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New Stream-reach Development: A Comprehensive Assessment of Hydropower Energy Potential in the United States

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Front Cover Images

Left: Youngs Creek Project, Snohomish County Public Utility District, WA (image courtesy of Kim D. Moore and Neil Neroutsos, Snohomish County Public Utility District)

Youngs Creek Project was online in October 2011 with an estimated capacity of 7.5 MW and an annual production of 18,000 MWh—enough to power about 1,500 homes. It is the first new hydro project in Washington state in nearly 20 years. It received the *Renewable Energy World magazine's 2012 Hydro Project of the Year* award.

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Right: Cheoah River, Graham County NC (image courtesy of Ryan A. McManamay)

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NEW STREAM-REACH DEVELOPMENT: A COMPREHENSIVE ASSESSMENT OF HYDROPOWER ENERGY POTENTIAL IN THE UNITED STATES

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ABSTRACT

The rapid development of multiple national geospatial datasets related to topography, hydrology, and environmental characteristics in the past decade has provided new opportunities to refine and more accurately characterize the nation's hydropower resource potential in undeveloped stream-reaches. The U.S. Department of Energy (DOE) Water Power Program tasked Oak Ridge National Laboratory with evaluating the new stream-reach development (NSD) resource potential of more than 3 million U.S. streams in order to help individuals and organizations evaluate the feasibility of developing new hydropower sources in the United States. A methodology was designed to identify and characterize stream-reaches with high energy density and, most importantly, to compile and spatially join the energy potential of stream-reaches with information related to natural ecological systems; sensitive species; areas of social and cultural importance; and policy, management, and legal constraints. Additionally, this assessment focuses specifically on undeveloped stream-reaches, unlike previous assessments that covered all types of streams (i.e., including river segments with existing hydropower plants or non-powered dams). An initial report on methodology (Hadjerioua et al., 2013) was reviewed and revised based on comments gathered from two peer review workshops.

This assessment was conducted at a "reconnaissance level" (RETScreen International, 2005) considering the "technical resource" that could be available for development (NRC, 2013), and using present-day assumptions about hydropower technology. The methodology alone does not produce estimates of generation, cost, or potential impacts of sufficient accuracy to determine project-specific feasibility or to justify investments. These potential high-energy-density areas should be regarded as worthy of more detailed site-by-site evaluation by engineering and environmental professionals; not all areas identified in this assessment will be practical or feasible to develop for various reasons. In addition to the resource potential, this assessment includes stream-reach level information on a number of environmental attributes, such as fish habitat and recreational use, to support further market analysis.

The estimated technical resource capacity for new stream-reach development is 84.7 GW, with total undeveloped NSD generation estimated at 460 TWh/year. When areas protected by federal legislation limiting the development of new hydropower (national parks, wild and scenic rivers, and wilderness areas) were excluded from the analysis, the estimated NSD capacity falls to 65.5 GW, slightly lower than the current existing U.S. conventional hydropower nameplate capacity (79.5 GW; NHAAP, 2013). Undeveloped NSD generation with these areas excluded is estimated to be 347.3 TWh/year, roughly 128% of the average 2002–2011 net annual generation from existing plants (272 TWh/year; EIA, 2013). Detailed findings organized by hydrologic regions are presented in separate chapters of this report.

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EXECUTIVE SUMMARY

The rapid development of multiple national geospatial datasets related to topography, hydrology, and environmental characteristics in the past decade has provided new opportunities for refining assessments of hydropower resource potential from currently undeveloped stream-reaches. From 2011 through 2013, Oak Ridge National Laboratory (ORNL) was tasked by the U.S. Department of Energy (DOE) Water Power Program with evaluating the new stream-reach development (NSD)[1] resource potential of more than 3 million U.S. streams. This wide spatial scope demands an approximate methodology that can (1) resolve aggregate potential within hydrologic regions and electric power systems and (2) enable the modeling of regional and national scenarios for existing and new electric power generation technology deployment through the development of curves for hydropower capacity cost versus supply. A methodology was hence designed that contains three main components: (1) identification of stream-reaches with high energy density; (2) topographical analysis of promising stream-reaches to estimate the characteristics of potential inundations of reservoirs; and (3) environmental attribution to spatially join the energy potential of stream-reaches with information related to the natural ecological systems; social and cultural settings; and policies, management, and legal constraints. This refined assessment utilizes a comprehensive set of recent U.S. geographic, topographic, hydrologic, hydropower, environmental, and socio-political datasets, including the 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 WaterWatch Runoff Dataset, DOE/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. In addition to the new data and methodology, the NSD assessment focuses specifically on undeveloped stream-reaches, unlike previous assessments that examined all types of streams without further breakdown (i.e., including river segments with existing hydropower plants or non-powered dams). An initial report on methodology (Hadjerioua et al., 2013) 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).

After the assessment was implemented across the entire United States, major findings were summarized in this final report. The estimated NSD capacity and generation, including both higher-energy-density (>1 MW per reach) and lower-energy-density (<1 MW per reach) stream-reaches, are shown in Table ES.1 for each hydrologic region. The highest potential was identified in the Pacific Northwest Region (32%), followed by the Missouri Region (15%) and the California Region (9%). In total, the undeveloped NSD capacity is 84.7 GW, and the undeveloped NSD generation is estimated to be 460 TWh/year. When areas protected by federal legislation limiting the development of new hydropower (national parks, wild and scenic rivers, and wilderness areas) were excluded from the analysis, the estimated NSD capacity falls to 65.5

[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 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.

GW, slightly lower than the current existing U.S. conventional hydropower nameplate capacity (79.5 GW; NHAAP, 2013). Undeveloped NSD generation with these areas excluded is estimated to be 347.3 TWh/year, roughly 128% of the average 2002–2011 net annual generation from existing plants (272 TWh/year; EIA, 2013). Since the assessment was designed to identify potential run-of-river projects, NSD stream-reaches have higher capacity factors (53%–71%), especially compared with conventional larger-storage peaking-operation projects that usually have capacity factors of around 30%.

Table ES.1. Summary of NSD Findings by Hydrologic Regions

	Hydrologic region	Capacity (MW)	Generation (MWh/year)	Capacity factor
01	New England	2,143	12,433,000	66%
02	Mid-Atlantic	4,710	25,945,000	63%
03	South Atlantic-Gulf	2,561	14,205,000	63%
04	Great Lakes	1,425	8,444,000	68%
05	Ohio	4,757	25,288,000	61%
06	Tennessee	1,363	7,995,000	67%
07	Upper Mississippi	2,081	11,546,000	63%
08	Lower Mississippi	2,072	12,074,000	67%
09	Souris-Red-Rainy	151	787,000	60%
10	Missouri	11,686	69,011,000	67%
11	Arkansas–White–Red	6,013	33,994,000	65%
12	Texas-Gulf	783	3,666,000	53%
13	Rio Grande	1,637	9,310,000	65%
14	Upper Colorado	3,033	18,232,000	69%
15	Lower Colorado	2,613	16,273,000	71%
16	Great Basin	564	3,105,000	63%
17	Pacific Northwest	25,226	148,999,000	67%
18	California	7,054	37,987,000	61%
19	Alaska*	4,723	(not estimated)	(not estimated)
20	Hawaii*	145	699,000	53%
	Total	84,740	459,993,000	66%

*The Alaska and Hawaii potential are estimated by a different approach from that used for other regions.

The estimated NSD capacity and generation for both higher-energy-density and lower-energy-density stream-reaches are further summarized in Table ES.2 for each state. The downstream end of a stream-reach is treated as the possible development location to determine specific location within states. When a stream-reach is located on the border of multiple states, the potential capacity and generation are distributed evenly into each neighboring state to compute the state-based totals. The highest potential is found in Oregon, Washington, and Idaho—the three states in the Pacific Northwest—followed by California, Alaska, Montana, and Colorado.

The main NSD findings are aggregated by HUC10 Hydrologic Watersheds and released through NHAAP (http://nhaap.ornl.gov/) to support further hydropower research activities. Detailed results with location-specific features are available through a user agreement to ensure the appropriate use and interpretation of the location-specific results. Note that the primary goal of the NSD assessment is to provide a national-scale, reconnaissance-level analysis to identify high-energy-intensity stream-reaches and classify new potential areas using a range of technical, socioeconomic, and environmental characteristics. The NSD assessment is not intended to determine economic feasibility, justify financial investment for individual site development, or replace on-site physical and environmental assessments. For site-specific hydropower development, all design characteristics, including hydraulic head and flow, should be reevaluated based on more accurate direct measurement.

Table ES.2. Summary of NSD Findings by States

State	Potential capacity (MW)	Potential generation (MWh/year)	State	Potential capacity (MW)	Potential generation (MWh/year)
AK*	4,723	(not estimated)	MT	4,763	28,201,000
AL	663	3,522,000	NC	857	5,067,000
AR	1,253	6,685,000	ND	252	1,524,000
AZ	2,484	1,5459,000	NE	1,942	11,917,000
CA	6,983	3,7564,000	NH	407	2,410,000
CO	4,295	2,5623,000	NJ	171	1,006,000
CT	151	865,000	NM	1,280	7,193,000
DE	6	35,000	NV	232	1,245,000
FL	170	956,000	NY	1,900	10,715,000
GA	621	3,604,000	OH	535	2,800,000
HI*	145	699,000	OK	1,147	5,838,000
IA	736	3,869,000	OR	8,920	53,353,000
ID	7,018	41,015,000	PA	2,889	15,795,000
IL	599	3,241,000	RI	13	71,000
IN	581	3,123,000	SC	309	1,844,000
KS	2,479	14,931,000	SD	230	1,363,000
KY	675	3,301,000	TN	1,002	5,618,000
LA	790	4,463,000	TX	1,580	8,089,000
MA	194	1,114,000	UT	1,376	8,246,000
MD	223	1,212,000	VA	1,234	6,869,000
ME	1,132	6,532,000	VT	401	2,344,000
MI	449	2,866,000	WA	7,381	43,788,000
MN	568	3,191,000	WI	556	3,513,000
MO	2,512	14,514,000	WV	1,851	9,910,000
MS	1,129	6,449,000	WY	2,960	10,776,000

* The AK and HI potential are estimated by a different approach from that used for the other 48 states.

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ABBREVIATIONS, ACRONYMS, and INITIALISMS

ac-ft	acre-foot
ACF	Apalachicola-Chattahoochee-Flint Subregion (HUC 0313)
ACT	Alabama-Coosa-Tallapoosa Subregion (HUC 0315)
AEA	Alaska Energy Authority
BLM	Bureau of Land Management
COMID	NHDPlus Object Identifier
DBEDT	Hawaii Department of Business, Economic Development, and Tourism
DOD	Department of Defense
DOE	U.S. 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
FIS	Flood Insurance Study
GAP	Gap Analysis Program
GIS	Geospatial Information System
HUC	hydrologic unit code
HUC02	hydrologic region
HUC04	hydrologic subregion
HUC06	hydrologic basin
HUC08	hydrologic subbasin

HUC10	hydrologic watershed
HUC12	hydrologic subwatershed
IUCN	International Union for the Conservation of Nature
NED	National Elevation Dataset
NFHAP	National Fish Habitat Action Plan
NHAAP	National Hydropower Asset Assessment Project
NHD	National Hydrography Dataset
NHDPlus	National Hydrography Dataset Plus
NID	National Inventory of Dams
NOAA	National Oceanic and Atmospheric Administration
NPD	non-powered dam
NPS	National Park Service
NSD	new stream-reach development
NSDP	new stream-reach development population
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
NWSRA	National Wild and Scenic River Act
ORNL	Oak Ridge National Laboratory
PAD-US	Protected Area Database for the United States
Reclamation	U.S. Bureau of Reclamation
SSP	stream segment population
USACE	U.S. Army Corps of Engineers
USFS	U.S. Forestry Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

WaterWatch	USGS WaterWatch Program
WBD	Watershed Boundary Dataset

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LIST OF VARIABLES

A_{NSD}	inundated surface area (acre)
c	unit conversion factor, $(0.3048)^4$
E_{NSD}	potential hydroelectric energy at an NSD stream-reach (watt * hour)
GW	gigawatt (10^9 watt)
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 watt * hour)
P	hydroelectric power (watt)
P_{NSD}	potential hydropower capacity at an NSD stream-reach (Watt)
Q	flow (ft^3/s)
Q_{30}	30% exceedance quantile from daily flow-duration curve
$Q_{NHDPlus}$	annual mean flow (ft^3/s) provided by NHDPlus
S_0	average channel slope
T_{NSD}	residence time (day)
TWh	terawatt hour (10^{12} watt * hours)
V_{NSD}	reservoir storage (acre * ft)
η	generating efficiency
γ	specific weight of water, 9800 N/m^3

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1. INTRODUCTION

1.1. Scope and Objective

With the rapid development of multiple national geospatial datasets for topography, hydrology, and environmental characteristics in the past decade, new opportunity arises for the refinement of hydropower resource potential from undeveloped stream-reaches. Through 2011 to 2013, the Oak Ridge National Laboratory (ORNL) was tasked by the U.S. Department of Energy (DOE) Water Power Program to evaluate the new stream-reach development (NSD)[2] resource potential for more than 3 million U.S. streams. This wide spatial scope demands an approximate methodology that may (1) resolve aggregate potential within hydrologic regions and electric power systems and (2) enable 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. A methodology hence was designed that contains three main components: (1) identification of stream-reaches with high energy density, (2) topographical analysis of opportunity stream-reaches to estimate inundated surface area and reservoir storage, and (3) environmental attribution to spatially join the energy potential of stream-reaches with information related to the natural ecological systems; social and cultural settings; and policies, management, and legal constraints. An initial report on methodology (Hadjerioua et al., 2013) 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).

After implementing the assessment for the entire United States, this report summarizes the major findings across various hydrologic regions. A summary of the methodology is provided in Section 2. The national findings are summarized in Section 3. More detailed findings in each hydrologic region are discussed in Sections 4–23. A comparison with the previous resource assessment is provided in Appendix A.

1.2. Limitations of the Study

Since this assessment is designed to accommodate the whole of more than 3 million U.S. streams, it is targeted at the higher "reconnaissance level" (RETScreen International, 2005). The methodology considers only the physical characteristics of each 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 density, 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-density areas should be regarded as worthy of more detailed site-by-site evaluation by

[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.

engineering professionals. More detailed information about the assumptions and intended use of these results is available in the NSD methodology report.

1.3. Availability of the Results

These results are distributed through the National Hydropower Asset Assessment Project (NHAAP) Public Portal (http://nhaap.ornl.gov/) to support further research activities. The following major variables are 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), Endangered Species Act (ESA) federally listed fish species (no. species), International Union for the Conservation of Nature (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), U.S. national park (presence/absence), Wild and Scenic River (presence/absence), 303d listed waterbodies (no. waterbodies), American Whitewater boating runs (no. boating runs), boat ramps (no. boat ramps), fishing access points (no. access locations), surface water use ($l/day^{-1} \cdot km^{-2}$), ground water use ($l/day^{-1} \cdot km^{-2}$), urban land cover (%), population density ($individuals/km^{-2}$), dams in local watershed (no. dams), total dams in entire upstream network (no. dams), land disturbance index (score from National Fish Habitat Action Plan [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 (FERC).

2. SUMMARY OF METHODOLOGY

This section summaries the NSD methodology developed by Hadjerioua et al. (2013). The assessment incorporates, by reference, the hydrologic unit code (HUC) hierarchy of region (HUC02), subregion (HUC04), basin (HUC06), subbasin (HUC08), watershed (HUC10), and subwatershed (HUC12). This hierarchy was originally specified in the U.S. 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 effort, subregion (HUC04) is selected as the fundamental hydrologic unit for modeling, parameter estimation, and analyses of energy potential. The methodology contained two parts—resource evaluation that quantified hydropower potential at undeveloped U.S. stream-reaches (summarized in Section 2.1) and environmental attribution that labeled environmental and social-economical characteristics to the identified NSD stream-reaches (summarized in Section 2.2). Both parts were reviewed and revised based on the comments gathered from two peer review workshops (December 2011 for resource evaluation and June 2012 for environmental attribution). A pilot study was conducted for Alabama-Coosa-Tallapoosa (ACT) and Apalachicola-Chattahoochee-Flint (ACF) hydrologic subregions and included in the initial methodology report (Hadjerioua et al., 2013). The methodology was then implemented for the entire conterminous United States. Given that some critical data are unavailable in Alaska and Hawaii, it was decided to summarize the undeveloped hydropower potential from existing literatures in these two regions, rather than conduct new geospatial assessments based on limited data. The Alaska and Hawaii data source and results are reported in Sections 22 and 23.

2.1. Resource Evaluation

2.1.1. Data Sources

Hydropower resource assessment requires several types of data, including watershed boundaries, river geometry, topography, and water availability. These data enable the estimation of two critical variables for hydropower generation—net hydraulic head (height difference between upstream pool and tailwater elevation) and design flow. Head and flow can then be augmented with data and computation to estimate additional parameters, such as storage volume, inundated area, and other NSD attributes. 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 2.1 summarizes the data used for resource evaluation.

2.1.2. Energy Production Model

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

Table 2.1. Summary of Data Used for Resource Evaluation

Data type	Data source	Note
Watershed boundary	• USDA/NRCS Watershed Boundary Dataset (WBD; USGS and USDA-NRCS, 2009)	
River geometry, existing water bodies	• USGS/EPA National Hydrography Dataset Plus (NHDPlus; http://www. horizon-systems.com/nhdplus/ NHDPlusV1_home.php)	NSD assessment is based on NHDPlus version 1
Existing dams	• USACE National Inventory of Dams (NID, http://www.nid.usace.army.mil)	NSD assessment is based on NID version 2010
Topography	• USGS National Elevation Dataset (NED; Gesch et al., 2002)	1/3 arc-second (about 10-m) resolution is used
Flow estimates	• USGS National Water Information System (NWIS; http://waterdata.usgs. gov/nwis) • USGS WaterWatch Runoff (Brakebill et al., 2011) • NHDPlus	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	• FEMA Flood Insurance Study (FIS, http://www.msc.fema.gov/)	100-year flood lines are used to derive the reference height

Notes: USDA = US Department of Agriculture; NRCS = Natural Resources Conservation Service; EPA = Environmental Protection Agency; USACE = US Army Corps of Engineers; FEMA = Federal Emergency Management Agency.

$$P = c * \gamma * \eta * H * Q \quad (2.1).$$

In Eq. (2.1), η is the generating efficiency, γ = 9800 N/m^3 is the specific weight of water, and c = $(0.3048)^4$ is the unit conversion factor. For the purpose of hydropower resource assessment, future hydropower plant operation is usually considered to be around the optimal operating point; therefore η can be reasonably assumed to be a constant 0.85 (e.g., USACE, 1983).

For flow, although there is no precise answer regarding what threshold should be used for hydropower resource assessment, Q_{30}, defined as the 30% exceedance quantile from the daily flow-duration curve, is generally regarded as a suitable empirical value that would result in an estimate in the range of the optimal installed capacity per dollar of capital investment (Section 3.1, Reclamation, 2011). The NSD assessment hence used Q_{30} as the plant hydraulic capacity for consistency with Reclamation (2011). As described in the details in Hadjerioua et al. (2013), for each HUC04 subregion, a conversion ratio is estimated by comparing Q_{30} from USGS NWIS daily streamflow gauge stations to the corresponding NHDPlus annual mean flow, so that the ratio can be used to estimate Q_{30} for each NHDPlus flowline.

For hydraulic head, a reference height, H_{ref}, defined as the height from a future development location to the nearest FEMA 100 year flood line, is used to estimate the hydropower potential at an NSD stream-reach. Although the purpose of FEMA flood analysis is unrelated to hydropower, the current flood zones may provide valuable insights for inferring the selection of future NSD stream-reaches. To be more specific, owing to regulatory constraints, there are usually fewer existing residences or civil structures in FEMA 100 year flood zones (i.e., they are relatively empty); hence, the FEMA 100 year flood line can be regarded as an invisible boundary of existing civil development. So if NSD inundation is limited to the regions within FEMA 100 year flood zones, there is more of a chance that new hydro development will affect fewer existing structures and would potentially be less costly.

With the above simplification, the potential NSD capacity P_{NSD} (Watt) can be estimated by

$$P_{NSD} = c * \gamma * \eta * H_{ref} * Q_{30} \quad (2.2).$$

To estimate the potential energy, we further synthesized 20 years of monthly streamflow time series (from January 1989 to December 2008) using USGS WaterWatch unit runoff (Brakebill et al., 2011) for each NSD stream-reach. In month m, let $Q_{WW,m}$ (cfs) be the synthesized WaterWatch streamflow and T_m (hour) be the total number of hours; Eq. (2.3) can then be used to estimate the potential energy production, $E_{NSD,m}$ (watt * hour/month):

$$E_{NSD,m} = \begin{cases} c * \gamma * \eta * H_{ref} * (Q_{30} * T_m), & Q_{WW,m} > Q_{30} \\ c * \gamma * \eta * H_{ref} * (Q_{WW,m} * T_m), & 0 \le Q_{WW,m} \le Q_{30} \end{cases} \quad (2.3).$$

Since our target is new run-of-river projects with limited storage, the flow $Q_{WW,m}$ that is greater than Q_{30} can hardly be stored and is assumed to be spilled directly. After the monthly energy $E_{NSD,m}$ is estimated, the potential mean annual energy production, E_{NSD} (watt * hour/year), and monthly energy production, E_{JAN}, E_{FEB}, …, and E_{DEC} (watt * hour/month), can be estimated. The energy estimators can be improved in future studies by increasing the resolution and accuracy of the streamflow time series.

It should be noted that Eqs. (2.2) and (2.3) are based on a reservoir-impoundment model (i.e., the location of a future powerhouse is assumed to be immediately downstream of a dam with all available net hydraulic head resulting from the impoundment). Another common choice is the flow-diversion model, which uses penstocks/conduits to divert water from an upstream intake point to a downstream powerhouse and then return the flow back to the stream. The flow-diversion model does not require a dam higher than the reservoir-impoundment model and so may result in less 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 in a corresponding reservoir-impoundment model with a similar head. In order to capture the total U.S. hydropower energy potential, the NSD assessment is based on the reservoir-impoundment model. Based on some further assumptions (see Hadjerioua et al., 2013), the alternative power potential using the flow-diversion model can be calculated by reducing the hydraulic head to account for the frictional loss through diversion.

2.1.3. Procedures for Resource Evaluation

The general assessment procedures are described below, with an overall flowchart shown in Figure 2.1.

1. **Preliminary selection of stream segment population (SSP).** There are around 3 million raw NHDPlus flowlines in the conterminous United States (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 new run-of-river projects, it was decided to exclude NHDPlus flowlines with estimated annual mean flow $Q_{NHDPlus}$ of less than 35 cfs, in which the excluded flowlines will need at least 400 ft of head for 1 MW of 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 overlap with existing water bodies are also removed, since the water may have been regulated by existing dams (i.e., not in the new hydro resource class).

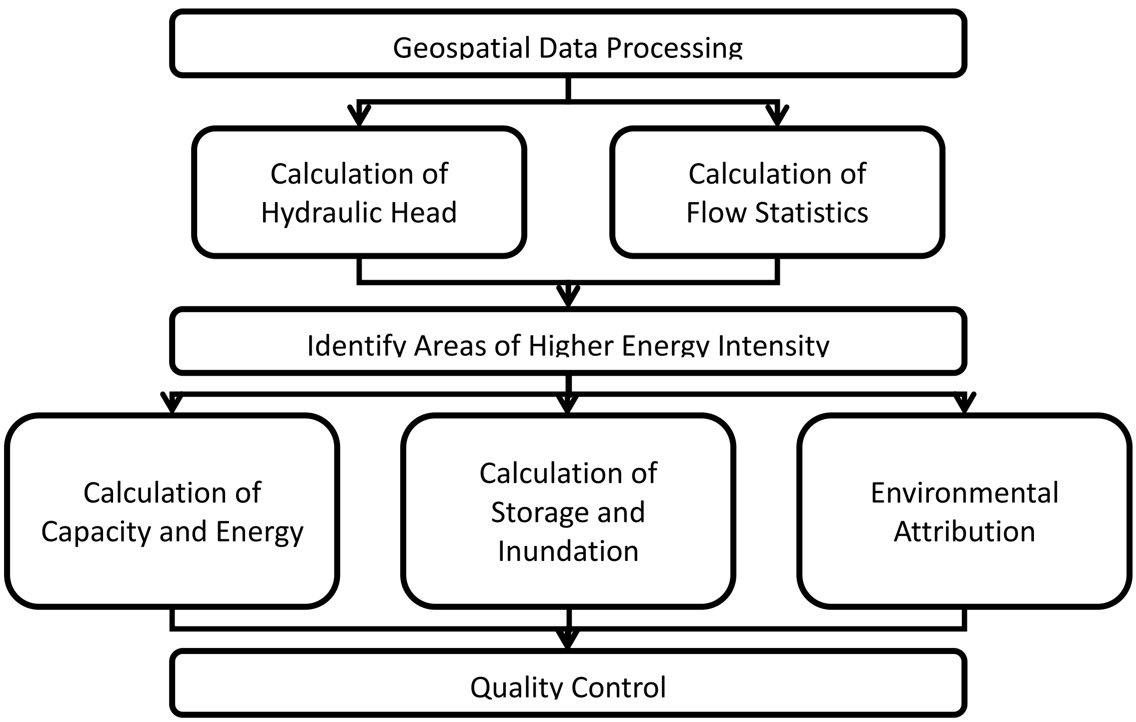

Figure 2.1. General steps of the NSD methodology.

2. **Discretization of NHDPlus flowlines.** Given that the NHDPlus flowlines vary in length (from less than a mile to several miles), all NHDPlus flowlines in SSP are discretized into 150 m long subsegments to better identify the potential NSD stream-reaches. 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 2.2. The interpolated elevation may be inconsistent with the corresponding 10 meter NED, mainly because the original NHDPlus elevation was derived from the 30 m NED. Quality control was performed to filter out those stream-reaches with larger inconsistencies in elevation between NHDPlus and NED. Based on the findings from national implementation, elevations from different datasets are mostly consistent at the identified NSD stream-reaches and are not a source of significant uncertainty.

3. **Calculation of reference height (H_{ref}).** A reference height, H_{ref}, defined as the height from a discretized subsegment 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 subsegment, 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. Elevations of these end points are then looked up from the 10 m NED and used to calculate H_{ref}. If the FEMA 100 year flood lines are missing for too many locations, the median H_{ref} from all other identified subsegments in the same HUC04 subregion is used instead.

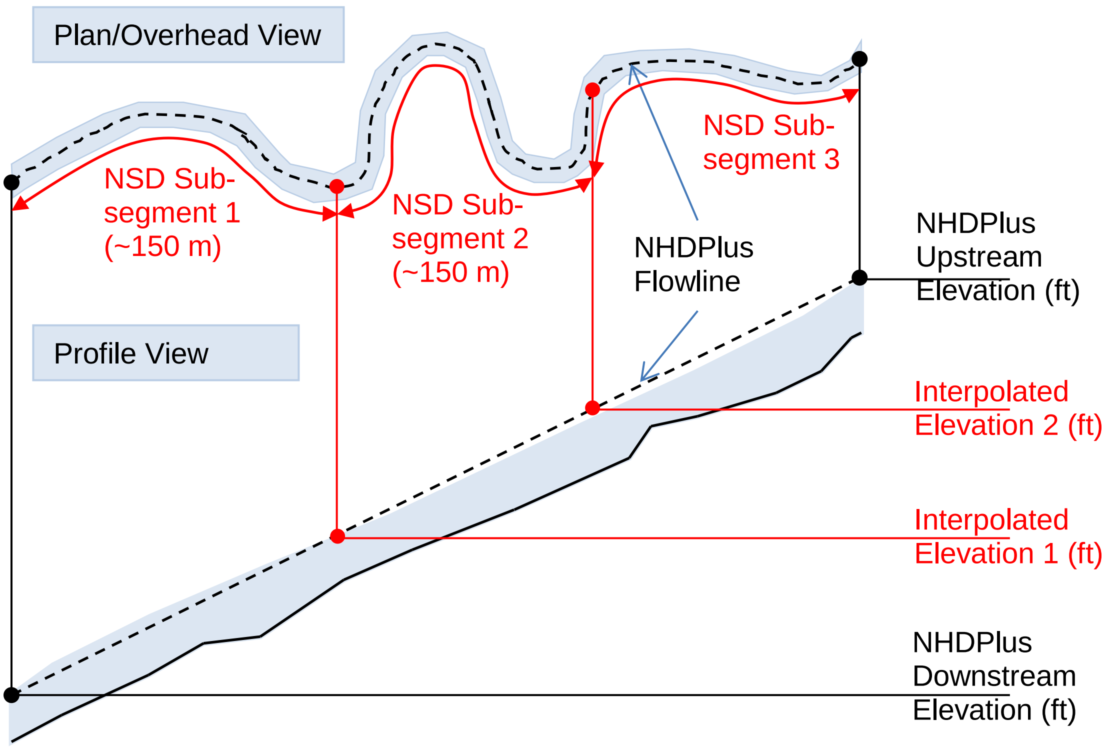

Figure 2.2. Illustration of NHDPlus flowline discretization.

4. **Calculation of plant hydraulic dapacity (Q_{30}).** For each subregion, all USGS NWIS gauge stations with complete 1989–2008 daily observations are identified. The 30% daily exceedance flow (Q_{30}) is then computed at each gauge station. Consistent with Step 1, gauges with Q_{30} of less than 35 cfs were excluded. At the same location as the USGS gauge station, the corresponding NHDPlus annual mean flow $Q_{NHDPlus}$ was identified for comparison. Given that a strong linear relationship is typical between Q_{30} and $Q_{NHDPlus}$, a conversion ratio was estimated to calculate Q_{30} based on $Q_{NHDPlus}$, so that the plant hydraulic capacity can be estimated at each NHDPlus subsegment. 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.

5. **Stream-reach 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_{30}, and average channel slope S_0 (elevation drop divided by the river length). Although

the product of H_{ref} and Q_{30} is proportional to power, implying that higher dam height may result in larger power output, raising dam height usually comes with a tradeoff 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. Following the decreasing order of HQS, NHDPlus subsegments are identified and transferred from SSP to the new stream-reach development population (NSDP). All subsegments that will be inundated by the identified NSDP will be removed from the SSP before the next iteration. The process will be repeated until all potential sites with 1 MW of minimum raw potential have been identified and included in the NSDP. The detailed stream-reach identification methods can also be found in Pasha et al. (2014).

6. **Calculation of storage (V_{NSD}) and delineation of inundated surface area (A_{NSD}).** Once a potential stream-reach and a targeted dam height (H_{ref}) have been suggested, it is of interest to identify those upstream regions that may be inundated as a result of new hydro development. By estimating the flow direction of each 10 m 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 m resolution flow duration grids from NHDPlus dataset are insufficient and must be re-estimated (based on the 10 m resolution NED).

7. **Calculation of hydropower capacity (P_{NSD}) and hydroelectricity energy (E_{NSD})**. After the reference height (H_{ref}) and plant hydraulic capacity (Q_{30}) are estimated, Eq. 2.2 is used 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} serves 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.

8. **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 m resolution NED and it can be inconsistent with the 10 m. 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.

Because a new hydropower cost modeling effort was just initiated in mid-2013, the originally planned cost estimation task (Hadjerioua et al., 2013) is deferred until more credible cost data and models have become available to the research team.

2.2. Environmental Attribution

In an NSD assessment, environmental attributes are considered to be ecological, socioeconomic, 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. The environment is considered to be a defined area surrounding each potential hydropower site, the size of which depends upon the particular issue under consideration.

A four-step process is used to discern the ecological, socioeconomic, and legal/geopolitical attributes of interest for each potential area of new hydropower development:

1. Hypothesis generation is used to compile a comprehensive list of potential environmental issues and information required to evaluate each issue.
2. Spatial and tabular datasets are gathered using internet sources. The availability of needed information is assessed, and, based on data availability, a prioritized list of data sets is generated.
3. Some datasets are not in a format or scale applicable to this analysis or lacked additional relevant information. Thus derived datasets are created at similar spatial scales using geospatial processing and tabular data summarization.
4. All spatial datasets are used to attribute each identified stream-reach with environmental information in a tabular format.

2.2.1. Data Sources

Assessing potential environmental issues related to hydropower development requires compiling information on natural resources, geopolitical boundaries, existing infrastructure, cultural, aesthetic, and recreational needs. Before any information is gathered, potential impediments to new hydropower development (including possible environmental, geopolitical, and socioeconomic concerns) are identified via external consultation or document reviews. Environmental impact statement (EIS) reports and FERC license approval articles are inspected to identify potential issues. Once a sufficient list of issues is generated, the various types of information required to characterize and analyze each are produced. Information is preferred at the scale of the entire country or conterminous United States. Internet searches are also 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 are 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; therefore, all potential development areas within the same HUC08 would share similar attribution for these variables. Table 2.2 summarizes the major environmental data sources used in this section.

Table 2.2. Summary of Data Sources Used in the Environmental Attribution

Data type	Data source	Note
Fish species digital distribution	• NatureServe digital distribution maps of freshwater fishes of the United States	Spatially summarizes federally listed fish species and traits
Federally listed species (ESA)	• U.S. FWS endangered species program	Species lists provide types of organisms and listed status
Federal and IUCN ranking status for fish	• NatureServe explorer species data	Lists provide an indication of fish imperilment and vulnerability
Critical habitats	• U.S. FWS Critical Habitat Portal	Polygon and polyline coverage of federally listed species
Conservation lands	• USGS GAP analysis—Protected area database of the United States	Geopolitical boundaries (national parks, state parks, historic landmarks)
County boundaries	• U.S. Census Bureau	United States 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), and so on
Fishing and boat ramp access	• DeLorme Publishing Company (2012)	Point locations of fishing and boat ramp access points
Kayak/raft access	• American Whitewater, National Whitewater Inventory (AW, 2012)	Locations of boat launch/take out points for whitewater boating
Waterfalls	• Geology.com, U.S. Waterfalls (http://geology.com/waterfalls/)	Point locations of each state's waterfalls

2.2.2. Methodology

All data layers used in this analysis are illustrated in Figure 2.3. Most data sources listed in Table 2.2 can be used directly in assigning environmental attributes to hydropower development areas. However, the existing resolution and presentation of some raw data sources may preclude meaningful environmental attribution. Thus some raw data are summarized into new derived data layers for attribution (Figure 2.3).

Based on Section 2.1, potential stream-reaches for new development and inundated areas were identified, providing virtual dams (points) and associated impoundments (polygons) (Figure 2.4). Because dams have potential downstream effects, downstream stream-reaches (i.e., tailwaters) should be included as elements 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 km or 10 miles would be sufficient to capture most 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 16 km (Figure 2.4). Because NHDPlus flowlines vary in length, tailwater reach lengths also vary. Environmental attribution was conducted separately for points (dams), lines (tailwaters), and polygons (impoundments).

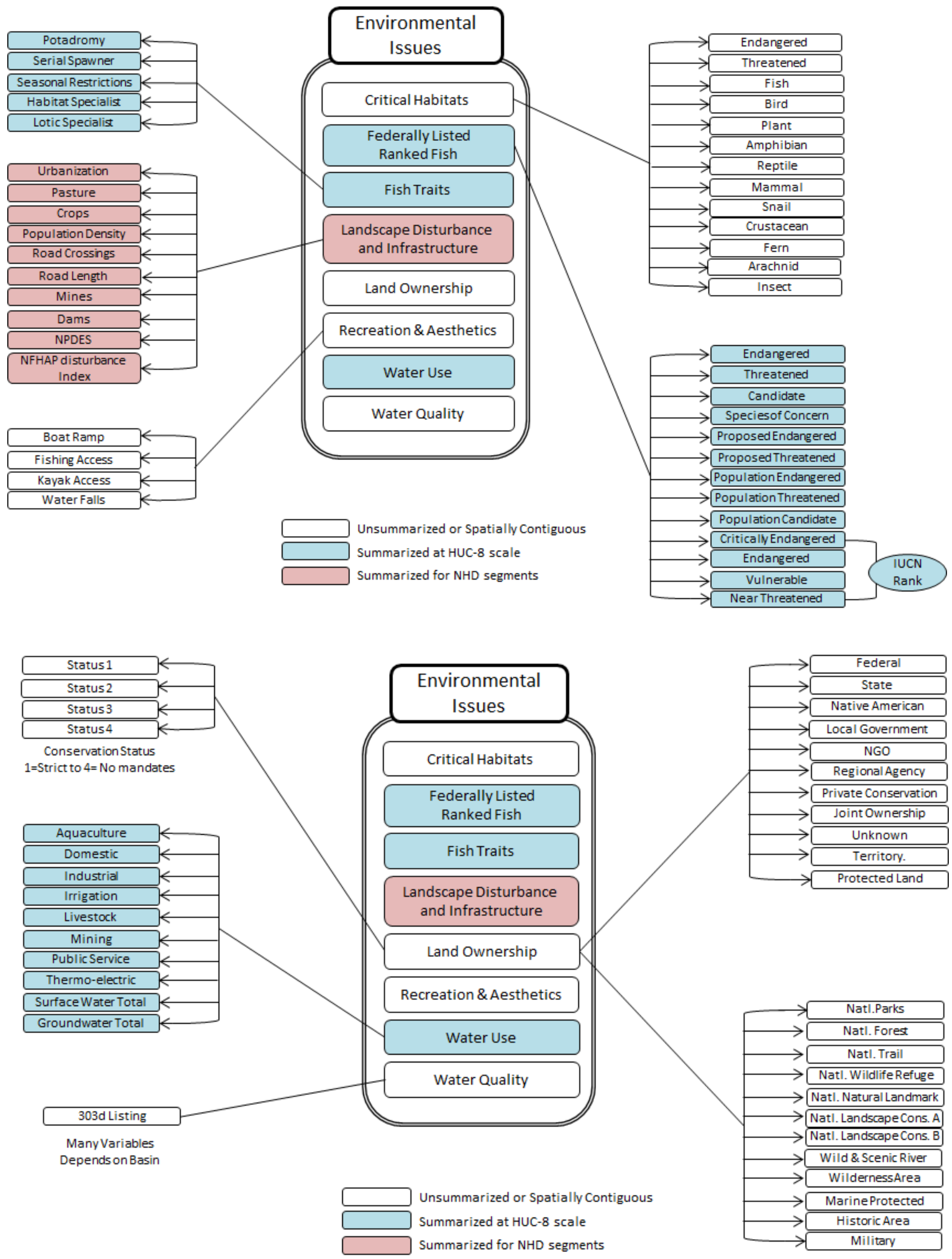

Figure 2.3. Conceptual organization of data layers and variables. Chart does not represent structural linkages (i.e., database connections) but hierarchical organization. Major environmental issue categories in the center are further divided into many variables, which are factors actually attributed to potential hydropower development areas. Color codes represent whether data layers have been summarized and the scale of summarization.

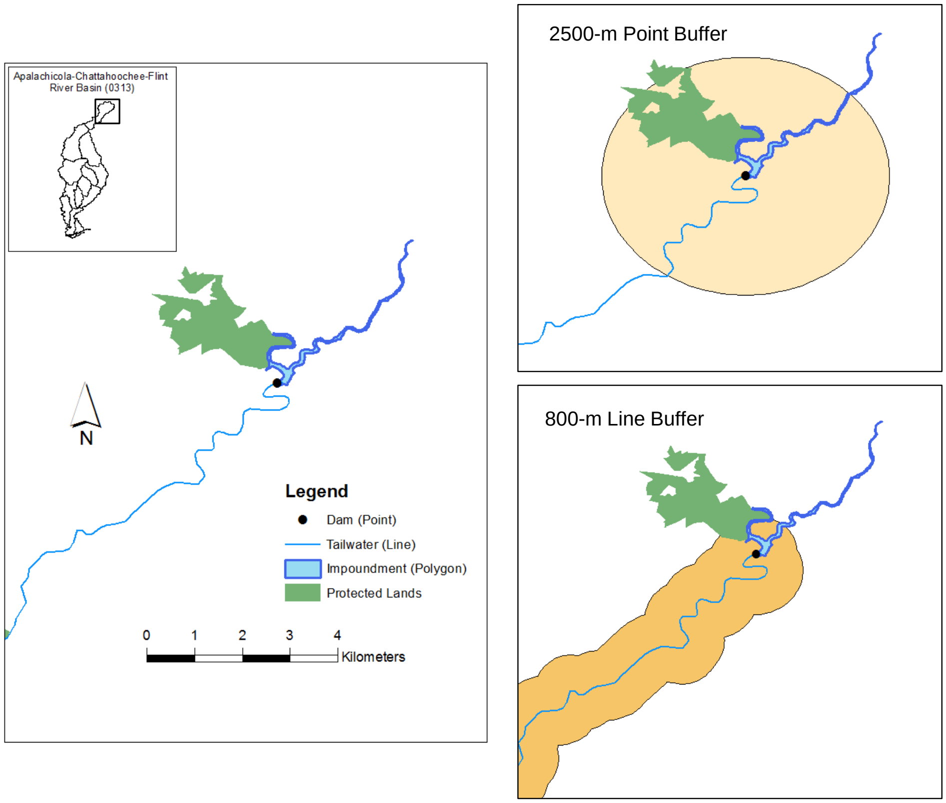

Figure 2.4. Example of virtual new hydropower site consisting of a point (dam), line (tailwater), and polygon (impoundment) and examples of buffers applied to the point and line.

Buffers are required to ensure that layers of different GIS transformations can interact despite potential errors in spatial display or inaccuracies in the underlying data layers. But 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 (ESRI, 2012). 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 2000 m of large settlements, 500 m of single dwellings, and 1000 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 1500 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 2.3). Points were buffered with an 8 km (5 mile) radius to assess potential critical habitat issues related to potential road development, power line development, and associated construction (Figure 2.4). 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 ft), 5.1 km (3.2 mile), 15.7 km (9.7 mile), and 32.2 km (20 mile) (FERC 2003, FERC 2011 a,b,c,d). Two projects reviewed did not have transmission lines associated with facilities because 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 the 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 because they were derived by highly 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 do 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 mile]) were used to attribute polygons depending on the data layer (Table 2.3). 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, such as road access, can arise because of land ownership proximity despite touching boundaries. 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 2.3).

Table 2.3. 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	8,000	800	800
Land ownership	Land owner (agency)	2,500	800	800
Land ownership	Land designation	2,500	800	800
Land ownership	Land conservation status	2,500	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	2,500	800	800

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 polygon 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 Analysis Program (GAP) status code (Figure 2.3). 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 only binary responses to indicate the presence or absence of a potential environmental issue, the number of entities possibly affected by hydropower development was 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 provides the reason for impairment (e.g., temperature, low oxygen, sediment, pollutant). After 303d waterbodies were joined 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. Data within NFHAP are 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 locations 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 and so have 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 upstream and downstream flowlines.

3. SUMMARY OF FINDINGS

3.1. Summary of National Resources

The estimated NSD capacity and generation, including both higher-energy-density (>1 MW per reach) and lower-energy-density (<1 MW per reach) stream-reaches, are summarized in Table 3.1 for each hydrologic region. The highest potential is identified in the Pacific Northwest Region (32%), followed by the Missouri Region (15%) and the California Region (9%). In total, the undeveloped NSD capacity is 84.7 GW, around the same size as the existing U.S. conventional hydropower nameplate capacity (79.5 GW; NHAAP, 2013). In terms of energy, the total undeveloped NSD generation is estimated to be 460 TWh/year, around 169% of average 2002–2011 net annual generation from existing conventional hydropower plants (272 TWh/year; EIA, 2013). Given the run-of-river assumption, NSD stream-reaches have higher capacity factors (53%–71%), especially compared with conventional larger-storage peaking-operation projects that usually have capacity factors of around 30%.

Table 3.1. Summary of NSD Findings by Hydrologic Regions

	Hydrologic region	Capacity (MW)	Generation (MWh/year)	Capacity factor
01	New England	2,143	12,433,000	66%
02	Mid-Atlantic	4,710	25,945,000	63%
03	South Atlantic-Gulf	2,561	14,205,000	63%
04	Great Lakes	1,425	8,444,000	68%
05	Ohio	4,757	25,288,000	61%
06	Tennessee	1,363	7,995,000	67%
07	Upper Mississippi	2,081	11,546,000	63%
08	Lower Mississippi	2,072	12,074,000	67%
09	Souris-Red-Rainy	151	787,000	60%
10	Missouri	11,686	69,011,000	67%
11	Arkansas–White–Red	6,013	33,994,000	65%
12	Texas-Gulf	783	3,666,000	53%
13	Rio Grande	1,637	9,310,000	65%
14	Upper Colorado	3,033	18,232,000	69%
15	Lower Colorado	2,613	16,273,000	71%
16	Great Basin	564	3,105,000	63%
17	Pacific Northwest	25,226	148,999,000	67%
18	California	7,054	37,987,000	61%
19	Alaska*	4,723	(not estimated)	(not estimated)
20	Hawaii*	145	699,000	53%
	Total	84,740	459,993,000	66%

*The Alaska and Hawaii potential are estimated by a different approach from other regions.

The estimated NSD capacity and generation, including both higher-energy-density (>1 MW per reach) and lower-energy-density (<1 MW per reach) stream-reaches, are further summarized in Table 3.2 for each state. The downstream end of a stream-reach is treated as the possible development location to determine specific location within states. When a stream-reach is located on the border of multiple states, the potential capacity and generation are distributed evenly into each neighboring state to compute the state-based totals. The highest potential is found in Oregon, Washington, and Idaho, the three states in the Pacific Northwest, followed by California, Alaska, Montana, and Colorado.

Table 3.2. Summary of NSD Findings by States

State	Potential capacity (MW)	Potential generation (MWh/year)	State	Potential capacity (MW)	Potential generation (MWh/year)
AK*	4,723	(not estimated)	MT	4,763	28,201,000
AL	663	3,522,000	NC	857	5,067,000
AR	1,253	6,685,000	ND	252	1,524,000
AZ	2,484	1,5459,000	NE	1,942	11,917,000
CA	6,983	3,7564,000	NH	407	2,410,000
CO	4,295	2,5623,000	NJ	171	1,006,000
CT	151	865,000	NM	1,280	7,193,000
DE	6	35,000	NV	232	1,245,000
FL	170	956,000	NY	1,900	10,715,000
GA	621	3,604,000	OH	535	2,800,000
HI*	145	699,000	OK	1,147	5,838,000
IA	736	3,869,000	OR	8,920	53,353,000
ID	7,018	41,015,000	PA	2,889	15,795,000
IL	599	3,241,000	RI	13	71,000
IN	581	3,123,000	SC	309	1,844,000
KS	2,479	14,931,000	SD	230	1,363,000
KY	675	3,301,000	TN	1,002	5,618,000
LA	790	4,463,000	TX	1,580	8,089,000
MA	194	1,114,000	UT	1,376	8,246,000
MD	223	1,212,000	VA	1,234	6,869,000
ME	1,132	6,532,000	VT	401	2,344,000
MI	449	2,866,000	WA	7,381	43,788,000
MN	568	3,191,000	WI	556	3,513,000
MO	2,512	14,514,000	WV	1,851	9,910,000
MS	1,129	6,449,000	WY	2,960	10,776,000

*The AK and HI potential are estimated by a different approach from the other 48 states.

The higher-energy-density stream-reaches (>1 MW per reach) are further shown in Figure 3.1, with potential capacity aggregated to HUC08 subbasins for illustration. The detailed regional results are discussed in the remaining sections of this report. For more insight into this new assessment, Appendix A provides a comparison with the previous national hydropower resource assessment.

3.2. Summary of Environmental Attribution

The total estimated NSD capacity from higher-energy-density stream-reaches (>1 MW per reach) overlapping with various environmental concerns is summarized for each hydrologic region. The proportion of capacity from stream-reaches intersecting environmental concerns varies according to region and the environmental variable. For example, a high proportion of the total NSD capacity in the Pacific Northwest Region is associated with stream-reaches overlapping ESA critical habitats whereas no or very little capacity is associated with stream-reaches overlapping critical habitats in the Great Lakes, Mid-Atlantic, Ohio, Texas-Gulf, and Upper Mississippi regions (Figure 3.2). In contrast, water-quality concerns are pervasive, affecting considerable NSD capacity in all regions (Figure 3.3). The Pacific Northwest, California, Lower Colorado, Great Basin, and Upper Colorado regions have higher proportions of NSD capacity from stream-reaches falling within HUC08 subbasins with three or more fish

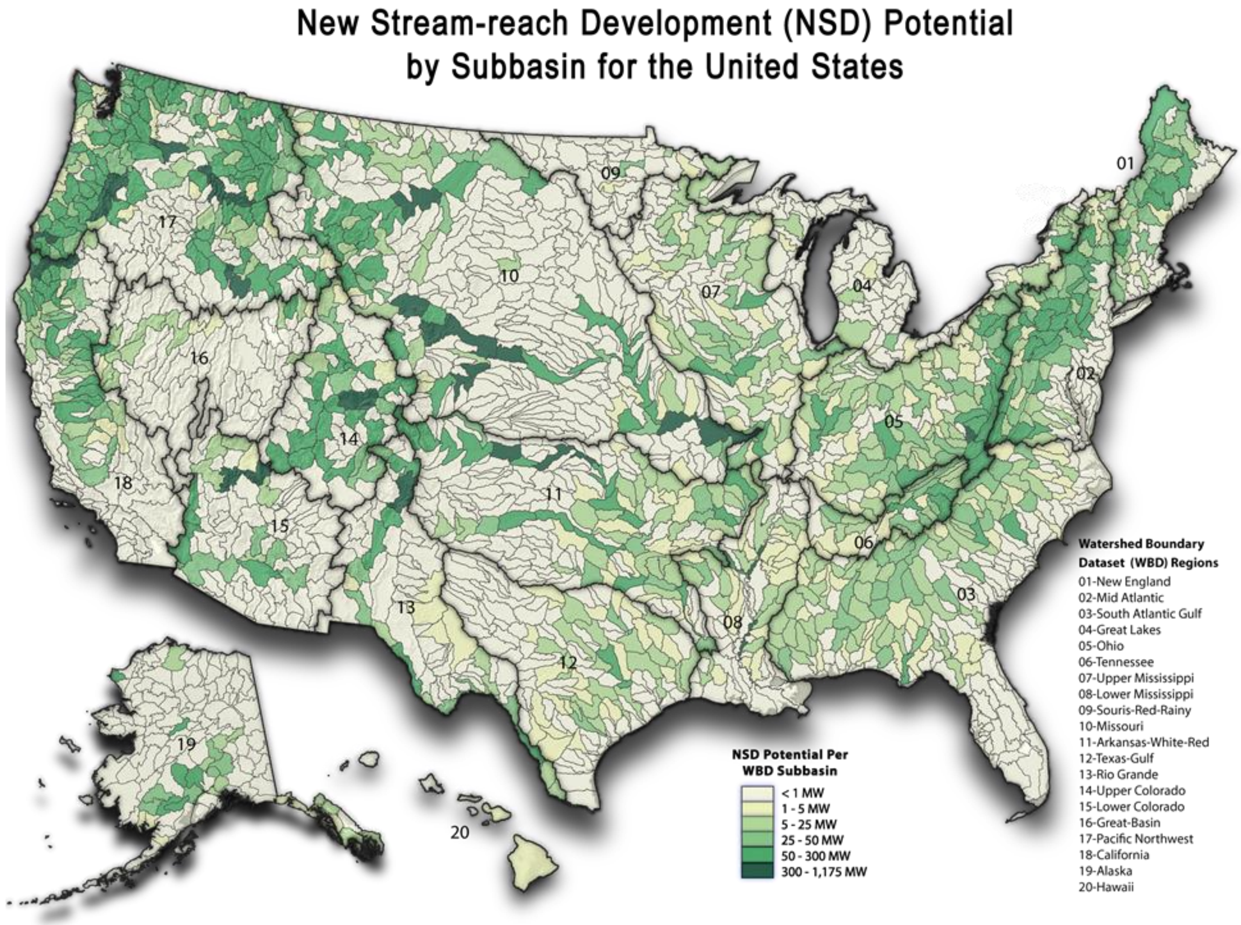

Figure 3.1. Potential new hydropower capacity in the United States (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC08 subbasins for illustration).

species falling under ESA listing categories (Figure 3.4). A considerable proportion of capacity is associated with national parks in the Upper and Lower Colorado Regions (Figure 3.5). Wild and Scenic Rivers overlap with a large number of stream-reaches in the California, Pacific Northwest, and Rio Grande regions (Figure 3.6). Recreation is prevalent across the nation and commonly overlaps with NSD stream-reaches. Recreational boating was associated with most NSD capacity in the eastern and western hydrologic regions but made up a lower proportion of capacity in the midwestern hydrologic regions (Figure 3.7). The proportion of capacity associated with fishing access areas is consistent across the nation; however, a large proportion was present in the Pacific Northwest Region (Figure 3.8). Water use ($l/day \cdot km^2$) is placed into categories of low, moderate, moderate-to-high, high, and very high based on percentile values (20%, 20%–40%, 40%–60%, 60%–80%, and > 80%) for each hydrologic region (to standardize usage across regions). Although water use varies greatly across hydrologic regions, the proportion of capacity associated with various use categories is consistent across the nation with the exception of the Upper and Lower Mississippi Regions (Figure 3.9).

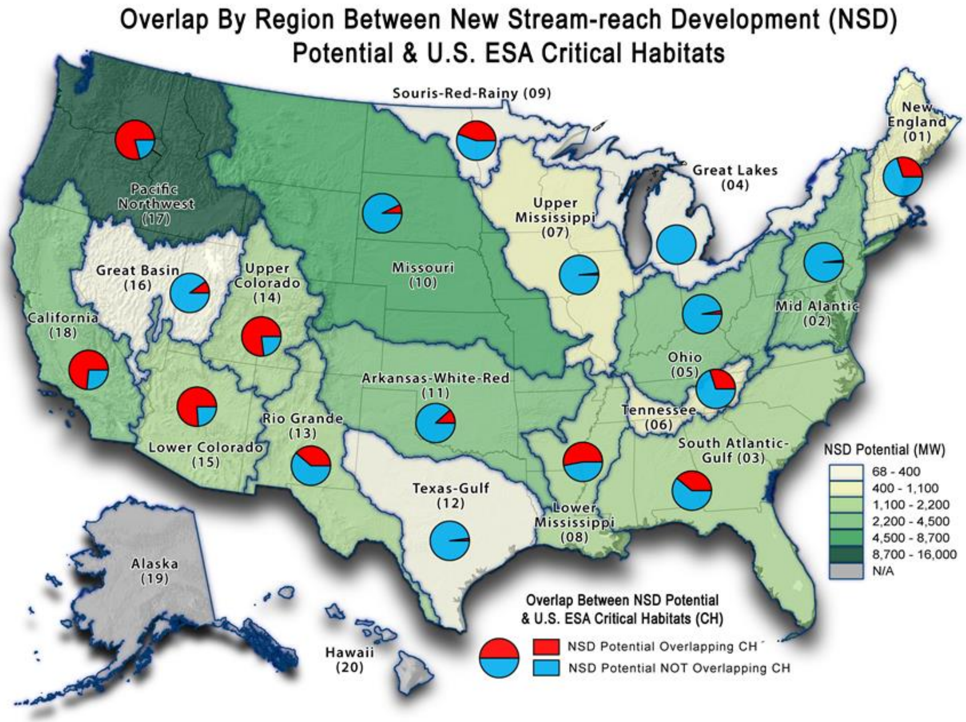

Figure 3.2. Overlap between NSD capacity potential and ESA critical habitats (stream-reaches with potential capacity >1 MW).

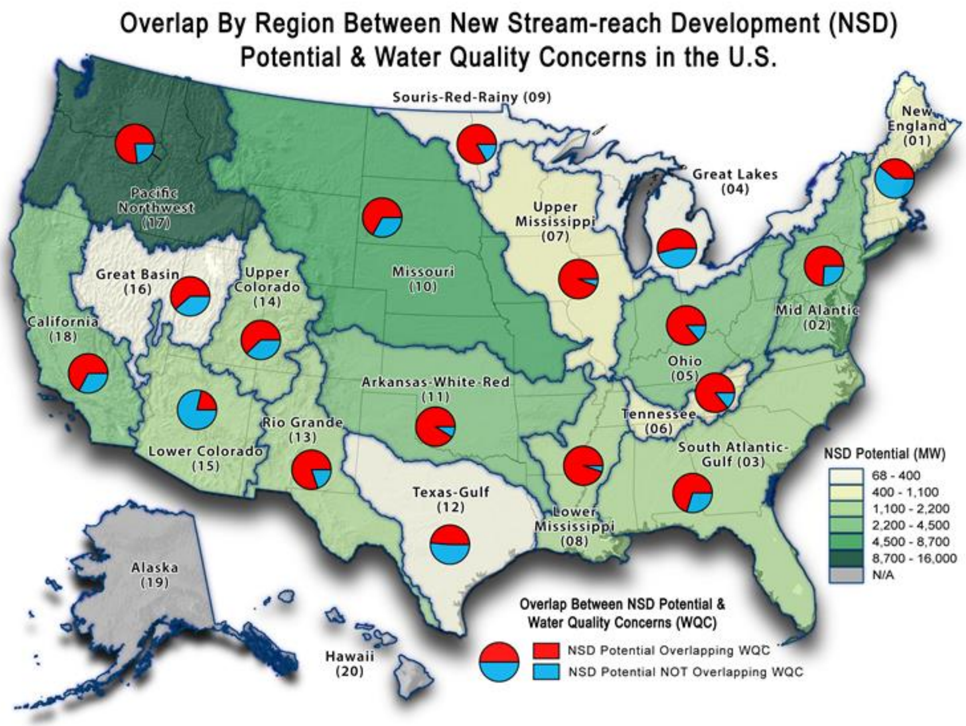

Figure 3.3. Overlap between NSD capacity potential and water quality concerns (stream-reaches with potential capacity >1 MW).

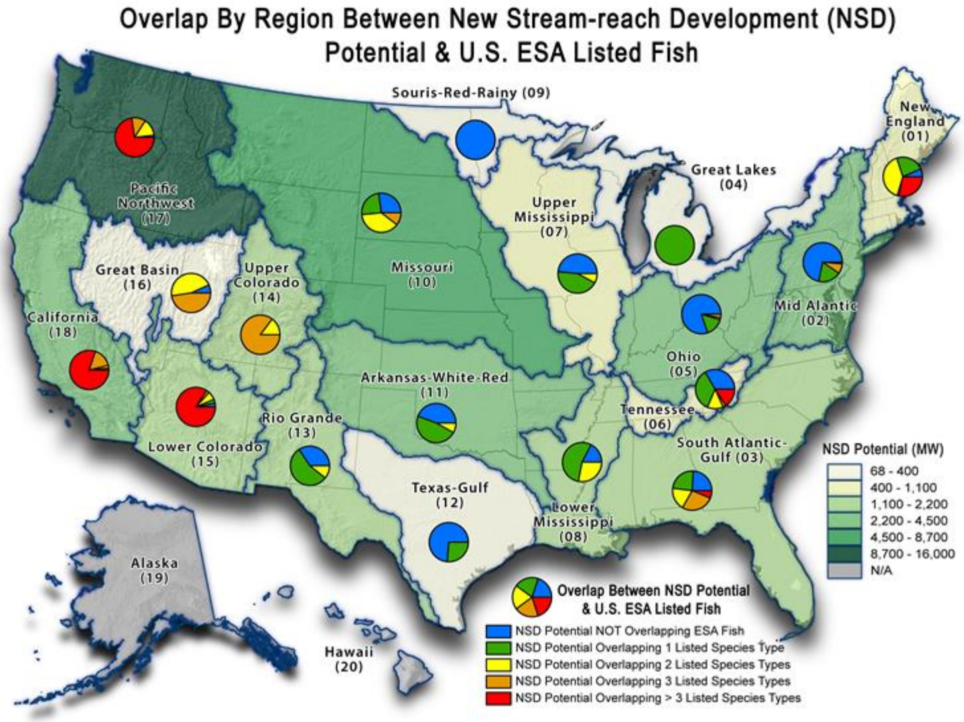

Figure 3.4. Overlap between NSD capacity potential and ESA listed fish (stream-reaches with potential capacity >1 MW).

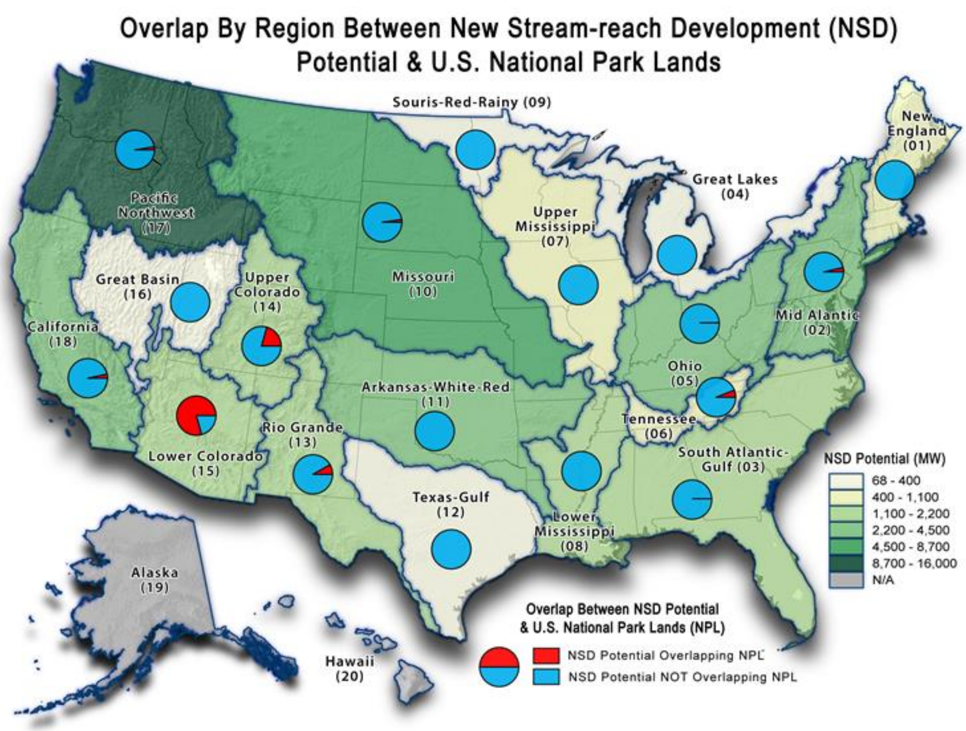

Figure 3.5. Overlap between NSD capacity potential and U.S. national parks (stream-reaches with potential capacity >1 MW).

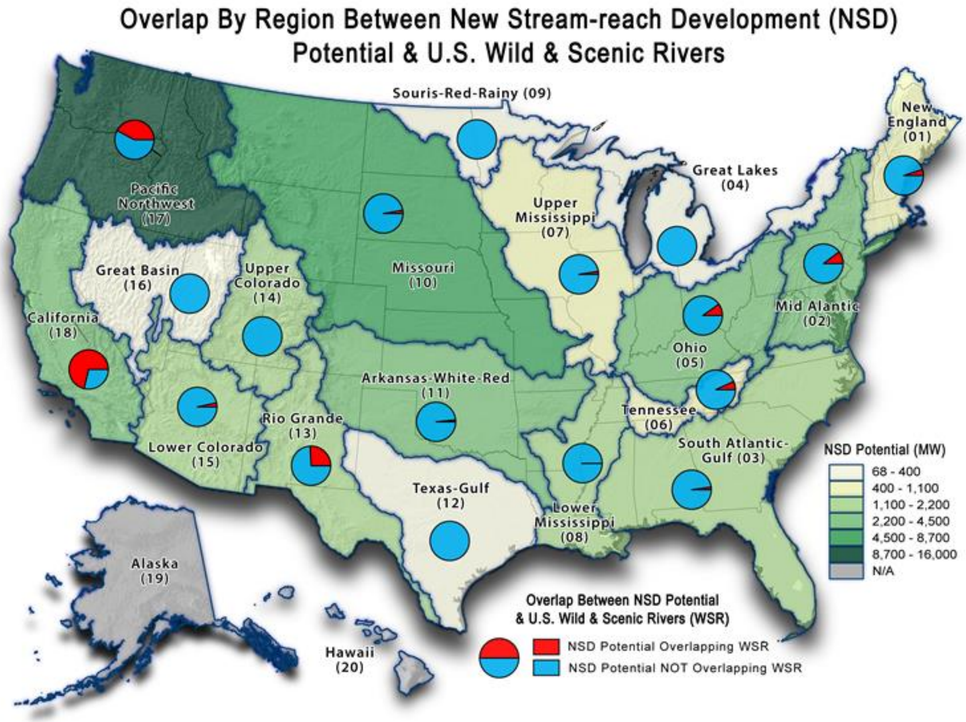

Figure 3.6. Overlap between NSD capacity potential and Wild and Scenic Rivers (stream-reaches with potential capacity >1 MW).

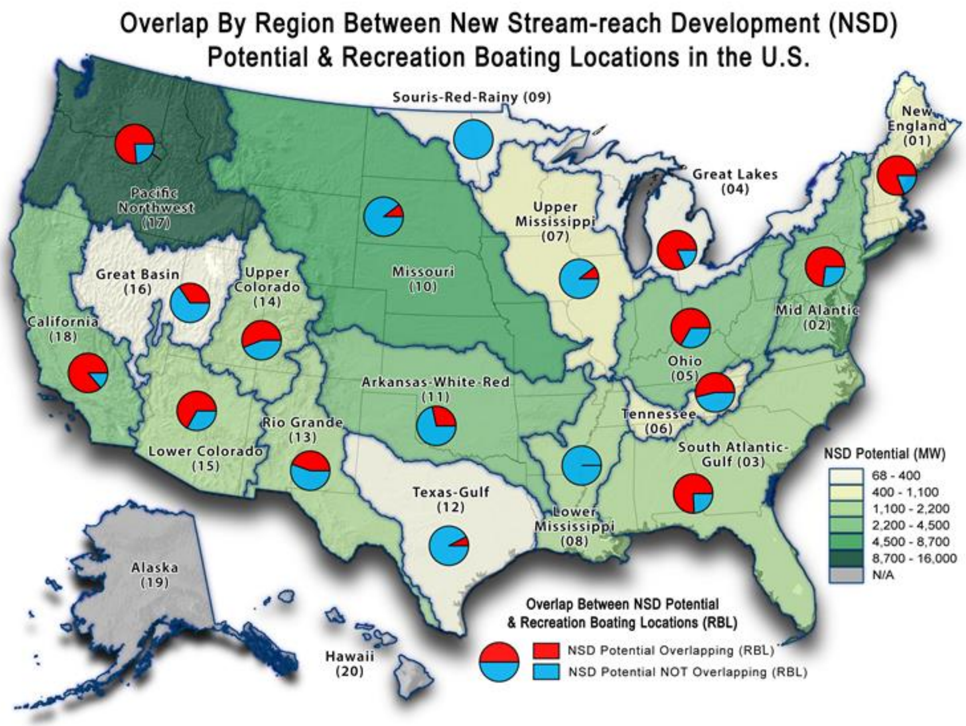

Figure 3.7. Overlap between NSD capacity potential and recreational boating locations (stream-reaches with potential capacity >1 MW).

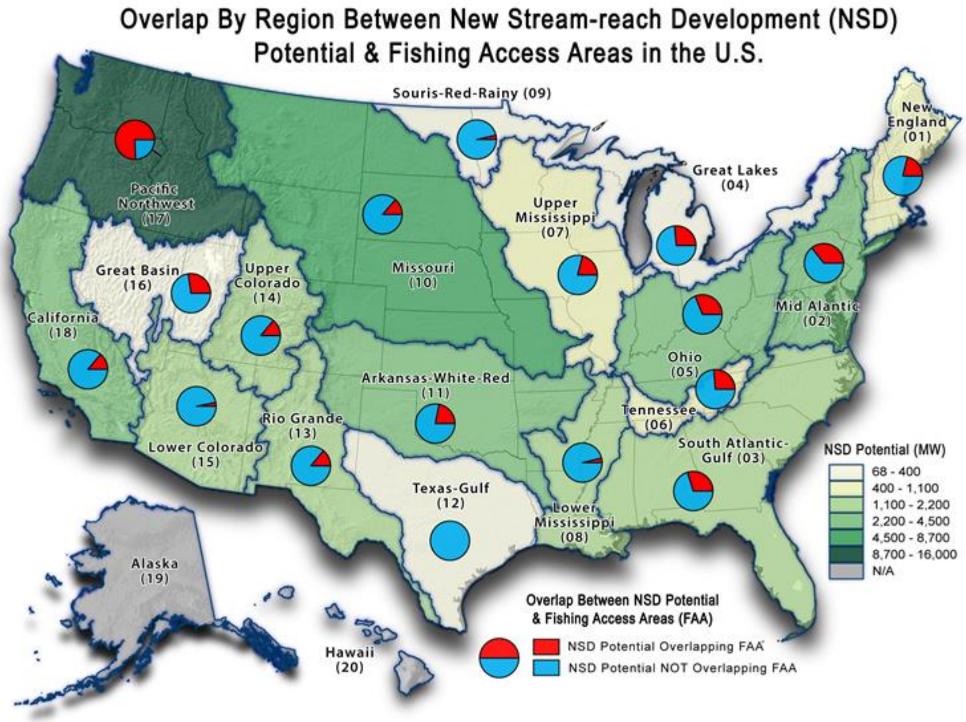

Figure 3.8. Overlap between NSD capacity potential and fishing access areas (stream-reaches with potential capacity >1 MW).

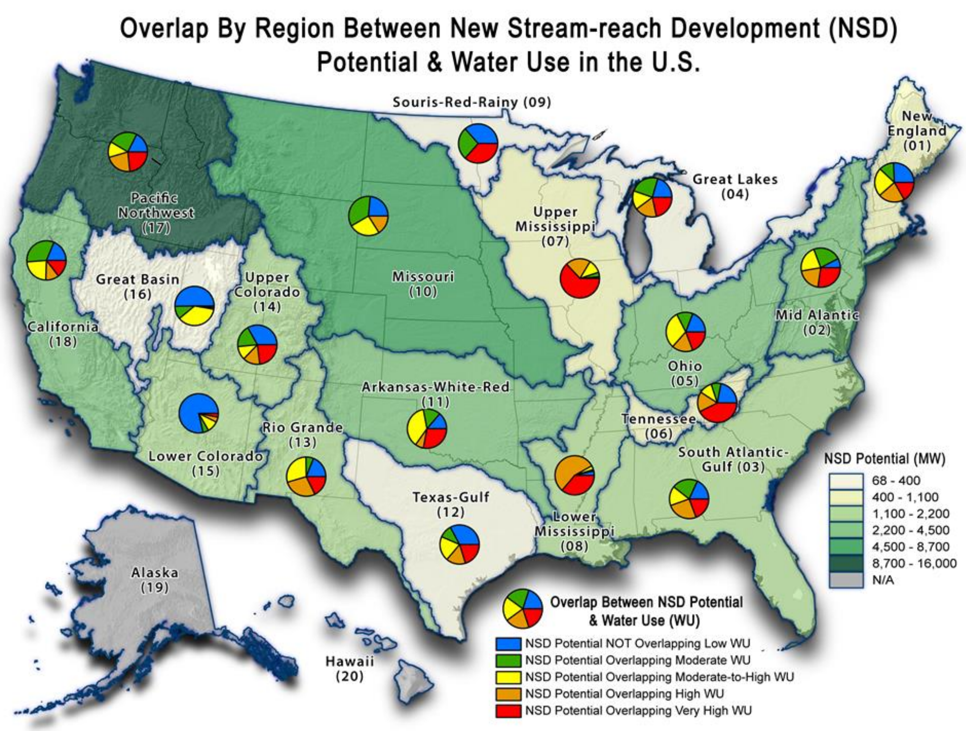

Figure 3.9. Overlap between NSD capacity potential and total freshwater water use (stream-reaches with potential capacity >1 MW).

By examing multiple environmental attributes jointly, further policy and research questions can be explored. For instance, when areas protected by federal legislation limiting the development of new hydropower (national parks, wild and scenic rivers, and wilderness areas) are excluded, the estimated NSD capacity falls to 65.5 GW, slightly lower than the current existing U.S. conventional hydropower nameplate capacity (79.5 GW; NHAAP, 2013), with undeveloped NSD generation estimated to be 347.3 TWh/year, which is roughly 128% of the average–2011 net annual generation from existing plants (272 TWh/year; EIA, 2013). In terms of hydrologic regions and states (Table 3.3 and Table 3.4), the biggest reductions are found in Pacific Northwest and Oregon, mainly due to the large overlapped with wild and scenic rivers.

Table 3.3. Summary of NSD Findings by Hydrologic Regions, Excluding Stream-reaches that are in Close Proximity to National Parks, Wild and Scenic Rivers, and Wilderness Areas

	Hydrologic region	**Capacity (MW)**	**Generation (MWh/year)**	**Capacity factor**
01	New England	2,025	11,791,000	66%
02	Mid-Atlantic	4,144	22,721,000	63%
03	South Atlantic-Gulf	2,439	13,494,000	63%
04	Great Lakes	1,338	7,870,000	67%
05	Ohio	3,795	19,986,000	60%
06	Tennessee	1,228	7,229,000	67%
07	Upper Mississippi	1,983	10,937,000	63%
08	Lower Mississippi	2,067	12,044,000	67%
09	Souris-Red-Rainy	142	737,000	59%
10	Missouri	10,705	63,090,000	67%
11	Arkansas–White–Red	5,771	32,687,000	65%
12	Texas-Gulf	762	3,565,000	53%
13	Rio Grande	1,103	6,237,000	65%
14	Upper Colorado	1,914	11,481,000	68%
15	Lower Colorado	622	3,761,000	69%
16	Great Basin	547	3,008,000	63%
17	Pacific Northwest	16,958	97,859,000	66%
18	California	3,275	18,084,000	63%
19	Alaska*	4,530	(not estimated)	(not estimated)
20	Hawaii*	145	699,000	55%
	Total	65,493	347,280,000	61%

**Given the different methodology and data format, the AK and HI environemtnal attribution is based on a 2000 meter buffer zone. Environemtnal attribution in other regions is based on the Hadjerioua et al. (2013) appraoch.*

Table 3.4. Summary of NSD Findings by States, Excluding Stream-reaches that Are in Close Proximity to National Parks, Wild and Scenic Rivers, and Wilderness Areas

State	Potential capacity (MW)	Potential generation (MWh/year)	State	Potential capacity (MW)	Potential generation (MWh/year)
AK*	4,530	(not estimated)	MT	3,914	23,413,000
AL	646	3,435,000	NC	796	4,697,000
AR	1,108	5,964,000	ND	252	1,523,000
AZ	515	3,090,000	NE	1,851	11,332,000
CA	3,360	18,570,000	NH	394	2,339,000
CO	3,802	22,699,000	NJ	61	359,000
CT	141	807,000	NM	917	5,113,000
DE	5	30,000	NV	226	1,208,000
FL	171	962,000	NY	1,809	10,192,000
GA	580	3,341,000	OH	491	2,561,000
HI*	145	699,000	OK	1,147	5,837,000
IA	738	3,876,000	OR	4,492	25,013,000
ID	4,937	28,645,000	PA	2,418	13,140,000
IL	573	3,092,000	RI	13	73,000
IN	582	3,132,000	SC	284	1,689,000
KS	2,479	14,931,000	SD	112	633,000
KY	662	3,242,000	TN	869	4,908,000
LA	789	4,461,000	TX	1,367	6,862,000
MA	176	1,012,000	UT	678	4,005,000
MD	189	1,036,000	VA	1,080	5,963,000
ME	1,059	6,146,000	VT	400	2,338,000
MI	380	2,407,000	WA	6,055	35,442,000
MN	516	2,870,000	WI	522	3,287,000
MO	2,450	14,145,000	WV	1,228	6,444,000
MS	1,112	6,361,000	WY	2,476	13,949,000

**Given the different methodology and data format, the AK and HI environemtnal attribution is based on a 2000 meter buffer zone. Environemtnal attribution in other states is based on the Hadjerioua et al. (2013) appraoch.*

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4. REGION 1—NEW ENGLAND

4.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation, and mean capacity factors in the New England Region are estimated and summarized in Table 4.1 for both larger (>1 MW) and smaller (<1 MW) stream-reaches. For comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation, and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 2.14 GW, around 118% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 12.43 TWh/year, around 167% of annual net generation from existing conventional hydropower plants. Given the run-of-river assumption, NSD stream-reaches have higher capacity factors, especially compared with other larger-storage peaking-operation projects in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 4.3 and 4.4.

Table 4.1. Summary of NSD Findings in Region 1—New England

	Capacity (MW)	Generation (MWh/year)	Mean Capacity factor
Potential in undeveloped stream-reaches (>1 MW)	1,050	6,161,000	67%
Potential in undeveloped stream-reaches (<1 MW)	1,093	6,272,000	66%
Existing hydropower—conventional hydro	1,821	7,436,000	47%
Existing hydropower—pumped storage	1,571		

4.2. Background Hydrologic Setting

The New England Region encompasses approximately 184,093 km^2 of drainage area in the Northeastern United States. The region extends from Maine to southwestern Connecticut, covering Maine, New Hampshire, Rhode Island, Connecticut, most of Massachusetts, part of Vermont, and small section of New York. This region includes the White Mountains in New Hampshire to gentle rolling hills and mountains in Vermont and Massachusetts to the floodplains in Massachusetts and Connecticut.

Several river systems are located in the New England Region (Figure 4.1), including the St. John, Penobscot, Kennebec, Androscoggin, St. Croix, Merrimack, Connecticut, Pawcatuck, and Byram, with a total length of 19,245 km (i.e., total length of streams with estimated discharge greater than 35 cfs). Metropolitan areas within the region include Portland (ME), Boston (MA), Providence (RI), Hartford (CT), and Manchester (NH). As shown in Figure 4.2, annual precipitation for the New England Region ranges from slightly over 800 to 1500 mm/year and annual runoff from about 400 to around 900 mm/year. Most of the precipitation occurs in the spring. The Connecticut River is tidally influenced from Hartford to Long Island Sound (EPA, 2000).

Existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are also shown in Figure 4.1. The region contains 359 hydropower dams and 102 major non-powered dams, with total storage capacities of around 11,473,000 ac-ft (ac-ft) and 985,000 ac-ft, respectively.

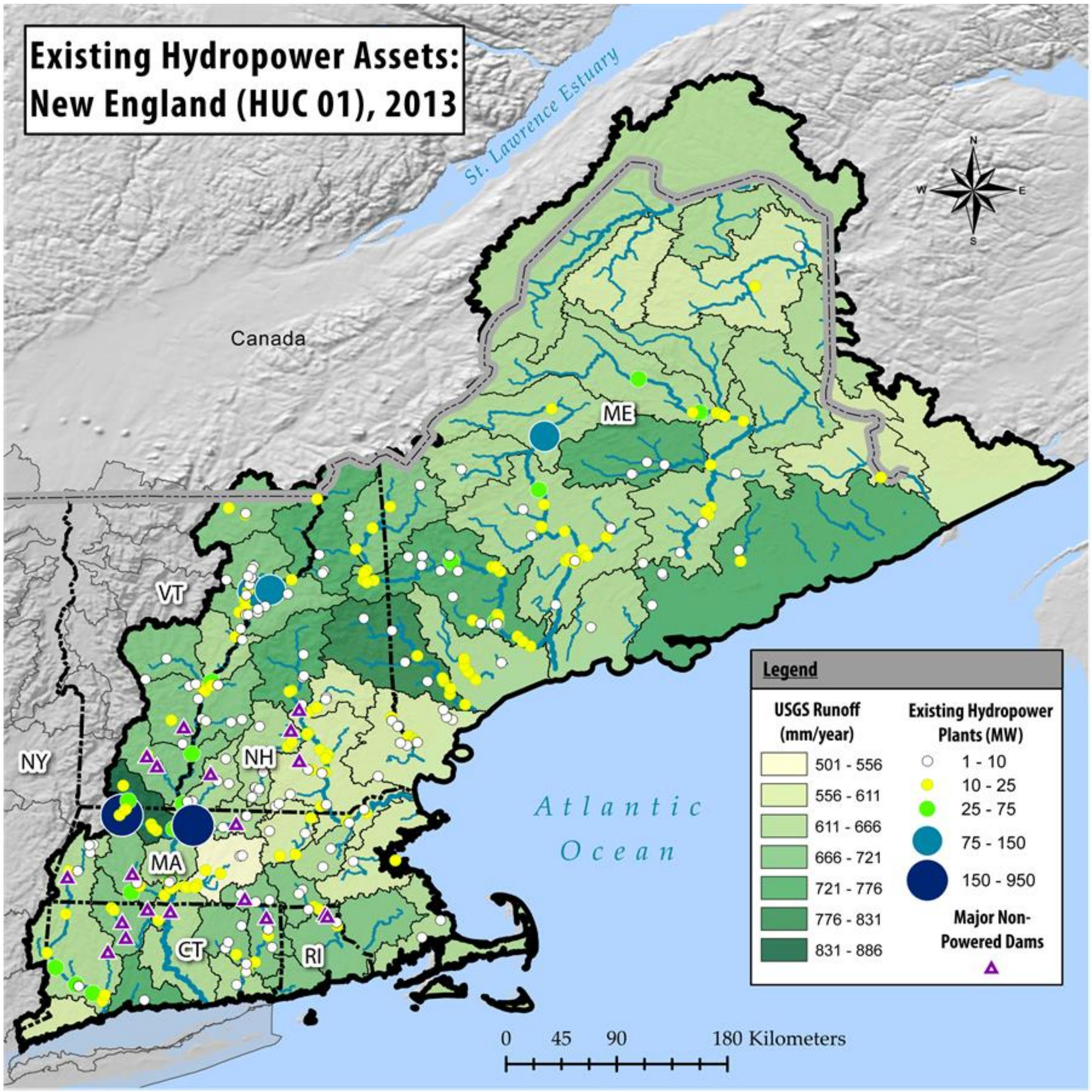

Figure 4.1. Locations of water control projects in Region 1—New England.

4.3. Potential New Hydropower Resources

A total of 283 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) are identified in the New England Region. The NSD results based on HUC04 subregions are summarized in Table 4.2. The highest hydropower potentials are located in the Connecticut Subregion (HUC 0108) and St. John Subregion (HUC 0101), followed by the Penobscot Subregion (HUC 0102), Kennebec Subregion (HUC 0103), and Androscoggin

Subregion (HUC 0104). In these subregions, the Connecticut, St. John, Penobscot, Kennebec, and Androscoggin rivers contain the highest potential for hydropower.

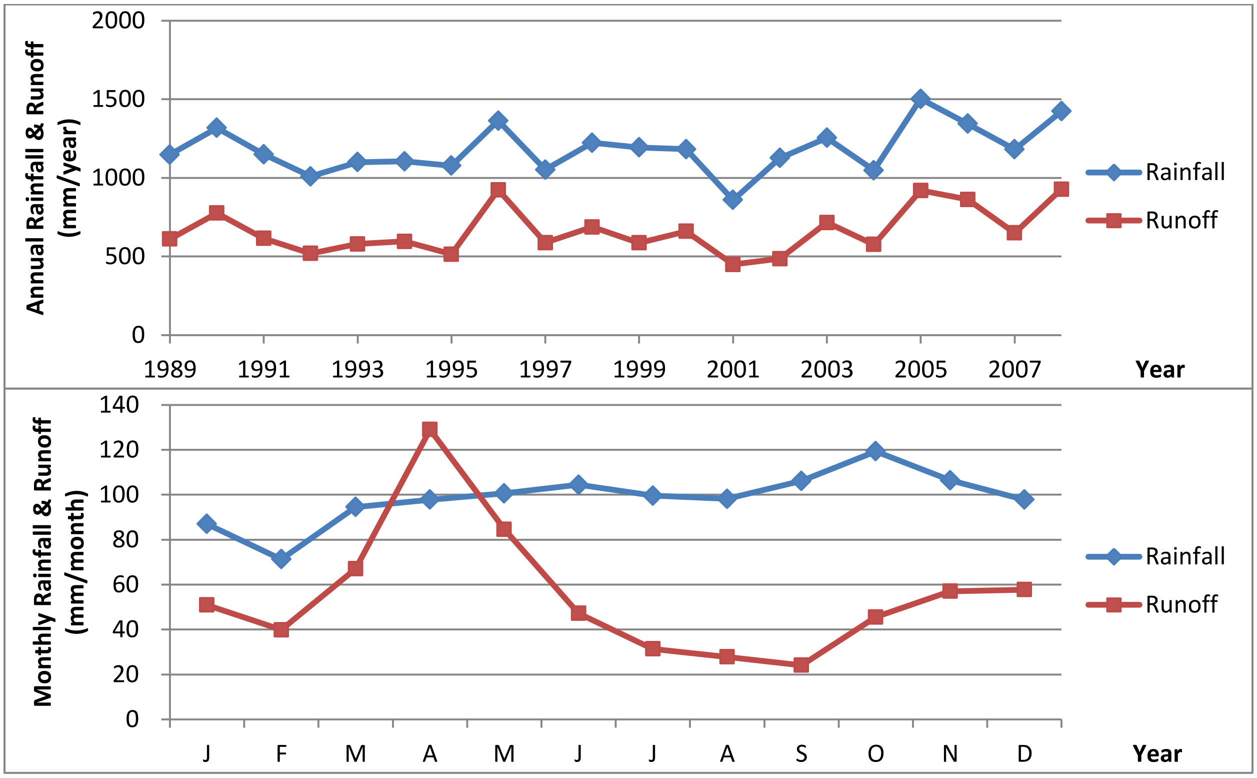

Figure 4.2. Annual and monthly rainfall and runoff of Region 1—New England.

Table 4.2. Summary of Potential New Hydropower Resources in Region 1—New England (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/ reach)	Average residence Time (days)
0101	St. John	34	215.6	1,133,846	33.2	2,682	17,553	5.4
0102	Penobscot	55	178.8	1,017,005	13.9	3,199	1,551	0.3
0103	Kennebec	58	174.7	1,125,622	14.4	2,715	1,004	0.2
0104	Androscoggin	26	110.6	720,201	17.1	3,581	1,808	0.2
0105	Maine Coastal	-	-	-	-	-	-	-
0106	Saco	11	36.3	202,409	17.8	2,538	4,468	1.0
0107	Merrimack	14	50.0	285,880	15.6	3,206	5,485	1.3
0108	Connecticut	63	238.8	1,417,097	37.0	1,777	17,321	9.7
0109	Massachusetts-Rhode Island Coastal	-	-	-	-	-	-	-
0110	Connecticut Coastal	22	45.4	259,180	20.9	1,606	1,270	0.9
0111	St. Francois	-	-	-	-	-	-	-

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 in Figure 4.3. The hydraulic head H_{ref} ranges from 8 ft to the 90th quantile of 44 ft with a median of about 18 ft, suggesting that many of the potential stream-reaches will require low-head hydropower technologies. The design flow Q_{30} ranges from 300 cfs to the 90th quantile of 5000 cfs with a median of just under 2000 cfs. The potential capacity P_{NSD} ranges from 1.25 MW to the 90th quantile of about 7.5 MW with a median of about 2.5 MW. The inundated surface area A_{NSD} ranges from 0 ac to the 90th quantile of 1200 ac with a median of 150 ac. This results in storage values V_{NSD} ranging from 0 to the 90th quantile of 12,500 ac-ft with a median of about 1,250 ac-ft and very short residence times T_{NSD} ranging from <1 day to the 90th quantile of 7 days with a median on the order of hours. In general, the relatively small inundation areas and storage volumes paired with the short retention times for this region are characteristic of run-of-river type hydro facilities. The results of > 1 MW stream-reach potential are illustrated in Figure 4.4, with potential capacity (MW) aggregated to the HUC10 watersheds. The higher-potential capacity sites are generally located on the major rivers in the hillier areas of the region.

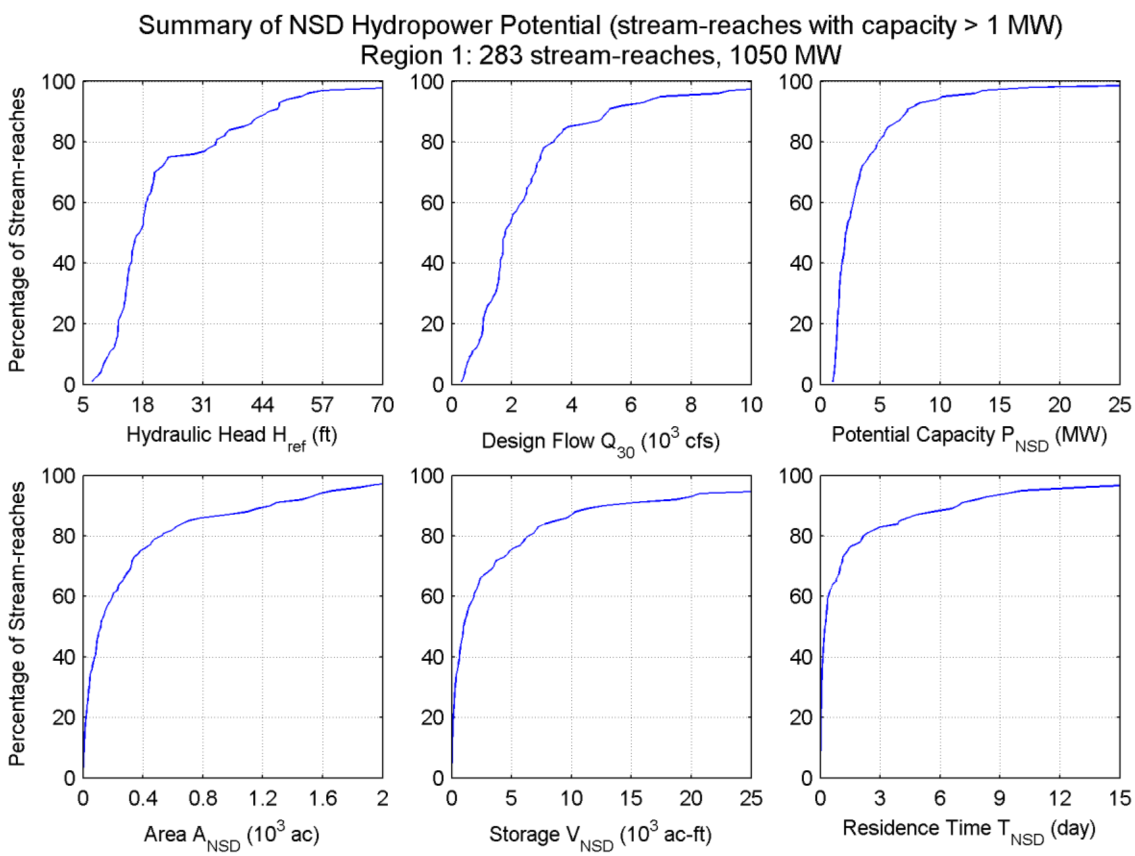

Figure 4.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 1—New England.

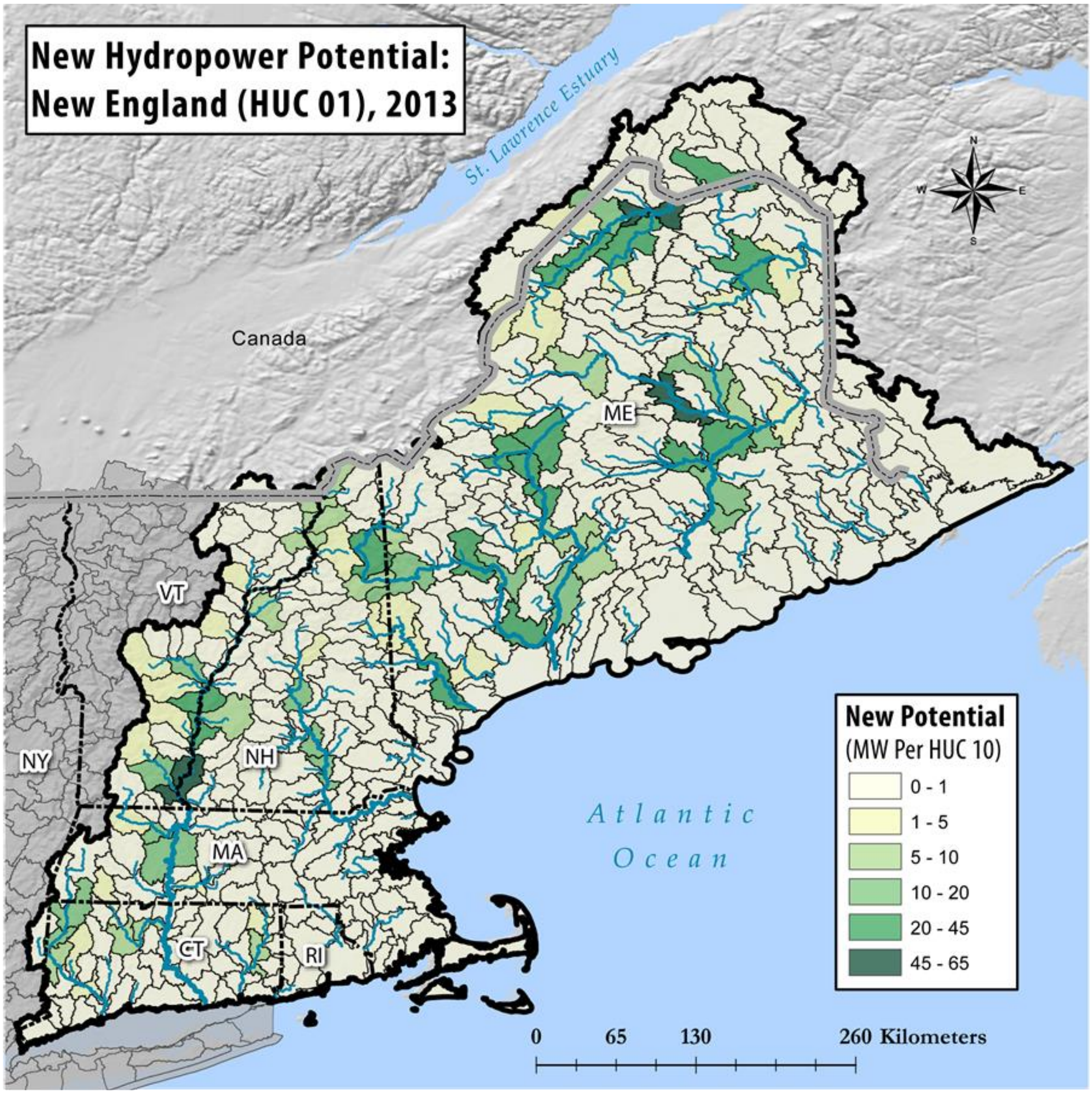

Figure 4.4. Potential new hydropower capacity in Region 1—New England (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC10 watersheds for illustration).

4.4. Environmental Characteristics

Sixty-two native fish species are documented in Region 1. Six of those species fall under ESA listing or candidate listing status and include alewife (*Alosa pseudoharengus*), Atlantic salmon (*Salmo salar*), Atlantic sturgeon (*Acipenser oxyrinchus*), blueback herring (*Alosa aestivalis*), shortnose sturgeon (*Scaphirhynchus platorynchus*), and threespine stickleback (*Gasterosteus aculeatus*) (Appendix B). Two fish species fall under IUCN vulnerable status. ESA-listed or candidate fish species are found in all subregions. Potadromous and anadromous fish species (10 species total) are also documented in all subregions (Table 4.3). Two HUC08 subbasins, the Mattawmkeag and Upper Connecticut-Masco, are considered critical watersheds and have one and two mussel species at risk, respectively (Master et al., 1998). Only one mammal, the Canada lynx (*Lynx canadensis*), and one reptile, the Plymouth red-bellied turtle (*Pseudemys rubriventris bangsi*), have critical habitat designations in Region 1 (Appendix B).

Table 4.3. Summary of Environmental Variables at HUC04 Subregions within Region 1 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	# recreation locations[a]	% Protected lands	Population density (ind/km^2)	Freshwater use (l/day·km^2)
0101	St. John	1	8	3	0	123; 25; 9	21.54	4.28	64.41
0102	Penobscot	1	9	6	2	193; 61; 48	21.26	4.88	103.69
0103	Kennebec	1	9	6	2	188; 41; 16	5.76	3.38	189.12
0104	Androscoggin	0	7	5	1	120; 24; 26	19.98	0.00	262.55
0105	Maine Coastal	0	9	5	1	287; 40; 14	17.17	10.14	166.23
0106	Saco	0	7	5	1	249; 34; 21	17.47	81.77	622.68
0107	Merrimack	0	6	4	2	349; 52; 21	20.52	202.76	1,692.99
0108	Connecticut	0	7	5	2	478; 107; 39	25.19	88.13	1,680.16
0109	Massachusetts-–Rhode Island Coastal	1	4	4	1	177; 4; 6	20.23	387.51	1,779.37
0110	Connecticut Coastal	0	4	4	2	156; 18; 14	14.34	278.01	3,501.04
0111	St. Francois	0	6	1	0	78; 2; 0	19.27	12.95	85.17

[a] Recreation locations refer to the number of boat-ramp and fishing access points, recreational boating, and waterfalls within each HUC04.

Over 7.5 million acres fall under protected land status in Region 1, almost 17% of the total area. Protected land coverage is fairly uniform across this region (Table 4.3). Most protected lands are privately owned (39%), followed by state (29%), federal (18%), local government (6.9%), and nongovernmental agency (6.1%) ownership. Federal lands are predominately owned by the U.S. Forestry Service (USFS) (14%); state lands have mixed ownership among natural resource departments and state parks. City-owned lands account for 6.7% of protected lands. The Nature Conservancy owns 3.8% of protected lands in Region 1. Region 1 includes 6 National Wild and Scenic Rivers. Twenty-one percent of protected lands fall under GAP status 1 and 2, and 71% and 8% of lands fall under status 3 and 4, respectively. Approximately 1505 boat ramp locations and more than 930 freshwater fishing access areas are located in Region 1 (Figure 4.5). Waterfalls and recreational boating river sections are abundant, totaling 218 and 409 different locations, respectively.

Water use is below average in Region 1 compared with the entire United States (Appendix B). However, within the region, water use varies considerably, with the Merrimack, Connecticut, Massachusetts-Rhode Island, and Connecticut Coastal subbasins displaying the highest values (Table 4.3). On average, the highest water usage is public consumption, followed by thermoelectric usage (Appendix B). Water quality concerns are average for the region, with most concerns related to mercury contamination, toxins, dissolved oxygen issues, and pathogens (Figure 4.6 and Appendix B).

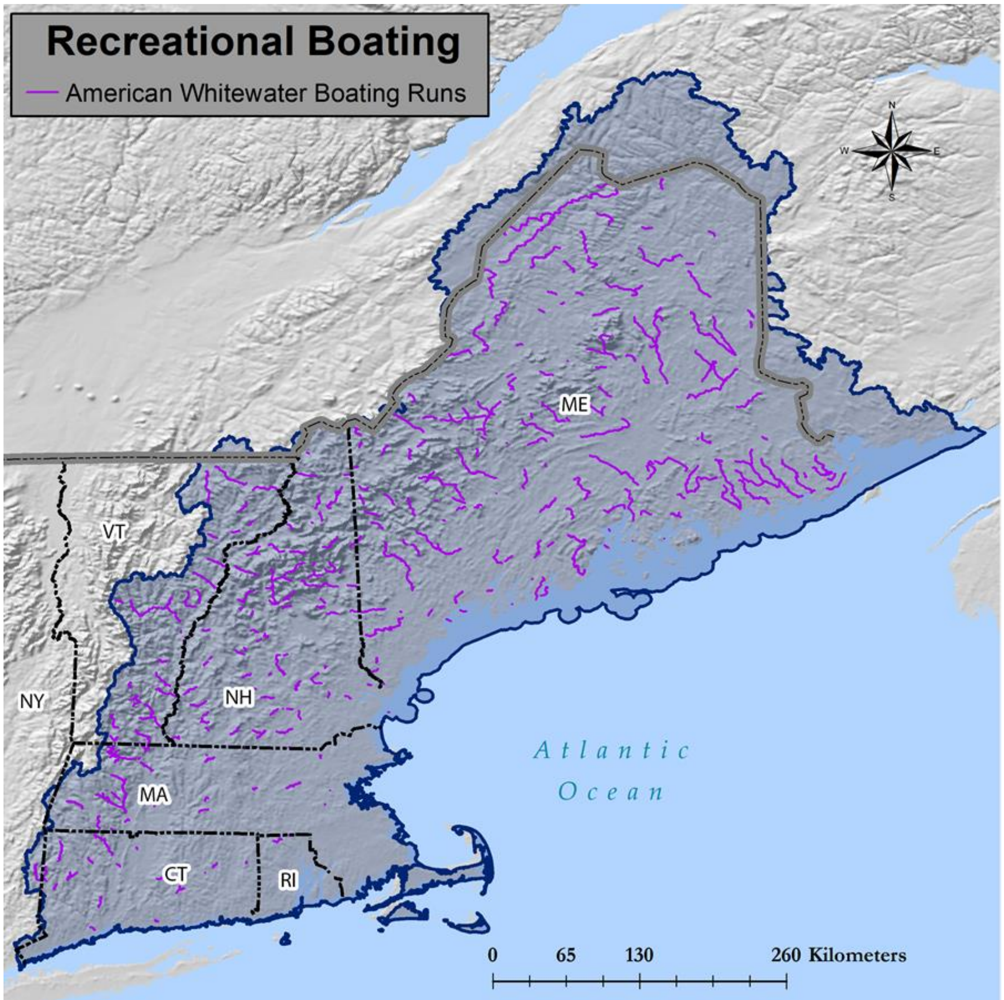

Figure 4.5. Whitewater boating runs in Region 1.

Most of the 283 new stream-reaches (89%) in Region 1 are located in HUC08 subbasins with at least one ESA-listed or candidate fish species (Figure 4.7). Critical habitats are present in the vicinity of 26% of new stream-reach locations. Protected lands are present at approximately 86% of new stream locations, with no sites intersecting national parks and 3.5% of sites intersecting Wild and Scenic Rivers (Figure 4.5). Thirty-six percent of stream-reaches intersect at least one 303D listed waterbody. Recreational boating is present on most of the stream-reaches (80%). Waterfalls, boat ramps, and fishing access locations are present at 36%, 48%, and 20% of new stream-reach locations, respectively. Total freshwater use is broken into five different categories (low, moderate, moderate-to-high, high, and very high) based on percentiles for each region (<0.2, 0.2–0.4, 0.4–0.6, 0.6–0.8, and >0.8).

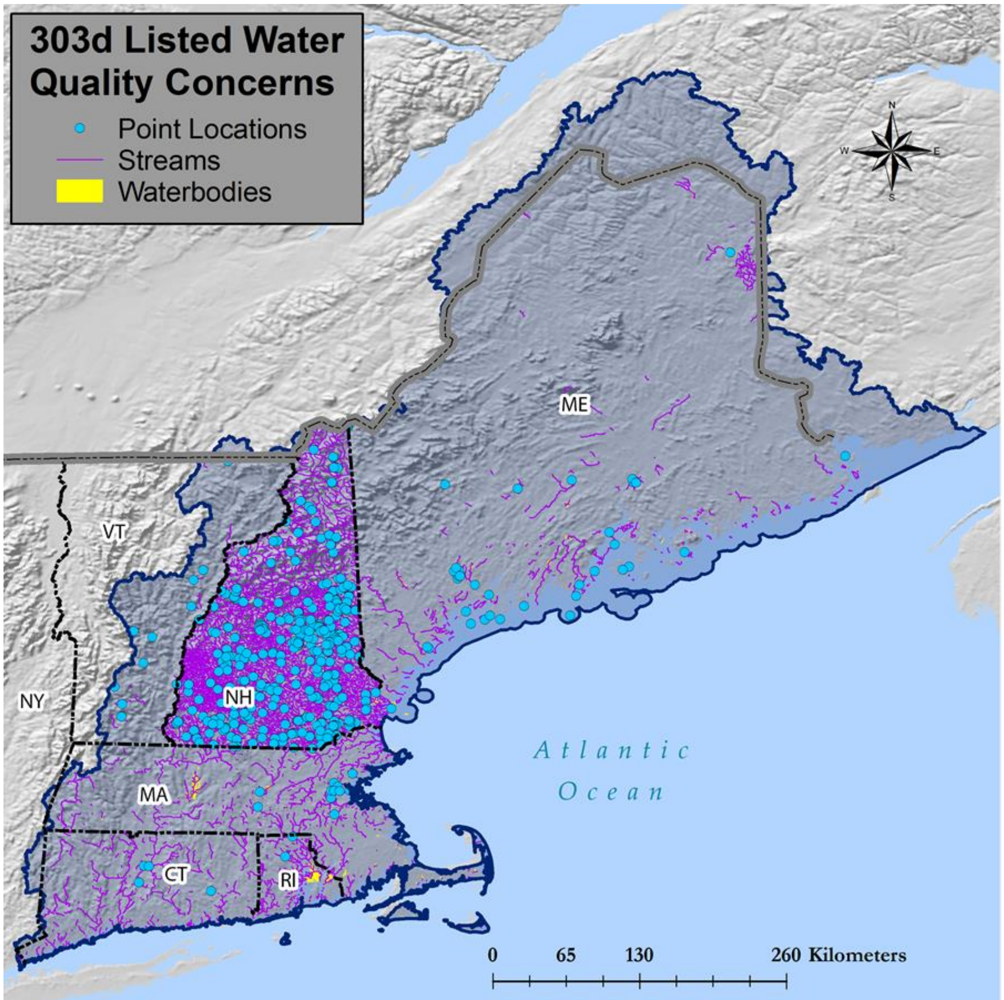

Figure 4.6. 303d listed streams and waterbodies in Region 1.

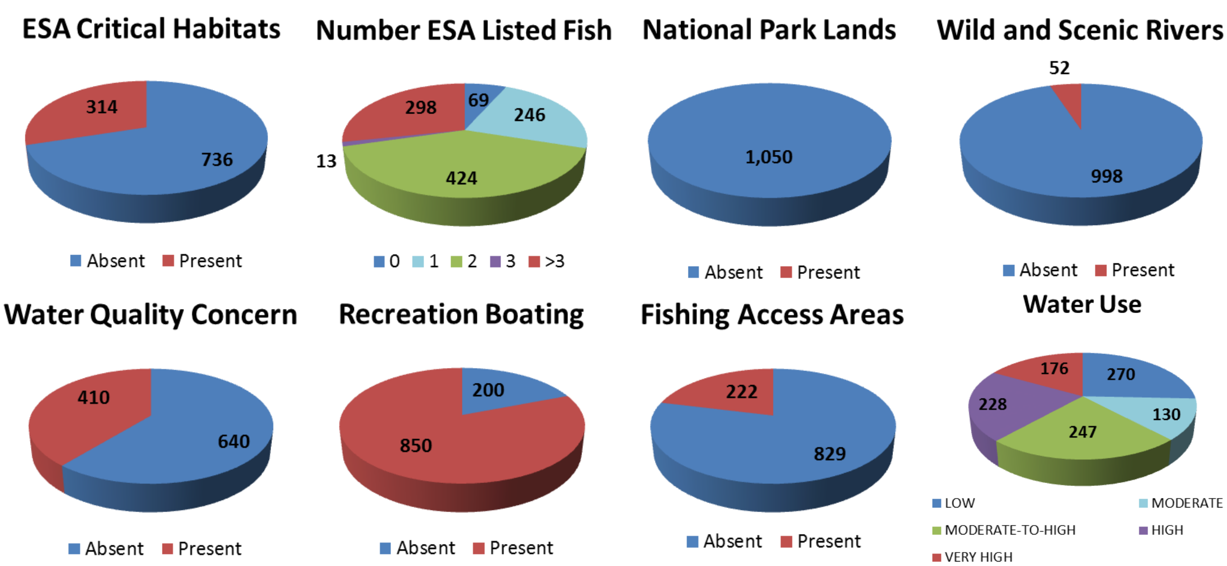

Figure 4.7. The potential capacity, in MW, associated with environmental attributes in Region 1—New England (stream-reaches with potential capacity >1 MW).

5. REGION 2—MID-ATLANTIC

5.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation, and mean capacity factors in the Mid-Atlantic Region are estimated and summarized in Table 5.1, for both larger (>1 MW) and smaller (<1 MW) stream-reaches. For comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation, and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 4.71 GW, around 219% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 25.95 TWh/year, around 332% of annual net generation from existing conventional hydropower plants. Given the run-of-river assumption, NSD stream-reaches have higher capacity factors, especially compared with other larger-storage peaking-operation projects in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 5.3 and 5.4.

Table 5.1. Summary of NSD Findings in Region 2—Mid-Atlantic

	Capacity (MW)	Generation (MWh)	Mean capacity factor
Potential in undeveloped stream-reaches (>1 MW)	3,043	16,711,000	63%
Potential in undeveloped stream-reaches (<1 MW)	1,667	9,234,000	63%
Existing hydropower—conventional hydro	2,148	7,818,000	42%
Existing hydropower —pumped storage	5,387		

5.2. Background Hydrologic Setting

The Mid-Atlantic Region encompasses approximately 297,200 km^2 in the eastern United States. The region extends from Vermont to Virginia, covering Vermont, Massachusetts, New York, Pennsylvania, New Jersey, Delaware, Maryland, District of Columbia, West Virginia and Virginia. The region covers from the Adirondack mountainous region in the north to the Appalachian Plateau, covering a large part of central and western New York and Pennsylvania. The topography transitions from the Plateau to the central lowlands and Piedmont areas extending from extreme eastern New York down through central and eastern Virginia. The flat coastal region dominates New Jersey, Delaware, and the extreme eastern section of Virginia (CARA, 2013).

Several river systems are located in the Mid-Atlantic Region (Figure 5.1), including the Hudson, Manasquan, Delaware, Susquehanna, Pocomoke, Potomac, Pocomoke and James rivers, with a total length of 30,686 km (i.e., total length of streams with estimated discharge greater than 35 cfs). Metropolitan areas within the subregion include Albany (NY), Rochester (NY), Buffalo

(NY), New York (NY), Pittsburg (PA), Philadelphia (PA), Baltimore (MD), Dover (DE), Washington D.C., and Richmond (VA). As shown in Figure 5.2, annual precipitation for the Mid-Atlantic Region ranges from 850 to 1450 mm/year and annual runoff from 300 to 800 mm/year. Most of the precipitation occurs in mid-summer and in early fall. Runoff is substantially lower during this period because of the abundance of vegetation and evapotranspiration in the region. The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are also shown in Figure 5.1. The region contains 187 hydropower dams and 65 major non-powered dams, with total storage capacities of around 14,479,616 and 3,815,575 ac-ft, respectively.

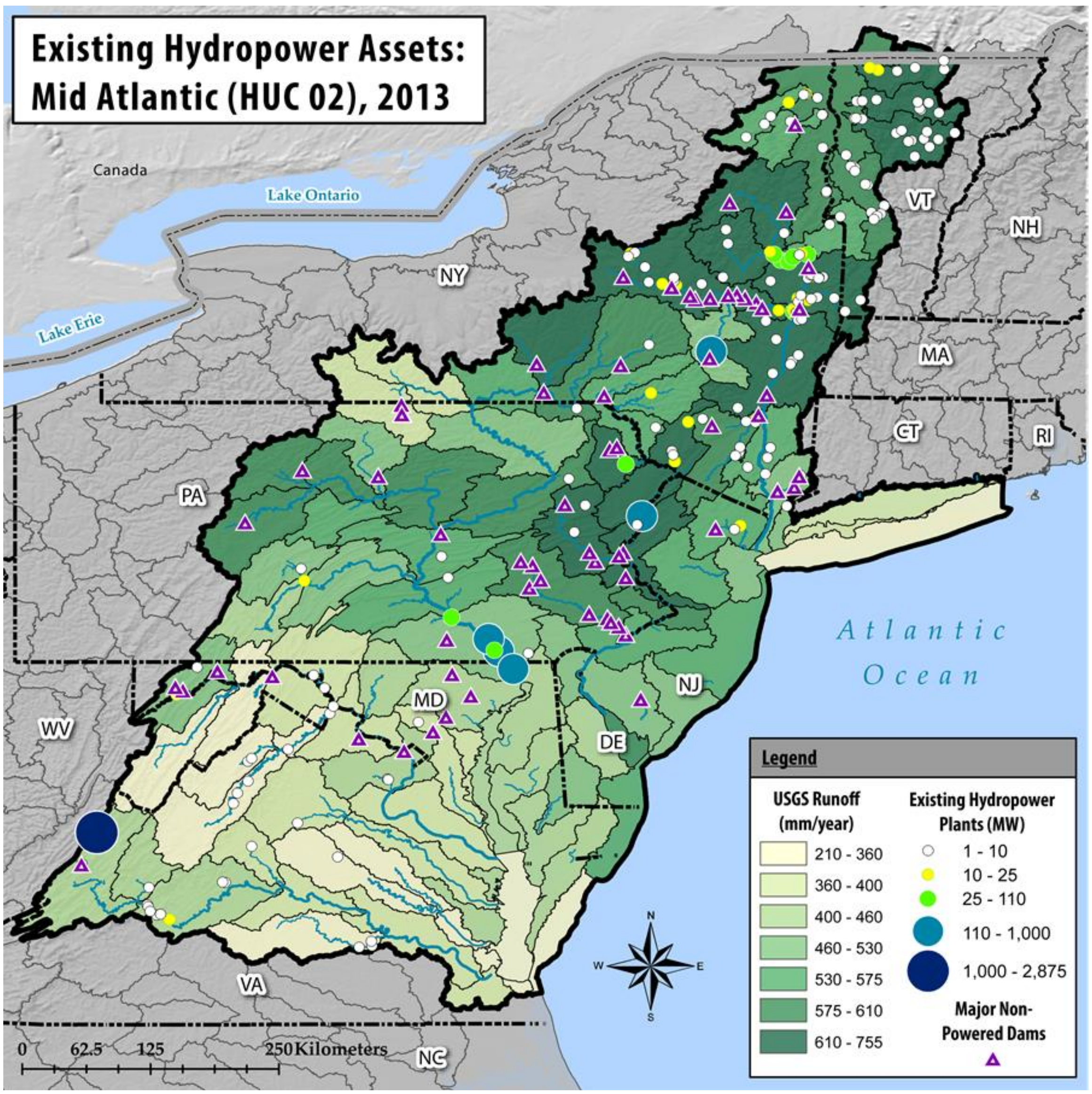

Figure 5.1. Locations of water control projects in Region 2—Mid-Atlantic.

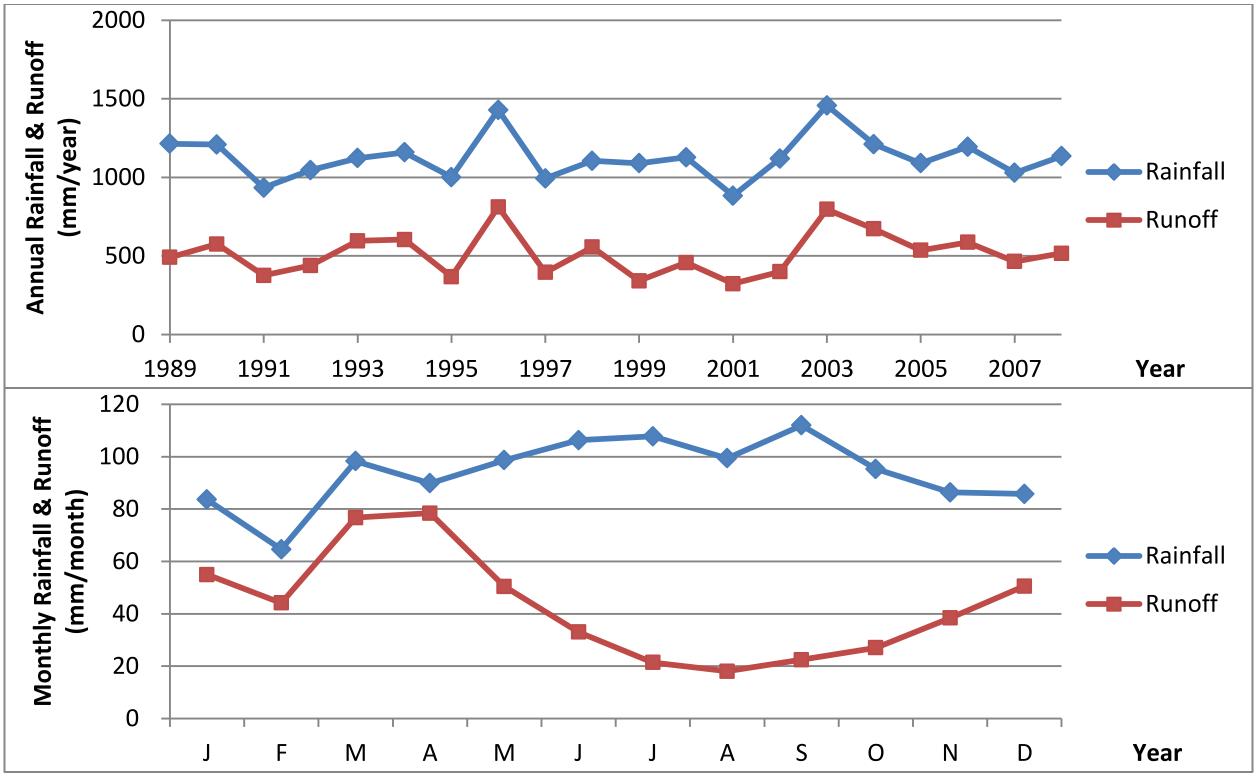

Figure 5.2. Annual and monthly rainfall and runoff of Region 2—Mid-Atlantic.

5.3. Potential New Hydropower Resources

A total of 580 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) were identified in the Mid-Atlantic Region. The NSD results based on HUC04 subregions are summarized in Table 5.2. The highest hydropower potential is located in the Susquehanna subregion (HUC 0205), yielding almost 100% more than the next-highest subregion, Delaware (HUC 0204). In the Susquehanna subregion, the Susquehanna and West Branch Susquehanna rivers contain the highest potential for hydropower, followed by the Juniata River.

Table 5.2. Summary of Potential New Hydropower Resources in Region 2—Mid-Atlantic (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/ reach)	Average residence time (days)
0201	Richelieu	50	114.4	683,437	37.4	1,072	9,170	5.3
0202	Upper Hudson	115	296.7	1,647,280	25.4	1,799	3,142	2.6
0203	Lower Hudson-Long Island	-	-	-	-	-	-	-
0204	Delaware	113	632.8	3,693,852	28.7	3,199	3,681	1.4
0205	Susquehanna	129	1,261.9	6,731,187	35.2	4,199	17,852	8.1
0206	Upper Chesapeake	-	-	-	-	-	-	-
0207	Potomac	93	428.6	2,304,671	26.7	2,636	5,181	1.7
0208	Lower Chesapeake	80	308.7	1,650,646	27.3	2,208	8,177	4.4

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 in Figure 5.3. The hydraulic head H_{ref} ranges from 0 to the 90th quantile of 50 ft with a median of about 28 ft. The design flow Q_{30} ranges from a few hundred cfs to the 90th quantile of 6000 cfs with a median of 1500 cfs. The potential capacity P_{NSD} ranges from 1 to the 90th quantile of about 9 MW with a median of about 4 MW. The inundated surface area A_{NSD} ranges from 0 to the 90th quantile of 1100 acres with a median of 250 acres. This results in storage values V_{NSD} ranging from 0 to the 90th quantile of 18,000 ac-ft with a median of about 3,000 ac-ft and very short residence times T_{NSD} ranging from <1 day to the 90th quantile of 11 days with a median of <1.5 days. In general, the relatively small inundation areas and storage volumes paired with the short retention times for this region are characteristic of run-of-river type hydro facilities. The results of > 1 MW stream-reach potential are illustrated in Figure 5.4, with potential capacity (MW) aggregated to the HUC08 subbasins. The higher-potential-capacity sites are generally located on the larger rivers in the Appalachian Plateau and Ridge and Valley region of eastern Pennsylvania.

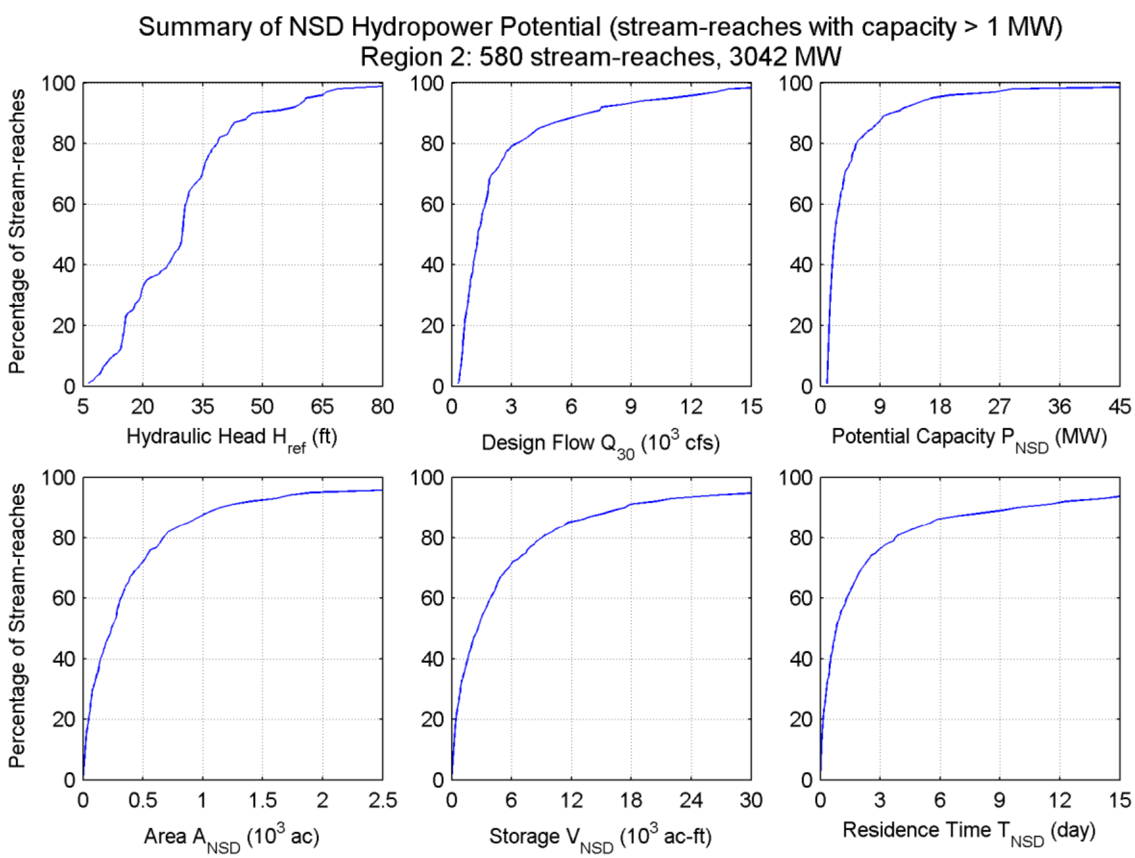

Figure 5.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 2—Mid-Atlantic.

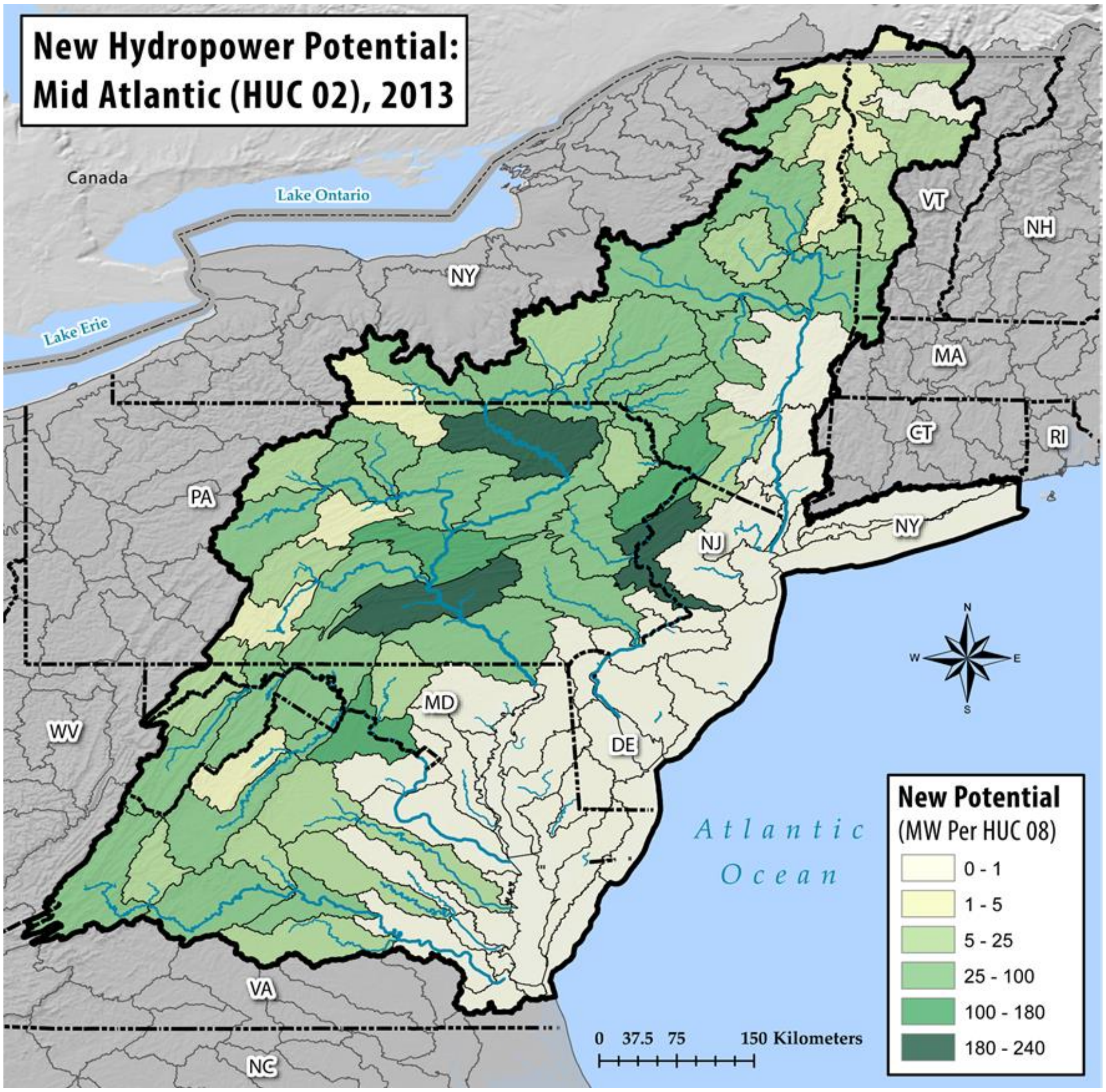

Figure 5.4. Potential new hydropower capacity in Region 2—Mid-Atlantic (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC08 subbasins for illustration).

5.4. Environmental Characteristics

Region 2 is home to 127 native fish species, 7 of which fall under an ESA category or IUCN vulnerable category (Appendix B). Alewife, Atlantic sturgeon, blueback herring, Maryland darter (*Etheostoma sellare*, potentially extinct), shortnose sturgeon, and threespine stickleback fall under ESA categories. Orangefin madtom (*Noturus gilberti*), although not falling under an ESA category, is classified as “vulnerable” under IUCN. Eleven fish species in Region 2 are considered potadromous or anadromous. The Chesapeake Bay drainage has at least four fish species and eight mussel species considered “at risk” (Master et al. 1998). Two species, the Maryland darter and the Virginia big-eared bat (*Corynorhinus townsendii virginianus*), have critical habitat designations in Region 2.

Approximately 13.5 million acres of protected lands are located in Region 2 (20% of total area); most are state owned (55%), followed by federally (25%), and privately owned (10%). State lands include departments of natural resources (26%), fish and wildlife lands (23%), and state parks (3.5%). Protected lands owned by federal entities primarily include USFS (14%), National Park Service (NPS) (4.3%), and Department of Defense (DOD) (3.9%). Most protected lands fall under GAP status 3 (55%), followed by 2 (22%), 3 (14%), and 1 (14%) status lands. Region 2 includes four national parkways, including a section of the Blue Ridge Parkway, and four National Wild and Scenic Rivers, including sections of the Delaware, Great Egg Harbor, and Maurice rivers. Region 2 also includes more than 1160 boat ramp locations (Figure 5.5), 741 freshwater fishing access locations (Figure 5.5), 175 waterfalls, and 576 recreational boating river sections.

Compared with other U.S. regions, water use is the second highest in Region 2 (Appendix B), with the highest usage occurring in the Lower Hudson–Long Island Subbasin (Table 5.3). The vast majority of water usage is a result of thermoelectric cooling, followed by public and domestic consumption (Appendix B). Similarly, water-quality concerns were also second highest in Region 2; toxins and dissolved oxygen were the main issues (Figure 5.6 and Appendix B).

Table 5.3. Summary of Environmental Variables at HUC04 Subregions within Region 2 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# Critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	# Recreation locations[a]	Protected lands (%)	Population density (ind/km^2)	Freshwater use (l/day/km^2)
0201	Richelieu	0	10	0	1	278; 74; 36	23.42	11.47	180.24
0202	Upper Hudson	0	6	5	2	136; 142; 42	23.43	66.85	2,410.01
0203	Lower Hudson-Long Island	0	4	5	2	141; 18; 3	16.09	10,401.12	15,736.37
0204	Delaware	0	6	5	2	328; 71; 45	19.99	215.59	4,392.77
0205	Susquehanna	1	6	4	2	295; 68; 52	17.45	51.40	1,761.39
0206	Upper Chesapeake	1	3	4	2	110; 20; 1	15.19	249.87	1,315.72
0207	Potomac	1	3	4	2	290; 155; 15	18.37	141.21	3,023.86
0208	Lower Chesapeake	0	3	5	3	431; 102; 17	17.26	75.53	3,031.18

[a]Recreation locations refer to the number of boat-ramp and fishing access points, recreational boating, and waterfalls within each HUC04 subregion.

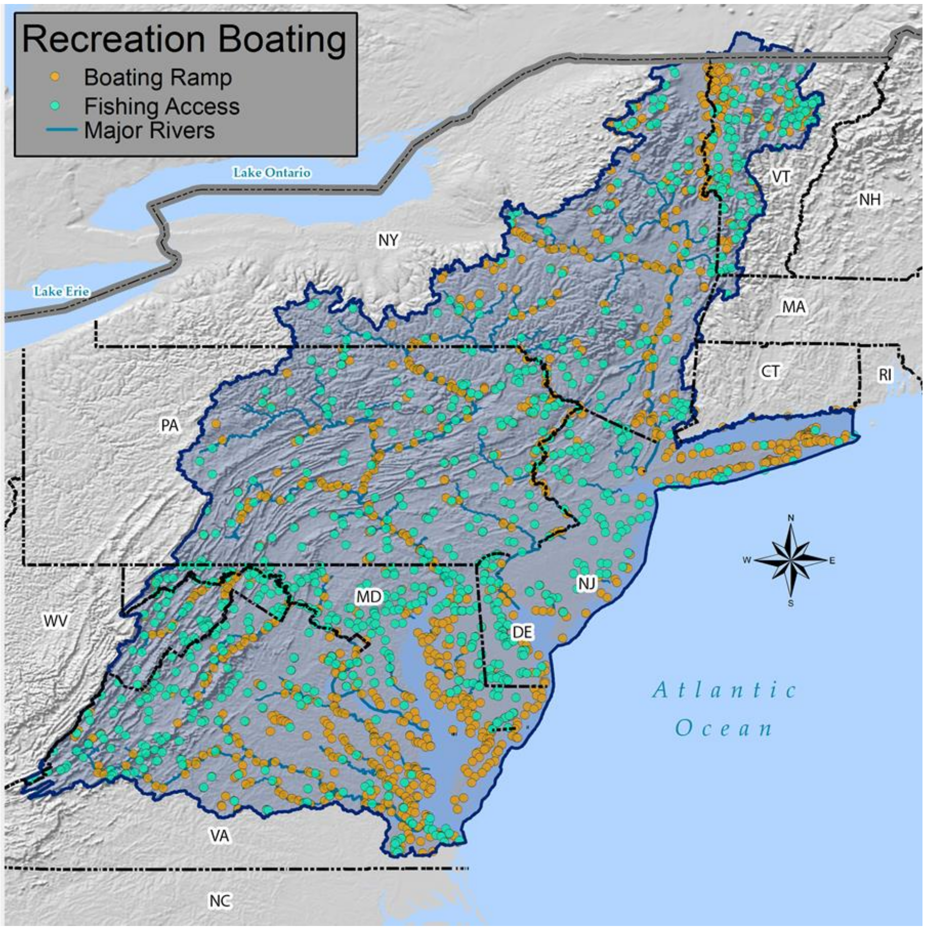

Figure 5.5. Boat ramp and fishing access areas in Region 2.

Only 22% of new stream-reaches (130 of 580 reaches) in Region 2 are located within HUC08 subbasins with at least one ESA-listed or candidate fish species present (Figure 5.7). Eight new stream-reaches, with a total of 9 MW, overlap with designated critical habitats. Almost 95% of stream-reaches intersect protected lands; however, very few stream-reaches intersect national parks (18 reaches) and Wild and Scenic Rivers (44 reaches). Water quality concerns are prevalent, being present at 378 stream-reaches. Recreational boating is also present at most stream-reaches (74%); boat ramp and fishing access locations are present in fewer reaches (47% and 27%, respectively). Almost 42% of stream-reaches have high or very high water use estimates (>60 percentile for Region 2).

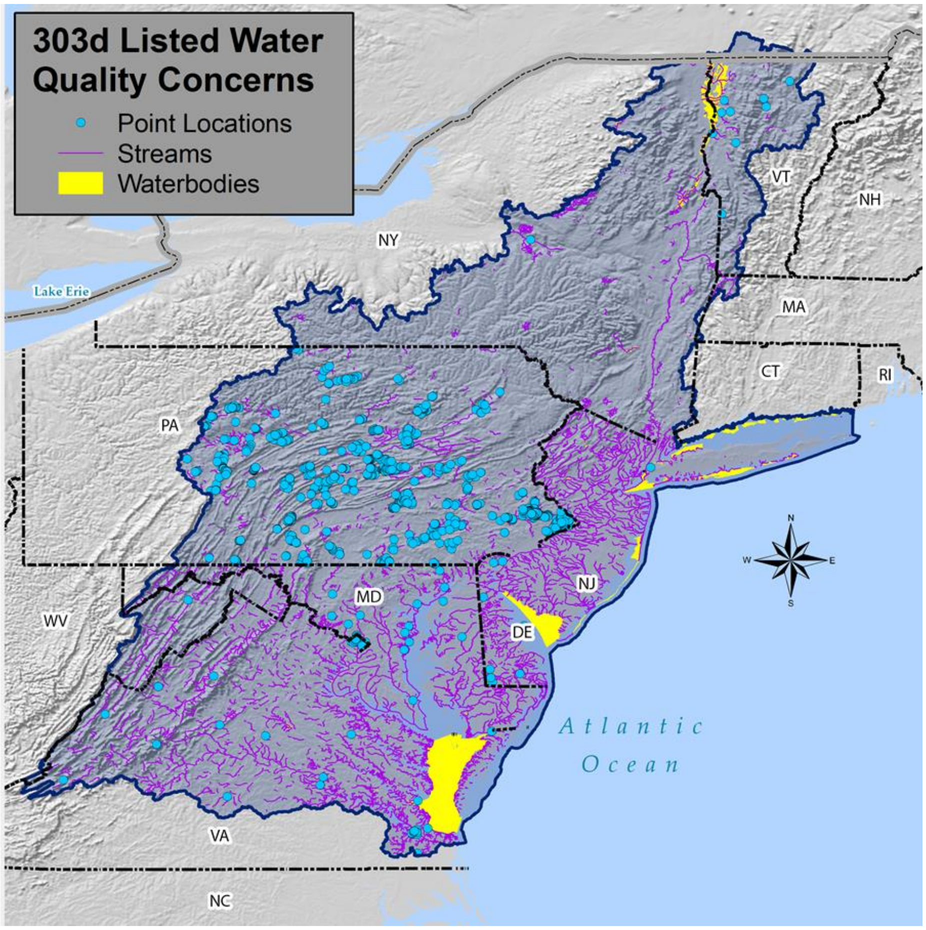

Figure 5.6. 303d listed streams and waterbodies in Region 2.

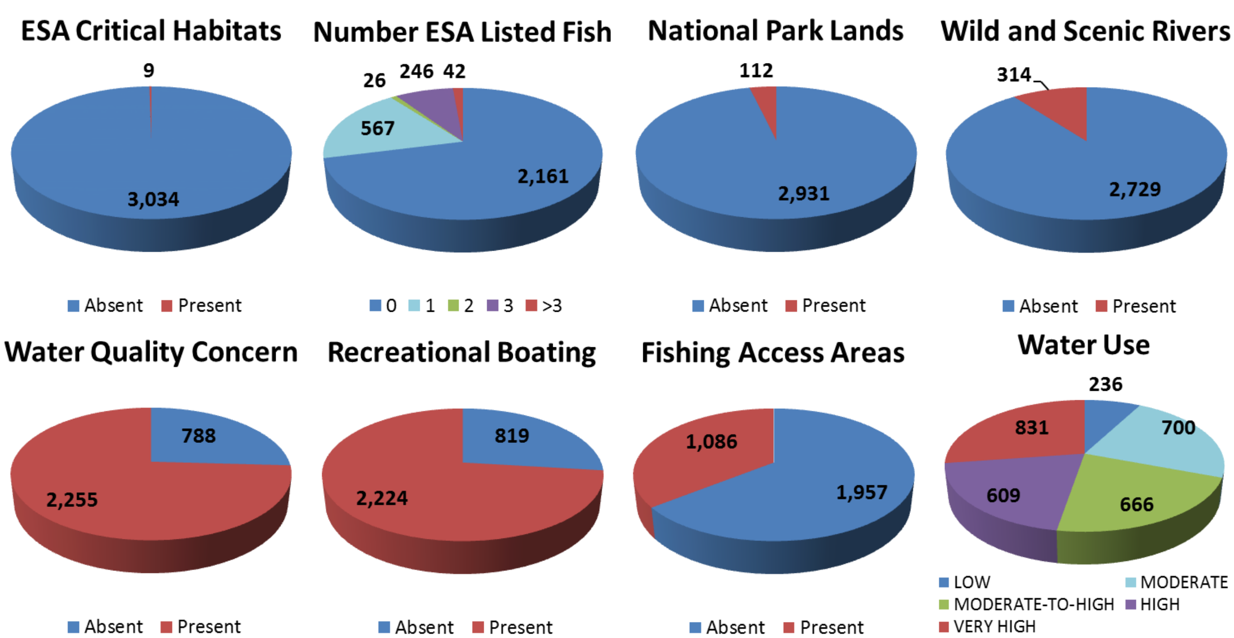

Figure 5.7. The potential capacity, in MW, associated with environmental attributes in Region 2—Mid-Atlantic (stream-reaches with potential capacity >1 MW).

6. REGION 3—SOUTH ATLANTIC-GULF

6.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation and mean capacity factors in the South Atlantic-Gulf Region are estimated and summarized in Table 6.1 for both larger (>1 MW) and smaller (<1 MW) stream-reaches. For comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation, and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 2.56 GW, around 35% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 14.21 TWh/year, around 106% of annual net generation from existing conventional hydropower plants. Given the run-of-river assumption, NSD stream-reaches have higher capacity factors, especially compared with other larger-storage peaking-operation projects in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 6.3 and 6.4.

Table 6.1. Summary of NSD Findings in Region 3 – South Atlantic-Gulf

	Capacity (MW)	**Generation (MWh)**	**Mean capacity factor**
Potential in undeveloped stream-reaches (>1 MW)	1,389	7,785,000	64%
Potential in undeveloped stream-reaches (<1 MW)	1,172	6,420,000	63%
Existing hydropower—conventional hydro	7,265	13,351,000	21%
Existing hydropower—pumped storage	4,070		

6.2. Background Hydrologic Setting

The South Atlantic-Gulf Region encompasses approximately 722,476 km^2 in the southeastern United States. The region is divided into two distinct geological sections by the fall line, which delineates the Coastal Plain (Florida, eastern Mississippi, southern parts of Alabama, Georgia, South and North Carolina, and a small part of Louisiana and Virginia) and parts of the Appalachian Highlands (northern parts of Alabama, Georgia, South and North Carolina, and a small part of Tennessee). The coastal plain consists of consolidated and semiconsolidated limestone, clay, and gravel and soft unconsolidated sand. This area contains the most productive groundwater because of its highly permeable clastic and limestone aquifers. The Appalachian Highlands area consists of hard consolidated rock that yields less groundwater flow. The groundwater outflow supports base flow for the streams in the region. For the Coastal Plain, base flow conservatively averages about 55% of the total streamflow. For the Appalachian Highlands, base flow conservatively averages about 40% of the streamflow (Cederstrom et al., 1979).

Several river systems are located in the South Atlantic-Gulf Region (Figure 6.1), including the Roanoke, Neuse, Cape Fear, Pee Dee, Santee, Savannah, Altamaha, St. Johns, Caloosahatchee, Peace, Kissimmee, Withlacoochee, Aucilla, Suwannee, Ochlockonee, Apalachicola, Escambia, Choctawhatchee, Alabama, Coosa, Tallapoosa, Tombigbee, Black Warrior, and Pearl rivers, with a total length of 30,686 km (i.e., total length of streams with estimated discharge of more than 35 cfs). Metropolitan areas within the region include Birmingham (AL), Montgomery (AL), Atlanta (GA), Albany (GA), Columbus (GA), Macon(GA), Savannah (GA), Thomasville (GA), Tallahassee (FL), Gainesville (FL), Jacksonville (FL), Tampa (FL), Orlando (FL), Fort Lauderdale (FL), Charleston (SC), Wilmington (NC), and Charlotte (NC), as well as some very small portions of southern Virginia. As shown in Figure 6.2, annual precipitation for the South Atlantic-Gulf region Ranges from 1000 to 1600 mm/year and annual runoff from 200 to 600 mm/year. Most of the precipitation occurs from late spring through early fall.

The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are also shown in Figure 6.1. The regions contain 149 hydropower dams and 61 major non-powered dams with storage capacities of about 64,345,241 ac-ft and 22,322,719 ac-ft, respectively.

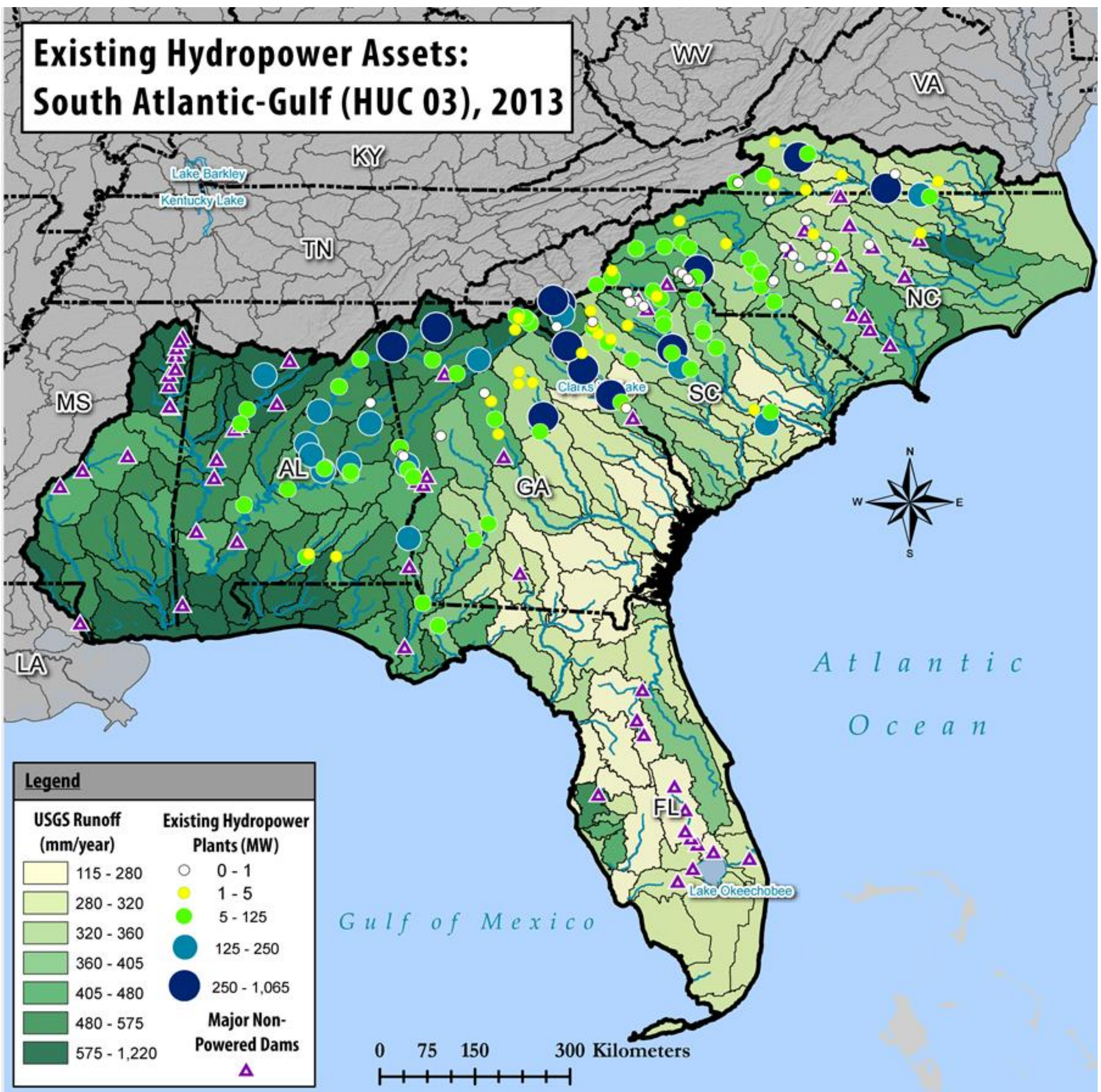

Figure 6.1. Locations of water control projects in Region 3—South Atlantic-Gulf.

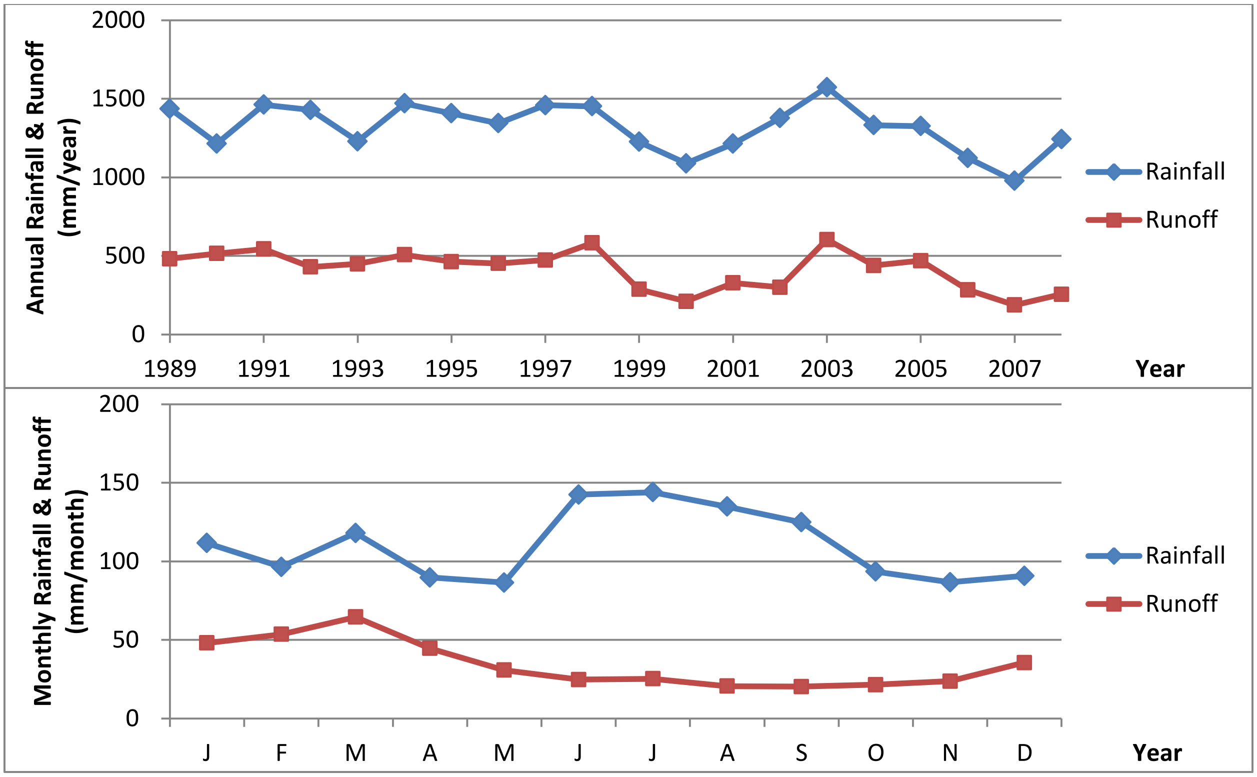

Figure 6.2. Annual and monthly rainfall and runoff of Region 3—South Atlantic-Gulf.

6.3. Potential New Hydropower Resources

A total of 393 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) were identified in South Atlantic-Gulf Region. The NSD results based on HUC04 subregions are summarized in Table 6.2. The highest hydropower potentials are located in the Apalachicola and Alabama Subregions (HUC 0313 and 0315). In the Alabama Subregion, the highest hydropower potential is found in the Alabama, Tallapoosa, and Coosa rivers. In the Apalachicola Subregion, the highest hydropower potential is found in the Apalachicola and Chattahoochee rivers.

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 in Figure 6.3. The hydraulic head H_{ref} ranges from 5 to the 90th quantile of 40 ft with a median of 22 ft, suggesting that many of the potential stream-reaches will require low-head hydropower technologies. The design flow Q_{30} ranges from 400 to 6000 cfs with a median of about 1200 cfs. The potential capacity P_{NSD} ranges from 1 to the 90th quantile of about 7 MW with a median of about 2 MW. The inundated surface area A_{NSD} ranges from 0 to the 90th quantile of 6000 ac with a median of 1000 ac. This results in storage values V_{NSD} ranging from 0 to the 90th quantile of 59,000 ac-ft with a median of about 10,000 ac-ft and very short residence times T_{NSD} ranging from <1 day to the 90th quantile of 25 days with a median of about 2 days. In general, the relatively small inundation areas and storage volumes paired with the short retention times for this region are characteristic of run-of-river type hydro facilities. However, there are some sites that are characteristic of reservoir-storage type hydro projects but make up only a small

Table 6.2. Summary of Potential New Hydropower Resources in Region 3—South Atlantic-Gulf (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/reach)	Average residence time (days)
0301	Chowan–Roanoke	29	100.3	594,149	29.3	2,525	22,748	16.1
0302	Neuse–Pamlico	7	20.2	106,414	24.2	1,622	47,561	13.4
0303	Cape Fear	15	58.1	296,619	30.1	2,296	11,805	5.5
0304	Pee Dee	32	132.1	771,744	39.1	2,393	30,246	27.3
0305	Edisto–Santee	41	166.6	993,938	32.8	2,553	29,621	14.9
0306	Ogeechee–Savannah	29	78.0	475,897	31.2	1,798	5,286	3.6
0307	Altamaha–St. Marys	22	69.8	383,546	12.5	3,569	12,950	2.7
0308	St. Johns	-	-	-	-	-	-	-
0309	Southern Florida	-	-	-	-	-	-	-
0310	Peace–Tampa Bay	-	-	-	-	-	-	-
0311	Suwannee	10	24.1	112,830	14.8	2,652	8,238	3.6
0312	Ochlockonee	3	4.0	18,833	15.9	1,327	23,486	13.4
0313	Apalachicola	48	214.5	1,295,550	17.6	3,538	12,435	1.6
0314	Choctawhatchee–Escambia	23	58.9	329,940	18.8	2,131	31,294	6.4
0315	Alabama	44	206.1	1,154,046	27.5	3,088	21,546	4.8
0316	Mobile–Tombigbee	35	89.9	442,585	23.7	1,943	17,289	8.4
0317	Pascagoula	27	72.7	363,452	26.0	1,521	48,561	25.1
0318	Pearl	28	93.4	445,827	12.1	4,359	9,910	1.7

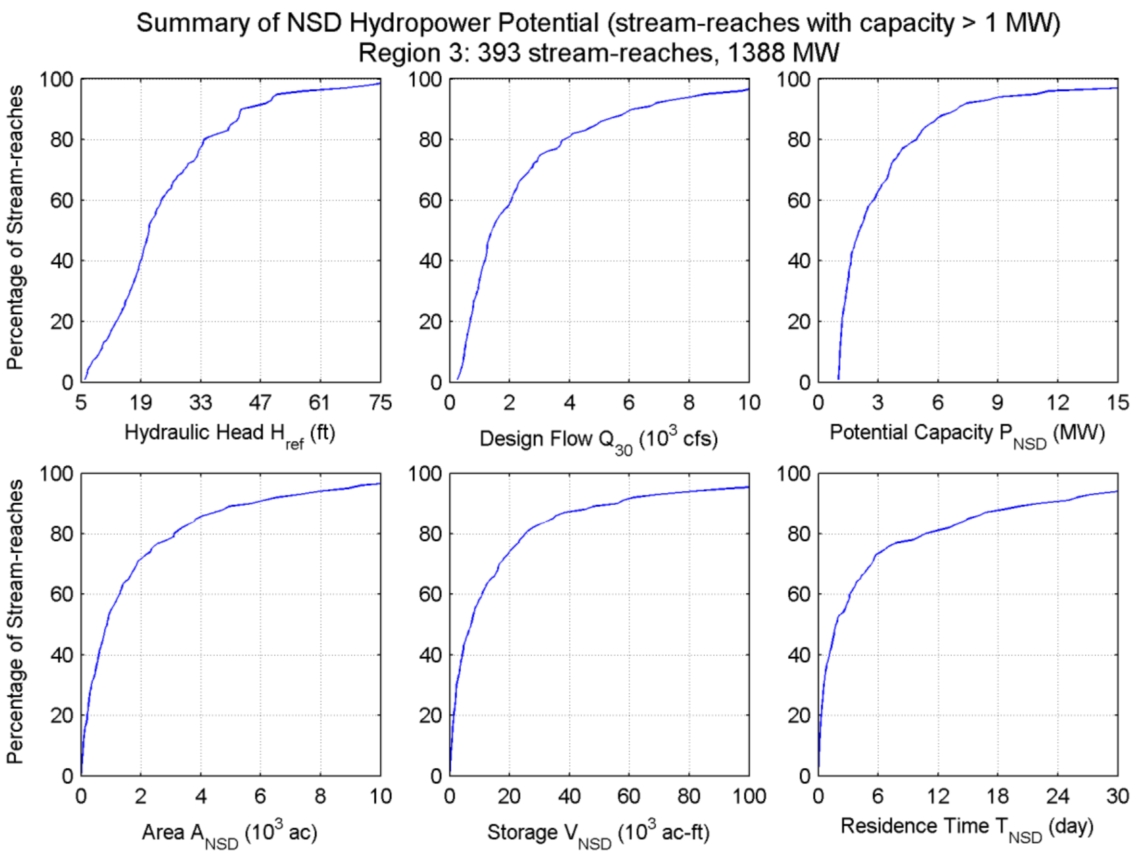

Figure 6.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 3—South Atlantic-Gulf.

percentage of the total sites of interest in this U.S. region. The results of > 1 MW stream-reach potential are illustrated in Figure 6.4, with potential capacity (MW) aggregated to the HUC08 subbasins. The higher-potential-capacity sites are generally located along the fall line that divides the two distinct coastal and mountainous regions and in the higher elevations along the northern section of the region. There are also a few higher potential sites located along larger rivers adjacent to the Gulf of Mexico.

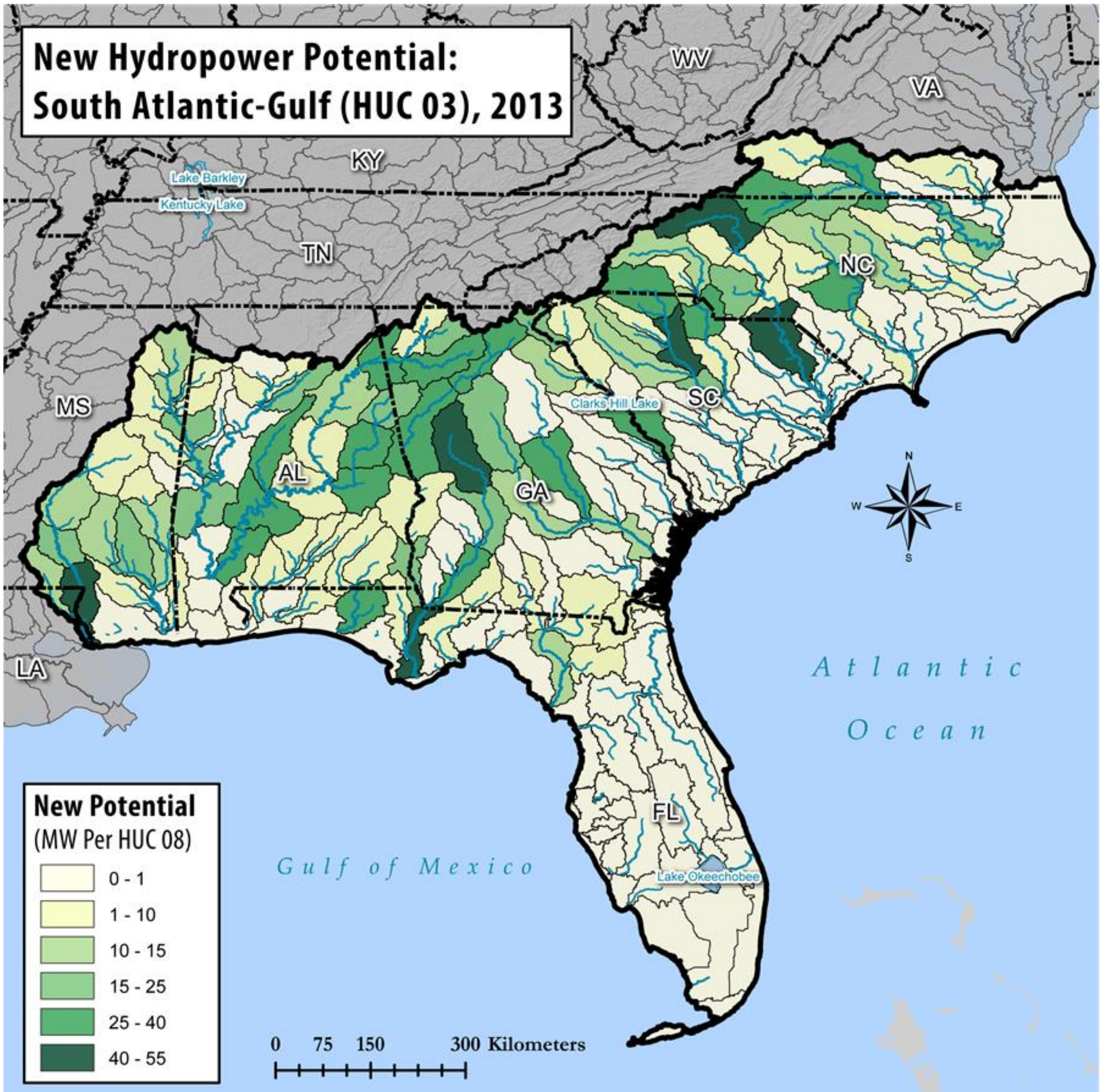

Figure 6.4. Potential new hydropower capacity in Region 3—South Atlantic-Gulf (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC08 subbasins for illustration).

6.4. Environmental Characteristics

Compared with other regions, Region 3 boasts the highest diversity of freshwater fish, including almost 600 native species. Region 3 contains some of the most diverse basins in the world, including the Mobile (236 fish species), Roanoke (90 species), and Conasauga (78 species) basins (USGS, 2001). Twenty-seven fish species fall under some ESA criteria with 17 of those species or one of their populations having threatened or endangered status (Figure 6.5 and Appendix B). Thirty-nine fish species fall under IUCN vulnerable status (Figure 6.5 and Appendix B). Over 40% of HUC08 subbasins in Region 3 are considered critical watersheds, containing 1 to more than 20 fish and mussel species at risk (Mathews et al. 1998). HUC08 subbasins with the most species at risk include the Conasauga (24), Spring (19), Upper Tombigee (15), Buttahtchee (15), and Sipsey (15). A total of 20 potadromous and anadromous fish species are documented in all subregions, suggesting a common potential concern (Table 6.3). Region 3 contains critical habitat designations for 2 amphibians, 1 arachnid, 1 insect, 3 birds, 19 clam species, 23 fish species, and 3 mammals (Figure 6.6 and Appendix B).

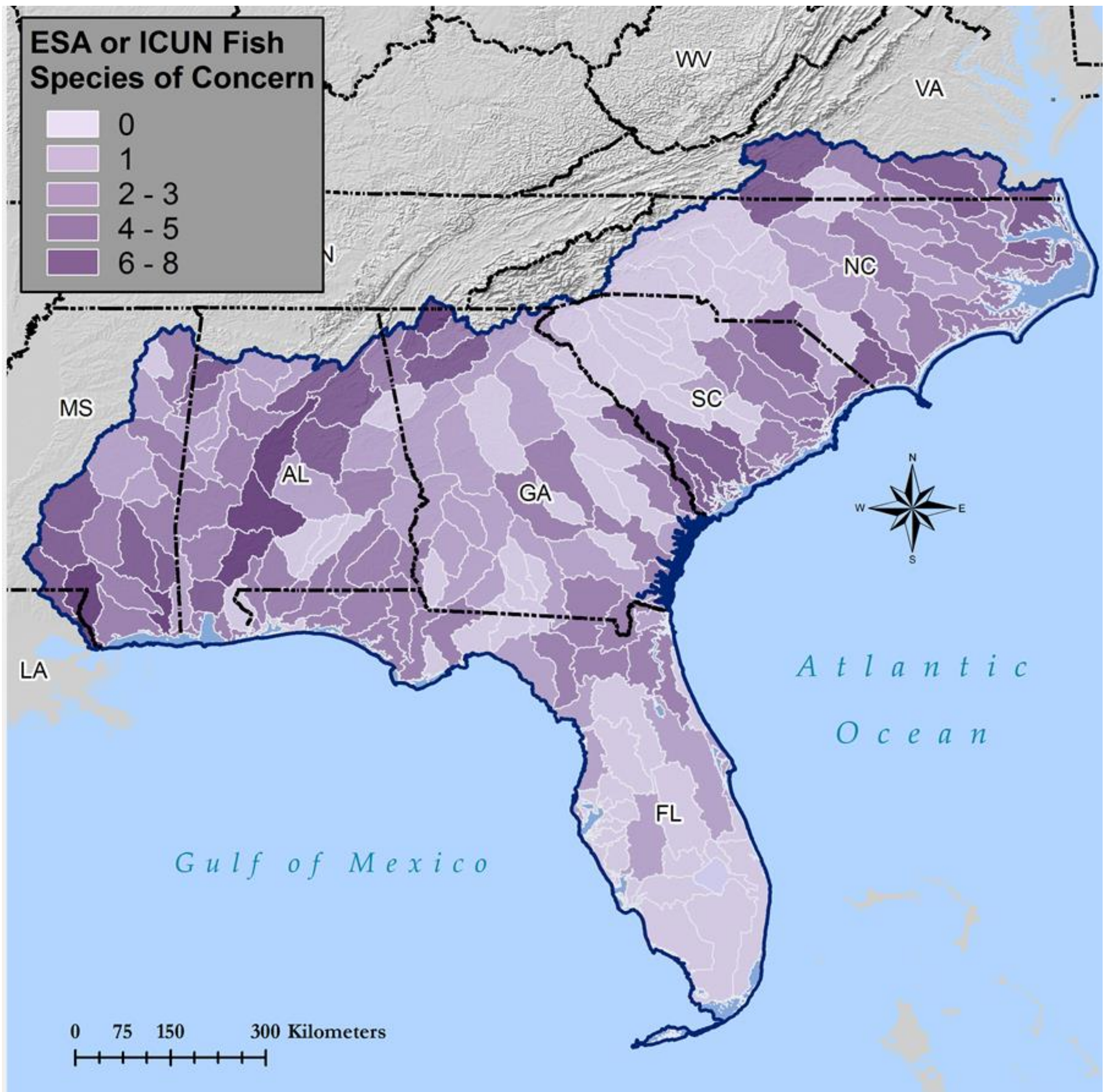

Figure 6.5. Fish species of concern (number per HUC08 sub-basin) in Region 3.

There are over 20 million acres of protected lands (conservation lands) within Region 3, constituting over 11% of the total area. Most protected land is federally owned (61%), predominately by USFS (23%), NPS (14%), and DOD (14%). Among the largest national parks are Everglades, Biscayne, and Congaree. State lands constitute 33% of protected lands, comprising state fish and wildlife, departments of natural resources, department lands, and state parks. Approximately 4% of protected lands fall under GAP 1 and 2 statuses and 5.3% and 1.8% of protected lands fall under GAP 3 and 4 statuses, respectively. Region 3 includes two national parkways (Blue Ridge and Natchez Trace parkways) and seven rivers protected under the National Wild and Scenic River Act. In total, there are 2345 boat ramp locations, 628 freshwater fishing access areas, and 409 recreational boating river sections. In addition, there are approximately 109 waterfalls within the region.

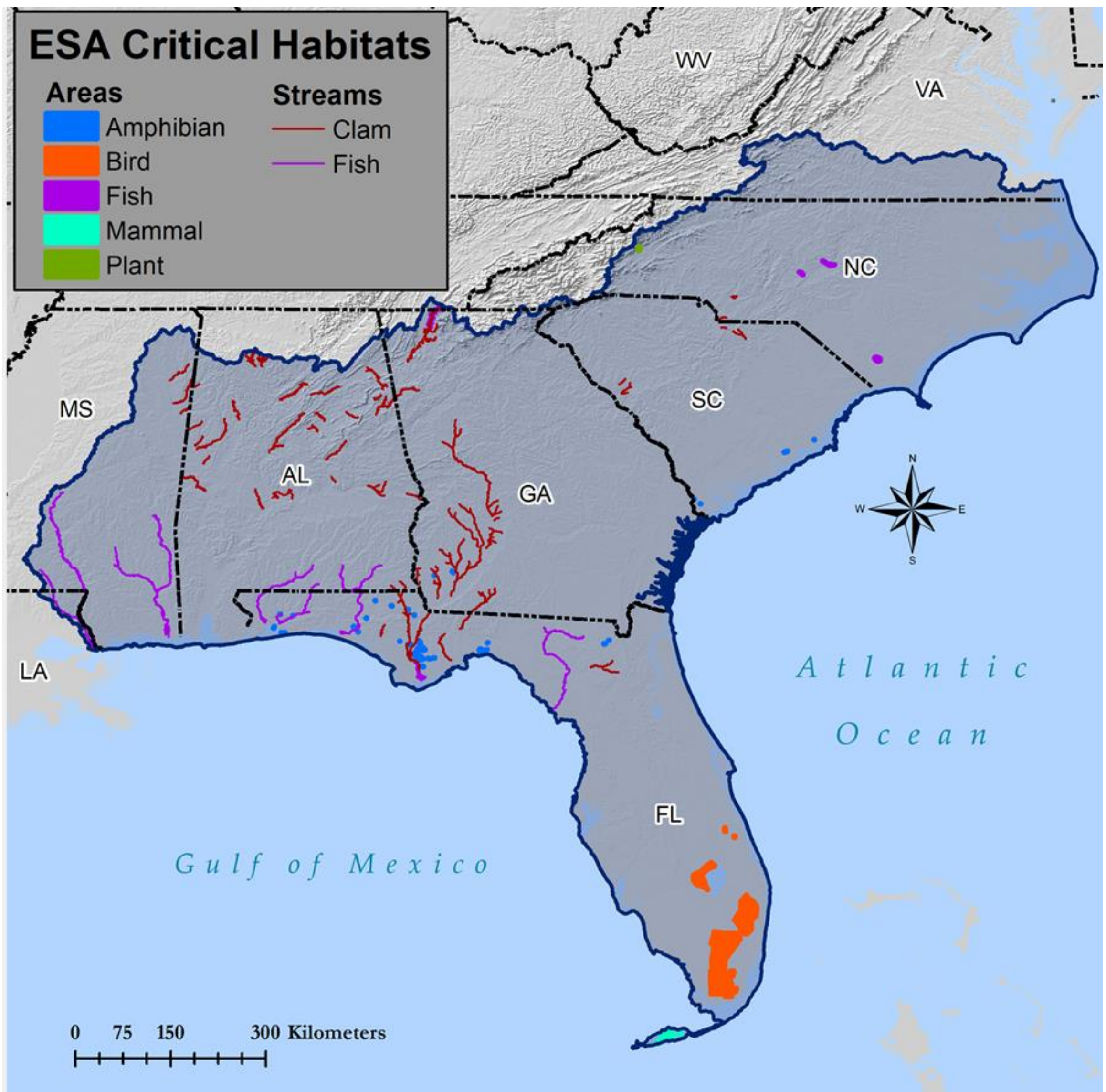

Figure 6.6. Critical habitats of federally endangered and threatened species in Region 3.

Total freshwater use in Region 3 is moderate compared with other areas of the United States (Appendix B) with the highest usage occurring in the Edisto-Santee and Ogeechee-Savannah subregions (Table 6.3). Water usage is dominated by thermoelectric consumption, followed by public consumption and irrigation (Appendix B). The level of water quality concerns (number of 303D-listed waterbodies) is moderate in Region 3 compared with the rest of the United States (Appendix B). Harmful metals such as mercury and pathogens (e.g., *E. coli* bacteria) are the most prevalent water quality concerns.

Thirty-nine percent of stream-reaches, with a total of 542 MW, are located within the vicinity of designated critical habitats (Figure 6.7). Over 76% of stream-reaches are located in HUC08 subbasins containing at least one fish species falling under an ESA category. Sixty percent of stream-reaches intersect protected lands, but only one stream-reach intersects a national park. Twenty stream-reaches, totaling 30 MW, intersect Wild and Scenic Rivers. Water quality concerns are very prevalent, intersecting 67% of all stream-reaches. Recreational boating and boat ramps are also prevalent, intersecting 72% and 81% of stream-reaches, respectively. Fishing access locations are identified at 35% of stream-reaches. Almost 42% of stream-reaches are located in HUC08 subbasins with high or very high total water use (>60% for the region).

Table 6.3. Summary of Environmental Variables at HUC04 Subregions within Region 3 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# Critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	# Recreation locations[a]	Protected lands (%)	Population density (ind/km^2)	Freshwater use (l/day/km^2)
0301	Chowan–Roanoke	0	4	5	7	260; 34; 12	7.68	28.59	2,060.03
0302	Neuse–Pamlico	1	4	3	2	57; 13; 3	7.02	55.06	852.42
0303	Cape Fear	2	4	5	4	47; 18; 1	8.16	73.19	945.80
0304	Pee Dee	3	6	5	5	165; 19; 10	3.79	53.44	2,045.02
0305	Edisto-Santee	6	6	3	4	343; 83; 19	7.52	73.95	4,682.41
0306	Ogeechee–Savannah	4	7	3	3	270; 80; 23	13.04	36.93	3,613.10
0307	Altamaha–St. Marys	4	4	3	2	131; 21; 1	5.98	48.66	1,170.85
0308	St. Johns	4	2	3	2	157; 0; 0	23.99	130.02	1,631.43
0309	Southern Florida	7	2	0	0	178; 0; 0	34.85	112.32	2,291.60
0310	Peace–Tampa Bay	2	2	1	1	102; 1; 0	14.69	225.55	1,844.47
0311	Suwannee	10	4	1	3	74; 6; 0	11.93	20.67	535.18
0312	Ochlockonee	9	4	1	3	36; 0; 0	19.82	41.71	524.96
0313	Apalachicola	12	6	1	3	235; 50; 11	9.33	46.53	1,137.78
0314	Choctawhatchee–Escambia	16	5	3	5	98; 0; 1	12.44	40.24	758.60
0315	Alabama	12	7	10	15	289; 63; 20	6.92	43.81	1,702.72
0316	Mobile–Tombigbee	9	6	6	9	261; 19; 6	4.47	35.77	1,742.77
0317	Pascagoula	3	6	3	5	106; 2; 2	10.91	32.84	861.90
0318	Pearl	2	5	2	6	73; 0; 0	4.45	26.50	329.43

[a] Recreation locations refer to the number of boat-ramp and fishing access points; recreational boating; and waterfalls within each HUC04.

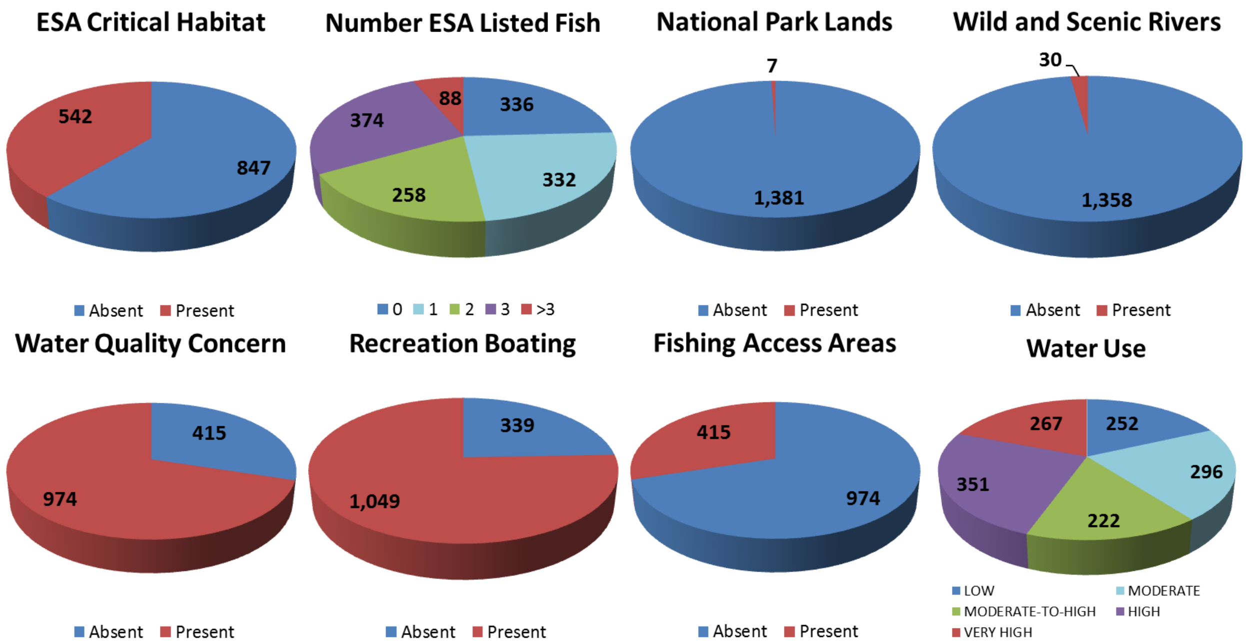

Figure 6.7. The potential capacity, in MW, associated with environmental attributes in Region 3—South Atlantic-Gulf (stream-reaches with potential capacity >1 MW).

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7. REGION 4—GREAT LAKES

7.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation, and mean capacity factors in the Great Lakes Region are estimated and summarized in Table 7.1 for both larger (>1 MW) and smaller (<1 MW) stream-reaches. For comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation, and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 1.43 GW, around 31% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 8.44 TWh/year, around 34% of annual net generation from existing conventional hydropower plants. The lower ratio of potential NSD resources to existing hydropower development suggests that many of the hydraulically feasible stream-reaches may have been used for hydropower development in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 7.3 and 7.4.

Table 7.1. Summary of NSD Findings in Region 4—Great Lakes

	Capacity (MW)	Generation (MWh)	Mean capacity factor
Potential in undeveloped stream-reaches (>1 MW)	265	1,538,000	66%
Potential in undeveloped stream-reaches (<1 MW)	1,160	6,906,000	68%
Existing hydropower—conventional hydro	4,604	24,991,000	62%
Existing hydropower—pumped storage	2,219		

7.2. Background Hydrologic Setting

The Great Lakes Region encompasses approximately 311,442 km^2 in the mideastern United States. This region contains the most northern sections of Minnesota, Wisconsin, and Michigan and small parts of Indiana, Ohio, Pennsylvania, and New York.

In addition to the Great Lakes, several river systems are located in this region (Figure 7.1), including the St. Lawrence, Montreal, St. Louis, Carp, Milwaukee, Manistique, Fox, St. Joseph, Grand, Au Sable, St. Clair, Saginaw, Detroit, Huron, Vermilion, Ashtabula, Niagara, Genesee, Oswego and English rivers, with a total length of 30,380 km (i.e., total length of streams with estimated discharge greater than 35 cfs). Metropolitan areas within the region include Duluth (MN), Milwaukee (WI), Grand Rapids (MI), Toledo (OH), Cleveland (OH), and Buffalo (NY). As shown in Figure 7.2, annual precipitation for the Great Lakes region ranges from 750 to 100 mm/year and annual runoff from 275 to 400 mm/year. Most of the precipitation falls from the summer to early fall. The peak of the runoff occurs the spring around April, which is indicative of the snowmelt runoff.

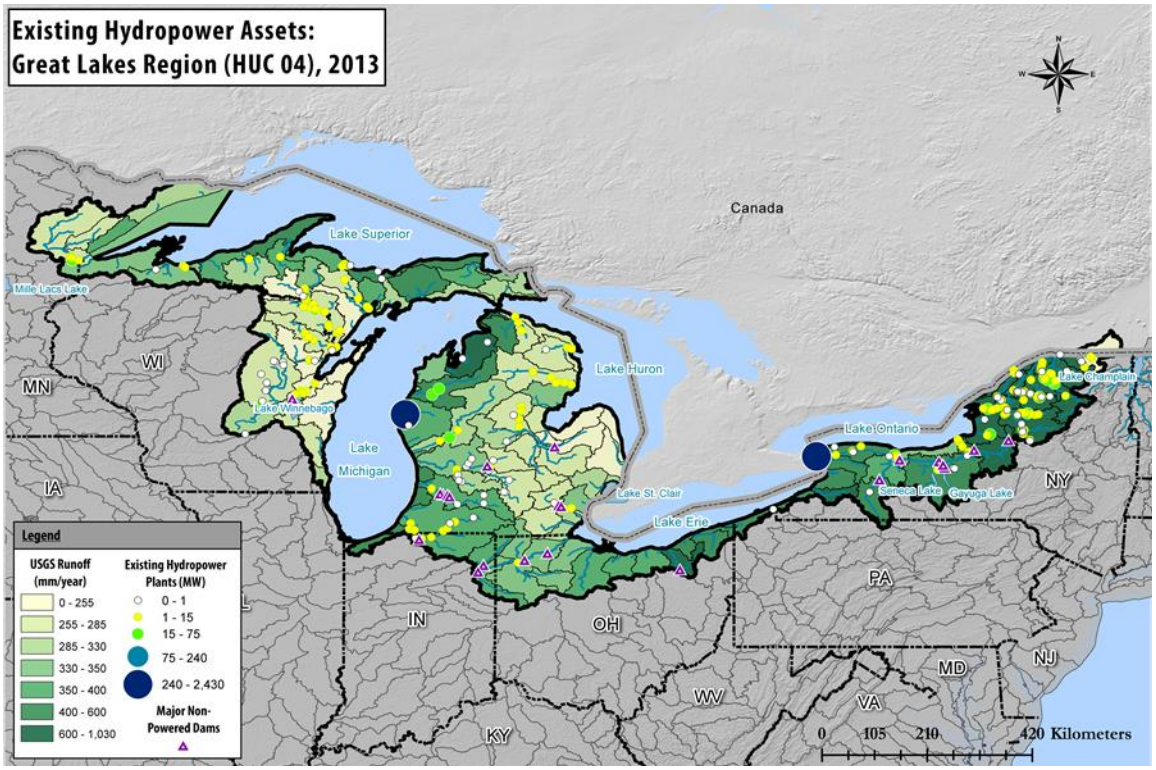

Figure 7.1. Locations of water control projects in Region 4—Great Lakes.

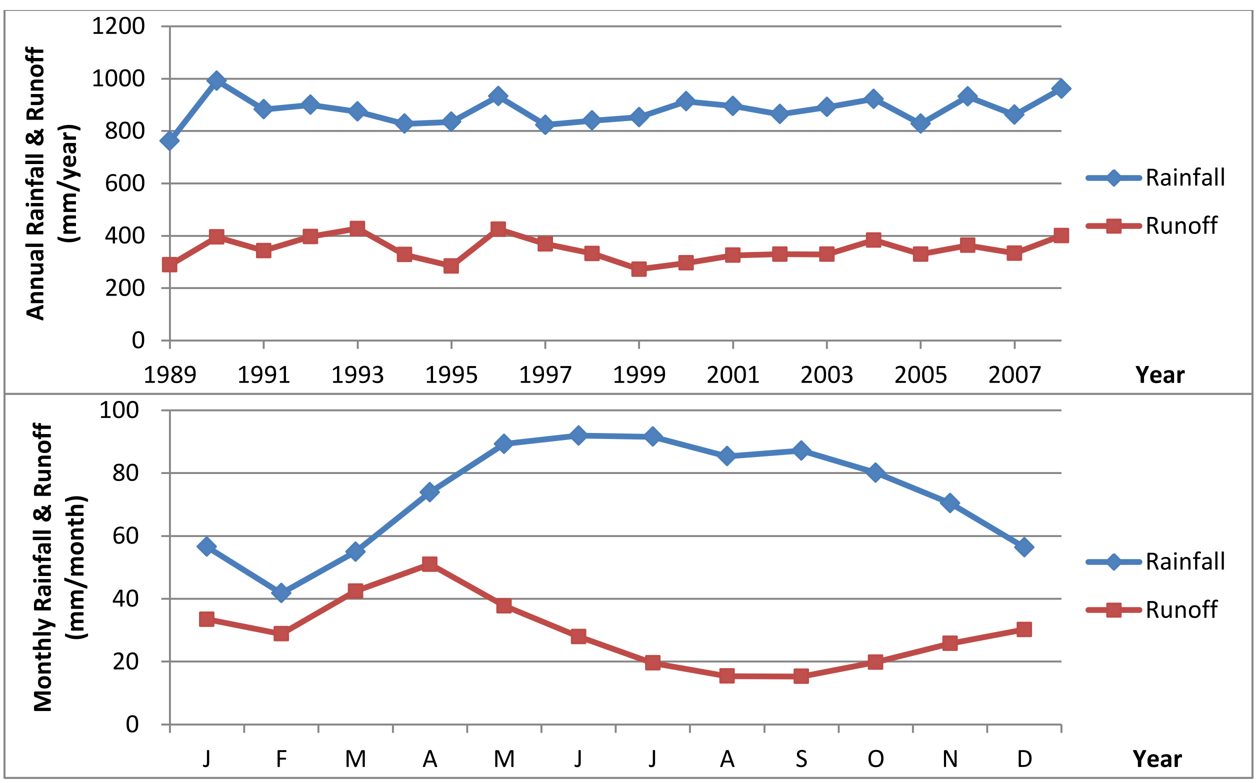

Figure 7.2. Annual and monthly rainfall and runoff of Region 4—Great Lakes.

The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are also shown in Figure 7.1. The region contains 256 hydropower dams and 22 major non-powered dams, with total storage capacities of around 290,835,586 ac-ft and 2,459,560 ac-ft, respectively.

7.3. Potential New Hydropower Resources

A total of 131 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) were identified in the Great Lakes Region. The NSD results based on HUC04 subregions are summarized in Table 7.2. The highest hydropower potential is located in the Northeastern Lake Ontario–Lake Ontario–St. Lawrence Subregion (HUC 0415), followed by the Southwestern Lake Ontario Subregion (HUC 0413), Western Lake Erie Subregion (HUC 0410), and the Southeastern Lake Michigan Subregion (HUC 0405). In the Northeastern Lake Ontario–Lake Ontario–St. Lawrence Subregion, the Black River contains the highest hydropower potential, followed by the Raquette and Oswehatchie rivers. The Genesee, Maumee, Grand, and Saint Joseph rivers contain the next-highest potential for the HUC 0413, HUC 0410, and HUC 0405 subregions.

Table 7.2. Summary of Potential New Hydropower Resources in Region 4—Great Lakes (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# of Stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/reach)	Average residence time (days)
0401	Western Lake Superior	3	3.1	18,026	6.3	2,282	446	0.1
0402	Southern Lake Superior–Lake Superior	-	-	-	-	-	-	-
0403	Northwestern Lake Michigan	12	15.7	112,047	6.2	2,939	947	0.1
0404	Southwestern Lake Michigan	-	-	-	-	-	-	-
0405	Southeastern Lake Michigan	12	31.5	194,172	9.5	3,937	10,185	2.7
0406	Northeastern Lake Michigan–Lake Michigan	-	-	-	-	-	-	-
0407	Northwestern Lake Huron	-	-	-	-	-	-	-
0408	Southwestern Lake Huron–Lake Huron	1	1.3	7452	7.8	2,256	8,241	2.1
0409	St. Clair-Detroit	-	-	-	-	-	-	-
0410	Western Lake Erie	9	32.8	165,434	16.9	3,263	7,435	1.5
0411	Southern Lake Erie	-	-	-	-	-	-	-
0412	Eastern Lake Erie-Lake Erie	9	11.9	64,371	26.0	707	1,036	0.7
0413	Southwestern Lake Ontario	28	43.6	228,785	16.1	1,349	2,921	0.9
0414	Southeastern Lake Ontario	4	7.0	37,152	6.4	3,836	666	0.1
0415	Northeastern Lake Ontario–Lake Ontario–St. Lawrence	53	118.1	710,109	15.6	2,022	703	0.2

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 in Figure 7.3. The hydraulic head H_{ref} ranges from 6 to the 90th quantile of 19 ft with a median of about 15 ft, suggesting that many of the potential stream-reaches will require low-head hydropower technologies. The design flow Q_{30} ranges from about 759 cfs to the 90th quantile of 4600 cfs with a median of 1500 cfs. The potential capacity P_{NSD} ranges from 1 to the 90th quantile of about 4 MW with a median of about 1.75 MW. The inundated surface area A_{NSD} ranges from 0 to the 90th quantile of 1000 ac with a median of 125 ac. This results in storage values V_{NSD} ranging from 0 to the 90th quantile of 5000 ac-ft with a median of about 1000 ac-ft and very short residence times T_{NSD} ranging from <1 day to the 90th quantile of 1.5 days with a median on the order of hours. In general, the relatively small inundation areas and storage volumes paired with the short retention times for this region are characteristic of run-of-river type hydro facilities. The results of > 1 MW stream-reach potential are illustrated in Figure 7.4, with potential capacity (MW) aggregated to the HUC08 subbasins. The higher-potential-capacity sites are generally located on the larger rivers in the northern New York and Ohio areas.

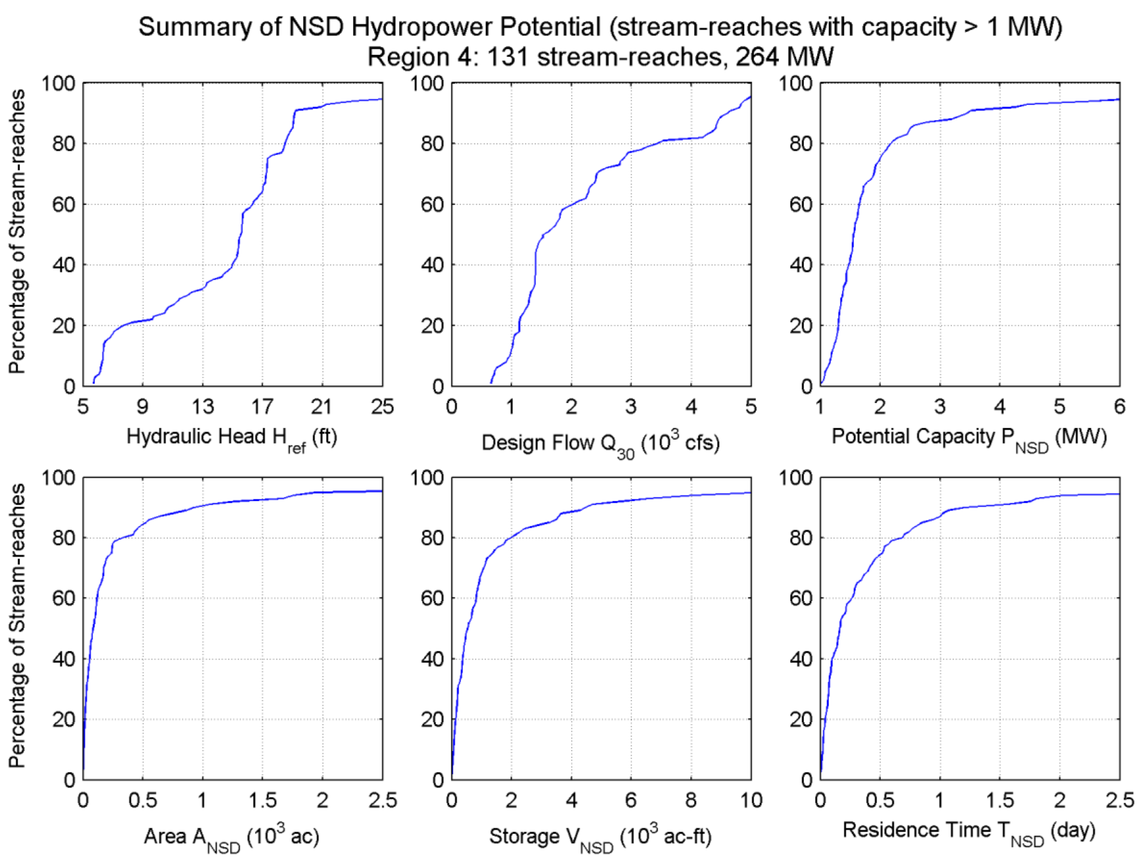

Figure 7.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 4—Great Lakes.

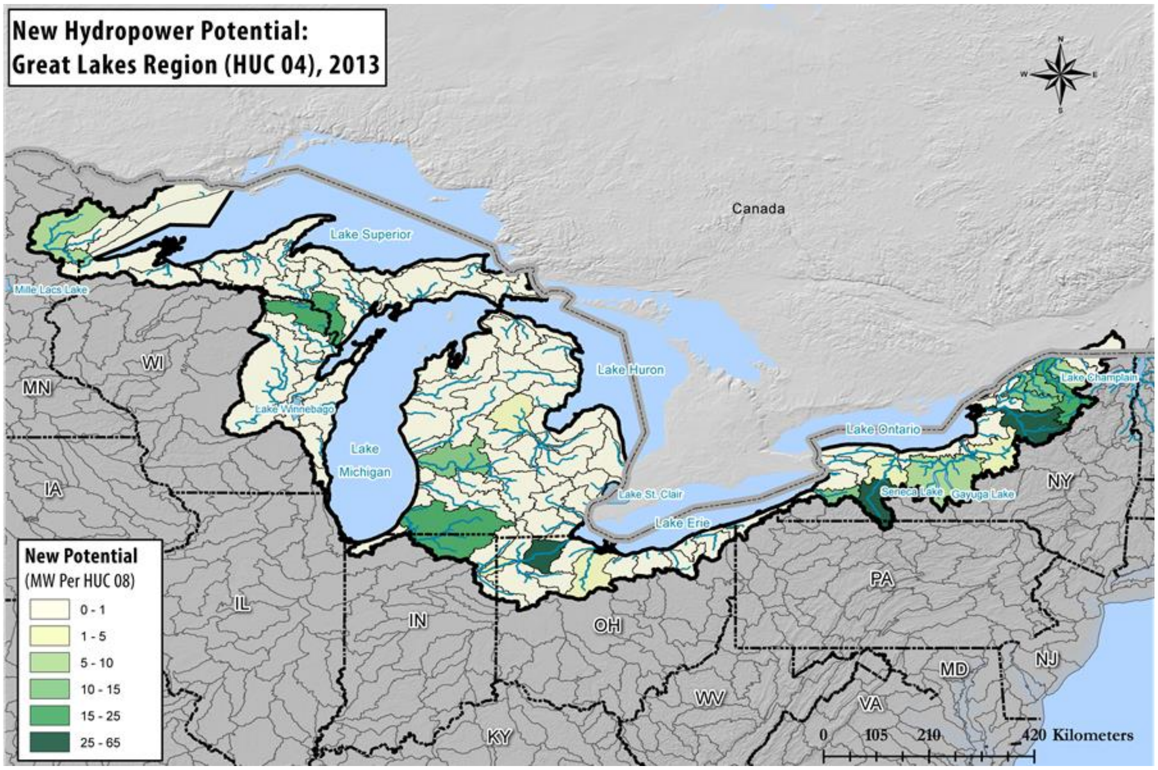

Figure 7.4. Potential new hydropower capacity in Region 4 Great Lakes (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC08 subbasins for illustration).

7.4. Environmental Characteristics

Of the 155 native fish species in Region 4, alewife, Atlantic salmon, and arctic grayling (*Thymallus arcticus*) fall under an ESA category (Appendix B). Bloater (*Coregonus hoyi*), Eastern sand darter (*Ammocrypta pellucida*), kiyi (*Coregonus kiyi*), and shortjaw cisco (*Coregonus zenithicus*) fall under the IUCN vulnerable categories. Eighteen species of fish are considered potadromous or anadromous in the region. Four critical watersheds are located in Region 4, with the St. Joseph, Wolf, and Black HUC08 subbasins having the most fish and mussels at risk (8, 6, and 4, respectively). Species with critical habitat designations in the region include gray wolf (*Canis lupus*), Canada lynx, and Hine's emerald dragonfly (*Somatochlora hineana*) (Figure 7.5).

The 15 million acres of protected land in Region 4 are primarily state owned (55%), followed by federally (35%) and privately owned land (6%). State forests (41%) and habitat/species management areas (8%) make up the bulk of state-owned lands. The USFS owns the most federal lands (31%), followed by DOD (2%) and USFWS (1%). Most lands fall under GAP status 3 (47%) and 2 (39%). Fourteen rivers have protection under the National Wild and Scenic Rivers Act in Region 4. Recreation locations are numerous, totaling 2360 boat ramp locations, 778 fish access locations, 276 waterfalls, and 516 recreational boating river sections.

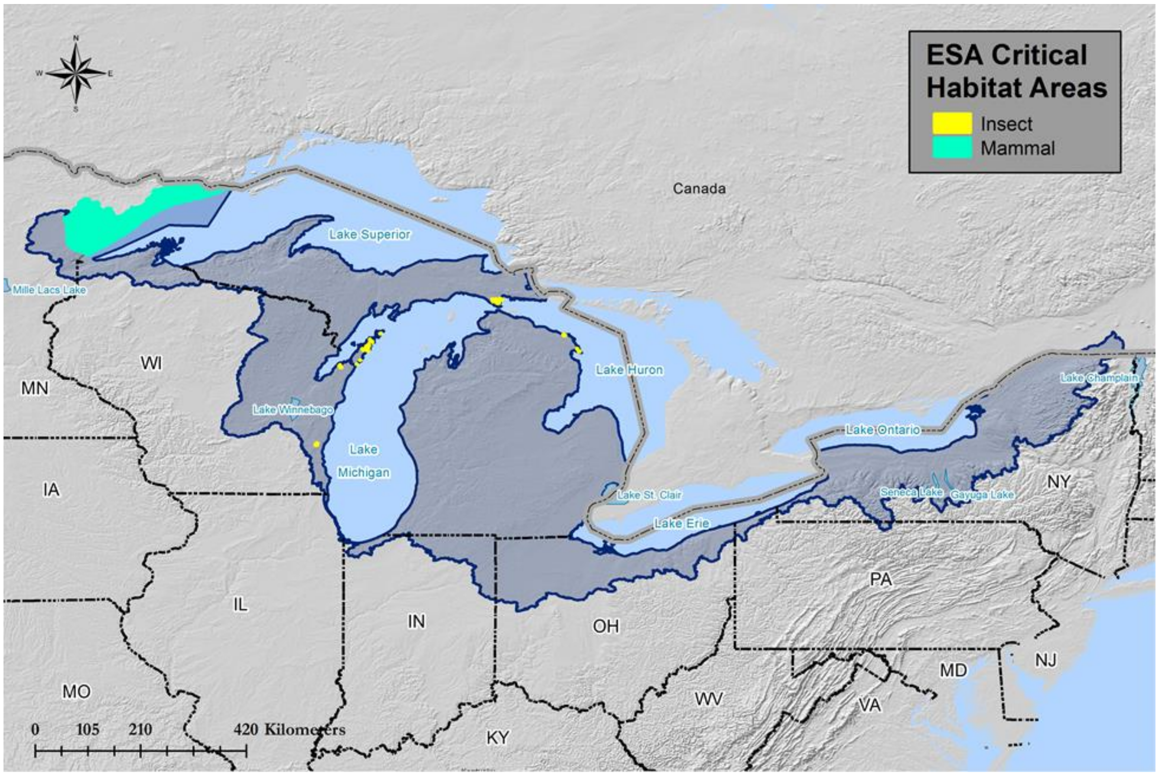

Figure 7.5. Critical habitats of federally endangered and threatened species in Region 4.

Water use is moderately high in Region 4, with most usage occurring as thermoelectric cooling, followed by public and industrial consumption (Appendix B). The highest amounts of water usage occur in the St. Clair–Detroit and Southwestern Lake Michigan Subbasins (Table 7.3). The highest number of water quality concerns in the United States is found in Region 4, most of which are classified as toxin or mercury contamination (Figure 7.6 and Appendix B).

Critical habitats are absent from 131 stream-reaches in Region 4 (Figure 7.7). Although 92% of stream-reaches intersect protected lands, none intersect national parks or Wild and Scenic Rivers. Thirteen percent of sites with a total of 34 MW are located in HUC08 subbasins containing at least one fish falling under ESA categories. Water quality concerns are common, occurring at 44% of stream-reaches. Recreational boating runs are very prevalent, overlapping with 85% of stream-reaches; however, boat ramps and fishing access locations are less common, only identified at 32% and 31% of stream-reaches, respectively. Most identified stream-reaches have low or moderate water usage.

Table 7.3. Summary of Environmental Variables at HUC04 Subregions within Region 4 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# Critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	# Recreation locations[a]	% Protected lands	Population density (ind/km^2)	Freshwater use (l/day/km^2)
0401	Western Lake Superior	2	12	0	3	332; 79; 25	38.69	7.15	470.18
0402	Southern Lake Superior–Lake Superior	2	14	0	3	149; 68; 89	28.05	6.52	235.30
0403	Northwestern Lake Michigan	1	14	0	1	889; 92; 36	17.36	16.68	1,858.22
0404	Southwestern Lake Michigan	1	11	0	1	52; 12; 0	5.47	412.64	10,401.13
0405	Southeastern Lake Michigan	0	10	0	1	371; 7; 0	2.81	87.44	1,765.94
0406	Northeastern Lake Michigan–Lake Michigan	1	13	1	1	261; 3; 0	33.06	9.70	277.07
0407	Northwestern Lake Huron	1	11	0	1	118; 2; 2	40.29	8.31	141.23
0408	Southwestern Lake Huron-Lake Huron	0	8	0	1	91; 1; 0	7.15	63.47	1,964.24
0409	St. Clair–Detroit	0	8	0	1	79; 3; 0	3.63	511.60	13,356.97
0410	Western Lake Erie	0	9	1	1	123; 9; 0	0.97	84.36	3,661.46
0411	Southern Lake Erie	0	6	1	1	36; 22; 9	6.55	328.28	4,375.74
0412	Eastern Lake Erie–Lake Erie	0	10	1	1	32; 26; 10	3.30	173.10	4,412.90
0413	Southwestern Lake Ontario	0	6	0	1	43; 9; 8	4.84	104.81	902.12
0414	Southeastern Lake Ontario	0	11	0	1	141; 26; 29	7.08	89.22	5,696.87
0415	Northeastern Lake Ontario–Lake Ontario–St. Lawrence	1	14	1	1	442; 159; 72	28.05	9.75	135.59

[a] Recreation locations refer to the number of boat-ramp and fishing access points, recreational boating, and waterfalls within each HUC04.

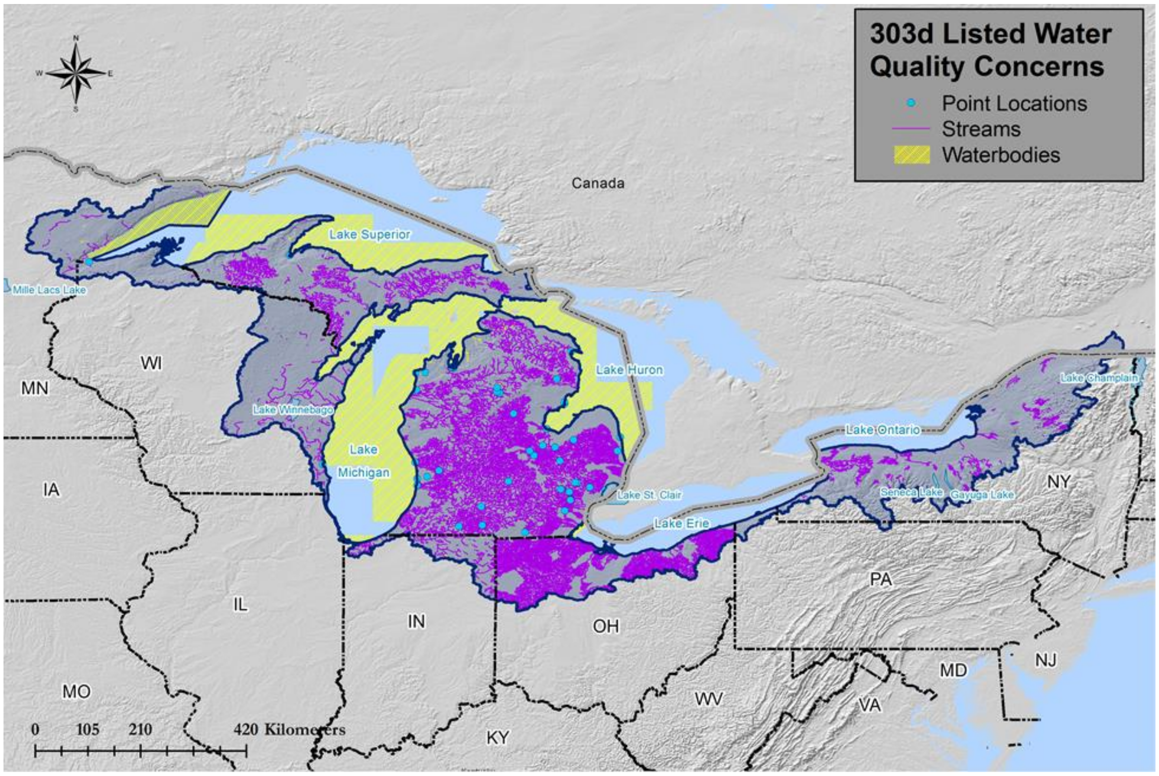

Figure 7.6. 303d listed streams and waterbodies in Region 4.

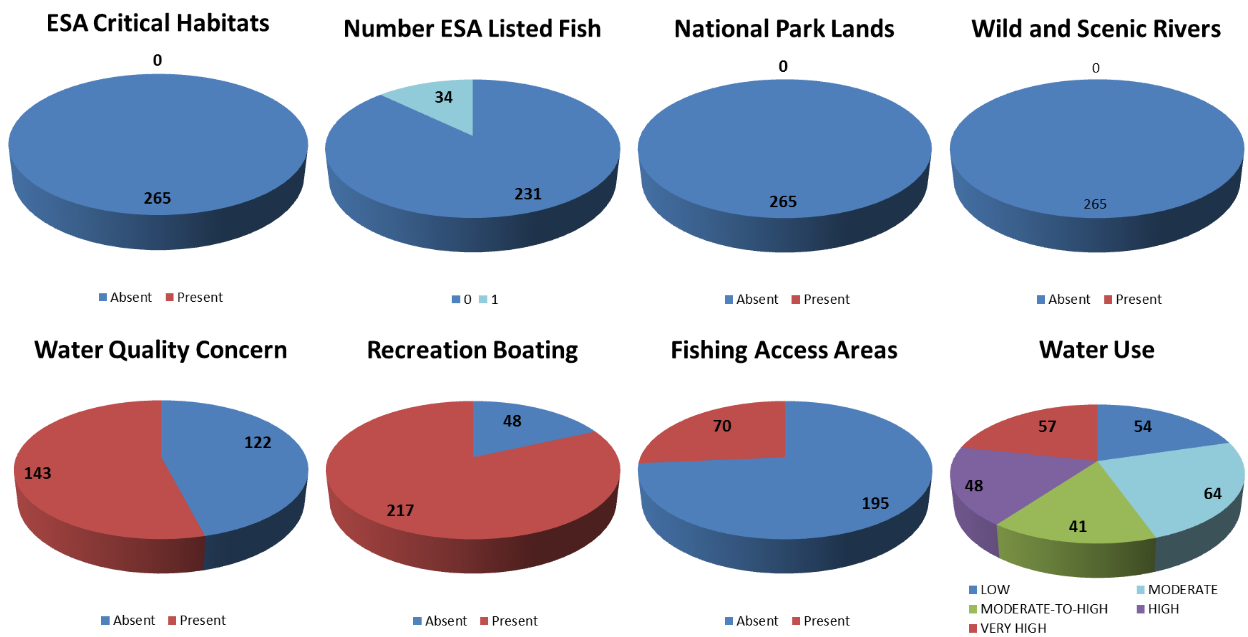

Figure 7.7. The potential capacity, in MW, associated with environmental attributes in Region 4—Great Lakes (stream-reaches with potential capacity >1 MW).

8. REGION 5—OHIO

8.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation and mean capacity factors in the Ohio Region are estimated and summarized in Table 8.1 for both larger (>1 MW) and smaller (<1 MW) stream-reaches. For comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation, and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 4.76 GW, around 216% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 25.29 TWh/year, around 379% of annual net generation from existing conventional hydropower plants. Given the run-of-river assumption, NSD stream-reaches have higher capacity factors, especially compared with other larger-storage peaking-operation projects in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 8.3 and 8.4.

Table 8.1. Summary of NSD Findings in Region 5—Ohio

	Capacity (MW)	Generation (MWh)	Mean capacity factor
Potential in undeveloped stream-reaches (<1 MW)	3,043	16,304,000	61%
Potential in undeveloped stream-reaches (>1 MW)	1,714	8,984,000	60%
Existing hydropower—conventional hydro	2,201	6,681,000	35%
Existing hydropower—pumped storage	469		

8.2. Background Hydrologic Setting

The Ohio Region encompasses approximately 421,961 km^2 in the mid-upper-west section of the United States. This region contains the eastern sections of Illinois, most of southern Indiana, most of Kentucky, southern sections of Ohio, western sections of Pennsylvania, some parts of Tennessee, North Carolina, Maryland, Virginia and New York, and most of West Virginia.

Several river systems are located in the Ohio Region (Figure 8.1), including the Ohio, Allegheny, Monongahela, Kanawha, Muskingum, Scioto, Big Sandy, Guyandotte, Great Miami, Kentucky, Licking, Green, Wabash, Patoka, White, and Cumberland rivers, with a total length of 51,632 km (i.e., total length of streams with estimated discharge greater than 35 cfs). Metropolitan areas within the region include Indianapolis (IN), Columbus (OH), Cincinnati (OH), Louisville (KY), Lexington (KY), Charleston (WV), and Pittsburg (PA). As shown in Figure 8.2, annual precipitation for the Ohio region ranges from 950 to 1350 mm/year and annual runoff from 300 to 700 mm/year. Most precipitation occurs from late spring through summer. The peak of the runoff occurs during early spring when the snow melts.

The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are shown in Figure 8.1. The region contains 55 hydropower dams and 129 major non-powered dams, with storage capacities of about 22,542,131 ac-ft and 16,233,505 ac-ft, respectively.

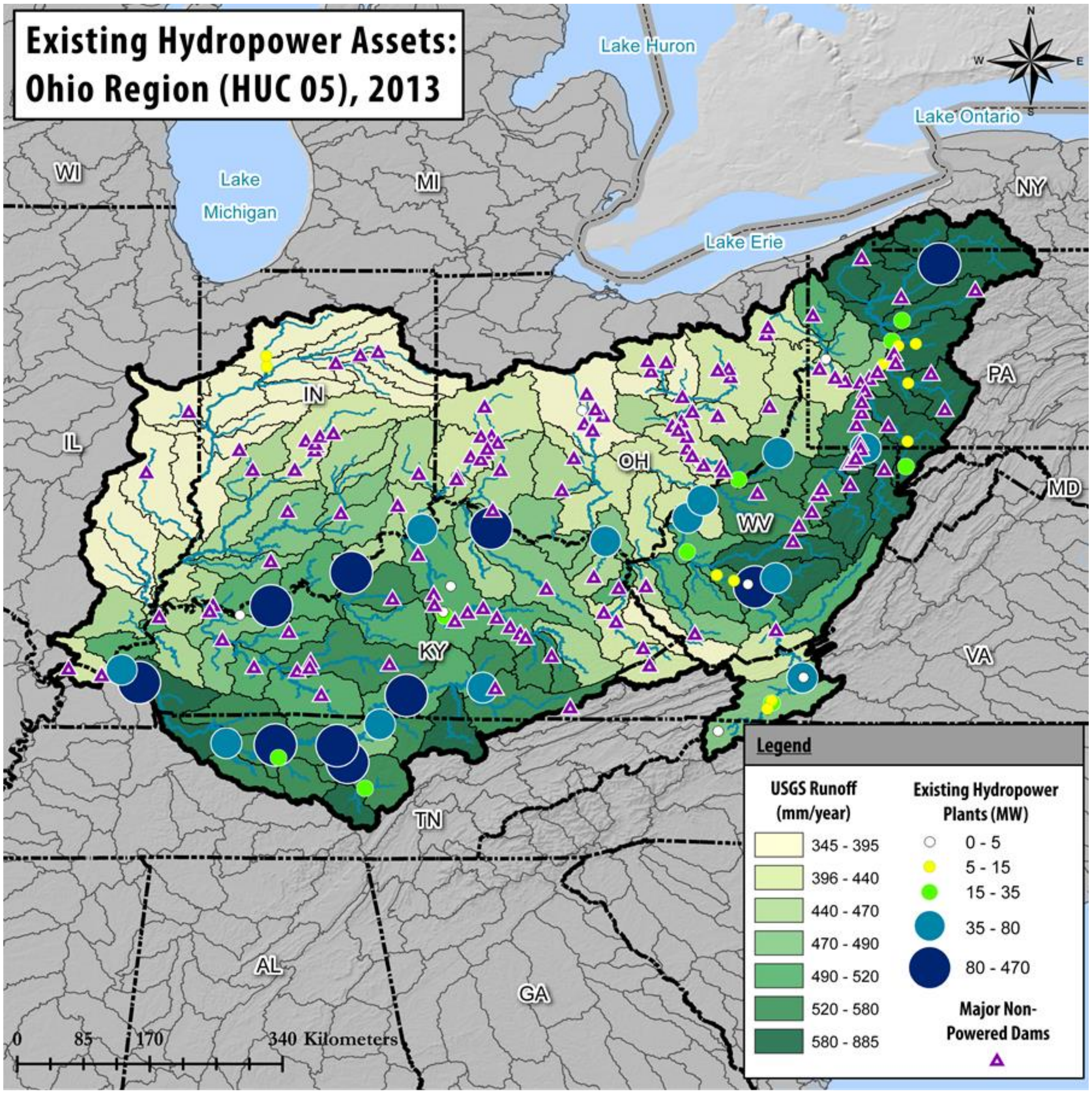

Figure 8.1. Locations of water control projects in Region 5—Ohio.

8.3. Potential New Hydropower Resources

A total of 699 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) were identified in the Ohio Region. An aggregation of the NSD results into HUC04 subregions is shown in Table 8.2. The highest hydropower potentials are found in the Kanawha Subregion (HUC 0505), followed by the Allegheny Subregion (HUC 0501) and Wabash Subregion (HUC 0512) in the New, Allegheny, Wabash, and East Fork White rivers.

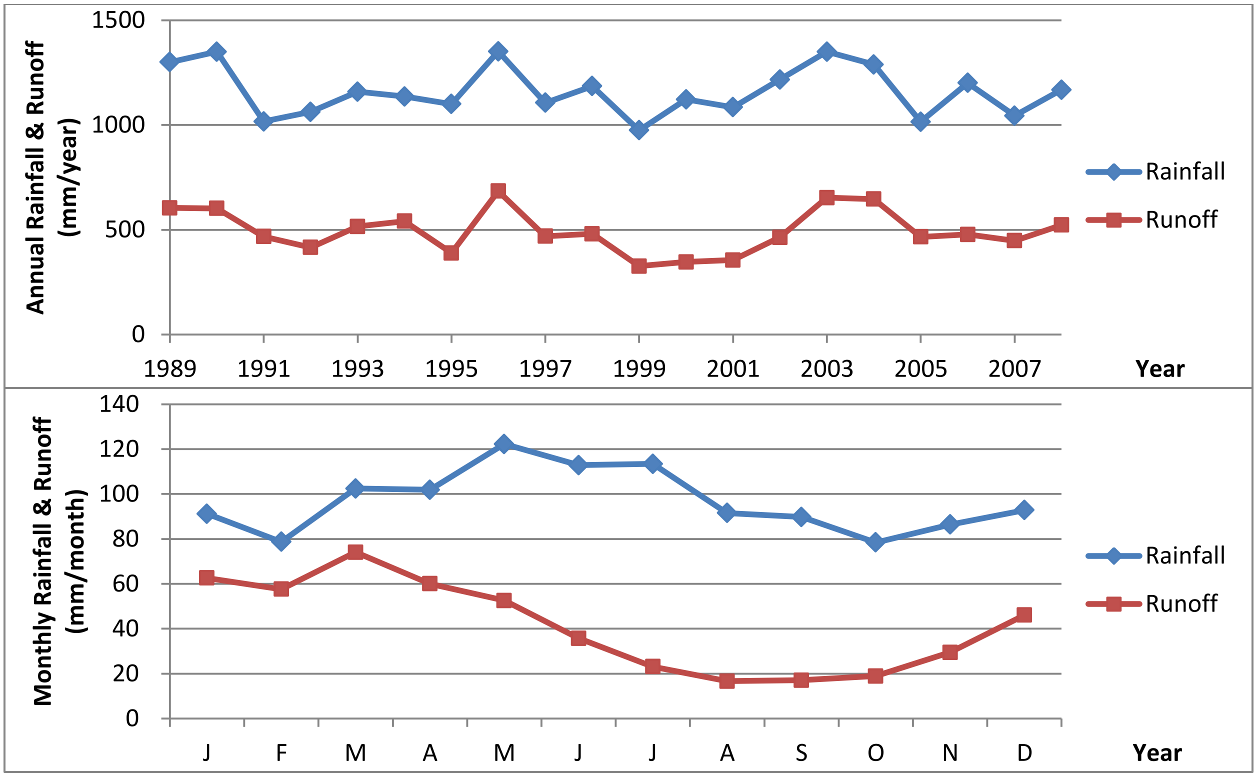

Figure 8.2. Annual and monthly rainfall and runoff of Region 5—Ohio.

Table 8.2. Summary of Potential new hydropower resources in Region 5—Ohio (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/reach)	Average residence time (days)
0501	Allegheny	87	424.2	2,323,264	23.5	3,282	5,918	2.4
0502	Monongahela	111	371.1	2,008,181	31.5	1,570	3,258	1.9
0503	Upper Ohio	24	86.9	471,331	25.7	3,260	9,551	5.8
0504	Muskingum	18	62.7	351,578	17.8	2,898	7,259	2.3
0505	Kanawha	174	954.0	5,293,479	37.2	2,069	6,596	3.6
0506	Scioto	12	52.0	268,306	16.6	3,752	19,652	2.7
0507	Big Sandy–Guyandotte	49	122.8	617,627	40.0	991	15,593	7.0
0508	Great Miami	26	61.4	324,322	21.8	1,902	8,394	5.8
0509	Middle Ohio	9	13.7	68,784	28.6	760	14,666	12.6
0510	Kentucky–Licking	41	160.7	764,354	33.0	1,980	17,057	8.4
0511	Green	23	76.1	386,285	23.6	2,256	17,995	8.0
0512	Wabash	66	445.9	2,390,224	22.7	4,260	51,803	17.2
0513	Cumberland	50	195.7	960,886	45.3	1,498	17,656	14.1
0514	Lower Ohio	9	16.0	74,987	26.1	1,180	10,634	5.3

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 in Figure 8.3. The hydraulic head H_{ref} ranges from 5 to the 90th quantile of 57 ft with a median of about 27 ft. The design flow Q_{30} ranges from about 400 cfs to the 90th quantile of 5000 cfs with a median of 1500 cfs. The potential capacity P_{NSD} ranges from 1 to the 90th quantile of about 9 MW with a median of about 3.75 MW. The inundated surface area A_{NSD} ranges from 0 to the 90th quantile of 2500 ac with a median of 400 ac. This results in storage values V_{NSD} ranging from 0 to the 90th quantile of 30,000 ac-ft with a median of about 4,000 ac-ft and residence times of T_{NSD} ranging from <1 day to the 90th quantile of 18 days with a median on the order of a few days. The results of > 1 MW stream-reach potential are illustrated in Figure 8.4 with potential capacity (MW) aggregated to the HUC08 subbasins.

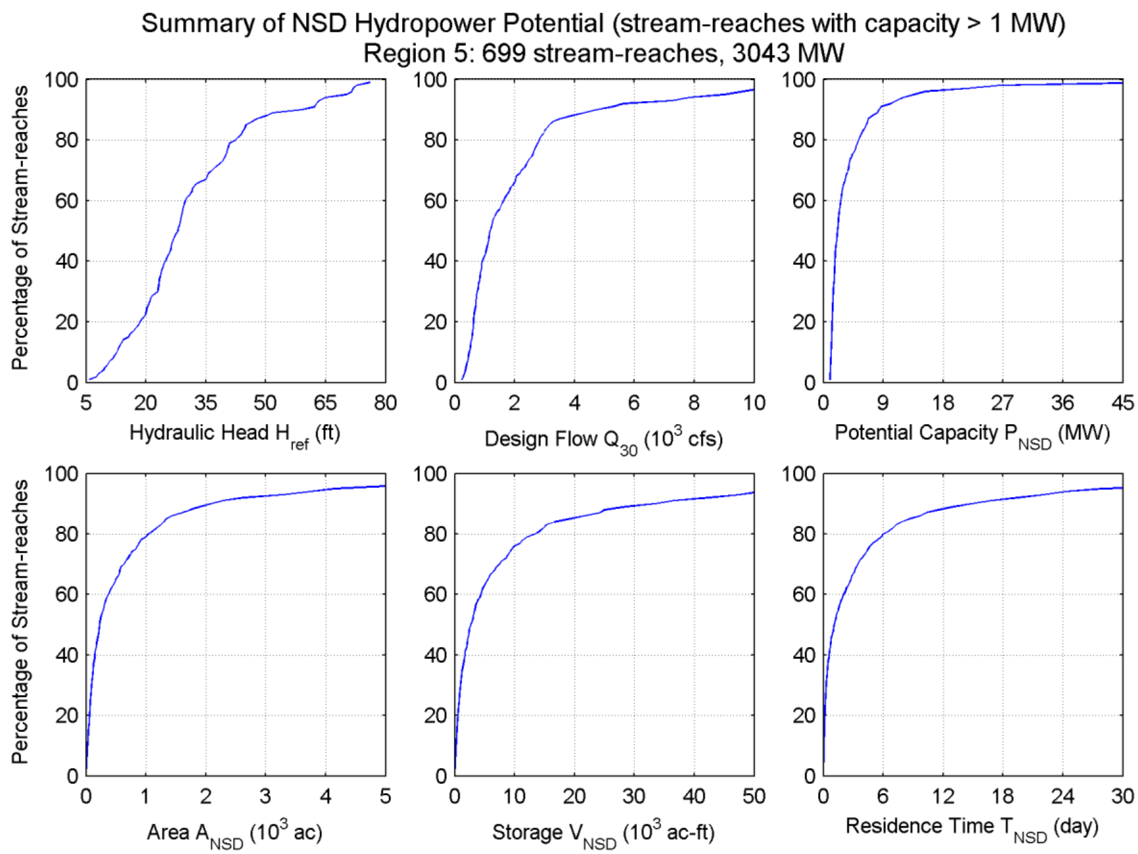

Figure 8.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 5—Ohio.

8.4. Environmental Characteristics

In Region 5, eight fish species fall under ESA categories, two of which also fall under IUCN vulnerable categories. An additional 14 fish species fall under IUCN vulnerability status. Well-known fish species of concern in the region include paddlefish (*Polyodon spathula*) and shortnose sturgeon (*Acipenser brevirostrum*). Of the 267 total native species, 13 are considered potadromous or anadromous (Figure 8.5). Twenty-eight HUC08 subbasins are considered critical watersheds, with the highest number of fish and mussels at risk in the Upper Green (29), South Fork Cumberland (22), and Tippecanoe (21) basins. Three mussel species, the Virginia big-eared bat, and Braun's rock-cress (*Arabis perstellata*), a plant species, have critical habitat designations in Region 5.

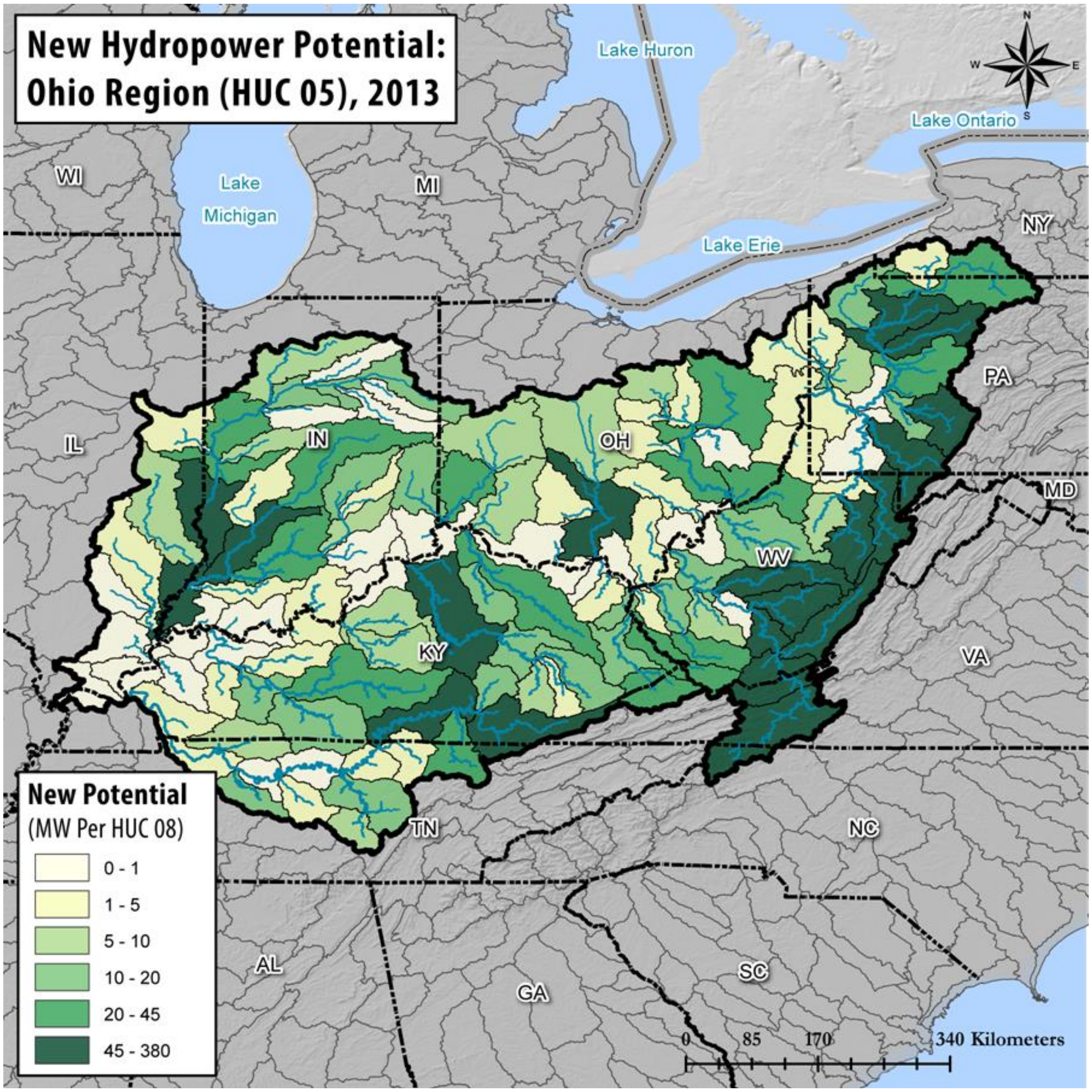

Figure 8.4. Potential new hydropower capacity in Region 5—Ohio (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC08 subbasins for illustration).

Protected lands make up less than 8% of the total area in Region 5 (7.8 million acres). Most lands are federal (55%) and are owned by the USFS (38%), DOD (12%), and NPS (4%). Daniel Boone, Monongahela, Shawnee, and Allegheny National Forests are the largest contiguous protected land areas. Mammoth Cave is one of the more prominent national parks in the region. Most protected lands fall under GAP status 3 (51%), followed by GAP status 2 (24%), 4 (20%), and 1 (5%). Region 5 includes nine National Wild and Scenic Rivers and two national parkways, including sections of the Blue Ridge and Natchez Trace parkways (Figure 8.6). Recreation in Region 5 includes 1487 boat ramp locations, 792 fish access locations, 96 waterfalls, and 528 recreational boating river sections.

Water use in Region 5 is moderately high with most usage occurring as thermoelectric cooling followed by public and industrial consumption (Appendix B). Water usage is mostly homogenous across the region; however, the lowest usage occurs in the Big Sandy-Guyandotte and Kentucky-Licking Subbasins (Table 8.3). Water quality concerns are average, with the majority classified as mercury, habitat, or toxins.

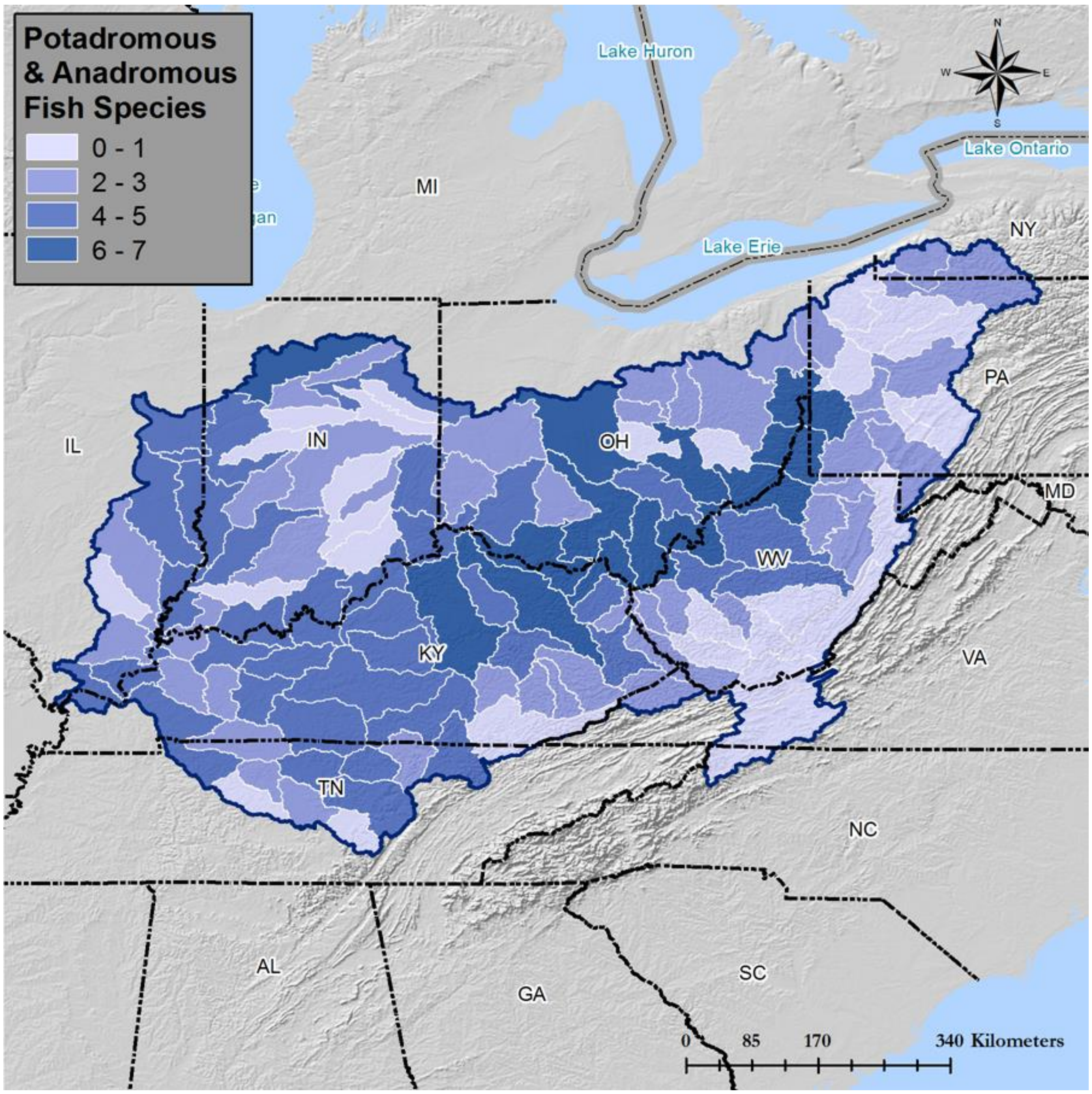

Figure 8.5. Potadromous and anadromous fish species (number per HUC08 subbasin) in Region 5.

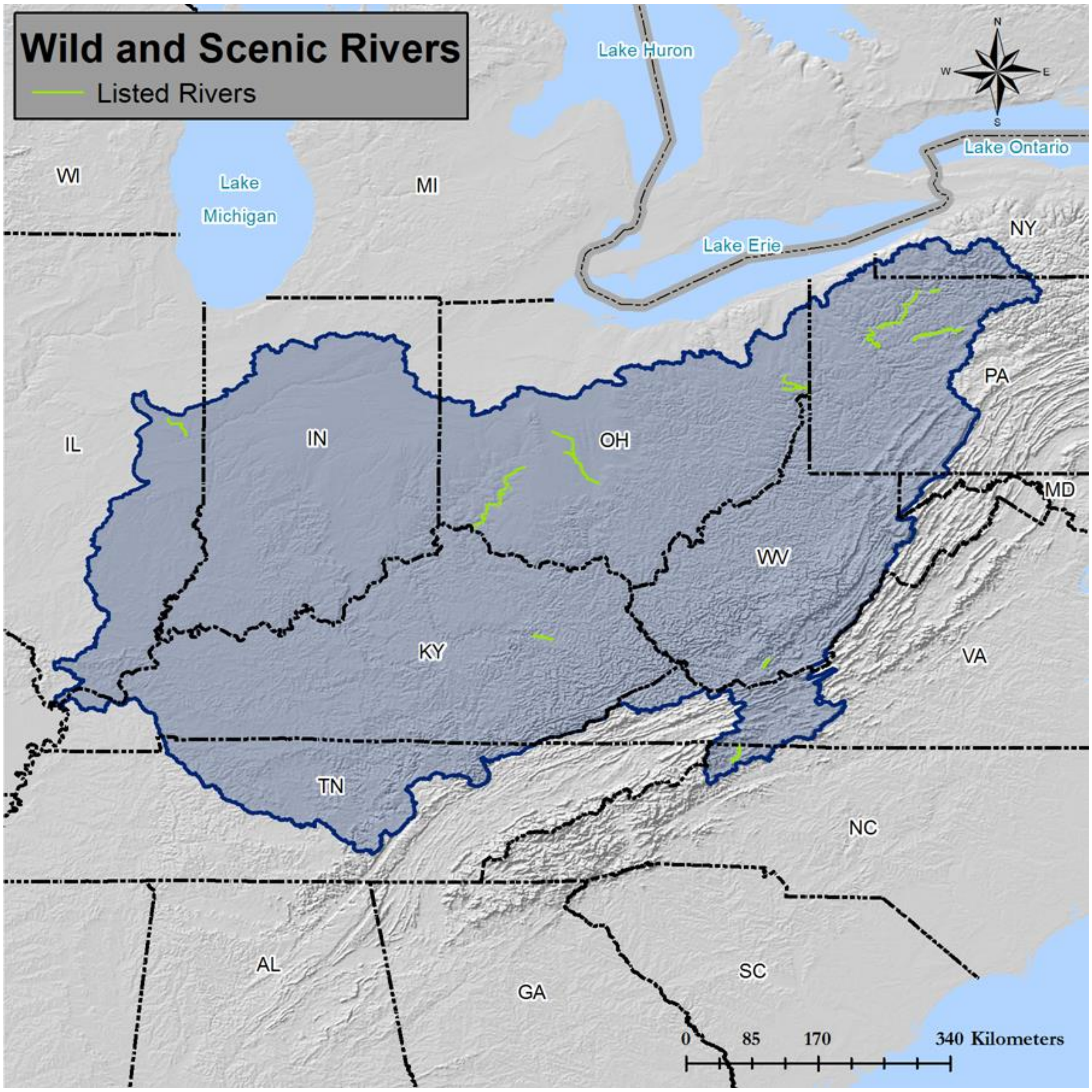

Figure 8.6. Wild and Scenic River Systems in Region 5.

Of the 699 total stream-reaches in Region 5, only 24 (86 MW) intersect critical habitat designations (Figure 8.7). Almost 16% of stream-reaches are located within HUC08 subbasins with at least one fish falling under ESA categories. Over 72% of stream-reaches intersect protected lands (~2.5 GW); however, only one stream-reach intersects a national park. Fifty-five stream-reaches (298 MW) intersect Wild and Scenic Rivers. Most stream-reaches (83%) overlap with water-quality concerns. Recreational boating is also very prevalent, overlapping with 64% of stream-reaches. Boat ramps and fishing access locations intersect 37% and 26% of stream-reaches, respectively. Over 1.1 GW of potential capacity overlaps within HUC08 subbasins having high or very high water use.

Table 8.3. Summary of Environmental Variables at HUC04 Subregions within Region 5 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# Critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	# Recreation locations[a]	Protected lands (%)	Population density (ind/km^2)	Freshwater use (l/day/km^2)
0501	Allegheny	0	6	0	4	160; 38; 2	14.72	86.94	1,766.49
0502	Monongahela	1	5	0	0	139; 108; 14	13.00	61.12	2,270.68
0503	Upper Ohio	0	8	1	3	233; 14; 6	5.22	84.59	6,981.28
0504	Muskingum	0	8	0	4	86; 6; 2	3.94	61.56	1,279.91
0505	Kanawha	0	8	1	7	265; 162; 19	14.67	28.68	2,442.36
0506	Scioto	0	8	1	4	56; 7; 1	3.90	81.87	1,045.67
0507	Big Sandy–Guyandotte	0	6	0	2	76; 17; 0	2.57	18.16	461.47
0508	Great Miami	0	6	1	3	42; 18; 3	1.90	134.77	2,516.45
0509	Middle Ohio	0	8	2	5	141; 27; 3	6.15	72.72	4,791.39
0510	Kentucky–Licking	0	7	1	4	150; 29; 1	6.45	10.15	528.03
0511	Green	0	7	0	7	110; 3; 0	2.69	9.02	2,448.17
0512	Wabash	0	10	1	6	323; 19; 6	3.34	44.90	1,832.05
0513	Cumberland	4	7	5	9	340; 59; 22	10.97	56.86	2,021.17
0514	Lower Ohio	0	6	1	6	158; 21; 17	12.02	45.54	5,773.60

[a] Recreation locations refer to the number of boat-ramp and fishing access points, recreational boating, and waterfalls within each HUC04.

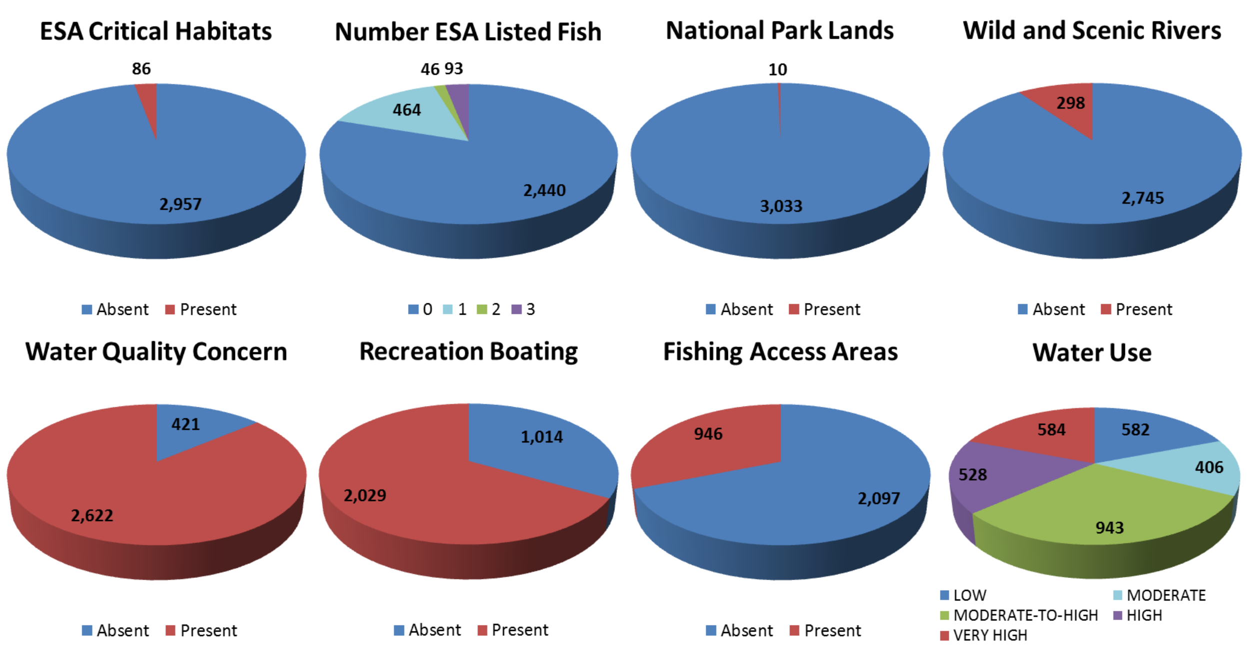

Figure 8.7. The potential capacity, in MW, associated with environmental attributes in Region 5—Ohio (stream-reaches with potential capacity >1 MW).

9. REGION 6—TENNESSEE

9.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation and mean capacity factors in the Tennessee Region are estimated and summarized in Table 9.1 for both larger (>1 MW) and smaller (<1 MW) stream-reaches. For comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation, and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 1.36 GW, around 33% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 8.00 TWh/year, around 55% of annual net generation from existing conventional hydropower plants. The lower ratios of potential NSD resources to existing hydropower development suggest that many of the hydraulically feasible stream-reaches may have been used for hydropower development in this region. Given the run-of-river assumption, NSD stream-reaches have higher capacity factors, especially compared with other larger-storage peaking-operation projects in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 9.3 and 9.4.

Table 9.1. Summary of NSD Findings in Region 6—Tennessee

	Capacity (MW)	Generation (MWh)	Mean capacity factor
Potential in undeveloped stream-reaches (>1 MW)	747	4,383,000	67%
Potential in undeveloped stream-reaches (<1 MW)	616	3,612,000	67%
Existing hydropower—conventional hydro	4,166	14,542,000	40%
Existing hydropower—pumped storage	1,809		

9.2. Background Hydrologic Setting

The Tennessee Region encompasses approximately 105,949 km^2 in the Tennessee valley and contains parts of Tennessee and North Carolina and small sections of Virginia, Georgia, Alabama, Kentucky and Mississippi. The region comprises mountainous, valley, and plateau geography.

Several river systems are located in the Tennessee Region (Figure 9.1), including the Tennessee, French Broad, Holston, and Sequatchie rivers, with a total length of 14,893 km (i.e., total length of streams with estimated discharge greater than 35 cfs). Metropolitan areas within the region include Knoxville (TN), Chattanooga (TN), and Huntsville (AL). As shown in Figure 9.2, annual precipitation for the Tennessee region ranges from 900 to 1700 mm/year, and annual runoff from 250 to 900 mm/year. Most of the precipitation occurs predominately in the winter and some in late summer.

The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are shown in Figure 9.1. The region contains 50 hydropower dams and 9 major non-powered dams, with storage capacities of about 28,961,324 ac-ft and 405,235 ac-ft, respectively. These facilities are mainly owned by the Tennessee Valley Authority (TVA).

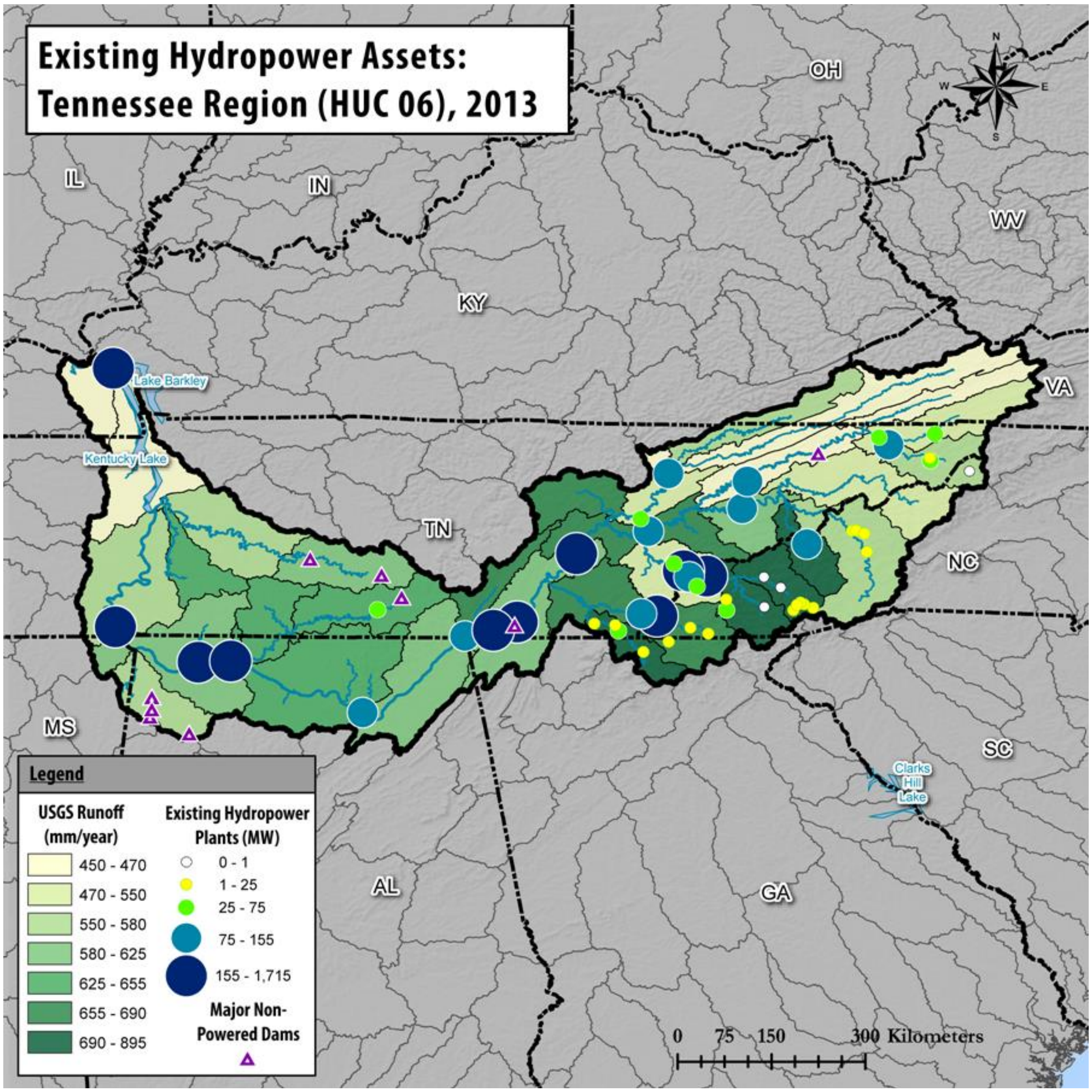

Figure 9.1. Locations of water control projects in Region 6—Tennessee.

9.3. Potential New Hydropower Resources

A total of 235 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) were identified in the Tennessee Region. The NSD results for the HUC04 subregions are summarized in Table 9.2. The highest hydropower potentials are found in the Upper Tennessee Subregion (HUC 0601) in the Tennessee, French Broad, Holston, and Clinch rivers.

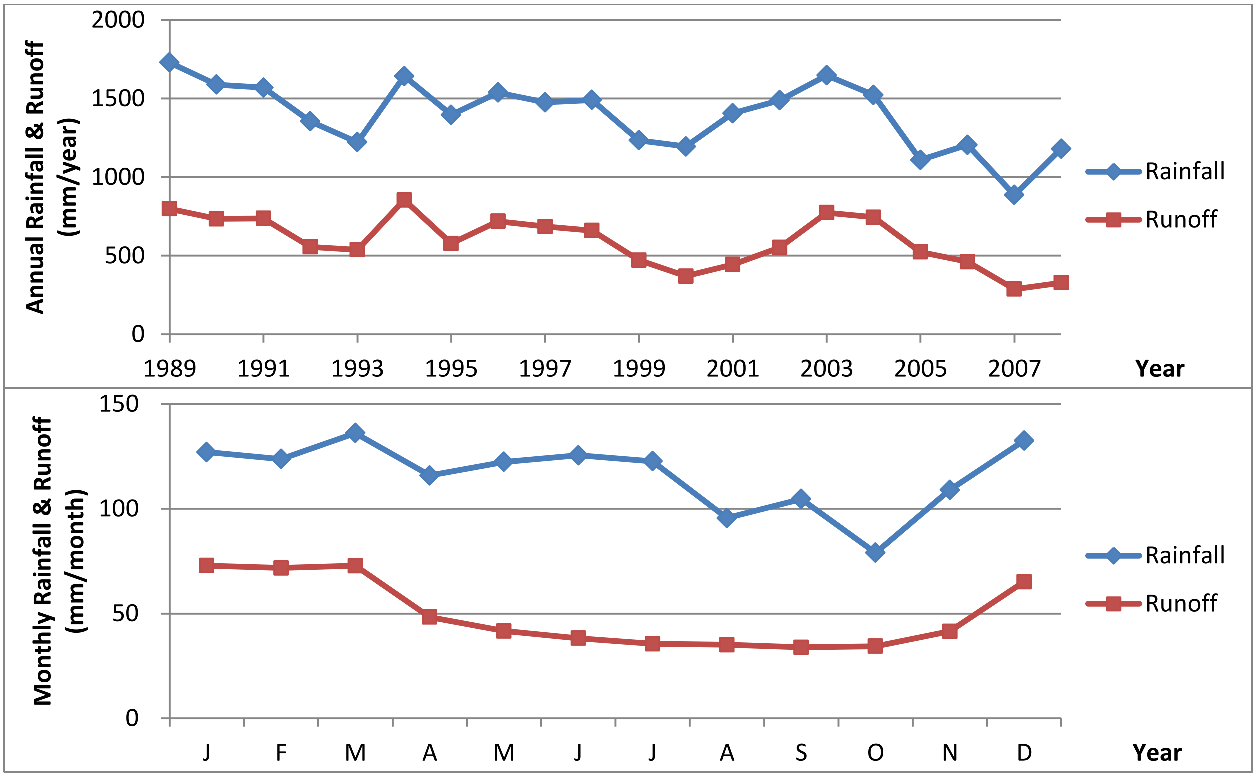

Figure 9.2. Annual and monthly rainfall and runoff of Region 6—Tennessee.

Table 9.2. Summary of Potential New Hydropower Resources in Region 6—Tennessee (Stream-Reaches With Potential Capacity >1 MW)

HUC04	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/reach)	Average residence time (days)
0601	Upper Tennessee	175	601.9	3,574,050	37.4	1,397	15,949	12.7
0602	Middle Tennessee–Hiwassee	24	55.6	353,524	23.1	1,457	6,114	3.4
0603	Middle Tennessee–Elk	14	26.0	135,005	20.0	1,299	9,054	4.3
0604	Lower Tennessee	22	63.6	320,656	24.6	1,740	10,614	3.3

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 in Figure 9.3. The hydraulic head H_{ref} ranges from 5 to the 90th quantile of 77 ft with a median of about 27 ft. The design flow Q_{30} ranges from about 250 cfs to the 90th quantile of 3000 cfs with a median of 1000 cfs. The potential capacity P_{NSD} ranges from 1 to the 90th quantile of about 5 MW with a median of about 2 MW. The inundated surface area A_{NSD} ranges from 0 to the 90th quantile of 1500 acres with a median of 250 acres. This results in storage values V_{NSD} ranging from 0 to the 90th quantile of 30,000 ac-ft with a median of about 4,000 ac-ft and residence times T_{NSD} ranging from <1 day to the 90th quantile of 20 days with a median on the order of a few days. The results of > 1 MW stream-reach potential are illustrated in Figure 9.4 with potential capacity (MW) aggregated to the HUC08 subbasins.

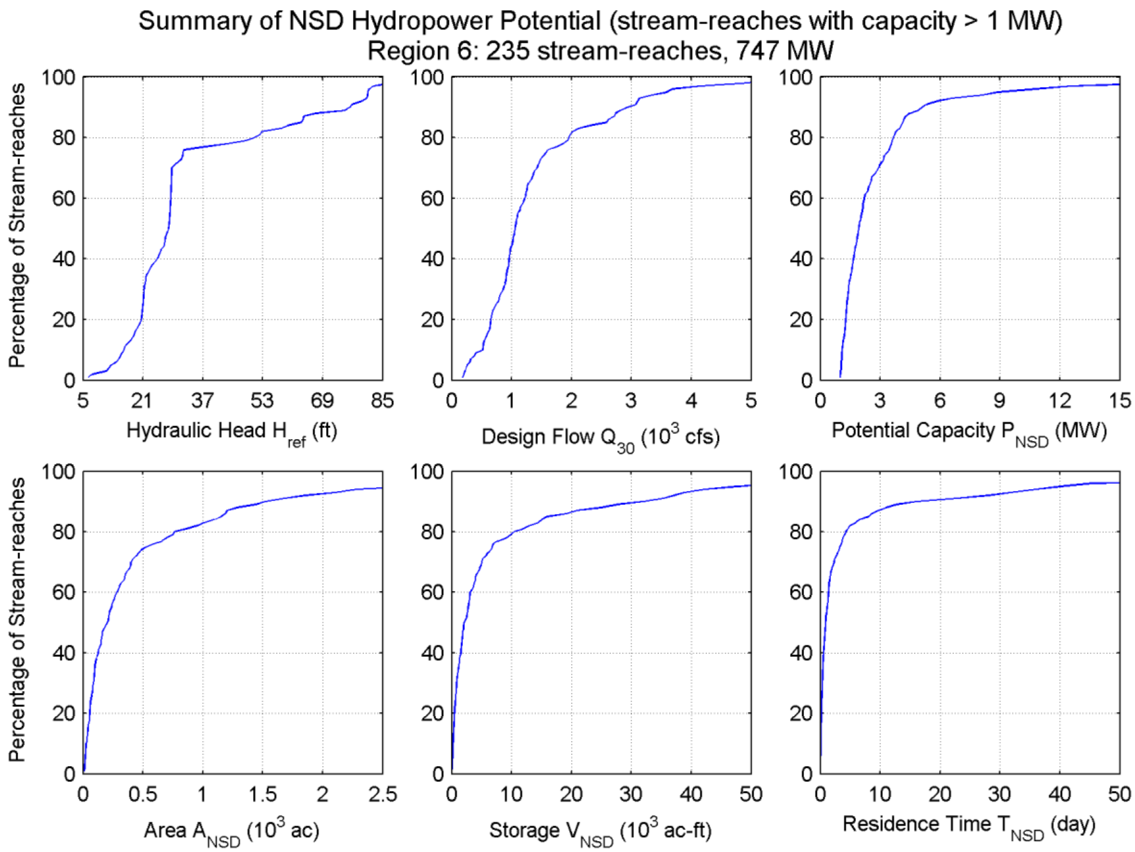

Figure 9.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 6—Tennessee.

9.4. Environmental Characteristics

Considering its small size, the Tennessee Region is one of the areas richest in aquatic species in the United States, with more than 250 native fish species and more than 100 freshwater mussel species (http://tn.water.usgs.gov/lten/tenn.html). The Clinch and Duck rivers are responsible for most of the high diversity found in the region (USGS, 2001). Fifty-one aquatic species (fish and mollusks) are listed as either threatened or endangered (USGS, 2001). Approximately 16 fish species are under ESA categories (Figure 9.5), 6 of which are currently listed as endangered and 6 of which are listed as threatened. Twenty-eight fish and mussel species are listed as endangered or threatened and 50 species are considered "at risk" in the Clinch River drainage alone (Master et al., 1998). Sixty-two percent of HUC08 subbasins in Region 6 are considered critical watersheds with 14 subbasins having at least 15 fish or mussel species at risk (Master et al., 1998). Fourteen additional fish species besides those under ESA categories also fall solely under IUCN vulnerable categories (Figure 9.5). Among the fishes of concern are paddlefish, sturgeon, and many endemic darter, madtom, minnow, and sucker species (Appendix B). Eleven species are potadromous or anadromous in the region. Five mussels, five fish, one plant, and one arachnid have critical habitat designations in the region (Figure 9.6).

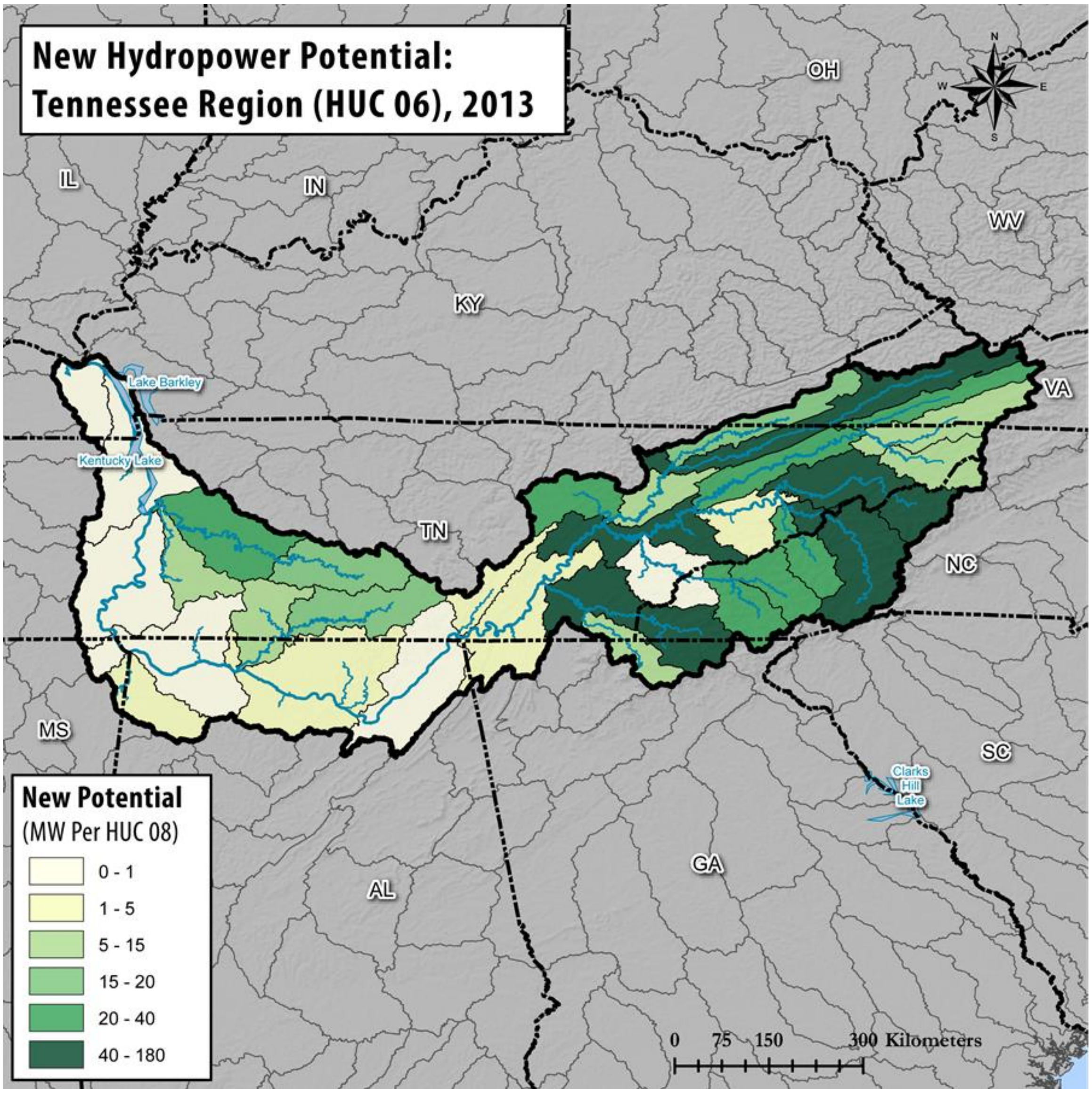

Figure 9.4. Potential new hydropower capacity in Region 6—Tennessee (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC08 subbasins for illustration).

Over 85% of the 3.5 million acres of protected land in Region 6 are federally owned by the USFS (57%), NPS (17%), TVA (9%), and DOD (2%). Great Smoky Mountains National Park is the largest parcel of protected land in this region. Cherokee, Nantahala, Pisgah, Chattahoochee, and George Washington–Jefferson National Forests are also among the largest tracts of protected land. State lands constitute approximately 11% of protected lands. The Eastern Cherokee Indian reservation, almost 50,000 acres, is located in the eastern section of the region. GAP status 3 lands are predominant (63%), followed by status 1 (18%) and 2 (15%) lands. The Obed River is the only National Wild and Scenic River in Region 6. The Blue Ridge and Natchez Trace parkways also have sections within the region. Despite its being among the smallest regions, the Tennessee region has a large number of recreational uses, with a total of 675 boat ramp locations, 286 fishing access locations, 149 waterfalls, and 258 recreational boating river sections.

On average, the highest amount of water use in the United States occurs in Region 6. Water use is fairly homogenous in the region (Table 9.3 and Figure 9.7), with the vast majority occurring as thermoelectric cooling, followed by industrial and public consumption. Water-quality concerns in Region 6 are average with most classified as mercury or toxin contamination.

Seventy-four percent of stream-reaches (497 MW) are located within HUC08 subbasins with at least one fish falling under an ESA category (Figure 9.8). Over 42% of stream-reaches (223 MW) intersect critical habitat designations. Almost 83% of stream-reaches (667 MW) potentially overlap with protected lands; 27 and 18 reaches overlap with a national park or Wild and Scenic River, respectively. Almost 79% of stream-reaches (643 MW) intersect water-quality concerns. Recreation is prevalent, with recreational boating, boat ramps, and fishing access locations intersecting 54%, 34%, and 15% of stream-reaches. Most stream-reaches overlap within HUC08 subbasins with high or very high water use values.

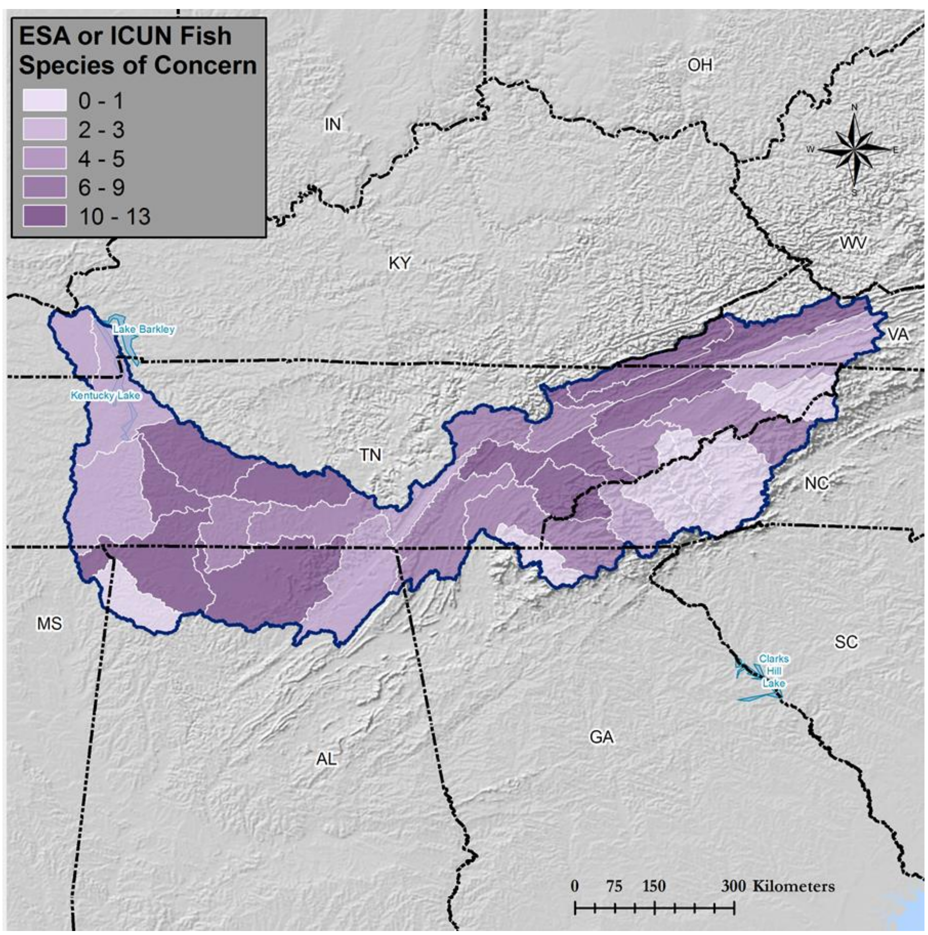

Figure 9.5. Fish species of concern (number per HUC08 subbasin) in Region 6.

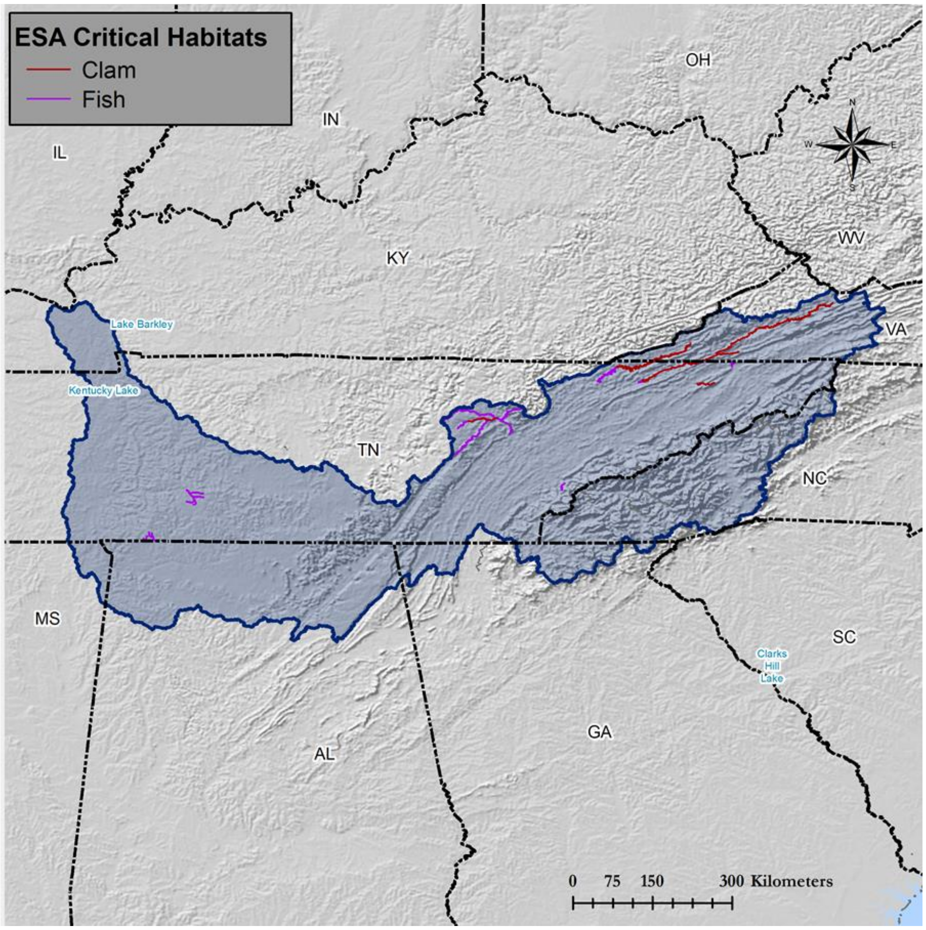

Figure 9.6. Critical habitats of federally endangered and threatened species in Region 6.

Table 9.3. Summary of Environmental Variables at HUC04 Subregions Within Region 6 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# Critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	# Recreation locations[a]	% Protected lands	Population density (ind/km^2)	Freshwater use (l/day/km^2)
0601	Upper Tennessee	10	9	11	14	509; 226; 93	20.85	50.85	4,114.52
0602	Middle Tennessee–Hiwassee	0	8	3	6	109; 63; 18	17.84	42.53	3,872.73
0603	Middle Tennessee–Elk	3	7	6	13	165; 29; 23	5.18	33.93	6,845.33
0604	Lower Tennessee	4	8	3	14	178; 3; 15	4.15	24.92	4,409.94

[a] Recreation locations refer to the number of boat-ramp and fishing access points, recreational boating, and waterfalls within each HUC04.

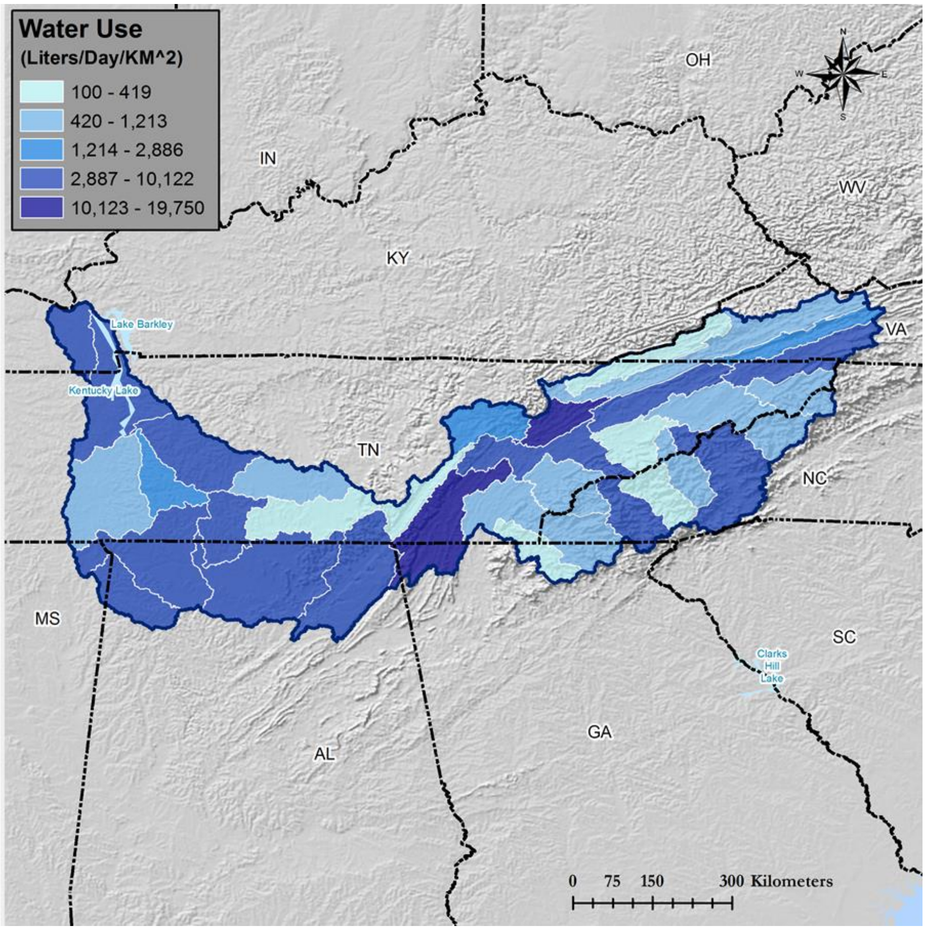

Figure 9.7. Average water use per HUC08 subbasin in Region 6.

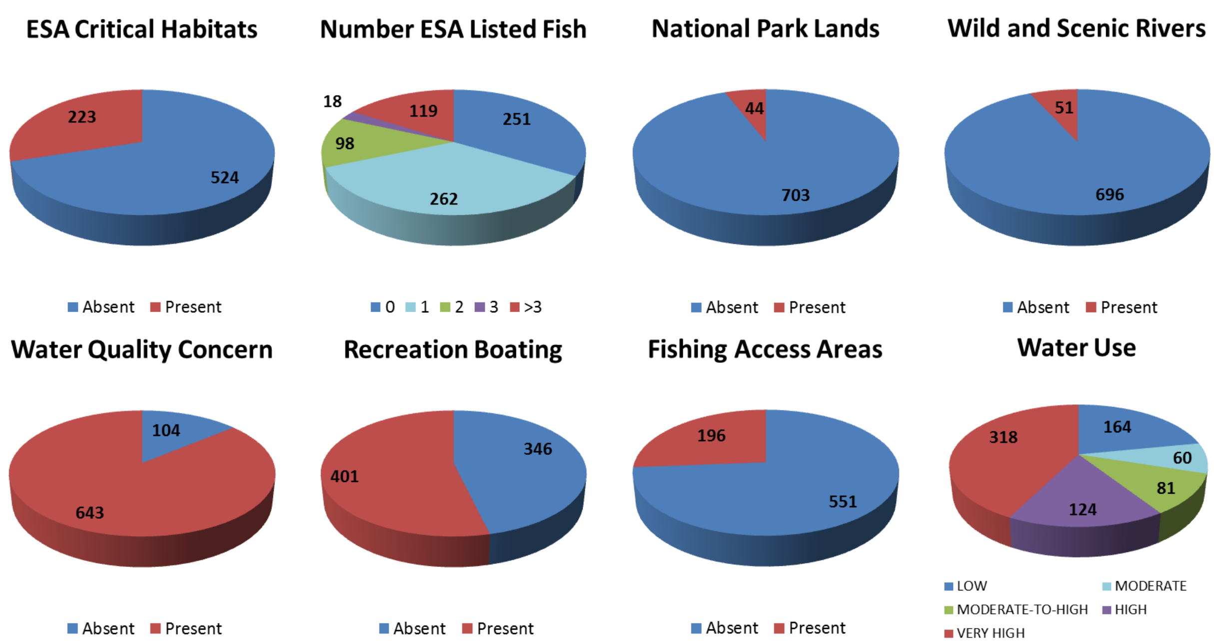

Figure 9.8. The potential capacity, in MW, associated with environmental attributes in Region 6—Tennessee (stream-reaches with potential capacity >1 MW).

10. REGION 7—UPPER MISSISSIPPI

10.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation and mean capacity factors in the Upper Mississippi Region are estimated and summarized in Table 10.1 for both larger (>1 MW) and smaller (<1 MW) stream-reaches. For comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation, and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 2.08 GW, around 225% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 11.55 TWh/year, around 398% of annual net generation from existing conventional hydropower plants. Given the run-of-river assumption, NSD stream-reaches have higher capacity factors, especially compared with other larger-storage peaking-operation projects in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 10.3 and 10.4.

Table 10.1. Summary of NSD Findings in Region 7—Upper Mississippi

	Capacity (MW)	Generation (MWh)	Mean capacity factor
Potential in undeveloped stream-reaches (>1 MW)	1,055	5,979,000	65%
Potential in undeveloped stream-reaches (<1 MW)	1,026	5,567,000	62%
Existing hydropower—conventional hydro	923	2,903,000	36%
Existing hydropower—pumped storage	31		

10.2. Background Hydrologic Setting

The Upper Mississippi Region encompasses approximately 492,026 km^2 of drainage area along the northern sections of the Mississippi River. This region contains eastern Minnesota, Iowa, and northeastern Missouri, in addition to the western sections of Wisconsin and Illinois and small sections of Nebraska and Indiana.

Several river systems are located in the Upper Mississippi Region (Figure 10.1), including the Mississippi, Minnesota, St. Croix, Root, La Crosse, Chippewa, Wisconsin, Iowa, Rock, Des Moines, Illinois, Fox, and Kaskaskia rivers, with a total length of 41,716 km (i.e., total length of streams with estimated discharge greater than 35 cfs). Metropolitan areas within the region include Minneapolis (MN), Cedar Rapids (IA), Davenport (IO), St. Louis (MO), and Chicago (IL). As shown in Figure 10.2, annual precipitation for the region ranges from 650 to 1100 mm/year and annual runoff from 100 to 500 mm/year. Most of the precipitation occurs during the summer; however, the peak runoff occurs in the early spring from snowmelt.

The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are also shown in Figure 10.1. The region contains 113 hydropower dams and 61 major non-powered dams with total storage capacities of around 10,494,851 ac-ft and 19,529,673 ac-ft, respectively.

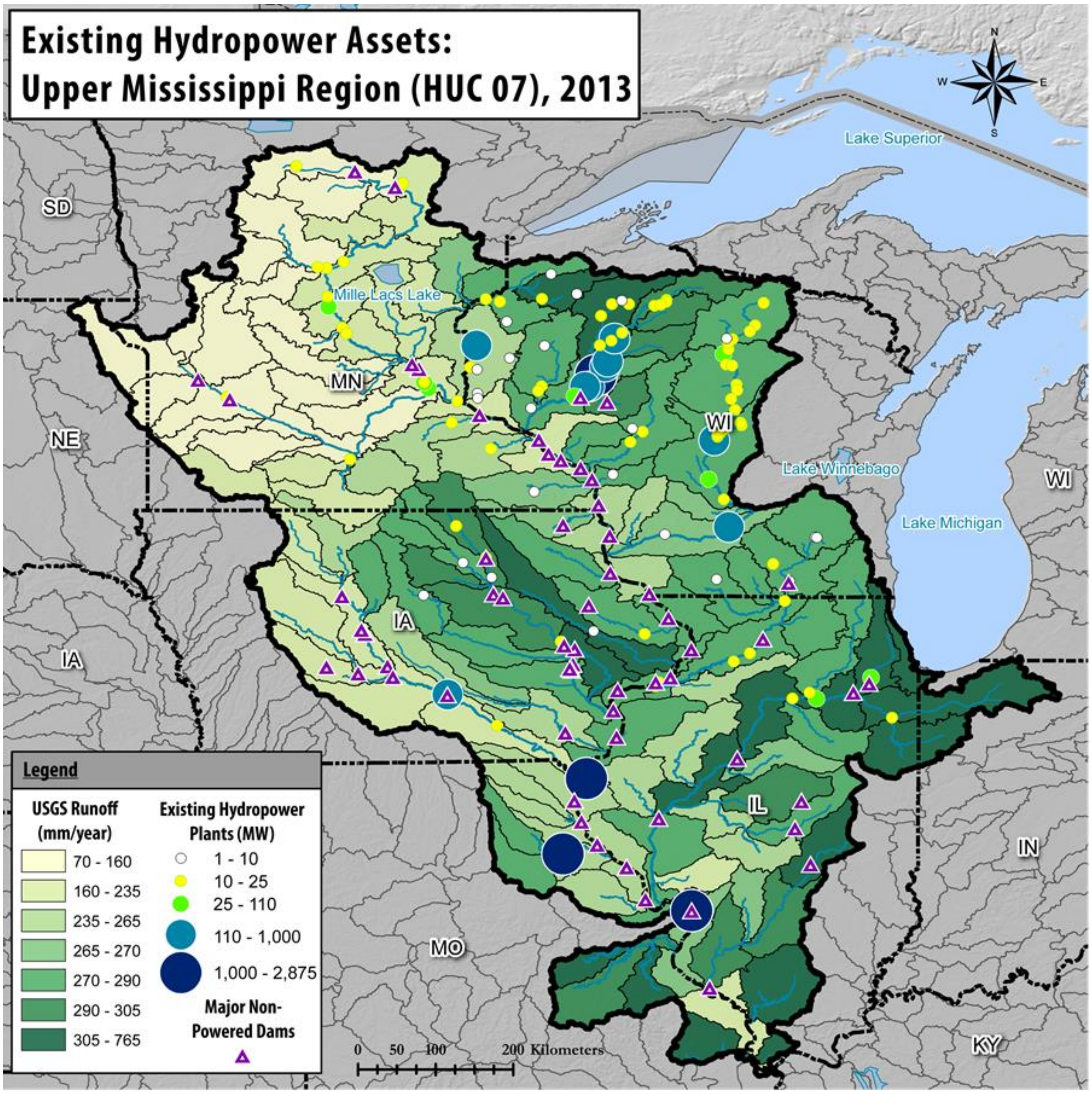

Figure 10.1. Locations of water control projects in Region 7—Upper Mississippi.

10.3. Potential New Hydropower Resources

A total of 230 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) are identified in the Upper Mississippi Region. The NSD results based on the HUC04 subregions are summarized in Table 10.2. In the Upper Mississippi Region, the highest hydropower potential is located in the Upper Mississippi–Iowa–Skunk–Wapsipinicon Subregion (HUC 0708), followed by the Des Moines Subregion (HUC 0710), Upper Mississippi–Kaskaskia–Meramec Subregion (HUC 0714), Mississippi Headwaters Subregion (HUC 0701), and Wisconsin Subregion (HUC 0707). In the Upper Mississippi–Iowa–Skunk–Wapsipinicon Subregion, the Mississippi River contains the highest hydropower potentials, followed by the Iowa, Des Moines, Kaskaskia, Meramec, and Wisconsin rivers in the other subregions.

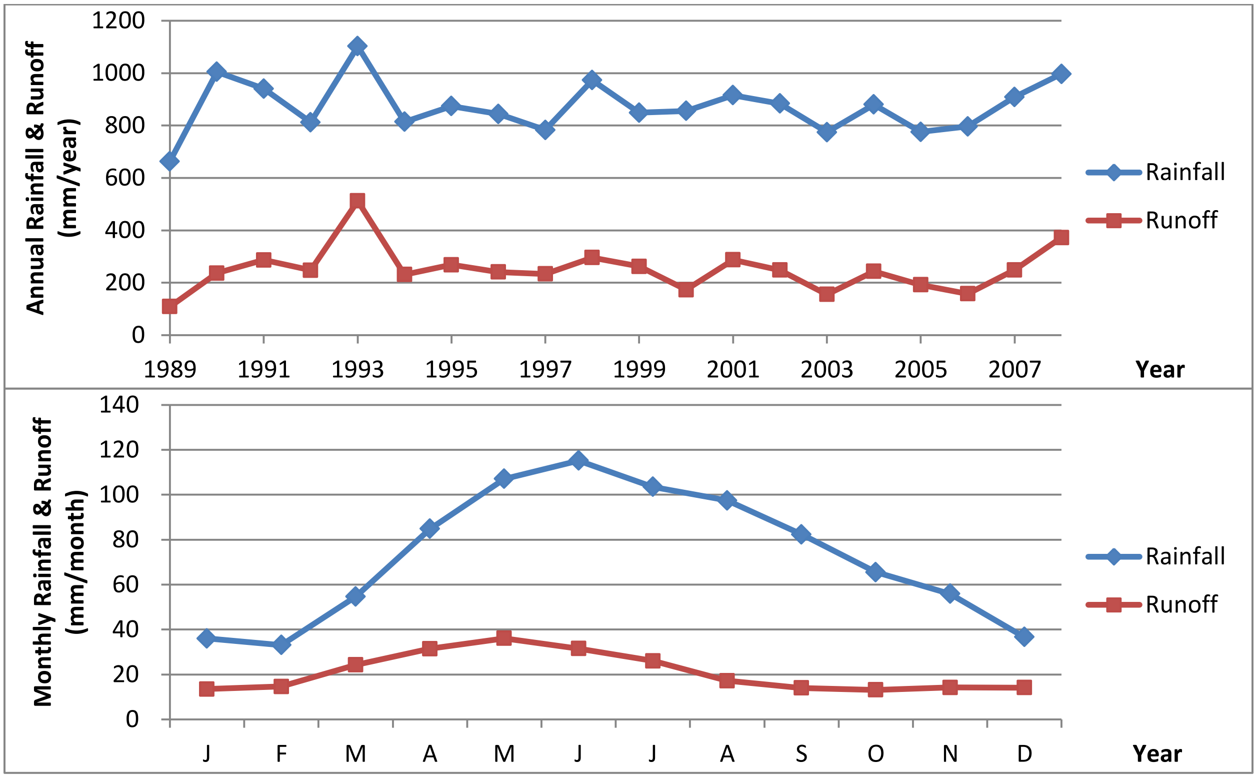

Figure 10.2. Annual and monthly rainfall and runoff of Region 7—Upper Mississippi.

Table 10.2. Summary of Potential New Hydropower Resources in Region 7—Upper Mississippi (Stream-Reaches with Potential Capacity >1 MW)

HUC4	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/reach)	Average residence time (days)
0701	Mississippi Headwaters	22	111.1	721,739	12.6	5,869	5,614	1.4
0702	Minnesota	6	22.8	109,605	12.3	4,586	1,522	0.4
0703	St. Croix	9	25.7	165,966	12.3	3,443	2,151	0.4
0704	Upper Mississippi–Black–Root	8	13.9	73,439	13.6	1,804	5,028	1.8
0705	Chippewa	22	63.9	392,519	12.4	3,507	6,665	0.8
0706	Upper Mississippi–Maquoketa–Plum	5	34.4	208,710	16.8	8,788	50,575	3.2
0707	Wisconsin	25	100.7	671,114	11.0	5,193	6,533	0.5
0708	Upper Mississippi–Iowa–Skunk–Wapsipinicon	43	198.1	1,060,741	16.5	4,963	31,354	8.2
0709	Rock	7	39.7	246,962	12.2	6,660	17,496	7.8
0710	Des Moines	21	151.3	719,882	17.8	5,944	17,339	4.6
0711	Upper Mississippi–Salt	6	43.6	248,504	33.5	15,704	143,444	189.3
0712	Upper Illinois	15	42.2	241,112	9.5	4,226	8,576	2.7
0713	Lower Illinois	17	61.9	312,960	19.4	3,321	21,963	6.6
0714	Upper Mississippi–Kaskaskia–Meramec	24	145.4	805,400	21.5	10,135	24,185	9.5

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 in Figure 10.3. The hydraulic head H_{ref} ranges from 5 to the 90th quantile of 28 ft with a median of about 14 ft, suggesting that many of the potential stream-reaches will require low-head hydropower technologies. The design flow Q_{30} ranges from about 800 cfs to the 90th quantile of 8500 cfs with a median of 2700 cfs. The potential capacity P_{NSD} ranges from 1.5MW to the 90th quantile of about 7.5 MW with a median of just under 3 MW. The inundated surface area A_{NSD} ranges from 0 to the 90th quantile of 6000 acres with a median of 1000 acres. This results in storage values V_{NSD} ranging from 0 to the 90th quantile of 50,000 ac-ft with a median of about 9,000 ac-ft, with residence times T_{NSD} ranging from <1 day to the 90th quantile of 12 days with a median on the order of a few days. In general, the inundation areas and storage volumes paired with the retention times for this region are characteristic of run-of-river to minor storage-type hydro facilities. The results of > 1 MW stream-reach potential are illustrated in Figure 10.4, with potential capacity (MW) aggregated to the HUC08 subbasins. The higher-potential-capacity sites are generally located on the larger tributary rivers feeding directly into the Mississippi River.

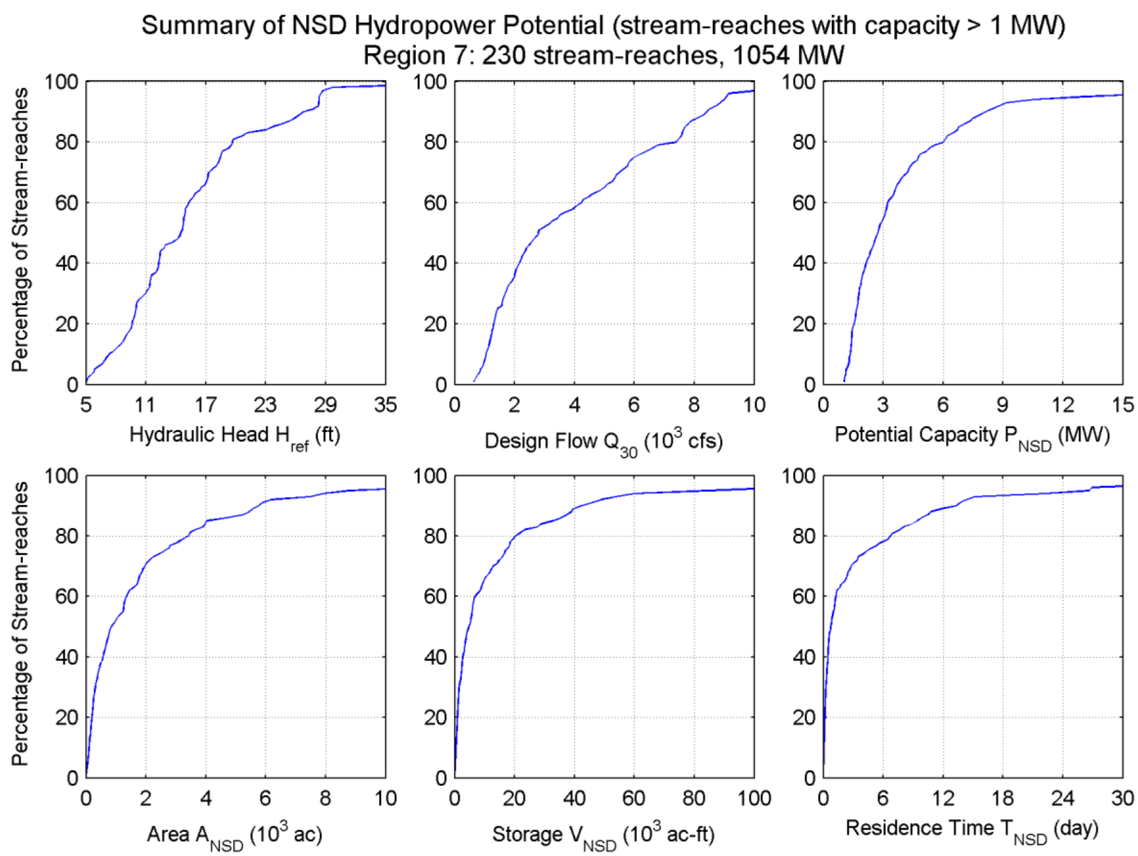

Figure 10.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 7—Upper Mississippi.

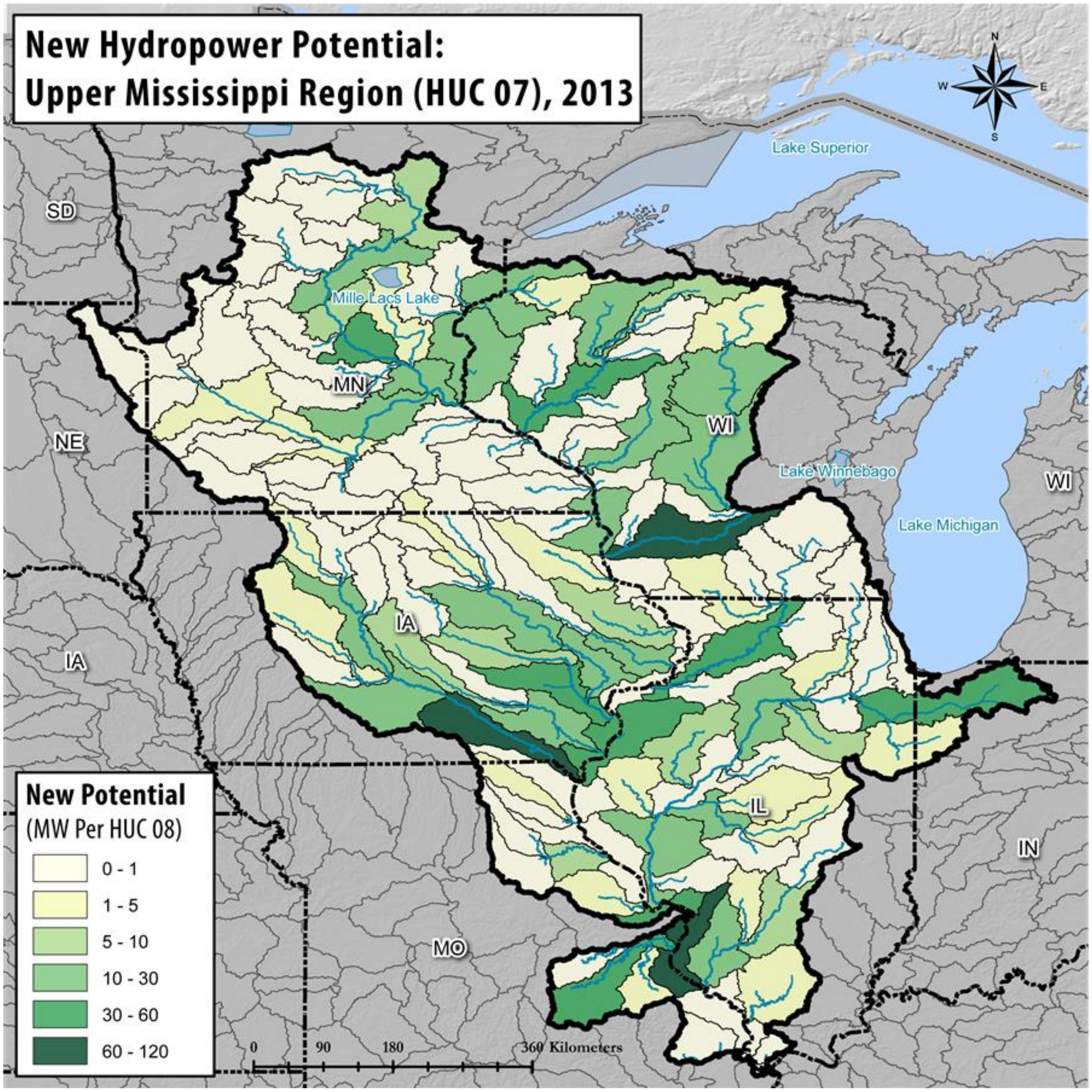

Figure 10.4. Potential new hydropower capacity in Region 7—Upper Mississippi (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC08 subbasins for illustration).

10.4. Environmental Characteristics

The Upper Mississippi Region includes 193 native fish species, 4 of which fall under an ESA category. Eight additional species fall under IUCN categories. Paddlefish, shovelnose sturgeon (*Scaphirhynchus platorynchus*), pallid sturgeon (*Scaphirhynchus albus*), and Topeka shiner (*Notropis topeka*) are among the fishes of concern in Region 7. Sixteen potadromous or anadromous fish species are documented in Region 7 (Figure 10.5). Eight critical watersheds are located in the region and contain anywhere from three to nine fish and mussel species at risk (Mathews et al., 1998). Only two species, Hine's emerald dragonfly (*Somatochlora hineana*) and Topeka shiner, have critical habitat designations.

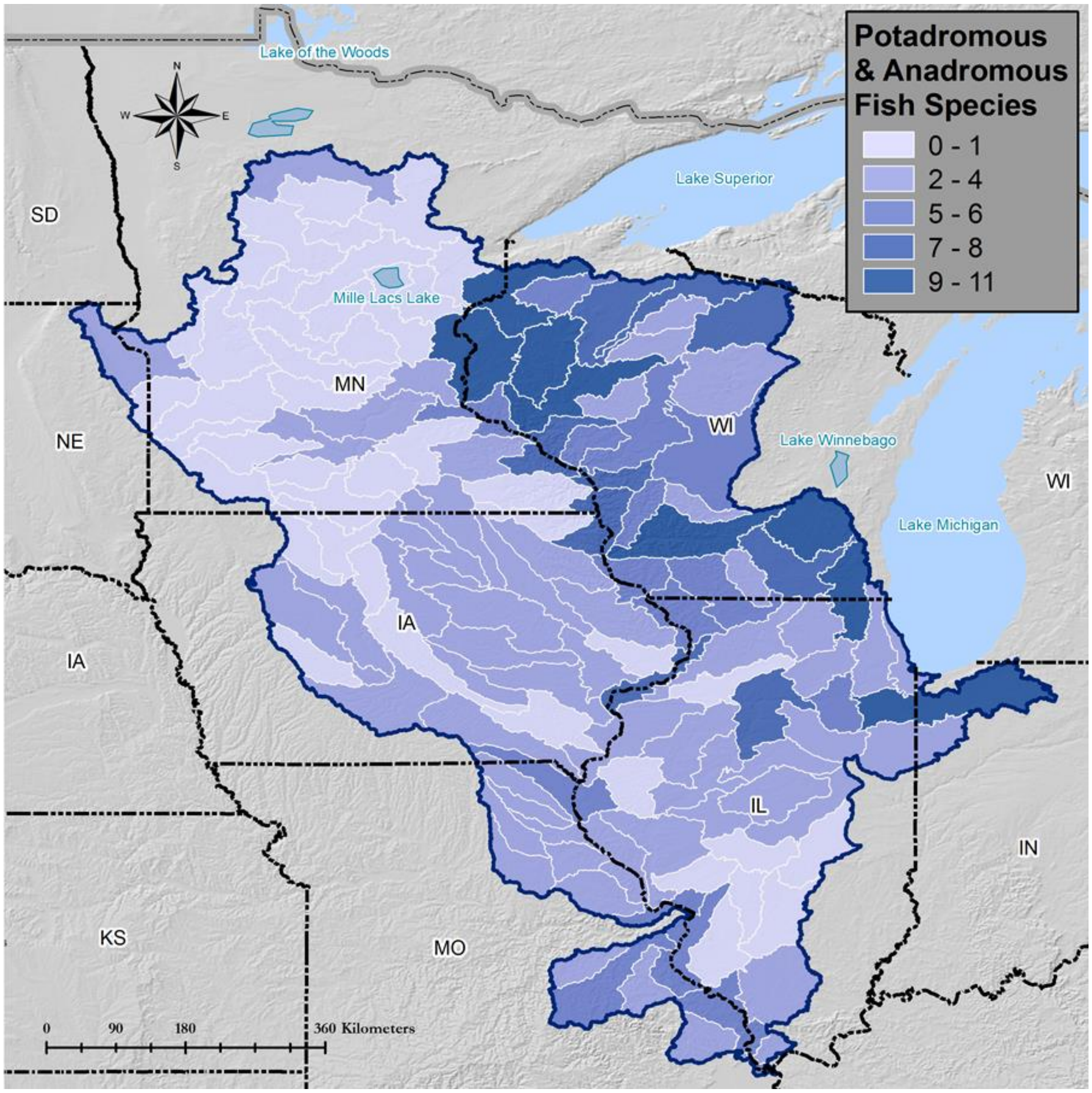

Figure 10.5. Potadromous and anadromous fish species (number per HUC08 subbasin) in Region 7.

Of the 9.6 million total acres of protected land in Region 7, over 54% are state-owned. State lands are primarily made up of state forests, habitat species management areas, and state parks. Among the largest tracts of land in the region are the Richard J. Dorer Memorial Hardwood and Chengwatana State Forests. Federal lands make up almost 35% of protected lands and are primarily owned by the USFS (16%), USFWS (7%), DOD (6%), and NPS (5%). Most federal lands are national forests, the largest of which is the Chippewah National Forest. Although there is no national park in this region, there are other types of NPS-owned properties, including historic sites, protected management areas, and national trails. Most of the protected lands fall under GAP statuses 3 (42%) and 2 (39%). Two National Wild and Scenic Rivers, the Paint and St. Croix, are located in this region. Recreation facilities include 4315 boat ramp locations, 839 fishing access locations, 24 waterfalls, and 161 recreational boating river sections (Figure 10.6).

Water use in Region 7 is slightly above the US average (Appendix B). Water use is fairly homogenous with the exception of extremely high values in the Upper Illinois Subbasin (Table 10.3). Most usage occurs as thermoelectric cooling or public consumption (Appendix B). Water-quality concerns are average in the region. Water-quality concerns are varied, however; many are related to mercury or nutrient issues, followed by algae, toxin, and pathogen concerns (Appendix B).

Of the 230 stream-reaches, seven reaches (18 MW) overlap with critical habitat designations (Figure 10.7). Almost 33% of stream-reaches overlap within HUC08 subbasins with one or more fish falling under ESA categories. No stream-reaches intersect national parks; however, nine stream-reaches (26 MW) intersect Wild and Scenic Rivers. Over 90% of stream-reaches overlap with protected lands (>1 GW). Most stream-reaches (88%) are associated with water-quality concerns. Recreational boating and fishing access areas are not as prevalent, overlapping with only 17% and 20% of stream-reaches. Boat ramps are abundant, overlapping with 63% of stream-reaches. Most of the stream-reaches are located in HUC08 subregions with very high water usage.

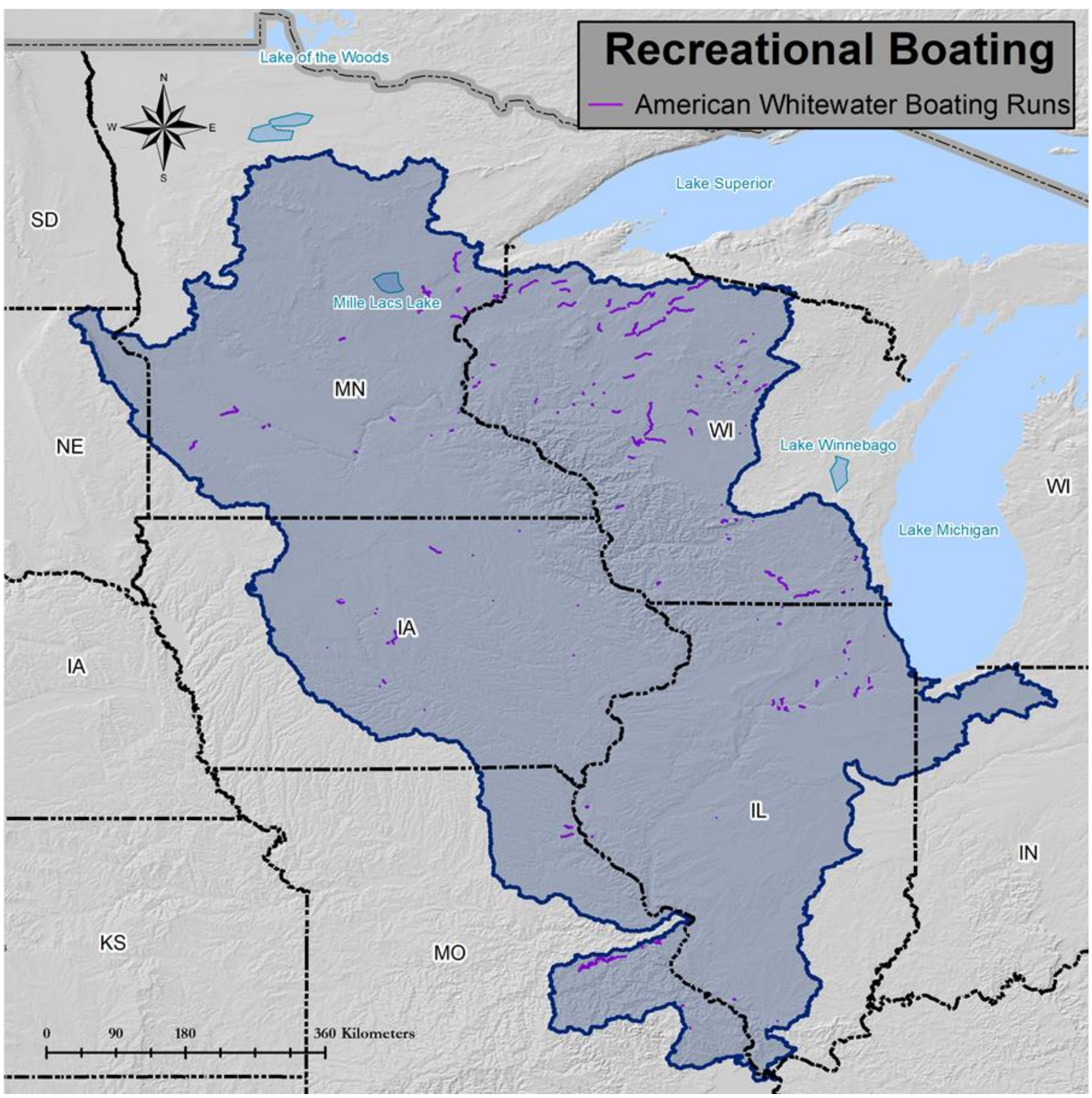

Figure 10.6. Whitewater boating runs in Region 7.

Table 10.3. Summary of Environmental Variables at HUC04 Subregions within Region 7 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# Critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	# Recreation locations[a]	% Protected lands	Population density (ind/km^2)	Freshwater use (l/day/km^2)
0701	Mississippi Headwaters	0	7	1	3	1,061; 2; 3	19.93	45.99	1,244.02
0702	Minnesota	1	7	2	3	327; 7; 4	3.88	3.64	261.89
0703	St. Croix	0	12	1	4	507; 21; 2	14.02	17.29	387.23
0704	Upper Mississippi–Black–Root	0	9	1	4	232; 14; 2	18.15	14.22	2,291.11
0705	Chippewa	0	13	1	5	663; 26; 5	14.98	10.82	274.22
0706	Upper Mississippi–Maquoketa–Plum	0	9	2	4	137; 4; 1	5.81	16.61	1,342.24
0707	Wisconsin	0	12	1	3	624; 26; 4	8.89	16.02	1,161.11
0708	Upper Mississippi–Iowa–Skunk–Wapsipinicon	1	9	1	3	209; 6; 0	1.24	28.35	1,463.54
0709	Rock	0	10	1	1	260; 7; 0	2.73	67.54	1,401.02
0710	Des Moines	1	5	1	0	156; 9; 0	2.05	9.25	141.12
0711	Upper Mississippi–Salt	0	8	3	4	121; 5; 1	2.03	25.92	1,534.93
0712	Upper Illinois	1	12	0	1	343; 14; 1	7.06	457.28	11,144.55
0713	Lower Illinois	0	8	1	3	219; 8; 0	2.28	32.21	3,335.85
0714	Upper Mississippi–Kaskaskia–Meramec	1	9	3	9	295; 12; 1	8.74	47.24	2,902.05

[a] Recreation locations refer to the number of boat-ramp and fishing access points, recreational boating, and waterfalls within each HUC04.

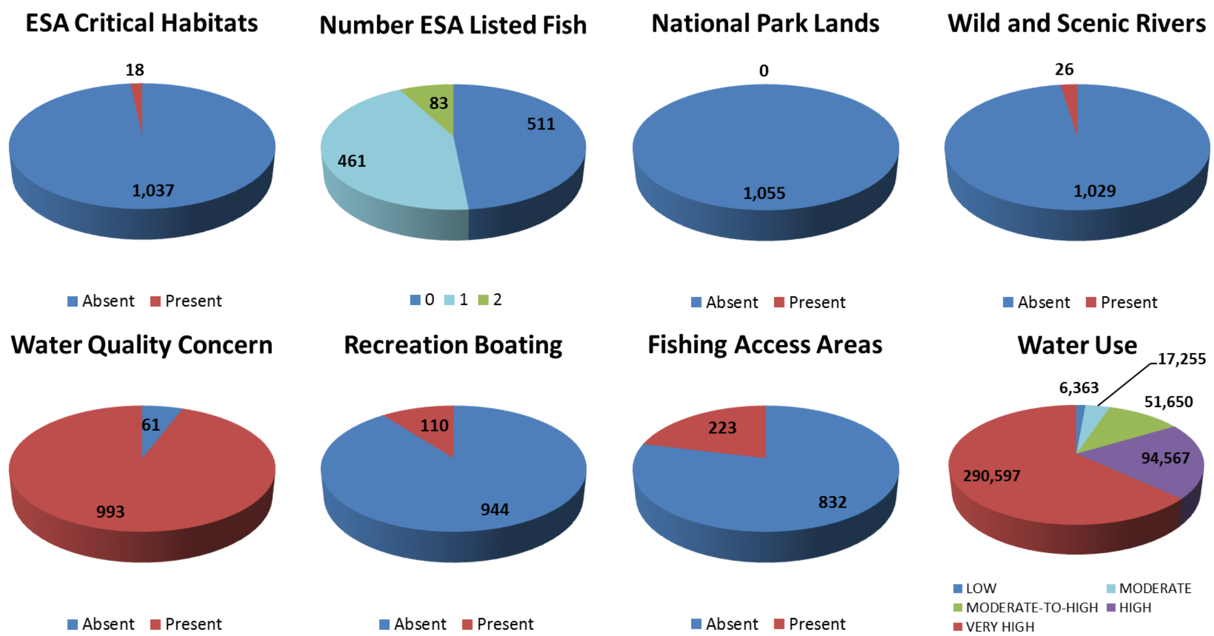

Figure 10.7. The potential capacity, in MW, associated with environmental attributes in Region 7—Upper Mississippi (stream-reaches with potential capacity >1 MW).

11. REGION 8—LOWER MISSISSIPPI

11.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation and mean capacity factors in the Lower Mississippi Region are estimated and summarized in Table 11.1 for both larger (>1 MW) and smaller (<1 MW) stream-reaches. For comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation, and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 2.07 GW, around 414% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 12.07 TWh/year, around 712% of annual net generation from existing conventional hydropower plants. The larger ratios of potential NSD resources to existing hydropower development should be mainly a result of the relatively lower hydropower development in this region. As the downstream area of the Mississippi River, the stream-reaches tend to be larger in flow but lower in hydraulic head. Therefore, although the power estimates may seem large (proportional to flow times head), it will require low-head technology that is generally more expensive and less efficient. In-stream navigation is also a more important function than hydropower in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 11.3 and 11.4.

Table 11.1. Summary of NSD Findings in Region 8—Lower Mississippi

	Capacity (MW)	Generation (MWh)	Mean capacity factor
Potential in undeveloped stream-reaches (>1 MW)	1,741	10,395,000	68%
Potential in undeveloped stream-reaches (<1 MW)	331	1,679,000	58%
Existing hydropower—conventional hydro	500	1,695,000	39%
Existing hydropower—pumped storage	28		

11.2. Background Hydrologic Setting

The Lower Mississippi Region encompasses approximately 271,879 km^2 of drainage area along the southern sections of the Mississippi River. This region includes eastern sections of Missouri, Arkansas, western sections of Kentucky, Tennessee and Mississippi, and most of Louisiana. The region comprises primarily a flood plain all along the Mississippi River with tributary rivers feeding into the Mississippi River.

Several river systems are located in the Lower Mississippi Region (Figure 11.1), including the Mississippi, Arkansas, White, St. Francis, Yazoo, Red, Ouachita, Boeuf, Tensas, Lower Old, Buffalo, Lower Grand, Tangipahoa, and Sabine rivers, with a total length of 33,791 km (i.e., total length of streams with estimated discharge greater than 35 cfs). Metropolitan areas within the region include Jonesboro (AR), Shreveport (LA), and Memphis (TN). As shown in Figure 11.2, annual precipitation for the Lower Mississippi ranges from 1050 to 1700 mm/year and annual runoff from 250 to 750 mm/year. Most precipitation occurs from late winter through mid-summer. Most of the runoff occurs from winter through early spring.

The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are shown in Figure 11.1. The region contains 7 hydropower dams and 17 major non-powered dams with total storage capacities of around 7,531,461 ac-ft and 9,721,495 ac-ft, respectively.

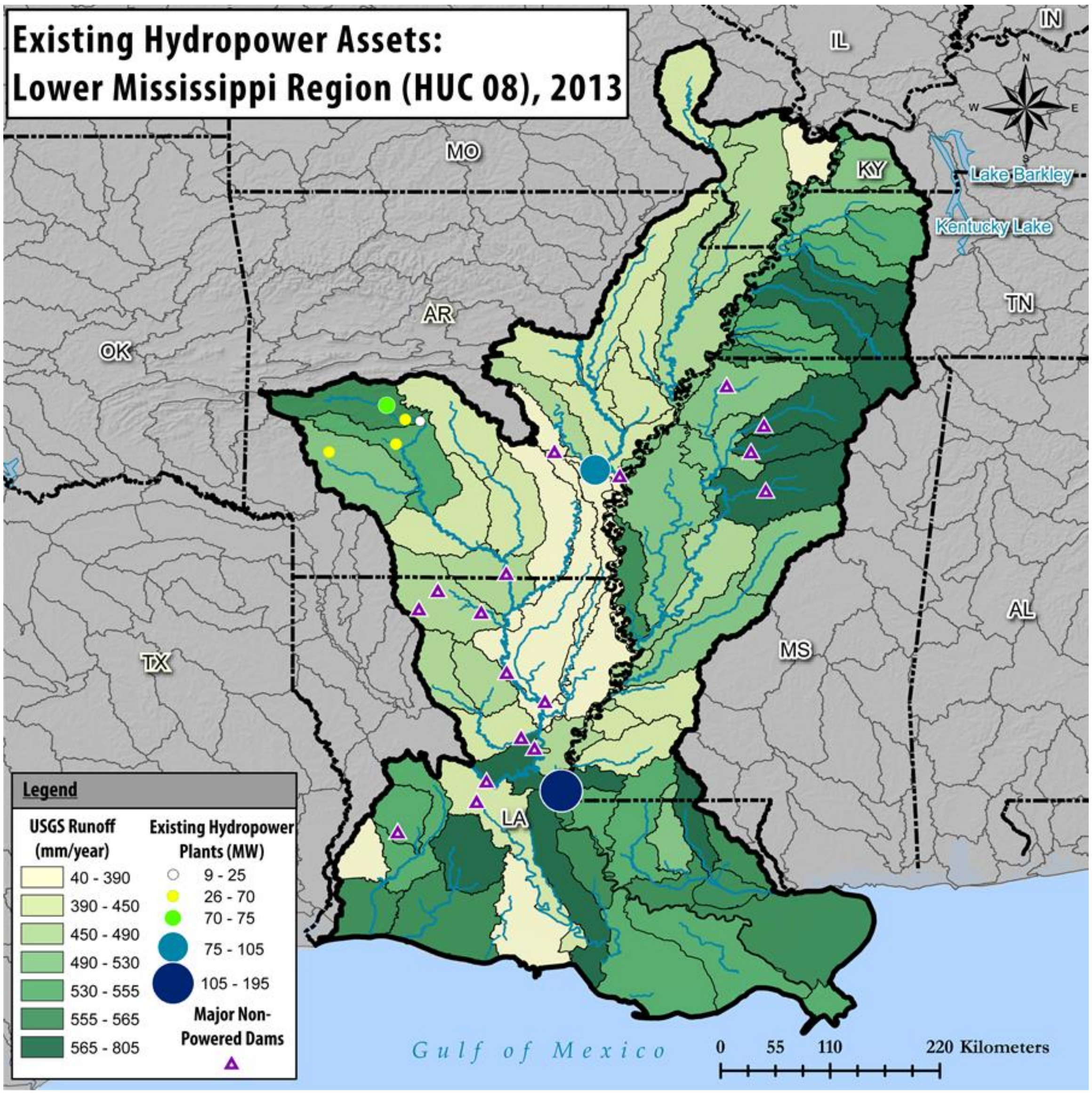

Figure 11.1. Locations of water control projects in Region 8—Lower Mississippi.

11.3. Potential New Hydropower Resources

A total of 90 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) are identified in the Lower Mississippi region. The NSD results based on the HUC04 subregions are summarized in Table 11.2. The highest hydropower potential is found in the Lower Mississippi–Big Black and St. Francis Subregions (HUC 0806 and 0802). In these two subregions, the Mississippi River contains the highest hydropower potential, with the Big Black, Arkansas, and White rivers providing the next highest potential.

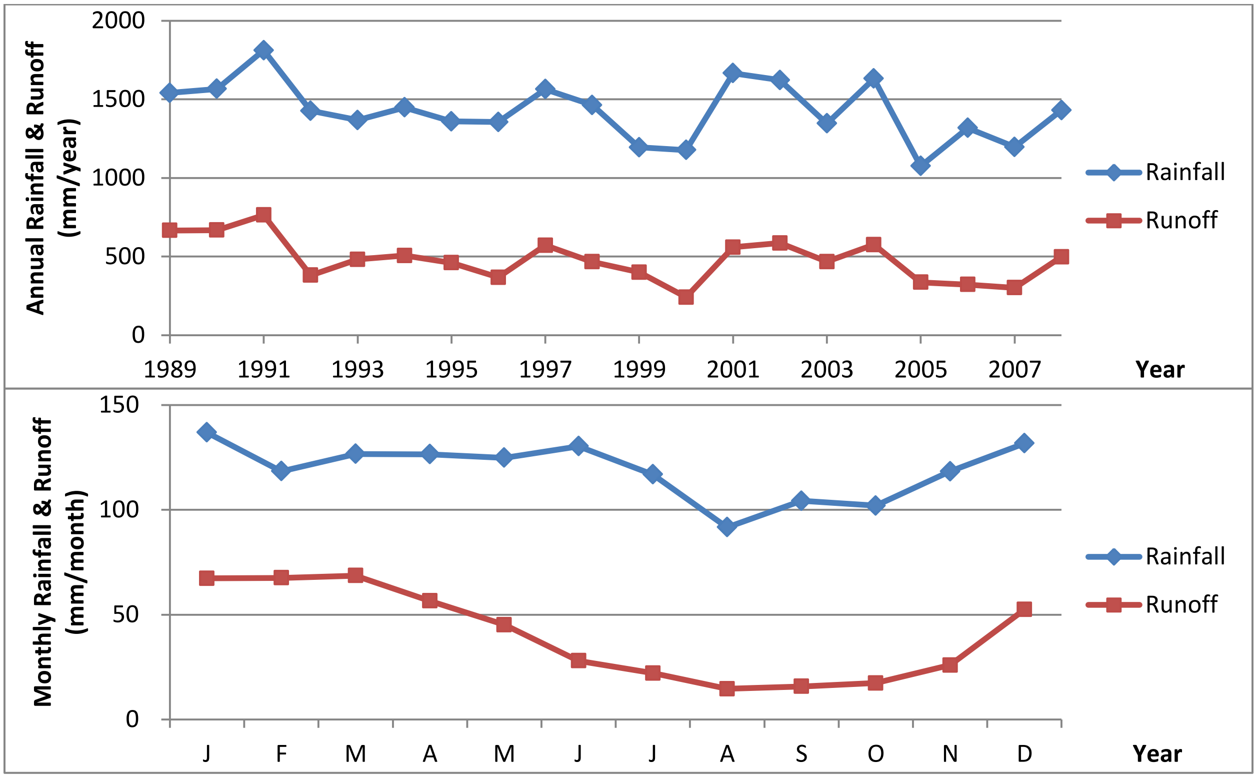

Figure 11.2. Annual and monthly rainfall and runoff of Region 8—Lower Mississippi.

Table 11.2. Summary of Potential New Hydropower Resources in Region 8 Lower Mississippi (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac ft/reach)	Average residence time (days)
0801	Lower Mississippi–Hatchie	14	31.8	166,503	12.5	2,535	22,043	6.6
0802	Lower Mississippi–St. Francis	19	633.4	3,776,083	21.6	48,359	29,794	9.8
0803	Lower Mississippi–Yazoo	9	27.8	151,636	15.2	3,919	32,757	14.8
0804	Lower Red–Ouachita	27	86.3	444,381	23.0	2,635	63,471	87.9
0805	Boeuf–Tensas	1	1.2	5,220	17.7	921	417	0.2
0806	Lower Mississippi–Big Black	18	957.9	5,836,007	20.0	29,156	37,747	9.8
0807	Lower Mississippi–Lake Maurepas	-	-	-	-	-	-	-
0808	Louisiana Coastal	2	3.1	14,879	10.9	1,969	13,065	2.6

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 in Figure 11.3. The hydraulic head H_{ref} ranges from 0 to the 90th quantile of 35 ft with a median of about 19 ft, suggesting that many of the potential stream-reaches will require low-head hydropower technologies. The design flow Q_{30} ranges from about 0 cfs to the 90th quantile of 9000 cfs with a median of 2000 cfs. The potential capacity P_{NSD} ranges from about 2 MW to the 90th quantile of about 9 MW with a median of just under 3 MW. The inundated surface area A_{NSD} ranges from 0 to the 90th quantile of 12,000 acres with a median of 2,000 acres. This results in storage values V_{NSD} ranging from 0 to the 90th quantile of 90,000 ac-ft median of about 15,000 ac-ft with residence times T_{NSD} ranging from <1 day to the 90th quantile of about 22 days with a median on the order of about 4 days. The results of > 1 MW stream-reach potential are illustrated in Figure 11.4, with potential capacity (MW) aggregated to the HUC08 subbasins. The higher-potential-capacity sites are generally located on the larger tributary rivers feeding directly into the Mississippi River and in the hills of Arkansas.

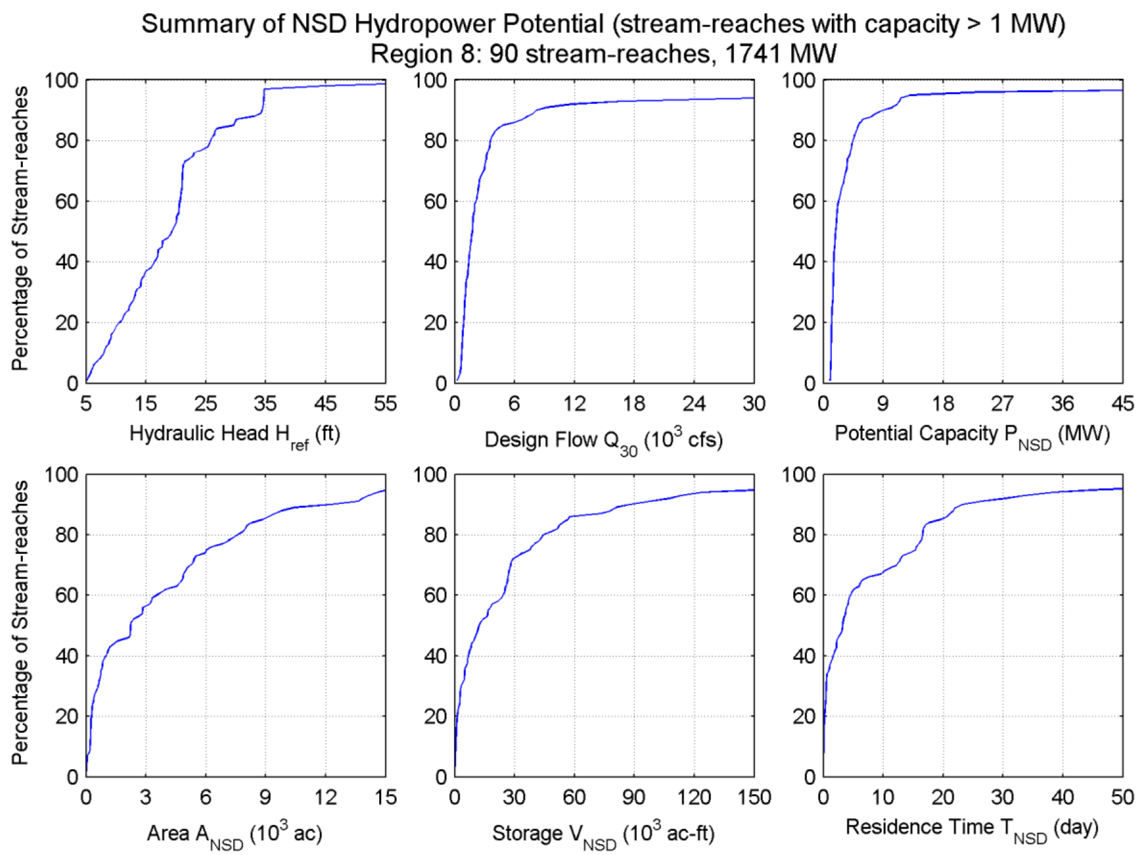

Figure 11.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 8—Lower Mississippi.

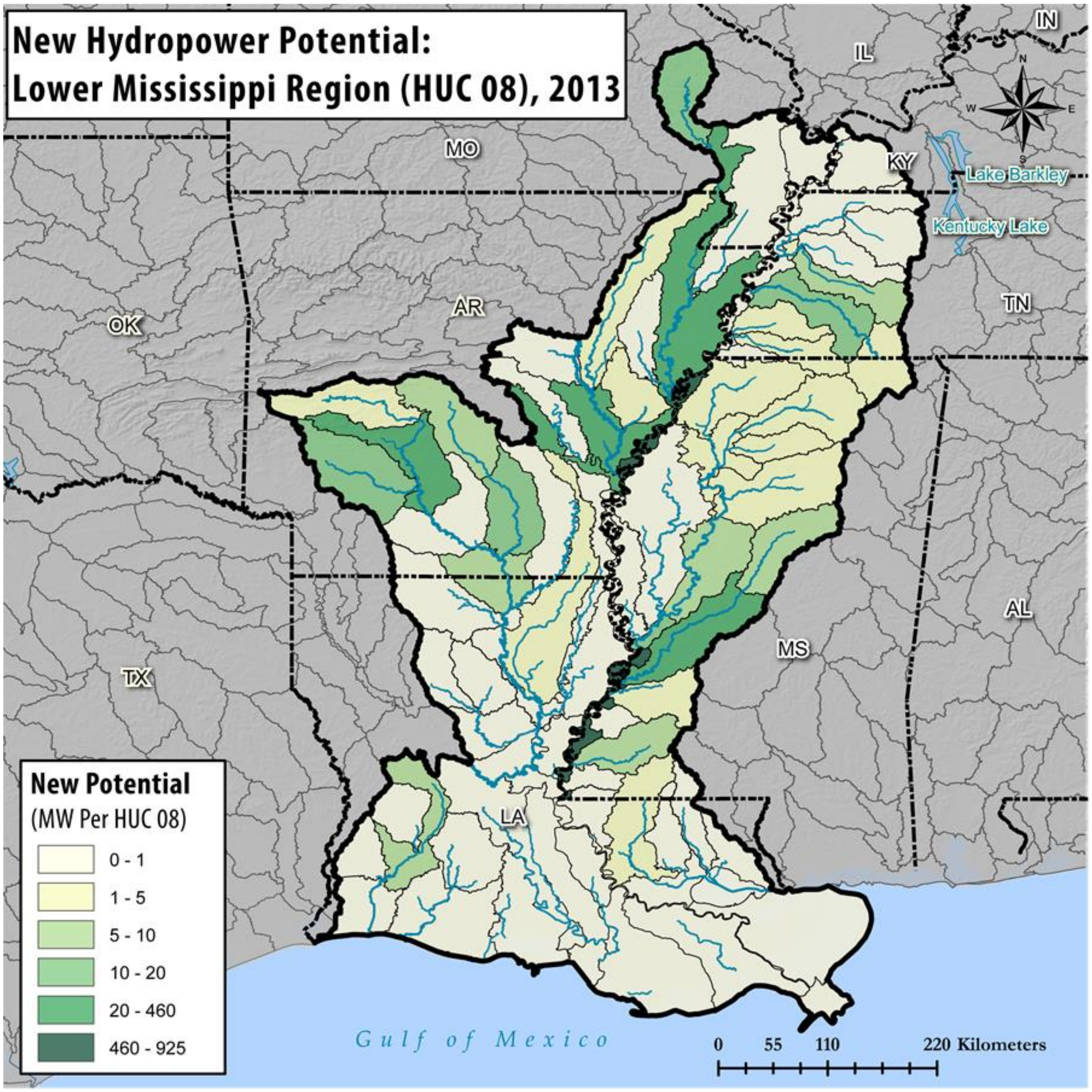

Figure 11.4. Potential new hydropower capacity in Region 8 Lower Mississippi (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC08 subbasins for illustration).

11.4. Environmental Characteristics

The Lower Mississippi Region is home to 220 native fish species, 19 of which are fishes of concern. Of those species, 6 fall under an ESA category and 17 fall under IUCN vulnerable categories (Figure 11.5 and Appendix B). Paddlefish, shortnose sturgeon, pallid sturgeon, Atlantic sturgeon, relict darter (*Etheostoma chienense*), and bayou darter (*Etheostoma rubrum*) are among the fishes of concern. Ten potadromous or anadromous species are documented in this region. At least one ESA fish species is found in all subbasins (Figure 11.6 and Table 11.3). Almost 21% of the HUC08 subbasins in Region 8 are critical watersheds, with the highest number of fish and mussels at risk in the Upper Ouachita Subbasin (20 species) (Mathews et al., 1998). Region 8 has critical habitat designations for Gulf sturgeon (*Acipenser oxyrinchus* *desotoi*), Louisiana black bear (*Ursus americanus luteolus*), and piping plover (*Charadrius melodus*).

Protected land coverage is not as extensive in Region 8 as in other areas of the United States. Approximately 4.9 million acres are protected, constituting only 7% of the total area. Most protected lands (57%) are federally owned by the USFS (29%, primarily national forest), USFWS (20%, primarily national wildlife refuge), and DOD (8%). Ouachita, Kisatchie, Homochitto, and Holly Springs are among the largest national forests, and White River is the largest national wildlife refuge. State lands make up 38% of protected lands and are primarily composed of habitat/species management areas. Hot Springs is the only national park in the region. The Little Missouri National Wild and Scenic River is the only river protected under the National Wild and Scenic River Act (NWSRA) in Region 8. A section of the Natchez Trace Parkway is also located in the region. Region 8 includes 601 boat ramps, 217 freshwater fishing access areas, 3 waterfalls, and 38 recreational boating river sections.

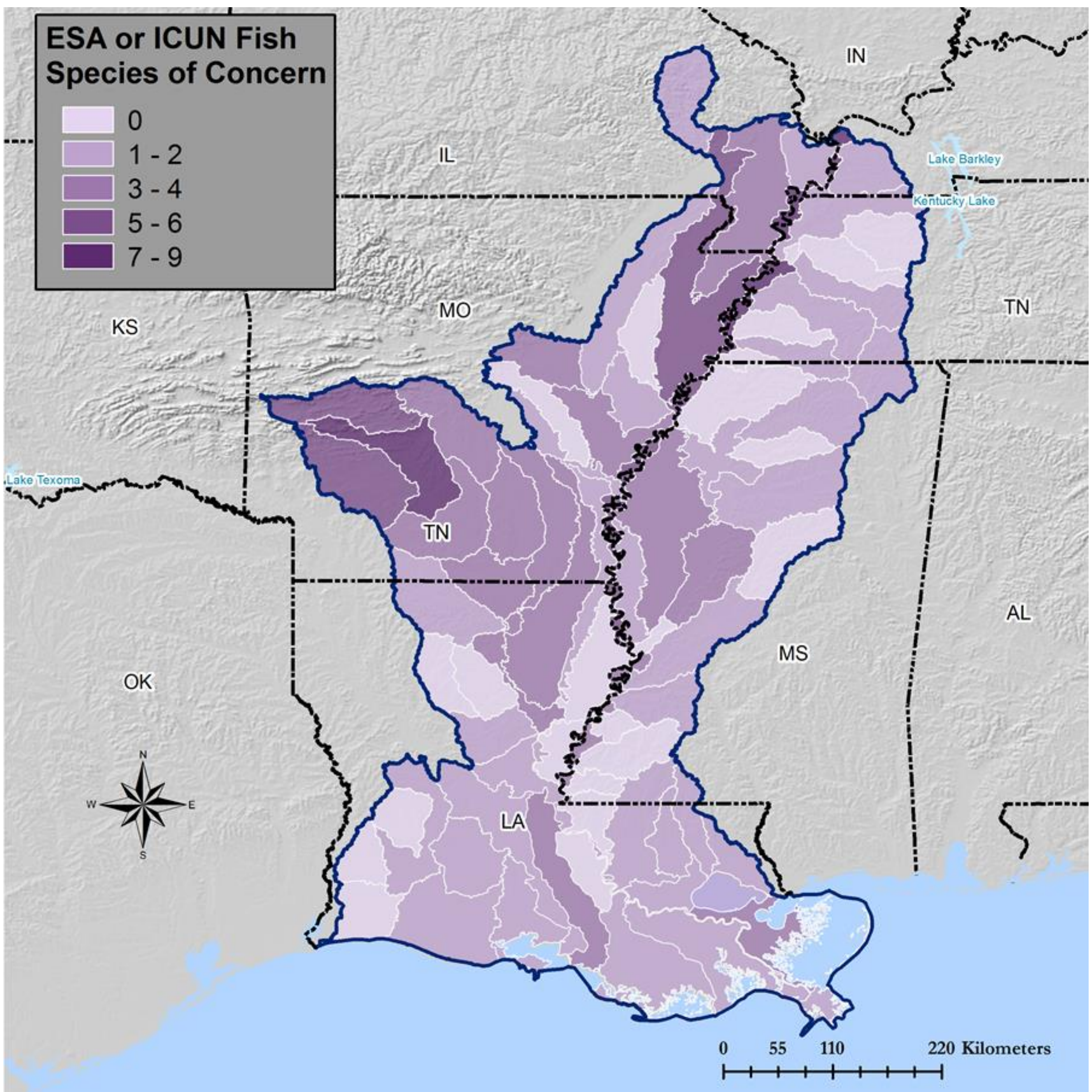

Figure 11.5. Fish species of concern (number per HUC08 subbasin) in Region 8.

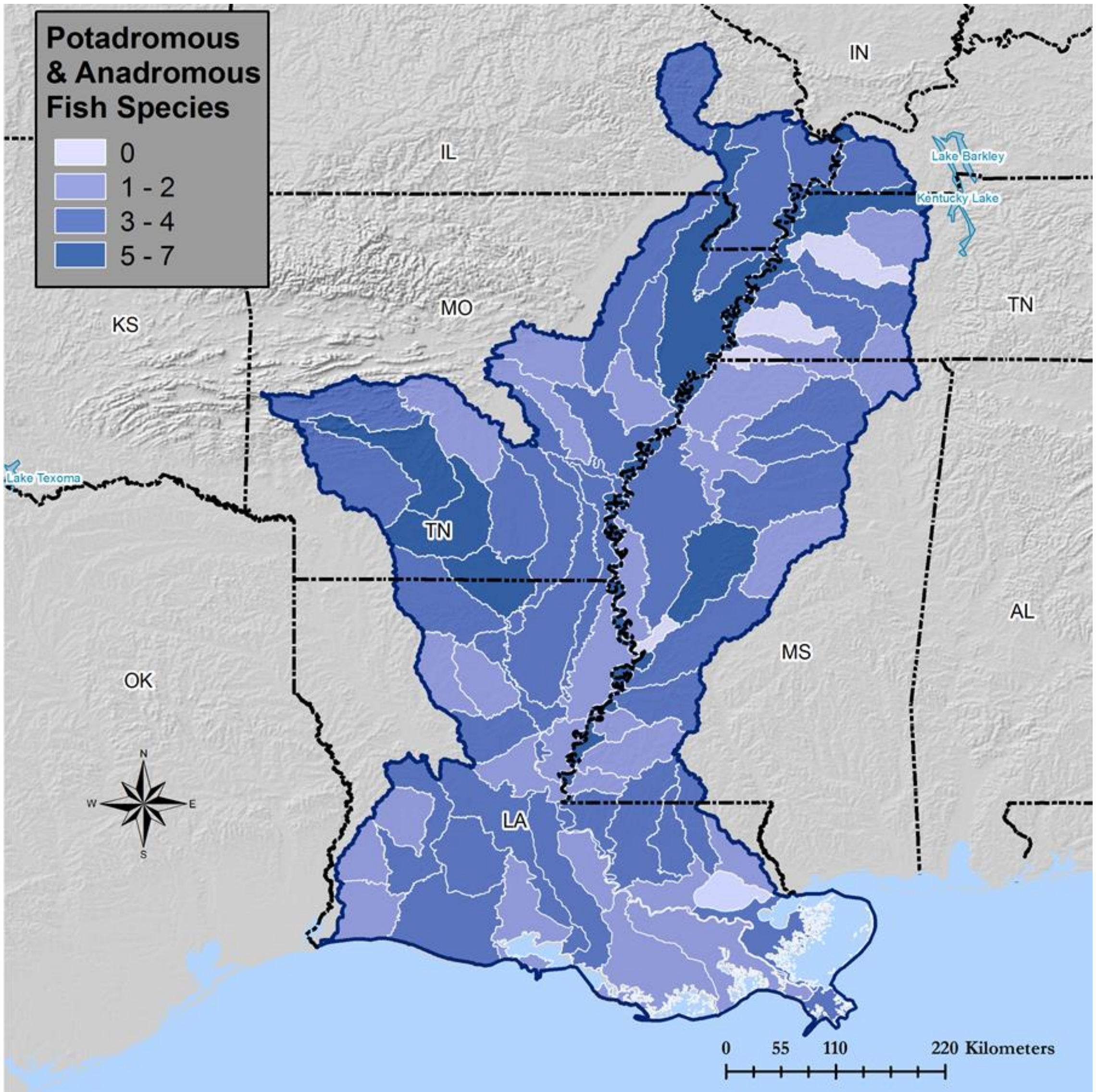

Figure 11.6. Potadromous and anadromous fish species (number per HUC08 subbasin) in Region 8.

Water use is relatively high in Region 8 compared with other regions in the United States. Most usage occurs as thermoelectric cooling or irrigation (Appendix B), with the highest values found in the Lower Mississippi and Lower Mississippi–St. Fancis Subbasins (Table 11.3). Water-quality concerns in Region 8 are average for the United States. Most water quality concerns are related to mercury contamination, pathogens, or dissolved oxygen (Appendix B).

Critical habitat designations overlap with only one stream-reach, which has a capacity of 920 MW (Figure 11.7). Over 15% of stream-reaches are located within HUC08 subbasins with at least one fish falling within an ESA category. Fifty-eight percent of stream-reaches (1.09 GW) overlap with protected lands; however, no stream-reaches intersect national parks and two intersect Wild and Scenic Rivers. Water-quality concerns are prevalent, occurring at 80% of stream-reaches. Recreational boating is not as common, found only at six stream-reaches. Boat ramps and fishing access areas intersect 54% and 24% of stream-reaches, respectively. Forty stream-reaches (>1.63 GW) are located in watersheds with high or very high water use.

Table 11.3. Summary of Environmental Variables at HUC04 Subregions within Region 8 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# Critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	Recreation locations[a]	# Protected lands (%)	Population density (ind/km^2)	Freshwater use (l/day/km^2)
0801	Lower Mississippi–Hatchie	0	8	3	7	60; 0; 0	3.28	75.84	1,831.26
0802	Lower Mississippi–St. Francis	0	9	2	8	266; 16; 0	6.21	17.94	7,130.38
0803	Lower Mississippi–Yazoo	0	7	3	6	163; 0; 0	5.54	18.51	2,194.36
0804	Lower Red–Ouachita	1	7	1	11	246; 22; 0	10.64	15.75	900.62
0805	Boeuf-Tensas	1	5	1	3	20; 0; 0	6.05	11.33	2,546.70
0806	Lower Mississippi–Big Black	1	6	2	6	23; 0; 2	5.95	19.19	526.48
0807	Lower Mississippi–Lake Maurepas	1	7	2	3	12; 0; 1	3.79	50.24	5,855.48
0808	Louisiana Coastal	2	5	2	2	27; 0; 0	10.52	30.82	2,156.62
0809	Lower Mississippi	2	6	3	3	10; 0; 0	7.80	148.91	9,943.24

[a]Recreation locations refer to the number of boat-ramp and fishing access points, recreational boating, and waterfalls within each HUC04.

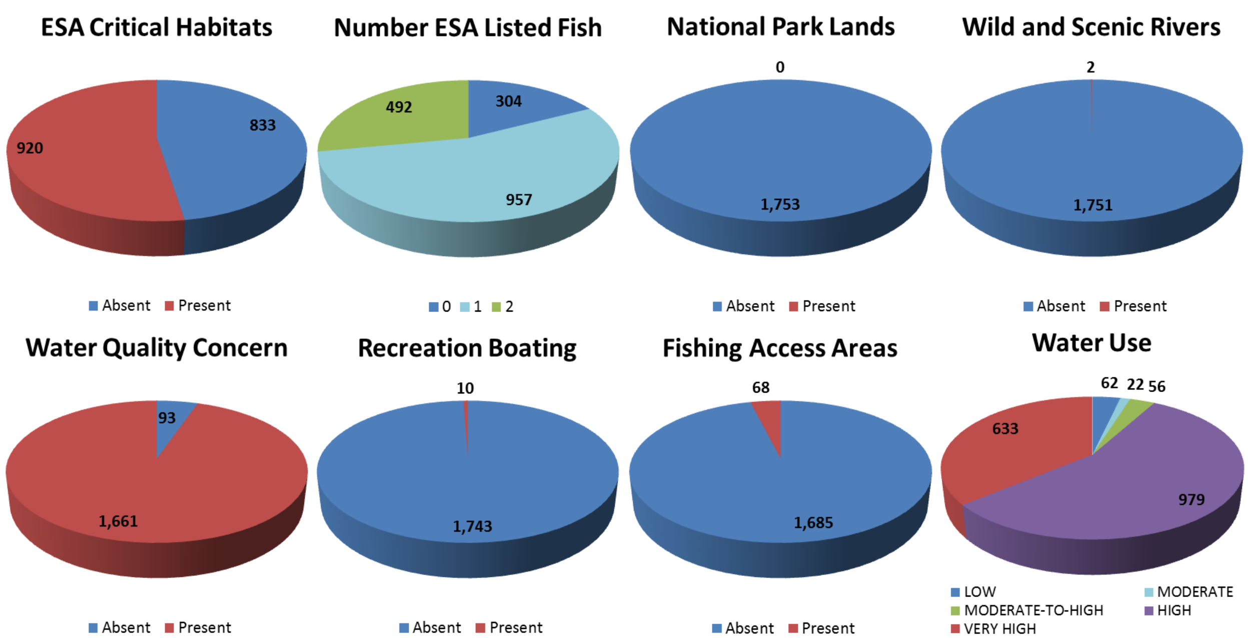

Figure 11.7. The potential capacity, in MW, associated with environmental attributes in Region 8—Lower Mississippi (stream-reaches with potential capacity >1 MW).

12. REGION 9—SOURIS-RED-RAINY

12.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation and mean capacity factors in the Souris–Red–Rainy Region are estimated and summarized in Table 12.1 for both larger (>1 MW) and smaller (<1 MW) stream-reaches. For comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation, and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 151 MW, around 685% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 787 GWh/year, around 1034% of annual net generation from existing conventional hydropower plants. The larger ratios of potential NSD resources to existing hydropower development should be mainly a result of the relatively lower hydropower development in this region. Souris–Red–Rainy was relatively rural with lower population and power demand; hence hydropower may not be the most economical choice for energy investment in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 12.3 and 12.4.

Table 12.1. Summary of NSD Findings in Region 9—Souris–Red–Rainy

	Capacity (MW)	Generation (MWh)	Mean capacity factor
Potential in undeveloped stream-reaches (>1 MW)	68.3	375,000	63%
Potential in undeveloped stream-reaches (<1 MW)	82.4	412,000	57%
Existing hydropower—conventional hydro	22	76,080	39%
Existing hydropower—pumped storage	0		

12.2. Background Hydrologic Setting

The Souris–Red–Rainy Region, situated along the Canadian border, encompasses approximately 153,318 km^2 of drainage area in the most northern sections of Minnesota and North Dakota, and a very small section of South Dakota. The region is made up of mostly of farmland and livestock.

Few river systems are located in the Souris–Red–Rainy Region (Figure 12.1), including the Souris, Red, Goose, Marsh, Sheyenne, and Rainy rivers, with a total length of 8315 km (i.e., total length of streams with estimated discharge greater than 35 cfs). Metropolitan areas within the region include Fargo (ND) and Grand Forks (ND). As shown in Figure 12.2, annual precipitation for the Souris–Red–Rainy region ranges from 420 to 650 mm/year and annual runoff from 25 to 130 mm/year. The precipitation occurs predominately in the summer. The runoff peak occurs during the early spring snowmelt.

The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are shown in Figure 12.1. The region contains eight hydropower dams and seven major non-powered dams with storage capacities of about 4,047,027 ac-ft and 900,300 ac-ft, respectively.

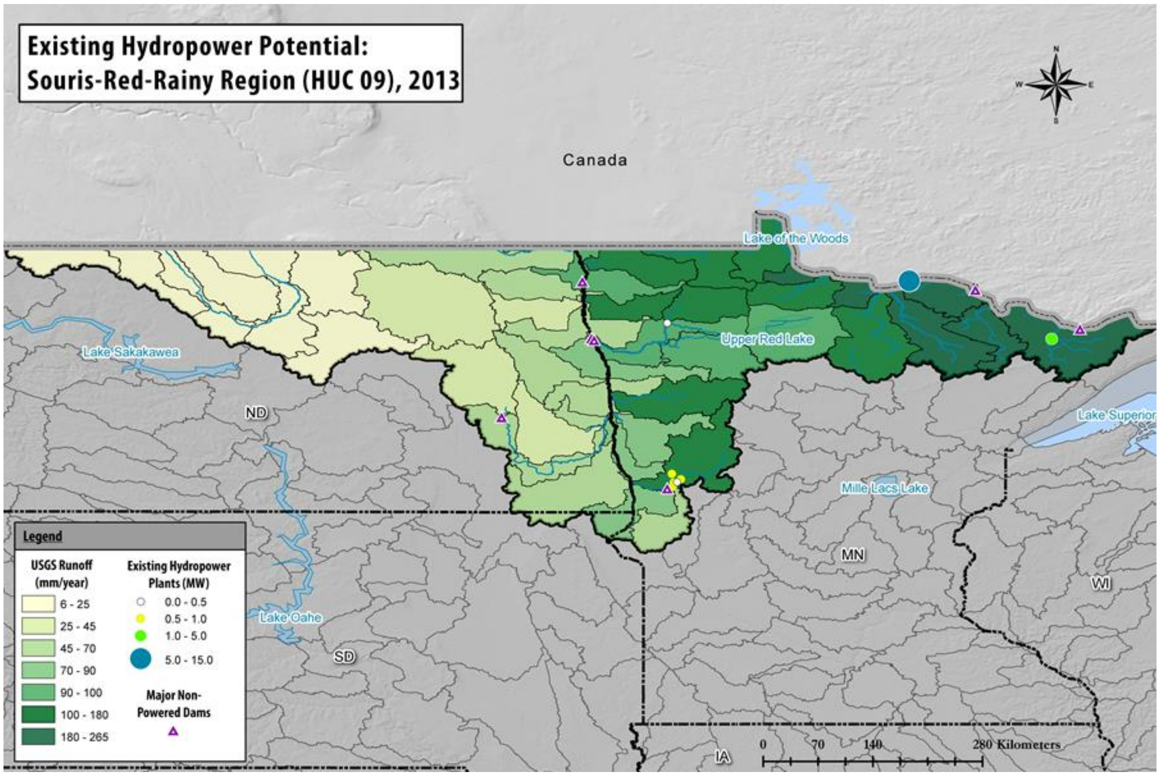

Figure 12.1. Locations of water control projects in Region 9—Souris–Red–Rainy.

12.3. Potential New Hydropower Resources

A total of 15 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) are identified in the Souris–Red–Rainy region. The NSD results based on the HUC04 subregions are shown in Table 12.2. The highest hydropower potential is found in the Red Subregion (HUC 0902), followed closely by the Rainy Subregion (HUC 0903). In these regions, the Red Lake River and the Rainy River contain the highest hydropower potential.

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 in Figure 12.3. The hydraulic head H_{ref} ranges from 7 to the 90th quantile of 41 ft with a median of 21 ft, suggesting that most of the potential stream-reaches will require low-head hydropower technologies. The design flow Q_{30} ranges from 1,000 to the 90th quantile of 10,500 cfs with a median of 2,500 cfs. The potential capacity P_{NSD} ranges from 1.5 to the 90th quantile of 7 MW with a median of 5 MW. The inundated surface area A_{NSD} ranges from 0 to the 90th quantile of 1600 acres with a median of 600 acres. This results in storage values V_{NSD} ranging from 0 to the 90th quantile of 25,000 ac-ft with a median of 5,000 ac-ft, with residence times T_{NSD} ranging from <1 day to the 90th quantile of 1 day a week with a median of about 2 days. The results of > 1 MW stream-reach potential are illustrated in Figure 12.4, with potential capacity (MW) aggregated to the HUC08 subbasins.

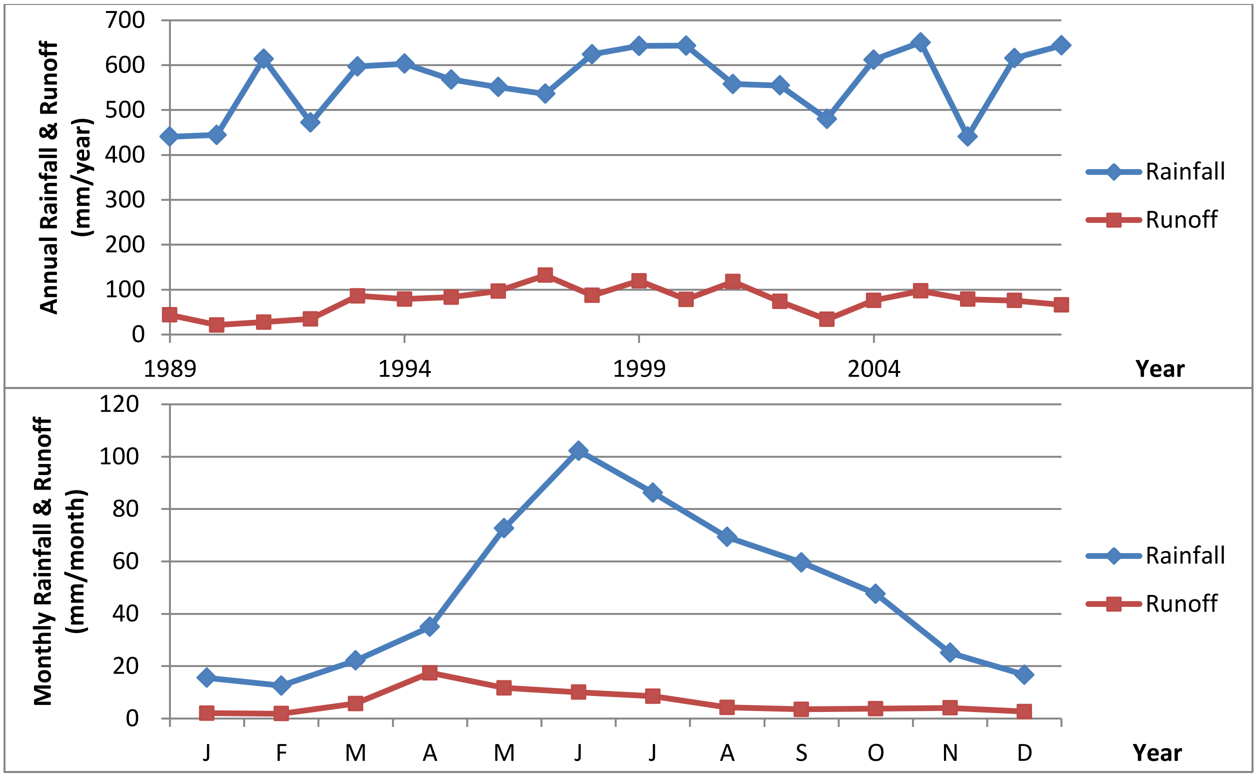

Figure 12.2. Annual and monthly rainfall and runoff of Region 9—Souris–Red–Rainy.

12.4. Environmental Characteristics

The Souris–-Red–Rainy Region has 84 native fish species, with no fish falling under ESA categories and only 1 fish species, shortjaw cisco, falling under IUCN vulnerability categories (Appendix B). Ten fish species are potadromous or anadromous (Figure 12.5). There are no critical watersheds in Region 9 (Mathews et al., 1998). Three species have critical habitat designations, including the gray wolf, Canada lynx, and piping plover.

In Region 9, there are over 10.8 million acres of protected lands, which make up approximately 19% of the total area. Most of these lands are owned by states (47%), the federal government (44%), or Native Americans (8%). State forests are the primary state-owned land type. The USFWS owns most of the federal lands in the region (21%), including the largest tract in the region, Dakota Tallgrass Prairie Wildlife Management Area. The USFS owns 17% of the protected lands, the largest of which includes the Boundary Waters Canoe Area Wilderness, part of Superior National Forest. Other federal entities include NPS (4% of lands) and Bureau of Indian Affairs (1% of lands). Voyageurs National Park is the only national park in the region. There are several tribal lands and reservations, the largest of which include the Lake Traverse, Spirit Lake, and Blackfeet reservations. GAP status 3 lands make up the largest area (47%), followed by status 2 (32%), status 1 (12%), and status 4 (9%) lands. There are no rivers protected under the NWSRA in Region 9. Recreation is average in the region, with 478 boat ramps, 152 fishing access locations, 48 waterfalls, and 13 recreational boating river sections.

On average, Region 9 has the lowest amount of water use in the United States. Most usage is for irrigation or thermoelectric cooling (Appendix B), with the highest values reported in the Rainy Subbasin (Table 12.3). Water-quality concerns are average and are primarily related to elevated nutrient loads and mercury contamination (Figure 12.6 and Appendix B).

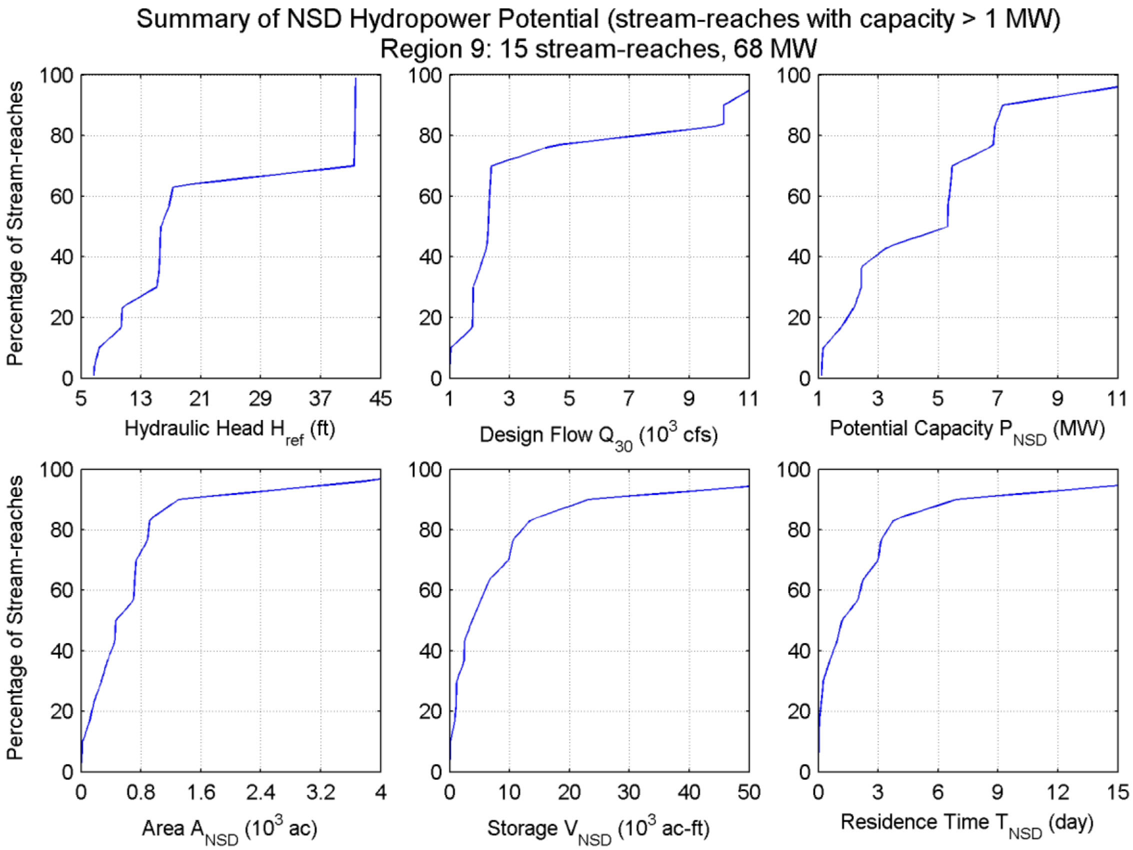

Figure 12.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 9—Souris-Red-Rainy.

Table 12.2. Summary of Potential New Hydropower Resources in Region 9 Souris–Red–Rainy (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/reach)	Average residence time (days)
0901	Souris	-	-	-	-	-	-	-
0902	Red	8	37.9	209,219	31.5	2,087	15,401	4.7
0903	Rainy	7	30.3	165,440	12.4	5,757	3,184	0.7

Table 12.3. Summary of Environmental Variables at HUC04 Subregions within Region 9 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# Critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	# Recreation locations[a]	% Protected lands	Population density (ind/km^2)	Freshwater use (l/day/km^2)
0901	Souris	1	0	0	0	18; 0; 0	4.37	3.13	42.57
0902	Red	2	3	0	0	345; 4; 0	15.28	6.14	85.57
0903	Rainy	3	8	0	1	239; 9; 15	77.21	3.61	359.09

[a] Recreation locations refer to the number of boat-ramp and fishing access points, recreational boating, and waterfalls within each HUC04.

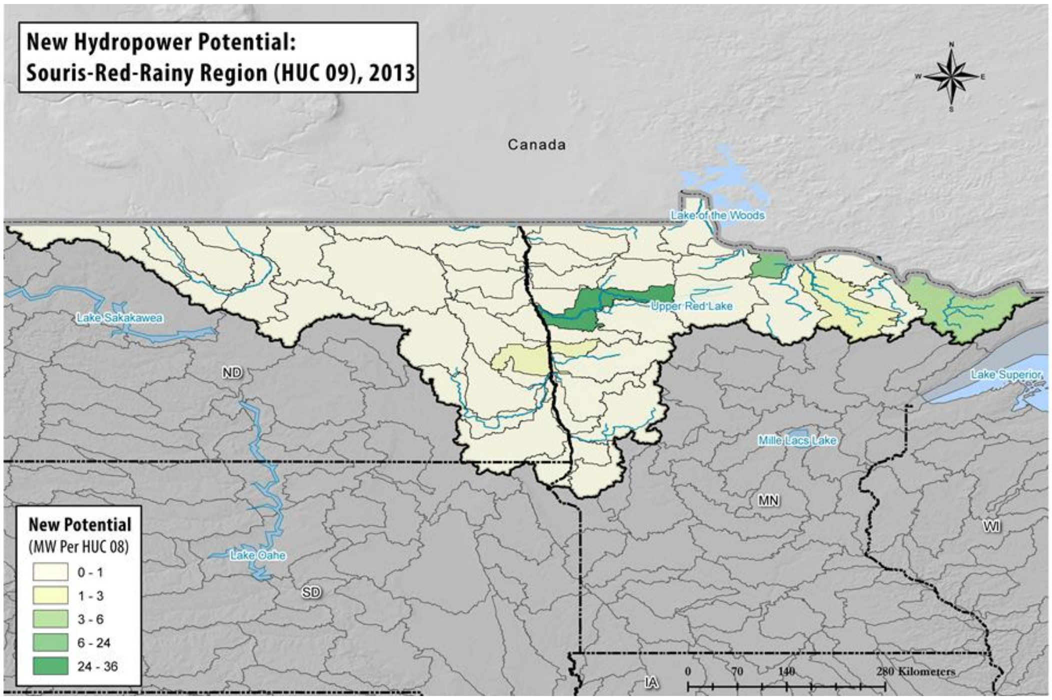

Figure 12.4. Potential new hydropower capacity in Region 9—Souris–Red–Rainy (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC08 subbasins for illustration).

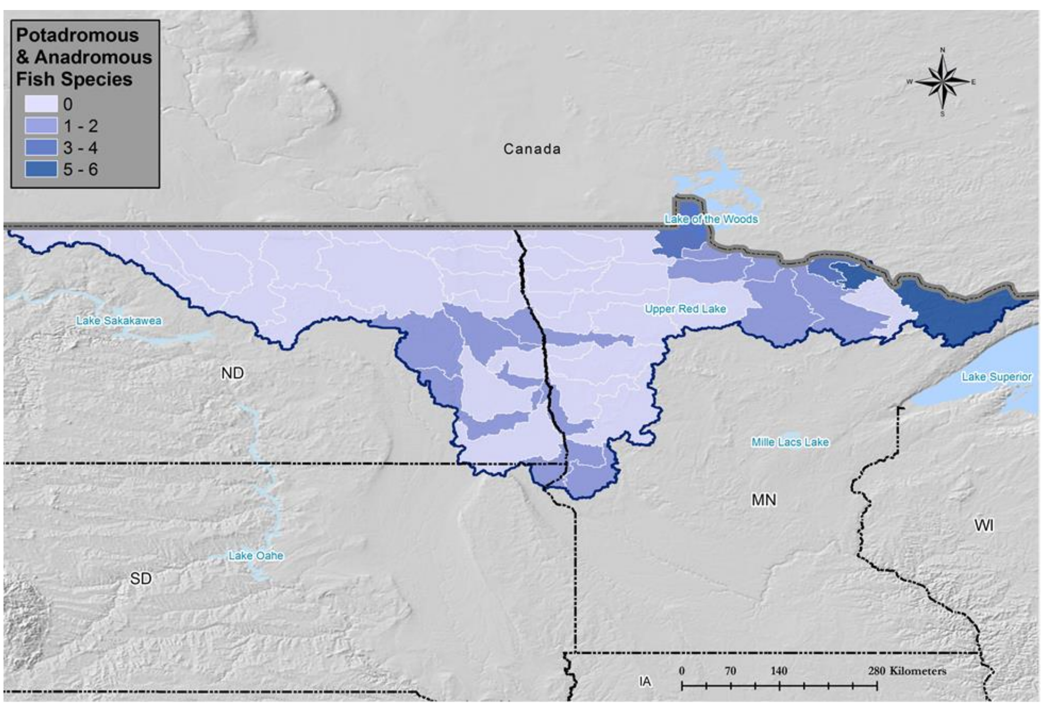

Figure 12.5. Potadromous and anadromous fish species (number per HUC08 subbasin) in Region 9.

Seven of the 15 stream-reaches in Region 9 intersect critical habitat designations, none of them for aquatic organisms (Figure 12.7). As mentioned previously, there are neither ESA fish species nor Wild and Scenic Rivers in this region. Twelve stream-reaches (44 MW) overlap with protected lands, but no stream-reaches intersect a national park. Water-quality concerns are present at almost all stream-reaches (14 reaches). Stream-reaches do not overlap with recreational boating runs and overlap with only one fishing access location. Ten stream-reaches (46 MW) overlap with boat ramps. Most stream-reaches are located within HUC08 subbasins with low water use for the region.

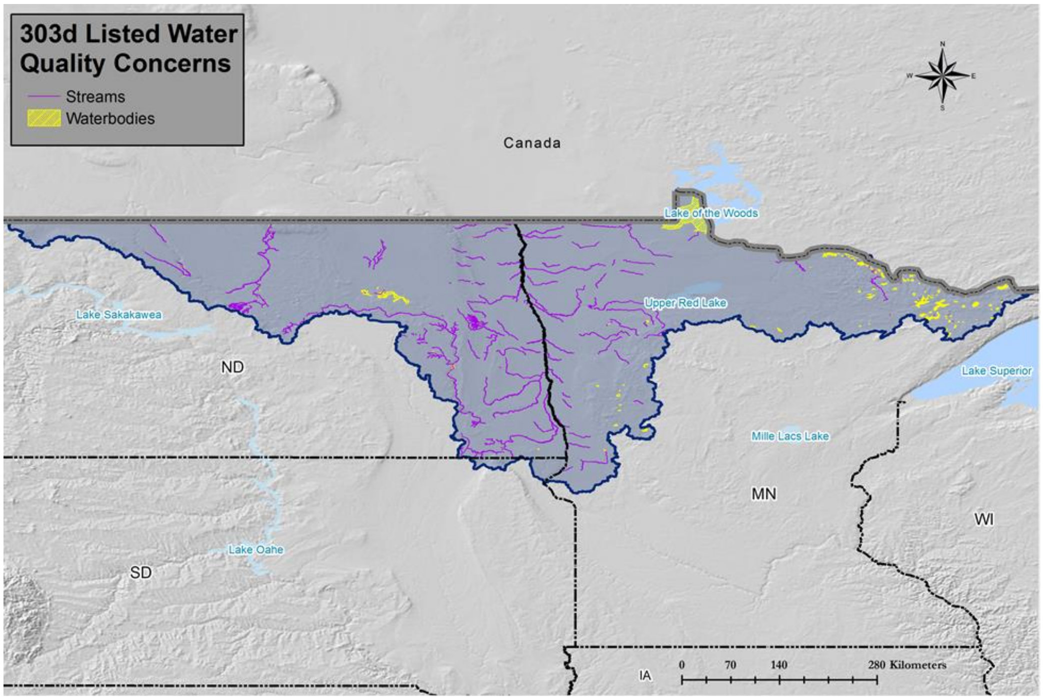

Figure 12.6. 303d listed streams and waterbodies in Region 9.

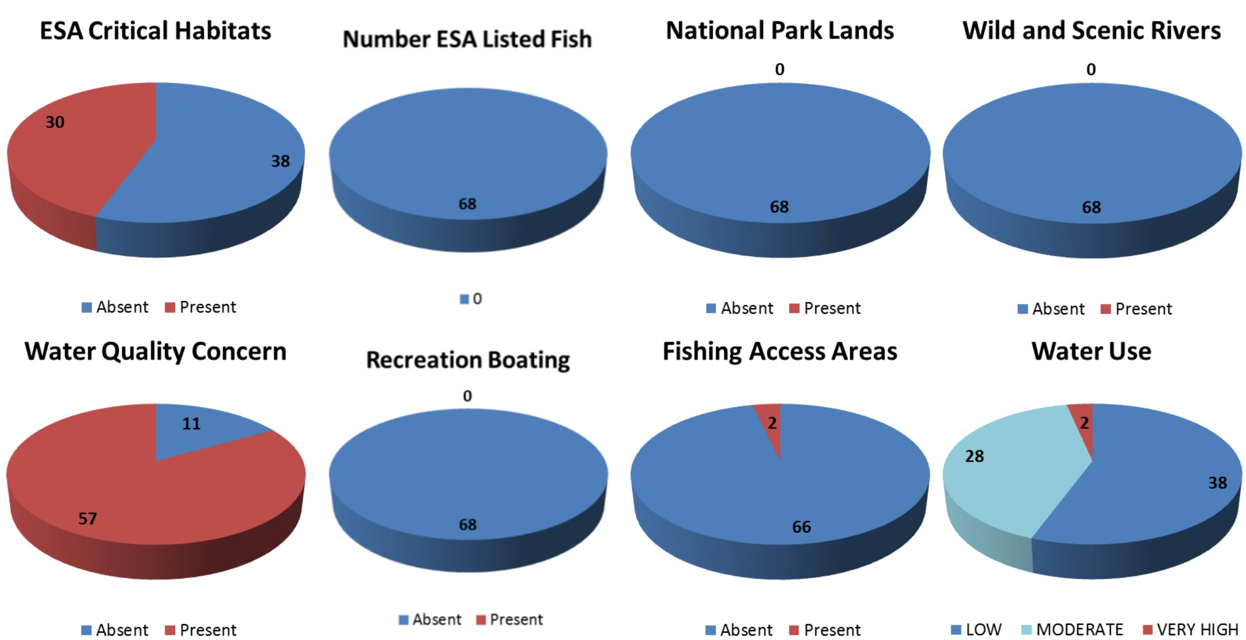

Figure 12.7. The potential capacity, in MW, associated with environmental attributes in Region 9—Souris-Red-Rainy (stream-reaches with potential capacity >1 MW).

13. REGION 10—MISSOURI

13.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation and mean capacity factors in the Missouri Region are estimated and summarized in Table 13.1, for both larger (>1 MW) and smaller (<1 MW) stream-reaches. For comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation, and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 11.69 GW, around 280% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 69.01 TWh/year, around 567% of annual net generation from existing conventional hydropower plants. Given the run-of-river assumption, NSD stream-reaches have higher capacity factors, especially compared with other larger-storage peaking-operation projects in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 13.3 and 13.4.

Table 13.1. Summary of NSD Findings in Region 10—Missouri

	Capacity (MW)	Generation (MWh)	Mean capacity factor
Potential in undeveloped stream-reaches (>1 MW)	8,659	51,826,000	68%
Potential in undeveloped stream-reaches (<1 MW)	3,027	17,185,000	65%
Existing hydropower—conventional hydro	4,172	12,178,000	33%
Existing hydropower—pumped storage	470		

13.2. Background Hydrologic Setting

The Missouri Region encompasses approximately 1,323,893 km^2 of drainage area in the upper midwestern section of the United States and contains parts of Missouri, Kansas, Colorado, Wyoming, North Dakota, South Dakota, Minnesota, Iowa, and all of Nebraska and Montana.

Multiple river systems are located in the Missouri Region (Figure 13.1), including the Missouri, Saskatchewan, Gallatin, Jefferson, Madison, Marias, Musselshell, Milk, Yellowstone, Big Horn, Powder, Tongue, Cheyenne, Belle Fourche, Cannonball, Heart, Knife, Grand, Moreau, White, Niobrara, James, Big Sioux, Platte, Loup, Elkhorn, Republican, Smoky Hill, Kansas, Big Blue, Chariton, Grand, Gasconade, and Osage rivers, with a total length of 48,904 km (i.e., total length of streams with estimated discharge greater than 35 cfs). Metropolitan areas within the subregion include Great Falls (MT), Billings (MT), Bismarck (ND), Rapid City (SD), Lincoln (NE), Topeka (KS), Denver (CO), and Kansas City (MO). As shown in Figure 13.2, annual precipitation for the Missouri region ranges from 400 to 700 mm/year, and annual runoff ranges from 20 to 120 mm/year. Precipitation occurs predominately in mid-summer, coincident with the peak runoff.

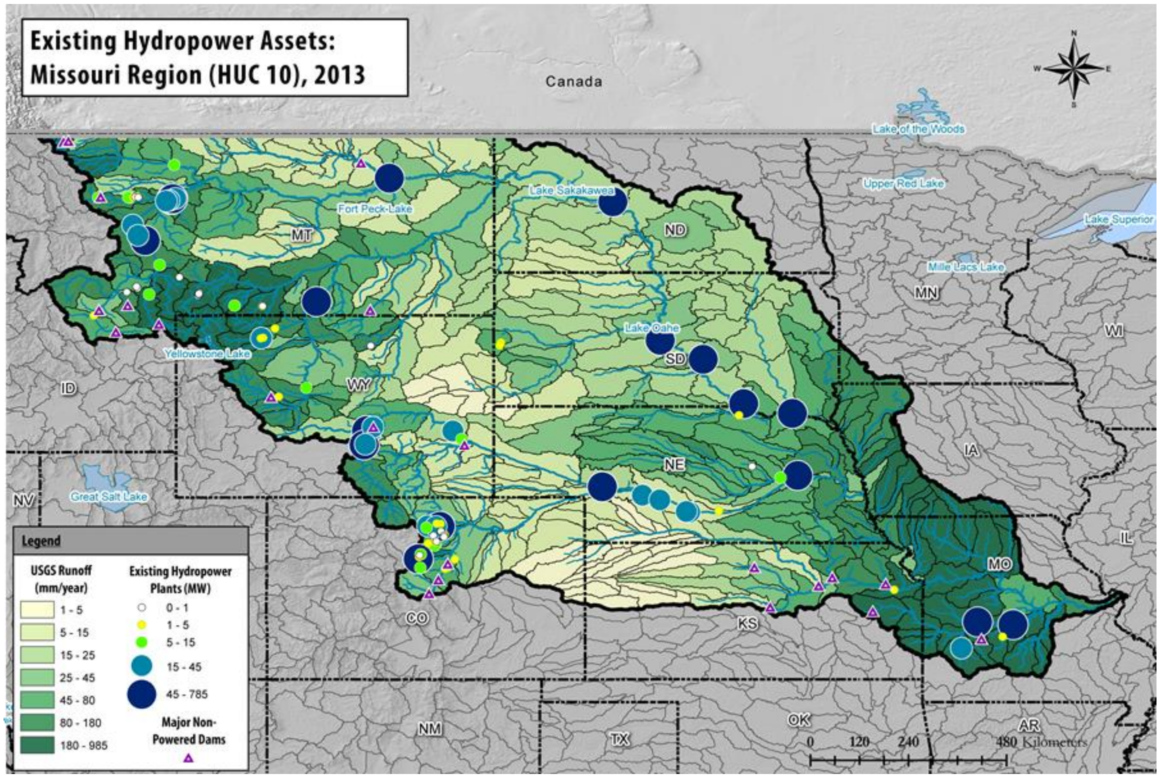

Figure 13.1. Locations of water control projects in Region 10—Missouri.

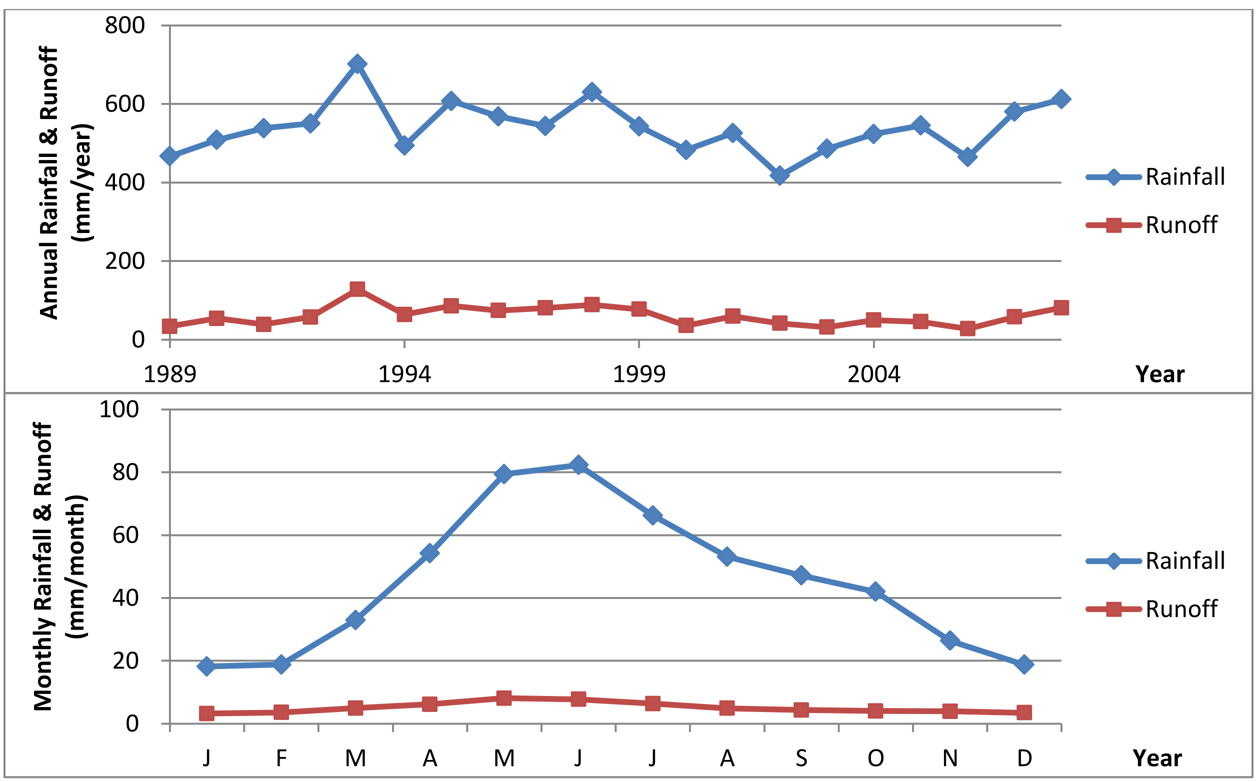

Figure 13.2. Annual and monthly rainfall and runoff of Region 10—Missouri.

The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are also shown in Figure 13.1. The region contains 92 hydropower dams and 22 major non-powered dams, with total storage capacities of around 158,121,517 ac-ft and 8,008,551 ac-ft, respectively.

13.3. Potential New Hydropower Resources

A total of 1462 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) are identified in the Missouri Region. The NSD results based on the HUC04 subregions are summarized in Table 13.2. The highest hydropower potentials are found in the North Platte Subregion (HUC 1018) and Lower Missouri Subregion (HUC 1030) and located on the North Platte and Missouri rivers. The second highest potentials are located in the Upper Yellowstone Subregion (HUC 1007), Lower Yellowstone Subregion (HUC1010), South Platte Subregion (HUC1019), and Missouri–Nishnabotna Subregion (HUC 1024) and located on the Yellowstone, South Platte, and Missouri rivers.

Table 13.2. Summary of Potential New Hydropower Resources in Region 10 Missouri (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/reach)	Average residence time (days)
1001	Saskatchewan	16	20.4	95,702	14.2	1,251	343	0.1
1002	Missouri Headwaters	78	112.2	782,309	16.7	1,202	532	0.2
1003	Missouri–Marias	87	208.7	1,339,531	11.5	2,948	1,978	0.2
1004	Missouri–Musselshell	9	102.9	687,868	32.2	4,947	27,123	0.9
1005	Milk	12	13.4	74,873	18.1	859	10,492	2.0
1006	Missouri–Poplar	9	70.6	466,223	16.8	6,484	27,354	0.7
1007	Upper Yellowstone	233	733.2	4,275,948	17.6	2,624	2,722	0.4
1008	Big Horn	157	368.9	2,121,414	19.8	2,333	3,392	0.7
1009	Powder–Tongue	30	31.9	184,015	27.6	536	13,462	4.7
1010	Lower Yellowstone	37	688.0	4,216,257	20.7	12,492	18,372	0.5
1011	Missouri–Little Missouri	2	34.9	220,585	9.4	25,855	13,716	0.2
1012	Cheyenne	10	22.2	131,736	28.2	1,094	14,810	15.3
1013	Missouri–Oahe	4	168.5	1,046,233	11.5	51,032	22,679	0.3
1014	Missouri–White	-	-	-	-	-	-	-
1015	Niobrara	-	-	-	-	-	-	-
1016	James	-	-	-	-	-	-	-
1017	Missouri–Big Sioux	7	218.2	1,349,706	13.4	32,312	28,854	0.3
1018	North Platte	384	2,259.0	13,097,866	12.9	7,030	1,744	0.3
1019	South Platte	163	672.8	4,095,478	8.2	7,196	954	0.2
1020	Platte	162	361.3	2,298,111	7.8	3,975	840	0.0
1021	Loup	-	-	-	-	-	-	-
1022	Elkhorn	-	-	-	-	-	-	-
1023	Missouri–Little Sioux	8	180.4	1,101,906	9.5	33,104	7,972	0.1
1024	Missouri–Nishnabotna	9	676.3	4,165,794	22.5	46,302	260,204	2.2
1025	Republican	-	-	-	-	-	-	-
1026	Smoky Hill	-	-	-	-	-	-	-
1027	Kansas	15	106.0	540,519	21.0	4,924	29,571	11.4
1028	Chariton–Grand	4	18.2	78,231	22.9	2,931	18,466	10.5
1029	Gasconade–Osage	11	56.8	282,130	22.3	4,105	19,545	9.8
1030	Lower Missouri	15	1,533.8	9,173,726	18.7	76,245	197,175	1.4

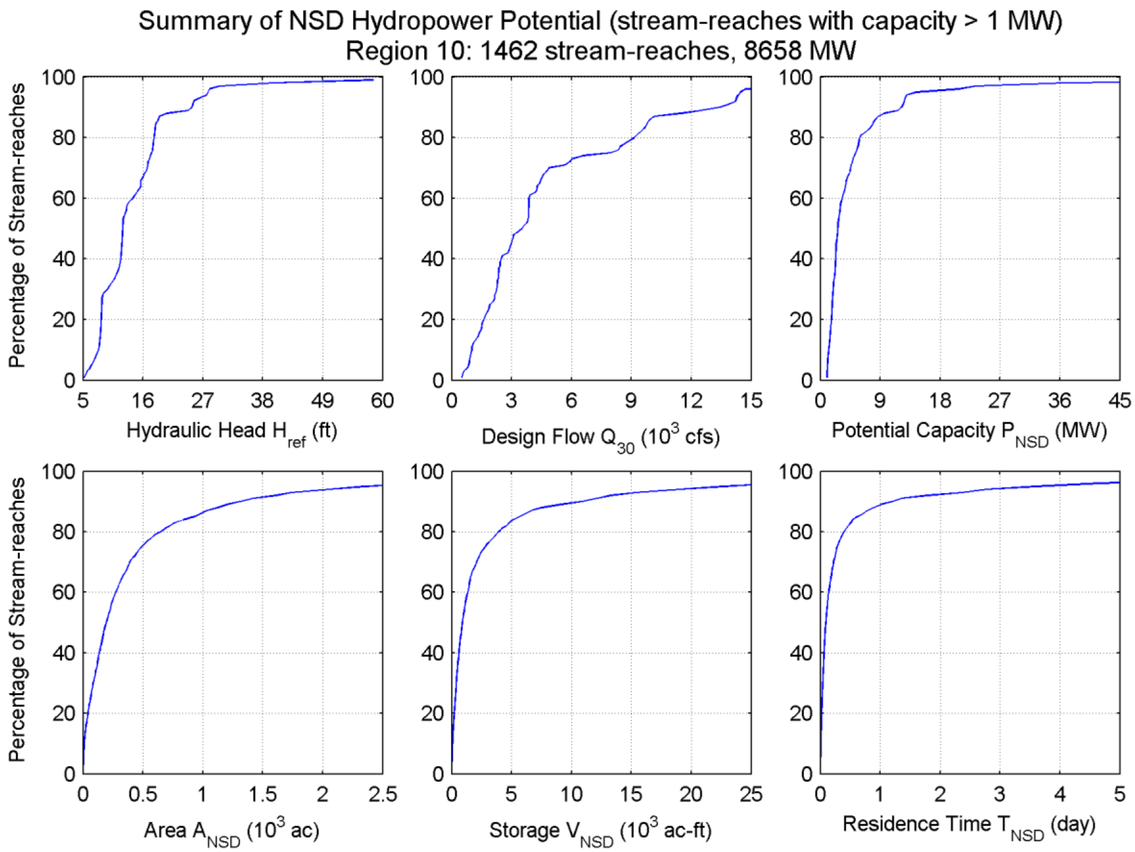

Figure 13.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 10—Missouri.

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 in Figure 13.3. The hydraulic head H_{ref} ranges from 5 to the 90th quantile of 21 ft with a median of 12 ft, suggesting that many of the potential stream-reaches will require low-head hydropower technologies. The design flow Q_{30} ranges from 900 to the 90th quantile of 12,000 cfs with a median of 4,000 cfs. The potential capacity P_{NSD} ranges from 1.5 to the 90th quantile of 12 MW with a median of about 3.5 MW. The inundated surface area A_{NSD} ranges from 1250 to the 90th quantile of 1500 acres with a median of 250 acres. This results in storage values V_{NSD} ranging from 0 to the 90th quantile of 12,500 ac-ft with a median of 1 ac-ft with residence times T_{NSD} ranging from <1 day to the 90th quantile of a few days with a median on the order of a few hours. The results of > 1 MW stream-reach potential are illustrated in Figure 13.4, with potential capacity (MW) aggregated to the HUC08 subbasins.

13.4. Environmental Characteristics

At least 160 native fish species are documented in the Missouri Region. Nine fish species fall under ESA categories, and 14 species fall under IUCN vulnerability status (Figure 13.5 and Appendix B). Well known fishes of concern include arctic grayling, cutthroat trout sub-species (*Oncorhynchus clarkia spp.*), bull trout (*Salvelinus confluentus*), paddlefish, pallid sturgeon, shovelnose sturgeon, and Topeka shiner. Fourteen potadromous or anadromous fish species are reported, many of which are of concern. There are eight critical watersheds in the region, with the highest number of at risk fish and mussel species in the Niangua (five species) and Sac (five species) subbasins (Mathews et al., 1998). Twelve species have critical habitat designations, including three birds, two insects, two mammals, two plants, and three fish. Fish species with critical habitat designations include bull trout, Niangua darter (*Etheostoma nianguae*), and Topeka shiner.

Over 78 million acres of protected lands are located in Region 10 (23% of total area, Figure 13.6). Most of the protected lands are federal (56%), Native American (25%), or state (15%). The USFS (27%), Bureau of Land Management (BLM) (21%), NPS (3%), and DOD (2%) own most of the federal lands in this region. Most protected lands fall into GAP status 3 (58%) or 4 (27%) (Figure 13.6). Yellowstone is the largest national park found in the region. Four rivers are protected under NWSRA in Region 10, including the Clarks Fork Yellowstone, Missouri, Niobrara, and Cache rivers. A total of 1045 boat ramps, 1218 fishing access locations, 131 waterfalls, and 178 recreational boating river sections are located in the region.

Water use is below average in Region 10 compared with the remainder of the United States (Figure 13.7 and Appendix B). Most usage is reported as irrigation or cooling for thermoelectric power plants (Table 13.3 and Appendix B). Similarly, water-quality concerns in Region 10 are below average but also varied, with concerns including (from greatest to least prevalence): mercury contamination, algal nuisance, elevated nutrient loads, reduced dissolved oxygen, elevated pathogen levels, and temperature issues.

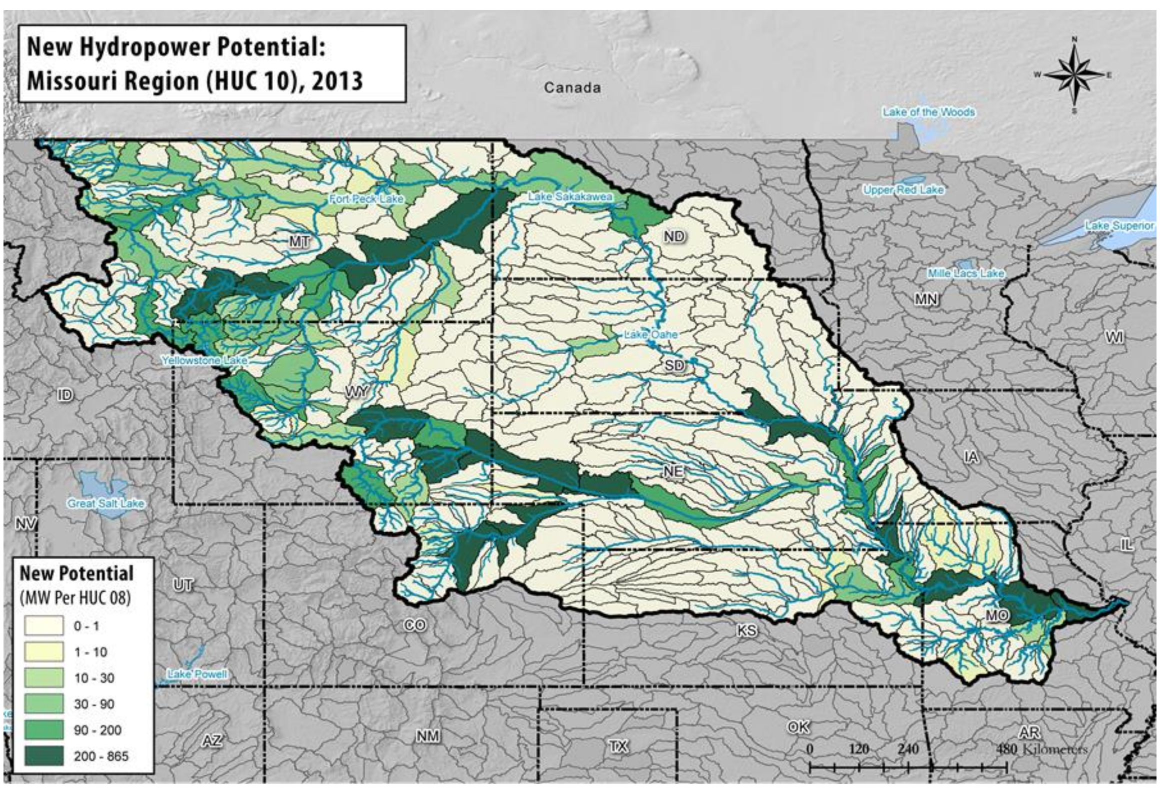

Figure 13.4. Potential new hydropower capacity in Region 10—Missouri (aggregated to HUC08 subbasins for illustration).

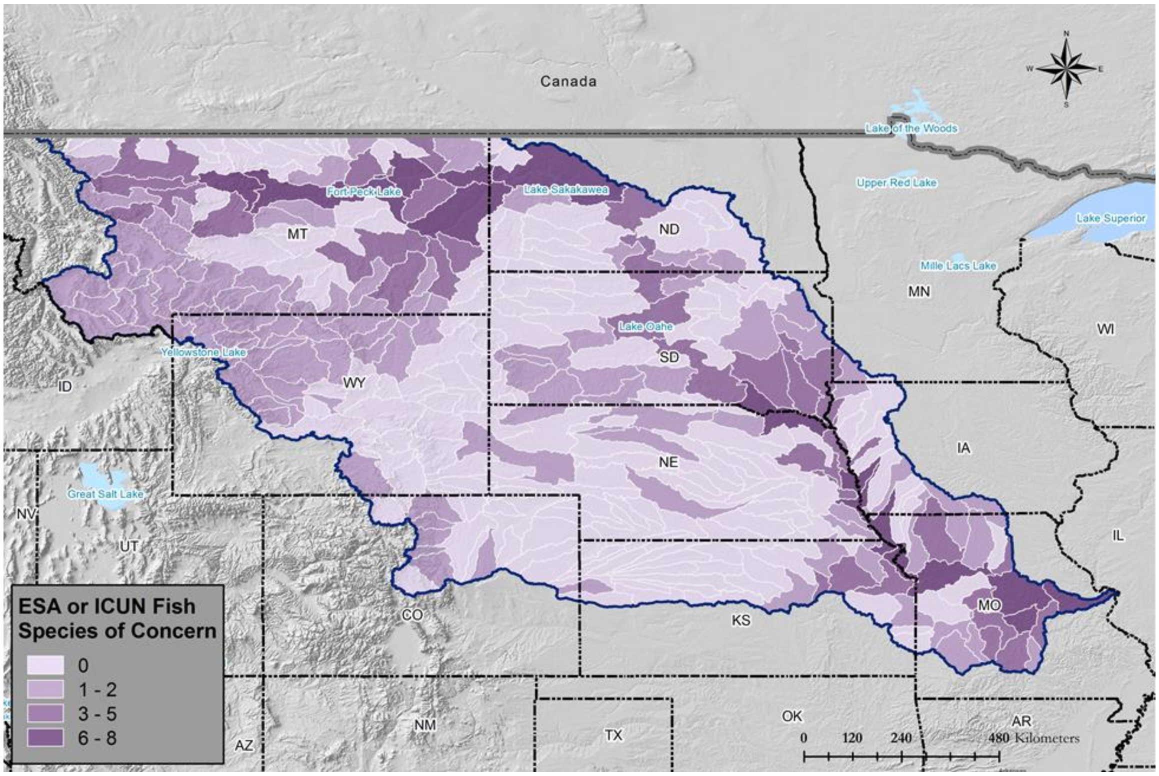

Figure 13.5. Fish species of concern (number per HUC08 subbasin) in Region 10.

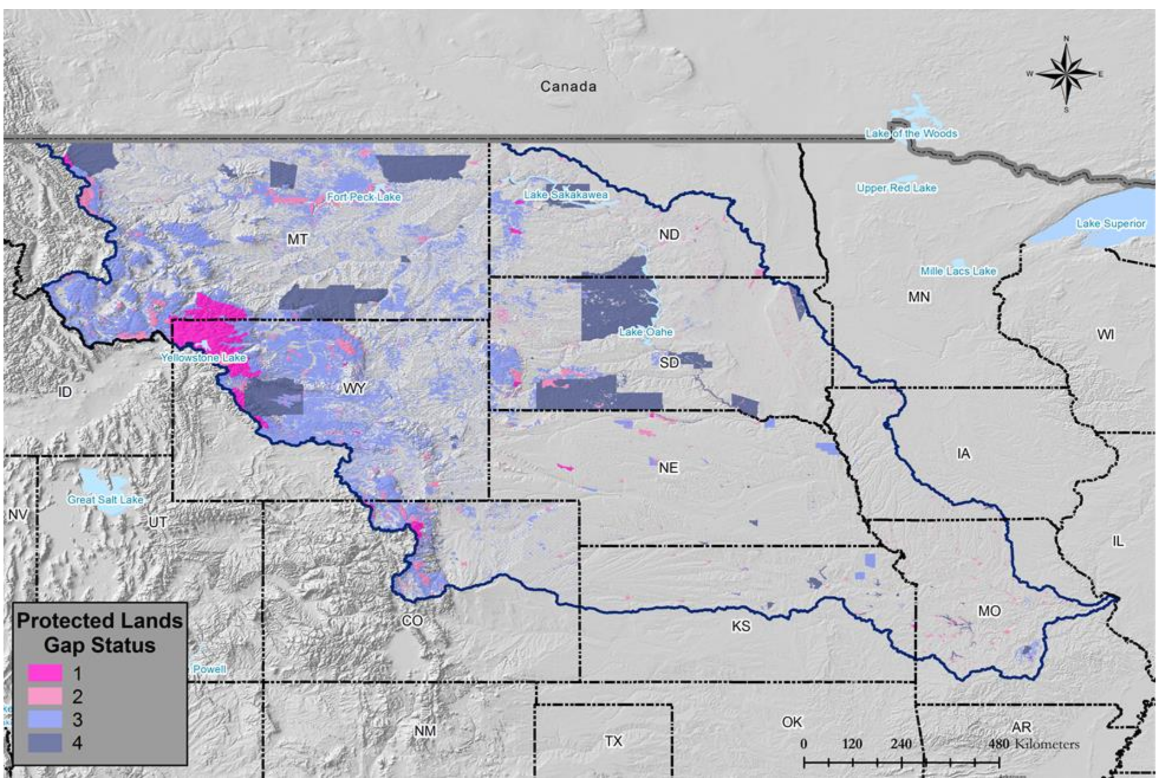

Figure 13.6. Protected lands according to Gap Status (conservation management regime) in Region 10.

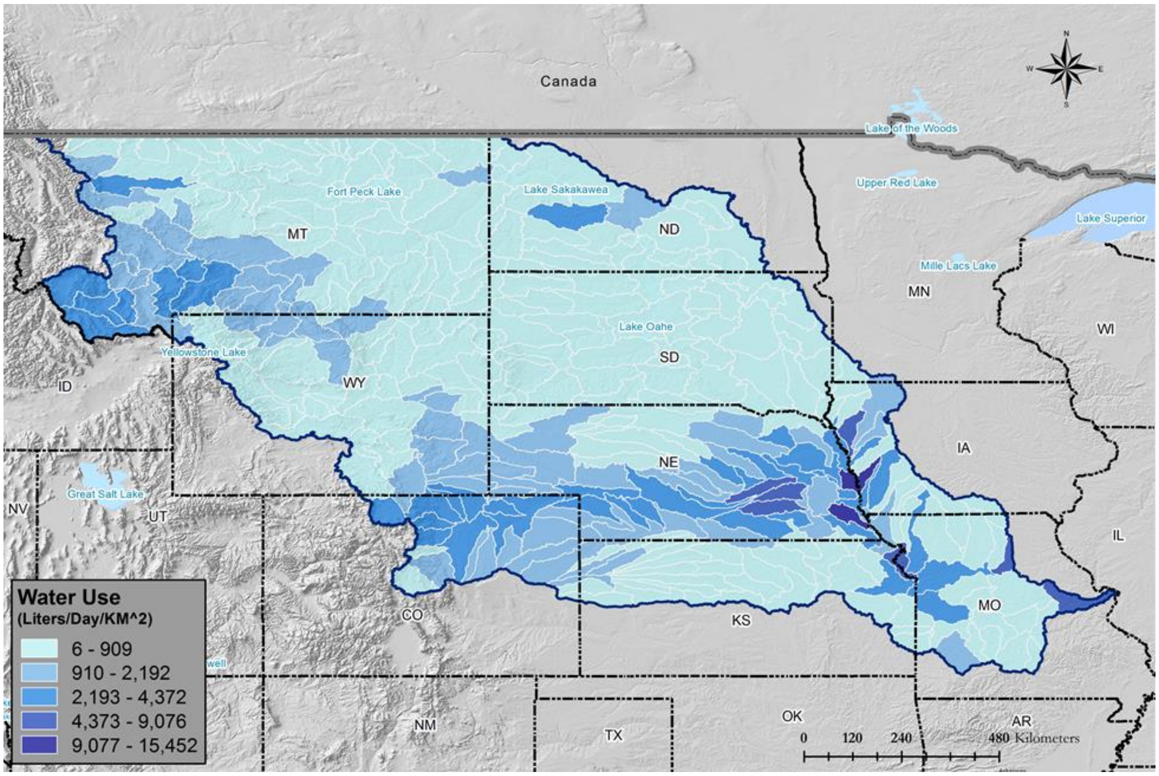

Figure 13.7. Average water use per HUC08 subbasin in Region 10.

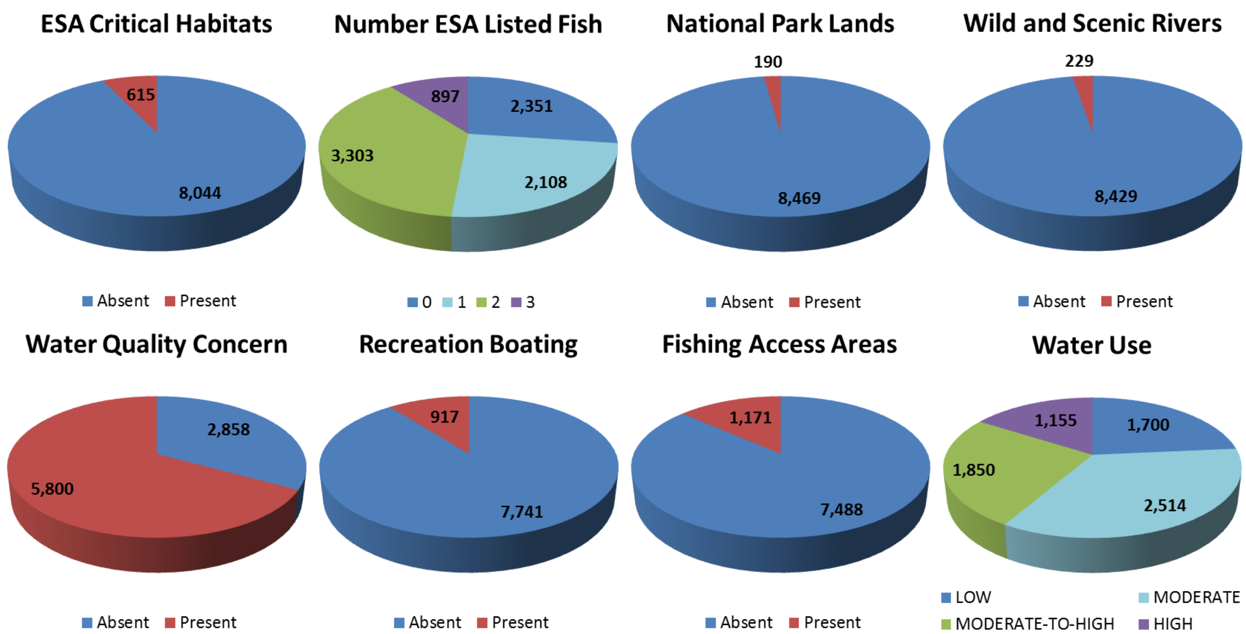

Figure 13.8. The potential capacity, in MW, associated with environmental attributes in Region 10—Missouri (stream-reaches with potential capacity >1 MW).

Of the 1462 stream-reaches in Region 10, 7% intersect critical habitat designations (Figure 13.8). Sixty-four percent of stream-reaches are located in HUC08 subbasins with at least one fish falling under an ESA category. Protected lands are prevalent, overlapping 95% of stream-reaches(~ 8.09 GW). National parks and Wild and Scenic Rivers intersect 7% and 2.5% of stream-reaches, respectively. Water-quality concerns are associated with 54% of stream-reaches (~ 5.8 GW). Recreation is less common at stream-reaches than in other regions, with recreational boating, boat ramps, and fishing access areas identified at 22%, 11%, and 11% of stream-reaches, respectively. Most of the stream-reaches are located in HUC08 subbasins with low and moderate water usage.

Table 13.3. Summary of Environmental Variables at HUC04 Subregions within Region 10 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# Critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	# Recreation locations[a]	% Protected lands	Population density (ind/km^2)	Freshwater use (liters/day/km^2)
1001	Saskatchewan	0	4	1	1	26; 0; 27	76.65	1.87	409.46
1002	Missouri Headwaters	1	3	2	0	44; 12; 26	67.39	2.68	2,443.70
1003	Missouri–Marias	1	6	4	5	55; 14; 20	27.00	3.54	1,314.89
1004	Missouri–Musselshell	1	7	3	6	23; 1; 1	34.02	0.53	396.51
1005	Milk	2	5	1	4	10; 0; 0	28.13	1.01	488.58
1006	Missouri–Poplar	1	5	2	6	9; 0; 0	10.02	1.06	539.74
1007	Upper Yellowstone	1	4	1	0	35; 33; 22	47.95	5.43	1,733.54
1008	Big Horn	1	4	1	1	90; 12; 11	56.06	1.56	849.07
1009	Powder–Tongue	0	6	3	5	28; 7; 0	34.13	1.05	425.20
1010	Lower Yellowstone	0	5	2	6	4; 0; 0	19.62	0.89	595.89
1011	Missouri–Little Missouri	1	5	2	6	40; 0; 0	22.50	1.20	102.93
1012	Cheyenne	1	2	0	1	76; 9; 6	23.48	2.42	342.11
1013	Missouri–Oahe	1	4	2	5	148; 0; 0	7.57	1.93	373.91
1014	Missouri–White	0	6	1	4	88; 0; 0	7.53	1.75	88.44
1015	Niobrara	0	4	2	2	64; 3; 5	4.05	1.35	582.22
1016	James	1	4	3	4	119; 0; 0	3.28	2.38	59.69
1017	Missouri–Big Sioux	2	6	3	6	185; 1; 2	2.63	7.80	251.34
1018	North Platte	3	4	2	1	133; 26; 7	34.67	2.76	1,312.58
1019	South Platte	3	3	2	1	111; 53; 27	21.53	44.64	1,899.59
1020	Platte	3	3	2	5	86; 0; 0	0.80	30.20	3,695.51
1021	Loup	0	1	1	0	35; 1; 2	1.58	2.19	1,440.86
1022	Elkhorn	1	2	2	2	18; 0; 0	0.22	12.35	2,467.79
1023	Missouri–Little Sioux	1	7	3	6	91; 0; 0	1.66	34.81	3,981.06
1024	Missouri–Nishnabotna	1	6	2	6	105; 0; 1	1.01	16.46	2,898.51
1025	Republican	0	2	0	0	65; 0; 0	2.37	2.36	1,444.07
1026	Smoky Hill	0	1	1	1	61; 0; 1	1.18	3.62	354.61
1027	Kansas	0	5	2	4	88; 2; 0	2.13	22.11	2,181.77
1028	Chariton–Grand	0	6	2	5	97; 0; 0	2.20	7.84	1,144.68
1029	Gasconade–Osage	2	8	3	11	256; 0; 0	5.91	13.23	495.52
1030	Lower Missouri	0	9	3	7	99; 4; 0	2.38	70.25	2,702.27

[a]Recreation locations refer to the number of boat-ramp and fishing access points, recreational boating, and waterfalls within each HUC04.

14. REGION 11—ARKANSAS–WHITE–RED

14.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation and mean capacity factors in the Arkansas–White–Red Region are estimated and summarized in Table 14.1 for both larger (>1 MW) and smaller (<1 MW) stream-reaches. For comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation, and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 6.01 GW, around 279% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 33.99 TWh/year, around 579% of annual net generation from existing conventional hydropower plants. Given the run-of-river assumption, NSD stream-reaches have higher capacity factors, especially compared with other larger-storage peaking-operation projects in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 14.3 and 14.4.

Table 14.1. Summary of NSD Findings in Region 11—Arkansas–White–Red

	Capacity (MW)	Generation (MWh)	Mean capacity factor
Potential in undeveloped stream-reaches (>1 MW)	4,442	25,865,000	66%
Potential in undeveloped stream-reaches (<1 MW)	1,571	8,129,000	59%
Existing hydropower—conventional hydro	2,157	5,872,000	31%
Existing hydropower—pumped storage	896		

14.2. Background Hydrologic Setting

The Arkansas–White–Red Region encompasses approximately 642,284 km^2 of drainage area in the central states of the United States, containing parts of Colorado, Kansas, New Mexico, Texas, Louisiana, Arkansas, and Missouri, and all of Oklahoma.

Several river systems are located in the Arkansas–White–Red Region (Figure 14.1), including the Arkansas, White, Red, Walnut, Cimarron, Neosho, Verdigris, Canadian, Beaver, Washita, Little, Big Cypress, and Sulphur rivers, with a total length of 40,139 km (i.e., total length of streams with estimated discharge greater than 35 cfs). Metropolitan areas within the region include Wichita (KS), Tulsa (OK), Oklahoma City (OK), and Little Rock (AR). As shown in Figure 14.2, annual precipitation for the Arkansas–White–Red region ranges from 800 to 1600 mm/year, and annual runoff ranges from 630 to 900 mm/year. Most of the precipitation occurs from early spring through summer. The runoff generally coincides with this pattern for the region.

The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are shown in Figure 14.1. The region contains 41 hydropower dams and 55 major non-powered dams, with total storage capacities of around 72,548,529 ac-ft and 25,687,289 ac-ft, respectively.

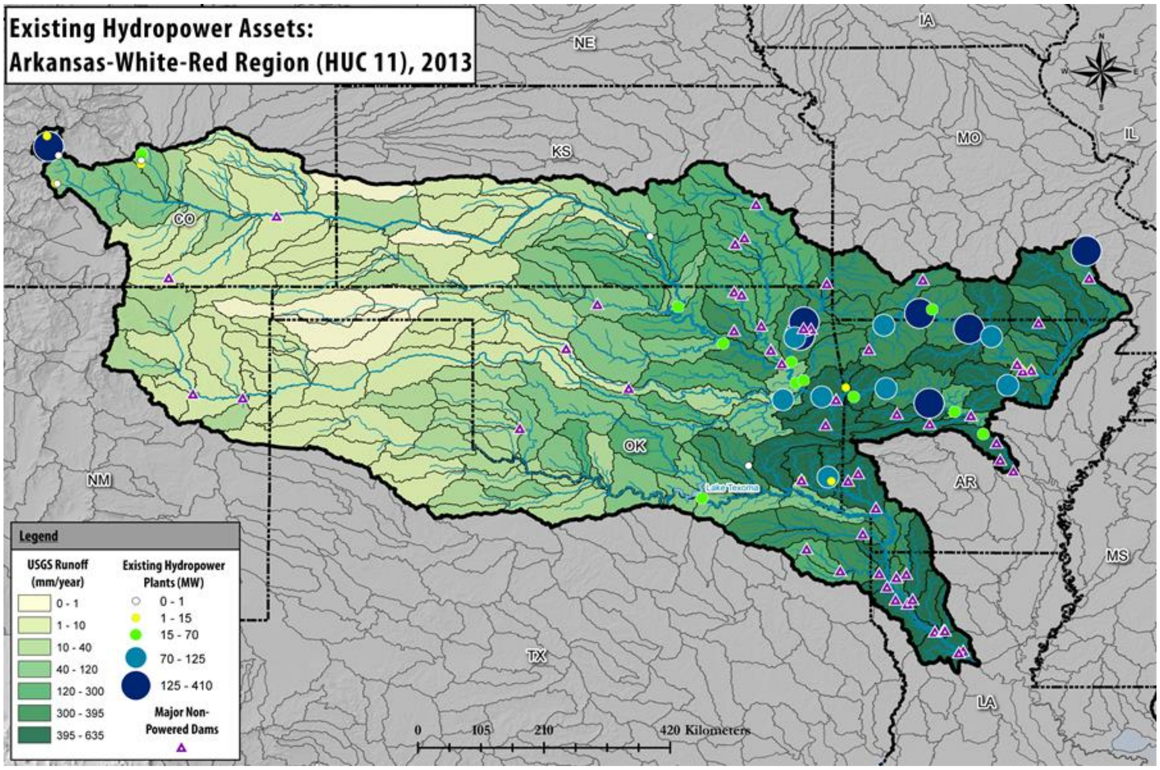

Figure 14.1. Locations of water control projects in Region 11—Arkansas–White–Red.

14.3. Potential New Hydropower Resources

A total of 781 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) are identified in the Arkansas–White–Red Region. The NSD results based on the HUC04 subregions are summarized in Table 14.2. The highest hydropower potentials are found in the Middle Arkansas Subregion (HUC 1103), followed by the Upper Arkansas Subregion (HUC1102) located in the Arkansas River.

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 in Figure 14.3. The hydraulic head H_{ref} ranges from 5 to the 90th quantile of 29 ft with a median of 20 ft, suggesting that many of the potential stream-reaches will require low-head hydropower technologies. The design flow Q_{30} ranges from 700 to the 90th quantile of 13,500 cfs with a median of 2,700 cfs. The potential capacity P_{NSD} ranges from 1.5 to the 90th quantile of 11 MW with a median of about 4 MW. The inundated surface area A_{NSD} ranges from 0 to the 90th quantile of 3,000 acres with a median of 500 acres. This results in storage values V_{NSD} ranging from 0 to the 90th quantile of 32,000 ac-ft with a median of 1,500 ac-ft with residence times T_{NSD} ranging from <1 day to the 90th quantile of about 11 days with a median on the order of a day. The results of > 1 MW stream-reach potential are illustrated in Figure 14.4, with potential capacity (MW) aggregated to the HUC08 subbasins.

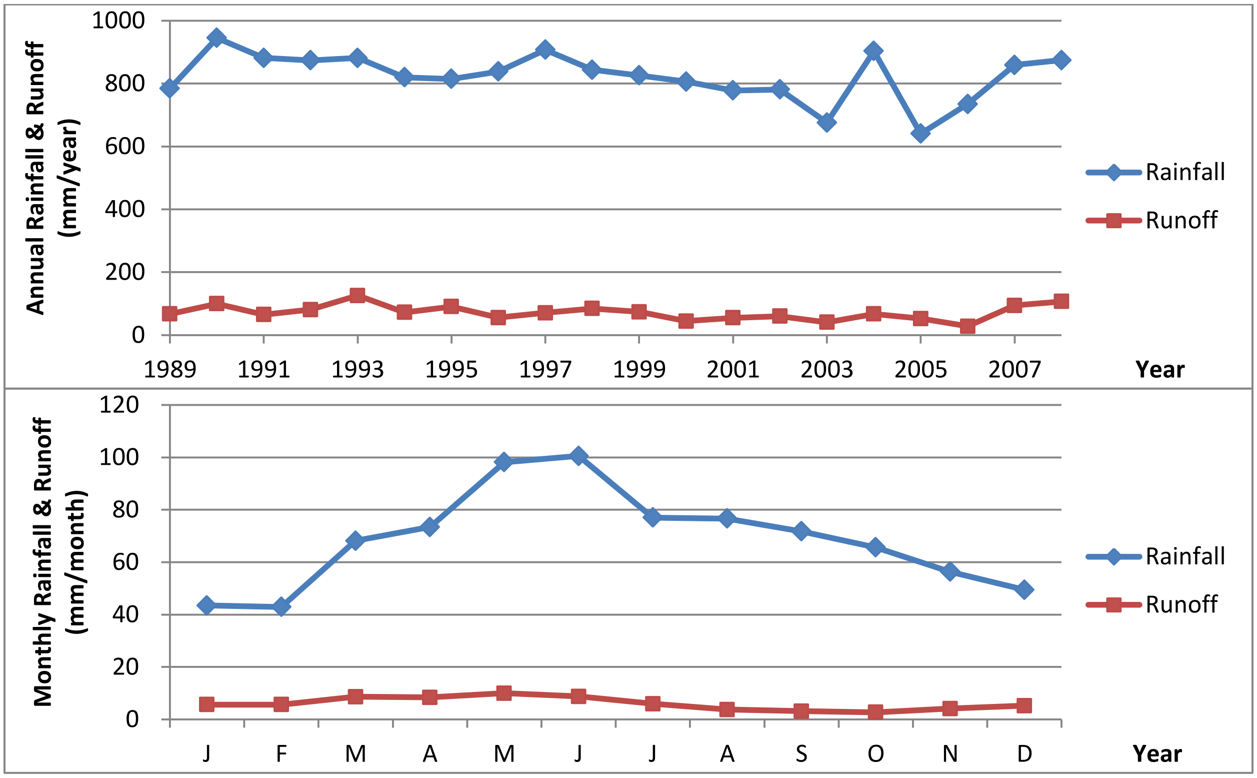

Figure 14.2. Annual and monthly rainfall and runoff of Region 11—Arkansas–White–Red.

Table 14.2. Summary of Potential New Hydropower Resources in Region 11 Arkansas–White–Red (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/reach)	Average residence time (days)
1101	Upper White	66	390.8	2,147,334	37.0	2,695	34,751	23.3
1102	Upper Arkansas	181	678.4	4,306,507	18.4	2,822	3,164	0.5
1103	Middle Arkansas	220	1,897.8	11,830,373	9.2	13,079	864	0.1
1104	Upper Cimarron	-	-	-	-	-	-	-
1105	Lower Cimarron	17	26.7	138,590	21.0	1,057	17,747	9.3
1106	Arkansas–Keystone	14	192.6	1,019,757	21.1	9,000	25,907	2.6
1107	Neosho–Verdigris	34	86.8	374,648	19.1	2,130	12,163	4.3
1108	Upper Canadian	13	23.7	128,702	23.6	1,075	4,314	3.4
1109	Lower Canadian	104	414.7	2,236,791	24.5	2,274	20,621	7.4
1110	North Canadian	4	4.8	24,904	15.8	1,053	3,490	1.4
1111	Lower Arkansas	30	222.4	1,130,952	25.0	6,415	24,872	15.4
1112	Red headwaters	-	-	-	-	-	-	-
1113	Red–Washita	42	79.4	406,362	21.9	1,279	22,976	10.2
1114	Red–Sulphur	56	423.9	2,119,858	23.7	7,059	38,420	22.9

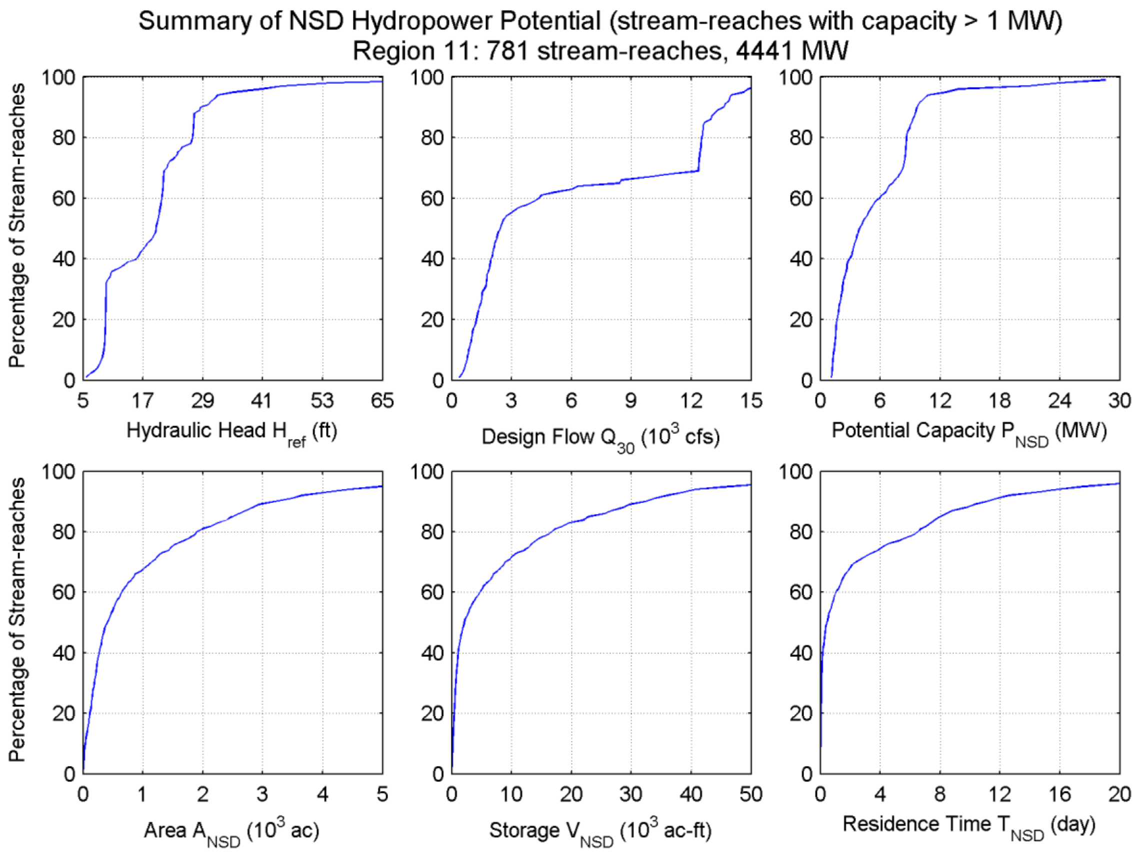

Figure 14.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 11—Arkansas–White–Red.

14.4. Environmental Characteristics

The Arkansas–White–Red Region is home to 210 native fish species and has a high number of vulnerable fish species. Nine fish fall under ESA categories, including Leopard darter (*Percina pantherina*), Neosho madtom (*Noturus placidus*), Ozark cavefish (*Amblyopsis rosae*), shovelnose sturgeon, Topeka shiner, and populations of cutthroat trout (Figure 14.5). An additional nine fish species fall under IUCN vulnerability categories (Figure 14.5 and Appendix B). Eight potadromous/anadromous fish species are found in Region 11. Sixteen subbasins, most of which are located in the eastern half of the region, are considered critical watersheds with anywhere from 1 to 19 fish and mussel species at risk (Mathews et al., 1998). An additional four subbasins not classified as critical watersheds have multiple species at risk. Six fish species have critical habitat designations in Region 11, including Leopard darter and Arkansas River shiner (*Notropis girardi*).

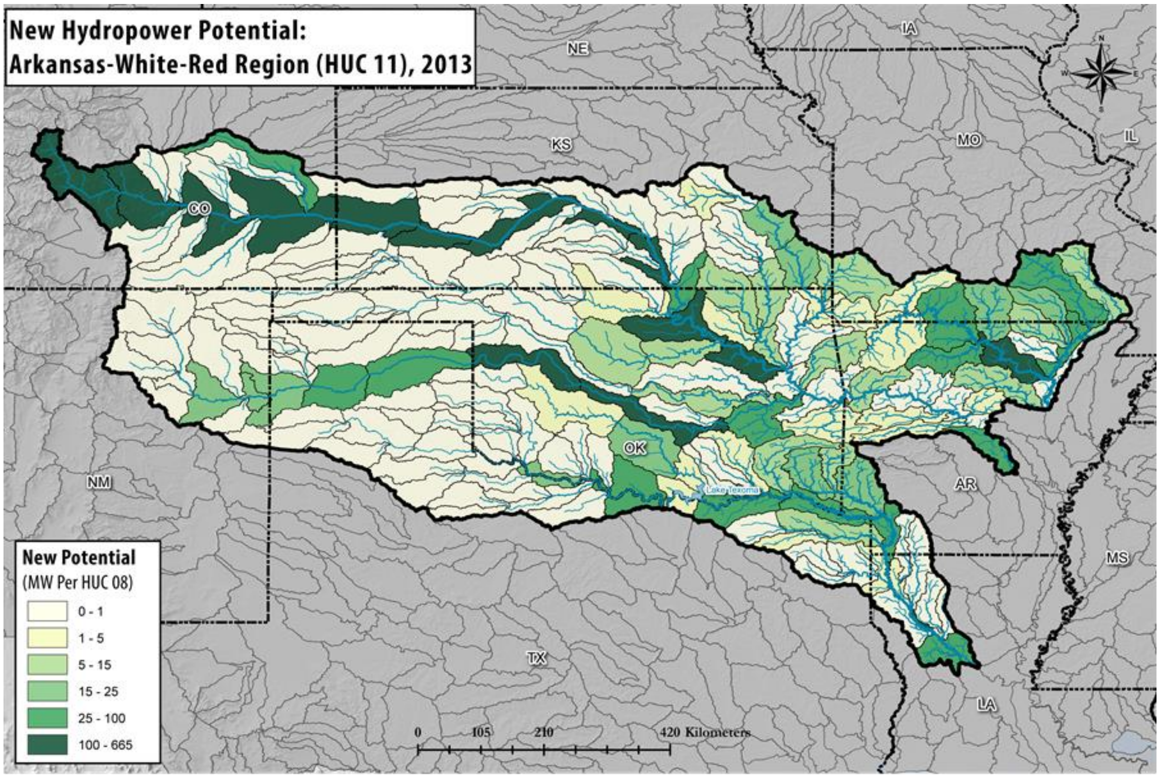

Figure 14.4. Potential new hydropower capacity in Region 11—Arkansas–White–Red (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC08 subbasins for illustration).

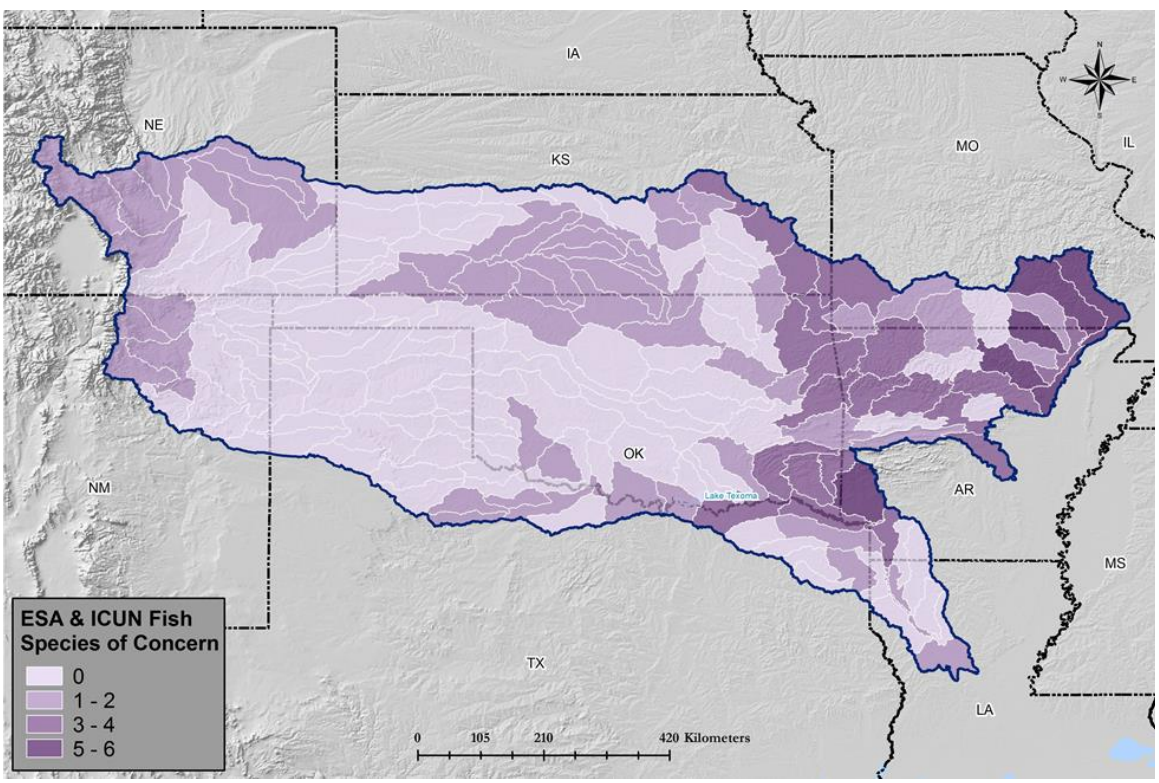

Figure 14.5. Fish species of concern (number per HUC08 subbasin) in Region 11.

Over 9.5% of the total area (15.1 million acres) in Region 11 is protected lands. Fifty-nine percent of protected lands are federally owned, and 36% are state-owned. Federal lands are primarily owned by the USFS (37%), DOD (14%), BLM (4.2%), FWS (2%), and NPS (1%). San Isabel, Mark Twain, Ouachita, and Ozark national forests, Comanche National Grassland, and Fort Carson Military Reservation are among the largest tracts of land in the region. State trust lands make up most of the state-owned lands. GAP status 3, 4, and 2 lands make up 41%, 31%, and 25% of protected lands, respectively. Nine National Wild and Scenic Rivers are located in Region 11. Recreation is prevalent and includes 1390 boat ramps, 486 fishing access locations, 60 waterfalls, and 204 recreational boating river sections.

Water use is well below the national average in Region 11 (Figure 14.6); however, the region receives far less rainfall than other areas (Figure 14.2). Main water consumption is irrigation, followed by thermoelectric cooling (Table 14.3 and Appendix B). Water quality is also below the U.S. average with most of the concerns related to dissolved oxygen, followed by mercury contamination, algal nuisance, and toxin and pathogen contamination (Appendix B).

Fifteen percent of stream-reaches (514 MW) overlap critical habitats (Figure 14.7). Almost 54% of stream-reaches (~ 2.48 GW) are located in HUC08 subbasins, with at least one fish falling under an ESA category. Fifty-nine percent of stream-reaches intersect protected lands, with none falling on national parks and 13 falling on WSRs. Water-quality concerns are associated with almost 87% of stream-reaches (>4 GW). Recreational boating, boat ramps, and fishing access areas overlapped with 32%, 25%, and 20% of stream-reaches, respectively. Most of the stream-reaches are located in HUC08 subbasins with low-to- moderate-to-high water use values.

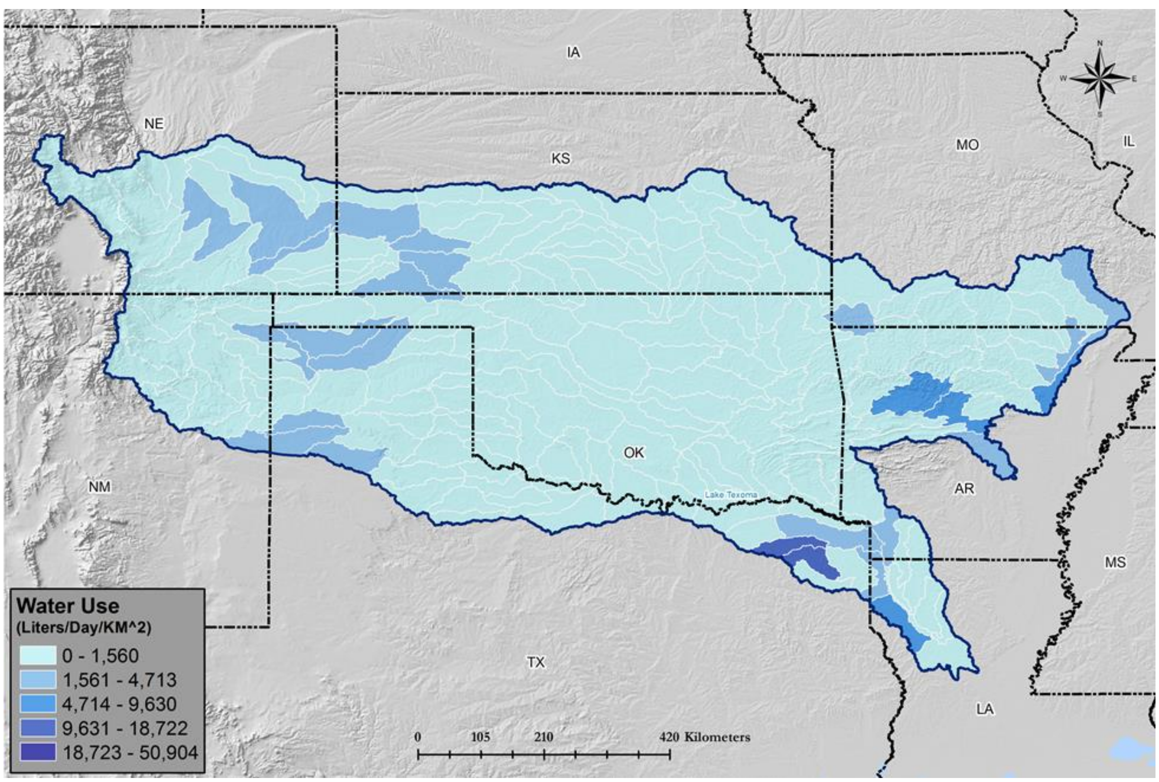

Figure 14.6. Average water use per HUC08 subbasin in Region 11.

Table 14.3. Summary of Environmental Variables at HUC04 Subregions within Region 11 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# Critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	# Recreation locations[a]	% Protected lands	Population density (ind/km^2)	Freshwater use (liters/day/km^2)
1101	Upper White	1	6	3	9	410; 66; 13	15.03	12.99	1,390.27
1102	Upper Arkansas	1	1	2	1	77; 15; 13	25.32	19.08	1,154.73
1103	Middle Arkansas	1	3	3	2	49; 0; 0	0.79	20.74	944.50
1104	Upper Cimarron	1	1	1	1	11; 0; 1	9.77	2.20	1,261.41
1105	Lower Cimarron	1	2	1	1	30; 1; 0	3.58	18.51	172.97
1106	Arkansas–Keystone	1	5	2	3	55; 1; 0	2.78	7.29	203.52
1107	Neosho–Verdigris	0	5	5	6	249; 4; 2	3.12	20.20	446.06
1108	Upper Canadian	2	1	1	0	16; 4; 0	22.36	1.41	154.80
1109	Lower Canadian	1	3	0	0	73; 1; 0	5.75	15.59	870.35
1110	North Canadian	0	2	0	0	90; 0; 0	4.73	15.30	1,169.79
1111	Lower Arkansas	0	6	3	7	370; 81; 5	21.94	38.54	1,541.17
1112	Red Headwaters	0	0	1	1	25; 0; 1	1.73	6.38	1,049.74
1113	Red–Washita	0	5	2	2	175; 4; 19	3.82	11.34	328.07
1114	Red–Sulphur	1	5	2	7	246; 27; 6	7.49	20.46	1,738.51

[a]Recreation locations refer to the number of boat-ramp and fishing access points, recreational boating, and waterfalls within each HUC04.

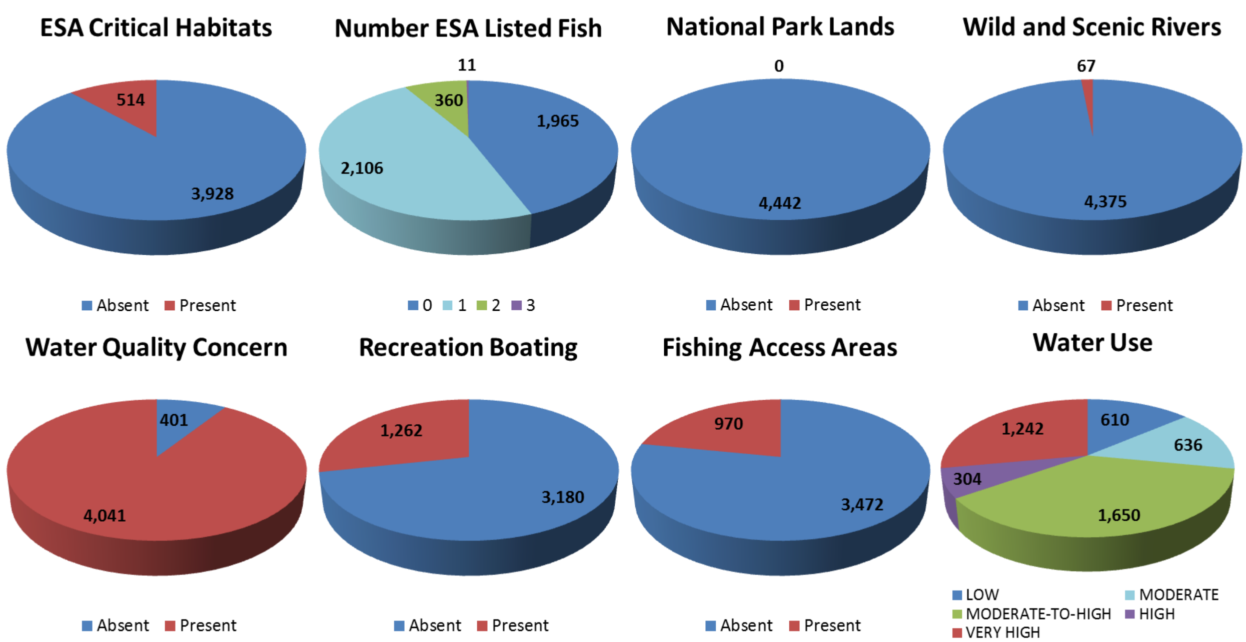

Figure 14.7. The potential capacity, in MW, associated with environmental attributes in Region 11—Arkansas–White–Red (stream-reaches with potential capacity >1 MW).

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15. REGION 12—TEXAS-GULF

15.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation, and mean capacity factors in the Texas–Gulf Region are estimated and summarized in Table 15.1 for both larger (>1 MW) and smaller (<1 MW) stream-reaches. By comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 783 MW, around 149% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 3.67 TWh/year, around 523% of annual net generation from existing conventional hydropower plants. Given the run-of-river assumption, NSD stream-reaches have higher capacity factors, especially compared with other larger-storage peaking-operation projects in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 15.3 and 15.4.

Table 15.1. Summary of NSD Findings in Region 12—Texas–Gulf

	Capacity (MW)	Generation (MWh)	Mean capacity factor
Potential in undeveloped stream-reaches (>1 MW)	395	1,917,000	55%
Potential in undeveloped stream-reaches (<1 MW)	388	1,749,000	52%
Existing hydropower—conventional hydro	525	701,000	15%
Existing hydropower—pumped storage	0		

15.2. Background Hydrologic Setting

The Texas–Gulf Region encompasses approximately 471,053 km^2 of drainage area in the western Gulf region of the United States; it contains very small sections of Mississippi and New Mexico and a large central section of Texas.

Several river systems are located in the Texas–Gulf Region (Figure 15.1), including the Sabine, Neches, Trinity, San Jacinto, Brazos, Little, Colorado, San Saba, Lavaca, Guadalupe, San Antonio, and Nueces rivers, with a total length of 25,079 km (i.e., total length of streams with estimated discharge greater than 35 cfs). Metropolitan areas within the region include Houston (TX), Dallas/Fort Worth (TX), San Antonio (TX), and Corpus Christi (TX). As shown in Figure 15.2, annual precipitation for the Texas–Gulf region ranges from 590 to 1100 mm/year, and annual runoff ranges from 10 to 150 mm/year. Most of the precipitation occurs in early summer and again in late fall during hurricane season.

The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are shown in Figure 15.1. The region contains 24 hydropower dams and 50 major non-powered dams, with storage capacities of about 44,984,357 ac-ft and 2,978,445 ac-ft, respectively.

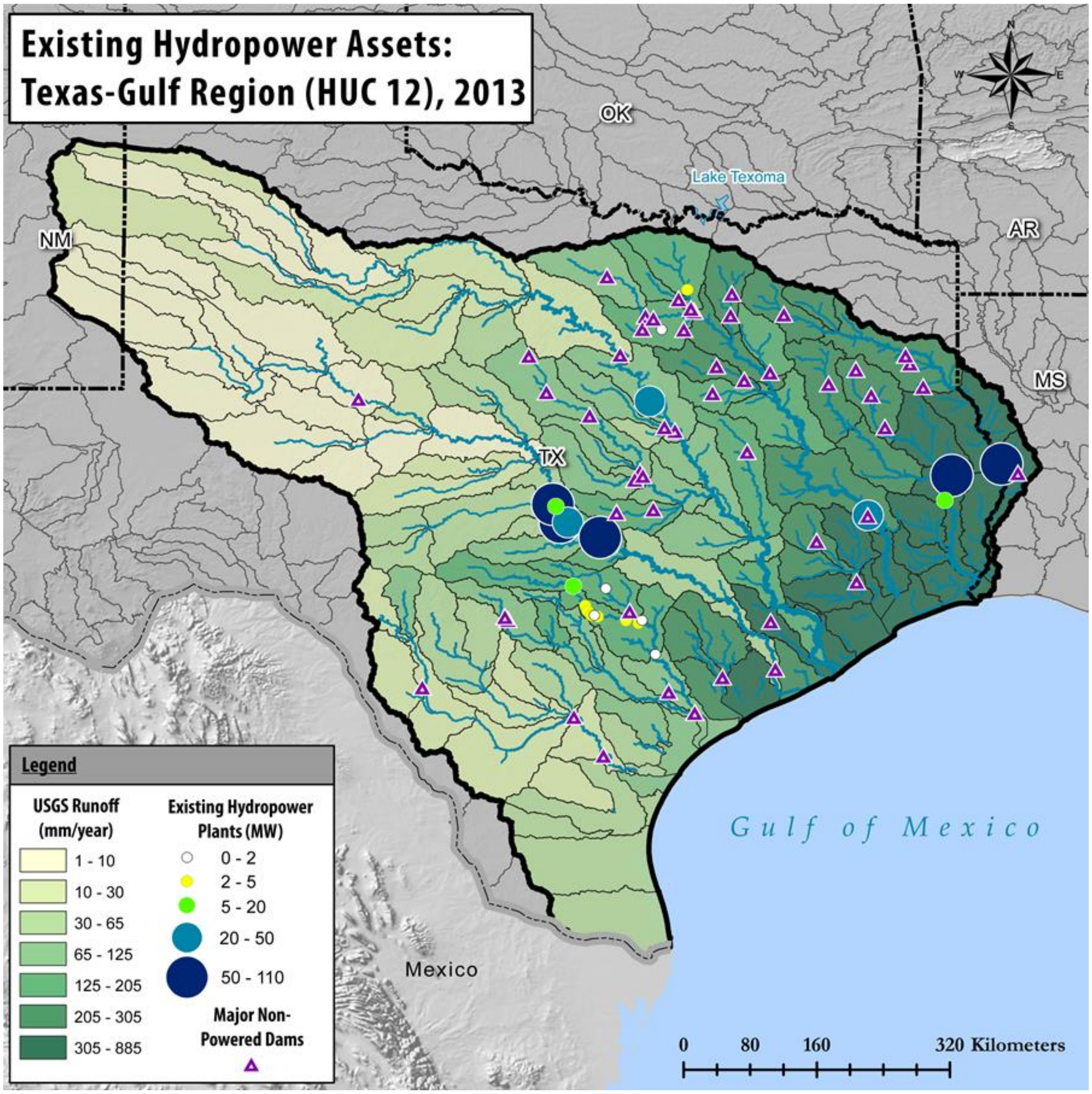

Figure 15.1. Locations of water control projects in Region 12—Texas–Gulf.

15.3. Potential New Hydropower Resources

A total of 117 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) are identified in the Texas–Gulf Region. The NSD results based on the HUC04 subregions are summarized in Table 15.2. The highest hydropower potential is found in the Lower Brazos Subregion (HUC 1207) located in the Brazos and Little rivers. The next highest hydropower potential is located in the Trinity Subregion (HUC 1203) and Central Texas Coastal Subregion (HUC1210) in the Trinity and San Antonio rivers, respectively.

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 in Figure 15.3. The hydraulic head H_{ref} ranges from 5 to the 90th quantile of 54 ft with a median of 25 ft. The design flow Q_{30} ranges from 400 to the 90th quantile of 7000 cfs with a median of about 1900 cfs. The potential capacity P_{NSD} ranges from 1 to the 90th quantile of 6.5 MW with a median of about 2.5 MW. The inundated surface area A_{NSD} ranges from 0 to the 90th quantile of 7500 acres with a median of 1500 acres. This results in storage values V_{NSD} ranging from 0 to the 90^{th} quantile of 80,000 ac-ft with a median of 15,000 ac-ft with residence times T_{NSD} ranging from <1 day to the 90th quantile of about 45 days with a median on the order of a day or two. The results of > 1 MW stream-reach potential are illustrated in Figure 15.4, with potential capacity (MW) aggregated to the HUC08 subbasins.

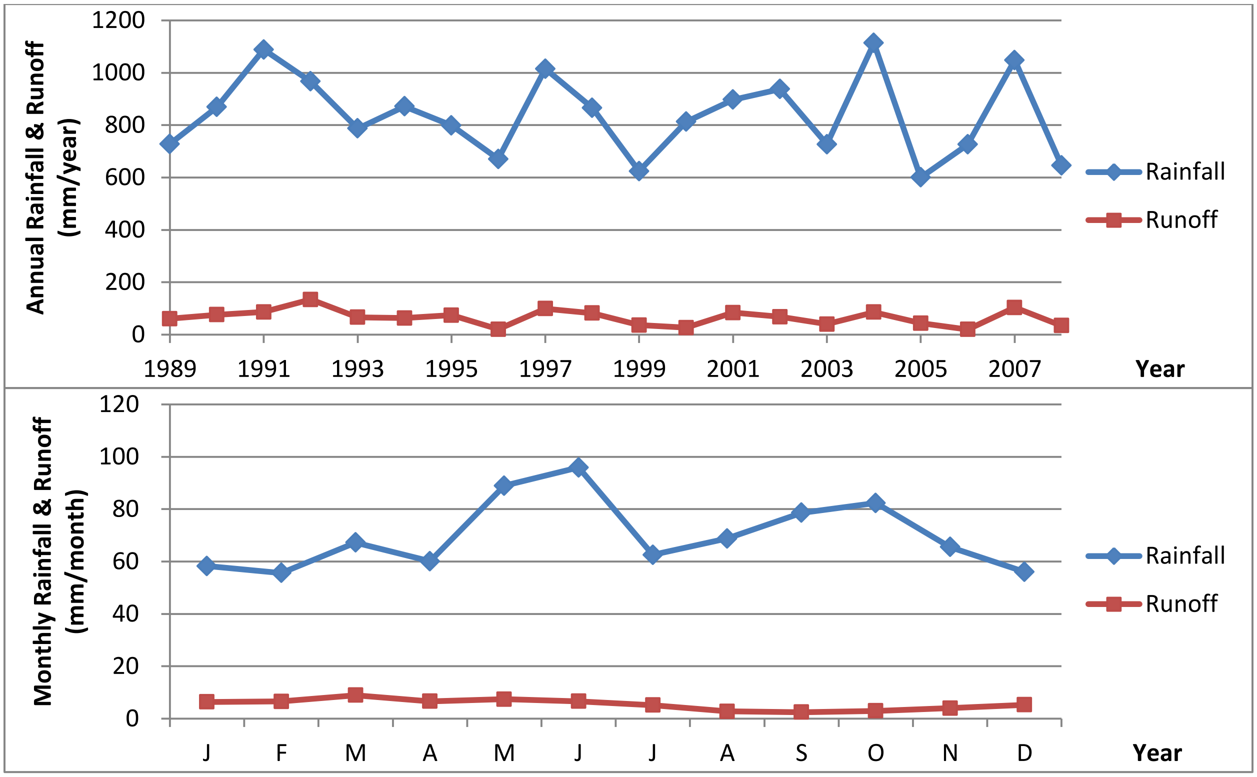

Figure 15.2. Annual and monthly rainfall and runoff of Region 12—Texas–Gulf.

Table 15.2. Summary of Potential New Hydropower Resources in Region 12—Texas–Gulf (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/reach)	Average residence Time (days)
1201	Sabine	10	33.4	151,158	12.2	5,185	16,310	3.8
1202	Neches	15	33.7	157,166	14.5	2,391	21,587	8.6
1203	Trinity	20	88.6	421,400	16.8	4,591	17,449	5.4
1204	Galveston Bay–San Jacinto	-	-	-	-	-	-	-
1205	Brazos headwaters	-	-	-	-	-	-	-
1206	Middle Brazos	3	3.9	18,606	30.6	586	10,876	2.7
1207	Lower Brazos	23	126.2	569,401	41.7	3,052	116,691	63.7
1208	Upper Colorado	-	-	-	-	-	-	-
1209	Lower Colorado–San Bernard Coastal	17	40.3	211,478	28.6	1,210	14,184	2.5
1210	Central Texas Coastal	29	69.3	387,527	34.7	1,059	20,008	9.5
1211	Nueces–Southwestern Texas Coastal	-	-	-	-	-	-	-

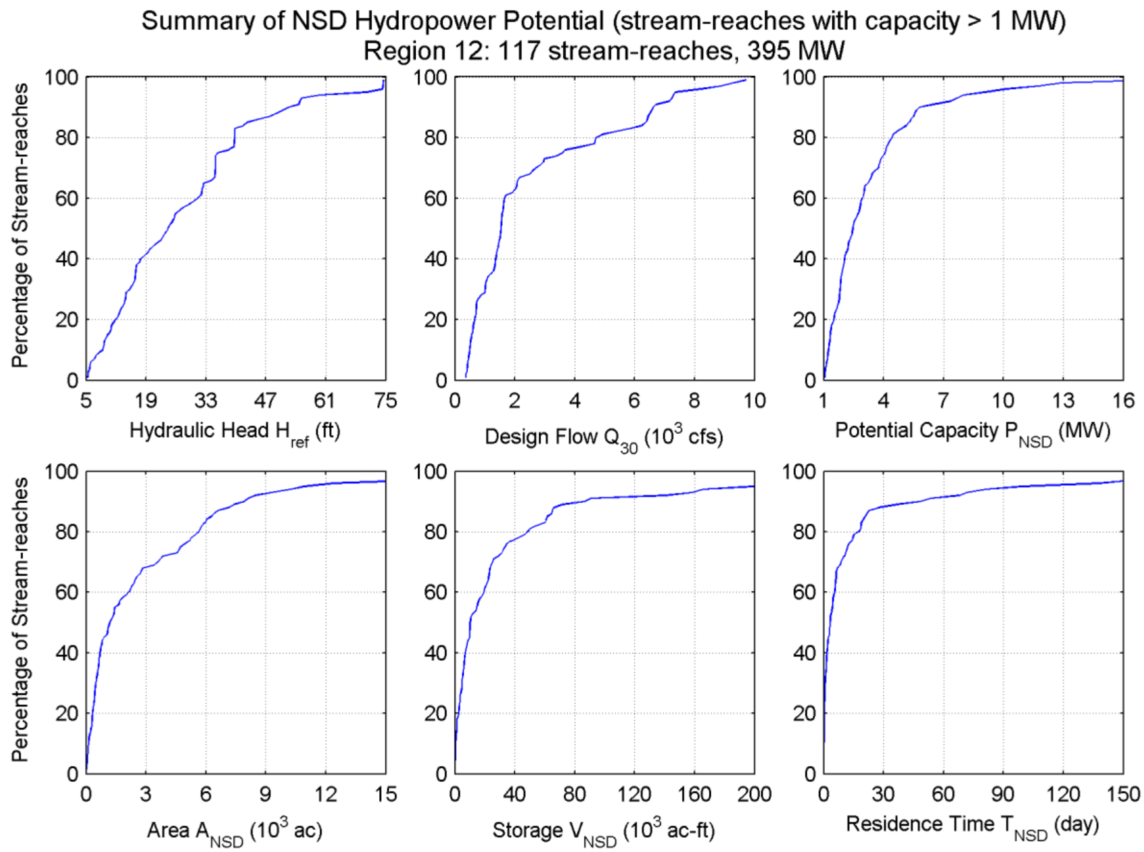

Figure 15.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 12—Texas-Gulf.

15.4. Environmental Characteristics

The Texas–Gulf Region includes 133 native fish species, 9 of which are species of concern. Of the five fish species falling under ESA categories, two species—Clear Creek gambusia (*Gambusia heterochir*) and fountain darter (*Etheostoma fonticola*)—are listed as endangered. An additional four species, including paddlefish, fall under IUCN vulnerability categories. Five species are considered potadromous or anadromous in the region. Twenty subbasins are considered critical watersheds, and the Middle Sabine and San Saba sub-basins have six fish and mussel species at risk (Mathews et al., 1998). Twenty-two species have critical habitat designations, including two fish species—San Marcos gambusia (*Gambusia georgei*) and fountain darter (Figure 15.5).

In Region 12, protected lands comprise almost 4.2 million acres, only 3.6% of the total area. Federal (65%), state (33%), and NGO (2%) lands make up the largest proportion of protected areas. The dominant federal entities include the USFS (29%), DOD (19%), FWS (10%), NPS (5%), and Bureau of Outdoor Recreation (1%). Among the largest tracts of USFS lands in the region are the Sabine, Davy Crockett, Angelina, and Sam Houston national forests and the Lyndon B. Johnson National Grassland. Other large tracts include Fort Hood Military Base, Padre Island National Seashore, and Aransas National Wildlife Refuge. State trust lands make up the vast majority of state-owned lands in the region. GAP status 4, 3, and 2 lands make up 37%, 34%, and 23% of protected areas, respectively. There are no National Wild and Scenic Rivers in Region 12. Recreation, which is not as prevalent as in other regions, includes 501 boat ramps, 150 fishing access locations, 23 waterfalls, and 112 recreational boating river sections.

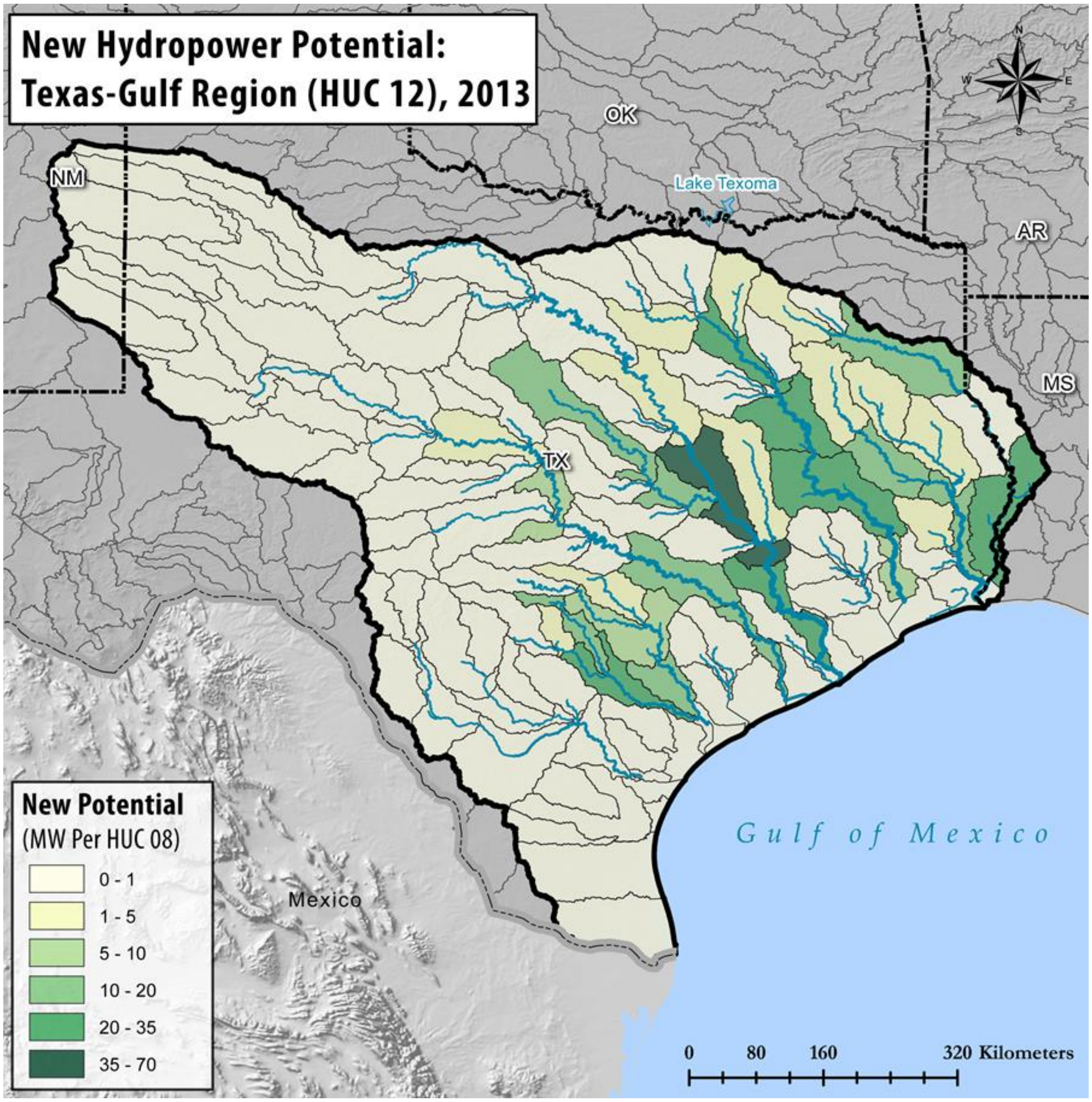

Figure 15.4. Potential new hydropower capacity in Region 12—Texas–Gulf (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC08 subbasins for illustration).

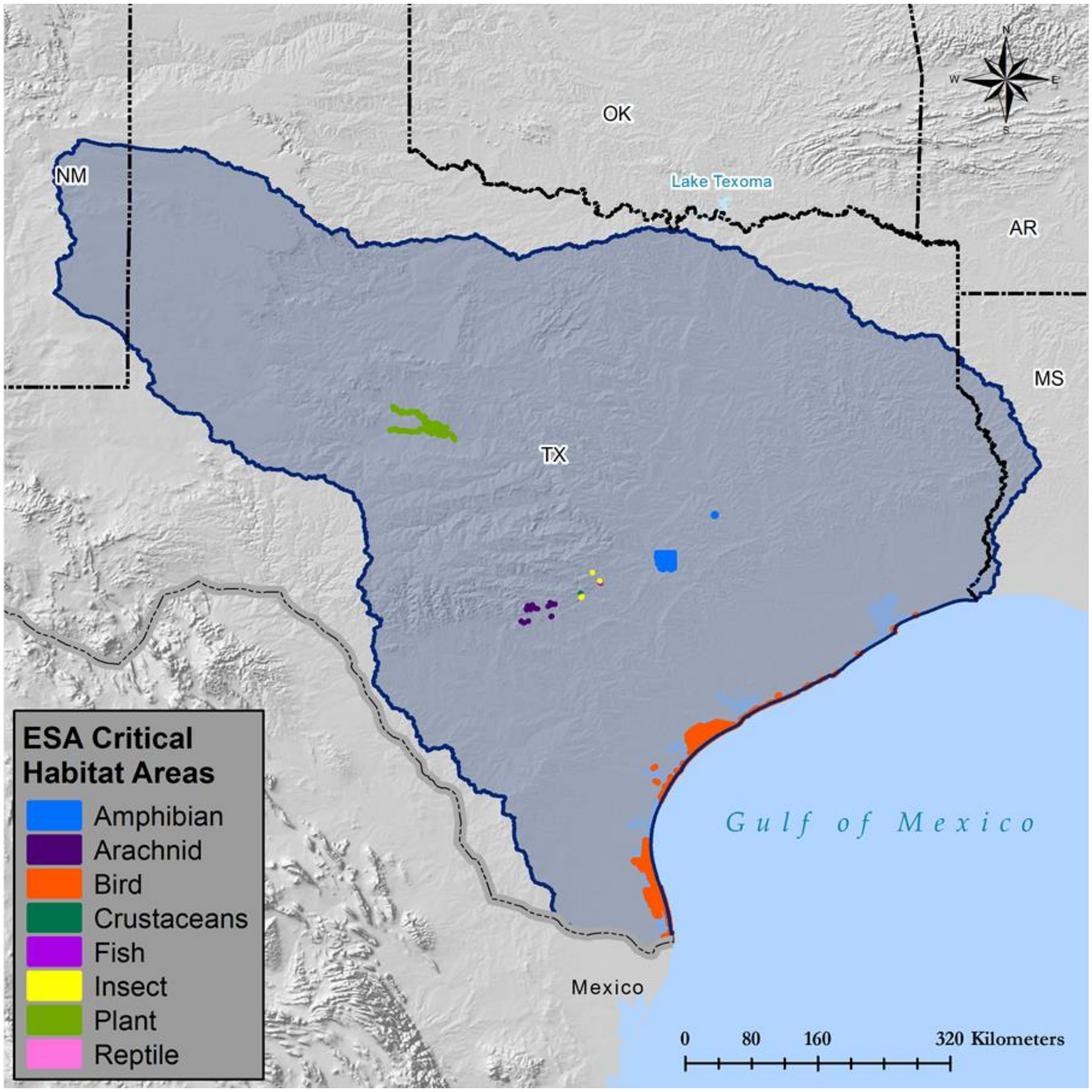

Figure 15.5. Critical habitats for federally endangered and threatened species in Region 12.

Water use is average in Region 12, with most of the usage for thermoelectric cooling, irrigation, or public consumption (Figure 15.6 and Appendix B). More water usage is reported in the eastern region, with the Galveston Bay–San Jacinto Subbasin having the highest values (Table 15.3). Water quality concerns are average in Region 12, with most concerns related to dissolved oxygen, mercury contamination, or elevated pathogen levels.

Only three stream-reaches (8 MW) intersect critical habitats (Figure 15.7). Almost 18% of stream-reaches (104 MW) are located within HUC08 subbasins containing one fish falling under ESA categories. Over 32% of stream-reaches intersect protected lands, with none at national parks. Roughly half (51%) of stream-reaches intersect water quality concerns. Recreational boating is uncommon, only overlapped with nine reaches. Boat ramps are identified at 18% of reaches, but fishing access areas are absent from reaches. Approximately one-third of potential capacity was associated with stream-reaches located within HUC08 subbasins with high or very high water usage.

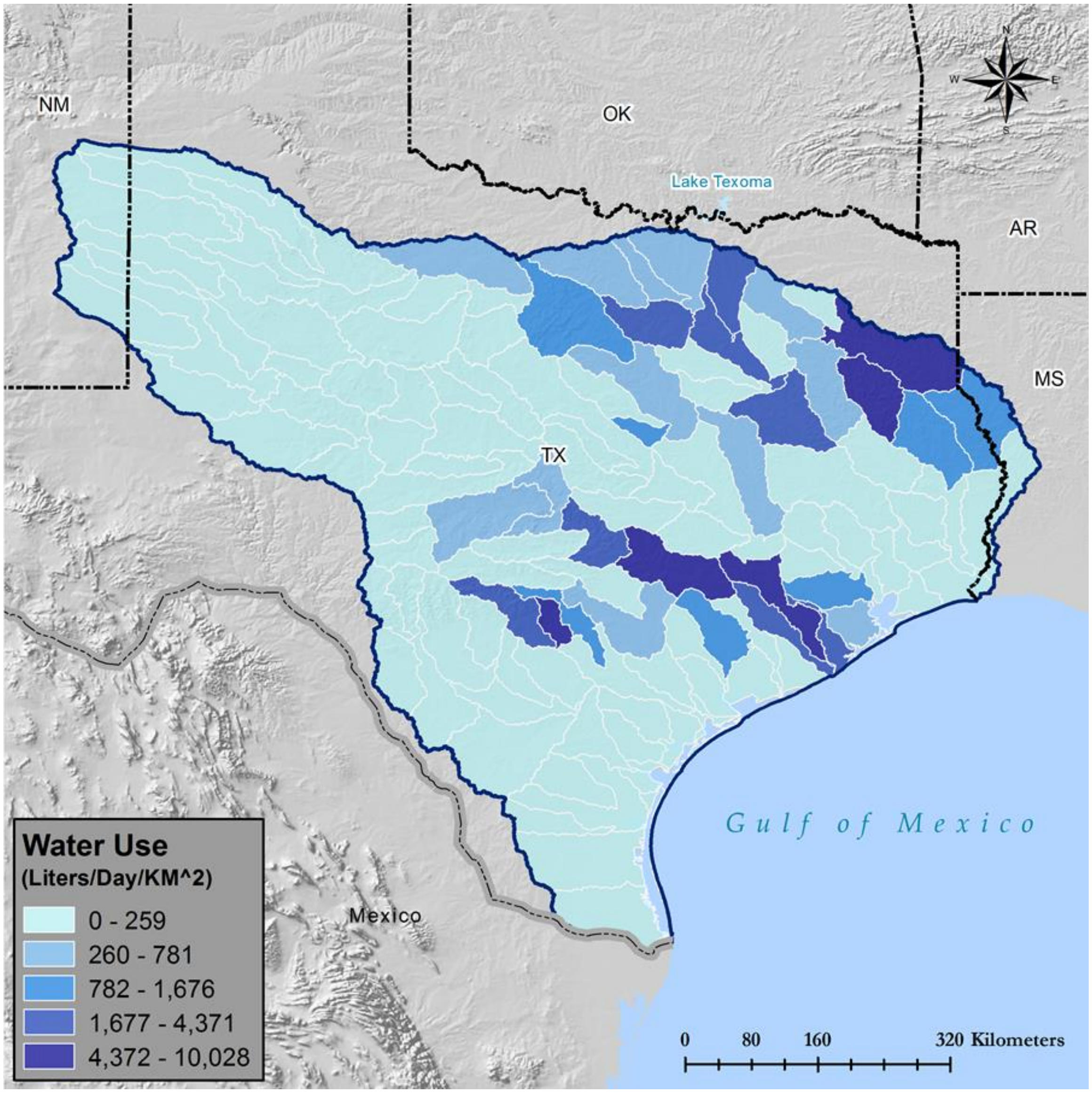

Figure 15.6. Average water use per HUC08 subbasin in Region 12.

Table 15.3. Summary of Environmental Variables at HUC04 Subregions within Region 12 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# Critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	# Recreation locations[a]	% Protected lands	Population density (ind/km^2)	Freshwater use (liters/day/km^2)
1201	Sabine	0	5	0	2	57; 7; 0	9.35	25.70	2,150.72
1202	Neches	0	5	0	2	77; 1; 0	14.52	23.88	2,341.71
1203	Trinity	0	2	0	0	152; 14; 3	2.92	128.41	2,707.82
1204	Galveston Bay–San Jacinto	2	5	1	1	55; 0; 0	7.92	234.47	3,519.64
1205	Brazos Headwaters	0	0	2	1	3; 4; 3	2.24	13.89	2,436.98
1206	Middle Brazos	0	2	2	1	74; 11; 2	0.69	16.86	653.82
1207	Lower Brazos	2	3	2	2	65; 15; 3	2.85	34.48	1,361.90
1208	Upper Colorado	0	0	0	0	14; 0; 0	6.04	9.05	643.17
1209	Lower Colorado–San Bernard Coastal	5	3	2	2	71; 34; 6	0.95	21.35	1,259.56
1210	Central Texas Coastal	19	3	1	4	78; 18; 6	2.01	56.69	1,372.05
1211	Nueces–Southwestern Texas Coastal	2	2	0	1	30; 8; 0	1.34	27.83	617.98

[a]Recreation locations refer to the number of boat-ramp and fishing access points, recreational boating, and waterfalls within each HUC04.

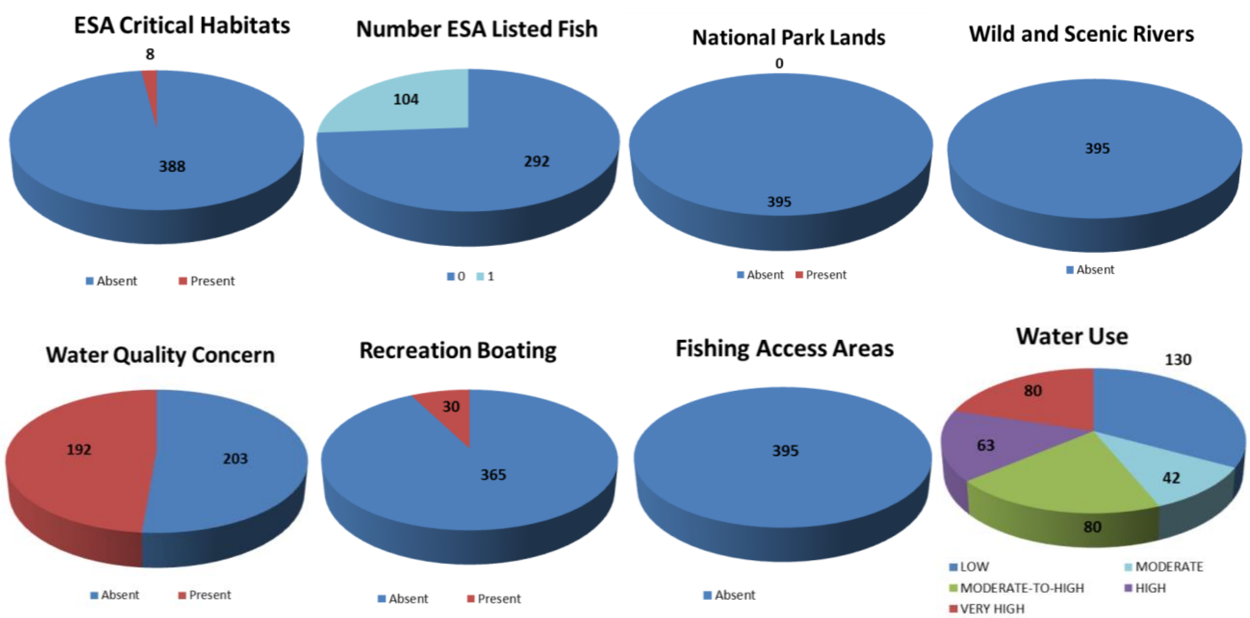

Figure 15.7. The potential capacity, in MW, associated with environmental attributes in Region 12—Texas-Gulf (stream-reaches with potential capacity >1 MW).

16. REGION 13—RIO GRANDE

16.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation, and mean capacity factors in the Rio Grande Region are estimated and summarized in Table 16.1 for both larger (>1 MW) and smaller (<1 MW) stream-reaches. For comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation, and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 1.64 GW, around 1030% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 9.31 TWh/year, around 2984% of annual net generation from existing conventional hydropower plants. The largest ratios of potential NSD resources to existing hydropower development mainly should be because of the relatively lower hydropower development in this region. The Rio Grande Region is one of the driest in this country, and hydropower may not be a prioritized usage for its limited fresh water resource. Given the run-of-river assumption, NSD stream-reaches have higher capacity factors, especially compared with other larger-storage peaking-operation projects in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 16.3 and 16.4.

Table 16.1. Summary of NSD Findings in Region 13—Rio Grande

	Capacity (MW)	Generation (MWh)	Mean capacity factor
Potential in undeveloped stream-reaches (>1 MW)	1,336	7,705,000	66%
Potential in undeveloped stream-reaches (<1 MW)	301	1,605,000	61%
Existing hydropower—conventional hydro	159	312,000	22%
Existing hydropower—pumped storage	0		

16.2. Background Hydrologic Setting

The Rio Grande Region encompasses approximately 343,023 km^2 of drainage area in the lower mid-southwestern section of the United States and contains parts of Texas, New Mexico, and Colorado.

Several river systems are located in the Rio Grande Region (Figure 16.1), including the Rio Grande, Jornada Draw, Mimbres, Devils, Pecos, and Delaware rivers, with a total length of 5762 km (i.e., total length of streams with estimated discharge greater than 35 cfs). Metropolitan areas within the region include Albuquerque (NM) and Las Cruces (NM). As shown in Figure 16.2, annual precipitation for the Rio Grande region ranges from 270 to 1600 mm/year, and annual runoff ranges from 200 to 700 mm/year. The main precipitation falls in early spring and summer.

The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are also shown in Figure 16.1. The region contains 8 hydropower dams and 10 major non-powered dams, with total storage capacities of around 15,570,696 ac-ft and 2,918,093 ac-ft, respectively.

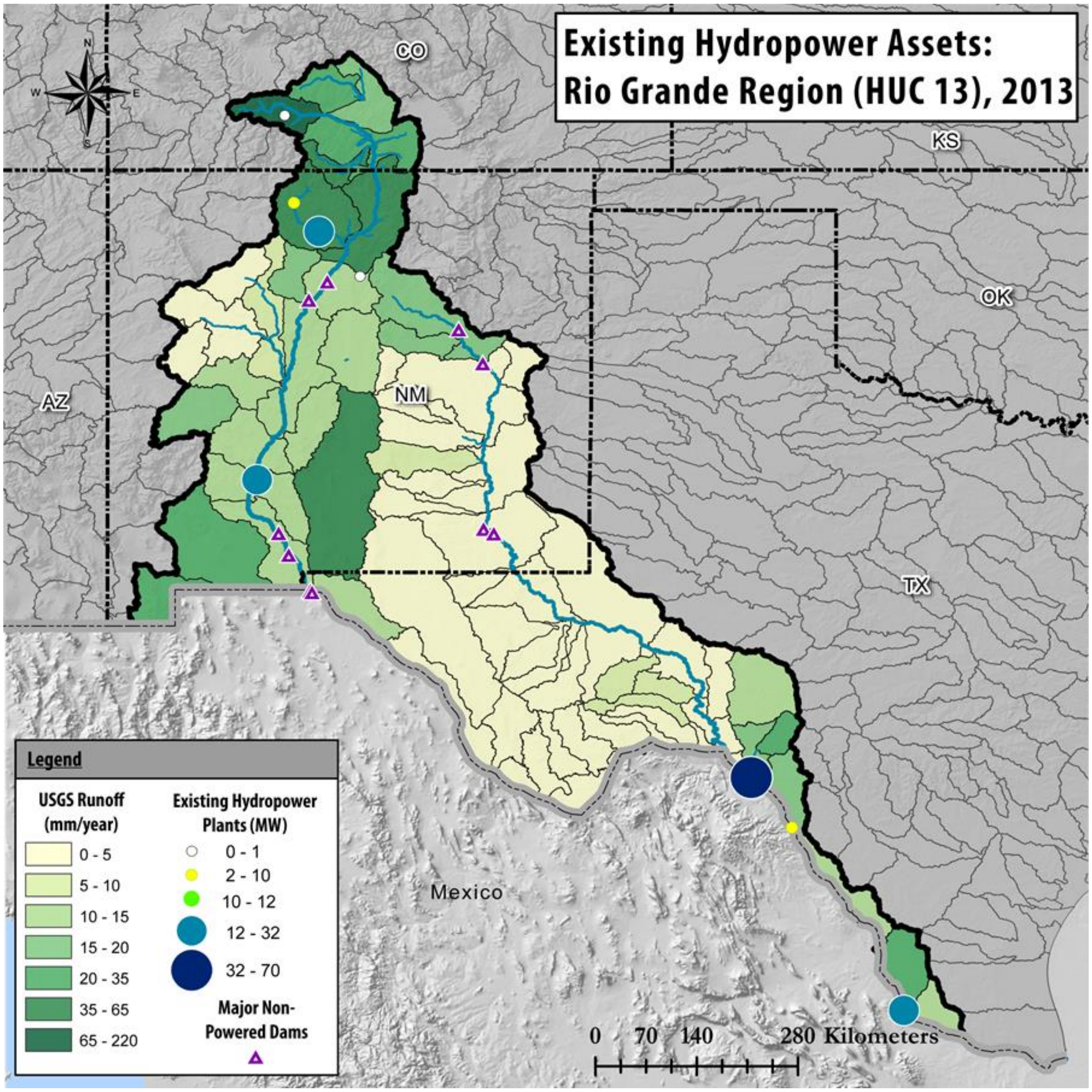

Figure 16.1. Locations of water control projects in Region 13—Rio Grande.

16.3. Potential New Hydropower Resources

A total of 267 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) are identified in the Rio Grande Region. The NSD results based on the HUC04 subregions are summarized in Table 16.2. The highest hydropower potentials are found in the Rio Grande—Elephant Butte Subregion (HUC 1302) located on the Rio Grande River. The second highest potential is located in the Rio Grande—Amistad Subregion (HUC 1304) also located on the Rio Grande River.

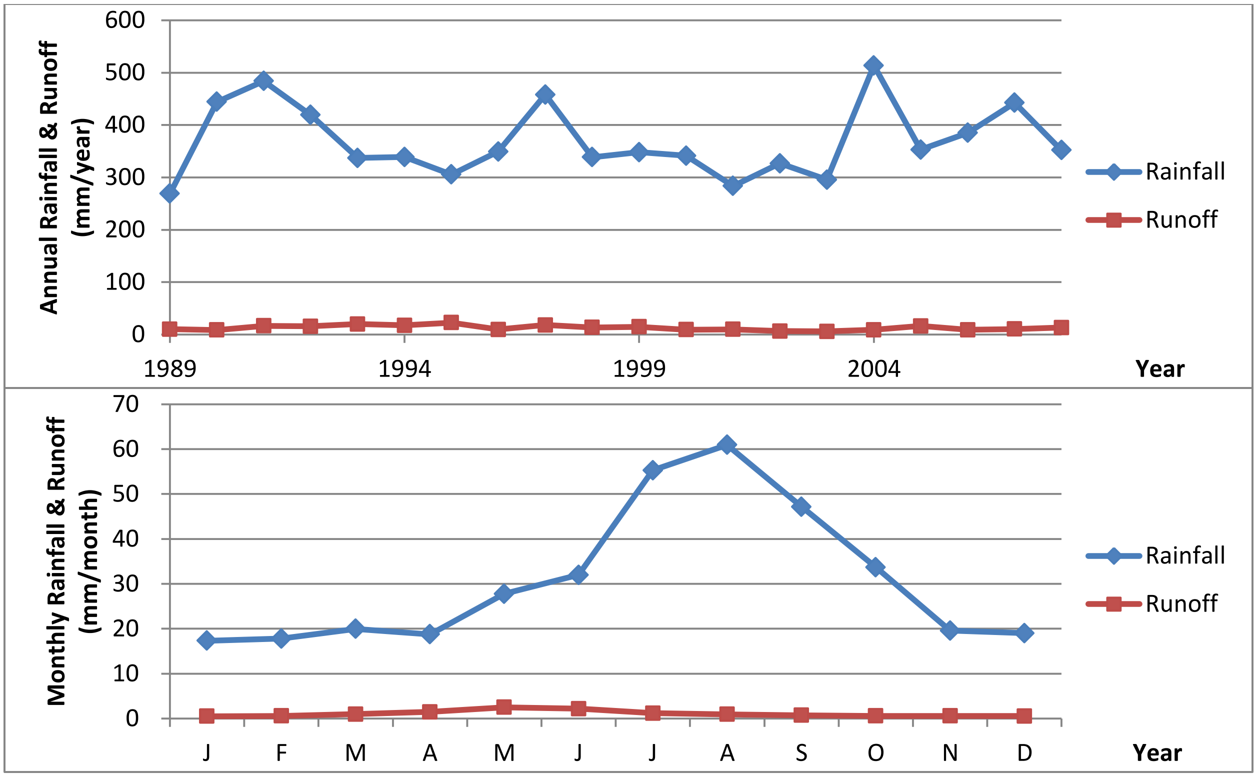

Figure 16.2. Annual and monthly rainfall and runoff of Region 13—Rio Grande.

Table 16.2. Summary of Potential New Hydropower Resources in Region 13—Rio Grande (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/reach)	Average residence time (days)
1301	Rio Grande headwaters	48	88.4	474,255	14.6	1,762	3,026	1.0
1302	Rio Grande–Elephant Butte	137	747.7	4,303,001	18.8	4,031	6,608	0.8
1303	Rio Grande–Mimbres	17	42.2	244,629	21.9	1,573	28,078	3.0
1304	Rio Grande–Amistad	42	324.7	1,905,382	53.9	1,976	162,904	15.6
1305	Rio Grande closed basins	-	-	-	-	-	-	-
1306	Upper Pecos	-	-	-	-	-	-	-
1307	Lower Pecos	-	-	-	-	-	-	-
1308	Rio Grande–Falcon	20	117.3	688,849	27.1	3,000	24,448	1.4
1309	Lower Rio Grande	3	15.8	88,945	17.9	4,196	130,797	5.1

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 in Figure 16.3. The hydraulic head H_{ref} ranges from 5 to the 90th quantile of 47 ft with a median of 22 ft. The design flow Q_{30} ranges from 1100 to the 90th quantile of 4700 cfs with a median of about 3200 cfs. The potential capacity P_{NSD} ranges from 1 to the 90th quantile of 9 MW with a median of about 5 MW. The inundated surface area A_{NSD} ranges from 0 to the 90th quantile of 4500 acres with a median of 500 acres. This results in storage values V_{NSD} ranging from 0 to the

90th quantile of 85,000 ac-ft with a median of 6,000 ac-ft with residence times T_{NSD} ranging from <1 day to the 90th quantile of about a week with a median of less than a day. The results of > 1 MW stream-reach potential are illustrated in Figure 16.4, with potential capacity (MW) aggregated to the HUC08 subbasins.

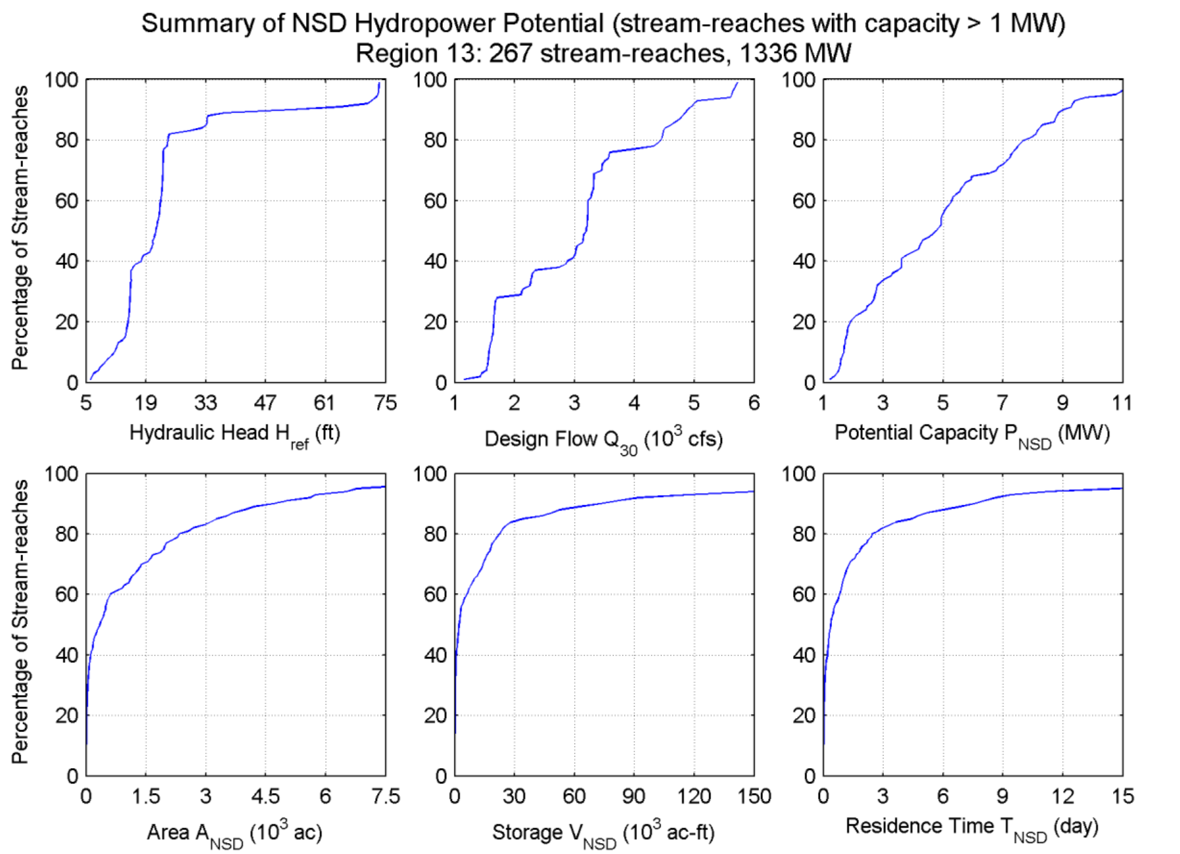

Figure 16.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 13—Rio Grande.

16.4. Environmental Characteristics

The number of fishes of concern in the Rio Grande Region is remarkable (Figure 16.5), given that only 79 native fish species inhabit the entire region, one of the smallest areas in the United States. Almost 14% (11) of fish species fall under ESA categories, and almost 18% (14) fall under IUCN vulnerability categories (Figure 16.5). Natural spring-fed pools in the arid region are unique habitats for many endemic small fishes, including the endangered Big Bend gambusia (*Gambusia gaigei*), Pecos gambusia (*Gambusia nobilis*), Commanche springs pupfish (*Cyprinodon elegans*), and Leon springs pupfish (*Cyprinodon bovinus*). Other endangered species in the region include Rio Grande silvery minnow (*Hybognathus amarus*) and speckled dace (*Rhinichthys osculus*, population endangered). Threatened species include Chihuahua chub (*Gila nigrescens*), Devils River minnow (*Dionda diabolic*), and Apache Trout (*Oncorhynchus* *gilae*). Three fish species are considered potadromous or anadromous in the region. Nineteen of the 70 subbasins in the region are classified as critical watersheds. Twelve species have critical habitat designations; these include Devils River minnow, Leon Springs pupfish, Pecos bluntnose shiner (*Notropis simus peconsensis*), and Rio Grande Silvery minnow (Figure 16.6).

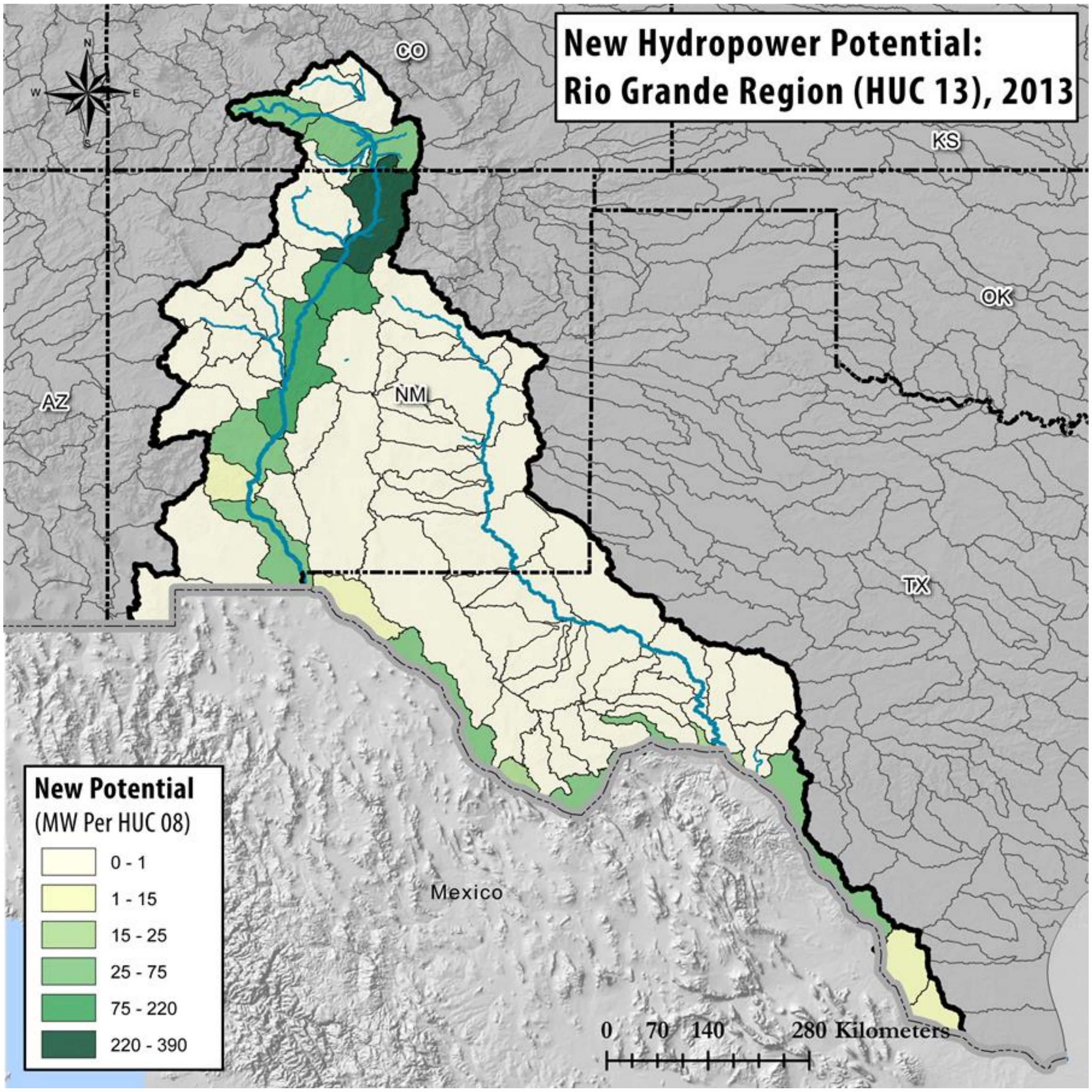

Figure 16.4. Potential new hydropower capacity in Region 13—Rio Grande (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC08 subbasins for illustration).

Almost 34 million acres of land (40% of the total area) are protected in Region 13. Most of the protected lands are federally owned (70%), followed by state (19%) and Native American (9%) owned lands. The dominant federal agencies in the region are BLM (31% of protected lands), USFS (23%), DOD (9%), NPS (4%), and USFWS (1%). The largest tracts in the region include BLM public lands, state trust lands, White Sands Missile Range, Fort Bliss, and several national forests, including Rio Grande, Cibola, Santa Fe, Carson, and Lincoln. National parks in the region include Big Bend, Great Sand Dunes, Guadalupe Mountains, and Carlsbad Caverns. The

Rio Grande, Rio Chama, Pecos, and East Fork Jemez National Wild and Scenic Rivers are located in Region 13. Far fewer recreation areas are found in Region 13 compared with other regions. The region includes 481 boat ramps, 56 fishing access locations, 20 waterfalls, and 49 recreational boating river sections.

Water use in Region 13 is well below the national average, most likely because of the arid climate. The highest water use is irrigation, occurring in the headwaters of the Rio Grande (Table 16.3). Water-quality concerns are low in the region, with most occurring as mercury contamination, low dissolved oxygen, or elevated toxin levels (Appendix B).

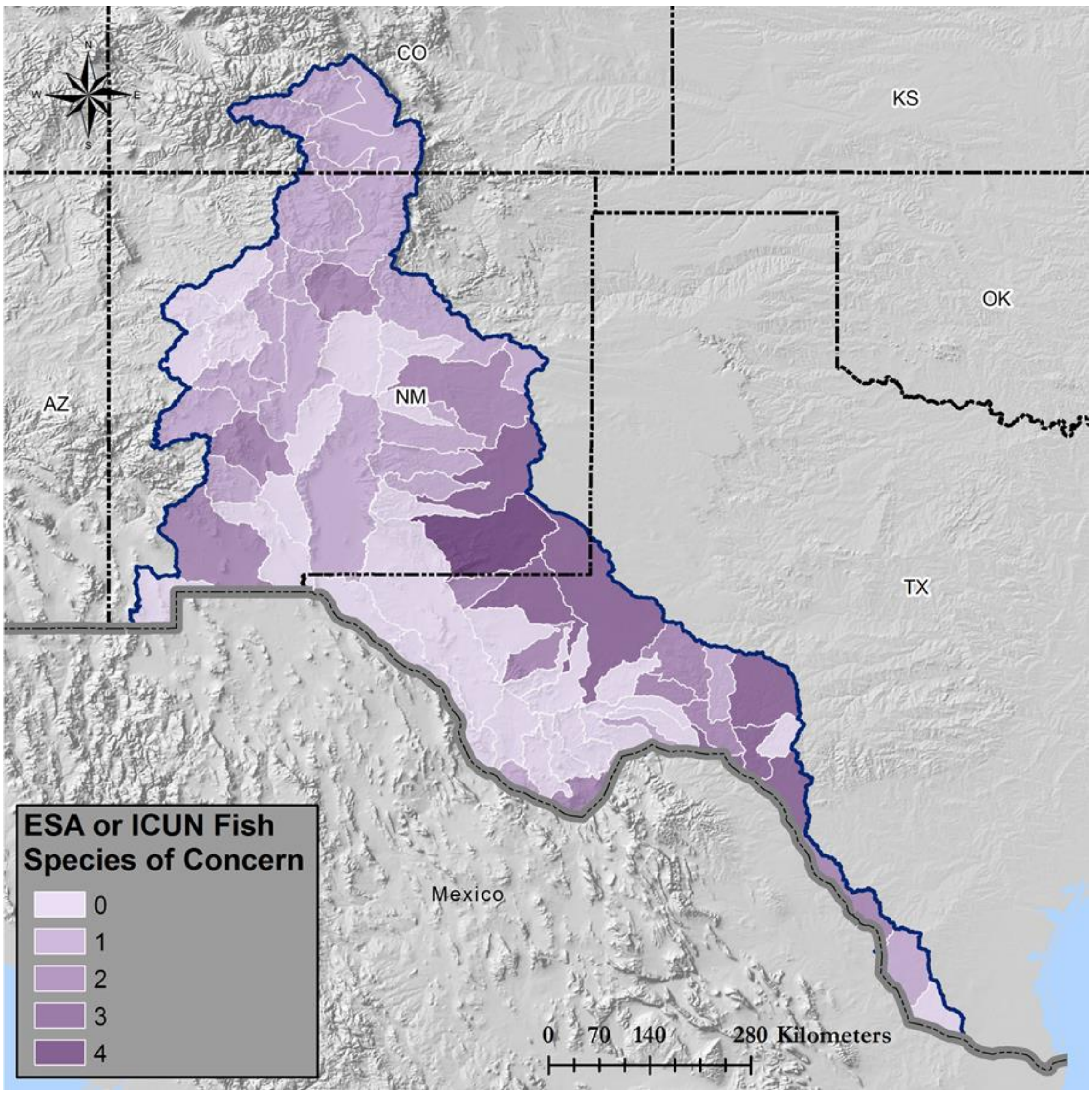

Figure 16.5. Fish species of concern (number per HUC08 subbasin) in Region 13.

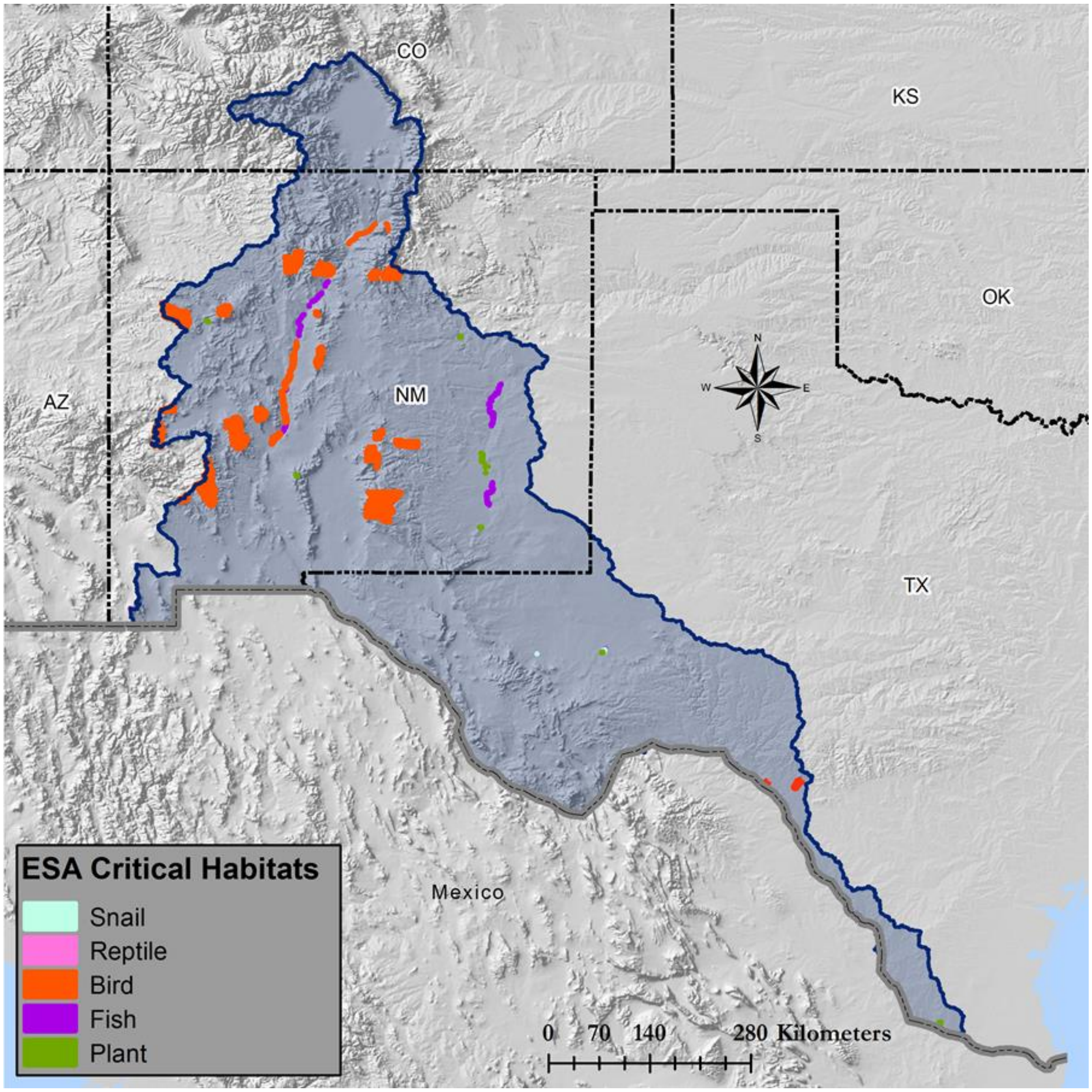

Figure 16.6. Critical habitats for federally endangered or threatened species in Region 13.

Critical habitat designations overlapped with 32% of the 267 stream-reaches (Figure 16.7). Seventy-two percent of stream-reaches (877 MW) are located within HUC08 subbasins, with one to two fish falling under an ESA category. Almost 87% of stream-reaches overlap with protected lands (1122 MW), with 13 stream-reaches (4.8%) falling on national parks and 68 stream-reaches (25%) on WSRs. Water quality concerns are associated with almost 81% of stream-reaches. Recreational boating, boat ramps, and fishing access areas are identified at 43%, 1.5%, and 16% of stream-reaches, respectively. Water use is relatively evenly distributed among stream-reaches.

Table 16.3. Summary of Environmental Variables at HUC04 Subregions within Region 13 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# Critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	# Recreation locations[a]	% Protected lands	Population density (ind/km^2)	Freshwater use (liters/day/km^2)
1301	Rio Grande Headwaters	0	1	1	0	28; 8; 5	59.44	2.23	3,412.16
1302	Rio Grande–Elephant Butte	6	2	3	1	30; 23; 8	52.53	10.88	358.22
1303	Rio Grande–Mimbres	2	2	3	2	4; 0; 0	72.30	6.79	700.69
1304	Rio Grande–Amistad	0	2	2	5	13; 15; 4	12.61	8.81	171.36
1305	Rio Grande Closed Basins	2	0	0	1	0; 0; 0	44.91	6.47	265.84
1306	Upper Pecos	4	2	3	4	18; 2; 3	43.03	2.66	330.88
1307	Lower Pecos	3	1	3	7	4; 2; 0	5.52	1.63	140.76
1308	Rio Grande–Falcon	1	1	1	4	6; 0; 0	0.32	10.92	241.93
1309	Lower Rio Grande	2	1	0	0	1; 0; 0	4.51	83.35	1,709.69

[a]Recreation locations refer to the number of boat-ramp and fishing access points, recreational boating, and waterfalls within each HUC04.

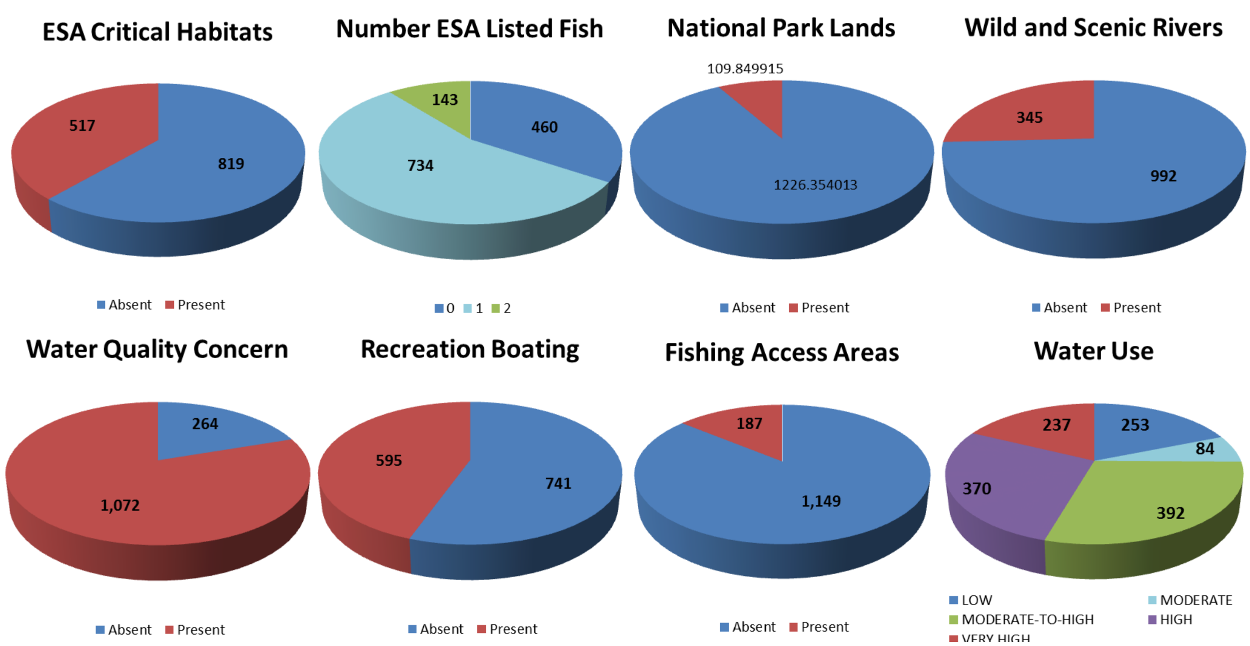

Figure 16.7. The potential capacity, in MW, associated with environmental attributes in Region 13—Rio Grande (stream-reaches with potential capacity >1 MW).

17. REGION 14—UPPER COLORADO

17.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation, and mean capacity factors in the Upper Colorado Region are estimated and summarized in Table 17.1 for both larger (>1 MW) and smaller (<1 MW) stream-reaches. For comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation, and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 3.03 GW, around 160% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 18.23 TWh/year, around 349% of annual net generation from existing conventional hydropower plants. Given the run-of-river assumption, NSD stream-reaches have higher capacity factors, especially compared with other larger-storage peaking-operation projects in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 17.3 and 17.4.

Table 17.1. Summary of NSD Findings in Region 14—Upper Colorado

	Capacity (MW)	Generation (MWh)	Mean capacity factor
Potential in undeveloped stream-reaches (>1 MW)	1,942	11,845,000	70%
Potential in undeveloped stream-reaches (<1 MW)	1,091	6,387,000	67%
Existing hydropower—conventional hydro	1,888	5,222,000	32%
Existing hydropower—pumped storage	0		

17.2. Background Hydrologic Setting

The Upper Colorado Region encompasses approximately 293,568 km^2 of drainage area in the lower west section of the United States and contains parts of Colorado, Utah, Arizona, New Mexico, and Wyoming.

Several river systems are located in the Upper Colorado Region (Figure 17.1), including the Colorado, Gunnison, Green, Yampa, White, San Juan, and Mancos rivers, with a total length of 14,111 km (i.e., total length of streams with estimated discharge greater than 35 cfs). Metropolitan areas within the region include Grand Junction (CO). As shown in Figure 17.2, annual precipitation for the Upper Colorado region ranges from 260 to 480 mm/year, and annual runoff ranges from 30 to 75 mm/year. Most of the precipitation occurs in the spring and fall.

The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are also shown in Figure 17.1. The regions contain 47 hydropower dams and 9 major non-powered dams, with total storage capacities of about 38,948,518 ac-ft and 985,929 ac-ft, respectively.

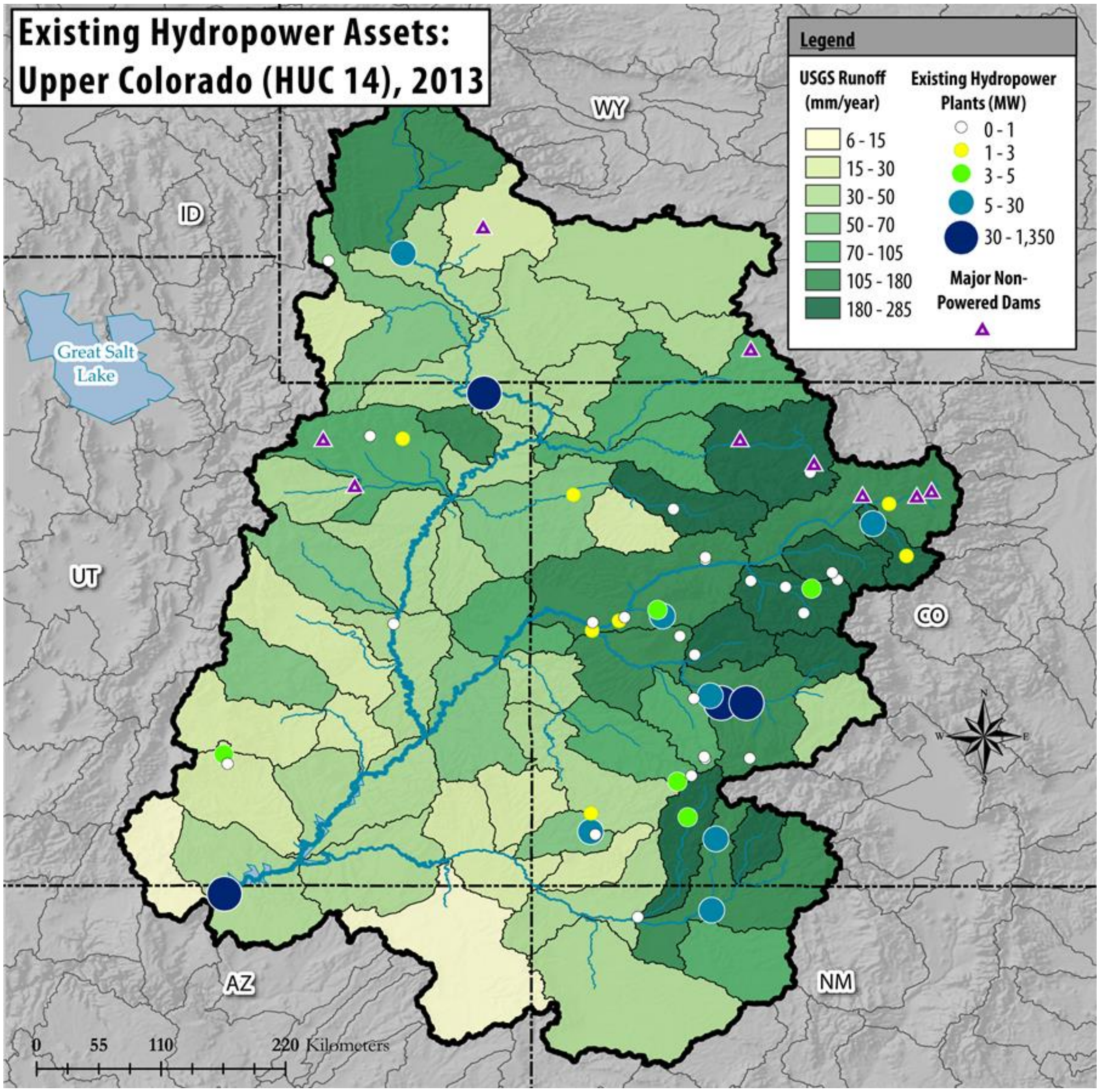

Figure 17.1. Locations of water control projects in Region 14—Upper Colorado.

17.3. Potential New Hydropower Resources

A total of 548 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) are identified in the Upper Colorado region. The NSD results based on the HUC04 subregions are summarized in Table 17.2. The highest hydropower potential is found in the Colorado Headwaters Subregion (HUC 1401) and Lower Green Subregion (HUC 1406) in the Colorado and Green rivers. The next significant hydropower potential is located in the San Juan Subregion (HUC 1408) and Gunnison Subregion (HUC 1402) in the San Juan and Gunnison rivers.

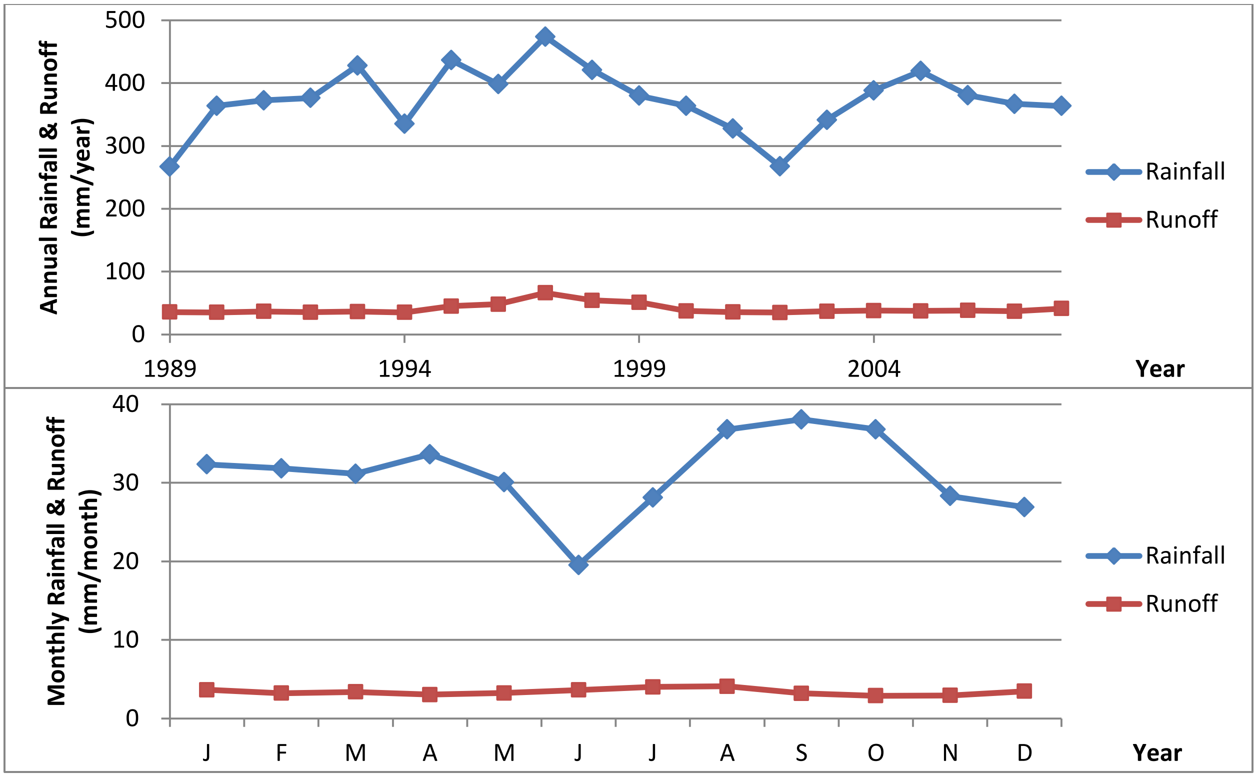

Figure 17.2. Annual and monthly rainfall and runoff of Region 14—Upper Colorado.

Table 17.2. Summary of Potential New Hydropower Resources in Region 14—Upper Colorado (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/reach)	Average residence time (days)
1401	Colorado headwaters	145	477.2	3,094,896	16.8	2,742	1,069	0.1
1402	Gunnison	73	245.8	1,521,138	23.6	2,169	881	0.1
1403	Upper Colorado–Dolores	10	187.3	1,197,535	42.5	6,143	24,262	1.0
1404	Great Divide–Upper Green	50	75.0	484,209	9.4	2,243	323	0.0
1405	White–Yampa	86	122.0	630,902	15.0	1,367	3,881	1.5
1406	Lower Green	53	396.0	2,275,176	21.1	4,882	6,679	0.3
1407	Upper Colorado–Dirty Devil	8	186.2	1,182,748	24.5	13,181	1,189	0.0
1408	San Juan	123	252.0	1,458,867	11.3	2,516	1,373	0.2

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 in Figure 17.3. The hydraulic head H_{ref} ranges from 0 to the 90th quantile of 25 ft with a median of 14 ft, suggesting that many of the potential stream-reaches will require low-head hydropower technologies. The design flow Q_{30} ranges from 1000 to the 90th quantile of 5500 cfs with a median of about 2100 cfs. The potential capacity P_{NSD} ranges from 1.75 to the 90th quantile of 7.5 MW with a median of about 2.5 MW. The inundated surface area A_{NSD} ranges from 0 to the 90th quantile of 500 acres with a median of 100 acres. This results in storage values V_{NSD}

ranging from 0 to the 90th quantile of 4000 ac-ft with a median of 800 ac-ft with residence times T_{NSD} ranging from a few hours to the 90th quantile of about 14 hours with a median on the order of a few hours. The results of > 1 MW stream-reach potential are illustrated in Figure 17.4, with potential capacity (MW) aggregated to the HUC08 subbasins.

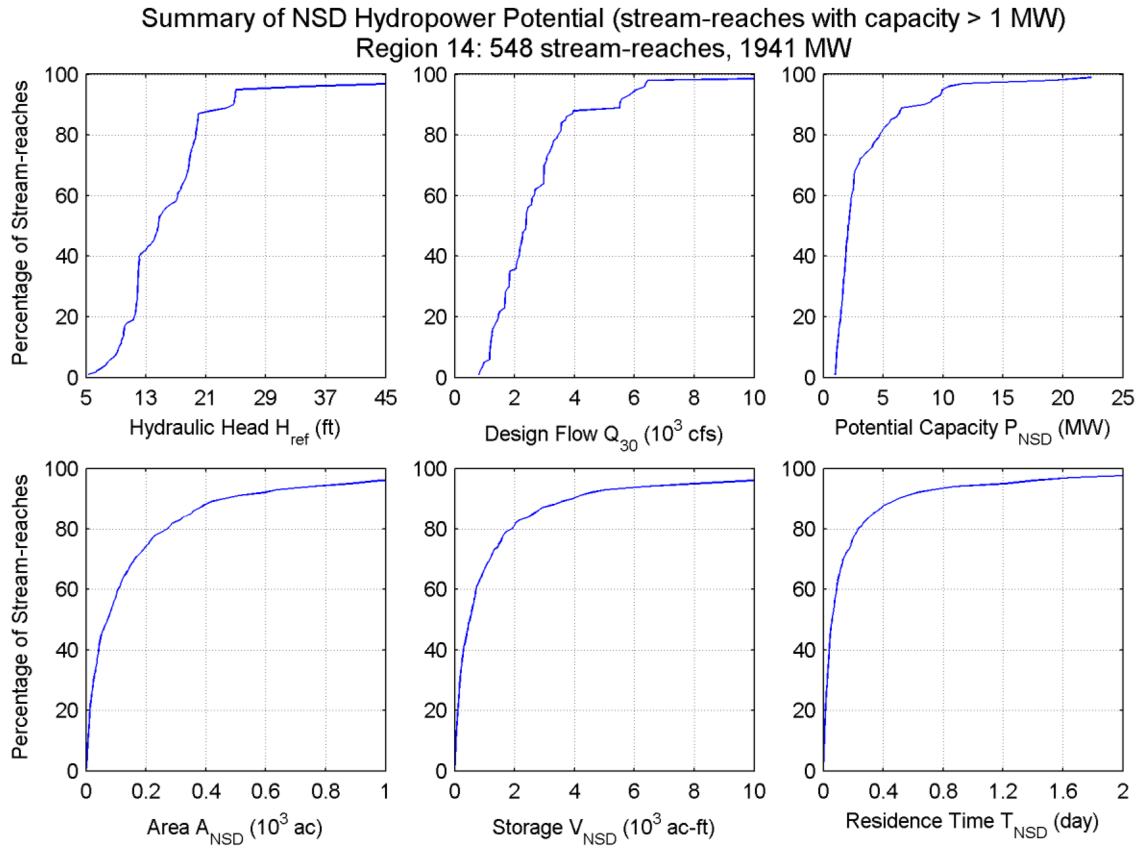

Figure 17.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 14—Upper Colorado.

17.4. Environmental Characteristics

Of the 17 native fish species in the Upper Colorado Region, 11 fall under ESA and 14 fall under IUCN vulnerability categories. Endangered fish species include Bonytail (*Gila elegans*), Colorado pikeminnow (*Ptychocheilus Lucius*), humpback chub (*Gila cypha*), and razorback sucker (*Xyrauchen texanus*), all of which have critical habitat designations. Species with populations falling under ESA categories include Cutthroat trout, speckled dace, and bluehead sucker (*Catostomus discobolus*). Cutthroat trout and associated sub-species are the only fish species classified as potadromous in the region. Nine critical watersheds are located in this region, including mainstem or tributaries of the Green, Yampa, Gunnison, and Upper Colorado River systems (Mathews et al., 1998). In total, nine species, including the four fish listed above, have critical habitat designations in the region (Figure 17.5).

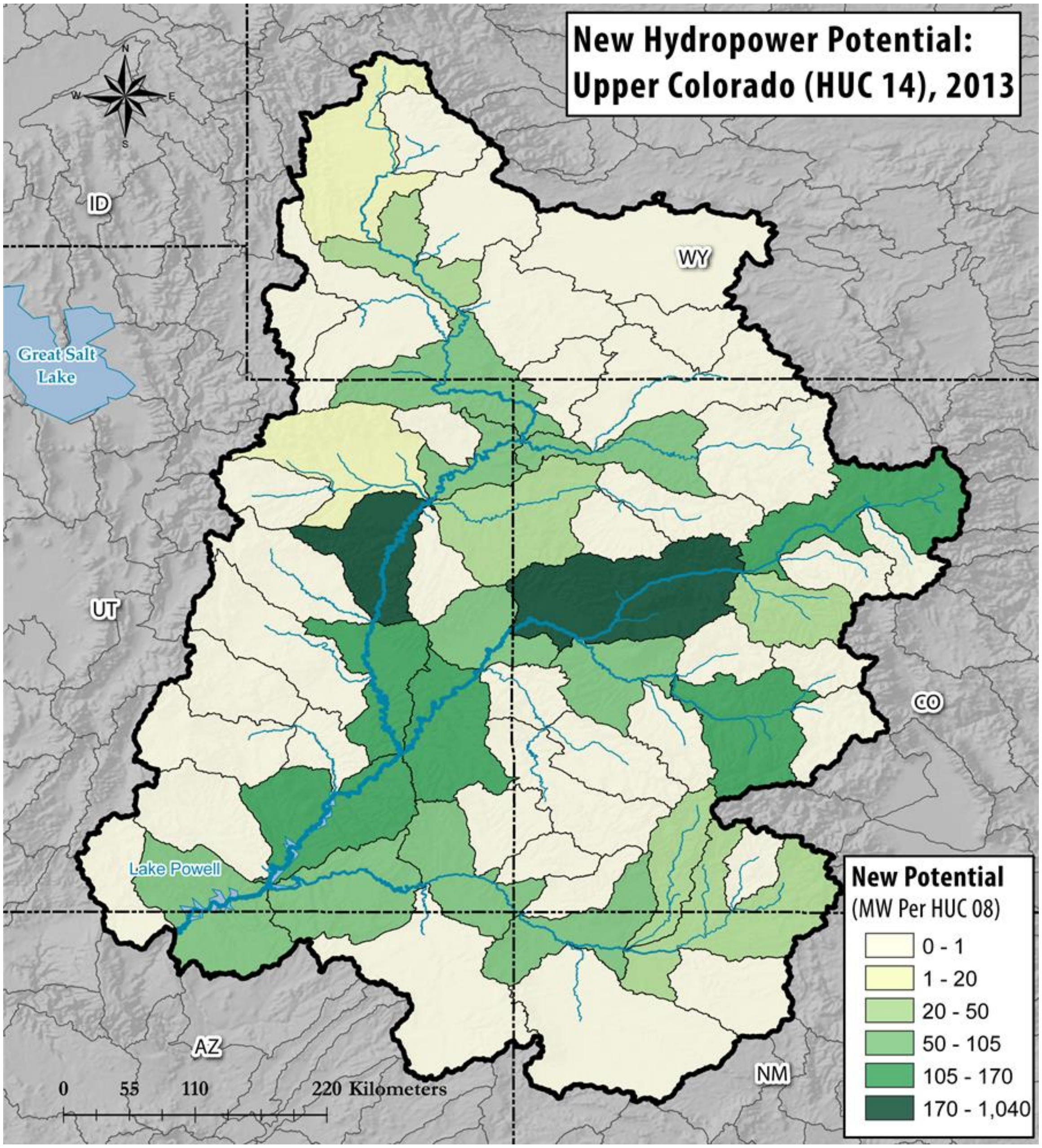

Figure 17.4. Potential new hydropower capacity in Region 14—Upper Colorado (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC08 subbasins for illustration).

Approximately 58 million acres of protected land (80% of the total area) are identified in Region 14 (Figure 17.6). Over 75% of protected lands are owned by federal entities, including BLM (31%), USFS (23%), DOD (9%), NPS (4%), and USFWS (1%). Native American lands, composed of many reservations, make up 19% of protected lands, followed by state-owned areas (6%), which are primarily composed of state trust lands. Besides BLM and state trust lands, the largest tracts include the Navajo Indian Reservation, Unitah and Ouray Indian Reservation, Glen Canyon National Recreation Area, and White River, San Juan, and Gunnison national forests. NPS lands include Canyonlands National Park, Rocky Mountain National Park, and Dinosaur National Monument. Region 14 has no rivers falling under NWSRA protection. Fewer boat ramps (113) are identified in Region 14 compared with other regions. However, other recreation types are common, including 226 fishing access locations, 52 waterfalls, and 172 recreational boating river sections.

The water usage of Region 14, primarily irrigation consumption, is slightly below the national average (Table 17.3 and Appendix B), with the highest values reported in the Gunnison Subregion. Overall, water quality concerns are very low relative to the remainder of the United States. Mercury contamination and low dissolved oxygen issues are the primary concerns (Appendix B).

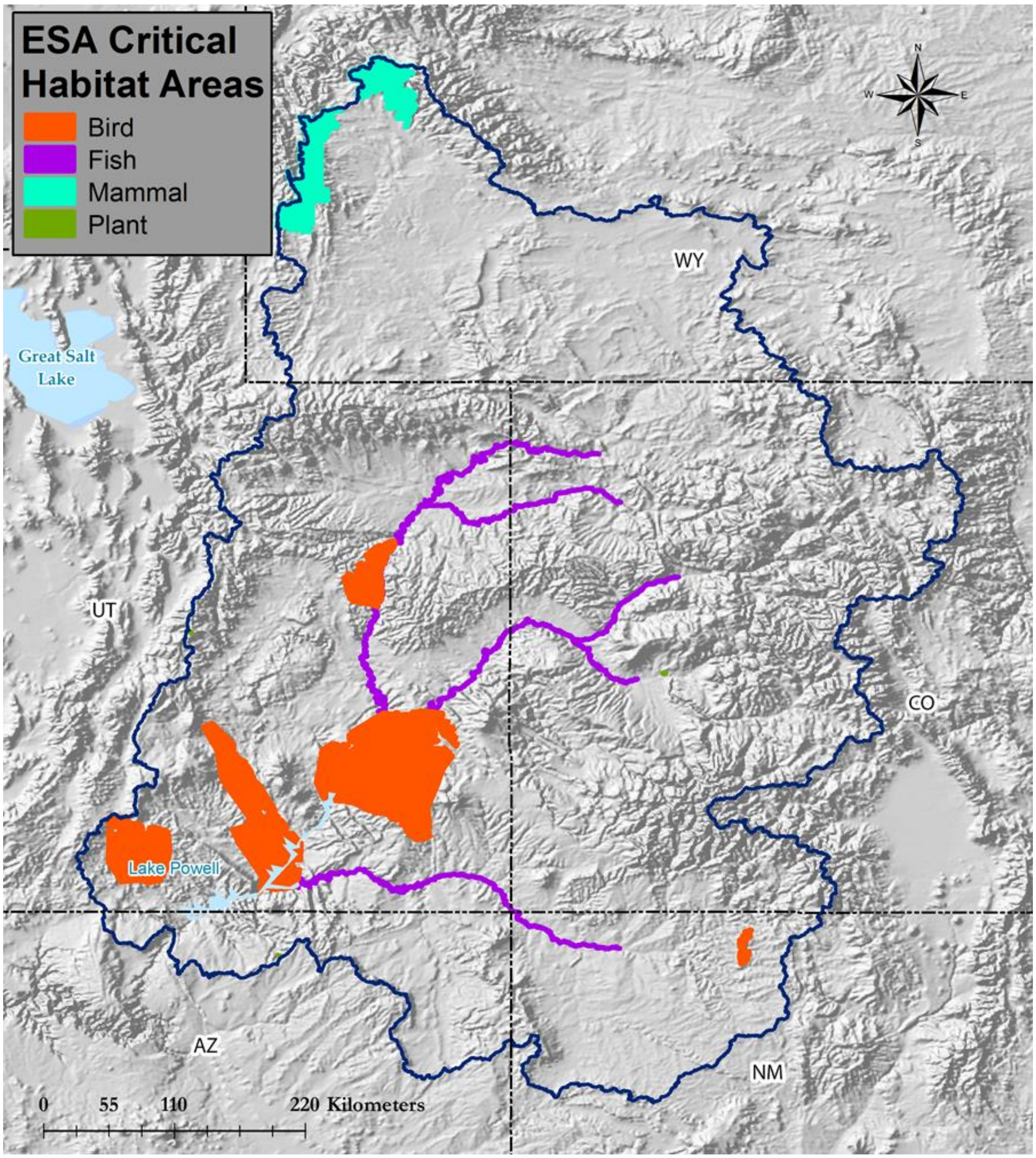

Figure 17.5. Critical habitats for federally endangered and threatened species in Region 14.

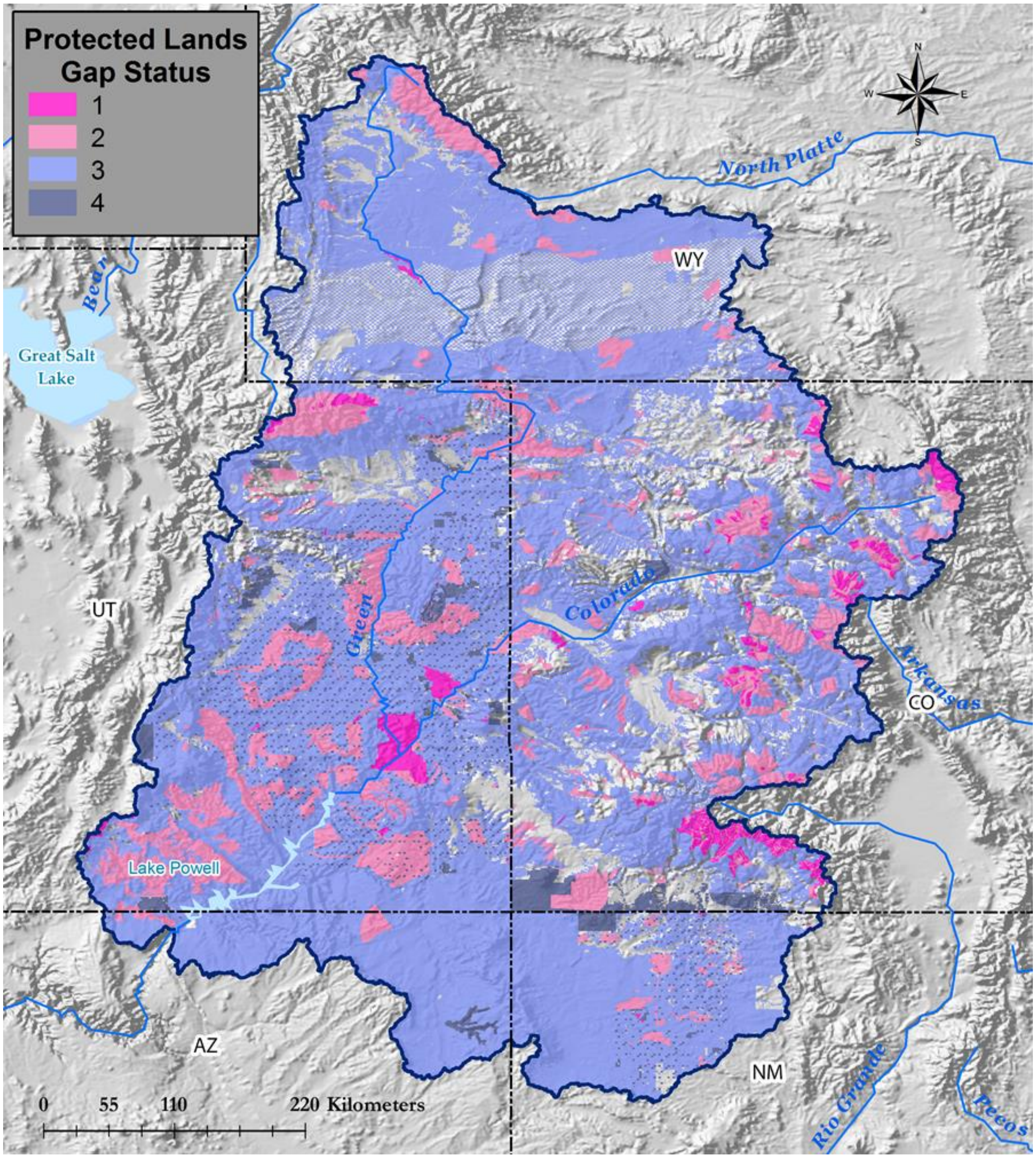

Figure 17.6. Protected lands according to Gap Status (conservation management regime) in Region 14.

Almost 67% of the 548 stream-reaches overlap with critical habitats (Figure 17.7). All stream-reaches are located within HUC08 subbasins with at least 1 fish falling under ESA categories. Similarly, all stream-reaches intersect protected lands, with 41 stream-reaches (402 MW) overlapped with national parks. Water-quality concerns are present at 50% of stream-reaches (>1.2 GW). Recreational boating is identified at 58% of stream-reaches; boat ramps and fishing access areas are present at 13% of stream-reaches with a total of 365 and 270 MW, respectively. Water usage is around uniform across stream-reaches, with 38% of reaches falling in the low to moderate categories.

Table 17.3. Summary of Environmental Variables at HUC04 Subregions within Region 14 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# Critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	# Recreation locations[a]	% Protected lands	Population density (ind/km²)	Freshwater use (liters/day/km²)
1401	Colorado Headwaters	4	1	6	3	47; 55; 12	71.10	8.58	1,866.29
1402	Gunnison	3	1	5	2	28; 23; 7	72.94	4.16	3,340.47
1403	Upper Colorado–Dolores	5	1	7	4	18; 16; 7	82.71	3.65	1,422.87
1404	Great Divide–Upper Green	5	1	5	2	77; 13; 13	73.40	1.47	431.49
1405	White–Yampa	4	1	6	3	20; 17; 3	67.91	1.48	846.68
1406	Lower Green	6	1	7	4	84; 24; 2	70.36	2.71	872.61
1407	Upper Colorado–Dirty Devil	7	1	6	3	25; 6; 2	87.21	0.90	327.39
1408	San Juan	3	1	5	2	40; 31; 6	31.08	4.08	833.26

[a]Recreation locations refer to the number of boat-ramp and fishing access points, recreational boating, and waterfalls within each HUC04.

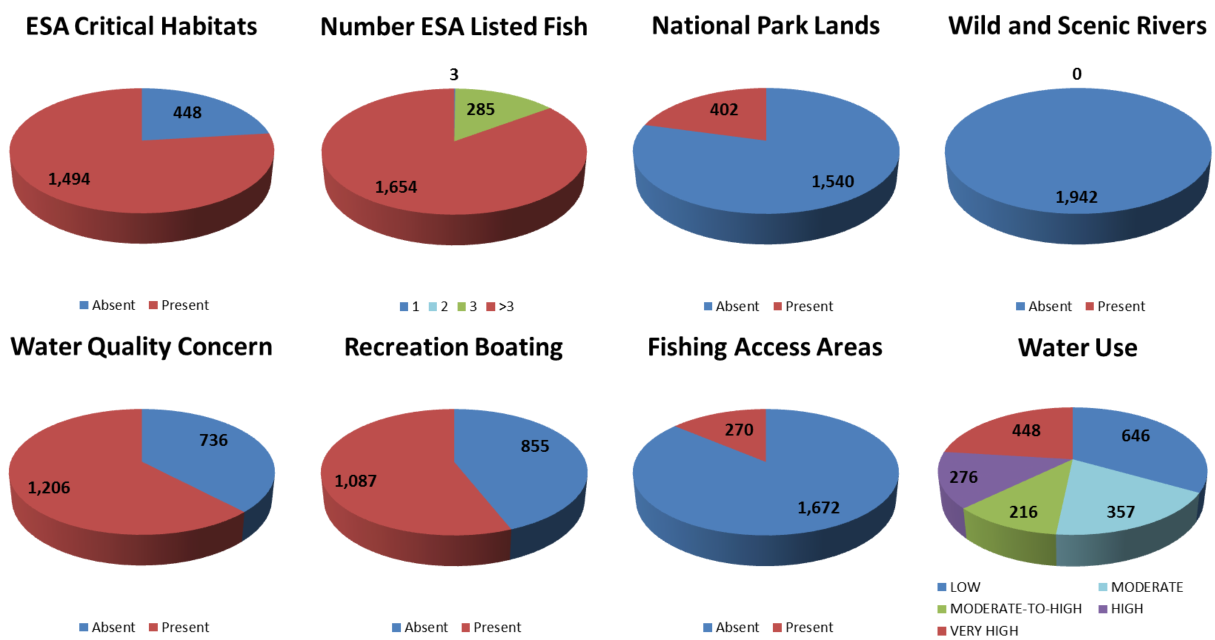

Figure 17.7. The potential capacity, in MW, associated with environmental attributes in Region 14—Upper Colorado (stream-reaches with potential capacity >1 MW).

18. REGION 15—LOWER COLORADO

18.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation, and mean capacity factors in the Lower Colorado Region are estimated and summarized in Table 18.1 for both larger (>1 MW) and smaller (<1 MW) stream-reaches. For comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation, and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 2.61 GW, around 100% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 18.23 TWh/year, around 276% of annual net generation from existing conventional hydropower plants. Given the run-of-river assumption, NSD stream-reaches have higher capacity factors, especially compared with other larger-storage peaking-operation projects in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 18.3 and 18.4.

Table 18.1. Summary of NSD Findings in Region 15—Lower Colorado

	Capacity (MW)	Generation (MWh)	Mean capacity factor[b]
Potential in undeveloped stream-reaches (>1 MW)	2,166	13,577,000	72%
Potential in undeveloped stream-reaches (<1 MW)	447	2,696,000	69%
Existing hydropower—conventional hydro	2,625	5,892,000	26%
Existing hydropower—pumped storage	194		

18.2. Background Hydrologic Setting

The Lower Colorado Region encompasses approximately 362,981 km^2 of drainage area in the Southwest United States and contains parts of New Mexico, Utah, Nevada, California, and most of Arizona.

Several river systems are located in the Lower Colorado Region (Figure 18.1), including the Colorado, Bill Williams, Gila, Salt, San Pedro, Santa Cruz, and Verde rivers, with a total length of 4708 km (i.e., total length of streams with estimated discharge greater than 35 cfs). Metropolitan areas within the region include Tucson (AZ), Flagstaff (AZ), and Las Vegas (NV). As shown in Figure 18.2, annual precipitation for the Lower Colorado region ranges from 190 to 460 mm/year, and annual runoff ranges from a trace to 40 mm/year. Most precipitation occurs from late summer to early fall, yielding a relatively small runoff.

The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are also shown in Figure 18.1. The region contains 30 hydropower dams and 8 major non-powered dams, with total storage capacities of around 36,983,949 ac-ft and 6,718,025 ac-ft, respectively.

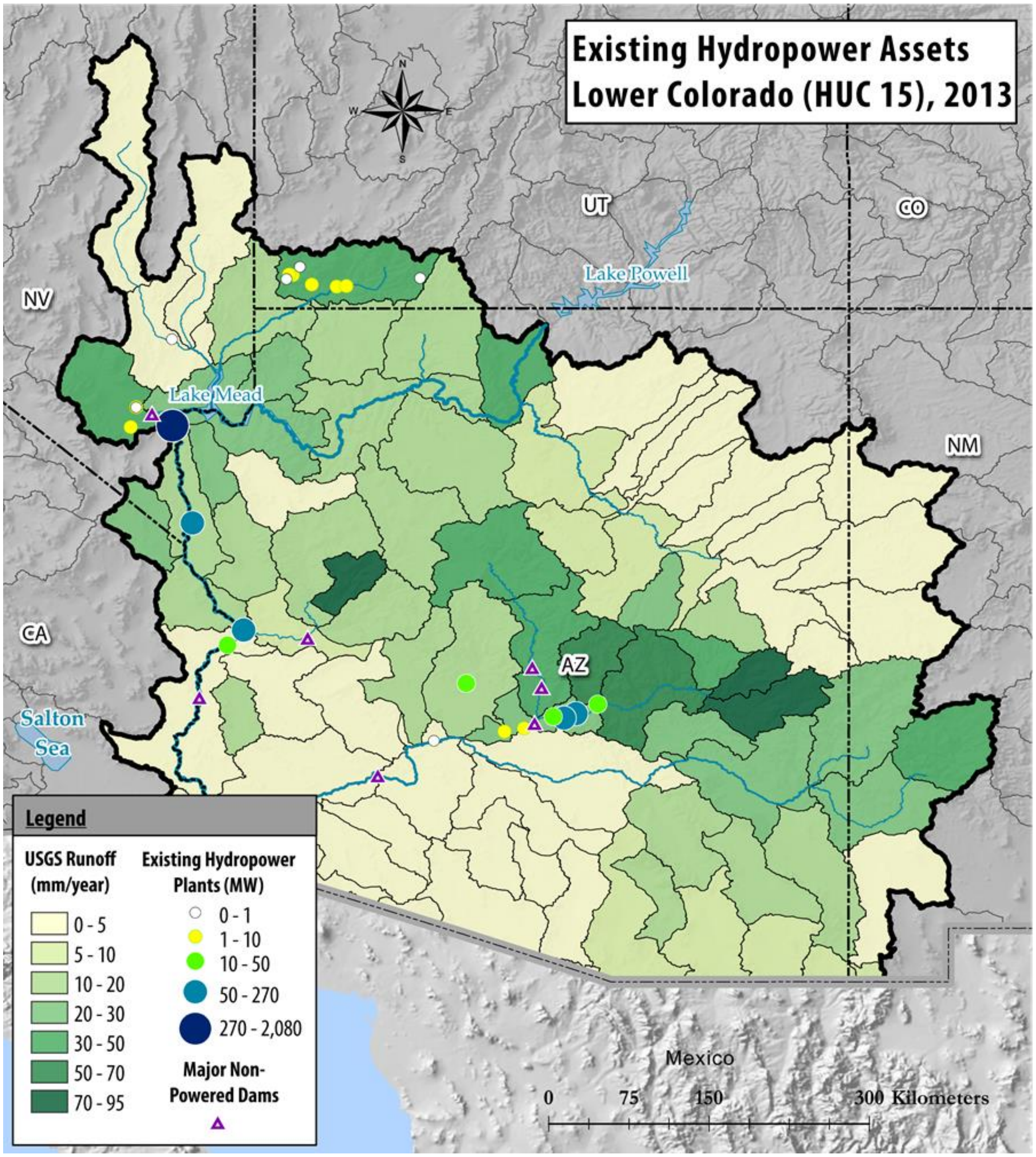

Figure 18.1. Locations of water control projects in Region 15—Lower Colorado.

18.3. Potential New Hydropower Resources

A total of 166 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) are identified in the Lower Colorado Region. The NSD results based on the HUC04 subregions are summarized in Table 18.2. The highest hydropower potential is located in the Lower Colorado–Lake Mead Subregion (HUC 1501) in the Colorado River. The next highest potential is located in the Lower Colorado Subregion (HUC 1503) in the Colorado River as well.

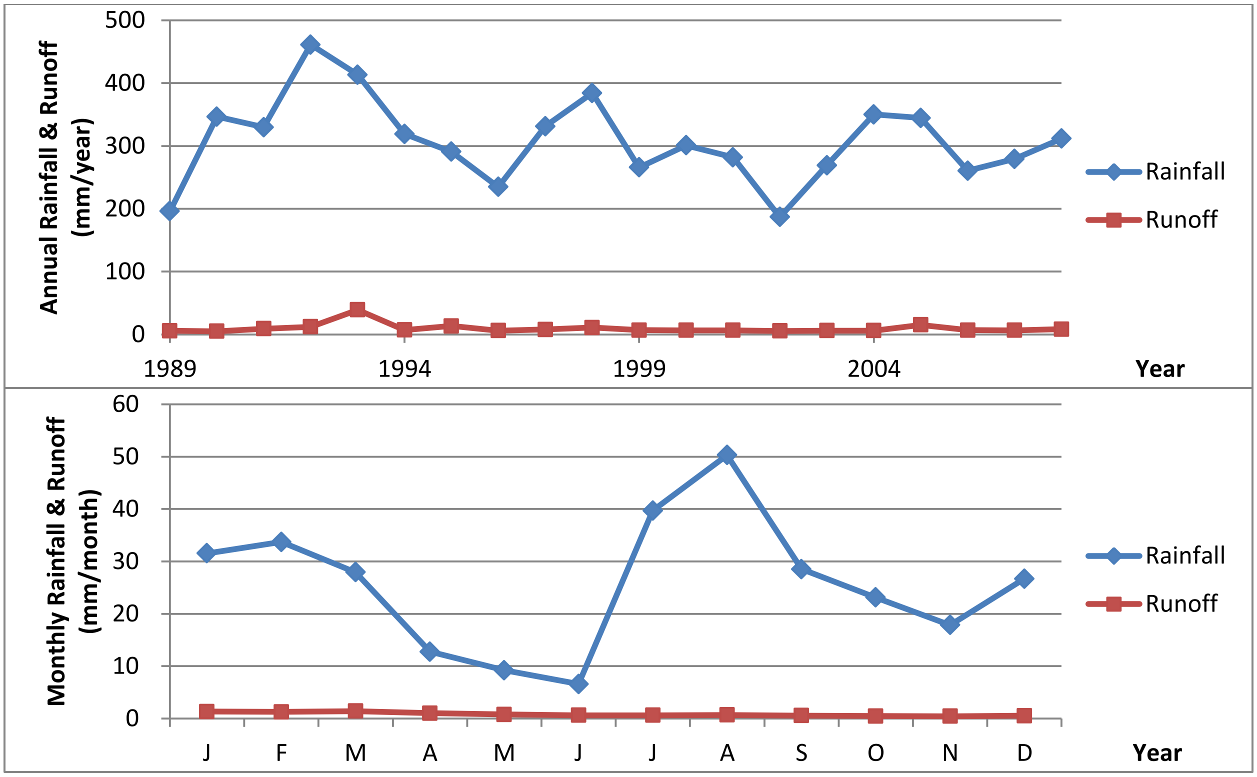

Figure 18.2. Annual and monthly rainfall and runoff of Region 15—Lower Colorado.

Table 18.2. Summary of Potential New Hydropower Resources in Region 15—Lower Colorado (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/reach)	Average residence time (days)
1501	Lower Colorado–Lake Mead	53	1,719.0	10,784,611	32.4	13,901	1,568	0.0
1502	Little Colorado	-	-	-	-	-	-	-
1503	Lower Colorado	20	299.2	1,898,739	14.3	14,583	20,421	0.3
1504	Upper Gila	14	15.6	92,507	25.9	601	11,333	20.3
1505	Middle Gila	41	55.1	337,288	23.5	797	7,587	9.9
1506	Salt	8	10.5	67,184	33.6	531	8,039	14.5
1507	Lower Gila	30	67.0	396,501	22.7	1,363	28,900	22.3
1508	Sonora	-	-	-	-	-	-	-

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 in Figure 18.3. The hydraulic head H_{ref} ranges from 5 to the 90th quantile of 41 ft with a median of 25 ft. The design flow Q_{30} ranges from 700 to the 90th quantile of 1400 cfs with a median of about 1500 cfs. The potential capacity P_{NSD} ranges from 1 to the 90th quantile of 40 MW with a median of about 3.7 MW. The inundated surface area A_{NSD} ranges from 0 to the 90th quantile of 3800 acres with a median of 500 acres. This results in storage values V_{NSD} ranging from 0 to the 90th quantile of 32,000 ac-ft with a median of 5,000 ac-ft, with residence times T_{NSD} ranging from a few hours to the 90th quantile of about 1 month with a median of a few days. The results of > 1 MW stream-reach potential are illustrated in Figure 18.4, with potential capacity (MW) aggregated to the HUC08 subbasins.

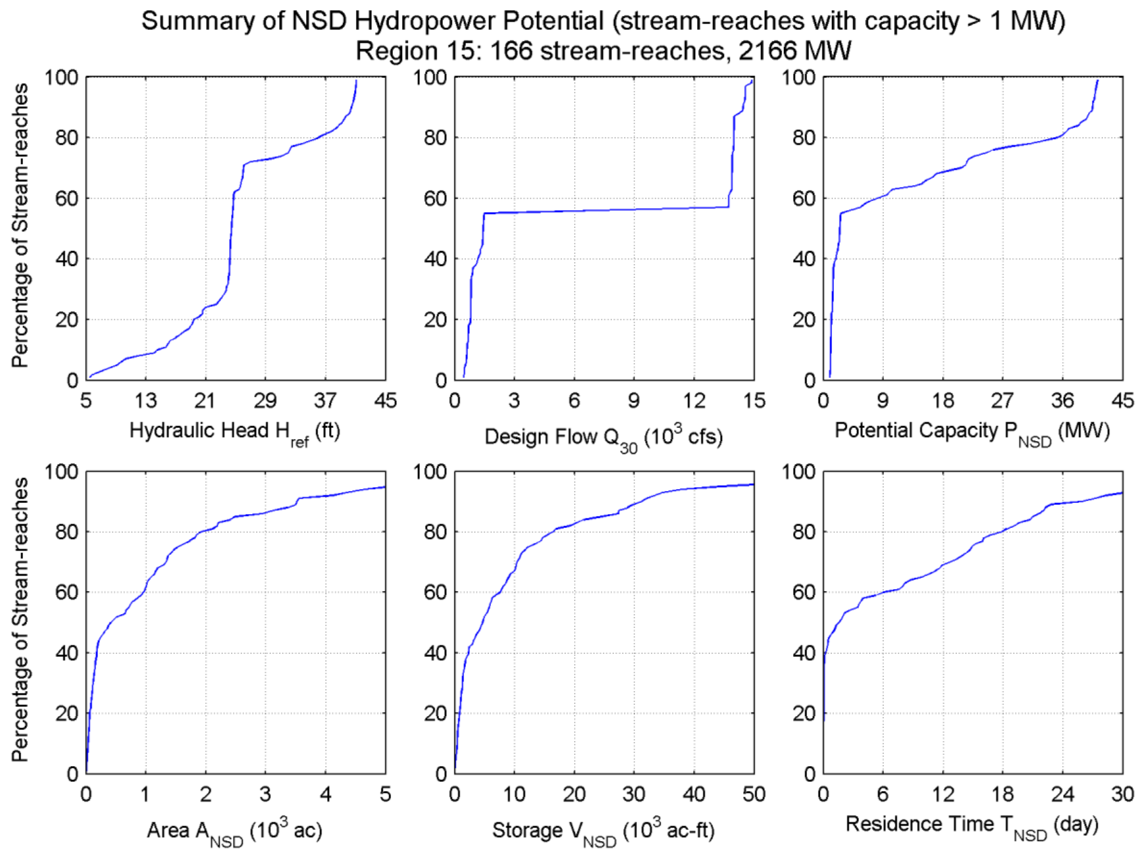

Figure 18.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 15—Lower Colorado.

18.4. Environmental Characteristics

Twenty-three of the 34 native fish species in the Lower Colorado Region fall under ESA categories, including 11 endangered and 6 threatened species. Four species have populations that are endangered (2) or threatened (2). Six of the fish under ESA categories are western chubs, a species in the *Gila* genus (Cyprinidae or minnow family). Razorback sucker, desert pupfish (*Cyprinodon macularius*), Devil's Hole pupfish (*Cyprinodon diabolis*), Moapa dace (*Moapa coriacea*), White River spinedace (*Lepidomeda albivallis*), and woundfin (*Plagopterus argentissimus*) are other endangered fishes in the region. Cutthroat trout is the only species considered potadromous in the region. Eighteen critical watersheds located in this region each have one to seven fish or mussel species at risk (Mathews et al., 1998). Twenty-six species have critical habitat designations, including several listed above (Figure 18.5).

Almost 74 million acres of protected land, 82% of the total area, are located in Region 15 (Figure 18.6). Federal lands comprise 61% of protected areas and are owned by BLM (30%), USFS (20%), NPS (4.5%), DOD (4%), and USFWS (3%). Many Indian reservations are located in this region, with a total of 23% of protected lands. State lands, primarily state trust areas, account for 14% of protected lands. Besides BLM and state lands, the largest tracts include Indian reservations, national forests, and military bases. Among the largest tracts is the 1.2 million acre Grand Canyon National Park (Figure 18.6). The vast majority of protected areas fall under GAP

Status 3 lands (61%), followed by status 4 (20%) and status 2 (15%) lands (Figure 18.6). The Verge National Wild and Scenic River is located in Region 15. Recreation includes 182 boat ramps, 196 fishing access locations, and 39 waterfalls. Of the 49 recreational boating river sections, three include various sections of the Colorado River.

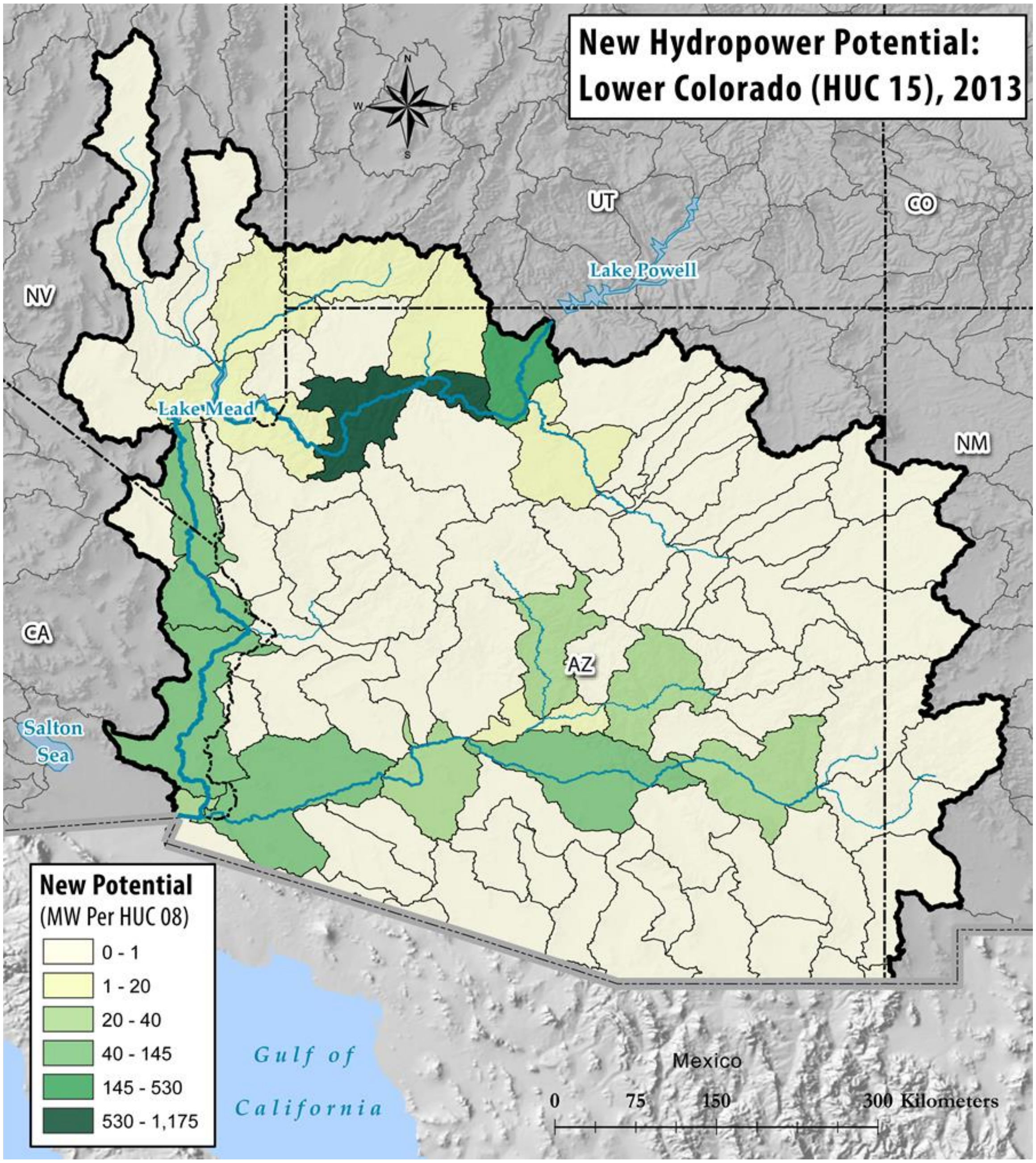

Figure 18.4. Potential new hydropower capacity in Region 15–Lower Colorado (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC08 subbasins for illustration).

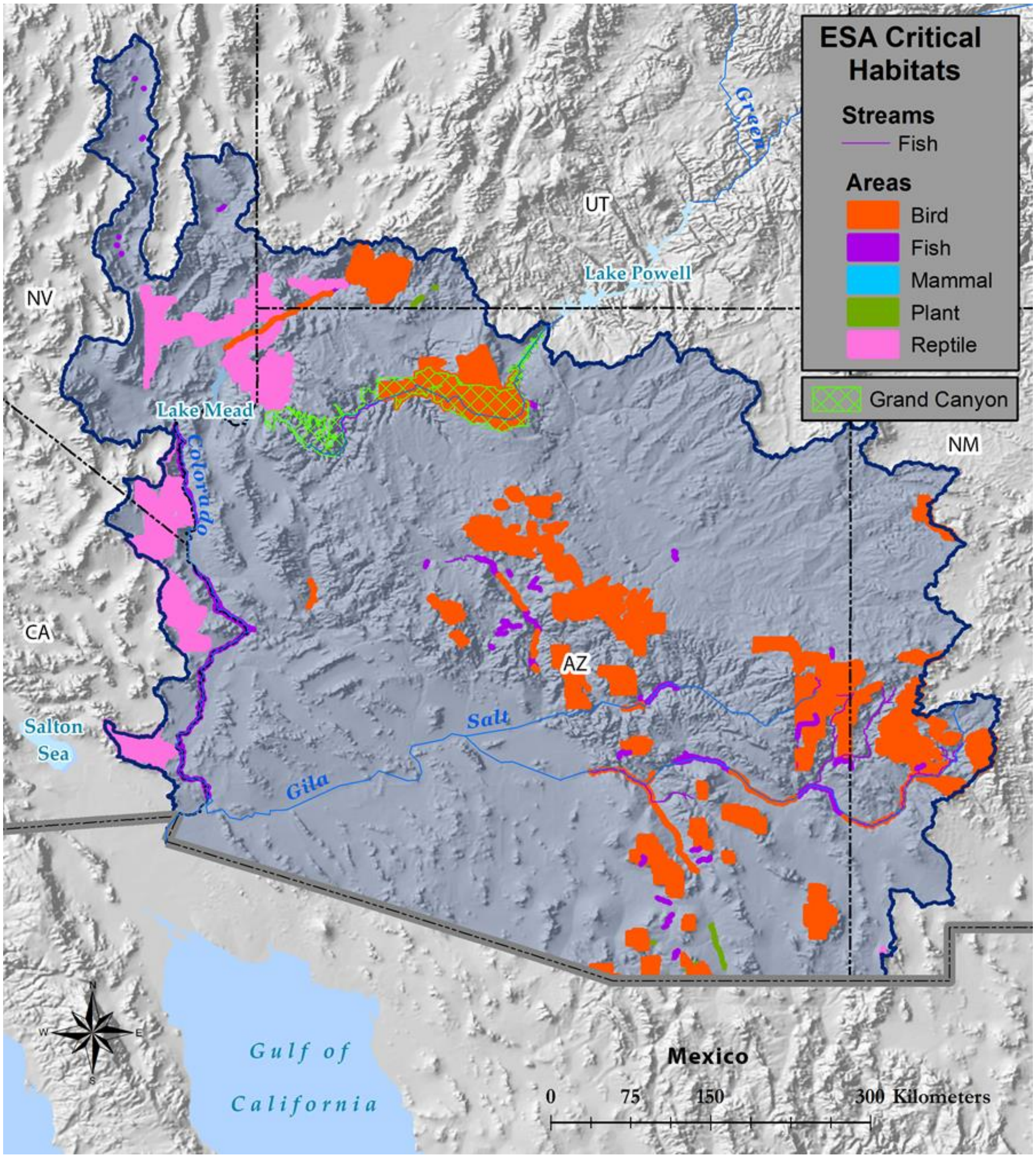

Figure 18.5. Critical habitats for federally endangered and threatened species along with spatial coverage of Grand Canyon National Park in Region 15.

Similar to the Upper Colorado Region, water use is below the national average in Region 15. Most water use is for irrigation, followed by domestic consumption (Appendix B). Highest levels of water use are reported in the Lower Gila Subregion (Table 18.3). Water quality concerns are the least prevalent in Region 15. Mercury contamination, dissolved oxygen, nutrient loading, and toxins are the main concerns.

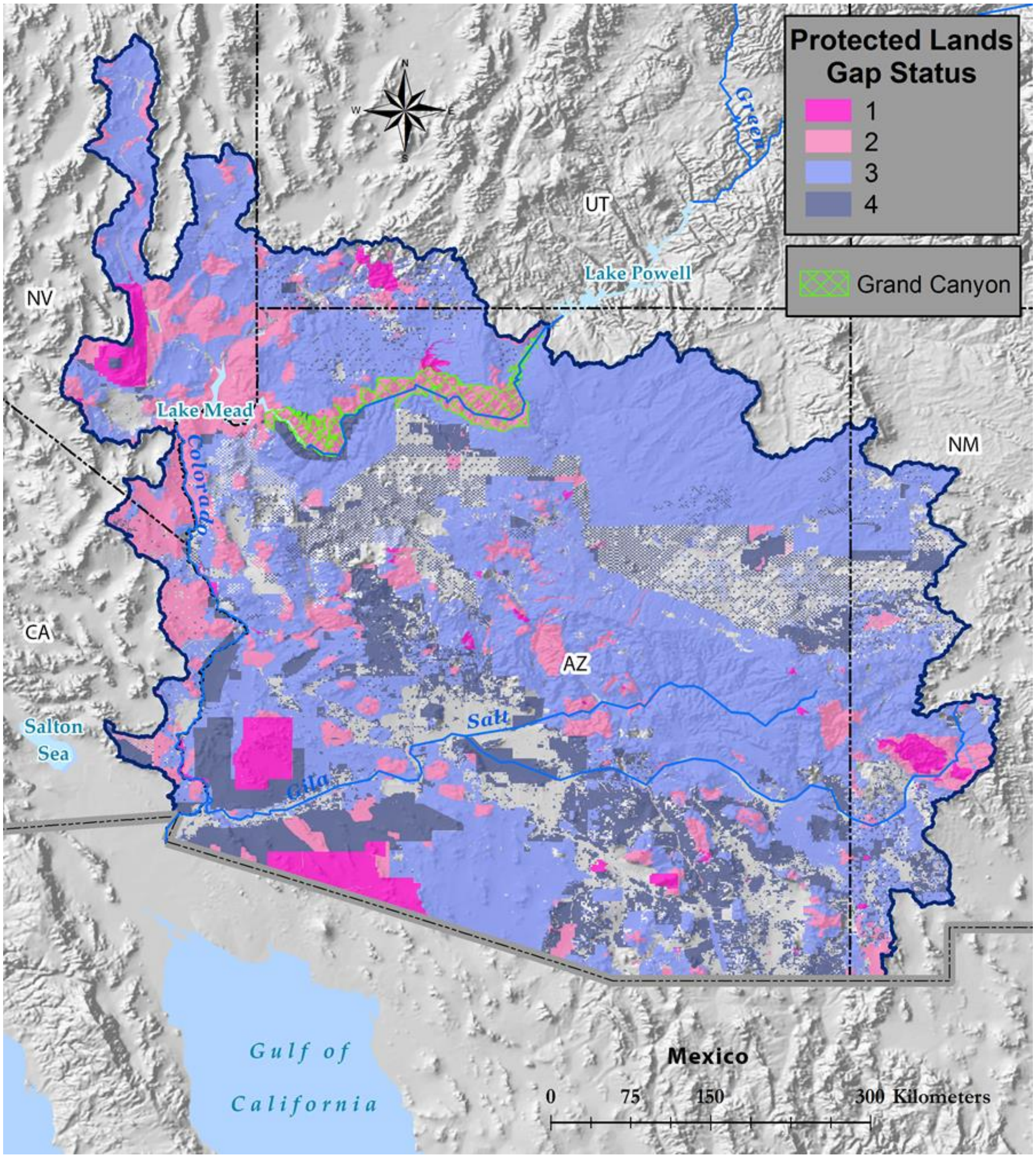

Figure 18.6. Protected lands according to Gap Status (conservation management regime) in Region 15. Grand Canyon National Park location is labeled.

Over 54% of the 166 stream-reaches (1.65 GW) overlap with critical habitats (Figure 18.7). Most stream-reaches (82%) are located in HUC08 subbasins with at least one fish falling under an ESA category. All stream-reaches intersect protected lands, with 32% percent of stream-reaches overlapping national parks, primarily Grand Canyon National Park. The total potential capacity associated with those reaches is around 1.7 GW, roughly 79% of the total energy capacity for Region 15. Eleven stream-reaches intersect Wild and Scenic Rivers. Water quality concerns are not as prevalent as in other regions, intersecting only 33% of stream-reaches. Recreational boating is relatively common, identified at 46% of stream-reaches (~ 1.45 GW). Other recreation—boat ramps and fishing access areas—are less common, only identified at 9 and 16 stream-reaches, respectively. The majority of stream-reaches fall within HUC08 subbasins with low water use values.

Table 18.3. Summary of Environmental Variables at HUC04 Subregions within Region 15 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# Critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	# Recreation locations[a]	% Protected lands	Population density (ind/km^2)	Freshwater use (liters/day/km^2)
1501	Lower Colorado–Lake Mead	11	1	11	6	59; 11; 20	79.34	13.84	297.60
1502	Little Colorado	5	0	7	5	85; 4; 4	29.99	2.95	63.38
1503	Lower Colorado	6	0	6	4	87; 3; 3	79.79	12.95	1,582.63
1504	Upper Gila	8	0	7	4	28; 8; 4	71.54	2.53	294.56
1505	Middle Gila	7	0	5	3	16; 1; 3	54.77	24.70	1,315.55
1506	Salt	7	0	7	5	93; 23; 2	59.90	22.01	564.42
1507	Lower Gila	2	0	3	1	10; 0; 3	80.69	72.59	2,297.38
1508	Sonora	8	0	3	3	0; 0; 0	37.68	18.44	716.79

[a]Recreation locations refer to the number of boat-ramp and fishing access points, recreational boating, and waterfalls within each HUC04.

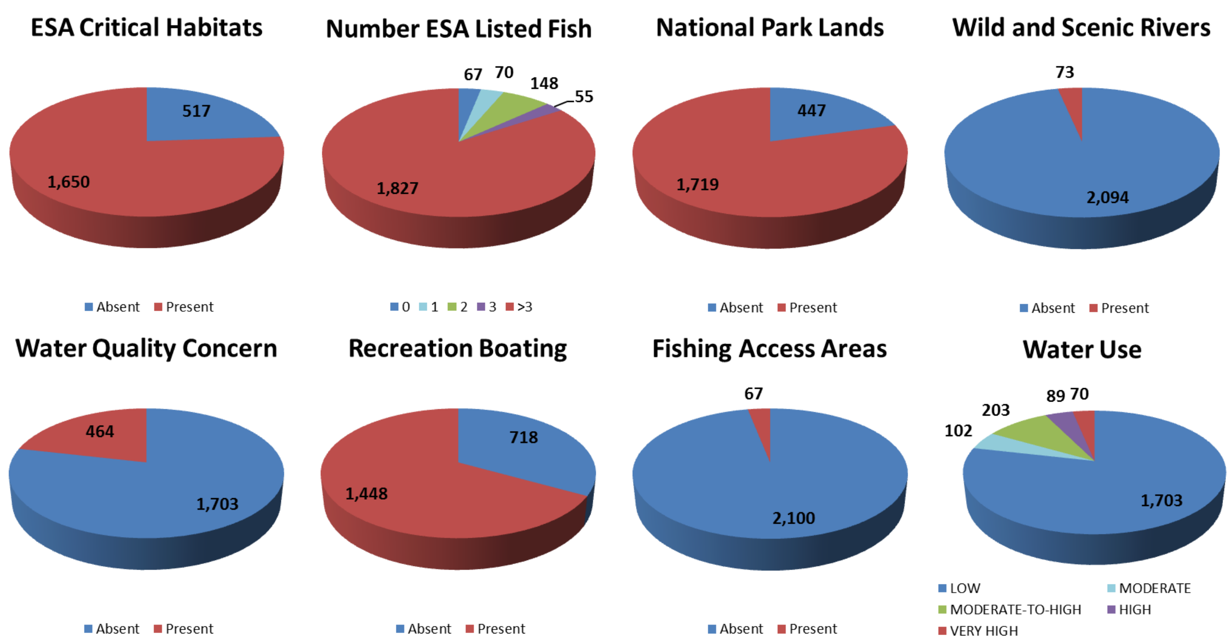

Figure 18.7. The potential capacity, in MW, associated with environmental attributes in Region 15—Lower Colorado (stream-reaches with potential capacity >1 MW).

19. REGION 16—GREAT BASIN

19.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation, and mean capacity factors in the Great Basin Region are estimated and summarized in Table 19.1 for both larger (>1 MW) and smaller (<1 MW) stream-reaches. For comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation, and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 564 MW, around 262% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 3.11 TWh/year, around 650% of annual net generation from existing conventional hydropower plants. Given the run-of-river assumption, NSD stream-reaches have higher capacity factors, especially compared with other larger-storage peaking-operation projects in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 19.3 and 19.4.

Table 19.1. Summary of NSD Findings in Region 16—Great Basin

	Capacity (MW)	Generation (MWh)	Mean capacity factor
Potential in undeveloped stream-reaches (>1 MW)	148	845,000	65%
Potential in undeveloped stream-reaches (<1 MW)	416	2,260,000	62%
Existing hydropower—conventional hydro	215	478,000	25%
Existing hydropower—pumped storage	0		

19.2. Background Hydrologic Setting

The Great Basin Region encompasses approximately 367,049 km^2 of drainage area in the western lower-central part of the United States and contains small sections of California, Wyoming, Idaho, and Oregon, and larger sections of Nevada and Utah.

Several river systems are located in the Great Basin Region (Figure 19.1), including Bear, Weber, Jordan, Humboldt, Carson, Truckee, and Walker rivers, with a total length of 7662 km (i.e., total length of streams with estimated discharge greater than 35 cfs). Metropolitan areas within the region include Salt Lake City (UT). As shown in Figure 19.2, the annual precipitation for the Great Basin region ranges from 210 to 470 mm/year, and annual runoff ranges from 20 to 90 mm/year. Most precipitation occurs during the winter months. The peak runoff coincides with the spring snowmelt.

The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are also shown in Figure 19.1. The region contains 73 hydropower dams and 6 major non-powered dams, with total storage capacities of around 1,304,569 ac-ft and 451,670 ac-ft, respectively.

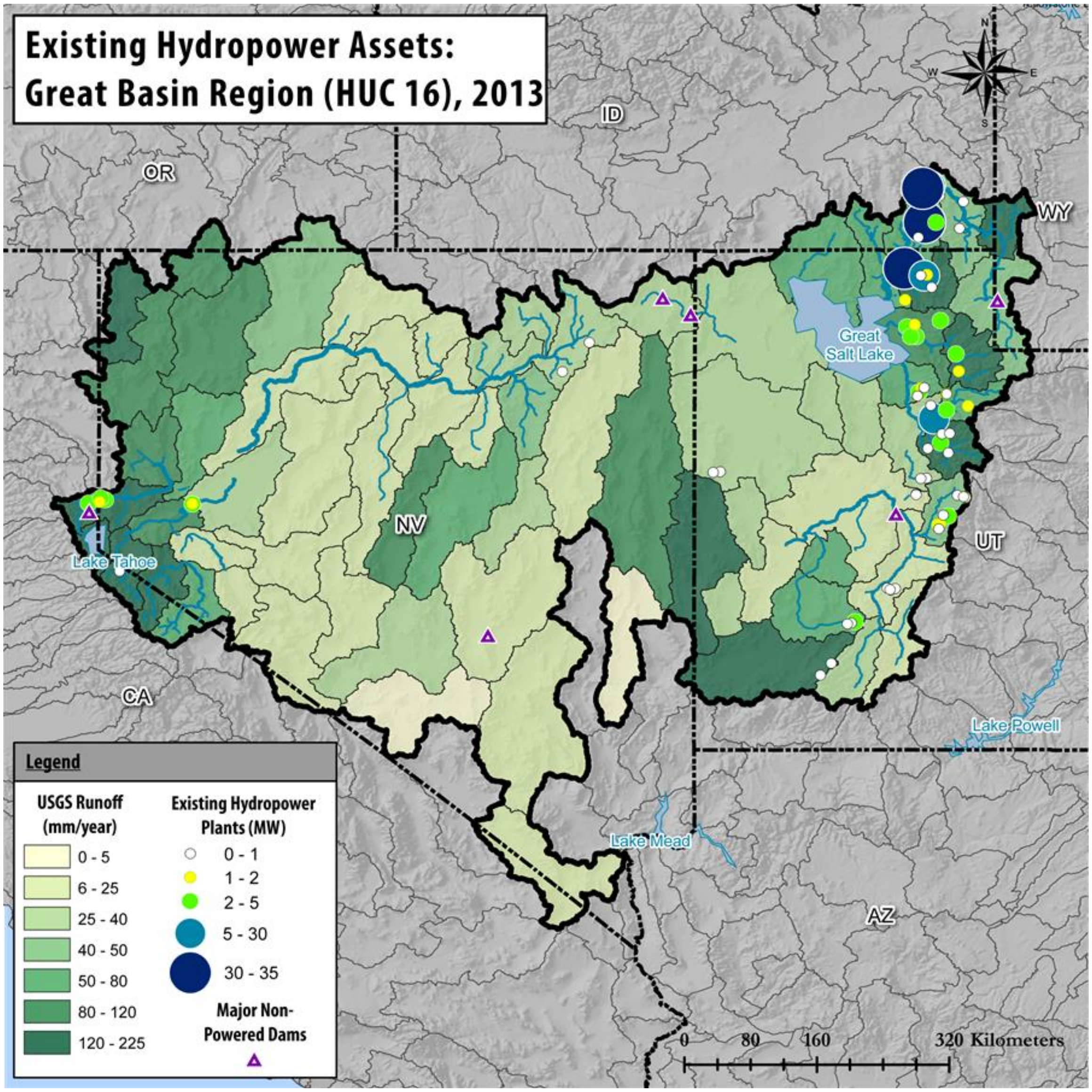

Figure 19.1. Locations of water control projects in Region 16—Great Basin.

19.3. Potential New Hydropower Resources

A total of 106 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) are identified in the Great Basin Region. The NSD results based on the HUC04 Subregions are summarized in Table 19.2. The highest hydropower potentials are found in Bear Subregion (HUC 1601), followed by the Central Lahontan Subregion (HUC 1605), and the Bear, West Walker, West Fork of Old River, Carson, and Truckee rivers.

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 in Figure 19.3. The hydraulic head H_{ref} ranges from 11 to the 90th quantile of 41 ft with a median of 21 ft, suggesting that many of the potential stream-reaches will require low-head hydropower technologies. The design flow Q_{30} ranges from 300 to the 90th quantile of 1200 cfs with a median of about 1000 cfs. The potential capacity P_{NSD} ranges from 1.1 to the 90th quantile of 1.8 MW with a median of about 1.3 MW. The inundated surface area A_{NSD} ranges from 0 to the 90th quantile of 1200 acres with a median of 150 acres. This results in storage values V_{NSD} ranging from 0 to the 90th quantile of 12,000 ac-ft with a median of 1,500 ac-ft, with residence times T_{NSD} ranging from a few hours to the 90th quantile of about 4 days with a median of less than a day. The results of > 1 MW stream-reach potential are illustrated in Figure 19.4, with potential capacity (MW) aggregated to the HUC08 subbasins.

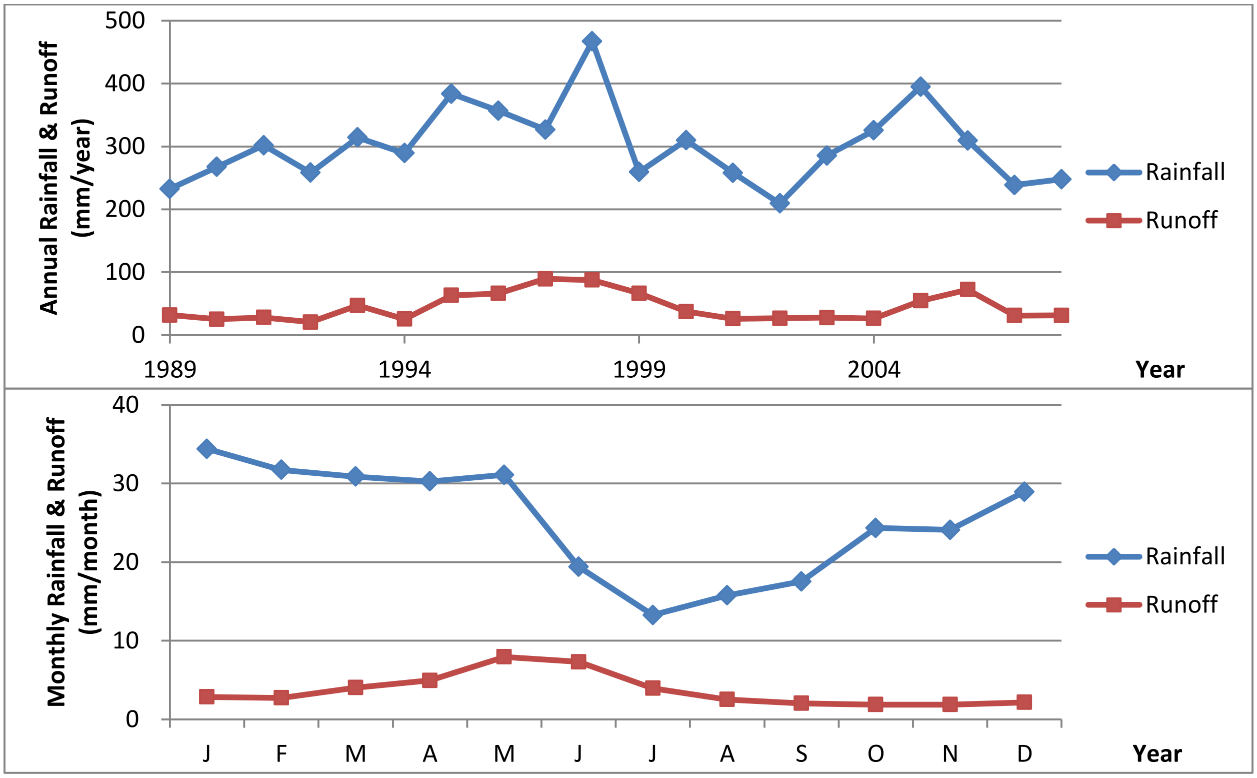

Figure 19.2. Annual and monthly rainfall and runoff of Region 16—Great Basin.

Table 19.2. Summary of Potential New Hydropower Resources in Region 16—Great Basin (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/reach)	Average residence time (days)
1601	Bear	47	71.8	418,909	19.3	1,125	2,309	0.4
1602	Great Salt Lake	15	19.4	106,384	40.5	444	2,281	2.0
1603	Escalante Desert–Sevier Lake	-	-	-	-	-	-	-
1604	Black Rock Desert–Humboldt	-	-	-	-	-	-	-
1605	Central Lahontan	44	57.1	320,117	24.4	929	7,993	4.4
1606	Central Nevada Desert Basins	-	-	-	-	-	-	-

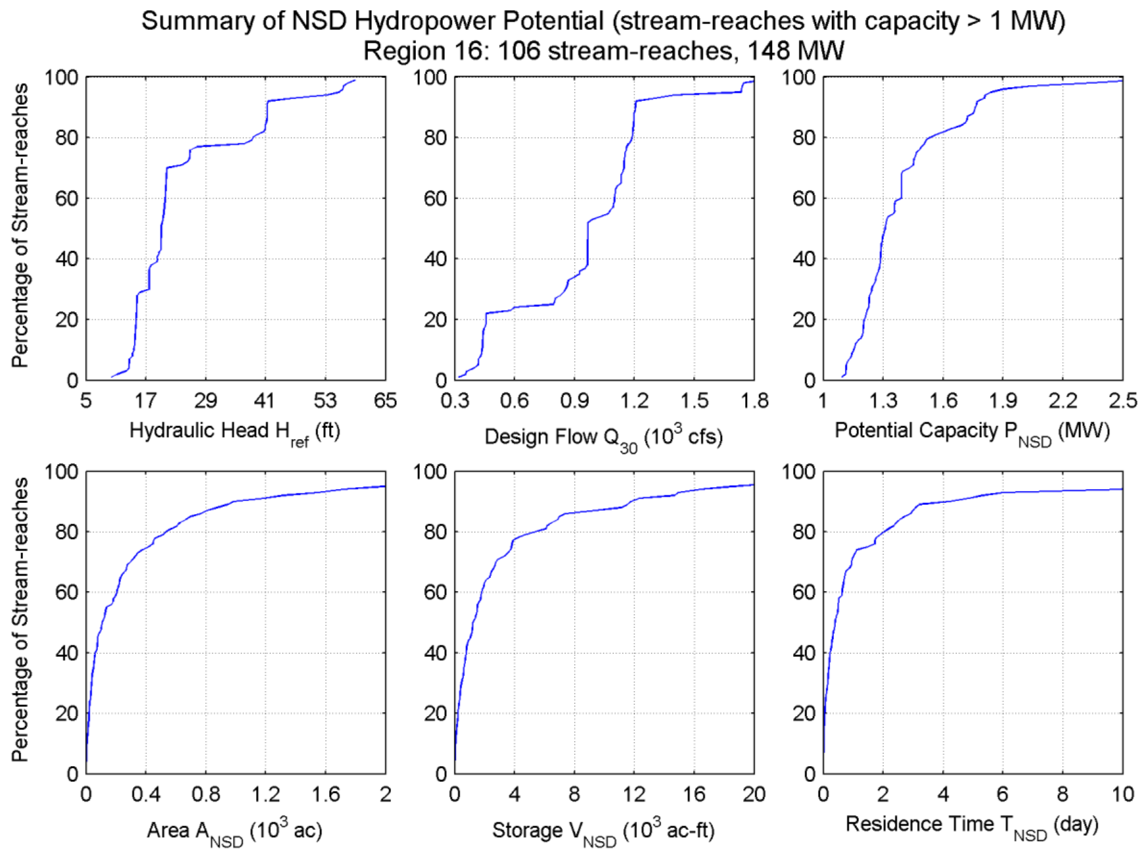

Figure 19.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 16—Great Basin.

19.4. Environmental Characteristics

The Great Basin Region includes 31 native fish species, 9 of which fall under ESA categories and 7 of which fall under IUCN vulnerability categories (12 total fish species, Figure 19.5). Endangered fish include Cui-Cui (*Chasmistes cujus*) and June sucker (*Chasmistes liorus*), and threatened species include desert dace (*Eremichthys acros*) and Railroad Valley springfish (*Crenichthys nevadae*). Eight fish species are considered potadromous or anadromous in the region. Thirteen subbasins are critical watersheds, with the Bear Lake Subbasin containing the most species at risk (Mathews et al., 1998). Six species have critical habitat designations, including Mexican spotted owl, Canada lynx, desert tortoise (*Gopherus agassizii*), and all the fish listed above except Cui-Cui.

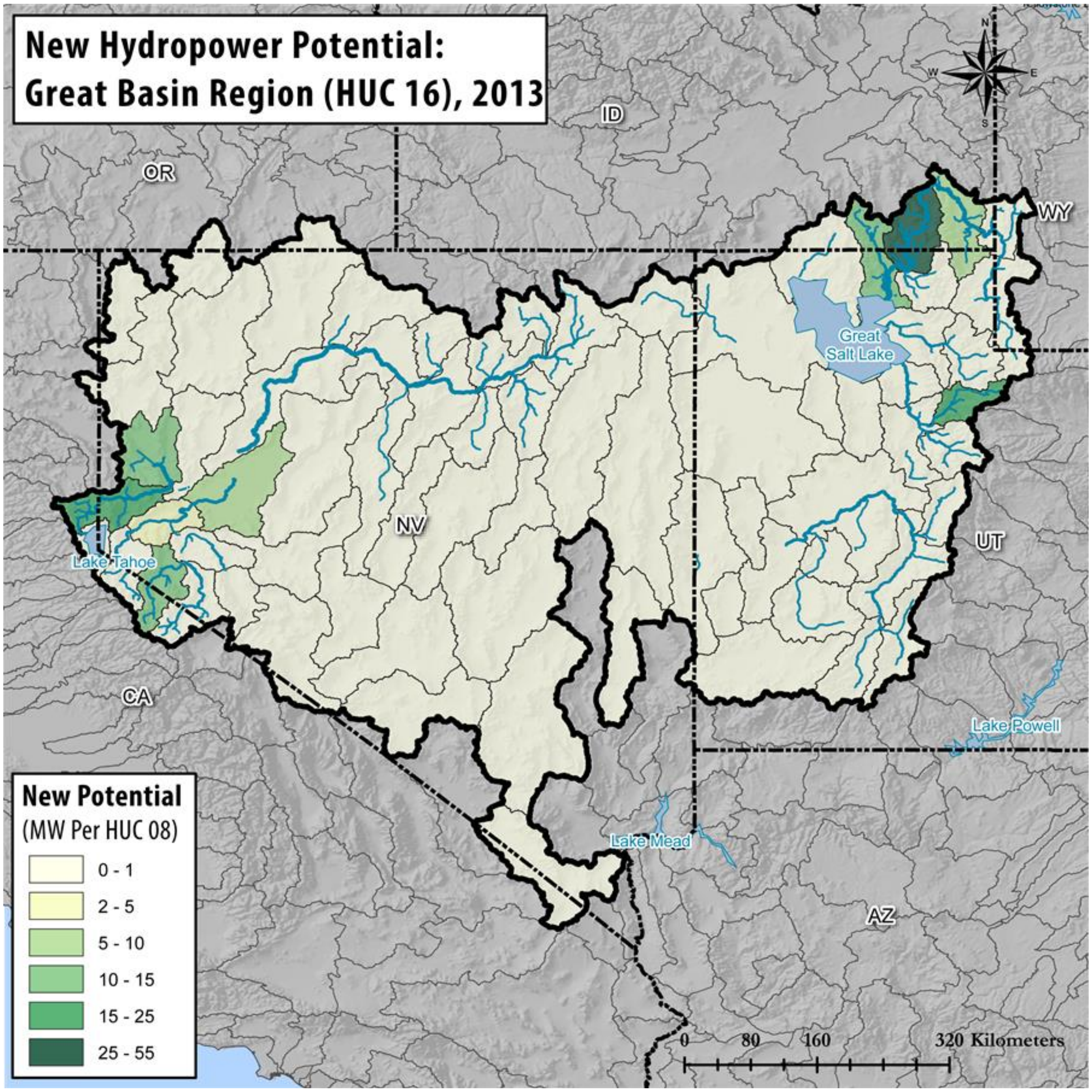

Figure 19.4. Potential new hydropower capacity in Region 16—Great Basin (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC08 subbasins for illustration).

Seventy-eight percent (over 71 million acres) of the total area in Region 16 comprises protected lands. The vast majority of lands are federally owned (95%), followed by state (3%) and Native American (1%) ownership. The primarily owners of federal lands are the BLM (71%), USFS (15%), DOD (6%), and USFWS (2%). State lands are primarily composed of state land board areas. Among the largest tracts of land are BLM public lands, DOD's Nevada Test and Training Range, State Trust lands, and Toiyabe, Fishlake, Humboldt, and Dixie national forests. Seventy-eight percent of protected lands in Region 16 are classified as GAP Status 3. No NWSR sections are located in Region 16. As with Region 14, boat ramps (83) are not as prevalent as in most other regions. Other recreation includes 267 fishing access locations, 22 waterfalls, and 47 recreational boating river sections.

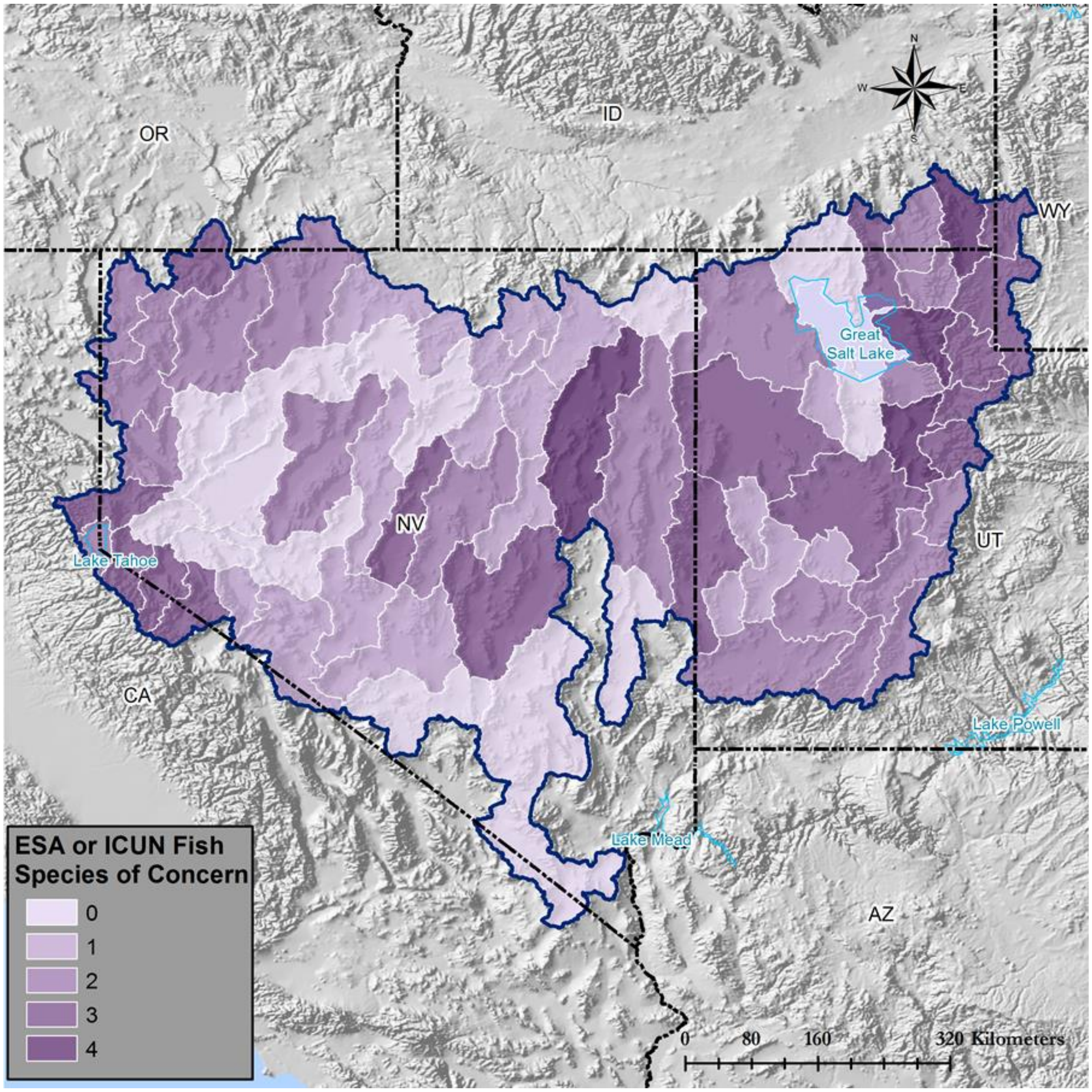

Figure 19.5. Fish species of concern (number per HUC08 sub-basin) in Region 16.

Water use is well below the national average (Figure 19.6); however, many areas are highly arid and lack substantial annual precipitation (Figure 19.2). Irrigation and public consumption make up most of the water use in the region (Figure 19.6, Table 19.3, and Appendix B). Water quality concerns are average with elevated nutrient loads, mercury contamination, and elevated total dissolved solids making up most of the issues.

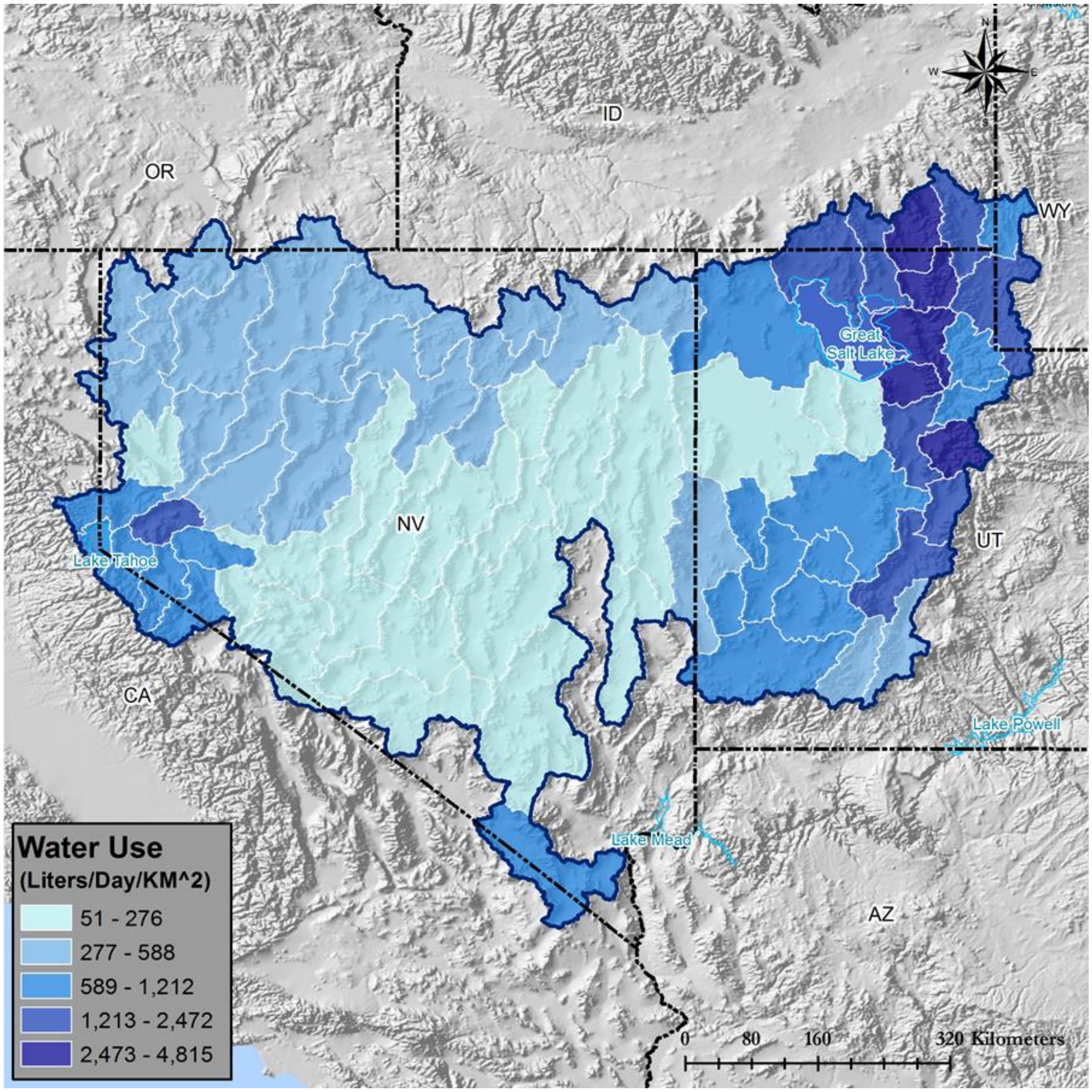

Figure 19.6. Average water use per HUC08 subbasin in Region 16.

Eleven of the 106 stream-reaches in Region 16 intersect critical habitats (Figure 19.7). The vast majority of stream-reaches (93%) are located in HUC08 subbasins with at least one fish falling under ESA categories. Almost all reaches (98%) intersect protected lands; however, none overlap with national parks. Water quality concerns are identified at 66% of stream-reaches, with a total of 91 MW. Recreational boating, boat ramps, and fishing access areas intersect 36%, 6.6%, and 27% of stream-reaches, respectively, with a total of 51 MW, 11 MW, and 40 MW, respectively. Very few stream-reaches are located in HUC08 subbasins with high or very high water use.

Table 19.3. Summary of Environmental Variables at HUC04 Subregions within Region 16 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# Critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	# Recreation locations[a]	% Protected lands	Population density (ind/km^2)	Freshwater use (liters/day/km^2)
1601	Bear	1	3	3	1	43; 9; 0	44.11	8.94	2,200.34
1602	Great Salt Lake	1	4	5	1	57; 22; 9	64.38	50.45	1,287.22
1603	Escalante Desert–Sevier Lake	1	3	3	1	52; 4; 1	75.92	2.08	1,019.42
1604	Black Rock Desert–Humboldt	1	3	4	2	78; 0; 1	75.51	3.29	338.87
1605	Central Lahontan	0	5	4	1	83; 12; 10	65.86	12.90	713.53
1606	Central Nevada Desert Basins	3	3	4	2	37; 0; 1	95.06	4.16	203.87

[a]Recreation locations refer to the number of boat-ramp and fishing access points, recreational boating, and waterfalls within each HUC04.

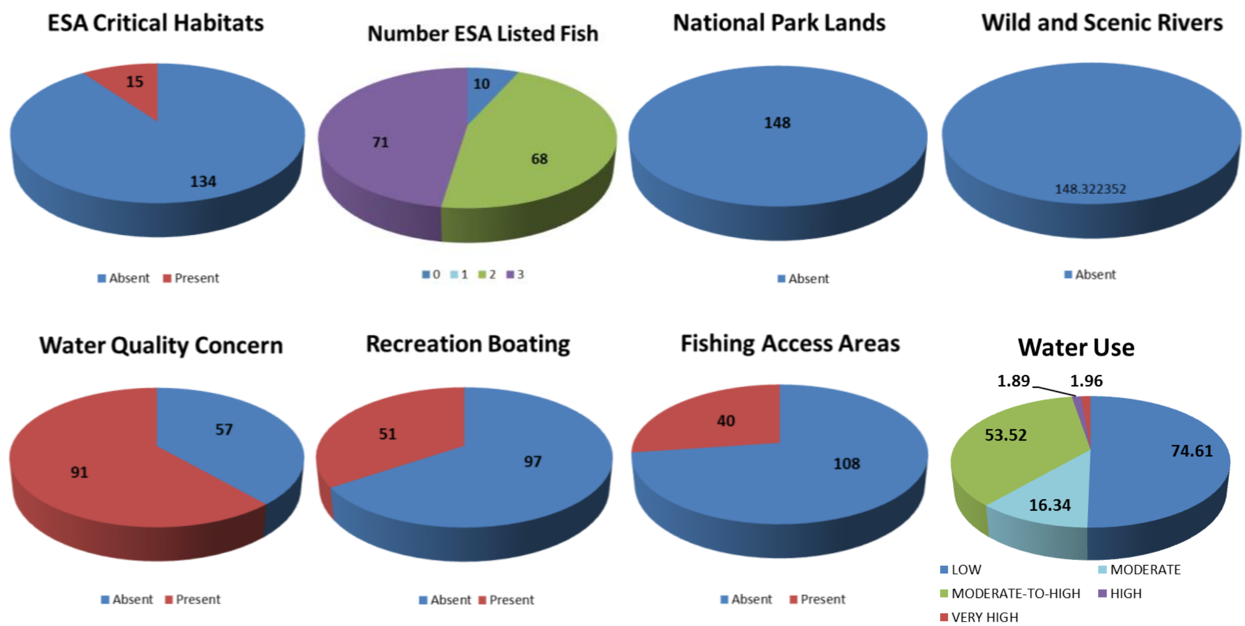

Figure 19.7. The potential capacity, in MW, associated with environmental attributes in Region 16—Great Basin (stream-reaches with potential capacity >1 MW).

20. REGION 17—PACIFIC NORTHWEST

20.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation and mean capacity factors in the Pacific Northwest Region are estimated and summarized in Table 20.1 for both larger (>1 MW) and smaller (<1 MW) stream-reaches. For comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation, and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 25.23 GW, around 76% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 149.00 TWh/year, around 118% of annual net generation from existing conventional hydropower plants. Given the run-of-river assumption, NSD stream-reaches have higher capacity factors, especially compared with other larger-storage peaking-operation projects in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 20.3 and 20.4.

Table 20.1. Summary of NSD Findings in Region 17—Pacific Northwest

	Capacity (MW)	Generation (MWh)	Mean capacity factor
Potential in undeveloped stream-reaches (>1 MW)	15,997	96,756,000	69%
Potential in undeveloped stream-reaches (<1 MW)	9,228	52,244,000	65%
Existing hydropower—conventional hydro	33,324	126,084,000	43%
Existing hydropower—pumped storage	314		

20.2. Background Hydrologic Setting

The Pacific Northwest Region encompasses approximately 711,654 km^2 in the Northwestern United States. The region consists of the entire state of Washington, most of Oregon (except a small area in the southern part of the state), most of Idaho, western Montana, and very small regions of northern Nevada, Utah and California. The region comprises mountains, plateaus, and a major river plain. The coastal mountain range, the Cascade Mountain range, and the Rocky Mountain Range encompass the Columbia and Central Oregon Plateau and the Snake River Plain (USGS, 2013). The coastal plain consists of consolidated and semiconsolidated limestone, clay, gravel, and soft unconsolidated sand. This area contains the most productive groundwater because of its highly permeable clastic and limestone aquifers. The groundwater outflow supports base flow for the streams in the region. For the Coastal Plain, base flow conservatively averages about 55 percent of the total streamflow.

Several river systems are located in the Pacific Northwest Region (Figure 20.1), including the Columbia, Kootenai, Pend Oreille, Spokane, Snake, Yakima, Weiser, Salmon, Clearwater, John Day, Deschutes, Willamette, and Umpqua rivers, with a total length of 63,372 km (i.e., total length of streams with estimated discharge greater than 35 cfs). The Columbia River, its tributaries, and other streams that discharge into the Pacific Ocean are responsible for most of the drainage of the Pacific Northwest region. Metropolitan areas within the region include Seattle (WA), Yakima (WA), Spokane (WA), Walla Walla (WA), Portland (OR), Eugene (OR), and Boise (ID). As shown in Figure 20.2, annual precipitation in the Pacific Northwest Region ranges from 700 to 1150 mm/year, and annual runoff ranges from 200 to 500 mm/year. Most precipitation occurs from late fall through winter and a slight amount into early spring.

The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are also shown in Figure 20.1. The Pacific Northwest Region contains 336 hydropower dams and 27 major non-powered dams, with total storage capacities of around 59,987,949 ac-ft and 1,477,693 ac-ft, respectively.

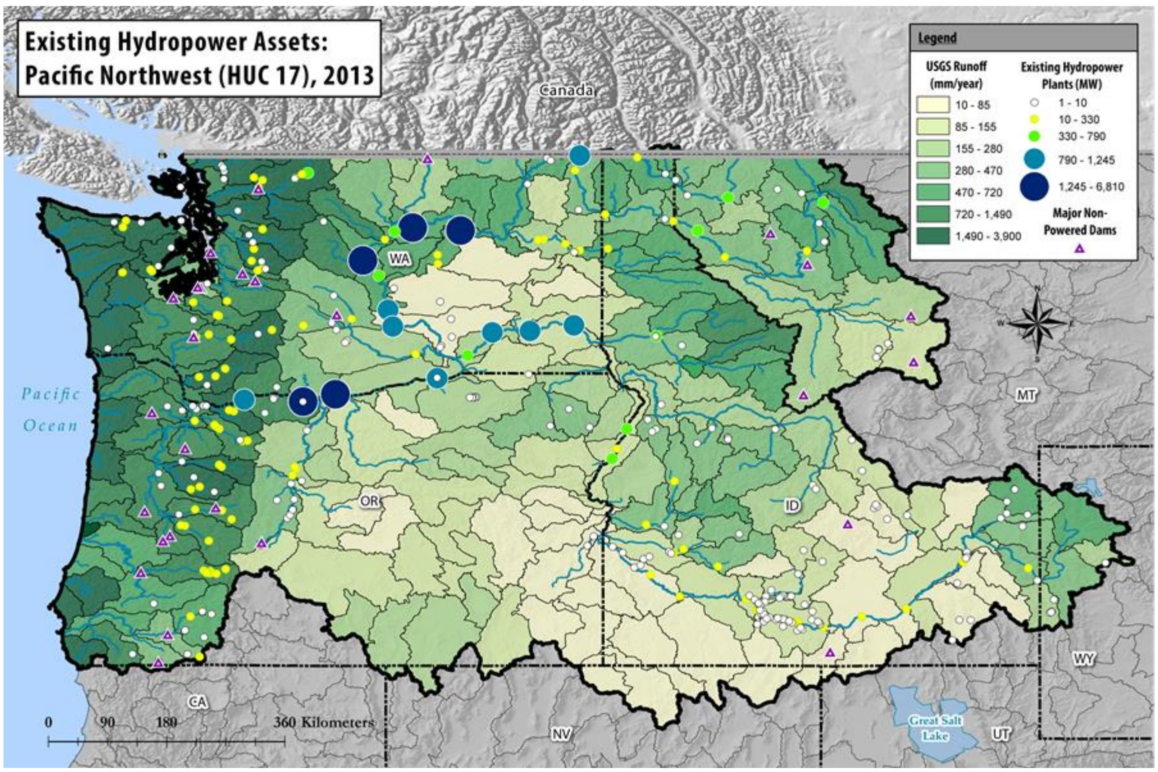

Figure 20.1. Locations of water control projects in Region 17—Pacific Northwest.

20.3. Potential New Hydropower Resources

A total of 3,793 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) are identified in the Pacific Northwest Region. The NSD results based on HUC04 subregions are summarized in Table 20.2. The highest hydropower potentials are located in the Lower Snake Subregion (HUC 1706) and Middle Columbia Subregion (HUC 1707). In the Lower Snake Subregion, the highest hydropower potentials are located predominantly in the Snake River, followed by the Clearwater and Salmon rivers. In the Middle Columbia Subregion, the highest hydropower potential is found predominantly in the Deschutes River.

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 in Figure 20.3. The hydraulic head H_{ref} ranges from 5 to the 90th quantile of 41 ft with a median of about 14 ft, suggesting that many of the potential stream-reaches will require low-head hydropower technologies. The design flow Q_{30} ranges from 0 to the 90th quantile of 11,000 cfs with a median of 2,500 cfs. The potential capacity P_{NSD} ranges from 1 to the 90th quantile of about 10 MW with a median of about 2 MW. The inundated surface area A_{NSD} ranges from 0 to 400 acres with a median of about 50 acres. This results in storage values V_{NSD} ranging from 0 to

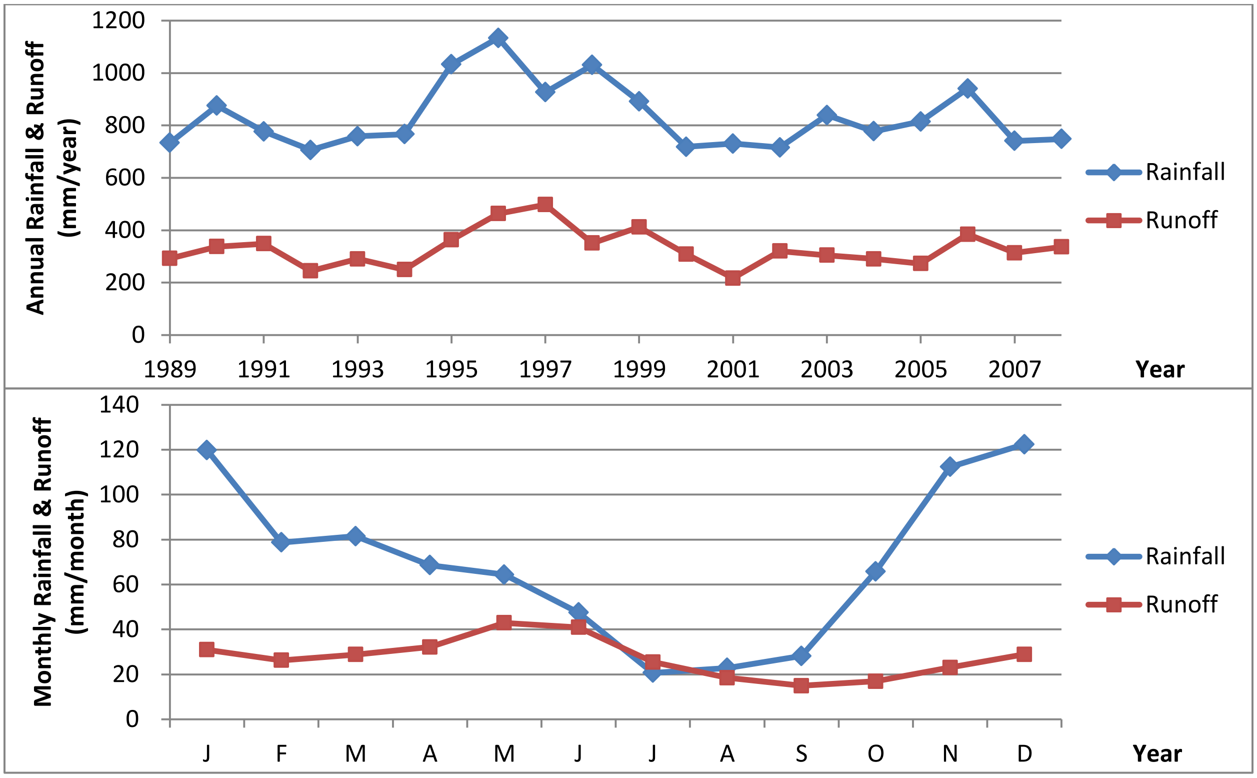

Figure 20.2. Annual and monthly rainfall and runoff of Region 17—Pacific Northwest.

Table 20.2. Summary of Potential New Hydropower Resources in Region 17—Pacific Northwest (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/reach)	Average residence time (days)
1701	Kootenai–Pend Oreille-Spokane	365	1,534.0	8,668,534	19.0	3,675	2,264	0.7
1702	Upper Columbia	198	1,075.1	6,583,428	11.7	5,489	1,509	0.1
1703	Yakima	116	423.6	2,609,643	18.0	2,829	2,214	0.3
1704	Upper Snake	172	1,626.6	-	34.5	5,180	11,118	7.9
1705	Middle Snake	140	516.9	3,120,023	12.7	3,182	5,049	0.5
1706	Lower Snake	984	3,696.7	22,302,267	9.3	6,211	379	0.2
1707	Middle Columbia	326	2,137.5	15,178,105	25.5	3,262	5,951	6.2
1708	Lower Columbia	154	622.0	3,663,198	15.4	5,357	691	0.2
1709	Willamette	288	1,355.6	8,138,632	32.8	2,644	9,923	3.5
1710	Oregon–Washington Coastal	602	1,804.7	9,497,362	24.9	2,285	3,738	2.6
1711	Puget Sound	448	1,204.0	7,624,078	15.2	2,689	1,060	0.2
1712	Oregon closed basins	-	-	-	-	-	-	-

the 90th quantile of 5000 ac-ft with a median of about 750 ac-ft and very short residence times T_{NSD} ranging from <1 day to the 90th quantile of about 1.5 days with a median on the order of several hours. In general, the relatively small inundation areas and storage volumes paired with the short retention times for this region are characteristic of run-of-river type hydro facilities. The results of > 1 MW stream-reach potential are illustrated in Figure 20.4, with potential capacity (MW) aggregated to the HUC08 subbasins. The higher potential capacity sites are generally located in the mountainous regions.

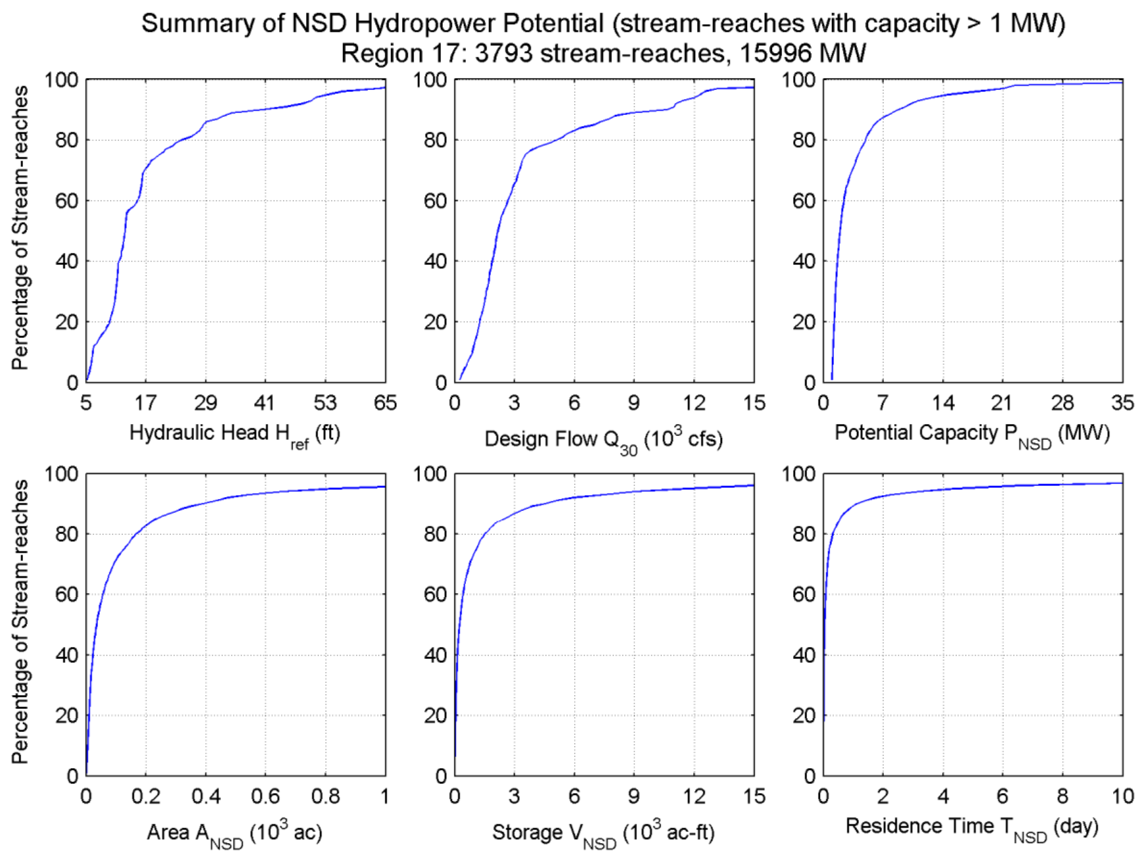

Figure 20.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 17—Pacific Northwest.

20.4. Environmental Characteristics

Region 17 has 70 native species of fish; for 16 of these species, either the entire species or a population falls under an ESA listing or candidate listing (Figure 20.5 and Appendix B). Eight of the species with ESA listing are salmon species, including populations of Chinook (*Oncorhynchus tshawytscha*), Chum (*O. keta*), Coho (*O. kisutch*), or Sockeye (*O. nerka*) salmon. Four trout species fall under ESA categories, including populations of cutthroat (*O. clarkii*), bull trout, dolly varden (*Salvelinus malma*), and steelhead (*O. mykiss*). Green sturgeon (*Acipenser medirostris*) along with two *Gila* species, Tui chub and Borax Lake Chub (*G. boraxobius*), are also documented in the region. Nineteen fish species are considered potadromous or anadromous, the majority of which are salmon or trout. The Lower Columbia, Grande Ronde, and Willapa Bay subbasins are among the 19 critical watersheds in the region. Twenty-eight species have critical habitat designations in Region 17, including 3 birds (marbeled murrelet, northern spotted owl, and western snowy plover), 1 crustacean (vernal pool shrimp), 15 fish, 2 insects, 1 mammal (Canada lynx), and 6 plants, as noted in Figure 20.6 and Appendix B. ESA and IUCN listed fish, potadromous fish, and critical habitats are documented in all subregions (Table 20.3).

Over 110 million acres of protected lands are identified in Region 17 (57% of total area, Figure 20.7). Most of the protected lands are federally owned (83%), followed by state (8.5%), and Native American ownership (6.6%). The predominant owner of protected lands is the USFS (49%), followed by BLM (27%), Bureau of Indian Affairs (6.6%), and NPS (3.25). Among the largest national parks are Glacier (635k acres), Yellowstone (448k acres), Grand Teton (310k acres), Mount Rainier (236k acres), and Mt. St. Helens (110k acres). Nineteen percent of protected lands fall under GAP 1 and 2 statuses, while 70% and 10% fall under GAP 3 and 4 statuses, respectively (Figure 20.7). Fifty-one river sections, totaling almost 3900 km of river, are protected under the Wild and Scenic Rivers Act. Recreation locations are abundant in region 17, including 1595 boat ramps, 1157 freshwater fishing access areas, 550 waterfalls, and 867 recreational boating river sections.

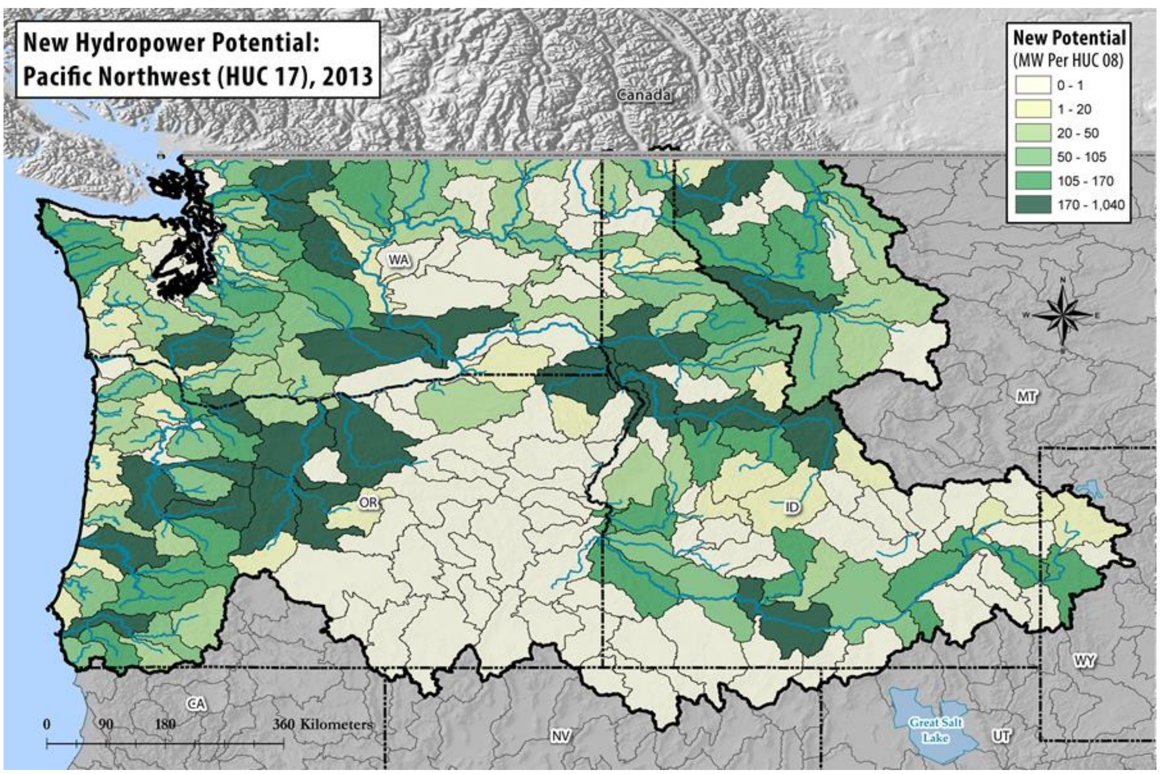

Figure 20.4. Potential new hydropower capacity in Region 17—Pacific Northwest (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC08 subbasins for illustration).

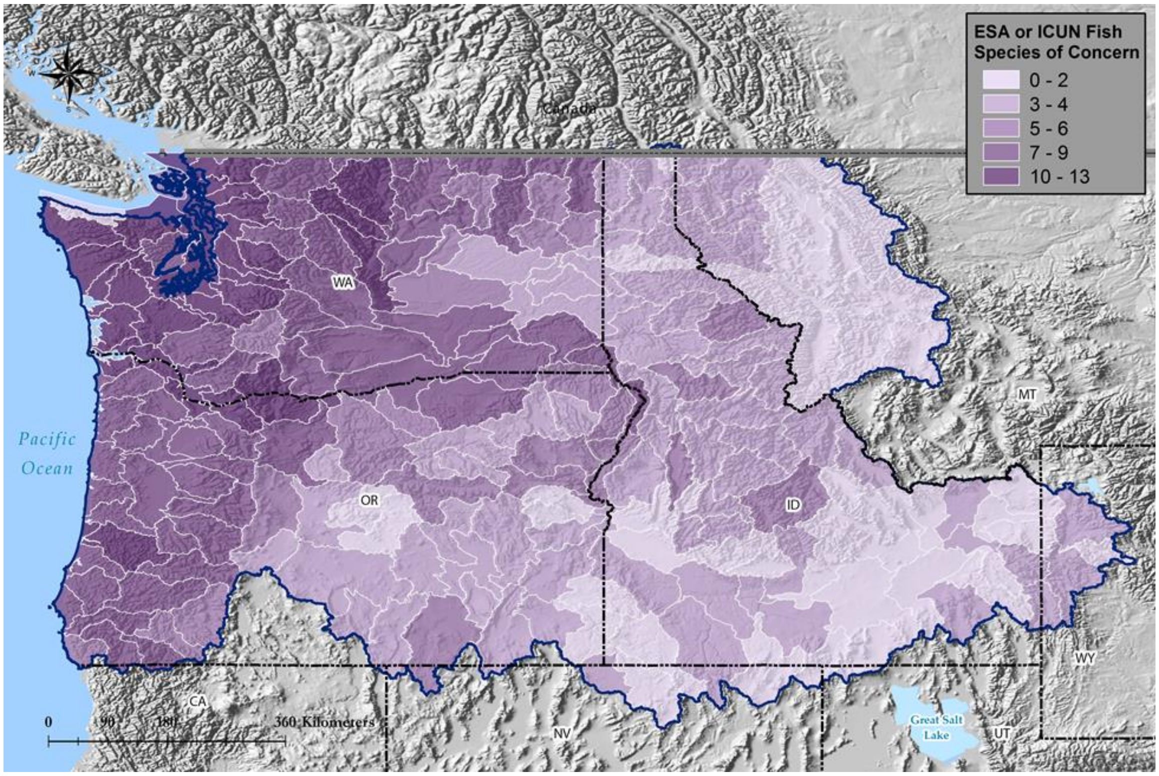

Figure 20.5. Fish species of concern (number per HUC08 subbasin) in Region 17.

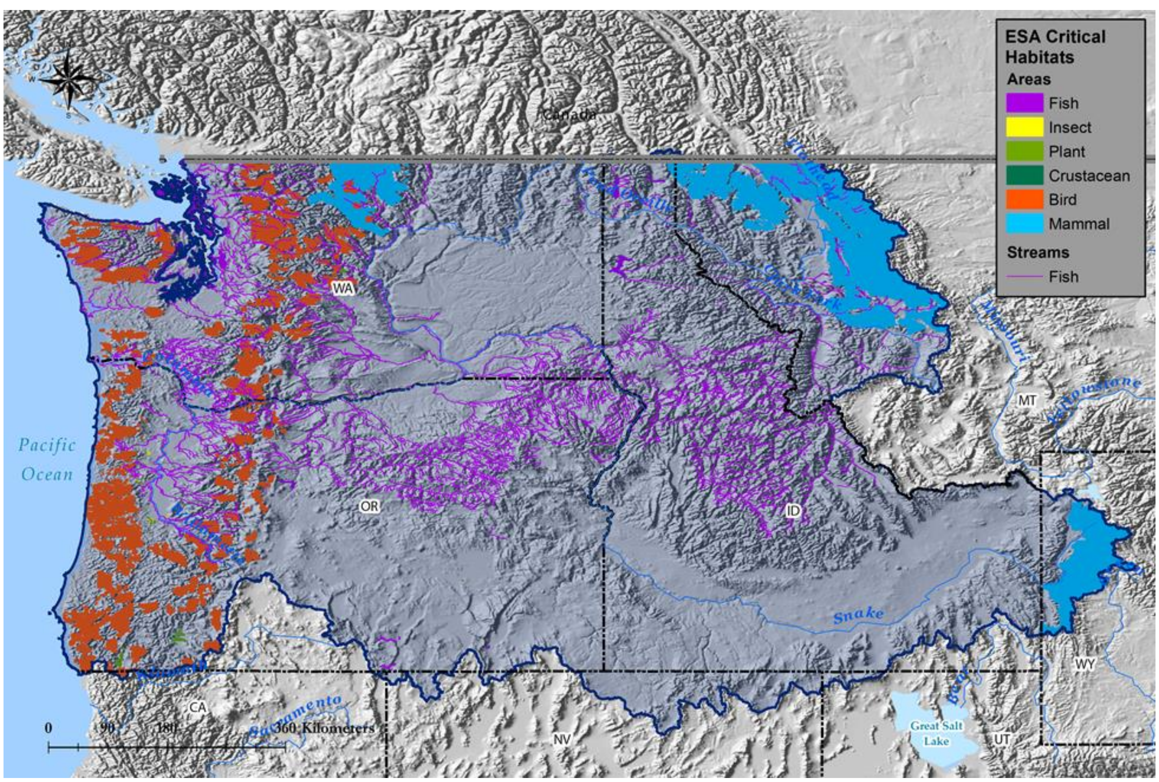

Figure 20.6. Critical habitats for federally endangered and threatened species in Region 17.

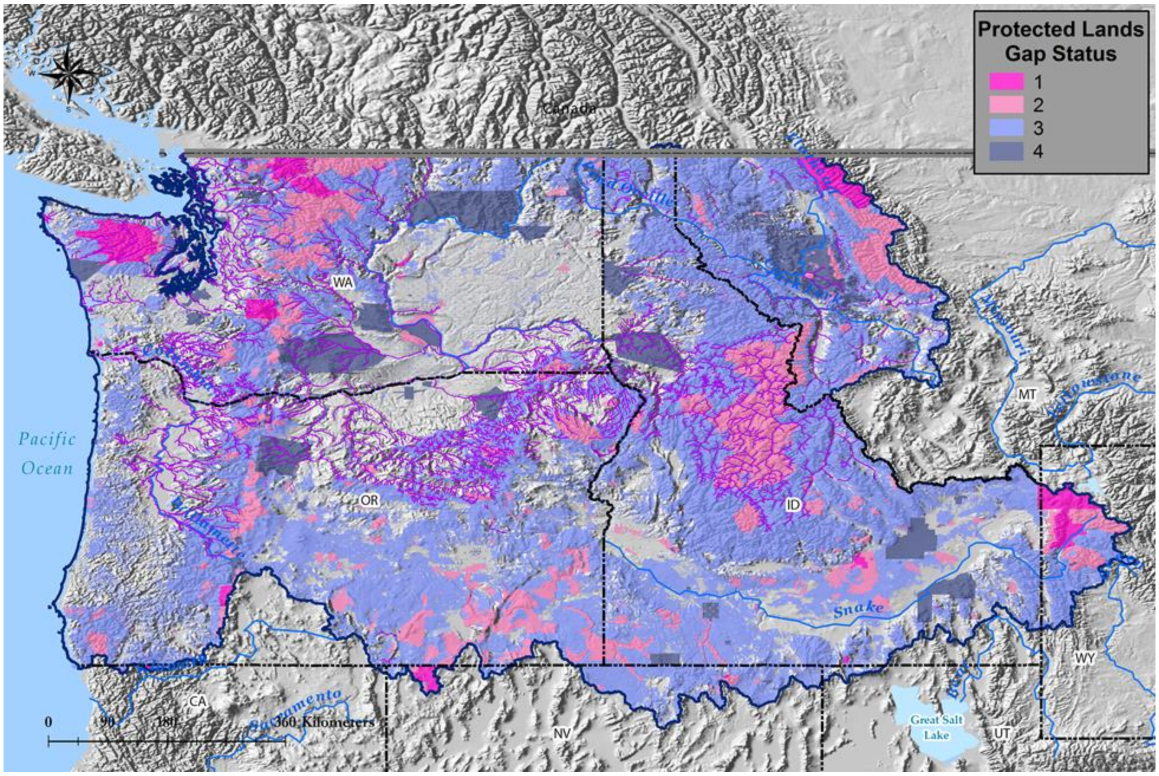

Figure 20.7. Protected lands according to Gap Status (conservation management regime) in Region 17.

Table 20.3. Summary of Environmental Variables at HUC04 Subregions within Region 17 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# Critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	# Recreation locations[a]	% Protected lands	Population density (ind/km^2)	Freshwater use (liters/ day/km^2)
1701	Kootenai–Pend Oreille–Spokane	4	8	8	1	283; 77; 65	66.50	11.94	584.59
1702	Upper Columbia	7	9	11	1	221; 35; 34	40.64	6.28	1,228.79
1703	Yakima	4	7	10	1	41; 19; 6	45.64	17.06	2,428.92
1704	Upper Snake	1	4	6	3	191; 57; 63	65.84	4.89	5,347.28
1705	Middle Snake	1	5	7	2	208; 47; 16	71.86	6.35	2,379.08
1706	Lower Snake	2	6	9	1	170; 88; 26	66.81	3.54	685.44
1707	Middle Columbia	10	6	11	1	218; 60; 52	37.62	5.83	1,215.52
1708	Lower Columbia	10	8	11	2	92; 76; 68	48.53	56.89	1,092.68
1709	Willamette	12	8	11	3	287; 113; 66	37.89	79.80	1,589.98
1710	Oregon–Washington Coastal	11	9	12	4	511; 149; 80	49.91	16.20	505.89
1711	Puget Sound	9	11	11	3	454; 145; 73	45.70	103.38	688.68
1712	Oregon Closed Basins	4	4	7	4	43; 1; 1	78.25	0.85	779.63

[a]Recreation locations refer to the number of boat-ramp and fishing access points, recreational boating, and waterfalls within each HUC04.

Population density is highest in the Puget Sound and Willamette subbasins and lowest in the Upper and Middle Snake River subbasins (Table 20.3). Water use is moderate in region 17 compared with other regions of the country (Appendix B); however, water usage is relatively high in the Middle and Lower Columbia subbasins (Table 20.3). Irrigation is by far the largest water usage category (Appendix B). Water quality concerns are average in region 17 compared with other regions of the United States, with most concerns classified as mercury/metal contamination, temperature, and algal issues.

Out of 3793 stream-reaches, 83% intersect at least one critical habitat (Figure 20.8). Almost all stream-reaches (99.9%) fell into HUC08 subbasins with at least one fish falling under an ESA category. Likewise, 99% of stream-reaches intersect protected lands, with 4.2% of stream-reaches (353 MW) overlapped with national parks and 41% (> 5.99 GW) overlapped with Wild and Scenic Rivers. Almost 66% of stream-reaches are associated with water quality concerns. Recreation is abundant with recreational boating, boat ramps, and fishing access areas intersecting 81%, 25%, and 78% of stream-reaches, respectively. Water use values are about equally distributed among stream-reaches in this region.

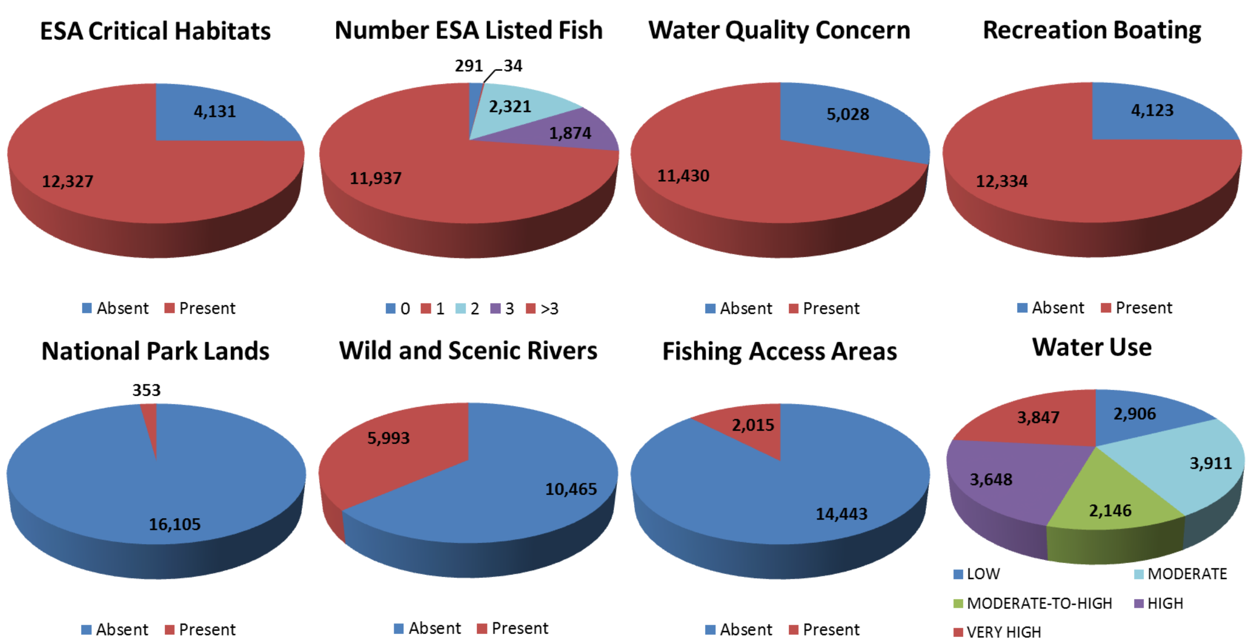

Figure 20.8. The potential capacity, in MW, associated with environmental attributes in Region 17—Pacific Northwest (stream-reaches with potential capacity >1 MW).

21. REGION 18—CALIFORNIA

21.1. Summary of Findings

Following NSD methodology (Hadjerioua et al., 2013), the potential capacity, annual generation, and mean capacity factors in the California Region are estimated and summarized in Table 21.1 for both larger (>1 MW) and smaller (<1 MW) stream-reaches. For comparison, the year-2011 nameplate capacity, 2002–2011 average annual generation, and capacity factor of existing hydropower facilities are also listed (NHAAP, 2013). The total undeveloped NSD capacity is 7.05 GW, around 69% of existing conventional hydropower nameplate capacity. In terms of energy, the total undeveloped NSD generation is 37.99 TWh/year, around 112% of annual net generation from existing conventional hydropower plants. Given the run-of-river assumption, NSD stream-reaches have higher capacity factors, especially compared with other larger-storage peaking-operation projects in this region. More detailed topographical analysis and environmental attribution are conducted for larger (>1 MW) stream-reaches and discussed in Sections 21.3 and 21.4.

Table 21.1. Summary of NSD Findings in Region 18—California

	Capacity (MW)	Generation (MWh)	Mean capacity factor
Potential in undeveloped stream-reaches (>1 MW)	4,029	22,108,000	63%
Potential in undeveloped stream-reaches (<1 MW)	3,025	15,879,000	60%
Existing hydropower—conventional hydro	10,292	34,034,000	38%
Existing hydropower—pumped storage	3,393		

21.2. Background Hydrologic Setting

The California Region encompasses approximately 417,288 km^2 in the Western United States. The region consists of most of the state of California and much smaller sections of southern Oregon and southwest Nevada. The region comprises mountains, plateaus, and a major river plain. The coastal mountain range, the Cascade Mountain range, and the Rocky Mountain Range encompass the Columbia and Central Oregon Plateau, and the Snake River Plain.

Several river systems are located in the California Region (Figure 21.1), including the Smith, Klamath, Sacramento, San Joaquin, and San Gabriel rivers, with a total length of 21,545 km (i.e., total length of streams with estimated discharge greater than 35 cfs). Metropolitan areas within the region include all the major cities in California—Los Angeles, San Diego, and Sacramento—in addition to Oregon's Klamath Falls. As shown in Figure 21.2, annual precipitation for the California region ranges from 380 to 950 mm/year, and annual runoff ranges from 100 to 450 mm/year. Most precipitation occurs in the winter months.

The existing hydropower plants and major non-powered dams (Hadjerioua et al., 2012) are also shown in Figure 21.1. The California Region contains 388 hydropower dams and 20 major non-powered dams, with total storage capacities of around 72,054,825 ac-ft and 914,994 ac-ft, respectively.

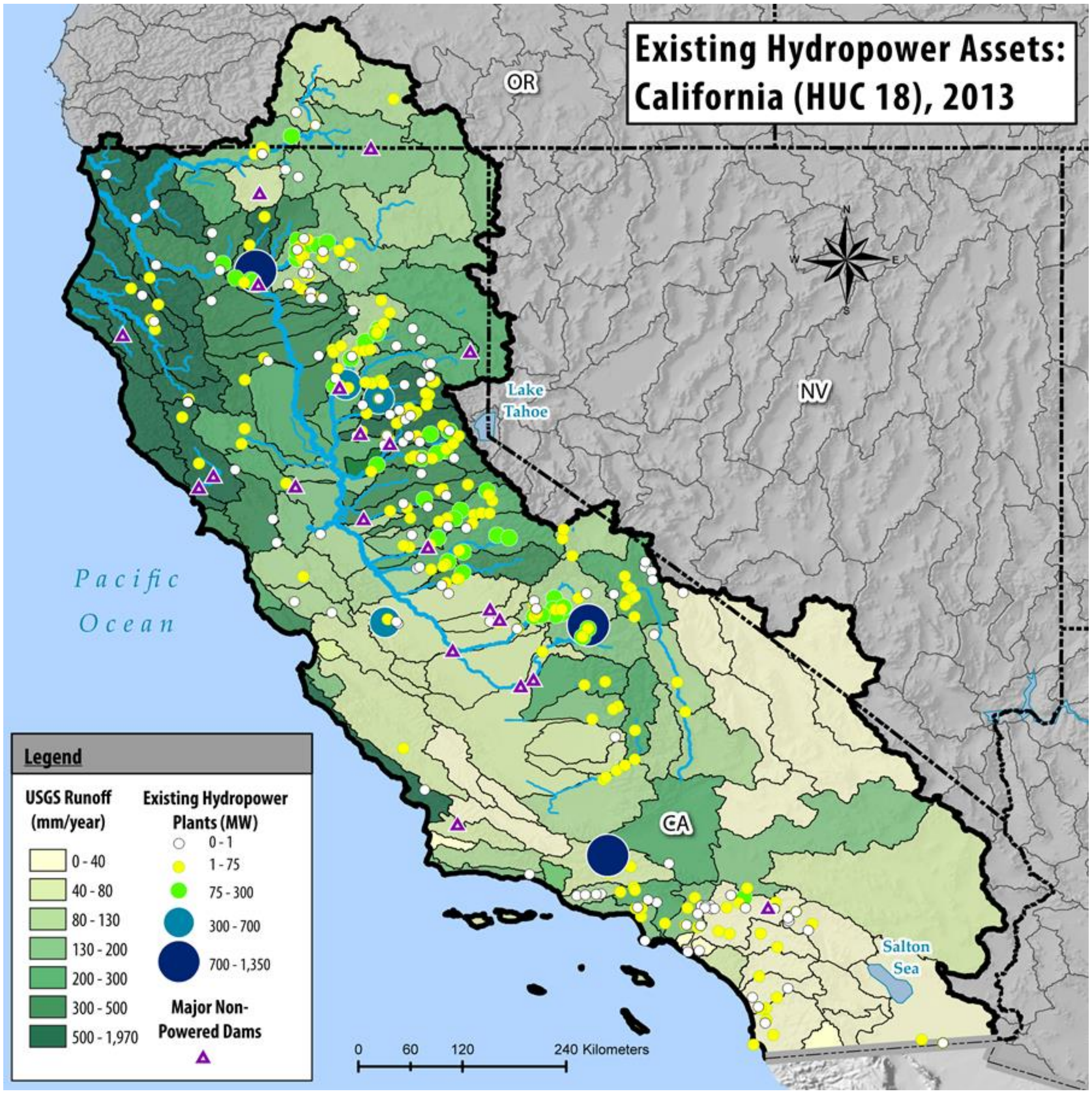

Figure 21.1. Locations of water control projects in Region 18—California.

21.3. Potential New Hydropower Resources

A total of 1145 stream-reaches of high energy density (with estimated potential capacity >1 MW per stream-reach) are identified in the California Region. The NSD results based on HUC04 subregions are summarized in Table 21.2. The highest hydropower potentials are located in the Klamath–Northern California Coastal Subregion (HUC 1801), followed by the Sacramento Subregion (HUC 1802). The hydropower potential in the remaining subregions is much lower. The highest hydropower potential in the Klamath–Northern California Coastal Subregion are located in the Klamath and Trinity rivers and to a lesser extent in the South Fork Smith, Eel, Salmon, and Smith rivers. For the Sacramento Subregion, the highest potential for hydropower is located mostly in the Sacramento River and, to a lesser extent, the Middle Fork American, McCloud, Feather, and Yuba rivers.

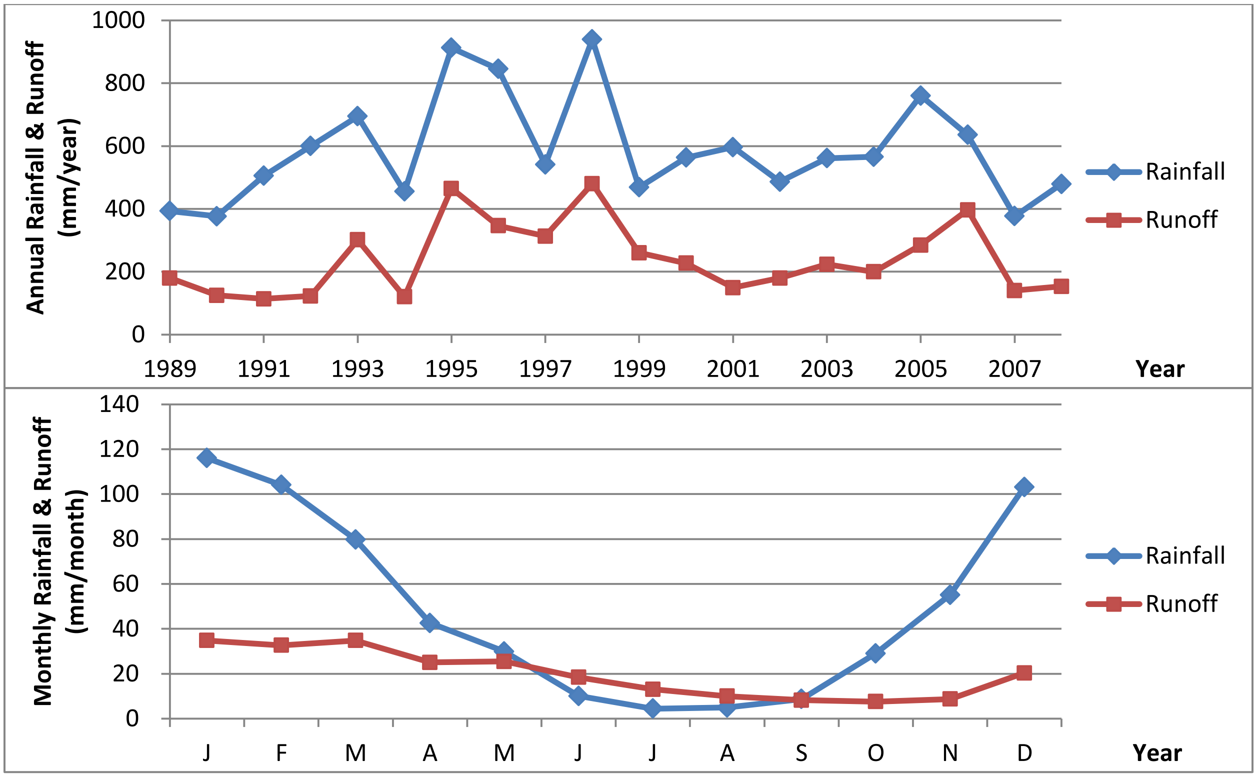

Figure 21.2. Annual and monthly rainfall and runoff of Region 18—California.

Table 21.2. Summary of Potential New Hydropower Resources in Region 18—California (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# of stream-reaches	Potential capacity (MW)	Potential energy (MWh)	Average head (ft/reach)	Average flow (cfs/reach)	Average storage (ac-ft/reach)	Average residence time (days)
1801	Klamath–Northern California Coastal	449	2,485.5	12,941,370	30.2	2,782	1,606	0.8
1802	Sacramento	435	1,062.4	6,509,479	27.3	1,695	2,756	2.0
1803	Tulare–Buena Vista Lakes	72	114.3	592,711	23.2	1,278	4,991	2.1
1804	San Joaquin	174	339.5	1,871,301	27.7	1,158	10,198	2.3
1805	San Francisco Bay	-	-	-	-	-	-	-
1806	Central California Coastal	-	-	-	-	-	-	-
1807	Southern California Coastal	-	-	-	-	-	-	-
1808	North Lahontan	-	-	-	-	-	-	-
1809	Northern Mojave–Mono Lake	15	27.3	193,242	16.7	1,517	7,145	2.9
1810	Southern Mojave–Salton Sea	-	-	-	-	-	-	-

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 in Figure 21.3. The hydraulic head H_{ref} ranges from 7 to the 90th quantile of 48 ft with a median of 23 ft, suggesting that most of the potential stream-reaches in theCalifornia region may require low-head hydropower technologies. The design flow Q_{30} ranges from 300 to the 90th quantile of 5000 cfs with a median of 1200 cfs. The potential capacity P_{NSD} ranges from 1 to the 90th quantile of 8 MW with a median of 2.5 MW. The inundated surface area A_{NSD} ranges from about 10 to the 90th quantile of 300 acres with a median of 50 acres. This results in storage values V_{NSD} ranging from 200 to the 90th quantile of 4000 ac-ft with a median of 500 ac-ft and very short residence times T_{NSD} ranging from <1 day to the 90th quantile of 2 days with a median on the order of hours. The results of > 1 MW stream-reach potential are illustrated in Figure 21.4, with potential capacity (MW) aggregated to the HUC08 subbasins. In general, higher potential capacity is located in the mountainous regions.

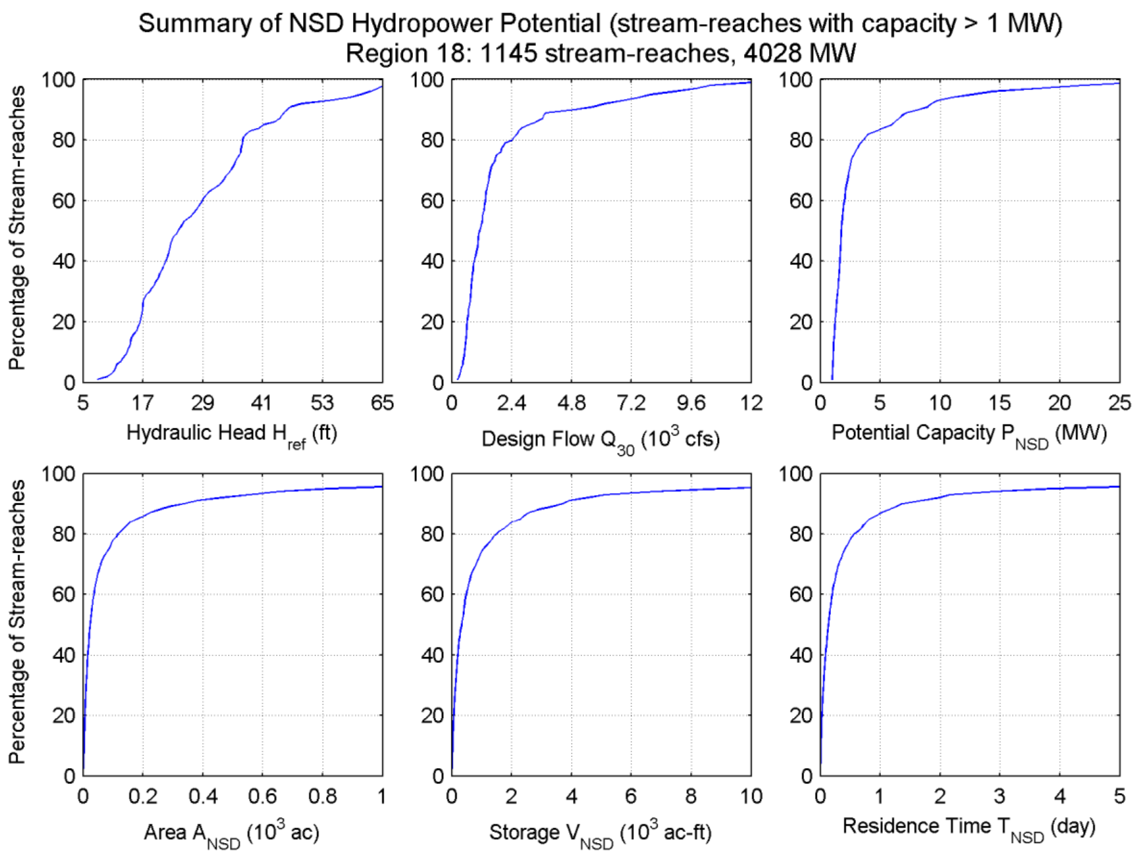

Figure 21.3. Cumulative distributions of hydraulic head H_{ref}, design flow Q_{30}, potential capacity P_{NSD}, inundated area A_{NSD}, storage V_{NSD}, and residence time T_{NSD} in Region 18—California.

21.4. Environmental Characteristics

The California Region is home to at least 60 fish species, 21 of which are listed or have a population listed under ESA categories (Figure 21.5). An additional five species fall under IUCN vulnerability categories (Figure 21.5). Similar to Region 17, many of these species are salmon or trout. Fourteen species are potadromous or anadromous. There are at least eight different steelhead populations, two Chinook salmon populations, and one Coho salmon population in this region. Although Chum salmon is found in the region, population status is uncertain as small spawning runs are confined to the Klamath, Trinity, and Smith rivers (UC, 2013). Only a sub-species of Sockeye Salmon (Kokanee) is reported in this region (Lake Tahoe) (UC, 2013).

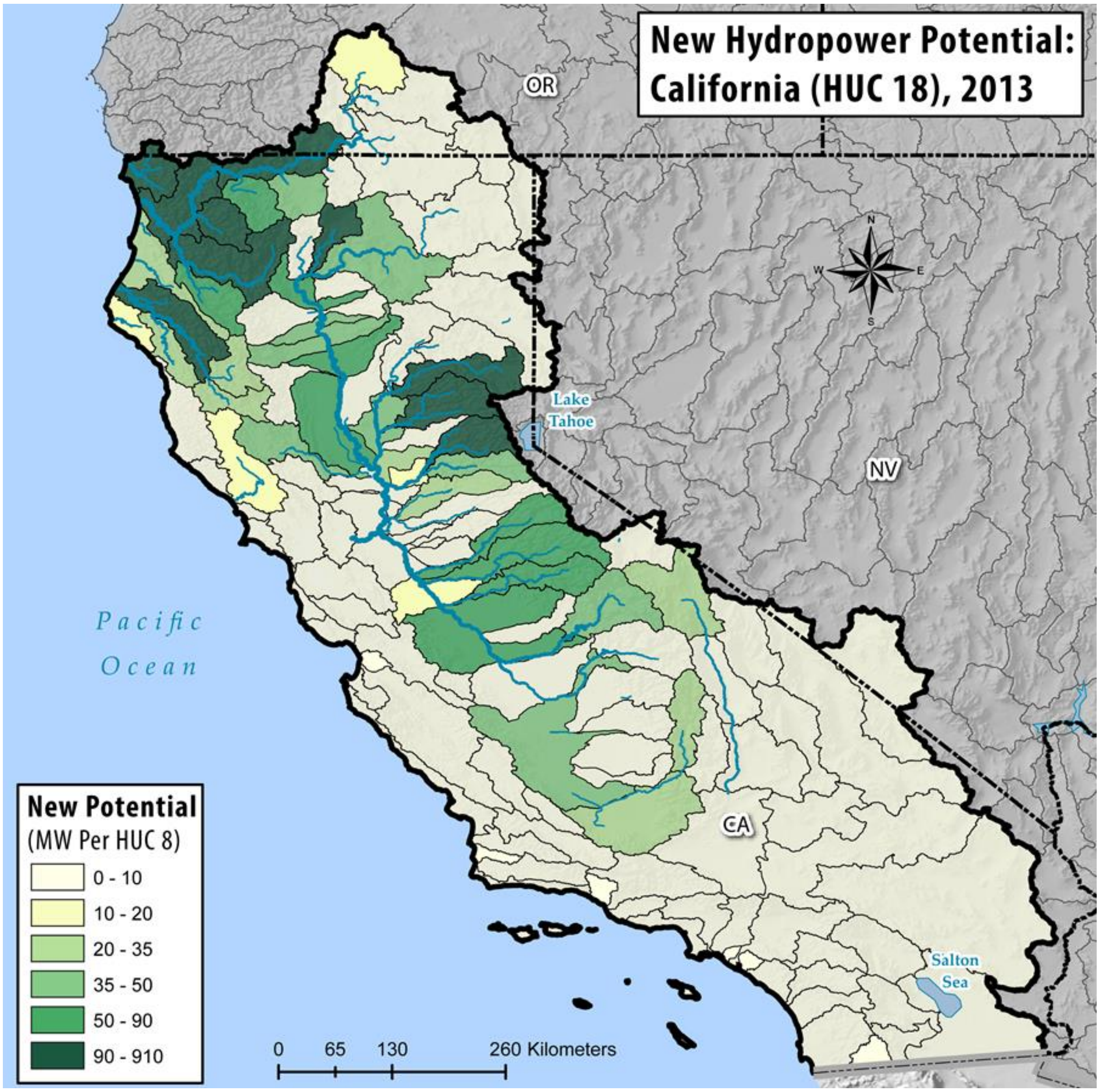

Figure 21.4. Potential new hydropower capacity in Region 18 California (higher-energy-density stream-reaches with >1 MW per reach, aggregated to HUC08 subbasins for illustration).

Several pupfish species (*Cyprinodon* spp.), sucker species (*Deltistes*, *Chasmistes*, *Catostomus* spp.), and white sturgeon (*Acipenser transmontanus*) are among other listed or vulnerable species in the region. Critical watersheds make up over 20% of the subbasins in the region, with the Lost (10 species), Upper Klamath Lake (9 species), and Sprague (8 species) subbasins having the highest number of fish species at risk. In Region 18, over 100 species have critical habitat designations, more than any other region in the conterminous United States (Figure 21.6). Species with critical habitats in Region 18 include 14 fish, many of which are mentioned above.

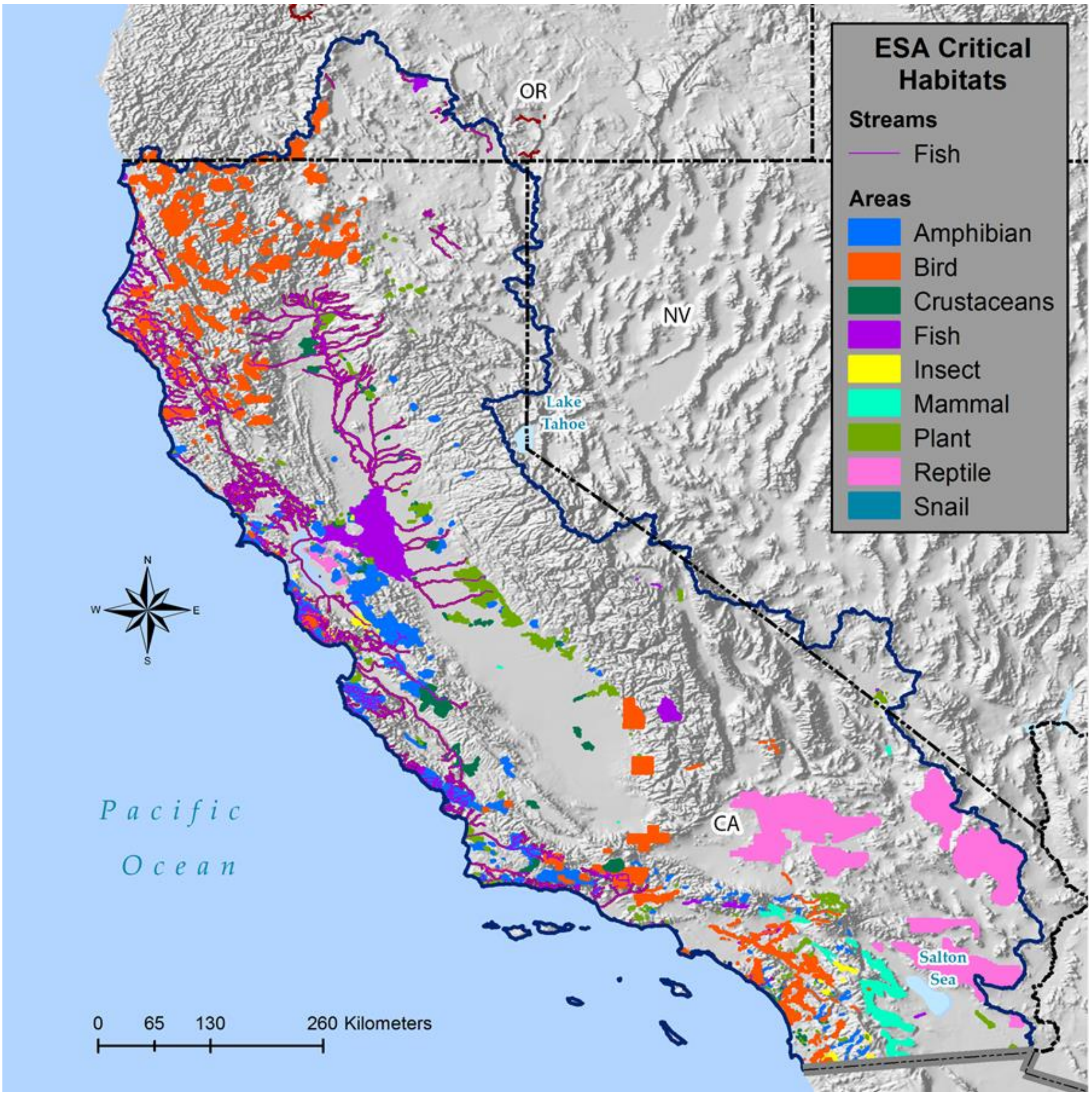

Figure 21.5. Critical habitats for federally endangered and threatened species in Region 18.

The California Region has a wide array of different protected lands, ranging from open BLM and national forests to national parks and monuments. In Region 18, there are over 57 million acres of protected land, which is more than 53% of the total area. Most protected lands are federally owned (91%), followed by state (4%) and local government lands (2%). Federal lands are owned primarily by the USFS (37%), BLM (32 %), NPS (13%), and DOD (7.3%). The largest tracts of land are held by the BLM, followed by Death Valley National Park and California Coastal National Monument. Many national forests are found in the region, among the largest including Modoc, Fremont–Winema, Shasta–Trinity, Klamath, Plumas, Lassen, Los Padres, Inyo, Sierra, and Sequoia. In addition to many national parks, monuments and preserves are found throughout Region 18, including Mojave National Preserve, John Muir National Monument, and Joshua Tree, Sequoia–Kings Canyon, and Yosemite national parks. Yosemite Falls, located within Yosemite National Park, is the highest waterfall in the United States with a vertical drop of 2425 ft. Among the largest DOD lands are China Lake Naval Air Weapons Station and Fort Irwin. Most of the protected lands fall under GAP status 3 (52%), followed by status 2 (20%) and status

1 (19%) lands. In Region 18, 16 river sections are protected under the NWSRA, totaling over 2600 river km. Recreation includes 544 boat ramps, 351 freshwater fishing access locations, 165 waterfalls, and 347 recreational boating river sections.

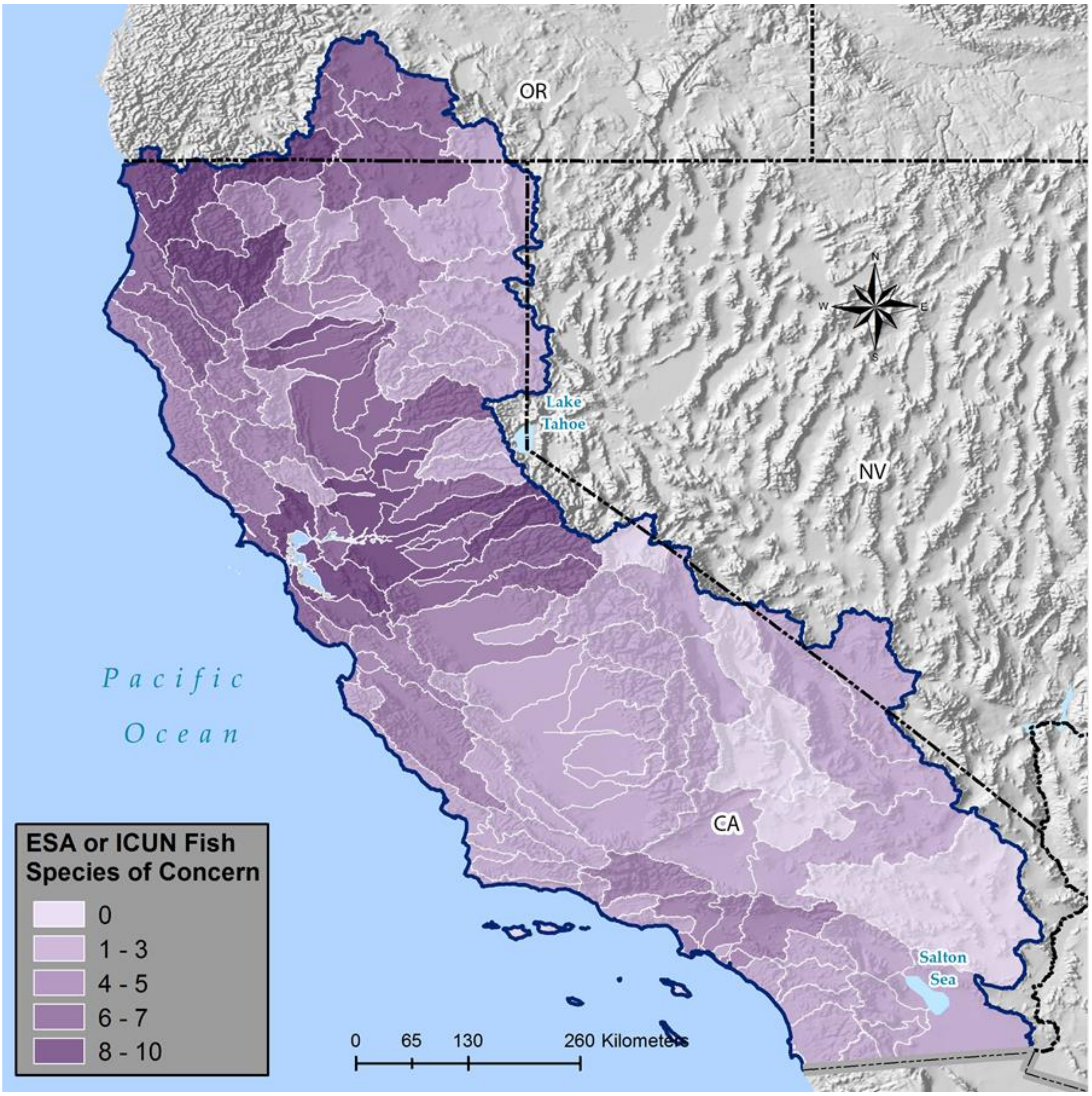

Figure 21.6. Fish species of concern (number per HUC08 subbasin) in Region 18.

Water use is above the national average in Region 18 with the Tulare–Buena–Vista Lakes and San Joaquin subregions having the highest values (Table 21.3). Irrigation consumption is quite high, followed by public consumption (Appendix B). Water quality concerns are average for the nation with most issues classified as elevated nutrient loads, toxins, or mercury contamination (Appendix B).

Critical habitat designations are present at 56% of stream-reaches (> 2.99 GW) in Region 18 (Figure 21.7). All stream-reaches are located in HUC08 subbasins with at least one fish falling under an ESA category. Almost 99% of stream-reaches intersect protected lands, with 4.2% of reaches overlapping national parks (145 MW) and 59% (> 2.9 GW) overlapping Wild and Scenic

Rivers. Water quality concerns are present at 50% of stream-reaches. Recreational boating is abundant, identified at 85% of stream-reaches; however, boat ramps and fishing access areas are less prevalent, identified at approximately 9% and 14% of stream-reaches, respectively. Approximately, 50% of stream-reaches are associated with low or moderate water use.

Table 21.3. Summary of Environmental Variables at HUC04 Subregions within Region 18 (Stream-Reaches with Potential Capacity >1 MW)

HUC04	HUC04 name	# Critical habitats	# Potad-anad fish	# ESA fish	# IUCN fish	# Recreation locations[a]	% Protected lands	Population density (ind/km^2)	Freshwater use (liters/day /km^2)
1801	Klamath–Northern California Coastal	12	11	13	6	145; 82; 18	50.34	13.69	668.87
1802	Sacramento	21	8	10	5	247; 113; 37	40.49	42.77	3,664.09
1803	Tulare–Buena Vista Lakes	13	3	2	1	38; 44; 15	31.87	35.48	6,647.19
1804	San Joaquin	21	6	6	4	143; 74; 42	34.91	76.97	6,050.93
1805	San Francisco Bay	17	8	8	4	47; 8; 14	27.48	444.02	3,043.11
1806	Central California Coastal	32	5	5	1	33; 12; 10	33.04	65.00	1,143.16
1807	Southern California Coastal	38	0	5	2	138; 13; 16	41.66	566.10	3,781.03
1808	North Lahontan	1	2	2	0	7; 1; 0	61.90	5.25	759.61
1809	Northern Mojave–Mono Lake	27	0	6	2	51; 1; 8	84.93	43.37	896.27
1810	Southern Mojave–Salton Sea	20	0	1	0	16; 0; 5	80.03	109.47	3,110.28

[a]Recreation locations refer to the number of boat-ramp and fishing access points, recreational boating, and waterfalls within each HUC04.

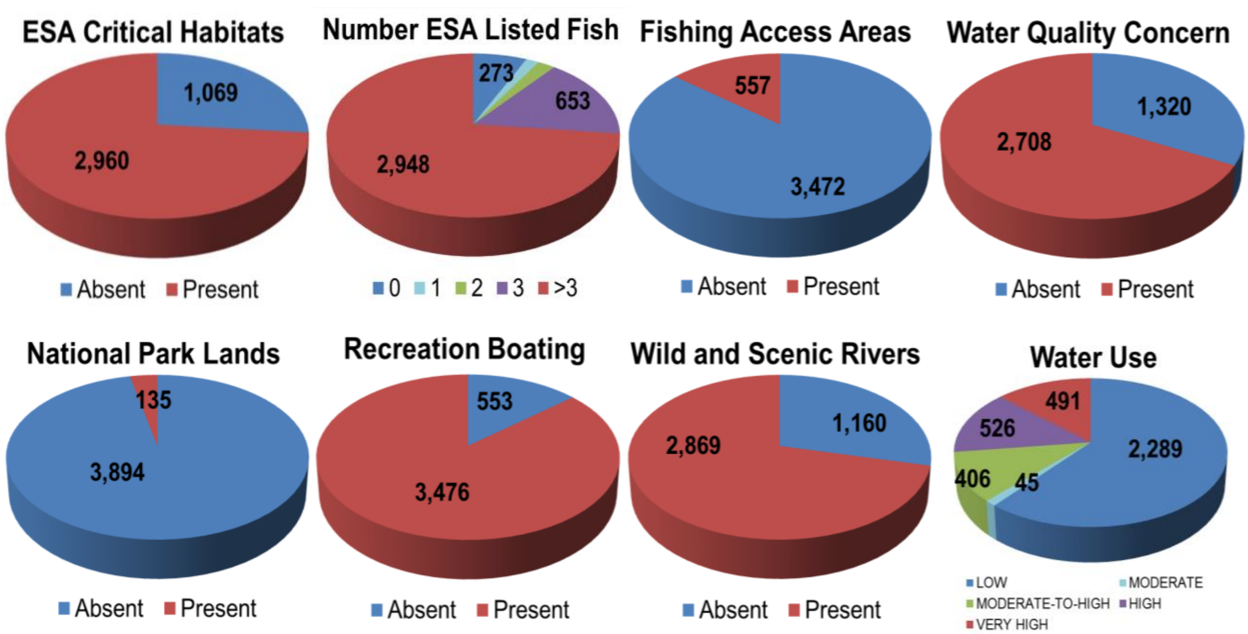

Figure 21.7. The potential capacity, in MW, associated with environmental attributes in Region 18—California (stream-reaches with potential capacity >1 MW).

22. REGION 19—ALASKA

22.1. Background and Data Collection

Hydropower is the largest source of renewable energy in Alaska, producing around 20% of the state's annual energy. The abundant hydrologic resources in Alaska maintain hydropower as an ideal and highly potential source of new capacity. Nevertheless, given data limitations (e.g., no NHDPlus coverage), the NSD resource potential cannot be evaluated through the same approach as used for the conterminous United States. Instead of conducting a new geospatial assessment based on limited data, this analysis relied on inputs from Alaska Energy Authority (AEA) and USACE Alaska District to summarize undeveloped hydropower potential from existing literatures.

The primary documentation source of undeveloped hydropower resources in Alaska is the AEA Hydropower Database (AEA, 2011), a comprehensive online hydropower database containing evaluated sites summarized in hundreds of hydropower reports since 1947. These reports range from reconnaissance-level studies with limited information to FERC permitting documents containing a wealth of information, such as design-level cost estimates.

22.2. Data Processing and Quality Control

Given that some project information in the AEA database was obtained from earlier studies, quality control was performed to select suitable sites according to the NSD objectives. Data for a total of 2,200 projects from 404 reports were included. Initial data screening was jointly conducted with the AEA and USACE staffs to identify duplicate or overlapping projects in multiple reports. In addition, high-level feasibility analysis was performed to exclude sites based on the following criteria jointly developed by AEA and USACE staffs:

1. Sites too large for rural hydroelectric production purposes
2. Sites involving land compatibility issues
3. Sites involving environmental concerns
4. Negative evaluation in original report
5. Sites located too far from the nearest community
6. Sites that are being or have been developed
7. Sites not feasible based on professional judgment
8. Other miscellaneous issues

The original database contains a conglomerate of information, often with inconsistent measurement units and types. Therefore, data were converted to consistent units, with a focus on run-of-river projects with estimated net head, annual average, and other essential information. In cases where a range of head, flow, or capacity is provided, an engineering judgment was made to select the most appropriate value. Efforts were also made to screen potential unit conversion errors within the database.

Given the immense number of projects in the database and the effort needed to cross-reference source documentation for accurate information, more in-depth quality control was performed on selected references. Within the AEA database, many projects lack capacity information or have unrealistic capacity factor values. Upon evaluation, questionable references were identified and intensively reviewed to verify, update, and modify other information when appropriate. In addition, projects that fall under other resource classes(e.g., non-powered dams and existing infrastructure) were also excluded and satellite imagery was used for verification.

22.3. Results

For "feasible" NSD potential, 1143 of the original 2200 sites were removed for being unfeasible or not applicable. In addition, 466 sites were excluded, since the capacity information was not available in the AEA database. From the remaining 591 sites, 154 duplicates were removed, with preference given to designs according to the project type (level of effort), project feasibility, and report date, among other factors. The resulting 437 sites have a total potential capacity of 4,723 MW.

A map of existing and feasible NSD hydropower sites in Alaska is provided in Figure 22.1. Since feasible projects had to meet various high-level feasibility criteria, most identified hydropower potential is located in South-central or Southeast Alaska, near population centers or in mountainous terrain.

Figure 22.2 provides a graphical representation of NSD project size distribution. Of the 437 projects identified, 76% have a capacity of less than 5 MW. As seen in Figure 22.3, however, 75% of the total feasible NSD potential stems from 31 large hydropower projects above 30 MW. The single-largest NSD project identified could provide 820 MW of capacity, nearly double the total current installed capacity in Alaska.

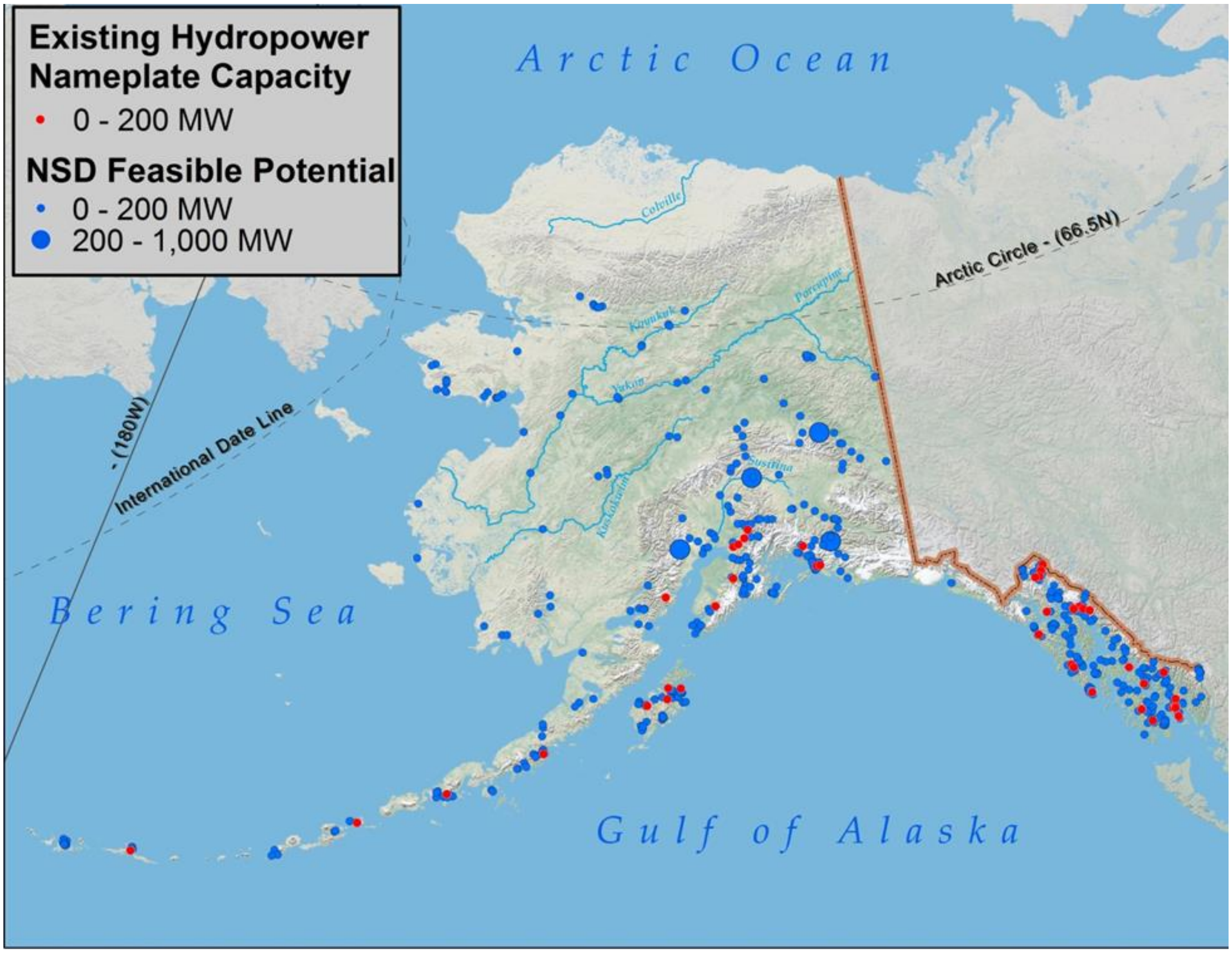

Figure 22.1. Map of existing and NSD hydropower sites in Alaska.

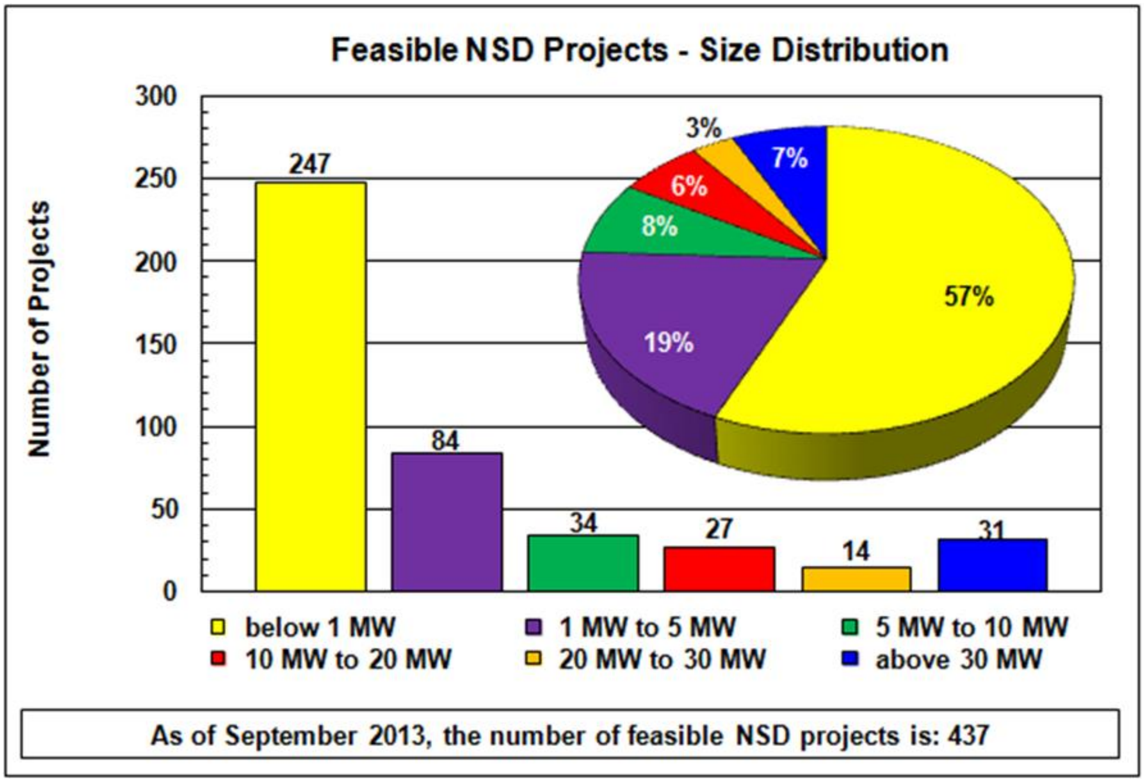

Figure 22.2. Project size distribution of Alaska NSD sites.

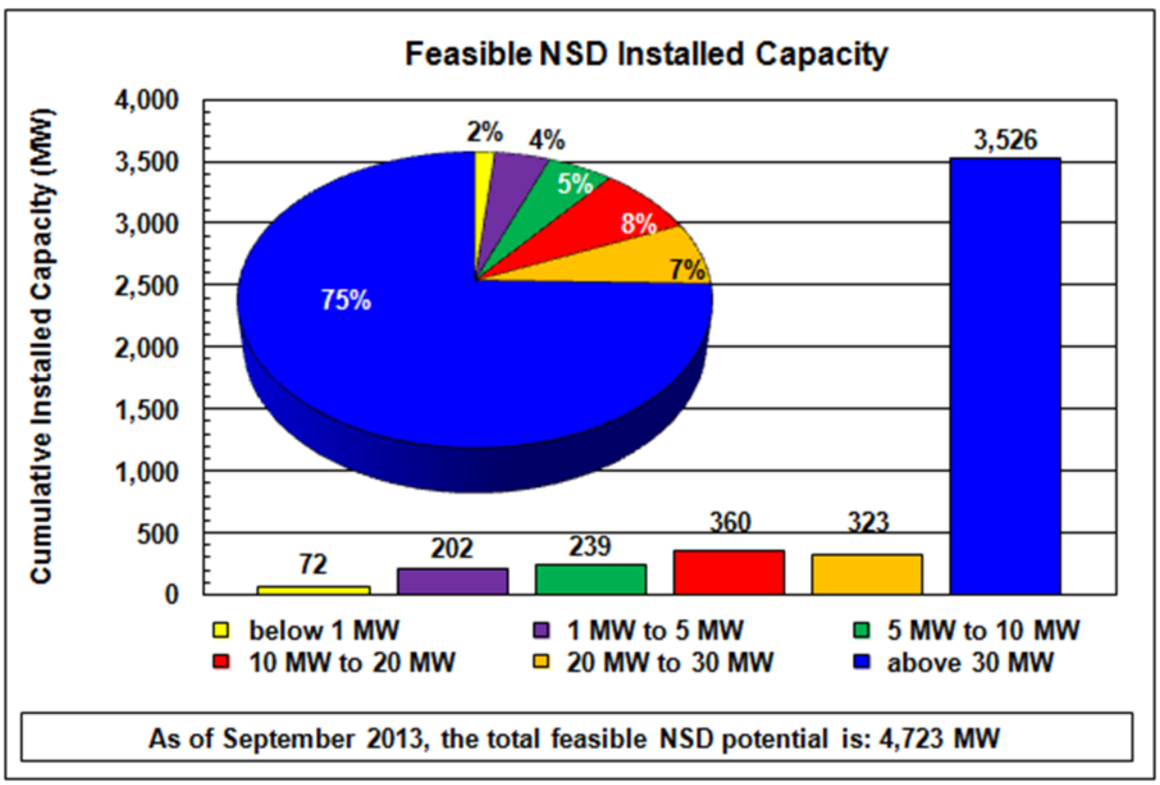

Figure 22.3. Cumulative potential installed capacity by size for Alaska.

23. REGION 20—HAWAII

23.1. Background and Data Collection

Given data limitations (e.g., no NHDPlus coverage), the NSD resource potential cannot be evaluated using the same approach as used for the conterminous United States. After consulting with the Hawaii Department of Business, Economic Development and Tourism (DBEDT) and USACE, the researchers decided to summarize the undeveloped hydropower potential from existing literatures rather than by conducting new geospatial assessment based on limited data. The USACE Honolulu District recently published a comprehensive assessment, *Hydroelectric Power Assessment—State of Hawaii*" (USACE, 2011) of Hawaii's current and potential hydropower resources. This study provided reconnaissance-level analysis of more than 160 potential sites collected from more than 50 previous studies. The status of potential sites ranged from operating, inactive, or previously-developed to proposed new projects; the study covered both conventional-hydro and pump-storage opportunities.

Because our focus is NSD potential, the operating, inactive, previously-developed, and pumped-storage projects were excluded from examination. Further quality control was performed by reviewing satellite images at project locations. Periodic consultation with USACE and DBEDT was also conducted to ensure the accuracy of the organized dataset.

23.2. Results

From the original 166 sites in USACE (2011), 76 existing, inactive, or duplicate sites were removed. In additional, 34 pumped-storage and 9 non-powered dam sites were also excluded. The remaining 47 potential projects, located across five different islands, are reported in this study.

A map of existing hydropower plant and NSD sites is shown in Figure 23.1. The island of Kauai has the most concentrated hydropower potential, while Hawaii and Maui also contain notable hydropower potential. The largest existing hydropower site—the 12 MW Wailuku River hydroelectric plant—is located on the island of Hawaii. Minor hydropower potential also has been identified on Molokai and Oahu.

Figure 23.2 provides a graphical representation of NSD project size distribution. Most of the identified projects would provide relatively low capacity—81% of identified sites are below 5 MW, and only three of the 47 sites are above 10 MW. Figure 23.3 shows the cumulative installed capacity for NSD projects, according to project size. The single-largest identified NSD site could provide 25 MW of capacity, representing 17% of the state's NSD potential. In addition, the nine sites with capacity above 5 MW comprise 65% of Hawaii's NSD potential. As noted by DBEDT staff and evidenced by the 34 identified projects removed from the USACE database, pumped storage hydropower is often considered for energy production in Hawaii, as flow availability is often highly seasonal.

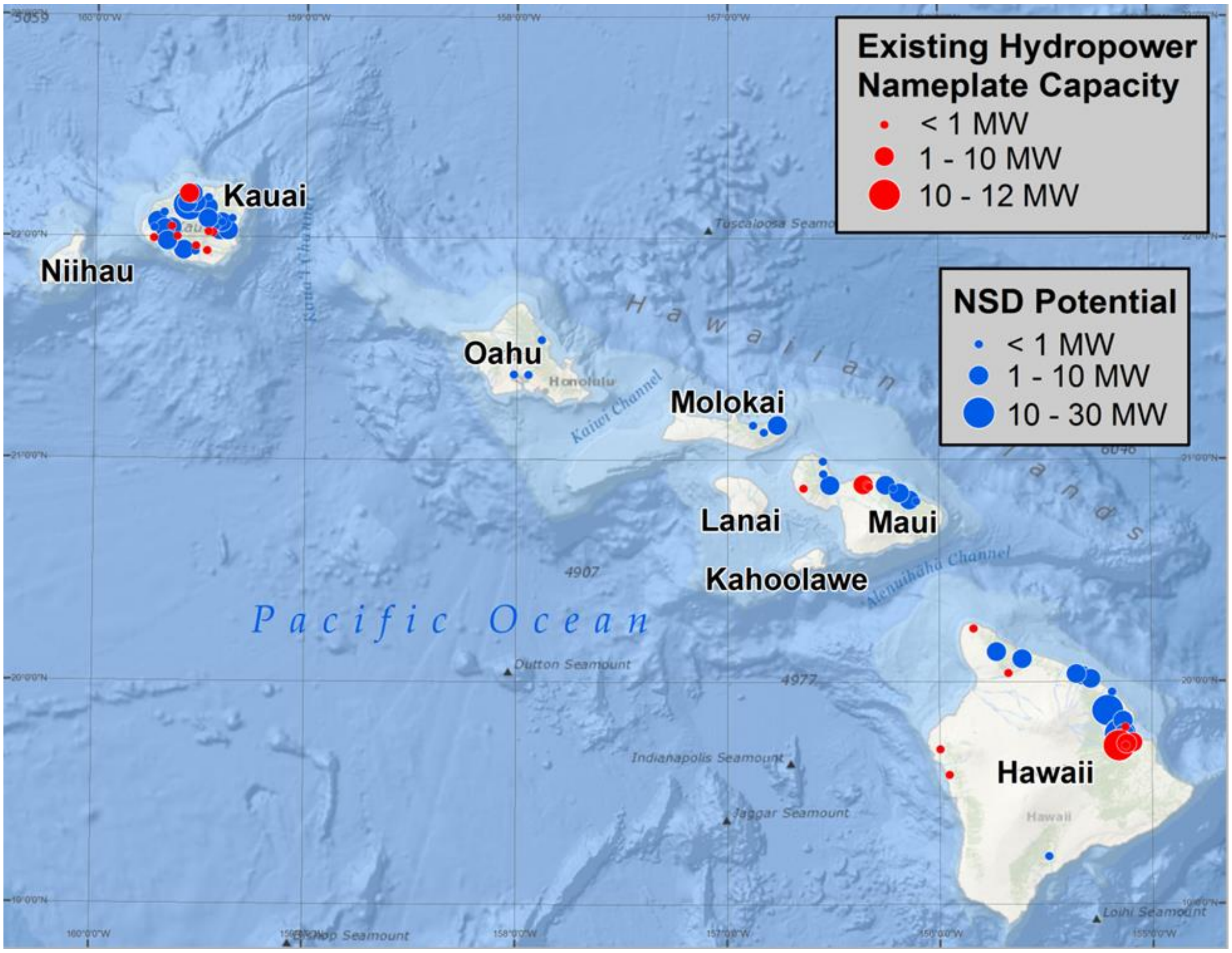

Figure 23.1. Map of existing and NSD hydropower sites in Hawaii.

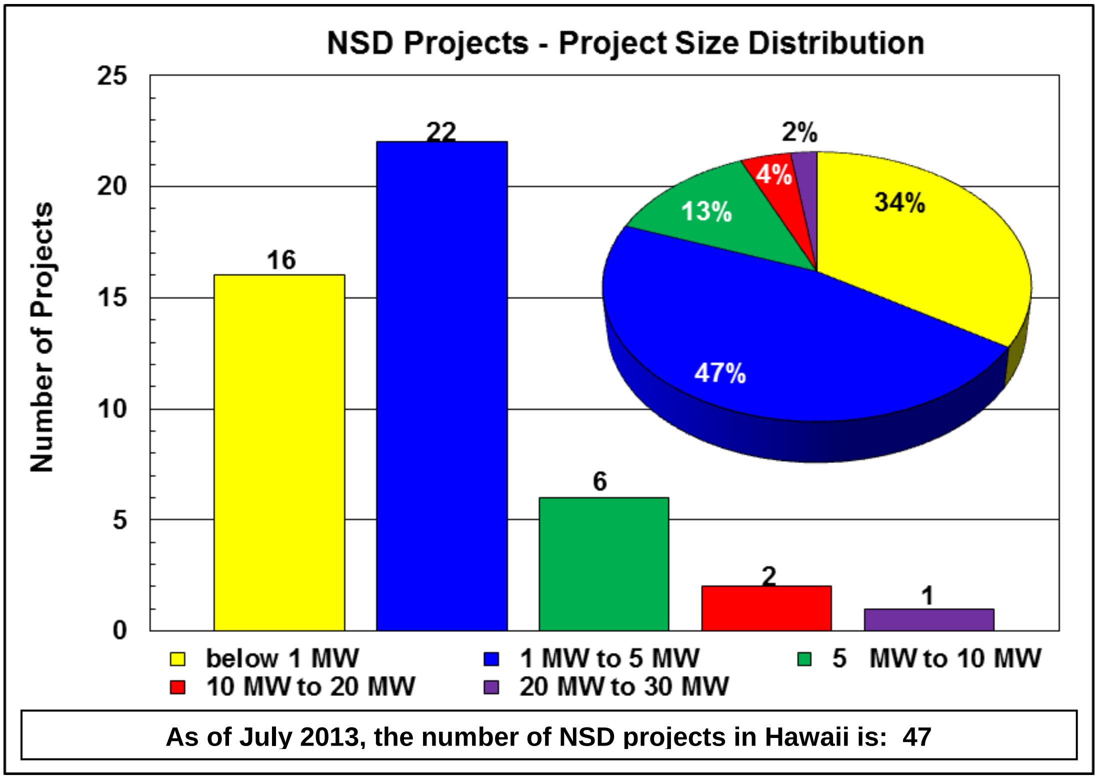

Figure 23.2. Project size distribution of Hawaii NSD sites.

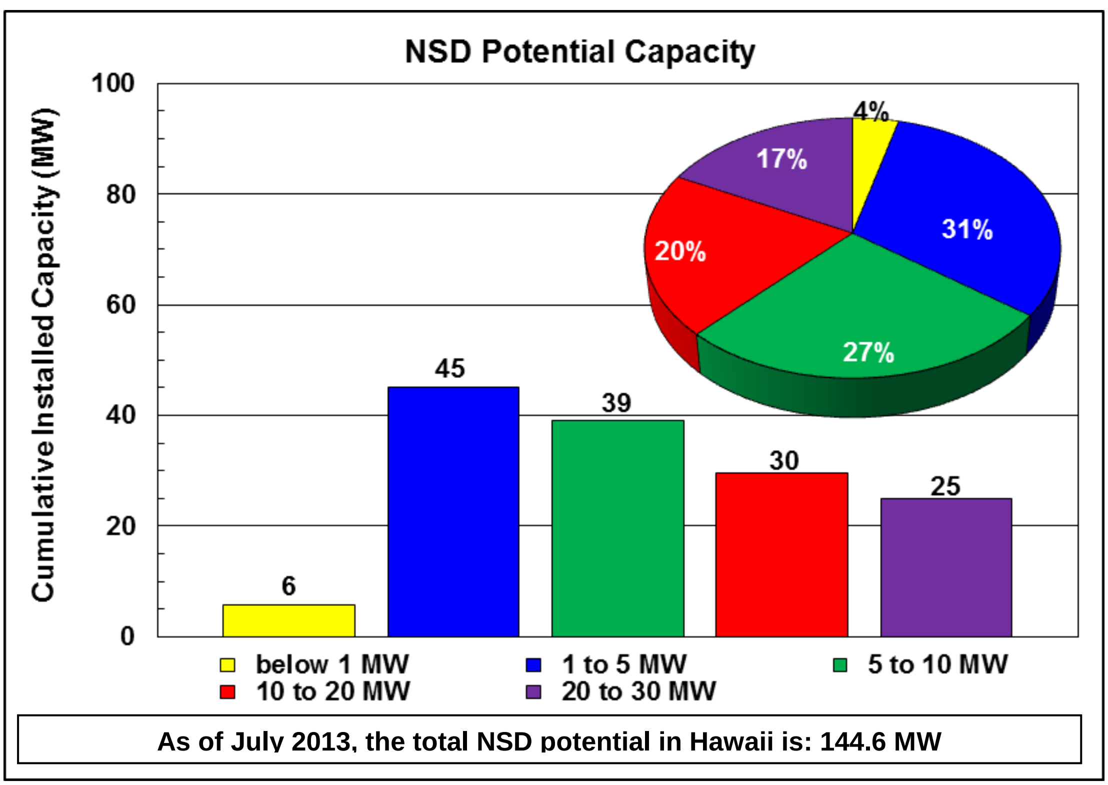

Figure 23.3. Cumulative potential installed capacity by size for Hawaii.

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24. CONCLUDING REMARKS

To evaluate the hydropower potential from new stream-reach development resources, a national assessment of more than 3 million U.S. streams was conducted in this study. Utilizing a comprehensive set of recent U.S. geographic, topographic, hydrologic, hydropower, environmental, and socio-political datasets, a spatially consistent method was designed for new run-of-river projects (Hadjerioua et al., 2013). The method contains three main components: (1) identification of stream-reaches with high energy density (Pasha et al., 2014); (2) topographical analysis of promising stream-reaches to estimate the characteristics of potential inundations of reservoirs; and (3) environmental attribution to spatially join the energy potential of stream-reaches with information related to the natural ecological systems; social and cultural settings; and policies, management, and legal constraints. Comparing to the previous assessments that included all streams types regardless of the presence of existing river infrastructure (i.e., hydropower plants or non-powered dams), this new assessment focuses specifically on undeveloped stream-reaches and may provide more direct estimates of new hydropower opportunities.

After the assessment was implemented across the entire United States, major findings in each hydrologic region were summarized in this final report. The estimated NSD capacity and generation, including both higher-energy-density (>1 MW per reach) and lower-energy-density (<1 MW per reach) stream-reaches, were estimated to be 84.7 GW and 460 TWh/year. When areas protected by federal legislation limiting the development of new hydropower (national parks, wild and scenic rivers, and wilderness areas) were excluded from the analysis, the estimated NSD capacity falls to 65.5 GW, slightly lower than the current existing U.S. conventional hydropower nameplate capacity (79.5 GW; NHAAP, 2013). Undeveloped NSD generation with these areas excluded is estimated to be 347.3 TWh/year, roughly 128% of the average 2002–2011 net annual generation from existing plants (272 TWh/year; EIA, 2013). Given the run-of-river assumption, NSD stream-reaches have higher capacity factors (53%–71%), especially compared with conventional larger-storage peaking-operation projects that usually have capacity factors of around 30%. The highest potential was identified in the Pacific Northwest Region (32%), followed by the Missouri Region (15%) and the California Region (9%). Among the states, the highest potential is found in Oregon, Washington, and Idaho—the three states in the Pacific Northwest—followed in order by California, Alaska, Montana, and Colorado. In addition to the resource potential, abundant environmental attributes were organized and attributed to the identified stream-reaches to support further hydropower market analysis. The prevalence of environmental variables and the proportion of capacity from stream-reaches intersecting environmental variables varied according to hydrologic region.

Since this assessment is designed to accommodate more than 3 million U.S. streams, it was targeted at the higher "reconnaissance level" (RETScreen International, 2005). The methodology considers only the physical characteristics of each 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 density, and classification of new potential areas for hydropower development using a range of technical, socioeconomic, 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-density areas should be regarded as worthy of more detailed site-by-site evaluation by engineering and environmental professionals.

These results are distributed through the NHAAP Public Portal (http://nhaap.ornl.gov/) to support further research activities. The main NSD findings are aggregated by HUC10 Hydrologic Watersheds for public usage. Detailed results with location-specific features are available through a user agreement to ensure the appropriate use and interpretation of the location-specific results. In particular, neither DOE nor ORNL recommends the use of these results to justify financial investments for individual site development, or to replace at-site physical or environmental assessments.

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APPENDIX A. SUMMARY OF DIFFERENCES FROM THE PREVIOUS NATIONAL HYDROPOWER RESOURCE ASSESSMENT

As mentioned previously, one major motivation to re-evaluate the national hydropower resources in this NSD assessment is because of the improvement of various national geospatial datasets on hydrogeography, topography, hydrology, and water infrastructures in the recent decade. These newly available datasets not only help improve the accuracy of resource estimates but also allow the enhancement of assessment methodology. To help understand the difference between this NSD assessment and the previous national hydropower resource estimates (Hall et al., 2004 and 2006), a summary of data and methodological difference is provided in Table A.1.

Table A.1. Summary of Difference between Hall et al. (2004, 2006) and NSD Assessment

Data/assessment	**Hall et al. (2004, 2006)**	**NSD assessment**
Hydropower resource class	Provide a total estimate of undeveloped hydropower potential covering non-powered dams, new hydro development, and others. Breakdown of each resource class is not possible	Provide estimates of new hydro development potential from undeveloped U.S. streams, designed specifically for new run-of-river projects
River geometry	Synthesized rivers from 30 m resolution digital elevation model (EDNA, http://edna.usgs.gov/)	More accurately digitalized rivers from aerial maps (NHDPlus, http://www.horizon-systems.com/nhdplus/)
Existing lakes and dams (used to exclude stream-reaches under existing and non-powered dam resource class)	Not considered	Use digitized lakes from aerial maps (NHDPlus) and National Inventory of Dams (NID, http://geo.usace.army.mil/) to exclude stream-reaches covered by existing lakes and dams
Treatment of existing hydropower	The new hydropower potential is estimated by subtracting the total raw power from existing hydropower capacity. This approach involves larger uncertainties	Exclude stream-reaches that are overlapped with existing hydropower plants, using the latest hydro inventory in the DOE/ORNL NHAAP Database (http://nhaap.ornl.gov/)
Elevation	30 m resolution NED(http://ned.usgs.gov/) in the conterminous United States	10 m resolution NED (http://ned.usgs.gov/) in the conterminous United States
Flow	Annual mean flow estimated by regional regression formula based on drainage area, precipitation, and temperature (Vogel et al., 1999)	Annual and monthly flow estimated by unit runoff that is derived from the USGS NWIS gauge observation (http://waterdata.usgs.gov/nwis)

Table A.1. Summary of difference between Hall et al. (2004, 2006) and NSD assessment (continued)

Data/assessment	**Hall et al. (2004, 2006)**	**NSD assessment**
Identification of stream-reaches	Stream-reaches are fixed to be 2 miles long.	Stream-reaches are identified based on higher product of head, flow, and slope. The length may vary in different geographical locations
Estimate of capacity	Raw power was calculated by using annual mean flow with 100% full efficiency	Capacity was estimated by the 30% exceedance flow quantiles (Q_{30}) with 85% efficiency
Estimate of energy	Not calculated	Monthly energy was estimated by the synthesized monthly flow time-series. Spill is considered. The capacity factor is around 70%
Other reservoir characteristics (surface inundation, reservoir storage, and residence time)	Not calculated	Geospatial assessment was performed using the 10 m resolution national elevation dataset
Environmental factors	Use selected environmental variables to directly exclude stream-reaches from further consideration	Attribute each stream-reach with potential environmental concerns to allow further policy analysis

To further understand the quantitative difference, a numerical comparison is performed. However, because of the drastic difference of data and methodology between these two assessments, a direct comparison (i.e., capacity to capacity) could be misleading. While capacity estimates are provided in both studies, they are based on different assumptions and have different physical meaning. The power equation used by Hall et al. (2004, 2006) is shown in Eq. A.1:

$$\mathrm{P} = \kappa\gamma[Q_i * \mathrm{H} + (Q_o - Q_i) * \mathrm{H}/2] \qquad \text{(A.1).}$$

where P (kWa) is the annual mean power, $\kappa = 1/11.8$ is the unit conversion factor, Q_i (ft^3/s) is the flow rate at the upstream end of a stream-reach, Q_o (ft^3/s) is the flow rate at the downstream end of a stream-reach, and H (ft) is the hydraulic head, defined as the elevation drop at each stream-reach. Compared with Eq. 2.2, the biggest differences are as follows:

1. Annual mean flow is used in Eq. A.1 while Q_{30} is used in Eq. 2.2.
2. An efficiency factor as 0.85 is assumed in Eq. 2.2.
3. The annual mean power (kWa, MWa, GWa) based on annual mean flow is conceptually different to the installed capacity (kW, MW, GW).

In addition, Eq. A.1 was computed for all 2 mile long Elevation Derivatives for National Applications (EDNA) flowlines (i.e., stream-reaches in Hall et al., 2004 and 2006), but Eq. 2.2 was only computed for the identified NSD stream-reaches, which was based on the 150 m subsegments discretized from NHDPlus flowlines with annual mean flow greater than 35 ft^3/s.

Therefore, the total capacity reported by these two studies (127 GWa versus 80 GW in the conterminous United States) should not be directly compared.

To evaluate the difference on a common ground, we start by computing the annual mean power for NHDPlus using the same approach as Hall et al. (2004, 2006). For each NHDPlus flowline, the annual mean power is computed using Eq. A.1. In Table A.2, the (a) total, (b) developed, (c) excluded, and (d) available annual mean power from Hall et al. (2004, 2006) are summarized for each hydrologic region. The sum of NHDPlus annual mean power from (e) total flowlines, (f) less than 35 ft^3/s flowlines, (g) flowlines overlapped with water bodies, (h) flowlines overlapped with existing hydro plants or infeasible for development, and (i) flowlines available for NSD assessment, are calculated for comparison.

By comparing the total annual mean power from both datasets (i.e., columns [a] and [e] in Table A.2), it can be seen that NHDPlus actually provides more total annual mean power (258 GWa) than EDNA does (208 GWa). Except for California and Great Lakes, the total NHDPlus mean power is consistently larger. The regional values are further illustrated in Figure A.1(a), in which a strong linear pattern can be observed. Since NHDPlus flowlines are accurately digitized from aerial maps (instead of indirectly derived from a digital elevation model), the NHDPlus flowlines can better capture the geographical locations of U.S. rivers and hence should be closer to reality.

Following total annual mean power, a series of deductions was performed in both assessments. In Hall et al. (2004, 2006), a “developed” annual mean power was estimated (35 GWa) by adjusting the total installed capacity (~100 GW) from existing hydropower plants. All EDNA stream-reaches were then overlapped with several selected environmental variables to identify the “excluded” stream-reaches and the corresponding annual mean power (47 GWa). After subtraction, a total of 126 GWa annual mean power was considered to be available in the conterminous United States.

In this NSD assessment, all flowlines less than 35 ft^3/s (41 GWa) were excluded directly since they are less likely to be developed (Hadjerioua et al., 2013). The flowlines overlapped with existing NHDPlus water bodies were then identified (38 GWa). During national assessment, it was observed that the NHDPlus water bodies have mostly been associated with existing dams (either powered or non-powered). Therefore, for the purpose of resource assessment on undeveloped stream-reaches, these flowlines were excluded since their hydropower potential fell under different hydropower resource classes (i.e., existing plant upgrade/expansion or non-powered dam development). In addition, using the latest DOE/ORNL NHAAP Database (NHAAP, 2013) flowlines that overlapped with existing hydropower plants were excluded during the quality control process (67 GWa). Some other flowlines that were judged to be infeasible for development (e.g., near an ocean) also were excluded during quality control. The result was 112 GWa of annual mean power for the remaining flowlines.

Table A.2. Comparison of Annual Mean Power in Conterminous United States

Hydrologic region	Annual mean power (GWa)								
	Hall et al. (2004, 2006)				NSD assessment				
	(a) total	(b) developed	(c) excluded	(d) available	(e) total	(f) < 35 ft^3/s	(g) overlapped with water bodies	(h) overlapped with existing hydro plants	(i) available for NSD assessment
01 New England	5.7	0.9	0.2	4.6	6.1	1.4	1.1	1.6	2.0
02 Mid-Atlantic	9.3	0.8	0.8	7.6	10.0	2.3	1.7	0.9	5.0
03 South Atlantic–Gulf	8.7	1.9	0.5	6.4	9.7	1.7	3.7	1.5	2.7
04 Great Lakes	4.4	2.9	0.3	1.2	4.3	0.8	1.1	0.9	1.5
05 Ohio	12.1	0.8	1.3	10.0	13.2	2.2	1.3	4.5	5.2
06 Tennessee	5.1	1.9	0.7	2.5	6.8	1.5	1.6	2.0	1.8
07 Upper Mississippi	5.8	0.4	0.6	4.7	6.5	0.7	0.7	3.4	1.8
08 Lower Mississippi	12.4	0.1	0.8	11.4	17.3	0.3	0.8	13.4	2.7
09 Souris–Red–Rainy	0.4	0.0	0.1	0.3	0.4	0.1	0.1	0.1	0.1
10 Missouri	15.8	1.8	4.6	9.4	28.4	3.2	4.9	3.1	17.2
11 Arkansas–White–Red	5.1	0.7	0.3	4.0	9.1	1.3	1.7	1.3	4.8
12 Texas–Gulf	1.8	0.1	0.1	1.6	2.2	0.4	0.7	0.1	1.0
13 Rio Grande	2.1	0.1	0.6	1.5	4.5	0.5	0.4	0.5	3.0
14 Upper Colorado	9.5	0.7	2.7	6.1	12.5	2.2	2.4	0.5	7.3
15 Lower Colorado	3.5	0.8	0.9	1.7	9.1	0.3	2.2	0.6	6.0
16 Great Basin	3.0	0.1	0.5	2.5	3.0	1.1	0.4	0.1	1.4
17 Pacific Northwest	76.4	16.6	20.0	39.8	92.8	16.1	10.1	28.5	38.1
18 California	27.0	4.7	12.0	10.2	22.1	5.1	2.6	4.3	10.1
Total	207.9	35.2	47.1	125.6	257.8	41.2	37.6	67.2	111.9

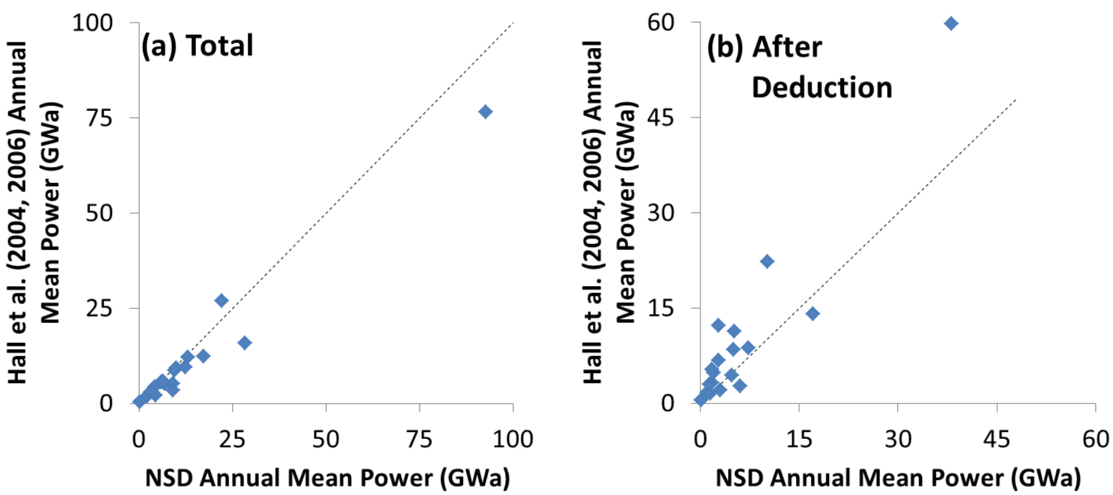

Figure A.1. Comparison of (a) total and (b) after deduction annual mean power between Hall et al. (2004, 2006) and NSD assessment.

Given that the environmental factors were labeled instead of excluded in the NSD assessment, a more appropriate evaluation will be comparing the sum of “excluded” and “available” annual mean power from Hall et al. (2004, 2006) (173 GWa, columns [c] and [d] in Table A.2) to the available flowlines for NSD assessment (112 GWa, column [i] in Table A.2). The reduction for Hall et al. (2004, 2006) is 17%, from 208 GWa to 173 GWa, mainly addressing the annual mean power that was believed to have been developed by existing hydropower plants. For NSD assessment, the reduction is 57%, from 258 GWa to 112 GWa, covering several sources of exclusion (smaller flowlines, lakes, dams, and existing hydropower plants). The regional values are further illustrated in Figure A.1(b), in which a larger spread can be seen.

While it appears that NSD provides a smaller resource estimate, the meaning of these two resource values is different. Through the “subtraction” approach, Hall et al. (2004, 2006) provided the upper bound of undeveloped hydropower potential across all resource categories (upgrade/expansion, non-powered dam development, new stream-reaches, and others). However, it should be noted that the “developed” annual mean power calculated from existing installed capacity cannot be associated with stream-reaches directly because the location of existing hydropower plants was not identified in Hall et al. (2004, 2006) and the annual mean power calculated from overlapping stream-reaches could also be very different from the ones translated from existing plant installed capacity. Therefore, while the total undeveloped hydropower resource estimate is valid, such potential cannot be further broken down into each resource class by classifying each stream-reach. In addition, given the ambiguous meaning of annual mean power, additional calculation will be required to translate the resource values into possible install capacity.

To provide more specificity for future hydropower development, the NSD assessment focuses on undeveloped stream-reaches, particularly for new run-of-river projects. The stream-reaches that are not suitable for new run-of-river development were not considered in this study, even though some of them still could be developed through non-powered dams or other approaches. The calculation in Table A.2 suggests that, even after a century of hydropower development, 43% of annual mean power remains on undeveloped stream-reaches that could be suitable for new development. To estimate the full hydropower resources, separate resource evaluation should be conducted for each resource class, such as the recent non-powered dam study (Hadjerioua et al., 2012). Given the different nature of each hydropower resource class, the most suitable assessment approach should be designed accordingly.

The last step is to address the difference between annual mean power calculated in Table A.2 (column [i], 112 GWa) to the capacity identified in NSD assessment (80 GW for both >1 and <1 MW stream-reaches). As mentioned, Q_{30} (instead of annual mean flow) and generation efficiency (0.85) are used in Eq. 2.2 to calculate NSD hydropower potential. By comparing Q_{30} derived from USGS NWIS daily streamflow gauge stations to the corresponding NHDPlus annual mean flow estimate, a conversion ratio was estimated for each HUC4 to help estimate Q_{30} for each NHDPlus flowline. By applying the ratio adjustment, the 112 GWa annual mean power (column [a] in Table A.3) becomes 100 GWa (column [b] in Table A.3). With further consideration of 0.85 efficiency, the value drops to 85 GWa (column [c] in Table A.3), which is close to the 80 GW NSD finding. The remaining difference should be mainly a result of different spatial units. While this appendix examined NHDPlus annual mean power in units of flowline (for a consistent comparison to Hall et al., 2004 and 2006), the NSD assessment was actually performed on discretized 150 meter sub-segments. As a result, some larger stream-reaches could cover multiple smaller NHDPlus flowlines, and other shorter stream-reaches could co-exist in a long NHDPlus flowline. The finer spatial resolution helps identify the location of potential stream-reaches more accurately.

Table A.3. Comparison of Annual Mean Power in the Conterminous United States

Hydrologic region		(a) NSD annual mean power (GWa)	(b) NSD annual mean power with flow adjustment (GWa)	(c) NSD annual mean power with flow and efficiency adjustment (GWa)
01	New England	2.0	2.2	1.9
02	Mid-Atlantic	5.0	5.4	4.6
03	South Atlantic–Gulf	2.7	2.5	2.1
04	Great Lakes	1.5	1.6	1.4
05	Ohio	5.2	5.5	4.6
06	Tennessee	1.8	1.7	1.4
07	Upper Mississippi	1.8	2.2	1.9
08	Lower Mississippi	2.7	2.3	2.0
09	Souris–Red–Rainy	0.1	0.1	0.1
10	Missouri	17.2	14.2	12.1
11	Arkansas–White–Red	4.8	6.5	5.5
12	Texas–Gulf	1.0	0.7	0.6
13	Rio Grande	3.0	2.0	1.7
14	Upper Colorado	7.3	4.1	3.5
15	Lower Colorado	6.0	2.9	2.5
16	Great Basin	1.4	0.7	0.6
17	Pacific Northwest	38.1	35.1	29.8
18	California	10.1	10.0	8.5
	Total	111.9	99.6	84.7

APPENDIX B. ADDITIONAL ENVIRONMENTAL ATTRIBUTION DATA

Table B.1. Fish Species Falling Under an ESA or IUCN Vulnerability Category and their Native Hydrologic Region(s)

Common name	Scientific name	NS	ESA	IUCN	Regions	# Regions
Alabama Cavefish	Speoplatyrhinus poulsoni	G1	LE	CR	06	1
Alabama Shad	Alosa alabamae	G2G3		EN	03, 06, 07, 08, 10, 11	6
Alabama Sturgeon	Scaphirhynchus suttkusi	G1	LE	CR	03	1
Alewife	Alosa pseudoharengus	G5	SC		01, 02, 03, 04, 05	5
Alvord Chub	Gila alvordensis	G2		VU	16, 17	2
Amargosa Pupfish	Cyprinodon nevadensis	G2	POPE		18	1
Amber Darter	Percina antesella	G1G2	LE	VU	03	1
Arctic Grayling	Thymallus arcticus	G5	POPC		4, 10	2
Arkansas Darter	Etheostoma cragini	G3G4	C	NT	10, 11	2
Arrow Darter	Etheostoma sagitta	G3G4	POPC		05	1
Ashy Darter	Etheostoma cinereum	G2G3		VU	05, 06	2
Atlantic Salmon	Salmo salar	G5	POPE	LC	01, 04	2
Atlantic Sturgeon	Acipenser oxyrinchus	G3	POPT	NT	01, 02, 03, 08	4
Barrens Topminnow	Fundulus julisia	G1		VU	05, 06	2
Bayou Darter	Etheostoma rubrum	G1	LT	NT	08	1
Bear Lake Sculpin	Cottus extensus	G1		VU	16	1
Beautiful Shiner	Cyprinella formosa	G3	LT	VU	15	1
Big Bend Gambusia	Gambusia gaigei	G1	LE	VU	13	1
Blackmouth Shiner	Notropis melanostomus	G2		VU	03	1
Blackside Dace	Phoxinus cumberlandensis	G2	LT	VU	05, 06	2
Bloater	Coregonus hoyi	G4		VU	04, 07	2
Blotchside Logperch	Percina burtoni	G2G3		VU	05, 06	2
Blue Shiner	Cyprinella caerulea	G2	LT	VU	03	1
Blue Sucker	Cycleptus elongatus	G3G4		NT	05, 06, 07, 08, 10, 11, 12, 13	8
Blueback Herring	Alosa aestivalis	G5	SC		01, 02, 03	3
Bluebarred Pygmy Sunfish	Elassoma okatie	G2G3		VU	03	1
Bluehead Sucker	Catostomus discobolus	G4	POPC		14, 15, 16, 17	4
Bluemask Darter	Etheostoma akatulo	G1	LE		05	1
Bluestripe Darter	Percina cymatotaenia	G2		EN	10	1

Table B.1. Fish Species Falling Under an ESA or IUCN Vulnerability Category and their Native Hydrologic Region(s) (continued)

Common name	Scientific name	NS	ESA	IUCN	Regions	# Regions
Bluestripe Shiner	Cyprinella callitaenia	G2G3		NT	03	1
Bluntnose Shiner	Notropis simus	G2	POPT	EN	13	1
Bonytail	Gila elegans	G1	LE	EN	14, 15	2
Borax Lake Chub	Gila boraxobius	G1	LE	VU	17	1
Boulder Darter	Etheostoma wapiti	G1	LE	VU	06	1
Bull Trout	Salvelinus confluentus	G3	POPT	VU	10, 17, 18	3
Caddo Madtom	Noturus taylori	G1		VU	08	1
Cahaba Shiner	Notropis cahabae	G2	LE	CR	03	1
Candy Darter	Etheostoma osburni	G3		NT	05	1
Cape Fear Shiner	Notropis mekistocholas	G1	LE	CR	03	1
Carolina Pygmy Sunfish	Elassoma boehlkei	G2		NT	03	1
Cherokee Darter	Etheostoma scotti	G2	LT		03	1
Chihuahua Chub	Gila nigrescens	G1	LT	CR	13	1
Chinook Salmon	Oncorhynchus tshawytscha	G5	POPT		17, 18	2
Chucky Madtom	Noturus crypticus	G1	PE		06	1
Chum Salmon	Oncorhynchus keta	G5	POPT		17, 18	2
Clear Creek Gambusia	Gambusia heterochir	G1	LE	VU	12	1
Coho Salmon	Oncorhynchus kisutch	G4	POPT		17, 18	2
Coldwater Darter	Etheostoma ditrema	G2		VU	03	1
Colorado Pikeminnow	Ptychocheilus lucius	G1	LE	VU	14	1
Comanche Springs Pupfish	Cyprinodon elegans	G1	LE	EN	13	1
Conasauga Logperch	Percina jenkinsi	G1	LE	VU	03	1
Coppercheek Darter	Etheostoma aquali	G2G3		VU	06	1
Crystal Darter	Crystallaria asprella	G3		VU	03, 07, 08, 10, 11	5
Cui-Cui	Chasmistes cujus	G1	LE	CR	16	1
Cumberland Darter	Etheostoma susanae	G1G2	PE		05	1
Cutthroat Trout	Oncorhynchus clarkii	G4	POPT		10, 11, 13, 14, 15, 16, 17, 18	8
Delta Smelt	Hypomesus transpacificus	G1	LT	EN	18	1
Desert Dace	Eremichthys acros	G1	LT	VU	16	1
Desert Pupfish	Cyprinodon macularius	G1	LE		15, 18	2
Devil’s Hole Pupfish	Cyprinodon diabolis	G1	LE	VU	15, 18	2
Devils River Minnow	Dionda diaboli	G1	LT	VU	13	1

Table B.1. Fish Species Falling Under an ESA or IUCN Vulnerability Category and their Native Hydrologic Region(s) (continued)

Common name	Scientific name	NS	ESA	IUCN	Regions	# Regions
Diamond Darter	Crystallaria cincotta	G1	C		05	1
Dolly Varden	Salvelinus malma	G5	PT		17	1
Duskytail Darter	Etheostoma percnurum	G1	LE		06	1
Eastern Sand Darter	Ammocrypta pellucida	G4		VU	04, 05	2
Etowah Darter	Etheostoma etowahae	G1	LE		03	1
Fountain Darter	Etheostoma fonticola	G1	LE	VU	12	1
Frecklebelly Madtom	Noturus munitus	G3		NT	03	1
Freckled Darter	Percina lenticula	G2		VU	03	1
Gila Chub	Gila intermedia	G2	LE	NT	15	1
Gila or Apache Trout	Oncorhynchus gilae	G3	LT	EN	13, 15	2
Goldline Darter	Percina aurolineata	G2	LT	VU	03	1
Green Sturgeon	Acipenser medirostris	G3		VU	17, 18	2
Grotto Sculpin	Cottus sp. 8	G2	C		07	1
Headwater Chub	Gila nigra	G2	C		15	1
Humpback Chub	Gila cypha	G1	LE	VU	14, 15	2
June Sucker	Chasmistes liorus	G1	LE		16	1
Kanawha Darter	Etheostoma kanawhae	G4		NT	05	1
Kanawha Minnow	Phenacobius teretulus	G3G4		VU	05	1
Kern Brook Lamprey	Lampetra hubbsi	G1G2		NT	18	1
Kiyi	Coregonus kiyi	G3		VU	04	1
Klamath Largescale Sucker	Catostomus snyderi	G3		NT	18	1
Laurel Dace	Phoxinus saylori	G1	PE		06	1
Least Chub	Iotichthys phlegethontis	G1	C	VU	16	1
Leon Springs Pupfish	Cyprinodon bovinus	G1	LE	CR	13	1
Leopard Darter	Percina pantherina	G1	LT	VU	11	1
Little Colorado Spinedace	Lepidomeda vittata	G1G2	LT	VU	15	1
Loach Minnow	Rhinichthys cobitis	G2	LT	VU	15	1
Longhead Darter	Percina macrocephala	G3		NT	05, 06	2
Longnose Darter	Percina nasuta	G3		NT	08, 11	2
Lost River Sucker	Deltistes luxatus	G1	LE	EN	18	1
Maryland Darter	Etheostoma sellare	GH	LE	EX	02	1
Moapa Dace	Moapa coriacea	G1	LE	CR	15	1
Modoc Sucker	Catostomus microps	G2	LE	EN	18	1
Neosho Madtom	Noturus placidus	G2	LT	NT	11	1

Table B.1. Fish Species Falling Under an ESA or IUCN Vulnerability Category and their Native Hydrologic Region(s) (continued)

Common name	Scientific name	NS	ESA	IUCN	Regions	# Regions
Niangua Darter	Etheostoma nianguae	G2	LT	VU	10	1
Northern Cavefish	Amblyopsis spelaea	G4		VU	05	1
Okaloosa Darter	Etheostoma okaloosae	G1	LT	EN	03	1
Olympic Mudminnow	Novumbra hubbsi	G3		NT	17	1
Orangefin Madtom	Noturus gilberti	G2		VU	02, 03	2
Oregon Chub	Oregonichthys crameri	G2	LT	VU	17	1
Ouachita Madtom	Noturus lachneri	G2		VU	08	1
Ouachita Shiner	Lythrurus snelsoni	G3		VU	11	1
Owens River Pupfish	Cyprinodon radiosus	G1	LE	EN	18	1
Ozark Cavefish	Amblyopsis rosae	G3	LT	VU	10, 11	2
Paddlefish	Polyodon spathula	G4		VU	03, 05, 06, 07, 08, 10, 11, 12	8
Paleback Darter	Etheostoma pallididorsum	G2		VU	08	1
Palezone Shiner	Notropis albizonatus	G1	LE		05, 06	2
Pallid Sturgeon	Scaphirhynchus albus	G2	LE	EN	07, 08, 10	3
Pearl Darter	Percina aurora	G1	C		03	1
Pecos Gambusia	Gambusia nobilis	G2	LE	VU	13	1
Pecos Pupfish	Cyprinodon pecosensis	G1		CR	13	1
Peppered Shiner	Notropis perpallidus	G3		NT	08, 11	2
Proserpine Shiner	Cyprinella proserpina	G3		VU	13	1
Pygmy Madtom	Noturus stanauli	G1	LE	VU	06	1
Pygmy Sculpin	Cottus paulus	G1	LT	CR	03	1
Railroad Valley Springfish	Crenichthys nevadae	G2	LT	VU	16	1
Rainbow Trout or Steelhead	Oncorhynchus mykiss	G5	POPT		17, 18	2
Razorback Sucker	Xyrauchen texanus	G1	LE	EN	14, 15	2
Redband Darter	Etheostoma luteovinctum	G4		NT	05, 06	2
Relict Dace	Relictus solitarius	G2G3		EN	16	1
Relict Darter	Etheostoma chienense	G1	LE		08	1
Rio Grande Darter	Etheostoma grahami	G2G3		VU	13	1
Rio Grande Silvery Minnow	Hybognathus amarus	G1	LE	EN	13	1
Roanoke Bass	Ambloplites cavifrons	G3		VU	03	1
Roanoke Logperch	Percina rex	G1G2	LE	VU	03	1
Rough Sculpin	Cottus asperrimus	G2		VU	18	1

Table B.1. Fish Species Falling Under an ESA or IUCN Vulnerability Category and their Native Hydrologic Region(s) (continued)

Common name	Scientific name	NS	ESA	IUCN	Regions	# Regions
Rush Darter	Etheostoma phytophilum	G1	PE		03	1
Rustyside Sucker	Thoburnia hamiltoni	G3		NT	03	1
Saltmarsh Topminnow	Fundulus jenkinsi	G3	SC		03, 08, 12	3
Santa Ana Sucker	Catostomus santaanae	G1	LT	VU	18	1
Sharphead Darter	Etheostoma acuticeps	G3		NT	06	1
Sharpnose Shiner	Notropis oxyrhynchus	G3	C	DD	11, 12	2
Shortjaw Cisco	Coregonus zenithicus	G3		VU	04, 09	2
Shortnose Sturgeon	Acipenser brevirostrum	G3	LE	VU	01, 02, 03	3
Shortnose Sucker	Chasmistes brevirostris	G1	LE	EN	18	1
Shoshone Sculpin	Cottus greenei	G2		VU	17	1
Shovelnose Sturgeon	Scaphirhynchus platorynchus	G4	LT	VU	05, 06, 07, 08, 10, 11	6
Sicklefin Chub	Macrhybopsis meeki	G3		NT	07, 08, 10	3
Sicklefin Redhorse	Moxostoma sp. 2	G2	C		06	1
Slackwater Darter	Etheostoma boschungi	G1	LT	EN	06	1
Slender Chub	Erimystax cahni	G1	LT	VU	06	1
Smalleye Shiner	Notropis buccula	G2	C	VU	12	1
Smoky Madtom	Noturus baileyi	G1	LE	CR	06	1
Snail Darter	Percina tanasi	G2G3	LT	VU	06	1
Sockeye Salmon	Oncorhynchus nerka	G5	POPE		17, 18	2
Sonora Chub	Gila ditaenia	G2	LT	VU	15	1
Southern Cavefish	Typhlichthys subterraneus	G4		VU	05, 06, 07, 08, 10, 11	6
Speckled Dace	Rhinichthys osculus	G5	POPE		13, 14, 15, 16, 17, 18	6
Spikedace	Meda fulgida	G2	LT	VU	15	1
Splittail	Pogonichthys macrolepidotus	G2		EN	18	1
Spotfin Chub	Erimonax monachus	G2	LT	NT	06	1
Spotted Darter	Etheostoma maculatum	G2		NT	05	1
Stargazing Darter	Percina uranidea	G3		NT	08, 11	2
Striated Darter	Etheostoma striatulum	G1		VU	06	1
Sturgeon Chub	Macrhybopsis gelida	G3		VU	07, 08, 10	3
Suwannee Bass	Micropterus notius	G3		NT	03	1
Tennessee Dace	Phoxinus tennesseensis	G3		NT	06	1
Threespine Stickleback	Gasterosteus aculeatus	G5	POPE	LC	01, 02, 17, 18	4
Tidewater Goby	Eucyclogobius newberryi	G3	LE	VU	18	1

Table B.1. Fish Species Falling Under an ESA or IUCN Vulnerability Category and their Native Hydrologic Region(s) (continued)

Common name	Scientific name	NS	ESA	IUCN	Regions	# Regions
Toothless Blindcat	Trogloglanis pattersoni	G1G2		VU	12	1
Topeka Shiner	Notropis topeka	G3	LE		07, 10, 11	3
Trispot Darter	Etheostoma trisella	G1		VU	03	1
Tui Chub	Gila bicolor	G4	POPE		16, 17, 18	3
Tuscumbia Darter	Etheostoma tuscumbia	G2		VU	06	1
Umpqua Oregon Chub	Oregonichthys kalawatseti	G2G3		NT	17	1
Vermilion Darter	Etheostoma chermocki	G1	LE		03	1
Virgin River Chub	Gila seminuda	G1	LE		15	1
Virgin Spinedace	Lepidomeda mollispinis	G1G2	POPT		15	1
Waccamaw Killifish	Fundulus waccamensis	G1		VU	03	1
Waccamaw Silverside	Menidia extensa	G1	LT	VU	03	1
Warner Sucker	Catostomus warnerensis	G1	LT	VU	17	1
Watercress Darter	Etheostoma nuchale	G1	LE	EN	03	1
White River Spinedace	Lepidomeda albivallis	G1	LE	CR	15	1
White River Springfish	Crenichthys baileyi	G2	POPE	VU	15	1
White Sands Pupfish	Cyprinodon tularosa	G1		VU	13	1
White Sturgeon	Acipenser transmontanus	G4	POPE	LC	17, 18	2
Widemouth Blindcat	Satan eurystomus	G1G2		VU	12	1
Wood River Sculpin	Cottus leiopomus	G2		VU	17	1
Woundfin	Plagopterus argentissimus	G1	LE	VU	15	1
Yaqui Chub	Gila purpurea	G1	LE	VU	15	1
Yellowcheek Darter	Etheostoma moorei	G1	PE	VU	11	1
Yellowfin Madtom	Noturus flavipinnis	G1	LT	VU	06	1

Notes: NS = Nature Serve Listing. Categories of NS: G1= critically imperiled; G2 = imperiled; G3 = vulnerable; G4 = apparently secure; G5 = secure. ESA = Endangered Species Act Listing. Categories of ESA: LE = listed endangered; LT = listed threatened; C = candidate; SC = species of concern; PE = proposed endangered; PT = proposed threatened; POPE = population endangered; POPT = population threatened; POPC = population candidate. IUCN = International Union for the Conservation of Nature Listing. Categories of IUCN: CR = critically endangered; EN = endangered: NT = near threatened; VU = vulnerable.

Table B.2. Average Water Use (liters/day/km2) in Different Usage Categories per Hydrologic Region

Region	Aquac.	Domest.	Industry	Irrigation	Livestock	Mining	Public	Thermo-electric	Total ground water use	Total surface water use	Total water use
01	30	271	104	30	2	7	431	356	168	2,844	3,012
02	81	906	153	46	9	21	965	3,180	445	9,214	9,660
03	14	197	109	255	13	16	302	854	395	2,253	2,648
04	12	280	405	36	7	37	453	2,313	138	3,173	3,310
05	10	165	297	11	10	30	296	1,902	187	2,396	2,583
06	213	123	260	17	11	7	206	4,079	89	4,722	4,811
07	11	154	131	76	18	16	234	1,557	244	1,819	2,063
08	99	139	665	1,217	3	5	215	1,459	1,336	2,358	3,694
09	4	11	18	112	3	22	16	46	22	202	224
10	7	42	6	758	13	4	64	406	410	855	1,266
11	6	60	21	534	22	1	97	200	499	404	903
12	2	283	152	415	15	5	394	731	512	1,618	2,130
13	4	75	2	691	4	8	87	11	284	536	820
14	14	21	2	1,174	1	1	27	20	60	1,188	1,248
15	2	135	3	660	2	17	193	10	412	480	892
16	16	95	5	793	4	7	123	6	242	750	992
17	108	107	81	1,150	5	5	143	34	367	1,179	1,546
18	51	514	6	2,019	17	5	821	5	994	3,626	4,620
19	37	3	1	0	0	0	4	0	26	21	47
20	3	238	17	140	2	3	355	20	1,795	142	1,937
21	1	423	9	47	10	2	859	3	156	3,124	3,280
Total	27	182	122	517	10	11	269	811	429	1,872	2,301

Table B.3. Approximated Arial Coverage (km2) of Dominant Water-Quality Concerns per Hydrologic Region

Region	Nutrient	Toxin	HG/metal	DO/ organic	Pathogen	pH	TDS	Sediment	Temp	Turbidity	Unknown	All
01	106	244	685	180	154	1	1	1	0	4	37	1,459
02	440	4,003	197	3,602	1,061	43	9	184	8	2	150	10,263
03	787	184	2,137	919	1,501	58	4	8	2	26	145	5,907
04	128	102,518	10,545	765	88	36	2	7	0	3	64	114,324
05	239	305	555	142	320	8	5	58	1	40	304	2,507
06	22	256	290	17	53	16	1	8	1	3	14	706
07	644	311	920	149	209	5	7	8	0	48	85	2,812
08	66	36	1,944	476	910	46	17	12	0	1	61	3,621
09	1,266	0	789	26	48	0	0	4	0	13	28	2,174
10	735	54	2,771	305	288	65	104	104	248	40	89	5,468
11	92	280	394	980	206	8	132	81	11	340	9	2,928
12	1	20	457	1,309	255	185	30	0	0	0	22	2,279
13	6	23	83	29	18	1	2	7	1	2	4	177
14	4	7	205	45	18	17	18	1	4	0	0	321
15	9	8	25	16	4	1	2	0	4	1	1	70
16	754	47	222	31	6	14	147	10	20	0	9	1,261
17	55	65	1,308	32	81	12	1	106	482	1	213	2,660
18	1,369	857	573	16	34	110	16	123	152	0	2	3,260
19	0	8	0	1	0	0	0	0	0	6	0	15
20	9	0	0	0	1	0	0	0	0	4	0	17
21	4	0	113	93	23	5	0	0	0	5	0	242
Total	6,736	109,224	24,216	9,131	5,278	631	499	723	935	540	1,238	162,469

Back Cover Images

Images courtesy of Michael J. Sale, Low Impact Hydropower Institute (LIHI)

Left: Newfound Hydroelectric Project, NH (LIHI Certificate #82)

Center: Oswego River Project, NY (LIHI Certificate #35)

Right: Prospect No. 3 Hydroelectric Project, OR (LIHI Certificate #109)

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