref}, the residence time (T_{NSD}) is found to be small at most of the NSD sites (less than 2 to 3 days). It is very different than the much larger reservoirs like Lake Mead and Hoover Dam (with residence time greater than years).

Furthermore, by gradually raising the virtual dam height, the inundated surface area, storage and residence time can be expressed as functions of dam height for each NSD site (illustrated in Figure 3-14) to facilitate the choice of other possible hydraulic heads. The figures will be constructed at each NSD site and will be available for the interested users. Currently, it takes around 5 minutes to complete the full topographical assessment of a NSD site and, hence, this step occurs after site identification instead of the opposite.

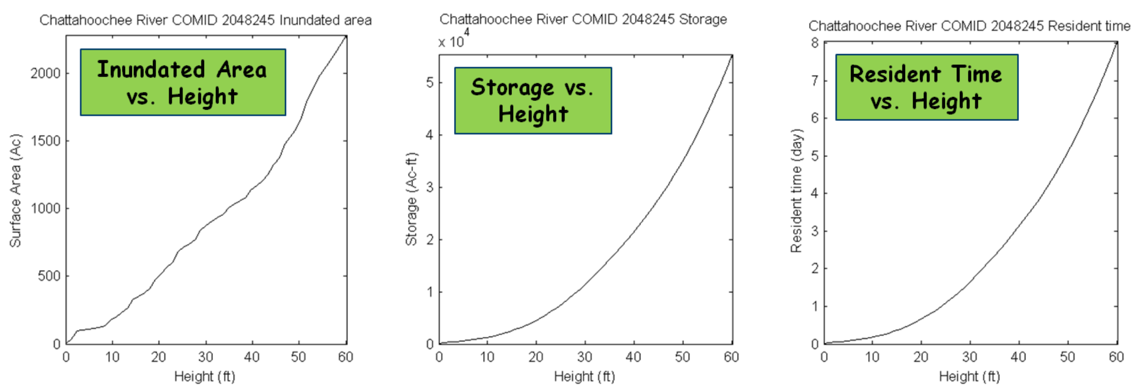

Figure 3-14 Illustration of Delineation of Inundated Surface Area

3.2.7. Diversion Alternative

3.2.7.1.Flow-diversion Model

While the aforementioned analysis focuses on the reservoir-impoundment model (in which the location of a potential power house is assumed to be immediately downstream of a dam with all available head resulting from the impoundment), other alternative power development models exist. One common choice is a flow-diversion model, which uses penstocks/conduits to divert water from an upstream intake point to a downstream powerhouse and then return flows back to streams. The penstocks can be located adjacent or parallel to the river channel or across watershed boundaries to nearby watersheds to achieve a higher head drop. The flow-diversion model does not require a dam higher than the reservoir-impoundment model and, hence, may result in a smaller surface inundation. Nevertheless, since only a portion of water can be diverted through conduits (i.e., sufficient streamflow is needed in the original river channel to sustain the existing ecology and environment), the amount of available energy is generally less than the correspondingly reservoir-impoundment model with a similar head (though specific examples to the contrary do exist).

The basis for site selection for the flow-diversion model is similar to that of a reservoir-impoundment model, but with the differences being associated with the systems' downstream location. For example, a site with a much smaller flow may be viable for profitable hydropower generation, as long as a suitable nearby location with a high head drop can be identified – even if it is located in a different watershed. The current NSD methodology does not presently account for downstream site possibilities located across watershed boundaries. Hence, it would be useful to utilize an alternate site searching criteria that incorporates aspects of the reservoir-impoundment and flow-diversion models and accounts for inter-watershed analysis.

In addition, given the longer piping associated with flow-diversion systems, the friction losses will become a controlling factor for design, which is jointly influenced by the flow velocity, diameter, length, and conduit material. The design of conduits (location, diameter, number of conduits, material, length, intake structure, etc.) is very site-specific and particular design requirements would ideally need to be based on a detailed cost and feasibility study. Given the limitations of resources and time, the siting for the flow-diversion model is based on the existing NSD evaluation methodology and is suitable for identifying power available using flow-diversion analysis. In addition, the flow-diversion analysis is adequate for making rough assessments and comparing relative design characteristics for each of the sites.

The results of the existing NSD evaluation methodology outlined in this report (Section 3.2.5) serve as the basis for evaluating areas for possible flow-diversion developments. The adjusted head, power, and other related preliminary penstock characteristics will be provided as alternative and complementing information. The length and elevation head for a pipe situated along a river reach is assumed to be equal to the previously computed reservoir inundation length and elevation head for a new dam. In other words, the powerhouse is assumed to be the same location (immediately downstream of the dam otherwise constructed in the dammed development model), and the upstream intake is located on the upper end of the reservoir with penstocks placed along the main channel. The sizing and number of penstock pipes, along with the available power potential, could thus be generally estimated for each NSD site. The associated energy balance relationship for the elevation heads and head losses associated with the penstock is:

$$z_1 - z_2 = h_f + h_T \qquad \text{(Eq. 3.10)},$$

where z_1 is the headwater elevation (ft) of the pipe, z_2 is the tailwater elevation (ft) of the pipe, $z_1 - z_2 = H_{ref}$ is the gross head (ft) of the system, h_f is the head loss (ft) attributable to pipe friction, and h_T is the head input to the turbines for hydropower generation.

The derivation of the energy expression assumes that the pressure and velocity heads at each end of the pathline, along which water travels from upstream at the pipe to its exit downstream, are equivalent, resulting in the simplified Eq. 3.10. In addition, minor losses associated with entrances, exits, and bends in the pipe are neglected as they represent just a fraction of the more significant head losses presented here, not to mention, they are impossible to determine at this stage as they are very specific to the design of the penstock.

The head loss (h_f) due to pipe friction can be estimated by the Darcy-Weisbach equation (Morris and Wiggert, 1972):

$$h_f = f \times \frac{L}{D} \times \frac{V^2}{2g} \qquad \text{(Eq. 3.11).}$$

where f is the friction factor (function of ε/D and Reynolds number), ε is the roughness height (ft), L is the penstock length (ft), D is the penstock diameter (ft), V is the average velocity (ft/s), and g = 32.2 ft/sec^2 is the gravitational constant. Therefore, the head available to the turbine (h_T) for energy production is dependent on the gross head less the friction head in the system. For the reservoir-impoundment model, L is zero and, hence, the friction loss can be neglected.

3.2.7.2.Diversion Option Assumptions

Determining an appropriate penstock system involves an optimum balance between pipe size and quantity, costs, and head pressure available for energy production. Maximizing energy production requires minimizing the head loss due to friction within the constraints of pipe size and costs. Using larger sized pipes reduces friction losses in the system, but is also more costly due to size and installation costs. Using smaller sized pipes are less costly, but potential energy production is sacrificed as a result of the increased frictional head loss. Each design and installation of a penstock system is unique according to site-specific conditions and to the level of acceptable financial tradeoffs for possible generation gain. As a result, it is difficult to assess an optimum scenario for all sites. Therefore, for purposes of this assessment, the following assumptions are established so that relative assessments and consistent comparisons can be made among the study sites:

1. An acceptable head loss attributable to friction is fixed as 13% of the total head loss.
2. Maximum pipe sizes are limited to 10 ft in diameter.

3. Multiple pipes are used for any case that requires pipe sizes in excess of 10 ft in diameter.
4. A roughness height, $\varepsilon = 0.0165$ ft, corresponding to riveted steel is used.
5. Entrance and exit losses, in addition to minor losses associated with pipe bends, are neglected.
6. The potential power available to a turbine does not include any mechanical or electrical production and transmission losses.
7. The length and elevation head for a pipe situated along a river reach is assumed to be equal to the previously computed reservoir inundation length and elevation head for a new dam at the site.

The aforementioned assumptions are necessary to establish a basis for site comparison. Since assessing system costs is outside the scope of this work, specific tradeoffs between system component design and available head for turbine power production is not investigated. Likewise, the *optimum* design for a penstock, in terms of pipe size and system head losses affecting power delivery to a turbine, is not determined. Instead, the system variables are fixed at typical values and used to establish a framework for which the power potential at all sites can be compared consistently and transparently relative to one another. In this fashion, the investigation results yield more of an insight to the relative comparison of site power production as opposed to the absolute. This is useful in determining the “hotspots” for potential power production using a diversion option. Nevertheless, the results determined herein are not unreasonable as potential estimates for power production using the diversion option.

For purposes of roughly assessing the relative differences between sites and their potential power and to be able to make quantative comparisons, some of the parameters are fixed in the analysis. The frictional losses are assumed to be 13% of the total head loss and stems from a “rule of thumb” recommendation that states that a pipe should be sized such that no more than 10% to 15% of the gross (total) head is lost as pipeline friction (Canyon Hydro, 2012). In addition, a commonly used maximum pipe diameter of 10 ft is used as the demarcation point at which additional quantities of pipe are used to convey the flow. From this, the number of pipes required can be used as a filter to roughly determine site feasibility. Further refinement of pipe sizes and number can be made for filtered sites as well.

Various combinations of the quantity and sizing of pipes associated with a conveyance system is possible for a particular site’s characteristics of head and flow. Since an economic analysis for the appropriate piping system design is not within the scope of this study, the focus here is to provide a means to easily and consistently compare the relative magnitude of differences associated with general penstock design requirements for each of the sites’ potential to produce power from diversion flow.

3.2.7.3.Diversion Option Methodology

The methodology associated with determining general penstock piping parameters, along with the corresponding power potential, is based on determining the friction factor (*f*) in Eq. 3.11 so that the head loss due to friction (h_f) in Eq. 3.10 can be used to solve for the head available to the turbine (h_T), from which the power is calculated. The friction factor (*f*) for turbulent flows is related to the physical characteristics of the pipe that include the roughness height of the pipe material (ε) and the diameter (D). The friction factor also depends on the pipe flow, which is used to determine the velocity and, hence, the Reynolds number (Re) of the flow. These parameters are related to the friction factor according to the following Colebrook equation (Sturm, 2001):

$$\frac{1}{\sqrt{f}} = -2.0\, log \left[\frac{\frac{\varepsilon}{D}}{3.7} + \frac{2.51}{Re\sqrt{f}} \right] \qquad \text{(Eq. 3.12),}$$

Where, Re is the Reynolds Number. The solution to this equation for the friction factor requires an iterative method. Based on the fixed values for the pipe diameter, roughness height (material), and given flow, Eq. 3.12 is solved for the friction factor (*f*).

If the diameter of the pipe that satisfies Eq. 3.12 is greater than the specified maximum of 10 ft, then the flow is divided among two or more pipes. An iterative method is used with an increasing number of pipes with the total flow divided evenly among the pipes until Eq. 3.12 is satisfied. Using the friction factor, the corresponding head loss due to friction is determined and the head available to the turbine is defined as :

$$H_{ref} - h_f = h_T = H_{eff} \qquad \text{(Eq. 3.13).}$$

From Eq. 3.13, the head available to the turbine is the gross head in the system (H_{ref} in this NSD assessment) reduced by the head attributed to the friction in the pipe, also referred here as the effective head (H_{eff}). The adjusted head (H_{eff}) can then be applied in Eq. 3.7 to calculate the adjusted power under the flow-diversion assumption.

This calculation of the power available by the system to a turbine does not include a loss to the system due to mechanical, electrical, and transmission losses. These losses would have to be considered to obtain the actual power produced by the turbine and available to the electrical grid.

3.3. Example of Results

The NSD assessment starts from two selected pilot Subregions, ACT (HUC 0315) and ACF (HUC 0313), both in the South Atlantic Gulf Region (HUC 03). The area spans across Alabama, Florida, Georgia and Tennessee (small portion), and covers the Atlanta metropolitan area. Although this area was not conventionally emphasized for hydropower development, given the high precipitation and slope gradient (from the Great Smoky Mountain to the Gulf of Mexico), it is expected that abundant new hydropower potential may be identified through more detailed examination. An illustration of several major geospatial datasets is shown in Figure 3-15, including the existing powered and NPDs, USGS gauge stations, NHDPlus flowlines and water bodies. Overall, there are over 63,600 NHDPlus stream segments and 9,100 water bodies in the ACT-ACF study area.

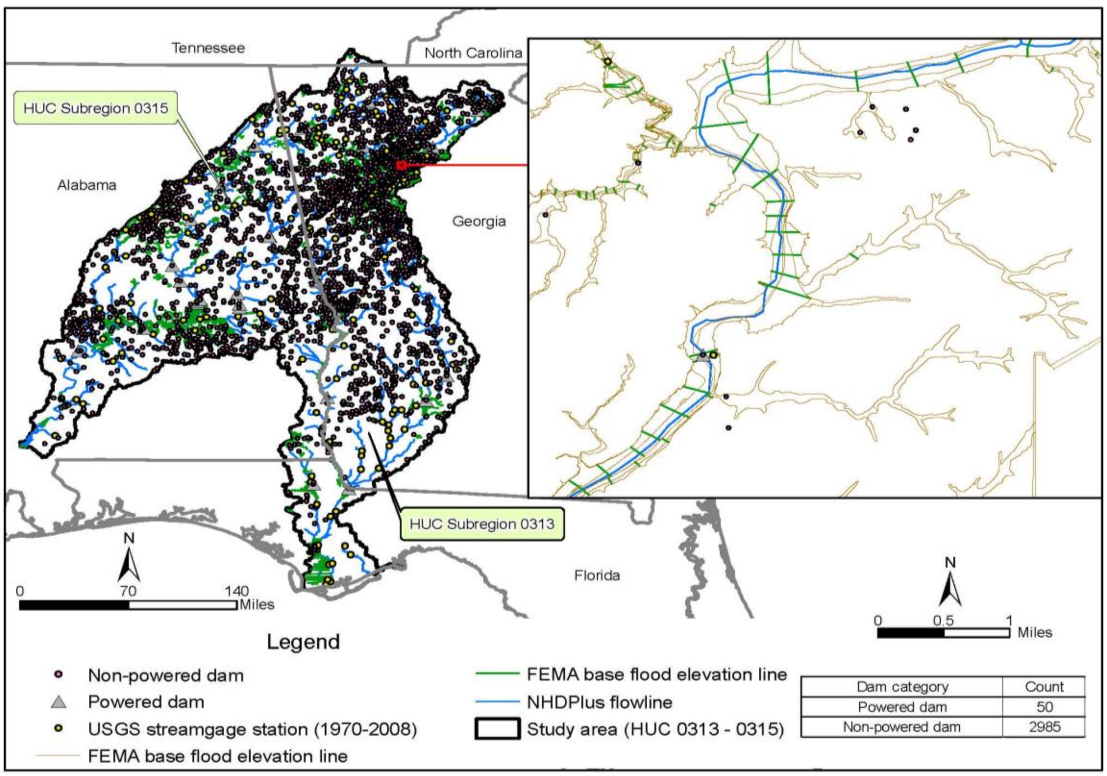

Figure 3-15 Example of Geospatial Data used in the ACT-ACF Pilot Study

Following the NSD methodology, around 100 potential areas for development are identified in ACF and ACT. The summary statistics of hydraulic head H_{ref} (ft), design flow Q_{30} (cfs), installed capacity P_{NSD} (MW), inundated area A_{NSD} (ac), storage V_{NSD} (ac-ft), and residence time T_{NSD} (day) are shown as an example in Figure 3-16. The hydraulic head (H_{ref}) ranges from 7–21 ft with median as 19 ft, suggesting that most of the potential ACF sites will require low-head hydropower technologies. The design flow (Q_{30}) ranges from 800–20,000 cfs with median as

2,500 cfs, skewed to the lower flow side. The installed capacity (P_{NSD}) ranges from 1–30 MW with median as 3 MW. As expected, the 100-year flood elevation approach results in smaller inundated surface area (A_{NSD} ranging from 4–18,000 acre with median as 360 acre). It also results in smaller storage (V_{NSD} ranging from 20–145,000 acre-ft with median as 2,300 acre-ft) and very short residence time (T_{NSD} ranging from less than 1 day to 13 days with median as 0.4 day).

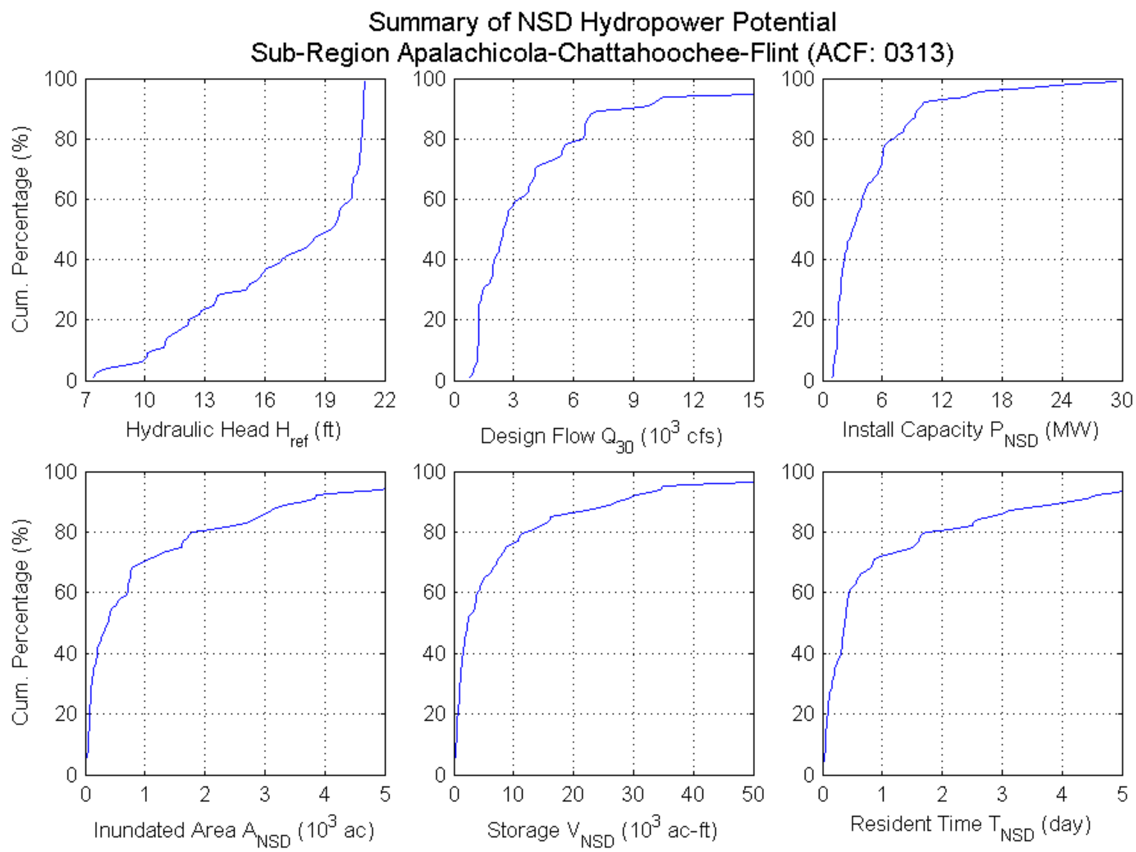

Figure 3-16 Hydraulic Head and Capacity Distribution in ACF (HUC04: 0313)

The summary statistics of ACT sites are shown in Figure 3-17. The hydraulic head ($H_{ref)}$ ranges from 11–42 ft with median as 23 ft, slightly higher than ACF, but still require low-head applications. The design flow (Q_{30}) ranges from 400–31,000 cfs with median as 1,800 cfs, generally drier than ACF. The install capacity (P_{NSD}) ranges from 1–32 MW with median as 3 MW, very close to the ACF results. Similarly, both inundated surface area (A_{NSD} ranging from 15–32,000 acre with median as 580 acre) and storage (V_{NSD} ranging from 240–453,000 acre-ft with median as 5,600 acre-ft) are small, but slightly larger than ACF, possibly due to the higher hydraulic head. The residence time (T_{NSD}) ranges from less than 1 day to 33 days with median as 1.4 day, again suggesting that these NSD sites have limited storage so the NSD assumptions should be reasonable.

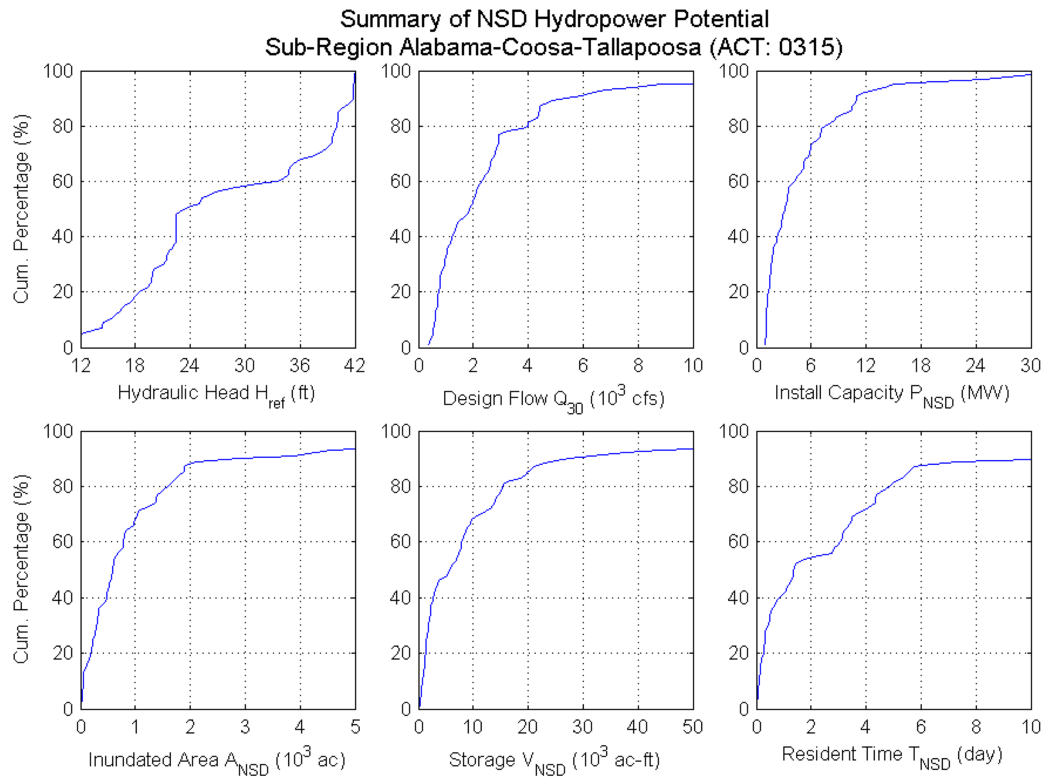

Figure 3-17 Hydraulic Head and Capacity Distribution in ACT (HUC04: 0315)

It should again be emphasized that the methodology described herein considers only the physical characteristics and does not consider feasibility issues arising from environmental impacts, cost, or benefits. In addition, these potential sites are subject to more detailed site-by-site quality control so adjustment is expected in the final report. The proposed methodology is focused specifically on small hydro sites (i.e., lower head and smaller storage). When targeting higher head or larger storage sites, the methodology and assumptions will need to be adjusted for re-assessment.

4. ENVIRONMENTAL ATTRIBUTION

The definition of environmental issues in any landscape (or riverscape) planning process can be subjective and susceptible to value-laden terms and opinion. The term "environment" can refer to natural ecological systems, social and cultural settings, policies and management, legal transactions, and computation/statistical procedures. Using "environment" as a descriptor is a loose term, complicated by undefined scales of association and poorly demarcated interactions. For example, environment can refer to all entities that could possibly interact in infinite space and time; whereas, the same term could refer to a subset of physico-chemical and biological factors that affect an organism within a defined area.

In this report, environmental issues are considered as ecological, socio-economic, and legal/geopolitical concerns that may arise with regard to potential hydropower development. All of these elements are considered environmental because they share substantial overlap with regard to landscape planning decisions and are difficult to tear apart. For example, a federally listed plant species may occupy lands within the vicinity of a potential hydropower site. The ecological needs associated with this organism are intertwined with legal ramifications (e.g., Endangered Species Act 1973) and the jurisdictional boundary where the organism was found (e.g., U.S. Forest Service). The environment is also considered as a defined-area surrounding each potential hydropower site, the size of which depends upon the particular issue under consideration.

A four-step process was used to discern the ecological, socio-economic, and legal/geopolitical attributes of interest for each potential area of new hydropower development. 1) Hypothesis generation was used to compile a comprehensive list of potential environmental issues and information required to evaluate each issue. 2) Spatial and tabular datasets were gathered using internet sources, the availability of needed information was assessed and, based on data availability, a prioritized list of data sets was generated. 3) Some datasets were not in a format or scale applicable to this analysis, or lacked additional relevant information. Thus, derived datasets were created at similar spatial scales using geospatial processing and tabular data summarization. 4) All spatial datasets were used to attribute each area identified by the process described in Chapter 3 with environmental information in a tabular format.

4.1. Data Sources

Assessing potential environmental issues related to hydropower development requires compiling information on natural resources, geopolitical boundaries, existing infrastructure, and cultural/aesthetic/recreational needs. Prior to gathering any information, potential impediments to new hydropower development (including possible environmental, geopolitical, and socio-economic concerns), were identified via group meetings and brief document reviews. Environmental Impact Statement (EIS) reports and FERC license approval articles were inspected to identify potential issues. Once a sufficient list of issues was generated, the various types of information required to characterize and analyze each were produced. Information was preferred at the scale of the entire country or conterminous United States. Internet searches were conducted through USGS, NatureServe, National Fish Habitat Action Plan (NFHAP), U.S. Census Bureau, USACE NID, U.S. Fish and Wildlife, Geology.com, EPA, National Wild and Scenic Rivers, National Atlas, and other webpages, including Google® searches. Potential issues to be characterized and attributed were finalized on the basis of information priority level and availability.

Because most sources of information are not confined to a specific spatial coverage (e.g., land ownership), environmental attribution can be provided at spatial scales congruent with prospective hydropower development areas (e.g., site-level, NHD scale). However, the finest resolution of water use and fish distributions is the HUC08 Subbasin; thus, all potential development areas within the same HUC08 would share similar attribution for these variables. Table 4-1 summarizes the major environmental data sources used in this section.

4.1.1. Watershed Boundary Dataset

See description in Section 3.1.1.

4.1.2. NatureServe Digital Distribution Maps of Freshwater Fishes of the United States

The NatureServe dataset contains current and historical distributions by HUC08 Subbasins of all native freshwater fishes of the United States (excluding Alaska and Hawaii) (NatureServe, 2010). The distribution maps were created to inform land-use decision-making, prioritize conservation actions, and protect freshwater biodiversity. The maps were created using an older version of the HUC (HUC 250-k) than the current WBD. Within the HUC 250-k version, there are 2,064 8-digit watersheds, compared to 2,295 in the WBD version.

Fish distribution maps were developed for 865 freshwater species from two main source types. Point locations of occurrence data were assembled from state natural heritage programs for 307 imperiled fish species and used to map distributions across 8-digit HUC boundaries. To supplement location data and provide distributions for the remaining species, “Fishes of” books from states (e.g., Fishes of Tennessee, Etnier and Starnes 1993) and scientific literature were used to compile current and historical locations. Maps were reviewed by regional and state

Table 4-1 Summary of Data Sources used in the Environmental Attribution

Data Type	Data Source	Note
Watershed Boundary	• Watershed Boundary Dataset (WBD), NRCS	Summarization scale for coarse resolution data.
Fish Species Digital Distribution	• NatureServe Digital Distribution Maps of Freshwater Fishes of the United States	Spatially summarize federally listed fish species and traits
Federally Listed Species (ESA)	• U.S. Fish and Wildlife Service Endangered Species Program	Species lists provide types of organisms and listed status
Federal and International Union for the Conservation of Nature (IUCN) Ranking Status for Fish	• NatureServe Explorer Species Data	Lists provide an indication of fish imperilment and vulnerability
Critical Habitats	• U.S. Fish and Wildlife Service Critical Habitat Portal	Polygon and polyline coverage of federally listed species
Conservation Lands	• USGS GAP Analysis – Protected Area Database of the U.S.	Geopolitical boundaries (National Parks, State Parks, Historic Landmarks)
County Boundaries	• U.S. Census Bureau	U.S. county boundaries and population estimates
Water Use	• USGS Water Use in the United States	Provide estimates of total consumptive usage in various categories
Water Quality (303d Listings)	• U.S. EPA Impaired Waters and Total Maximum Daily Load	Locations and listings of state 303d listings
Disturbance, Infrastructure, and Land Use	• National Fish Habitat Action Plan	Population density, number of dams, mining activity, land use (% urban, percent agriculture), etc.
Fishing and Boat Ramp Access	• DeLorme Publishing Company	Point locations of fishing and boat ramp access points
Kayak/Raft Access	• American Whitewater, National Whitewater Inventory	Locations of boat launch/take out points for whitewater boating
Waterfalls	• Geology.com U.S Waterfalls	Point locations of each state's waterfalls

experts. Despite the extensive effort in providing data as accurate as possible, caution is urged when using the NatureServe dataset as an absolute authority defining a fish species' presence and absence. For example, the presence of a particular fish species may be representative of only a sampled subset of waterbodies rather than the entire drainage network within each HUC boundary. Furthermore, the elemental data used to construct the NatureServe dataset is based on sampling conducted decades earlier and may not include the most recent distribution information. Thus, the NatureServe dataset does not provide an absolute presence or absence of a species. Rather, the data provides a potential for a species to be present. The freshwater species' distributions compiled provided the spatial framework to map federally listed fish species, vulnerable/imperiled fish species, and fish traits potentially affected by hydropower.

4.1.3. Federally Listed Species

The Endangered Species Act (ESA) is implemented by the U.S. Fish and Wildlife Service (USFWS) and the U.S. National Oceanic and Atmospheric Administration (NOAA) Fisheries Service. The law requires federal agencies, in consultation with the USFWS and NOAA Fisheries Service, "to ensure that actions they authorize, fund, or carry out are not likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of designated critical habitat of such species." The law also prohibits any action that causes a "taking" of any listed species of endangered fish or wildlife.

Lists of species within various taxonomic groups (vertebrates, invertebrates, non-flowering plants, and flowering plants) were compiled from the USFWS Endangered Species Program website for U.S. species (USFWS, 2012a). Species lists provided common/scientific names, the agency (USFWS or NOAA Fisheries Service) and USFWS region responsible for listing, the range in which the species is listed, and listed status (endangered, threatened, species of concern, and recovery). Lists were used to provide information to organize maps of critical habitats and inform maps of federally listed fish species.

4.1.4. ESA Listing Status and International Union for the Conservation of Nature Ranking for Fish

Although the ESA provides a listing of endangered species, the vulnerability of organisms to habitat modification may not be fully captured by federal listing alone. IUCN developed a 9-tiered ranking status based on evidence of extinction, population changes within the last 10 years (or 3 generations), the extent of an organism's geographical range, the occupancy within that range, population size, and the availability of data. Only the ranking status of extant fish was considered. IUCN ranks include critically endangered, endangered, vulnerable, near threatened, least concern, data deficient, and not evaluated. Critically endangered organisms are considered to be at high risk of extinction, with decreasing extinction risks from rankings at endangered to least concern. Thresholds for each category are provided in the IUCN Red List Categories and Criteria (IUCN, 2001).

The federal listing and IUCN ranking status was accessed for all freshwater fish species in the United States using NatureServe explorer. NatureServe listing and ranks were used because common and scientific names for less common and undescribed species were similar to those documented in the maps of fish distributions. Undescribed species are species that have been discovered as separate species from the existing phylogenetic clades, but not formally described and named. Lists were used in coordination with fish distribution maps to summarize numbers of listed/ranked fish species, per HUC08 Subbasin.

4.1.5. Critical Habitats

Critical habitats are areas considered essential for the conservation of a listed species (USFWS, 2012b). Special protections and/or restrictions are possible within areas designated as critical habitats. The ESA defines critical habitat for listed species as: "(i) the specific areas within the geographical area occupied by the {listed} species… on which are found those physical or biological features (I) essential to the conservation of the species and (II) which may require special management considerations or protection; and (ii) specific areas outside the geographical area occupied by the {listed} species …upon a determination by the Secretary that such areas are essential for the conservation of the species."

Critical habitat data layers, available as digital lines and polygons, are provided for federally listed species (endangered or threatened only) in which critical habitats have been designated, meaning not all federally listed species are represented (USFWS, 2012b). Lines typically represent stream bodies as critical habitat for fish and clams; whereas, polygons may represent critical habitats for all taxonomic groups. The data layers provide common and scientific names that can be linked to lists of federally listed species to organize species by status and taxonomic group.

4.1.6. Land Ownership and Land Conservation Status

Landscape development and planning requires details on the owner or custodian of property under which development is being considered. From a regulatory perspective, different entities (federal, state, local government, non-governmental organizations, regional agencies, and private parties) have widely varying regulations and restrictions on activities, permitting procedures, and land purchase rights. Although ownership may be similar (e.g., federal lands), land designations (e.g., National Park, U.S. Forest Service National Forest) may vary considerably and be subject to a variety of development constraints.

As a part of the Gap Analysis Program (GAP) launched by the USGS in 1989, the Protected Area Database for the United States (PAD-US) was developed to inventory and organize information on managed protected areas to support coordinated conservation management (USGS, 2012). The USGS GAP analysis provides information about the conservation status of species, the conservation lands and managers that support them, habitat distributions for species within various protected lands, and levels of biodiversity. Within the PAD-US database, protected areas are defined as marine and terrestrial areas dedicated to preserving biological diversity and natural, recreation, and cultural resources that are managed through legal/effective means. The PAD-US database provides spatial polygon coverage of protected area lands and a large suite of attributes, such as land name, manager name, current conservation status, and land designations. Of the many attributes, the PAD-US includes owner types (e.g., federal, state), land designations within each owner type (e.g., Wilderness Area, Wild and Scenic River), and GAP status codes (i.e., measured as intent to conserve biodiversity). The GAP status code indicates the degree of protection towards a natural state and allowable usage.

4.1.7. County Boundaries

Data layers for the United States (e.g., water use and population estimates) are often summarized at the county level; thus, GIS coverages are needed to make these layers spatially relevant. Shapefiles of county boundaries and census data (year 2000) were obtained from U.S. Census Bureau TIGER (Topologically Integrated Geographic Encoding and Referencing) product webpage (USCB, 2012). Because county shapefiles provide codes for each county, datasets for water use and census can be linked to spatial coverages. Existing infrastructure, specifically population and housing density, may aid in determining the potential impacts (displacement) or opposition to hydropower displacement. Although housing and population may be limited within the FEMA 100-year floodplain, populated areas may have higher recreational usage, cultural needs, environmental awareness, and even land ownership connections than rural areas.

4.1.8. Water Use in the United States

Water rights for water consumption, appropriation, and availability have become a contentious issue within and across legislative boundaries and basins in the United States. Impoundments, even those operated in run-of-river mode, may modify the timing and amount (e.g., evaporative losses) of water delivered downstream. In addition, upstream regulatory constraints on water timing and availability may govern hydropower operations. Thus, understanding the potential political context associated with each site location is necessary. Estimates of water use (millions of gallons per day) in various consumption categories (e.g., irrigation, thermoelectric) were obtained for each county in the United States by the USGS for 2005.

4.1.9. Water Quality

Under Section 303(d) of the Clean Water Act (1977), states are required to specify designated uses for all waterways (e.g., public water supply, protection of fish and wildlife, recreation). In addition, each state must identify and adopt water quality criteria that support each designated use category and determine a list of streams that are not meeting their designated uses (303d List). Under section 305(b) of the Clean Water Act, states are required to re-examine the 303d listing every three years to determine if water quality conditions have improved in order for waterbodies to support their designated uses.

Dams may alter water quality (e.g., dissolved oxygen, total maximum daily load levels) or intercept pollutant loads from upstream waterbodies. In addition, dams may or may not support each waterbody's designated use. Spatial coverage of lines, point locations, and polygons of waterbodies included on the 303d list for each state was available for the entire United States from EPA's impaired waters website. Spatial locations were accompanied by information regarding the cause of impairment (e.g., temperature, sediment). Potential water quality concerns could be assessed for prospective new hydropower development areas.

4.1.10. Existing Infrastructure and Land Use

Landscape planning requires knowledge of existing infrastructure (e.g., roads, population density, dams) that may impede or constrain development. In addition, pre-existing landscape disturbances may be important in understanding the relative or cumulative consequences of development on aquatic habitats. The NFHAP is a nationwide effort, including agencies (federal, state, tribal), landowners, conservation groups, academia, and industry to address the loss and degradation of aquatic habitats. The first major objective of the plan was to "conduct a condition analysis of all fish habitats within the United States." A cumulative disturbance index was created for approximately 2.23 million U.S. river reaches (NHD flowlines) from landscape anthropogenic activities using land use, roads, dams, mines, and point-source pollution sites. The underlying assumption is that downstream local habitat conditions will reflect conditions in the catchment upstream. Overall disturbance indices are accompanied by summarized disturbance variables, including land use (e.g., percent crop lands, percent urban land), roads, dams, mines, and point-source pollution sites summarized for each local watershed (immediate area draining into each NHD flowline) and the total upstream cumulative watershed (all watersheds for all upstream contributing NHD flowlines) through the NFHAP database (Figure 4-1).

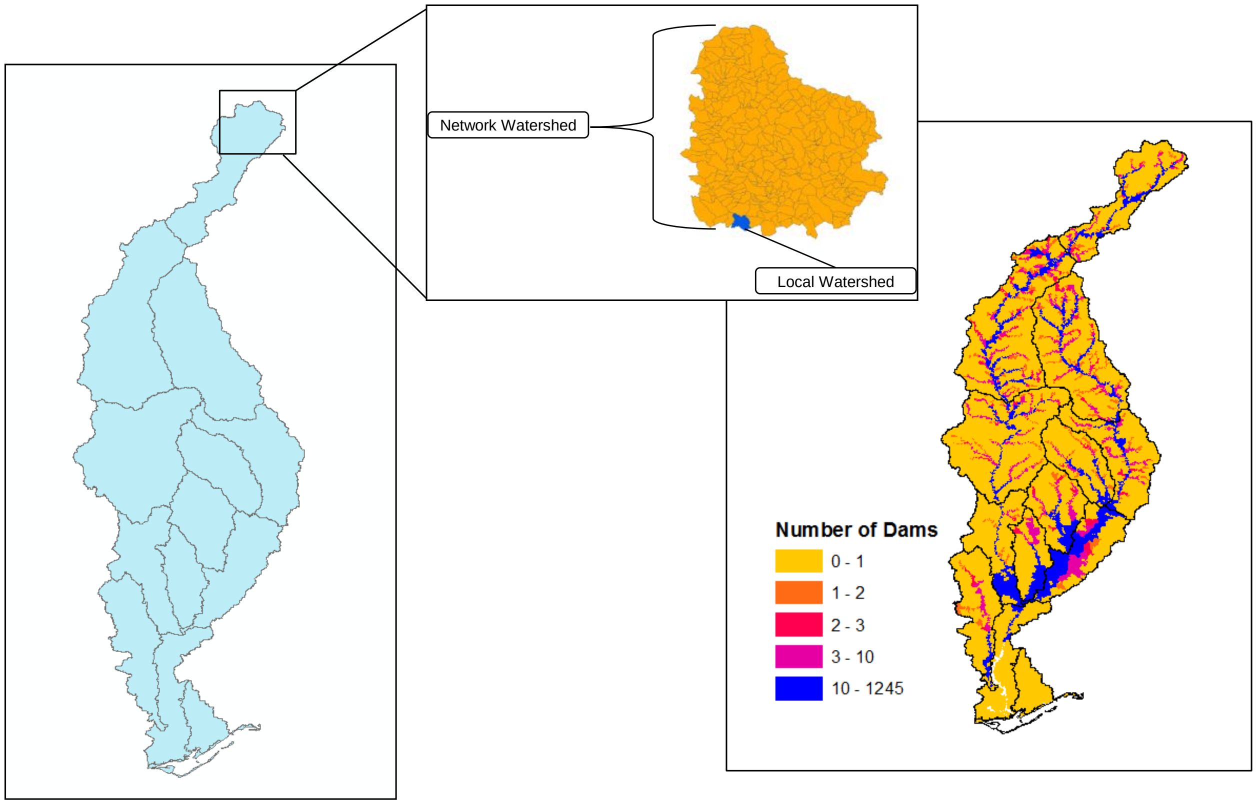

Figure 4-1 Example of maps created from data in the National Fish Habitat Action Plan. Data are summarized for each local NHD flowline and the entire upstream network draining into each NHD flowline. The total numbers of dams within the entire network upstream are plotted for each NHD flowline (right panel).

4.1.11. Fishing and Boat Ramp Access Points

Hydropower projects on navigable waterways have multiple socio-economic impacts, including potential effects to recreation. Recreational needs associated with waterways typically include fishing and boating. Point locations of freshwater and saltwater fishing access areas and locations of undeveloped and developed boat ramps were purchased from DeLorme Publishing Company, Inc. (DeLorme, 2012) for the entire United States. Point locations represent the potential for interaction with recreation interest groups.

4.1.12. Kayaking and Rafting Locations

Similar to fishing and boating, kayaking and rafting represent stakeholders whose interests may be impacted by hydropower development. Point locations of kayak/rafting launch and take-out locations were assembled from American Whitewater's National Whitewater Database (AW, 2012).

4.1.13. Waterfalls

Waterfalls are important geologic phenomena to tourism, aesthetics, and human well-being. However, they have also been used to harness energy (e.g., Niagara Falls) (NYPA, 2012). Geologic landforms and their potential associated socio-economic effects may be relevant to hydropower development planning. Point locations of waterfalls (2,310 total) within 48 states, their names, and county locations were assembled from Geology.com (Delaware and North Dakota were excluded from the website).

4.2. Methodology

4.2.1. New Derived Data Layers

All data layers used in this analysis are presented in Figure 4-2. The majority of data sources listed in Table 4-1 can be used directly in assigning environmental attributes to hydropower development areas. However, the existing resolution and presentation of some raw data sources precluded meaningful environmental attribution. Thus, the raw data sources were summarized into new derived data layers (Figure 4-2). For example, individual distribution maps for 865 fish species alone did not provide sufficient information to assess potential environmental issues (Figure 4-3). However, a summary of the number of fish species that are federally listed within a given area would provide a more concise and digestible estimate of potential concerns (Figure 4-3).

4.2.1.1. Critical Habitats According to Taxonomic Groups

Critical habitat maps from the USFWS were available in polyline and polygon format. However, within the composite dataset (all species' critical habitats), the only information furnished was the common name, scientific name, listing status, and listing date. Using endangered species program lists, lists were generated of all listed species and their taxonomic category. Taxonomic categories included: fish, birds, plants, amphibians, reptiles, mammals, crustaceans, snails, clams, arachnids, ferns, and insects. Species lists were joined to polyline and polygon attribute tables using scientific names as an identifier.

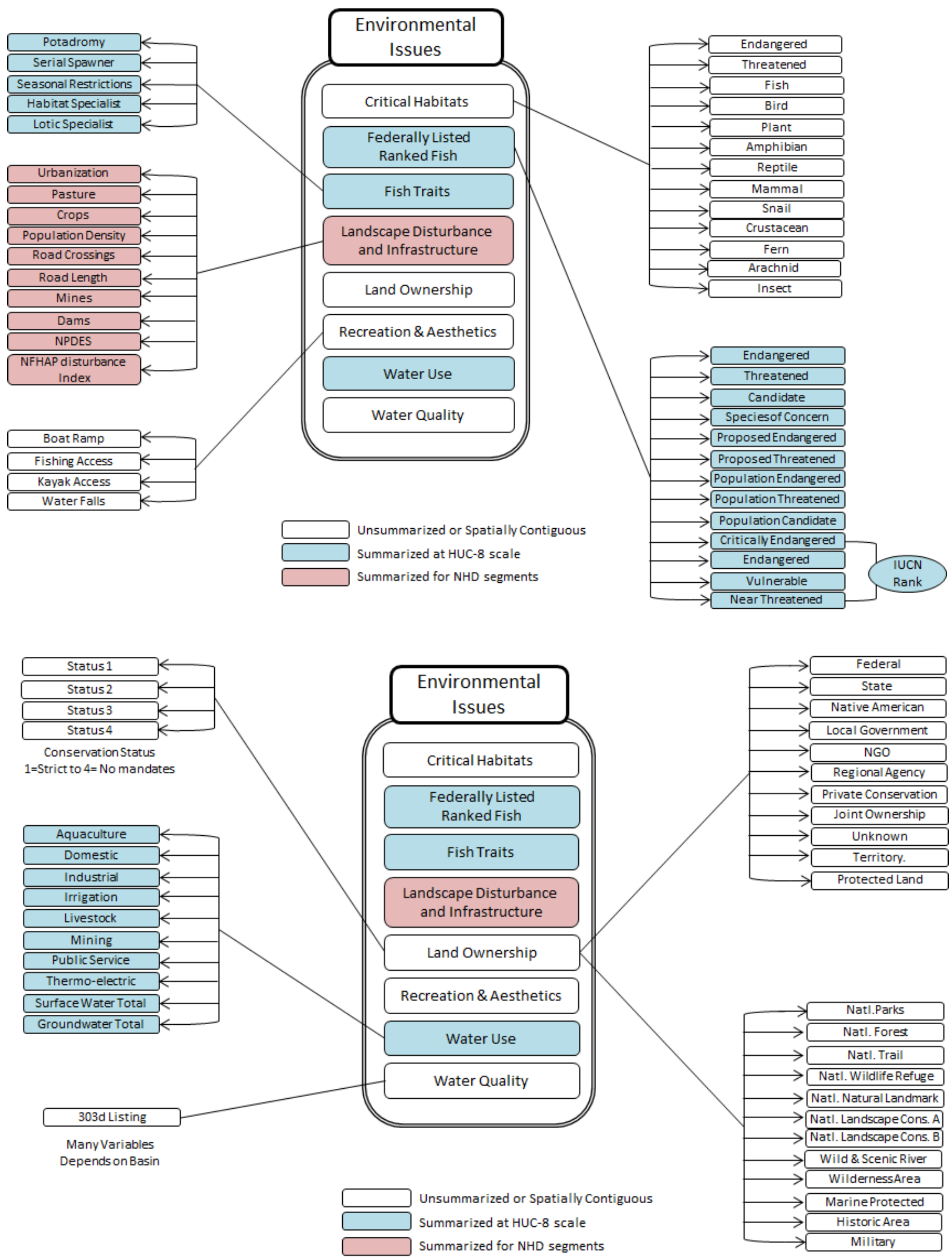

Figure 4-2 Conceptual Organization of Data Layers and Variables. Chart does not represent structural linkages (i.e., database connections) but hierarchical organization. Major environmental issue categories in the center are further divided into many variables, which are factors actually attributed to potential hydropower development areas. Color codes represent whether data layers have been summarized and the scale of summarization.

Table 4-2 Summary of derived datasets developed using data sources from Table 4-1

Derived Data Layer	**Data Source(s)**	**Note**
Critical Habitats according to Taxonomic Groups	• U.S. Fish and Wildlife Service Critical Habitat Portal • U.S. Fish and Wildlife Service Endangered Species Program – Federally Listed Species	Critical habitat polygons and polylines were categorized by listed status (endangered or threatened) and taxonomic group (e.g., fish, bird).
Maps of Fish Species that are Federally Listed or Imperiled (IUCN) across the U.S.	• Watershed Boundary Dataset (WBD), NRCS • NatureServe Digital Distribution Maps of Freshwater Fishes of the United States • NatureServe Explorer Species Data	Maps of the number of fish species (or populations) within each HUC08 falling under a federal listing or IUCN imperiled ranking status.
Maps of Fish Traits across the U.S.	• Watershed Boundary Dataset (WBD), NRCS • NatureServe Digital Distribution Maps of Freshwater Fishes of the United States • Fish Traits Database	Maps of the number of fish species within each HUC08 possessing various traits vulnerable to hydropower development (e.g., potadromy diadromy, habitat specialists, restricted temporal spawning)
Maps of Water Use across the U.S.	• Watershed Boundary Dataset (WBD), NRCS • County Boundaries (U.S. Census Bureau) • 2005 Water Use Estimates (USGS)	Maps of water user per area within each HUC08 calculated as a weighted-average according to county area comprising each HUC08.

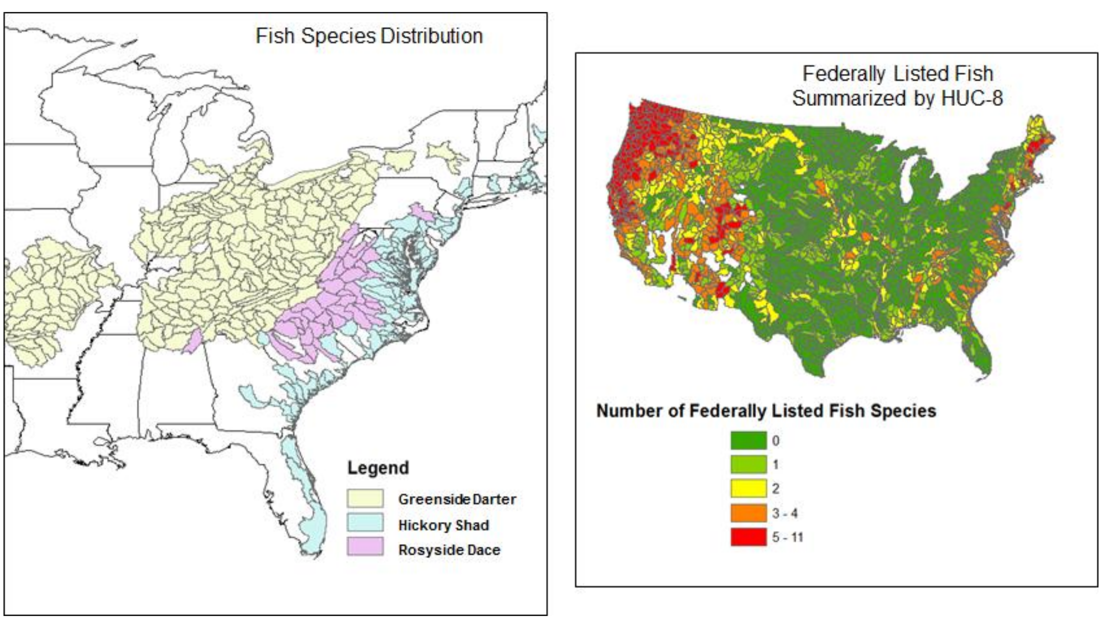

Figure 4-3 Example of Distributions for Three Fish Species (Left Panel) and Numbers of Federally Listed Fish Species Summarized by HUC08 (Right Panel).

4.2.1.2.U.S. Federally Listed and IUCN-Ranked Fish Species Maps

Current and historical (locally exterminated) digital geospatial distributions for 865 freshwater fish species were represented within an older HUC08 version (HUC-250k) and not the current WBD version. Overall there was substantial overlap among watersheds within the HUC-250k and WBD versions; however, some watershed boundaries showed substantial changes, especially in mid to southern California (Figure 4-4). Only current species distributions per HUC08 and recreated distributions for the WBD dataset were selected using the following procedures. First, a "select-by-location" function was used in ESRI ArcGIS to select WBD HUC08s with a centroid located within the distribution of each fish species. Tables of HUC08s were generated for each fish species where they were found. However, 104 of the 2,295 HUC08s had abnormal shapes, whose centroids fell outside of the HUC08 boundary; thus, leading to inaccurate results. In order to correct for any inaccuracies, the 104 HUC08s were partitioned into a separate dataset. Raster images (1 square kilometer grid cells) were then generated for each fish species' distribution. Using zonal statistics (ESRI, 2012), the number of cells and area that each fish distribution comprised were calculated within each of the 104 HUC08s. A fish was documented as present if at least 25% of the HUC08's area was comprised of the fish species' distribution. Tables were then updated for each species with a list of HUC08s.

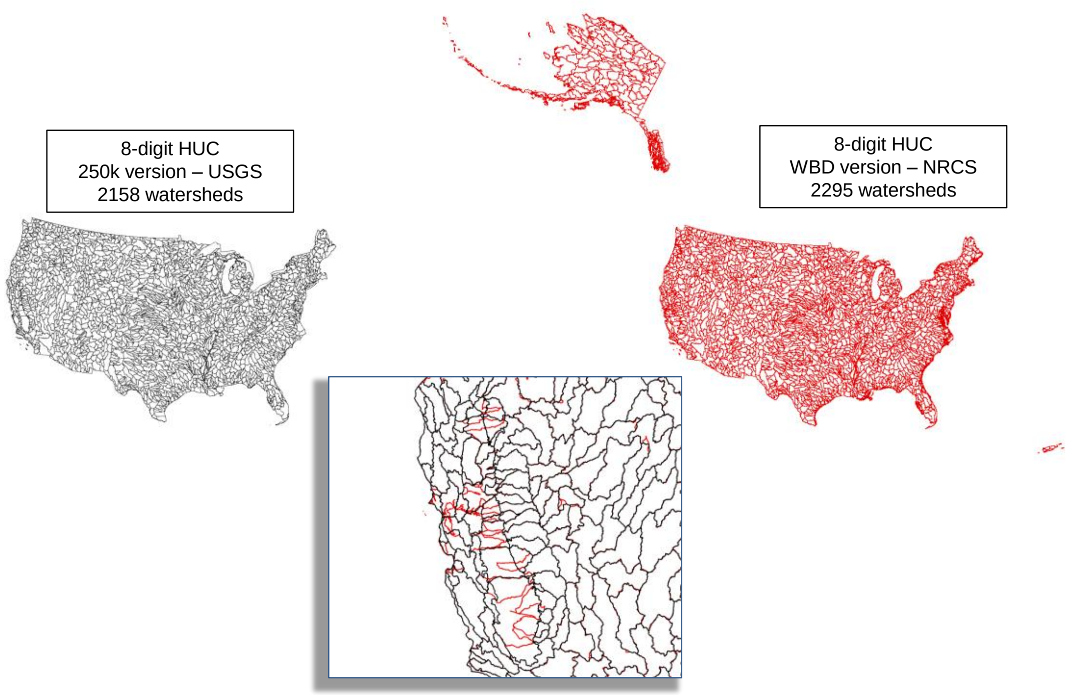

Figure 4-4 Two Versions of HUC08 Watershed Boundaries: the Older 250-k Version (left) and Newer Watershed Boundary Dataset (Right). Most areas show substantial overlap; however, southern California showed some substantial changes (middle/bottom inset).

All tables of HUC08s for each fish species were merged into a single composite dataset and joined to lists of federal listing status and IUCN ranking by scientific name. Care was taken to ensure that scientific nomenclature was similar between datasets. Numbers of fish species within each status/ranking category were summarized for each HUC08 using the summarize tool in ESRI ArcGIS (Figure 4-3). There are two sources of uncertainty that must be taken into account when using these datasets. First, the raw datasets of fish distributions from NatureServe were created from elemental point locations, distributions provided in literature, and expert opinion. NatureServe explicitly states in the metadata that these datasets should not be used as the absolute definitive authority as to a species' presence or absence. In addition, there is some uncertainty of watershed boundaries and whether point locations accurately fall within water boundaries of either HUC08 version. Given the spatial extent of HUC08 Subbasins and associated uncertainty, fish distribution maps should be interpreted as the potential rather than absolute occurrences of fish species at a potential site.

4.2.1.3.U.S. Fish Traits Maps

Maps of fish traits were created using the composite HUC08 dataset for all species (generated from Section 4.2.3) in conjunction with compiling fish traits using information from Frimpong and Angermeier (2009). Traits are characteristics of species' life history (e.g., maximum size, fecundity) or requirements regarding ecological needs (e.g., flowing water, temperature maxima). Traits may be an efficient way to evaluate landscape-level patterns in fish communities since groups of fish with common traits, rather than individual species, can be considered collectively (Frimpong and Angermeier, 2009). Mitigation measures below hydropower facilities, commonly associated with FERC relicensing procedures, are typically accompanied by concerns over fish habitat protection (e.g., fish passage).

The composite dataset from the above section was joined to lists of fish traits by scientific name. Five traits or trait combinations were selected as representative of fish characteristics that could be vulnerable to hydropower development: 1) potadromy (includes spawning migrations within freshwater and diadromy, migrating between freshwater and saltwater to spawn), 2) temporally restricted spawning season (i.e., spawning seasonality), 3) habitat specialists, 4) lotic specialists, and 5) geographically limited (small range). Justifications are provided for the choices of these trait/trait combinations: 1) <u>Potadromy/Diadromy:</u> Fish that migrate large distances to spawn or complete part of their life history requirements may be more susceptible to basin fragmentation and potential habitat modifications (i.e., lose a larger fraction of available habitat) due to new development. 2) <u>Temporally-restricted spawning season:</u> a narrower spawning season duration may indicate more specificity in required conditions for spawning and, thus, a greater likelihood of susceptibility to altered spawning due to new development. Some fish species are adapted to spawning within a short temporal window during specific times of the year characterized by unique daylight, temperature, and hydrologic conditions. 3) Habitat specialist: Fish that use a variety of habitats to spawn or complete their life history are typically considered to be generalist species. Conversely, fish that require very unique habitats (e.g., substrate, flow, river size) are considered specialists. A high proportion of specialists might identify a fish community that is more susceptible to potential habitat modifications and, therefore, would require greater mitigation due to new development. 4) Lotic specialist: Typically fish that prefer lotic habitats, or habitats with moving water, may respond negatively to impoundment. A ratio of species that prefer habitats with moving water may provide a surrogate for potential changes in community composition that may accompany site development. 5) Geographically limited: Fish with small geographic ranges suggest one or a combination of a few plausible causal mechanisms responsible: a) habitat requirements fall within a narrow range and are only found in a small geographic area, b) speciation of fishes and geographic isolation naturally led to small, distinct species pools, or c) existing habitat disturbance has reduced ranges dramatically. Regardless of the cause, a small range may cause fish to be more susceptible to potential habitat modification by elimination of habitats critical to population sustainability or reduced gene flow among isolated populations. The presence of such species at proposed developments will likely raise a greater number of concerns for hydro development.

The number and percent of species within each HUC08, falling into each trait category, were summarized. Potadromous/diadromous species were identified by Frimpong and Angermeier (2009) as a binary response variable. Species with temporally restricted spawning seasons (i.e., high spawning seasonality) were identified by species falling within the lowest tenth percentile spawning season duration (number of months) for all species (also binary response). Habitat specialist scores were calculated by summing the number of habitats and diet diversity characteristic of each species. Species with lower values were presumed to have more specific habitat needs. Lotic specialists were identified as species preferring lotic habitats or only found in lotic habitats. Habitat specialists were identified as those species having habitat specialist scores within the lowest tenth percentile (binary response). Geographic ranges (in square kilometers) were available for all species. Species with small ranges were identified as those with ranges falling within the lowest tenth percentile (binary response).

4.2.1.4.U.S. Water Use Maps

Using county boundaries from the U.S. Census Bureau and USGS water use year 2005 estimates, maps of water use were constructed according to consumption types for all HUC08 Subbasins across the entire United States. Consumption categories were represented as total freshwater use for each category (Figure 4-2). Total cumulative fresh surface and ground water use were also provided (Figure 4-2). Using a common county identifier, tabular county and water use datasets were joined. Water use totals (million gallons per day) represent the total cumulative use within each county. Water use was standardized for differences in county size by dividing the total estimate by county area. To avoid high significant digits in datasets, all water use values were then converted to 1000 gallons day^{-1} 100km^{-2}.

Estimating water use for new hydropower development sites, based on locations within counties, was prone to uncertainty since sites may fall on river systems that share multiple county boundaries. It was presumed that watershed boundaries would provide a more representative estimate since watersheds may take into account multiple surrounding counties. All water use values for each county were converted into raster grid cells (1 square kilometers resolution) (Figure 4-5). Using the zonal statistic tool in ESRI ArcGIS, average water use values were calculated for each watershed, thereby providing area-weighted estimates (Figure 4-5).

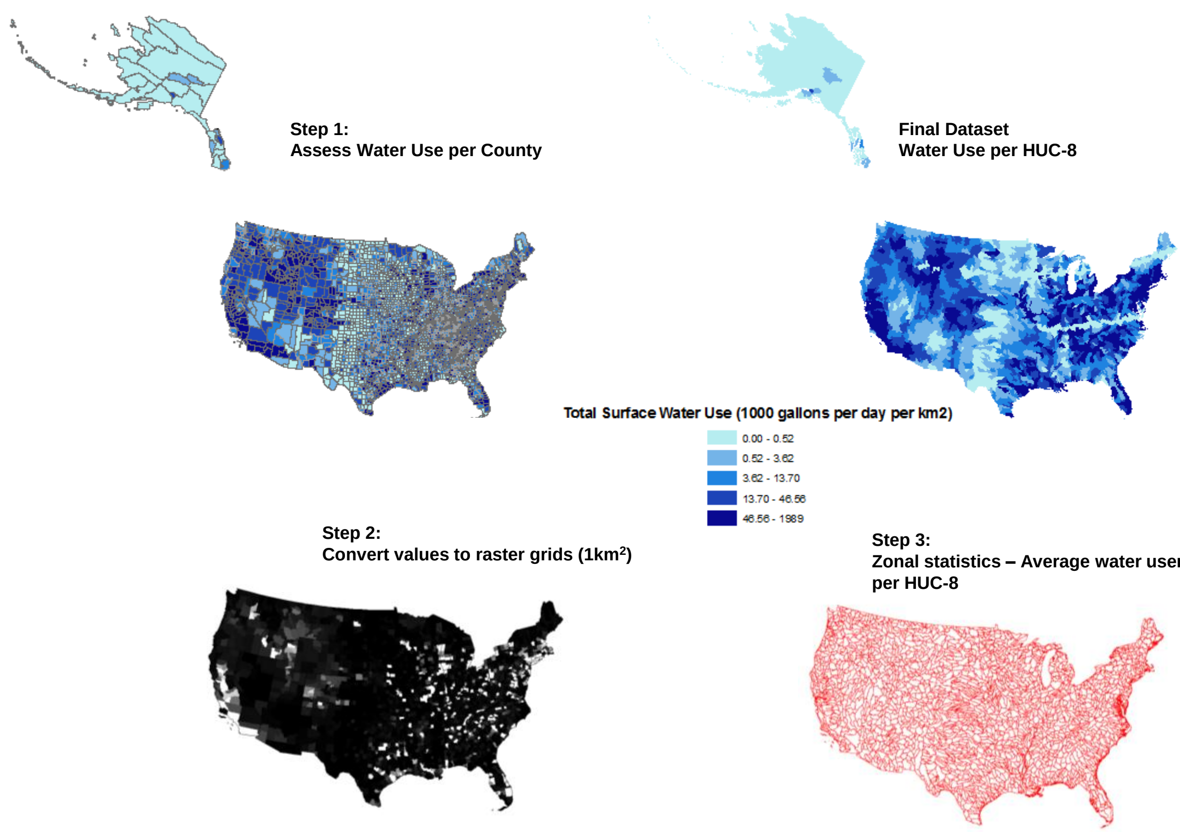

Figure 4-5 Steps of Calculating Water Use in Counterclockwise Order from Top Left. County level water use estimates from 2005 were collected from USGS and applied to county shapefiles from the U.S. Census Bureau (Step 1). Water use values were converted to raster images (Step 2). Zonal statistics were used to calculate water use per HUC08 (Step 3), which resulted in the final dataset.

4.2.2. Site Development – Points, Lines, and Polygons

Based on Section 3, potential stream-reaches for new development and inundated areas were identified, which provided virtual dams (points) and associated impoundments (polygons) (Figure 4-6). Because dams have potential downstream effects, downstream stream-reaches (i.e., tailwaters) should be included as an element of each virtual hydropower development. The length of a tailwater affected by hydropower development can vary with dam size and storage, dilution effects (from incoming tributaries), and the presence of migratory species. It was presumed that 16 kilometers or 10 miles would be sufficient to capture the majority of environmental issues. Based on topographic linkages among upstream/downstream reaches within NHDPlus, tailwater reaches were accumulated from the dam downstream using an additive procedure until their cumulative length reached a threshold of 16km (Figure 4-6). Because NHDPlus flowlines vary in length, tailwater reach lengths also vary. Environmental attribution was conducted separately for points (dams), lines (tailwaters), and polygons (impoundments).

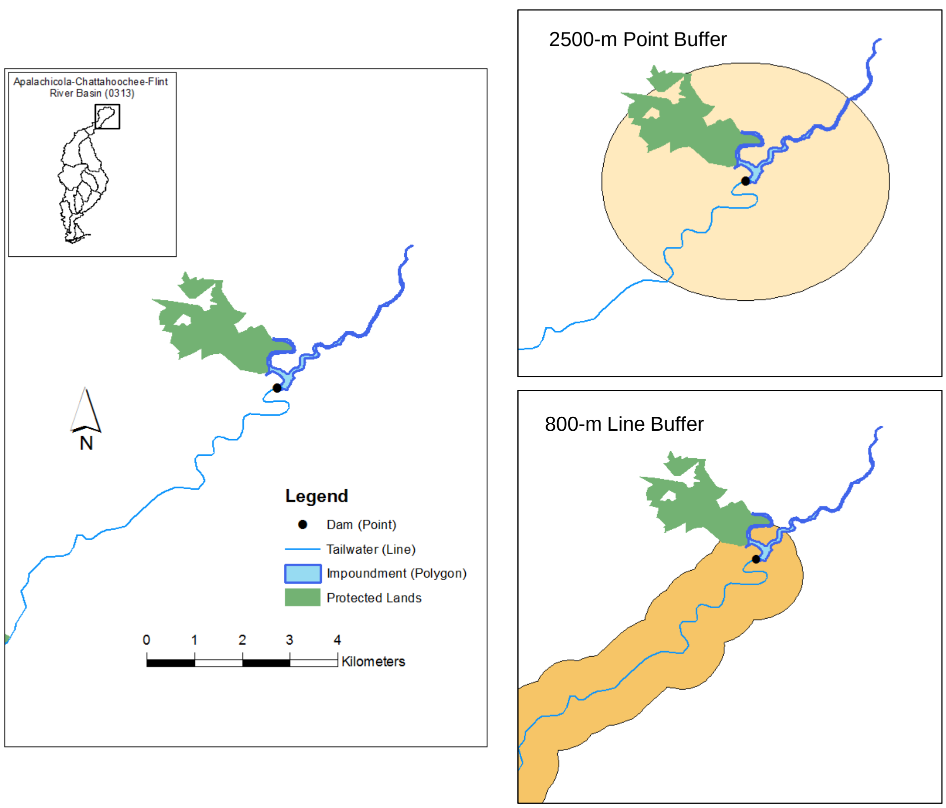

Figure 4-6 Example of Virtual New Hydropower Site Consisting of a Point (Dam), Line (Tailwater), and Polygon (Impoundment) and Examples of Buffers Applied to the Point and Line.

4.2.3. Buffering

Buffers are required for ensuring that layers of different GIS transformations can interact despite potential errors in spatial display or inaccuracies in the underlying data layers. In addition to addressing potential spatial errors, hydropower developments may be influenced by environmental issues regardless of whether boundaries of potential dam areas touch boundaries of environmental data layers. Buffers are polygons that extend a specified distance from the raw data layer. Different buffer lengths were established to points, lines, and polygons using the buffer analysis tool within ESRI ArcGIS. Although the available literature was used to inform decisions, there was a paucity of information on appropriate buffering distances with regard to energy development. Baban and Parry (2001) used a questionnaire targeting public and private sectors to determine criteria for locating wind farms in the United Kingdom. The resultant criteria suggested that wind farms should not be located within 2,000 meters of large settlements, 500 m of single dwellings, and 1,000 m of ecological areas or historical sites. Krewitt and Nitsch (2003) used 500 m as a minimum distance from potential wind farms to residential or industrial areas, roads, railroad lines, and nature protection areas. In an economic analysis of the effects of proximity to hydropower dams on property values, Bohlen and Lewis (2009) found very little evidence of any negative economic effects. However, they did suggest that land use within 1,500 m of a property can influence property values and, thus, public perception.

Buffers of variable widths were applied to points, polygons, and lines depending upon the data layer (Table 4-3). Points were buffered with an 8-km (5-mile) radius in order to assess potential critical habitat issues related to potential road development, power line development, and associated construction (Figure 4-6). A brief review of several randomly selected FERC documents revealed a variety of transmission line distances associated with hydropower projects ranging from 61 m (200 feet), 5.1 km (3.2 mi), 15.7 km (9.7 mi), and 32.2 km (20 mi) (FERC 2003, FERC 2011a,b,c,d). Two projects reviewed did not have transmission lines associated with facilities since switchyards abutted the powerhouse. Thus, the area required for land acquisition and electricity transmittance will in part depend upon generation capacity and the distance to nearest electrical grid. A 2500-m radius buffer was applied to points to assess land ownership, designation, and conservation status. Polygon (i.e., impoundment) boundaries were complex due to being derived by high-detailed Digital-Elevation-Model-derived topography. Because of boundary complexity, the buffer function could not be executed in ESRI ArcGIS. However, intersection tools in ESRI ArcGIS still allow a user to define the spatial extent to which layers can be selected from a known location. Thus, variable-distance selection measures (500 to 800 m (0.5 mi)) were used to attribute polygons depending on the data layer (Table 4-3). Best management practices typically recommend 15-30 m as a minimum forested area for buffering riparian corridors (NCFS, 2006); however, this is primarily related to water quality concerns, such as erosion and sedimentation, in relation to forestry practices or urban areas. Land ownership issues can arise due to land ownership proximity, despite touching boundaries, such as road access. In addition, lake development typically requires purchasing lands outside the potential impoundment. Thus, 800-m buffers provide a distance within the range of existing studies. Similar to polygons, 800-m radius buffers were also used for polylines because of issues related to land ownership proximity and habitat needs for animals with larger migratory potential (birds, amphibians, reptiles) (Table 4-3).

Table 4-3 Variable Buffer Widths According to Different Data Layers and Different Site elements (points, lines, and polygons).

		Buffer Width (m)		
Category	**Data Layer**	**Point**	**Line**	**Polygon**
Critical Habitat	Critical Habitats	8000	800	800
Land Ownership	Land Owner (Agency)	2500	800	800
Land Ownership	Land Designation	2500	800	800
Land Ownership	Land Conservation Status	2500	800	800
Water Quality	303d Waterbodies	500	500	500
Recreation	Fishing Access/Boat Ramp	500	500	500
Recreation	Kayak/Rafting Access	500	500	500
Recreation	Waterfalls	2500	800	800

4.2.4. Environmental Attribution

Environmental attributes were summarized separately for each point (potential dam location), line (tailwater reach), and polygon (impoundment). Attribution ranged from binary responses (1 or 0), indicating the presence or absence of a data layer, to counts (e.g., number of federally listed fish species), to continuous variables (e.g., percent urbanization, water use). The method of attribution depended on the environmental issue and the resolution of the data source. For environmental data sources summarized at the HUC08 Subbasin scale (maps of water use, listed ranked fish species, and fish traits), point, line, and polygons were attributed with HUC08 values based on their location within HUC08 boundaries. For environmental data layers not summarized into arbitrary units (e.g., fishing access points) or those with spatially contiguous coverage (e.g., conservation land polygons), intersection methods were used to determine potential effects for point, lines, and polygons. For layers of information summarized for NHD flowlines, the COMID, a code used for identifying each NHD flowline, was used to link environmental information to each point, line, and polygon.

Conservation lands within the PAD-US database provided a spatial mosaic of merged polygons, each representing a separate entity (e.g., park or landmark). The PAD-US database was used to categorize lands by owner type, designations regarding use and intent, and GAP status code

(Figure 4-2). Points, lines, and polygons were attributed with a binary response as to whether buffered areas intersected (touched the boundary of) each layer. Other datasets (critical habitats, 303d waterbodies, fishing/boat ramp access points, kayak/rafting access points, and waterfalls) were represented as smaller, more discrete locations rather than extensive spatial coverage. For example, critical habitats represented specific river segments (lines) or blocks of land (polygons) for individual species. For these datasets, rather than use only binary responses to indicate the presence or absence of a potential environmental issue, the amount of entities possibly affected by hydropower development were indicated. The Spatial Join function in ESRI ArcGIS was used to join one to many elements to each buffered point, line, and polygon based on intersection. The number of entities intersecting each buffered layer was then enumerated. For critical habitats, the number of species' critical habitats was enumerated within each taxonomic category. The 303d waterbody dataset represents each impaired waterbody as a specific point location, stream reach, or lake/impoundment and also provides the reason for impairment (e.g., temperature, low oxygen, sediment, pollutant). After joining 303d waterbodies to buffered layers, the number of water bodies within each impairment category was enumerated. Recreation datasets (fishing/boat ramp points, kayak/rafting points, and waterfall locations) were joined to buffered layers and enumerated.

The NFHAP database includes cumulative fish habitat disturbance indices, a suite of land use variables, and existing infrastructure summarized separately for each local NHDPlus flowline and for the network watershed upstream of each NHDPlus flowline (Figure 4-1). Data within NFHAP is provided as shapefiles and tabular attributes for all NHDPlus flowlines, each identified by a COMID. Because sites were created in association with NHDPlus flowlines, their location could be identified by COMID. A simple join procedure was used to attribute points and polygons with NFHAP information. However, tailwaters were represented by two or more NHDPlus flowlines, thereby having more than one COMID. The most upstream NHDPlus flowline and the most downstream NHDPlus flowline were attributed with NFHAP information. Values for the entire tailwater were then represented by averages of the up- and downstream flowlines.

4.3. Examples of Results

Distributions of potential new hydropower capacity within various environmental data categories (Figure 4-2) can provide an initial scope of feasibility that may inform estimates of total energy available within regions. Results can be displayed by coding stream-reaches identified for new potential hydropower development using histograms/frequency charts displaying the distribution of generation capacity and environmental attributes (Figure 4-7).

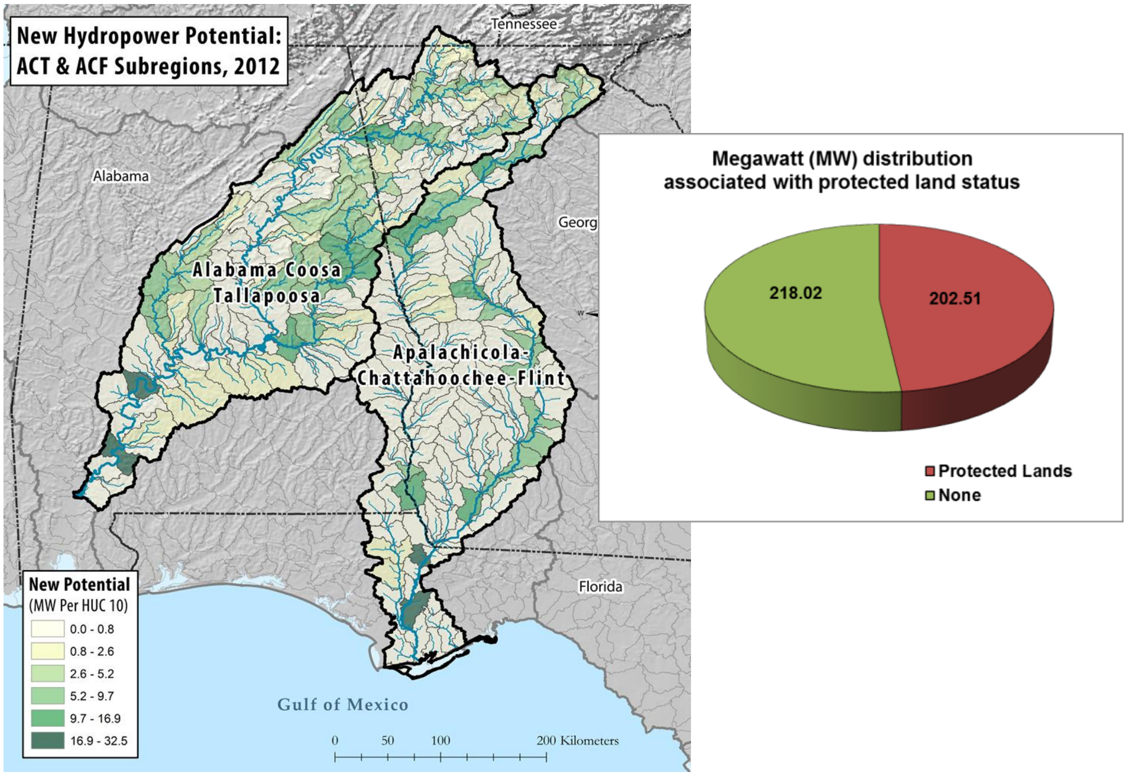

Figure 4-7 Map Example of Potential Hydropower Sites Within the Apalachicola-Chattahoochee-Flint (ACF) and Alabama-Coosa-Tallapoosa (ACT) River Basins Labeled According to the Number of Potadromous Fish Species Potentially Found at Each Site. Potential Megawatt Distribution is Evaluated According to the Number of Potadromous Fish Species (Right Panel).

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APPENDIX A. NSD Potential for Subregions Apalachicola-Flint-Chattahoochee (HUC 0313) and Alabama-Coosa-Tallapoosa (HUC 0315)

A.1. Summary of Findings

Following the NSD methodology, the main findings in Subregions Alabama-Coosa-Tallapoosa (HUC 0315) and Apalachicola-Chattahoochee-Flint (HUC 0313) are summarized in Table A-1. The nameplate capacity, year-2010 generation, and mean capacity factor from existing hydropower facilities are also summarized for comparison.

Table A-1 Summary of NSD Findings in Subregions 0313 and 0315

	Capacity (MW)	Generation (MWh)	Mean Capacity Factor[b]
Subregion 0313 (ACF) – including the Apalachicola, Chattahoochee, and Flint Rivers			
Potential in Undeveloped Stream-reaches (all)	291	1,771,305	69%
Potential in Undeveloped Stream-reaches (>1MW)	214	1,295,550	69%
Existing hydropower (year-2010 status)	722	1,800,205	28%
Subregion 0315 (ACT) – including the Alabama, Coosa, and Tallapoosa Rivers			
Potential in Undeveloped Stream-reaches (all)	471	2,591,692	63%
Potential in Undeveloped Stream-reaches (>1MW)	206	1,154,046	64%
Existing hydropower (year-2010 status)	1,968[a]	4,499,930	26%

Note: a. Not including the 1098 MW pumped-storage capacity

b. The NSD methodology is designed to identify smaller run-of-river projects, which typically have higher capacity factor (but lower capacity) comparing to other existing higher storage peaking projects in the ACT-ACF Subregions.

A.2. Background Hydrologic Setting

Hydrologic Subregions Alabama-Coosa-Tallapoosa (HUC 0315) and Apalachicola-Chattahoochee-Flint (HUC 0313) are often referred to as the ACT-ACF river systems. The ACT-ACF systems, depicted in Figure A-1, include 11,000 stream kilometers (i.e., total length of streams with estimated discharge greater than 60 cfs) within an area of 111,700 km^2.

Metropolitan areas within the Subregion include Atlanta (GA), Albany (GA), Columbus (GA), Birmingham (AL), and Montgomery (AL). As shown in Figure A-2, annual precipitation for ACT-ACF ranges from 800 to 1600 mm/year, and annual runoff from 200 to 700 mm/year. The main precipitation falls in early spring and summer. The basin is underlain by five major aquifer systems: crystalline rock aquifers in the Blue Ridge and Piedmont physiographic provinces, and four aquifer systems in the Coastal Plain physiographic province (Couch et al, 1996). The influence of groundwater exchange on the availability of surface water is not significant.

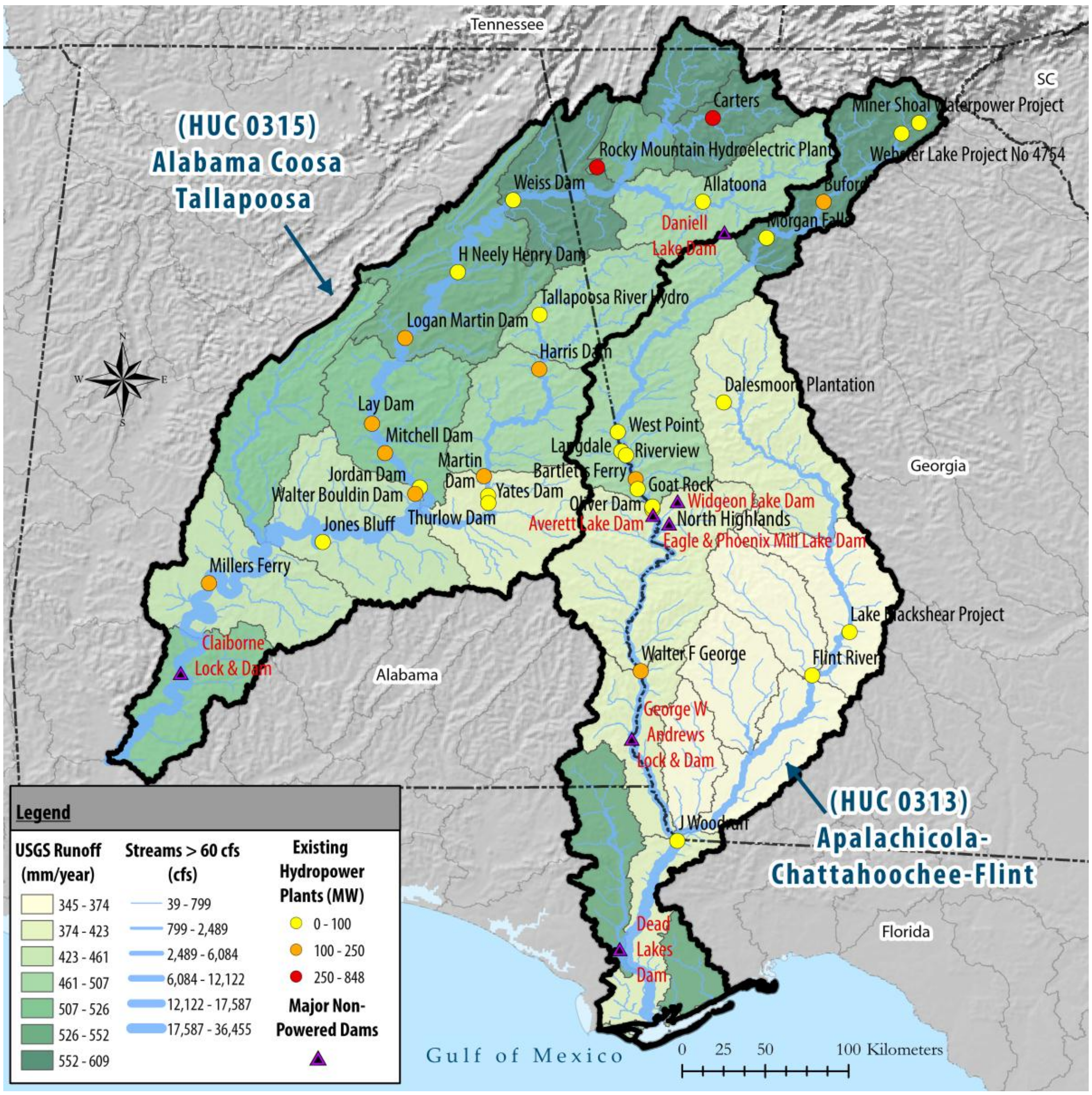

Figure A-1 Locations of water control projects in hydrologic Subregions 0313 and 0315.

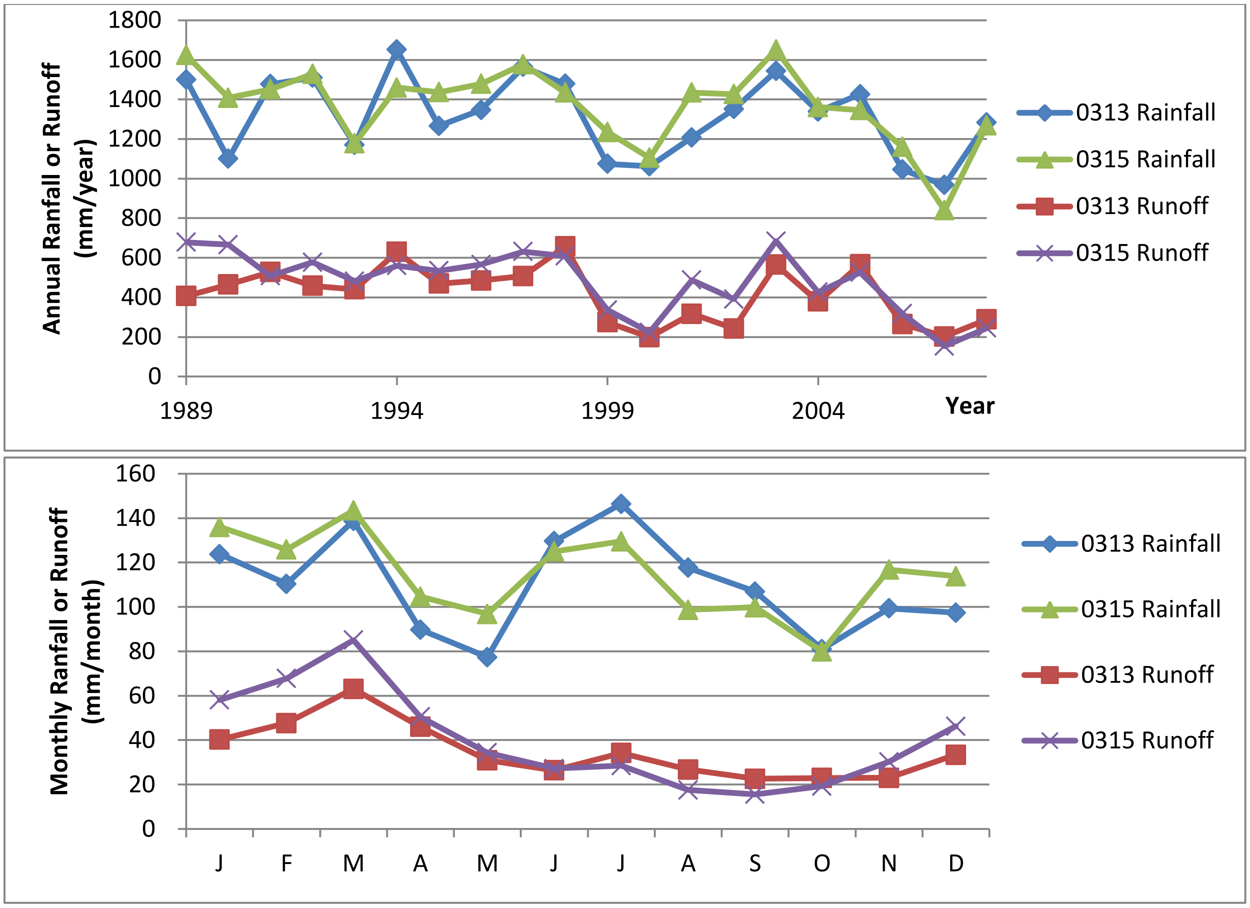

Figure A-2 Annual and monthly rainfall and runoff of Subregions 0313 and 0315

The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are shown in Figure A-1. The two Subregions contain 32 hydropower dams and 6 major non-power dams, with an aggregated storage capacity greater than 13 billion m^3. These facilities are mainly owned by the U.S. Army Corps of Engineers and Georgia Power.

A.3. Summary of Potential New Hydropower Resources

Following the NSD methodology, a total of 92 stream-reaches of high energy intensity (with estimated potential capacity greater than 1 MW per stream-reach) are identified in ACF (HUC 0313) and ACT (HUC 0315). By aggregating the NSD results into HUC08 Subbasins, a summary table is shown in Table A-2. In ACF, the highest hydropower potentials are found in Chattahoochee, Flint and Apalachicola Rivers, while in ACT the highest hydropower potentials are found in the Tallapoosa, Alabama and Etowah Rivers.

Table A-2 Summary of potential new hydropower resources in the ACF and ACT Subregions (stream-reaches with potential capacity greater than 1 MW)

HUC08	HUC08 Name	# of Stream-reaches	Potential Capacity (MW)	Potential Energy (MWh)	Average Head (ft/site)	Average Flow (cfs/site)	Average Storage (ac ft/site)	Average Residence Time (days)
03130001	Upper Chattahoochee	7	20.8	137633	17.0	2451	3658	0.6
03130002	Middle Chattahoochee-Lake Harding	5	28.1	184801	19.8	3933	17503	1.8
03130004	Lower Chattahoochee	2	21.5	136099	14.5	10277	5044	0.2
03130005	Upper Flint	22	39.8	224573	17.6	1459	8201	1.9
03130006	Middle Flint	4	18.2	103165	18.0	3461	17227	2.0
03130008	Lower Flint	4	31.1	179572	17.8	6184	6721	0.4
03130011	Apalachicola	2	52.4	313973	18.5	19616	89965	1.8
03130012	Chipola	2	2.6	15734	14.4	1263	8759	2.9
03150101	Conasauga	2	3.6	17938	19.8	1277	11837	4.1
03150102	Coosawattee	3	5.0	28895	22.6	1023	6412	2.5
03150103	Oostanaula	1	3.3	17952	15.5	2955	1437	0.2
03150104	Etowah	10	25.5	158407	19.8	1832	1651	0.5
03150105	Upper Coosa	1	13.1	76229	26.6	6860	453038	29.6
03150108	Upper Tallapoosa	10	15.7	88301	30.8	715	11064	8.4
03150109	Middle Tallapoosa	5	35.3	200896	39.2	2510	13081	2.4
03150110	Lower Tallapoosa	2	22.3	128616	27.5	5494	24216	1.8
03150202	Cahaba	8	24.4	126166	34.6	1324	24623	7.7
03150203	Middle Alabama	1	25.2	135696	11.9	29390	3823	0.1
03150204	Lower Alabama	1	32.5	174950	14.4	31447	8867	0.1
	Sum	92	420.5	2449596				

The summary statistics of hydraulic head H_{ref} (ft), design flow Q_{30} (cfs), potential capacity P_{NSD} (MW), inundated area A_{NSD} (ac), storage V_{NSD} (ac-ft), and residence time T_{NSD} (day) are shown as an example in Figure A-3. The hydraulic head H_{ref} ranges from 7–42 ft with median as 21 ft, suggesting that most of the potential ACF sites will require low-head hydropower technologies. The design flow Q_{30} ranges from 400–31,000 cfs with a median of 1,900 cfs, skewed to the lower flow side. The potential capacity P_{NSD} ranges from 1–32 MW with a median of 2.5 MW. As expected, the 100-year flood elevation approach results in smaller inundated surface area (A_{NSD} ranging from 4–32,000 acres with a median of 600 acres). It also results in smaller storage (V_{NSD} ranging from 20–450,000 acre-ft with median as 4,700 acre-ft) and very short residence time (T_{NSD} ranging from less than 1 day to 33 days with median as 0.9 day). The results are also illustrated in Figure A-4, with potential capacity (MW) aggregated to the HUC10 Watersheds. In general, higher potential capacity is suggested in the central ACF and ACT Subregions, suggesting the possibility for further more in-depth examination.

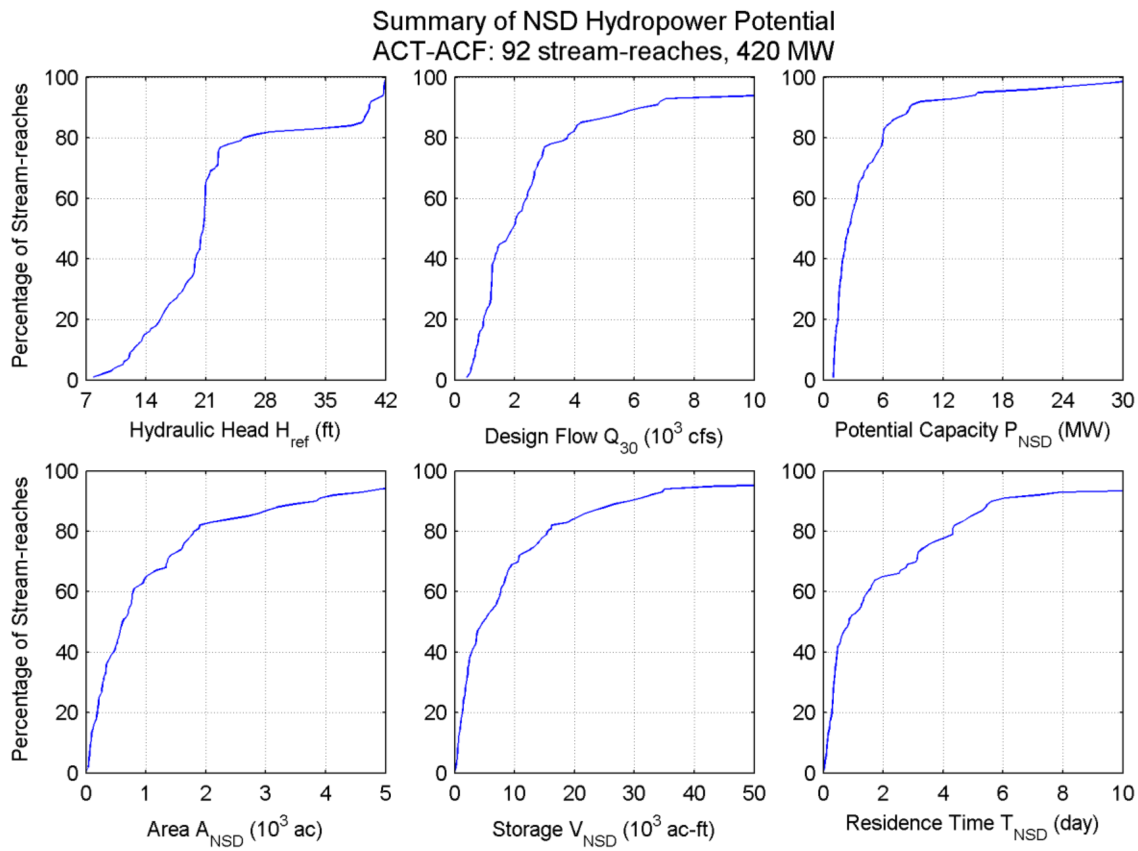

Figure A-3 Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in the ACF and ACT Subregions

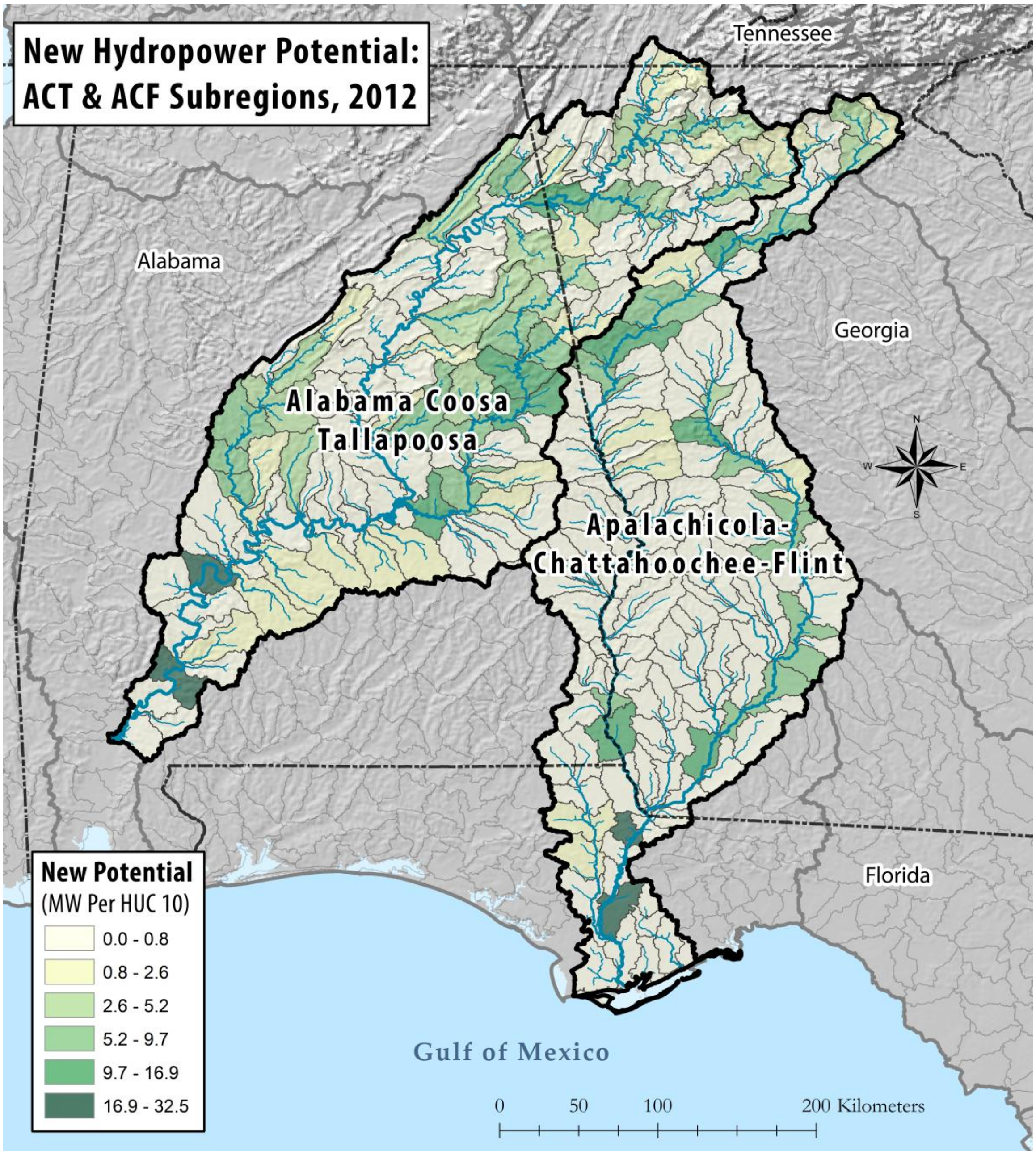

Figure A-4 Potential new hydropower capacity in the ACF and ACT Subregions (aggregated to HUC10 Watersheds for illustration).

A.4. Summary of Environmental Characteristics

A summary of environmental characteristics attributed to each reach is provided in Table A-3. The presence and extent of potential environmental concerns vary from reach to reach; however, potadromous fish species occur in all HUCs in both basins suggesting a common potential concern. The ACF basin contains critical habitat designations for 7 mussels, 1 fish, 2 salamanders, and 1 bird species. The 1 federally listed fish in the ACF is the Gulf Sturgeon (*Acipenser oxyrinchus desotoi*). Four fish species within the ACF are potadromous, or migrate within freshwater systems to complete a part of their life cycle. The majority of sensitive land (conservation lands) within the ACF is federally owned, followed by state ownership, and then private ownership. Surface water use ranges widely (Table A-3), but is highest in the upper portion of the basin near Atlanta. The ACT basin contains critical habitat designations for 10 mussels and 2 fish. Critical habitats are not designated for all ESA listed species. For example, there are 10 fish species in the ACT listed as endangered, threatened, proposed, or a species of concern. Within the ACT, there are 5 potadromous fish species. The primary owner of sensitive lands in the ACT is federal agencies, followed by state, and then private entities. Similar to the ACF, surface water use ranges considerably. The pie charts in Figure A-5 show the amount of NSD potential capacity overlapped with critical habitats, Potadromous fish, protected land, and ESA listed fish species.

Table A-3 Summary of Environmental Characteristics

HUC08	HUC08 Name	# of Critical Habitats	# of Potadromous Fish	Over-lapped with Sensitive Land	# of ESA Fish	# of IUCN Fish	Average Land Disturbance Index	Surface Water Usage (1000 gallons / 100 km^2 / day)
03130001	Upper Chattahoochee	0	2	Yes	0	1	2.1	67.2
03130002	Middle Chattahoochee-Lake Harding	0	3	Yes	0	1	3.6	49.5
03130004	Lower Chattahoochee	7	4	No	0	2	4.0	36.4
03130005	Upper Flint	7	2	Yes	0	1	4.3	11.0
03130006	Middle Flint	7	2	Yes	0	1	3.9	8.2
03130008	Lower Flint	7	3	No	0	1	3.6	25.1
03130011	Apalachicola	10	3	Yes	1	3	5.0	3.9
03130012	Chipola	7	3	No	0	2	4.5	33.0
03150101	Conasauga	12	4	Yes	4	8	2.7	19.4
03150102	Coosawattee	9	4	Yes	2	2	2.9	13.8
03150103	Oostanaula	9	3	Yes	2	3	1.2	161.7
03150104	Etowah	9	2	Yes	3	3	3.2	84.1
03150105	Upper Coosa	9	3	Yes	1	2	2.8	55.8
03150108	Upper Tallapoosa	1	2	Yes	0	0	3.6	3.9
03150109	Middle Tallapoosa	7	2	Yes	0	1	4.3	4.5
03150110	Lower Tallapoosa	9	3	Yes	0	2	3.2	6.7
03150202	Cahaba	16	4	Yes	3	8	4.1	60.5
03150203	Middle Alabama	0	4	No	2	6	4.8	5.5
03150204	Lower Alabama	0	4	No	3	6	4.6	13.0

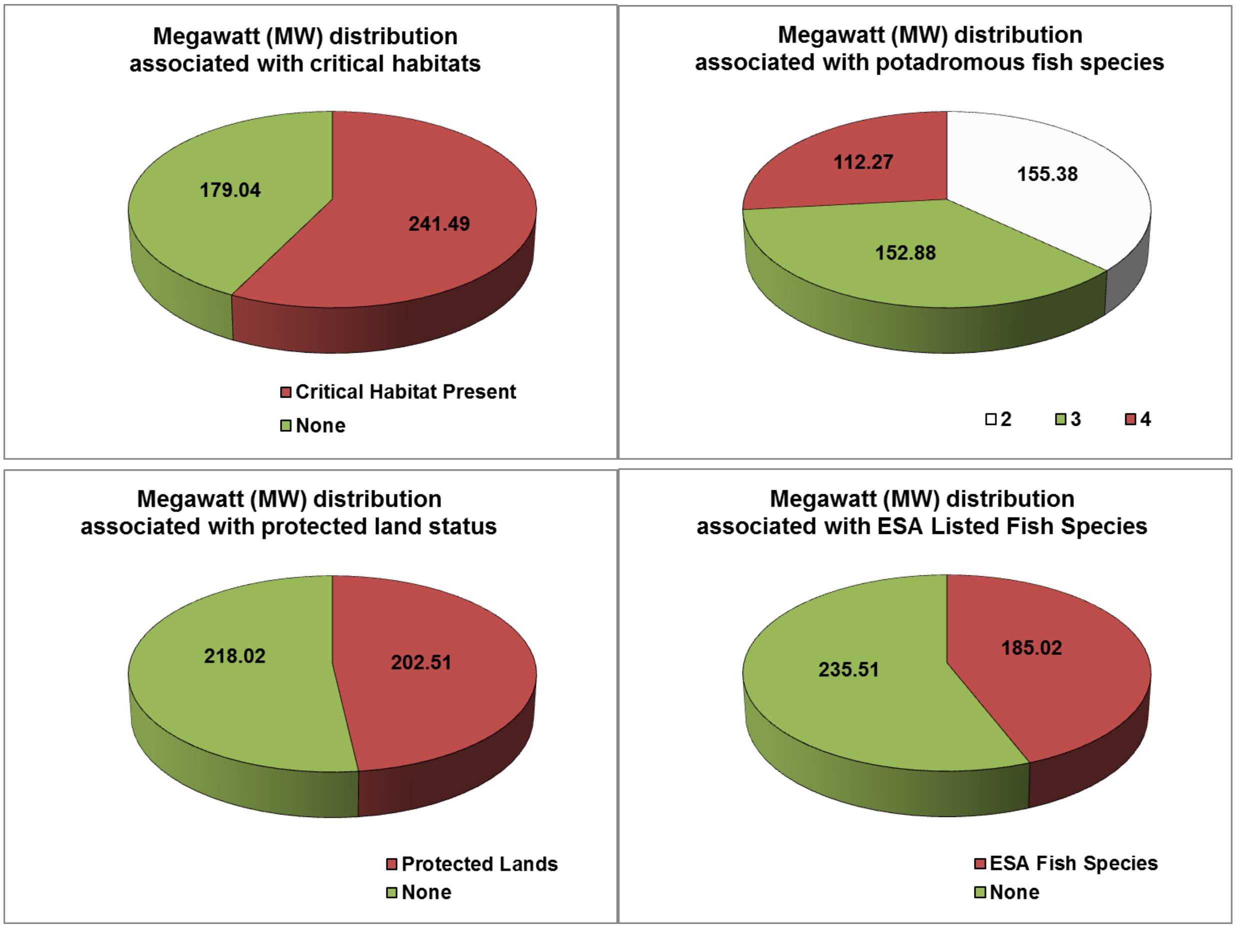

Figure A-5 The potential capacity associated with critical habitats, potadromous species, protected land, and ESA listed fish species

A.5. Limitations of the Study

The proposed NSD methodology will ideally result in estimates of potential capacity and monthly energy generation for the identified stream reaches, and can also estimate inundated areas, reservoir volumes, and approximate hydraulic heads for hypothetical development locations in those areas. The methodology was designed to accommodate the whole of over 3 million U.S. streams to identify opportunities for new hydropower development. Within the limitations of finite resources, this wide spatial scope demands an approximate methodology that (a) resolves aggregate potential within hydrologic regions and electric power systems and (b) enables the modeling of regional and national scenarios of existing and new electric power generation technology deployment through the development of hydropower capacity cost versus supply curves. The methodology considers only the physical characteristics of the stream and landscape and does not consider feasibility issues arising from environmental impacts, cost, or benefits. Although the methodology allows for the identification of stream reaches of high energy intensity, and classification of new potential areas for hydropower development using a range of technical, socio-economic, and environmental characteristics, it does not produce estimates of capacity, production, cost, or impacts of sufficient accuracy to determine absolute economic feasibility or to justify financial investments in individual site development. These potential high energy intensity areas should be regarded as worthy of more detailed site-by-site evaluation by engineering professionals. More detailed information about the assumptions and intended use of these results is available in the NSD methodology report.

A.6. Availability of the Assessment Results

These results are included in the NHAAP Public Portal (http://nhaap.ornl.gov/) to support further research activities. The following major variables will be available:

- **Basic Attributes:** Coordinates, State, County, Hydrologic unit, Site elevation (ft), River name, Channel Slope, Head (ft), Flow (cfs), Capacity (MW), Monthly Energy (MWh), Reservoir storage (ac ft), Inundated area (ac), and Residence time (day).
- **Environmental Attributes:** Critical habitats (no. species), ESA federally listed fish species (no. species), IUCN species of concern (no. species), potadromous or anadromous fish (no. species), protected land (presence/absence), land-ownership index (no. entities), land-designation index (no. designations), US National Park (presence/absence), Wild-and-Scenic River (presence/absence), 303d listed waterbodies (no. waterbodies), American Whitewater boating runs (no. boating runs), boatramps (no. boatramps), fishing access points (no. access locations), surface water use (liters day^{-1} km^{-2}), ground water use (liters day^{-1} km^{-2}), urban land cover (%), population density (individuals km^{-2}), dams in local watershed (no. dams), total dams in entire upstream newtork (no. dams), land disturbance index (score from NFHAP).

The NHAAP-NSD results are available in tiered form to encourage ease of use and appropriate use. Basic results depicting availability of new energy within basins are available from the Public Portal. Detailed results with location-specific features are available through a user-agreement to ensure that appropriate use and interpretations of the location-specific results are followed. In particular, neither ORNL nor DOE approves of the use of these results in support of site-specific permit applications to the Federal Energy Regulatory Commission.