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WIND & WATER POWER PROGRAM

An Assessment of Energy Potential at Non-Powered Dams in the United States

Boualem Hadjerioua, Principal Investigator
Yaxing Wei and Shih-Chieh Kao

Prepared for
the U.S. Department of Energy
Wind and Water Power Program
Budget Activity Number ED 19 07 04 2

Prepared by
OAK RIDGE NATIONAL LABORATORY
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Report

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Executive Summary

The United States has produced clean, renewable electricity from hydropower for more than 100 years, but hydropower-producing facilities represent only a fraction of the infrastructure development that has taken place on the nation's waterways. In contrast to the roughly 2,500 dams that provide 78 gigawatts (GW)[1] of conventional and 22 GW of pumped-storage hydropower, the United States has more than 80,000 non-powered dams (NPDs)—dams that do not produce electricity—providing a variety of services ranging from water supply to inland navigation. Importantly, many of the monetary costs and environmental impacts of dam construction have already been incurred at NPDs, so adding power to the existing dam structure can often be achieved at lower cost, with less risk, and in a shorter timeframe than development requiring new dam construction. The abundance, cost, and environmental favorability of NPDs, combined with the reliability and predictability of hydropower, make these dams a highly attractive source for expanding the nation's renewable energy supply.

To better characterize this unique national resource, the U.S. Department of Energy (DOE) Wind and Water Power Program has undertaken a national-scale analysis of U.S. dams to determine the ability of NPDs to provide hydroelectric power. DOE's Oak Ridge National Laboratory (ORNL), with input from DOE's Idaho National Laboratory, quantified the potential capacity and generation available from adding power production capability to U.S. NPDs. Of the more than 80,000 NPDs throughout the U.S., 54,391 dams were analyzed, with remaining dams eliminated from consideration due to erroneous geographic information, or erroneous flow or drainage area attributes that could not be resolved and corrected through independent investigation of maps and records. Anecdotal information suggests that these dams with missing or erroneous information are likely to be relatively small or have low potential to produce hydroelectric energy. Dams with a reported height of less than five feet were also excluded from analysis. A thorough quality control and review process ensured that the 54,391 remaining NPDs were analyzed and characterized as accurately as possible. Figure ES-1 demonstrates the spatial and capacity potential distribution of the nation's NPDs. Electric generating capacities included in the report were calculated using the assumption that all water passing a facility would be available for conversion into electrical energy and that hydraulic head at the facility would remain constant. The analysis did not consider the economic feasibility of developing each unpowered facility. The assessment provides preliminary information for stakeholders (such as developers, municipal planners, and policymakers), who can further evaluate the potential to increase hydropower production at NPD sites. Developers could use the information provided in this assessment to focus on more detailed analysis of sites that demonstrate a reasonable potential for being developed.

Adding power to U.S. NPDs has the potential to add up to 12 GW (12,000 megawatts or MW) of new renewable capacity—a potential equivalent to increasing the size of the existing conventional hydropower

[1] 1 gigawatt (GW)=1,000 megawatts (MW). On an annual basis, 1 MW of hydropower produces enough electricity to power nearly 400 U.S. homes. Each gigawatt could power up to 400,000 homes.

fleet by 15%. A majority of this potential is concentrated in just 100 NPDs, which could contribute approximately 8 GW of clean, reliable hydropower; the top 10 facilities alone could add up to 3 GW of new hydropower. Eighty-one of the 100 top NPDs are U.S. Army Corps of Engineers (USACE) facilities, many of which, including all of the top 10, are navigation locks on the Ohio River, Mississippi River, Alabama River, and Arkansas River, as well as their major tributaries. This study also shows that dams owned by the U.S. Bureau of Reclamation hold the potential to add approximately 260 MW of capacity; the Bureau has also engaged in an effort to conduct a more detailed evaluation of its own facilities.

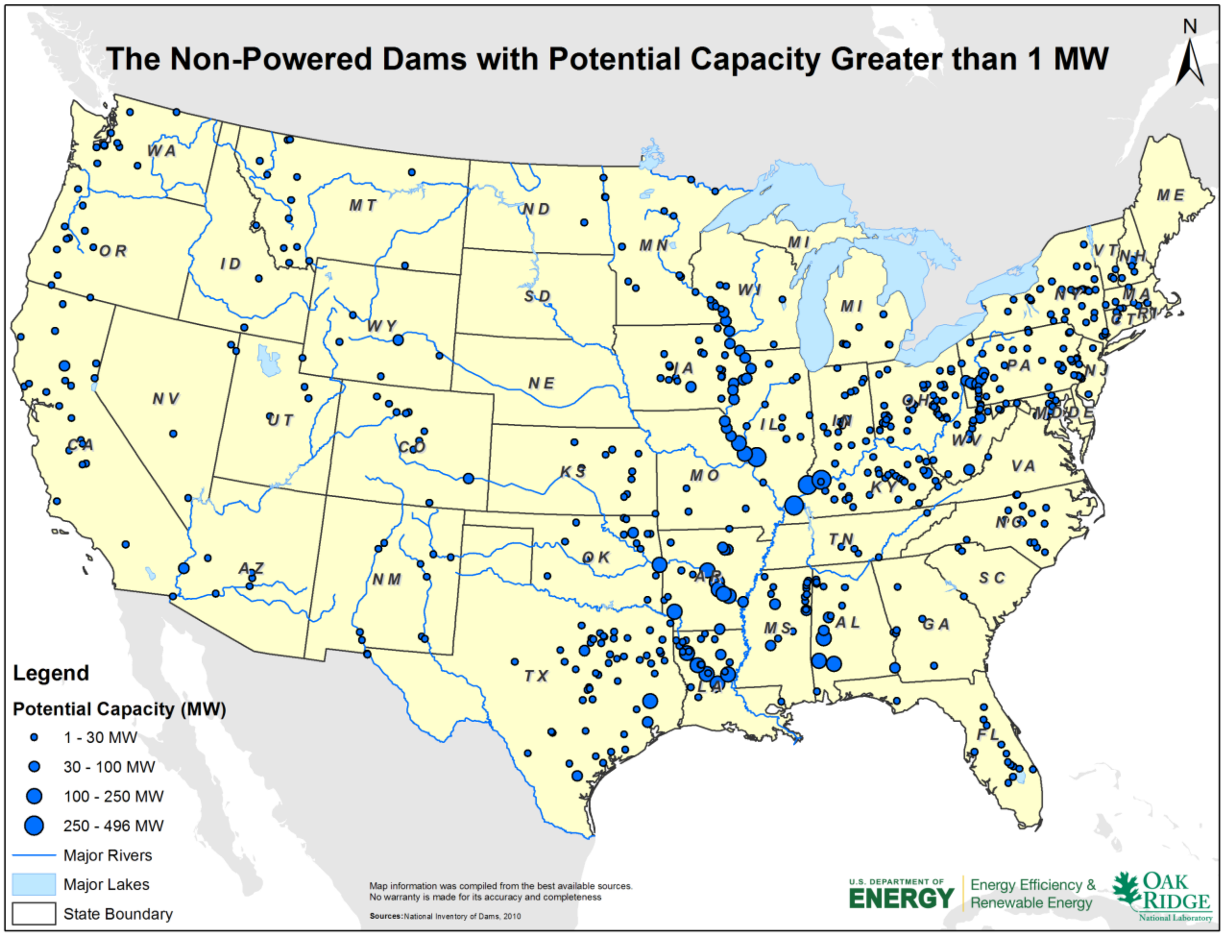

Figure ES-1: Locations of the top non-powered dams with potential hydropower capacities greater than 1 MW

For further information please contact:

Principal Investigator: Boualem Hadjerioua
Oak Ridge National Laboratory
P.O. Box 2008, MS 6036
Oak Ridge, TN 37831
Phone: (865) 574-5191
E-mail: *hadjeriouab@.ornl.gov*

Program Manager: Brennan T. Smith
Water Power Technologies
Oak Ridge National Laboratory
P.O. Box 2008, MS 6036
Oak Ridge, TN 37831
Phone: (865) 241-5160
E-mail: *smithbt@.ornl.gov*

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1 Introduction

This report describes a U.S. Department of Energy (DOE) Wind and Water Power Program study carried out by Oak Ridge National Laboratory (ORNL) with inputs from Idaho National Laboratory to assess the energy potential at non-powered dams (NPDs) throughout the United States. In this context, NPDs are dams that do not include hydraulic turbine (hydropower) equipment. Such dams were constructed for one or more non-energy benefits, including flood control, water supply, navigation, or recreation. Auxiliary dams that form parts of power-producing impoundments are not included in the NPD scope because the water they store already is associated with existing hydropower production.

This report addresses only the energy production potential of NPDs. The priority placed on this NPD assessment effort (relative to an assessment of energy potential from new impoundments, for example) is based on the hypothesis that many of the costs and environmental impacts of dam construction have already been incurred at NPDs and may not be significantly increased by the incorporation of new energy production facilities. Thus, the development of some NPD's for energy purposes is assumed to be achievable with lower installed cost, lower levelized cost-of-energy, fewer barriers to development, less technological and business risk, and in a shorter time frame than development requiring new dam construction. Future detailed studies of site-specific costs and impacts will be required to test this hypothesis. That is, the initial estimates of the number of developable NPDs and associated capacity additions will have to be refined with better information on such issues as environmental constraints (e.g., the environmental costs and benefits of changes in flow releases to optimize power production), dam integrity/safety issues, and multiple use conflicts.

NPDs in the United States range in size from small berms impounding farm ponds to large Ohio River and Mississippi River dams that pool water to maintain navigation depths during low-flow periods. The National Inventory of Dams (NID) includes more than 80,000 dams with physical heights ranging from about 4 feet to 770 feet. This study analyzed a subset of 54,391 NPDs with monthly average flows ranging from about 1 cubic feet per second (cfs) to 68,500 cfs.

1.1 The Context for NPD Resource Assessment

The assessment activities reported herein were aimed at quantifying, with a useful degree of certainty, the aggregated national, regional, and basin-scale added capacity and generation potential for NPDs. NPDs are one of several resource classes to be examined in the DOE Hydropower Resource Assessment. Additional resource classes include the following:

- Increased capacity and generation at existing powered facilities through unit upgrades, minimum flows units or additional units.
- New capacity from constructed waterways, such as irrigation canals and municipal water systems.
- New capacity and storage from new sustainable hydropower sites.

Each site considered for upgrade or new development in any of these resource classes has a set of cost, socioeconomic impact, and environmental impact attributes that have influenced and will influence the hydropower development and regulatory decisions for that site. This initial report on NPD potential does not address these costs and impacts. Development also is influenced by energy prices in different regions of the United States along with other incentives, such as state programs that provide tax credits or renewable energy credits.

At national and regional scales (the focus of this initial report), the geospatial databases included in the assessments reported herein enable automated analyses and aggregation of site potentials according to explicit rules. These rules include geo-registration to assign a dam to a specific stream segment, estimation of seasonal and monthly water availability, estimation of hydraulic head, and estimation of a capacity factor to determine rated capacity from annual production. Such rules engender assumptions, approximations, and uncertainty that render results that are only appropriate for reconnaissance-level studies of hydropower development.

In contrast to site-specific studies that would support project design, feasibility, and due-diligence studies for project development financing, the focus of these national- and regional-scale studies is to provide high-level summary statistics of the availability of hydropower resources. Avoidance of systematic processing errors that overestimate or underestimate aggregate national and regional energy and capacity statistics is a key concern. Conversely, uncertainty in the capacity and energy production estimates for individual sites (i.e., from relying on remote-sensing data and maps rather than “boots on the ground” observations of conditions) is problematic only if it biases trends among technology classes or geographic regions.

The availability and enhancement of national-scale datasets, such as NID and the National Hydrography Dataset (NHD), provide a foundation for rigorous estimates of NPD potential for production for the entire country. Previous assessments—including Hall et al. (2004), U.S. Department of Interior (DOI) et al. (2007), and U.S. Bureau of Reclamation (2011)—have also been consulted in preparing the estimates reported herein.

1.2 Water Availability and Hydrologic Regions

Water availability, along with physical relief, is the primary determinant of energy potential. It varies significantly among different geographical regions in the United States. To help understand our current resources at a regional level, Table 1 summarizes data for two important hydrologic variables, precipitation (P) and runoff (Q), and the Q/P ratios for the years 1971–2008 for each of the 18 major hydrologic regions of the continental United States. Both P and Q are expressed in inches. The Q/P ratio indicates the percent of precipitation that can eventually be utilized from streamflow after evapotranspiration, groundwater infiltration, and other internal hydrologic processes. Evaporation is believed to be the dominant factor affecting the Q/P ratio. Although the Q/P ratio does not directly contribute to the assessment of NPD potential, it can provide some background hydrologic understanding regarding the regional water availability that may be utilized for hydropower generation. For comparison, the existing hydropower capacity within each hydrologic region is illustrated in Figure 1.

Table 1. Mean Annual U.S. Water Availability from 1971–2008

Hydrologic Regions (HUC02)	Precip. P[a] (inch)	Runoff Q[b] (inch)	Q/P ratio (%)	Hydrologic Regions (HUC02)	Precip. P[a] (inch)	Runoff Q[b] (inch)	Q/P ratio (%)
1 New England	45.7	25.7	56.1	10 Missouri	20.7	2.5	11.8
2 Mid Atlantic	44.2	20.3	46.1	11 Arkansas-White-Red	31.7	2.9	9.1
3 South Atlantic-Gulf	52.1	17.2	33.1	12 Texas-Gulf	32.6	2.3	7.0
4 Great Lakes	34.5	14.0	40.5	13 Rio Grande	14.9	0.5	3.5
5 Ohio	45.1	19.4	43.0	14 Upper Colorado	14.9	1.8	11.9
6 Tennessee	54.6	23.2	42.5	15 Lower Colorado	12.7	0.4	3.5
7 Upper Mississippi	33.9	9.8	29.0	16 Great Basin	12.3	2.0	16.6
8 Lower Mississippi	56.5	19.1	33.9	17 Pacific Northwest	33.4	13.5	40.4
9 Souris-Red-Rainy	21.4	2.6	12.1	18 California	24.0	10.5	43.6

[a] Precipitation data was obtained from the PRISM Research Group, Oregon State University.
[b] Runoff data was obtained from the U.S. Geological Survey (USGS) WaterWatch Program.

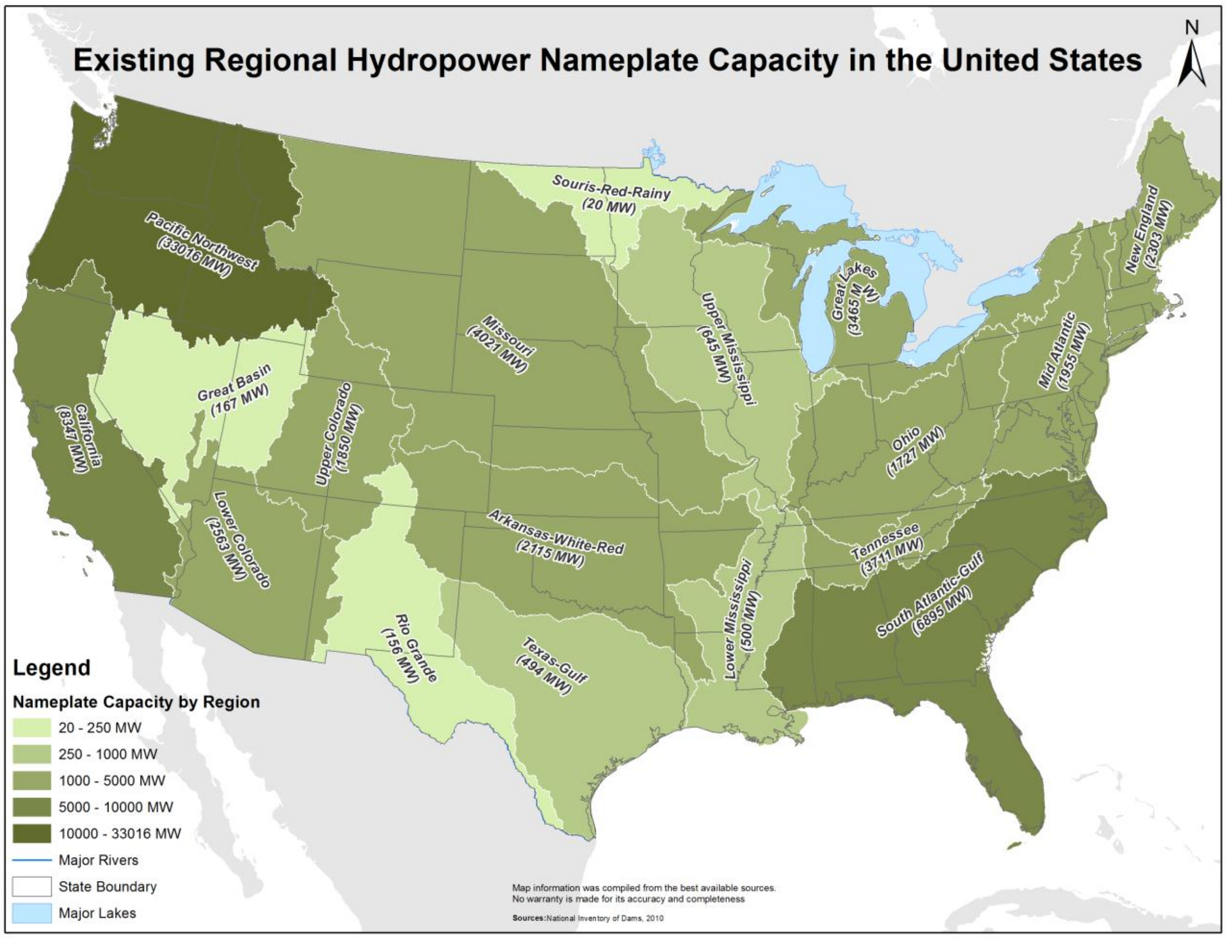


Figure 1. The existing hydropower capacity within each hydrologic region (Source: National Hydropower Asset Assessment Program Existing Hydropower Plant Summary, Hadjerioua et al., 2011)

For the Northeast and Great Lakes Regions (Regions 1, 2, and 4), both precipitation and runoff were abundant. The Q/P ratios are high due to higher latitude, since cooler temperatures reduce evaporation and evapotranspiration. Due to the sufficient water resources, there has been extensive, mostly nonfederal hydropower development in these regions. For the South Atlantic-Gulf Region (Region 3), the precipitation is among the highest, mostly due to hurricanes and summer convective storms. Although the high evaporation reduces the available runoff, there are still abundant water resources for hydropower generation. The high summer precipitation brings in challenges related to flood operation. The overall Mississippi River Basin (Regions 5–8, 10, and 11) covers nearly half of the U.S. territory. The eastern areas—the Ohio and Tennessee Regions (Regions 5 and 6)—are the wettest with low evaporation. These two regions have been historically important for hydropower generation, and they are still good potentials for future development. The western parts of the Mississippi River Basin (Regions 10 and 11) are much drier, and the greater evaporation causes large losses in effective precipitation. Other competing, consumptive water uses (e.g., municipal and irrigation) become important and may restrict the water availability for hydropower generation. The huge watershed area of the Mississippi River system results in high magnitude of streamflow downstream (Regions 7 and 8). To assist the river transportation, a series of locks and dams were built by the United States Army Corps of Engineers (USACE) to control the river stage. Many of these dams have not been utilized for hydropower generation, and—it will be shown later—they have the highest potential for NPD development.

The Souris-Red-Rainy Region (Region 9) is the upstream portion of river systems that drain north into Canada. Due to lower populations and available water resources, hydropower has not been a focus in this region. The Texas-Gulf and Rio Grande Regions (Regions 12 and 13) are among the driest in the United States. Although most of the NPDs are located in the State of Texas, the future hydropower potential is, in fact, limited by available precipitation and low Q/P ratios. The Colorado River system (Regions 14 and 15) also has relatively low precipitation and runoff. The regional water supply heavily relies on storage in large reservoirs, such as Glen Canyon Dam and Hoover Dam. Although not the main focus, these huge water storage projects permit high hydropower generation in these regions. The Great Basin (Region 16) is a closed watershed with limited water resources; there are comparatively fewer existing hydropower projects in this region. The Pacific Northwest (Region 17) is the most important region for U.S. hydropower generation. Both precipitation and runoff are abundant, and evaporation losses are low. The largest U.S. hydropower plant, Grand Coulee, is located in this region along with several other large projects (e.g., Chief Joseph). California (Region 18) is also an important hydropower provider; the numerous Central Valley projects in California create a large capacity for hydropower generation. One special feature of California is that flow diversion was utilized in several projects, resulting in high hydraulic head for hydropower generation. Although both the Pacific Northwest and California already provide large amounts of hydropower, the environmental concerns, such as fish habitat, may pose challenges for future development. Because the western United States (Regions 10–18) is much drier overall than the eastern regions, hydropower generation needs to be coordinated with other competing water usage. The DOI's Bureau of Reclamation (Reclamation) is assigned the responsibility of water management and supply in the western United States.

2 Methodology

2.1 Energy Production Models for a Non-Powered Dam

Consistent with previous studies (DOI et al., 2007; Reclamation, 2011), the following formula was utilized to estimate the potential hydropower generation at NPD sites:

$$\text{Potential Hydropower Generation (in megawatt hours or MWh)} = Q * \Delta H * \eta * T / 11800 \quad (1)$$

In Equation (1), ΔH (ft) is the gross head for hydropower generation, η is the generating efficiency (currently assumed to be 0.85 in this assessment), and Q (ft^3/s) is the average flow during the total generation period T (hour). While Equation (1) provides a straightforward way to estimate the power potential, there remain true challenges regarding how to estimate the parameters for a large number of NPDs given the available data. Ideally, the flow-duration curve based on at least 10 years of record needs to be developed at each NPD site so that wet, dry, and normal hydrological years can be captured. However, such a task is challenging at the national scale since most of the NPDs are located on ungauged streams or have limited historical observation. Therefore, in this assessment Q cannot be estimated by the commonly used 30% exceedance level from daily flow-duration curves (criterion used in Reclamation, 2011). Estimating the gross head—ΔH—available at the NPD with accuracy also is challenging. It is not possible, within the present effort, to obtain and analyze a daily headwater and tailwater elevation time series for each NPD. Thus, the potential energy must be estimated from available statistics for each site. For a national-level analysis, reasonable alternatives must be sought.

In this assessment, monthly hydropower generation was computed using a constant gross head derived from the NID and other methods (see head adjustment, Chapter 2.4) and the estimated monthly mean flow at each NPD site assuming that all flow can be utilized for hydropower generation. By summing the hydropower generation for each month, the potential annual generation can be estimated; this represents the maximum theoretical hydropower generation one may obtain at an NPD site. A regional capacity factor (C_f), which was computed from existing hydropower plants (Hadjerioua et al., 2011), was then utilized to estimate the potential capacity.

- **Capacity Factor Definition**: The ratio of the actual energy produced in a given period, to the hypothetical maximum possible—i.e., running full-time at rated power.

- **Regional Computed Capacity Factor**: Capacity factor for this study was computed based on 8-year (2001–2008) recorded Energy Information Administration (EIA) generation for all hydropower plants in the United States; a regional capacity factor then was developed and assigned to compute the potential site installed capacity.

- **Capacity Factor Limitations**: Since the actual hydropower production is mainly a function of hydrology, operational constraints, demand, and dam type (tributary, main stem, run of river, etc.), there will be some overestimation or underestimation in the computed installed capacity when using an overall regional historical capacity factor. It is expected that appropriate site-specific capacity factors could be determined after a detailed feasibility study addressing all site characteristics (hydrology, hydraulic, environment, demand, machinery, etc.).

The capacity factor was computed by:

$$\text{Capacity Factor } (C_f) = \text{Annual Generation} / (\text{Installed Capacity} * 365 * 24) \quad (2)$$

In Equation (2), the actual historical generation was observed at existing hydropower plants (collected from EIA, 2010). If all generating units in a hydropower plant run continuously year-long, the actual generation will be close to the installed capacity multiplied by the entire hours in one year; hence, the capacity factor will be close to one. However, because streamflow fluctuates significantly over time, actual capacity factors are significantly less than one. The C_f computed from existing plants provides one way to estimate the installed capacity from Equation (1). The following energy production model is therefore utilized in this assessment:

$$\text{Potential Capacity (MW)} = \text{Potential Power Generation (MWh)} / (C_f * 365 * 24) \qquad (3)$$

By using the above equations jointly, the potential hydropower generation and capacity are estimated at each NPD site. However, this capacity value assumes construction of a powerhouse that can pass all available water for the site for the generation of electricity; designed and developed powerhouses subject to economic limitations on size will be significantly smaller in capacity.

Several national-scale datasets (listed in Figure 2) were utilized for the assessment, and each component is discussed in the following subsections. For the reasons discussed in Section 1, the assessment aims to provide regionally comparable estimates of maximum NPD potentials for the entire United States for the purpose of policy considerations. The results may be used to identify potential regions and set priorities instead of getting a precise estimate at a specific site. Identification of the most appropriate sites and designs for investment will still rely on developers' efforts.

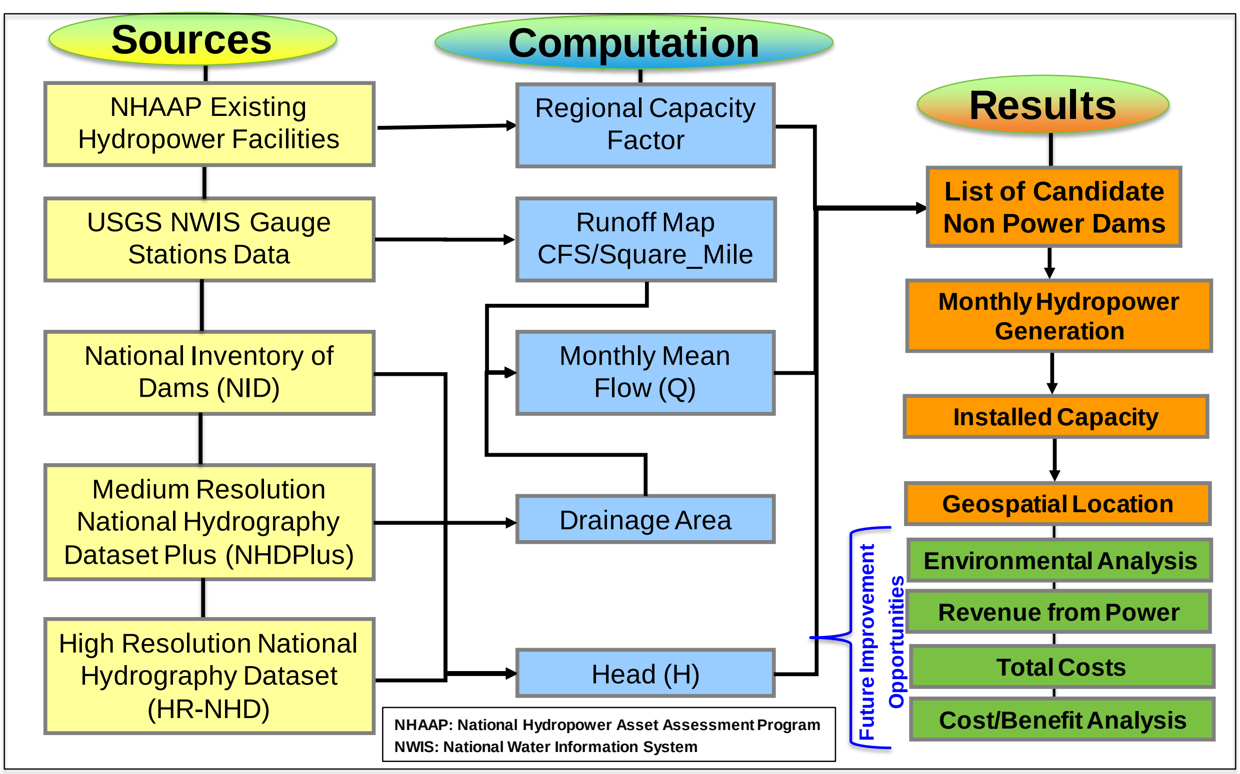


Figure 2. Approach to the NPD resource assessment

2.2 Data Requirements and Sources for Nationwide Assessment of NPD Potential

As noted above, in order to estimate potential hydropower capacity for NPDs using the electricity generation model, several types of information are needed: monthly flow, head, and monthly capacity factor. Most of the information is not readily available. A wide variety of data sources were utilized to assemble the information needed for the energy generation model.

2.2.1 USACE NID

NID was utilized in this assessment to provide a comprehensive list of the NPDs and their corresponding dam heights. The goal of NID is to include all dams in the United States that meet at least one of the following criteria:

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

Congress first authorized the USACE to inventory dams in the United States with the National Dam Inspection Act (Public Law 92-367) of 1972. The NID was first published in 1975, with a few updates—as resources permitted—over the next 10 years. The Water Resources Development Act of 1986 (P.L. 99-662) authorized USACE to maintain and periodically publish an updated NID, with re-authorization and a dedicated funding source provided under the Water Resources Development Act of 1996 (P.L. 104-3). USACE also began close collaboration with the Federal Emergency Management Agency (FEMA) and state regulatory offices to obtain more accurate and complete information. The National Dam Safety and Security Act of 2002 (P.L. 107-310) reauthorized the National Dam Safety Program and included the maintenance and update of the NID by USACE. The most recent Dam Safety Act of 2006 reauthorized the maintenance and update of the NID. The latest version of NID, 2007 (http://www.nid.usace.army.mil), contains data about 83,987 dams together with such information as their purpose, location, river name, drainage area, dam height, dam storage, ownership, and primary usage. Although the NID contains most of the dams in the United States, other NPDs that are missing in the database are included in this assessment when identified from the databases described below.

2.2.2 Dams from Reclamation

Data for about 450 dams, along with their characteristics, were collected from Reclamation. Among those dams were more than 100 that were not included in the NID. These dams are merged with NID as a full list of dams for NPD resource assessment.

2.2.3 National Hydropower Asset Assessment Program (NHAAP) Baseline Database

The NHAAP (Hadjerioua et al., 2011) describes the development and construction of the baseline engineering and geospatial information systems and integrated data sets that characterize the hydropower generation inventory in the United States. The NHAAP baseline database is designed to assess and analyze the existing national hydropower infrastructure and provide historical data to study and plan for future potential hydropower upgrades, as well as potential increases in the U.S. hydropower generation.

2.2.4 Natural Resources Conservation Service Watershed Boundary Dataset (WBD)

Watershed boundaries define the aerial extent of surface water drainage to a point. The intent of defining hydrologic units (HU) for the WBD is to establish a drainage boundary framework, accounting for all land and surface areas. The latest version of the WBD defines six HU levels: region (HUC02), subregion (HUC04), basin (HUC06), sub-basin (HUC08), watershed (HUC10), and subwatershed (HUC12). Only regions (HUC02) were used in this report's nationwide assessment.

2.2.5 USGS NHD

The NHD is a comprehensive set of digital spatial data representing the surface water of the United States using common features, such as lakes, ponds, streams, rivers, canals, and oceans. High-resolution (1:24,000-scale) NHDs, covering the entire conterminous United States, were used in the NPD resource assessment (Simley et al., 2009).

2.2.6 NHDPlus Version 1 from USGS and Horizon Systems Corporation

By integrating a variety of datasets—including the National Elevation Dataset (NED), the National Land Cover Dataset (NLCD), and the WBD—into the medium-resolution (1:100,000-scale) NHD, NHDPlus Version 1 adds a variety of useful attributes to NHD features. These attributes include cumulative drainage area characteristics, flow direction, flowline minimum/maximum elevations and slopes, and flow volume and velocity estimates for each flowline in the stream network. (http://www.horizon-systems.com/nhdplus/)

2.2.7 National Water Information System (NWIS) Gauge Observation from USGS

Data were collected from about 22,000 USGS NWIS gauge stations, including location, drainage area, and monthly streamflow observations over the past 30 years. Among those 22,000 stations, 5,595 provide continuous streamflow observations from 1999 to 2008.

2.3 Data Synthesis and Computation of Potential

2.3.1 Initial Dam Selection

The initial selection process identifies dams that are candidates for hydropower development. Existing hydropower impoundments and dams that impound water released through existing powerhouses elsewhere on an impoundment are excluded from this set. Also excluded are dams with erroneous coordinates that could not be resolved through independent investigation of maps and records, as well as dams with erroneous flow or drainage area attributes that could not be corrected though independent investigation. Finally, dams with a reported height of less than five feet were excluded.

2.3.1.1 Update NID Dams Location Using NHD

In order to estimate the NPD flow correctly, a precise dam location is required. However, it was observed that some NID coordinates were not sufficiently accurate and, hence, a correct linkage between NPD and stream segment could not be built. The problem was partially resolved by using high-resolution NHD. High-resolution NHD provides adjusted locations of 41,757 NID dams. In such cases, the dam location is adjusted to be on the high-resolution NHD flowline. After updating NID dam locations, 697 dams were identified as having invalid locations and 267 dams were outside of the conterminous United States, thus they were deleted from the analysis.

2.3.1.2 Exclude Existing Powered Dams, Auxiliary Dams, and Low Head Dams

Based on the NID attributes, existing powered dams, auxiliary dams, and low head dams were excluded.

1) **Criteria for selecting existing powered dams from NID:** When the "Purpose" field in NID contains "H," which means hydroelectric, the dams are considered existing powered dams. There are 2,569 NID dams identified as existing powered dams. However, it was observed that this NID attribute was not always accurate and up-to-date. The NHAAP database was utilized in the quality control process (Section 2.4) to resolve this issue.

2) **Criteria for selecting auxiliary dams from NID:** When the "OtherStructureID" field in NID contains some value (i.e., not null), the dams are considered auxiliary dams. Since they share the same headwater with the main dam, it would be an overestimation to include their potential in the full national portfolio. There are 703 NID dams identified as auxiliary dams.

3) **Criteria for selecting low head dams from NID:** When the "NID_Height" field in NID is missing or less than 5 feet, the dams are considered low head dams. There are 319 NID dams identified as low head dams.

It also should be noted that some dams may fit into multiple criteria. For instance, some auxiliary dams may have an "H" remark in the "Purpose" field. The NPDs that remained in the database after filtering through the three criteria are analyzed further to address these cases.

2.3.1.3 Identification of Dams on Streams with Negligible Streamflow

The spatial analysis process of dam context was performed using NHDPlus (1:100,000 scale) and high-resolution NHD (1:24,000 scale) to ensure accurate registration of dams to stream segments. The high-resolution NHD analysis is essential for correct registration of dams with negligible streamflow (DWNS) that impound very small streams. These streams do not appear in the medium resolution NHDPlus, so exclusive use of NHDPlus to register streams would erroneously assign DWNS to larger streams and overestimate their production potential.

The criteria for identifying DWNS, as long as any one is met, are as follows:

1) A dam is close to a high-resolution NHD flowline, but far from a lower-resolution NHDPlus flowline (Figure 3).

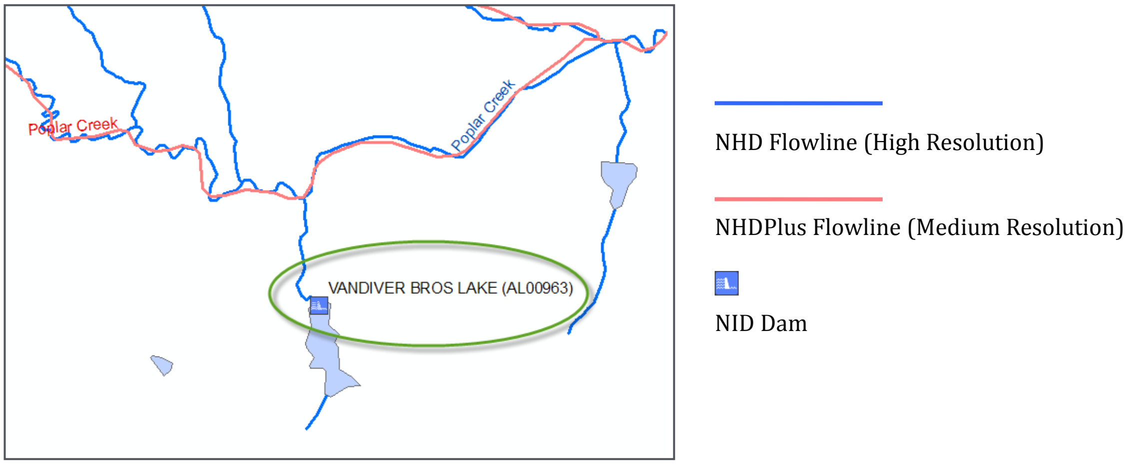


Figure 3. Illustration of the first criterion classification of DWNS – In this example, because the dam "Vandiver Bros Lake" is close to NHD flowline but far from NHDPlus flowline, it is designated as located on segment with negligible streamflow**.**

2) A dam is not close to either a high-resolution NHD flowline or an NHDPlus flowline (Figure 4).

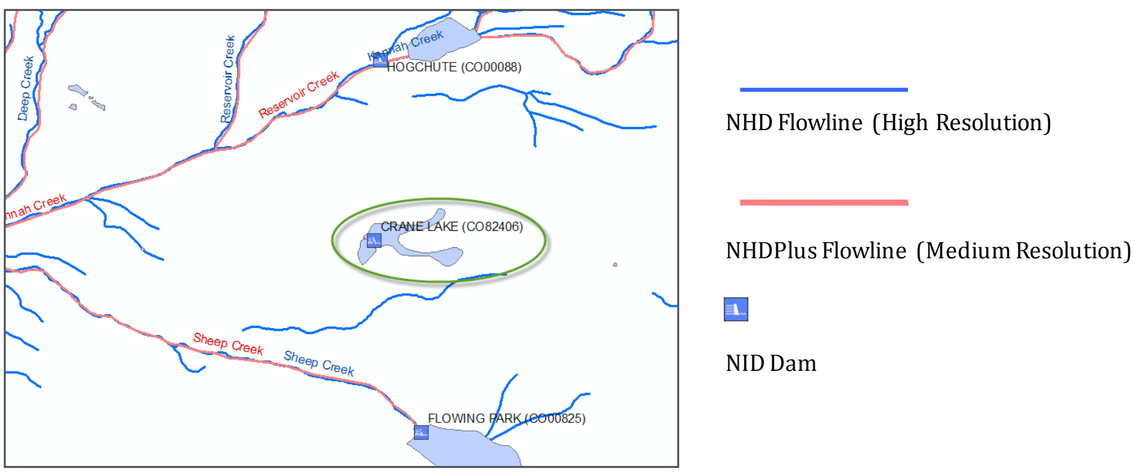


Figure 4. Illustration of the second criterion for selecting DWNS – In this example, because the dam "Crane Lake" is not close to any NHD flowline or NHDPlus flowline, it cannot be linked to any stream and is designated as located on segment with negligible streamflow**.**

There are 24,478 NID dams classified as DWNS. Although there may be some hydropower potential for these types of NPDs, given that there is very limited flow information to support the computation of their potential, they cannot be correctly estimated based on the current data availability. These 24,478 dams could be further analyzed in future small hydropower research efforts to estimate their aggregate potential, though this could be negligible. The remaining 55,707 NPDs can be estimated for their hydropower potential in the following steps.

2.3.2 Streamflow

Although the most credible approach to estimate available streamflow for hydropower generation is through stream gauge monitoring, many NPDs are not monitored or have streamflow records for a duration of less than 10 years. Some preliminary estimates are available at the national scale, such as the annual mean flow provided in NHDPlus; however, seasonal variability, which is crucial to hydropower production, is usually unavailable. Therefore, alternatives must be sought, especially given the large number of NPDs included in this assessment.

The monthly mean flow was estimated at each of the NPD sites by relying on several available data sources. The key concept of estimating monthly mean streamflow is based on the following equation:

$$\text{Streamflow} = \text{Drainage Area} * \text{Runoff} \tag{4}$$

In Equation (4), "Drainage Area" is the cumulative drainage area (square miles) of the basin above an NPD. "Runoff" is the monthly mean normalized streamflow (cfs/square mile) within an NPD's entire drainage area. Given that the streamflow magnitude is strongly correlated to drainage area, a runoff map has been widely applied in practice to estimate flow at ungauged locations. The monthly runoff at the HUC06 level was estimated in this study to help identify the monthly variability of streamflow. However, this over-simplification may also introduce some errors. A quality control procedure therefore is introduced (described in Section 2.4) to ensure the accuracy of the estimates.

2.3.2.1 Drainage Area

Two sources were utilized to estimate the drainage area for each NPD. The first source is NID. In NID, drainage area is provided for more than half of the dams, but the information sometimes is inaccurate. A better source of drainage area information is NHDPlus. For most of the flowlines (linear features, including stream/river, canal/ditch, pipeline, artificial path, coastline, and connector), NHDPlus provides the cumulative drainage area at the endpoint (outlet) of the flowline. The average length of flowlines in NHDPlus is about 1.2 miles. So, the drainage area of an NPD is approximately identical to the cumulative drainage area of the flowline on which the dam is located. Spatial analyses were performed using NID and NHDPlus stream network to find the flowline on which an NPD is located. Then, the corresponding drainage area provided in NHDPlus was used. This process is described in Figure 5.

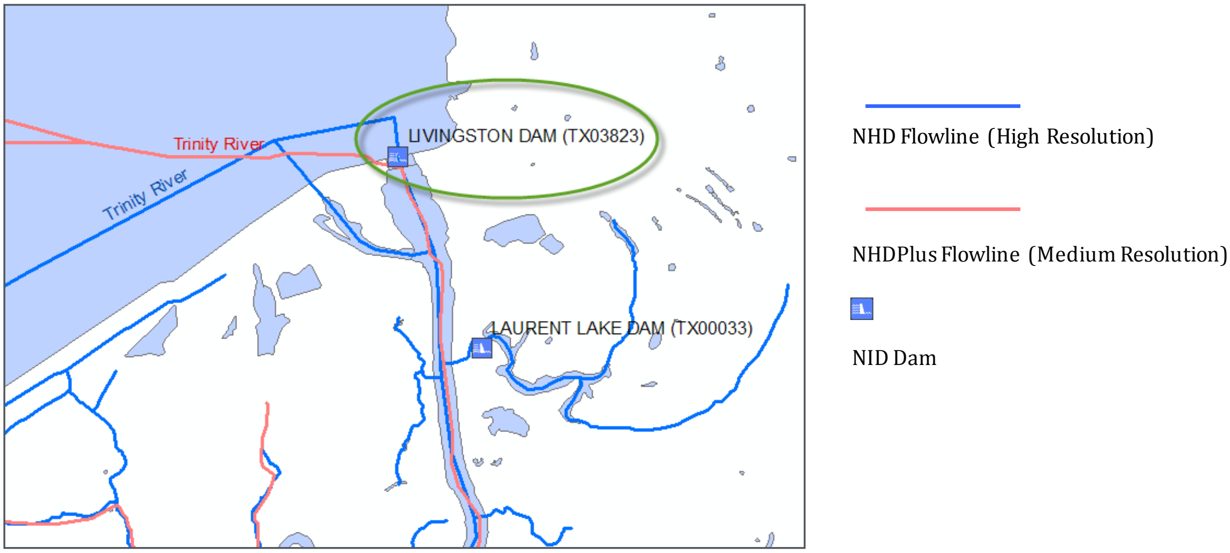


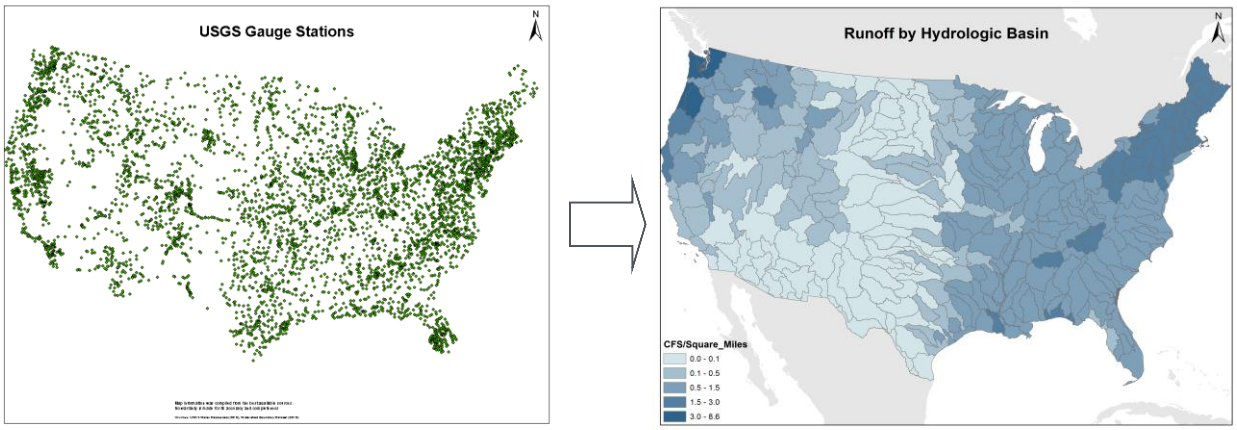
Figure 5. Illustration of linkage between NID and NHDPlus – In NID, Livingston Dam is linked to an NHDPlus flowline (in red color), which represents the Trinity River. The accumulative drainage area for this NHDPlus flowline is 16,572 square miles, which will be used as the dam's drainage area.

2.3.2.2 Runoff

The monthly mean runoff was calculated for all basins (HUC06) based on observation data from 5,595 USGS NWIS gauge stations with continuous streamflow observations between 1999 and 2008. The calculation is an area-weighted average method based on the streamflow observation, location, and drainage area of these 5,595 selected gauge stations. Within each HUC06, the mean runoff for each calendar month is computed from all stations located in that basin. The annual runoff is shown as an example in Figure 6. As shown, most of the surface water runoff is located in the eastern and northwestern United States.

2.3.2.3 Streamflow Calculation and Selection

For each NPD, the basin runoff and drainage area are applied in Equation (4) to estimate the monthly streamflow. Because there were two versions of drainage area, alternative estimates of streamflow were computed from the NHDPlus and NID. The selection of streamflow was based on this criterion: use the streamflow based on drainage area from NHDPlus unless it is at least 50 times greater than the streamflow based on drainage area from NID. The criterion was needed because, owing to inaccuracy of dam locations, the spatial analysis process might mistakenly find the wrong NHDPlus flowline on which that dam is located, which will significantly affect the accuracy of the drainage area retrieved from NHDPlus. As mentioned earlier, an additional quality control step is introduced later to ensure the reasonableness of the flow estimates. Figure 7 shows the calculated monthly mean streamflow for John Sevier Dam, located in Tennessee, which was derived by this method.



Observed flow for selected USGS gauge stations

Runoff (CFS/Square_Miles)

Figure 6. Illustration of runoff derivation

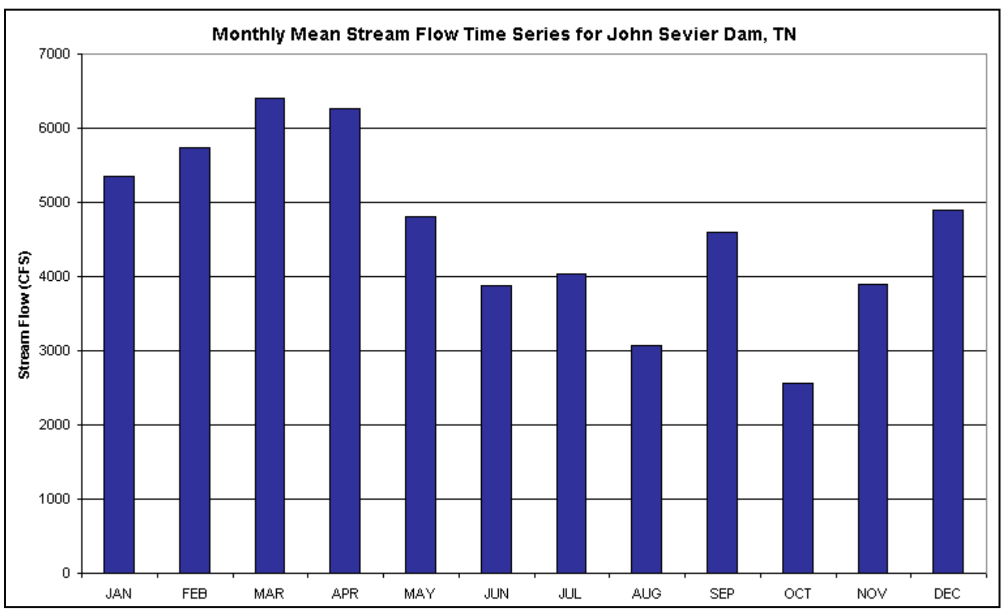


Figure 7. Monthly mean streamflow time series for John Sevier Dam, Tennessee

2.3.3 Hydraulic Head

Given the national scope of this study, the choices of penstock and pipeline—which are generally utilized to increase the hydraulic head for hydropower generation—were not considered. The focus is to identify NPD potential with the least new construction and, hence, only the head created by the current existing NPDs was considered. Although the most accurate estimate of hydraulic head is the height difference between headwater and tailwater elevations, such information is not commonly available in the databases. Therefore, the dam height information in NID was utilized as a surrogate to estimate hydraulic head. Four types of height information are provided in NID (graphically depicted in Figure 8), including the following:

1) **Hydraulic Height**: Vertical difference between the maximum design water level and the lowest point in the original streambed.

2) **Dam Height**: Vertical distance between the lowest point on the crest of the dam and the lowest point in the original streambed.

3) **Structural Height**: Vertical distance from the lowest point of the excavated foundation to the top of the dam. Top of dam refers to the parapet wall and not the crest.

4) **NID Height**: Maximum value among Hydraulic Height, Dam Height, and Structural Height.

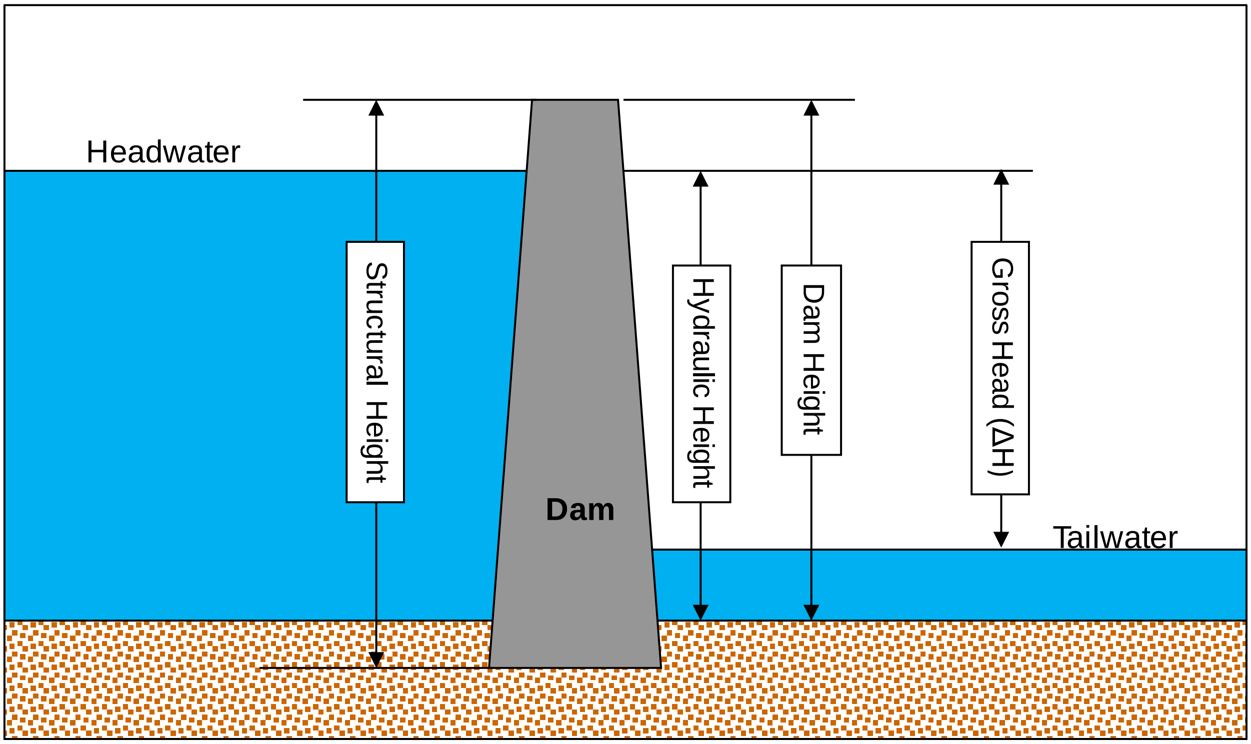


Figure 8. NID height definitions

Although it seems that the hydraulic height could be the best choice to represent the gross head, especially for sites with small tailwater depths, this information is not available for many NPDs. However, sometimes the hydraulic height given is equal to the dam height; in these instances, using the hydraulic height will grossly overestimate the computed potential power and, thus, the potential installed capacity. Therefore, as a "rule of thumb" estimate, 70% of the NID height is used. The following empirical rules estimate the gross head for the NPDs:

1) If Hydraulic Height is not provided, use 0.7 * NID Height.

2) If Hydraulic Height and NID Height are both provided and are equal, use 0.7 * NID Height.

3) If Hydraulic Height is provided but is greater than 0.7 * NID Height, use 0.7 * NID Height.

4) If Hydraulic Height is provided and is less than 0.7 * NID Height, use Hydraulic Height.

In the case of major main-stem NPDs and high dams (over 100 feet), these assumptions were supplemented by analysis of data from navigation lock lift heights and from gauge stations to gain a more realistic estimate of gross head (the difference between headwater and tailwater elevations). For other dams, there could be some high uncertainties between the NID dam height-based estimate and the actual gross head available for power generation. The primary uncertainty in estimating energy potential, based on these NID dam height assumptions, is that the influence of tailwater elevation and the absence of accurate data on tailwater elevation were not included in the current data sources. In addition, the seasonal variability of hydraulic head is not available in most of the cases. The current choices served as preliminary estimates. The 70% (or 0.7 multiplier factor) used with the NID dam height is based on the assumption that about 70% of the NID dam height should be considered as gross head available for power. The tailwater depth and the distance from the upper pool to the dam crest are assumed to be about 30%. This assumption is considered to be reasonable when the NID height is equal to dam height. When the NID height is equal to structural height, since there is an additional excavation depth to be included, the gross estimate head available for power could be overestimated; however, only 2% of the total number of NPDs with 0.4% of the total estimated potential installed capacity was computed using structural dam height in this study. The actual time-varying head at a specific site should be monitored as part of a feasibility study or characterized by detailed pool elevation records from the site operator. Summary for gross head estimation used in this study is shown in Table 2.

Table 2. Type of Heads Used to Estimate Potential Installed Capacity

Estimated Gross Head	Number of NPD	Total Potential Capacity (MW)
Adjusted using Lock and Dam lift from USACE	87	6,921.6
Computed using 0.7 * Dam Height	49859	3,744.2
Adjusted during quality control (NPD > 100 feet)	62	729.9
Using NID Hydraulic Height	3,329	599.8
Using 0.7 * NID Structural Height	1050	44.24
Adjusted from Reclamation Resource Assessment	4	21.5
Total	**54,391**	**12,061.2**

2.3.4 Capacity Factor

The regional capacity factor was obtained from the NHAAP database. By using Equation (2), the capacity factor of each existing hydropower plant with available generation and capacity data from 2001 to 2008 was computed (see Figure 9). The plant generation is then utilized as a weighting factor to average the capacity factor for each of the hydrologic regions (HUC02). Therefore, the regional capacity factor represented the ratio of current generation to the maximum possible generation when generators are constantly operated. The capacity factor was utilized in Equation (3) to estimate the potential NPD capacity.

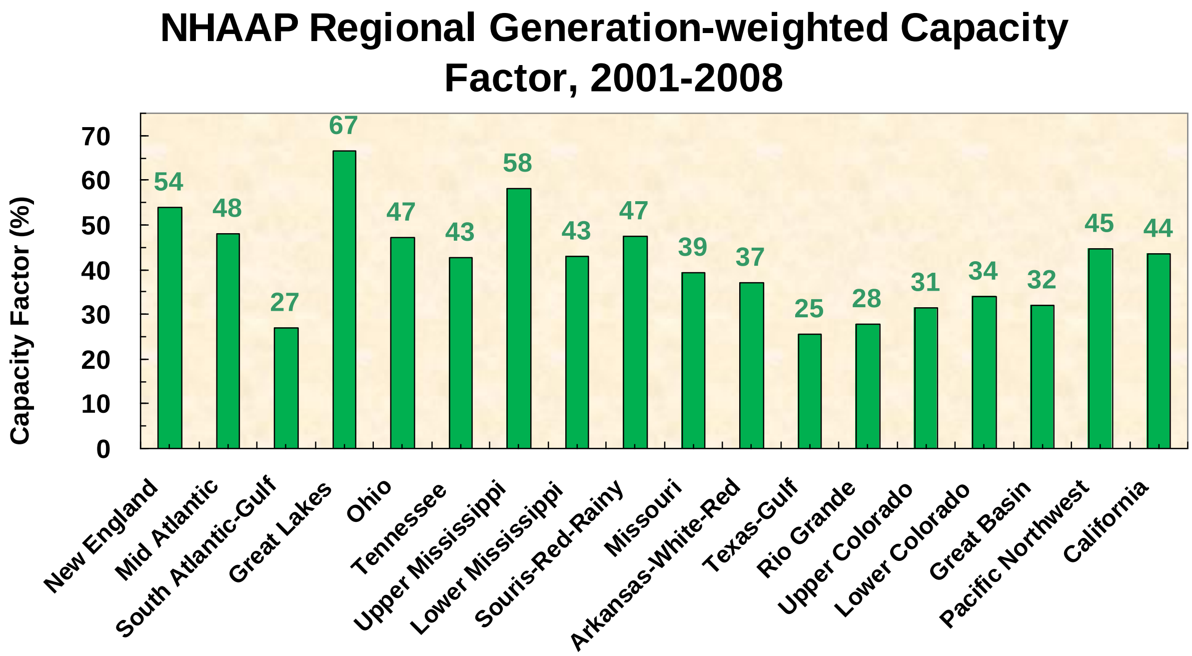


Figure 9. Computed regional capacity factors

2.3.5 Potential Generation and Capacity

With Equation (1), using hydraulic head and monthly mean streamflow, the mean monthly potential NPD generation was calculated. Mean annual potential NPD generation then can be derived by summing monthly estimates of generation together. The annual potential generation then is fed into Equation (3), along with the regional capacity factor, to estimate the potential capacity. A program was developed to automatically compute the power potential for all NPDs. The preliminary results then were examined through a quality control process.

2.4 Quality Control

Although most of the NID non-powered dams were linked to the NHDPlus stream segments through the algorithm described in Section 2.3, mismatches occasionally occurred. The mismatch typically resulted in unrealistically high flow, which then overestimated the power potential. These errors were usually caused by the following:

- Inaccurate coordinates and attributes of some NID dams
- Different regional hydrologic characteristics
- Inconsistent coordinates between NID and NHD
- Outdated information of some NID attributes
- Overestimated head (mostly for run-of-river dams).

As a result, quality control through manual checking was used to ensure the accuracy of the national estimates. The major quality control steps include the following:

1) **Removal of smaller ponds next to major rivers –** It is a fundamental GIS limitation that the same geographical units may have slightly different coordinates across various datasets. One common solution is to assign a tolerance distance when merging different datasets together (in this case, NID and NHD). However, since many ponds are located near major rivers (e.g., Ohio River), there were many cases that these off-stream ponds were pushed into major rivers and resulted in overestimated power potential. The problem, which was most common in HUC Region 5 (Ohio), was resolved by examining satellite images.

2) **Removal of existing hydropower plants** – While information was provided in the NID to indicate whether or not a dam was utilized for hydropower generation, such information was not always accurate and up-to-date. The latest hydropower plant inventory was obtained from the NHAAP to correct errors in the NID database. In cases where an NPD shares the same headwater with an existing hydropower dam, the NPD was excluded during the quality control process.

3) **Flow adjustment** – Although two different methods were utilized to estimate the monthly flow in ungauged streams, the most accurate estimates are derived directly from nearby gauge stations. During the quality control, the annual mean flow provided by NHDPlus was utilized as a reference standard to help with validating the flow estimates. If the annual flow estimate was not within a 10% difference of the value in NHDPlus, flow adjustment was considered. In most cases, the monthly flow estimates were rescaled to match the annual mean flow from NHDPlus.

4) **Head adjustment** – Much of the NPD power potential comes from the USACE navigation system (locks and dams). Due to the need of inland river transportation, the flow discharge at locks and dams was always high and can be a potential source of future hydropower. However, the NID dam height may not be reasonably used as a proxy of head in these cases due to the high tailwater elevation. Therefore, the average lift information was obtained from USACE to replace the original head estimate. Although this quality control step resulted in a 7 GW decrease of power potential, the locks and dams remain good candidates, even after the large reduction. In addition to locks and dams, head adjustment also was performed for those high head (> 100 ft) and high potential (> 1 MW) NPD sites. The normal pool head water elevation (usually taken from the dam owner website or the operation documents) and tail water elevation (usually taken from the downstream USGS gauge stations) were identified as the maximum bounding range of the available head. Although this process is considered to be realistic, it is extremely time- and resource-consuming, and elevation measured from different sources may be determined inconsistently. This process resulted in another 0.5 GW reduction of the power potential.

5) **Removal of under-construction sites** – It was noticed that some potentially developable sites already are under construction. For instance, several USACE locks and dams (e.g., Cannelton and Smithland) on the Ohio River are being developed for hydropower generation and, hence, were removed from the candidate list. Several other NPDs—including L&D 52 and 53, Newburgh, and J.T. Myers—are expected to be replaced or converted for hydropower generation in the near future. The national NPD estimate will be adjusted periodically when new information becomes available.

6) **Updated from other regional resource assessments** – Although flow and head can be estimated through the approach described in the previous section for a large number of NPDs nationwide, these estimates are only preliminary and will not be as accurate as the ones measured on-site. There have been many other regional efforts in evaluating potential hydropower sites in which the designed flow and head were determined based on the actual site conditions. Whenever a credible previous resource assessment becomes available, the information is utilized to improve the national NPD estimates in this study. Part of the Reclamation 2011 information was incorporated to provide more realistic estimate of head.

It should be noted that quality control is a time-consuming process and cannot be performed for all NPDs. Therefore, quality control checks commenced with the NPDs having the highest power estimates; these checks continued gradually following the descending order of power potential. At the current phase of this project, nearly 1,000 NPDs with high hydropower potential have been preliminarily checked.

Not all of the many NPDs analyzed have been subjected to detailed quality control checks for streamflow, head, energy, and capacity estimation. Quality control checking has focused on those dams with the greatest estimated energy production. The raw estimate from Section 2.3 revealed 54,801 NPD sites with potential capacities totaling 43.5 GW. The numbers were reduced to 54,561 NPDs with potential capacities totaling 19.7 GW after steps 1–3 (described in Section 2.4) were applied on part of the NPDs. The most recent estimate included steps 4–5 (described in Section 2.4); with the resulting potential capacity of 12 GW was based on the remaining 54,391 NPDs. While many of these NPDs of lesser potential have not received explicit quality control review, such checks are unlikely to result in substantial increases or decreases in potential capacity because the NPDs with the highest power estimates already have been subjected to the quality control process.

3 Results

3.1 Estimated Energy Availability

Following the methodologies described in Section 2, the potential generation and capacity are estimated for more than 54,000 NPDs in the conterminous United States. These preliminary hydropower potentials consider only approximations of site characteristics (e.g., dam height) and hydrologic variability without further assessment of site feasibility, environmental impact, and economical benefit. At the current phase of assessment, the total potential capacity and annual generation are estimated to be, respectively, 12 GW and 45 terawatt hours (TWh) per year—around 15% of the existing U.S. conventional hydropower total. Current economic limitations on project size will likely produce designs with less capacity than indicated herein.

3.1.1 Nationwide Potential

Although a large number of NPDs are assessed in this study, most of the energy potential is found in a relatively small subset of dams. As illustrated in Figure10, the top 597 NPD sites, each with a potential capacity greater than 1 MW, contribute nearly 90% of the estimated additional national capacity from NPDs. In particular, 40% of the national total is from the top 25 NPD sites only. Therefore, quality control of the top NPD sites was important to ensure the reliability of the national estimate. It should be noted that all sites with potential capacity greater than 1 MW have been examined during the quality control process.

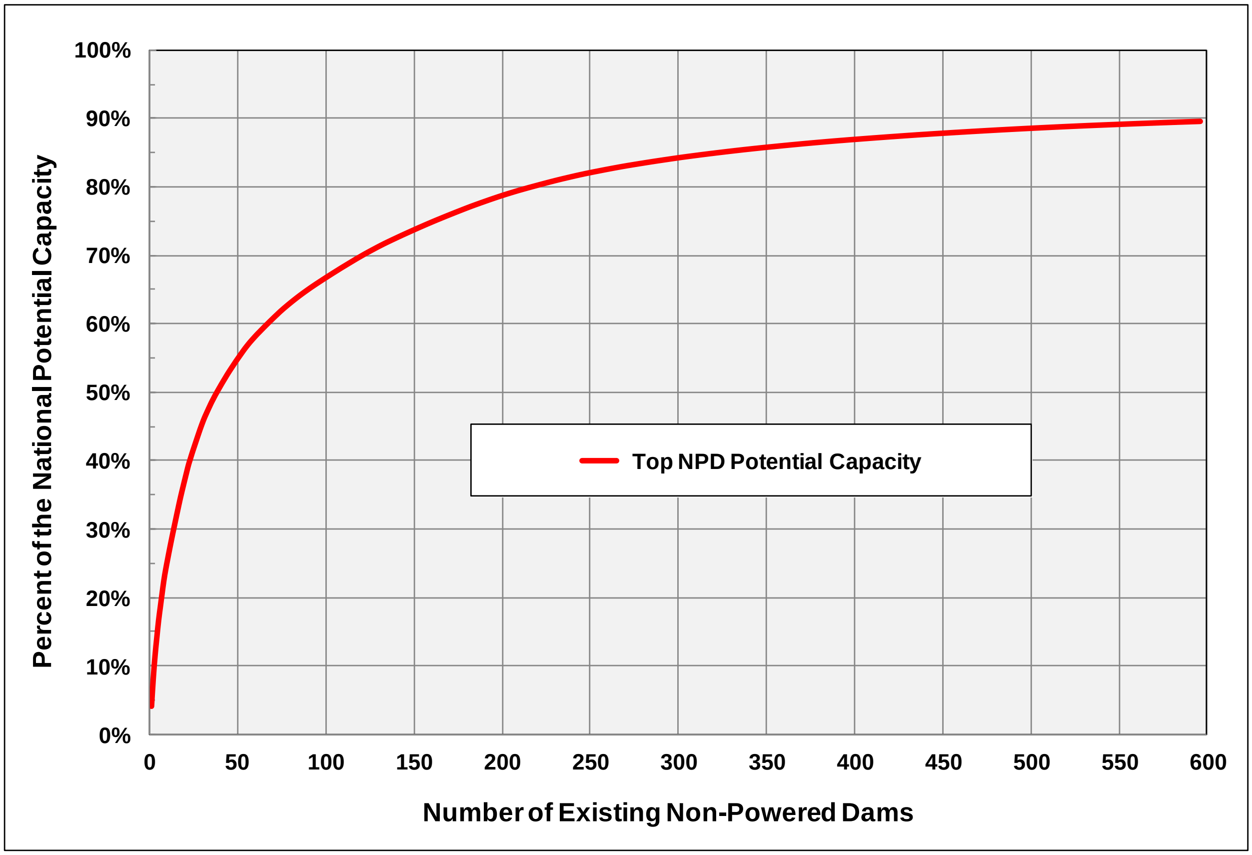


Figure 10. Cumulative potential capacity distribution of the top existing NPDs with the greatest potential added generation capacity

The top 597 NPDs have a potential capacity greater than 1 MW. A regional map of the NPD sites with potential capacity greater than 1 MW is shown in Figure 11. Most of the potential sites are found in the northeastern United States, Ohio River Basin, and Upper and Lower Mississippi River Basins. Specifically, high potentials are found for many USACE locks and dams—87 sites with a total potential of 6.9 GW. The finding is reasonable because the streamflow magnitude must be sufficiently large at locks and dams to support river transportation. Because locks and dams were built mainly for navigation purposes instead of municipal water supply and irrigation, there may be less concern about impacts regarding other competing water usage.

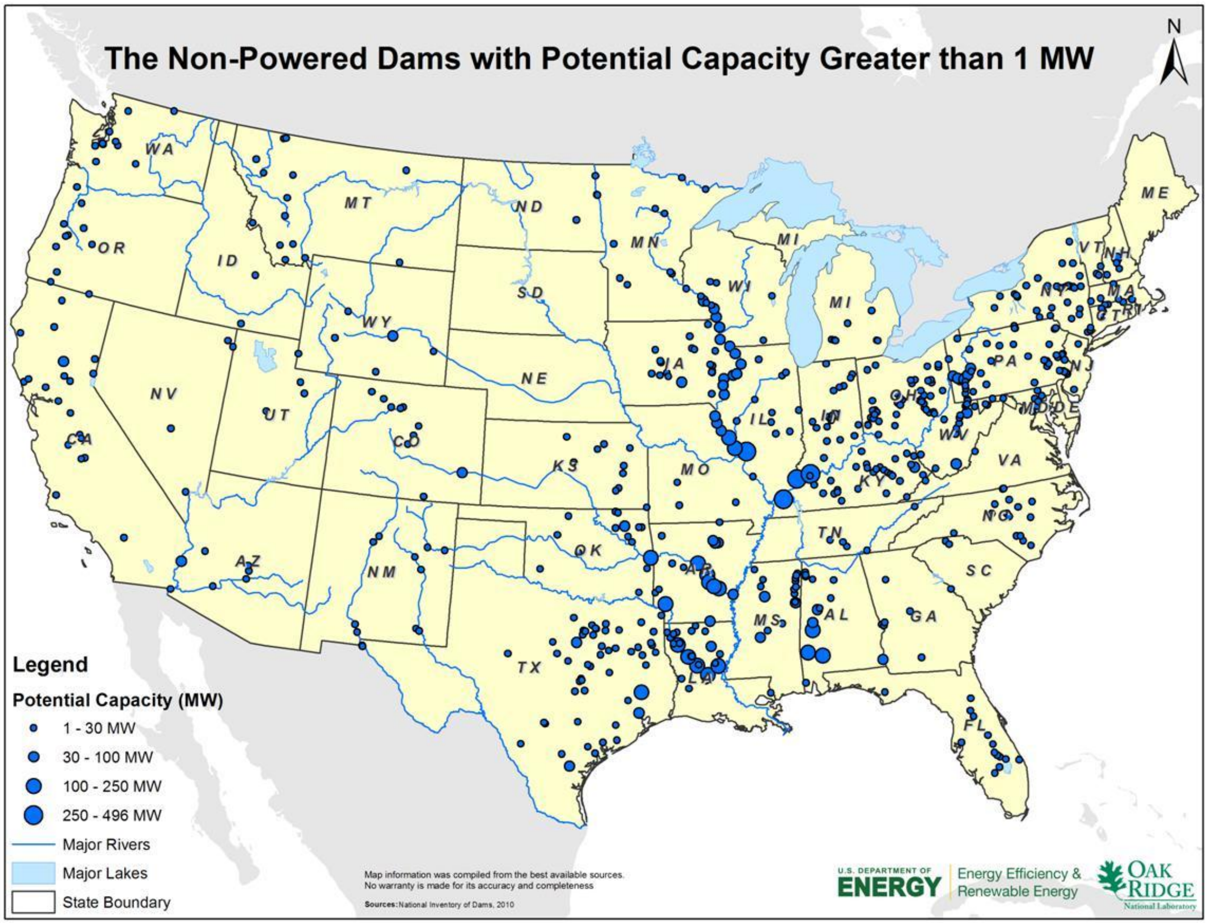


Figure 11. Location of the top NPDs with potential capacities greater than 1 MW

3.1.2 Regional Potential by River Basin and State

The NPD assessment is summarized in Table 3 by hydrologic regions. The top three regions are highlighted; namely Ohio, Upper Mississippi, and Arkansas-White-Red. As mentioned earlier, most of the hydropower potential identified within these three regions is located at navigation locks and dams located on relatively big rivers. The other summary is shown by state in Table 4. If a NPD was located on the boarder of multiple states, the potential capacity was distributed evenly into each neighboring state to compute the state total. According to this analysis, the greatest amount of hydropower potential is found in Alabama, Arkansas, Illinois, Kentucky, Pennsylvania, Texas, and Louisiana; this mainly is due to a series of Ohio River locks and high river flows. Many of these Ohio River locks are within the top 10 list of the potential NPD sites. It should be noted that other Ohio River locks and dams are not reflected in Table 3 and Table 4, including Cannelton, Smithland, and Meldahl, which were found to be suitable for hydropower development in the initial assessment. They were excluded during the quality control process because construction currently is underway to convert these NPDs for hydropower generation.

Table 3. Summary of NPD Assessment by Hydrologic Regions Totaling 12 GW of Potential

Hydrologic Regions (HUC02)	Potential Capacity (MW)	Potential Generation (TWh/yr)	Hydrologic Regions (HUC02)	Potential Capacity (MW)	Potential Generation (MWh/yr)
1 New England	243	1.110	10 Missouri	258	0.865
2 Mid-Atlantic	479	1.997	11 Arkansas-White-Red	1898	5.960
3 South Atlantic-Gulf	1618	3.778	12 Texas-Gulf	608	1.308
4 Great Lakes	156	0.903	13 Rio Grande	98	0.241
5 Ohio	3236	13.603	14 Upper Colorado	53	0.145
6 Tennessee	53	0.197	15 Lower Colorado	124	0.370
7 Upper Mississippi	2027	9.943	16 Great Basin	29	0.080
8 Lower Mississippi	743	2.802	17 Pacific Northwest	225	0.871
9 Souris-Red-Rainy	58	0.239	18 California	156	0.586

Table 4. Summary of NPD Assessment by State Totaling 12 GW of Potential

State	Potential Capacity (MW)	State	Potential Capacity (MW)	State	Potential Capacity (MW)
AL	922	ME	19	OH	288
AZ	80	MD	48	OK	339
AR	1136	MA	67	OR	116
CA	195	MI	48	PA	679
CO	172	MN	186	RI	13
CT	68	MS	271	SC	38
DE	3	MO	489	SD	12
FL	173	MT	88	TN	40
GA	144	NE	7	TX	658
ID	12	NV	16	UT	40
IL	1269	NH	63	VT	17
IN	454	NJ	33	VA	50
IA	427	NM	103	WA	85
KS	92	NY	295	WV	210
KY	1253	NC	167	WI	245
LA	857	ND	31	WY	45

3.2 Integration with Existing Hydropower Inventory and Other Renewable Energy Facilities

Figure 12 illustrates the generation potential listed in Table 3. It is interesting to note that while hydropower is already a significant source of electricity in the Pacific Northwest and California regions, the best potential for new development at NPDs is at locations with less existing hydropower usage; in particular, there was major potential found in the Ohio, Upper and Lower Mississippi, and Arkansas-White-Red regions. Therefore, new NPD development can help diversify the spatial distribution of national hydropower investment. More importantly, hydropower is found to be a complementary energy source with other renewables. A comparison is shown in Figure 13. 13. By overlaying the potential

NPD sites with National Renewable Energy Laboratory (NREL) estimates of wind and solar power potentials (NREL, 2011), it can be seen how the development of hydropower at NPDs may complement the development of other renewable technologies and augment the national portfolio. While more wind and solar power potentials are found in the western and southwestern United States, hydropower development through NPDs can provide clean renewables for other regions in the nation.

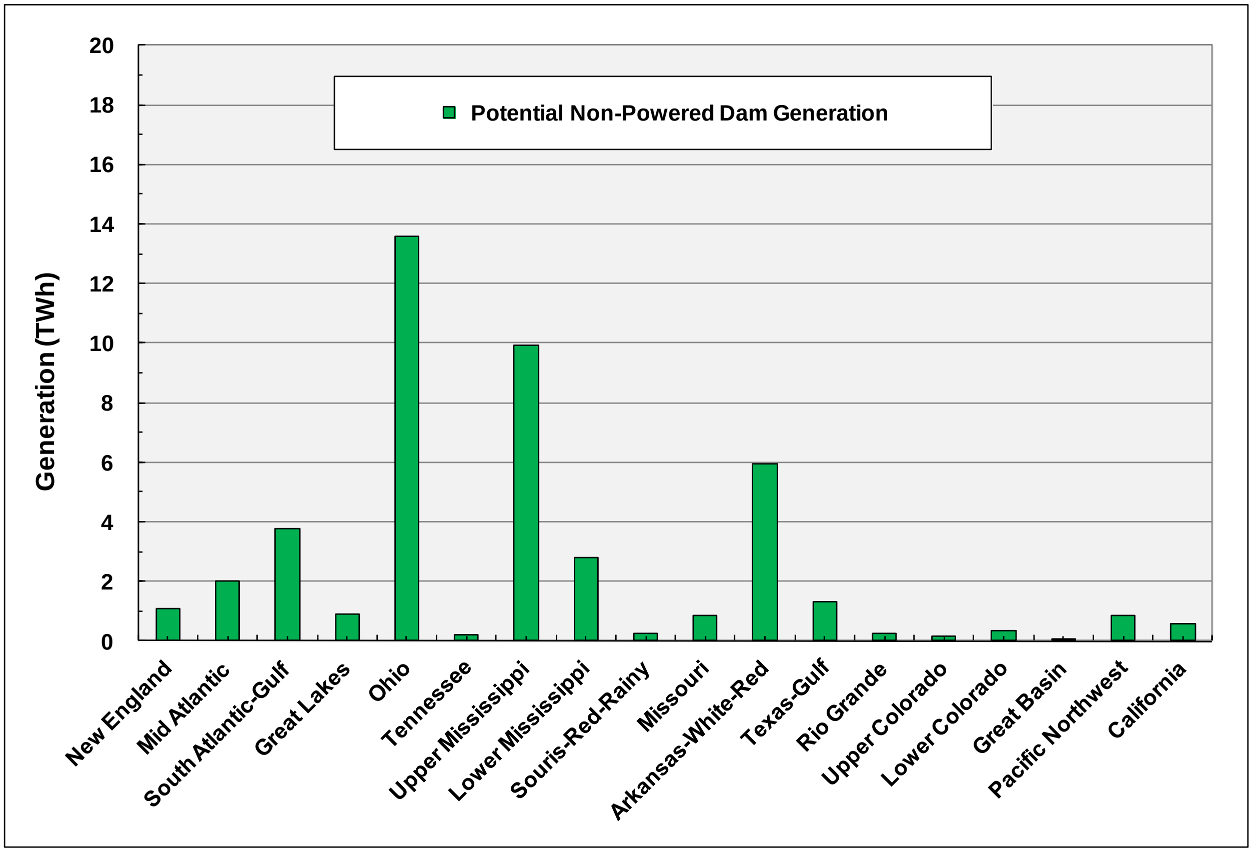
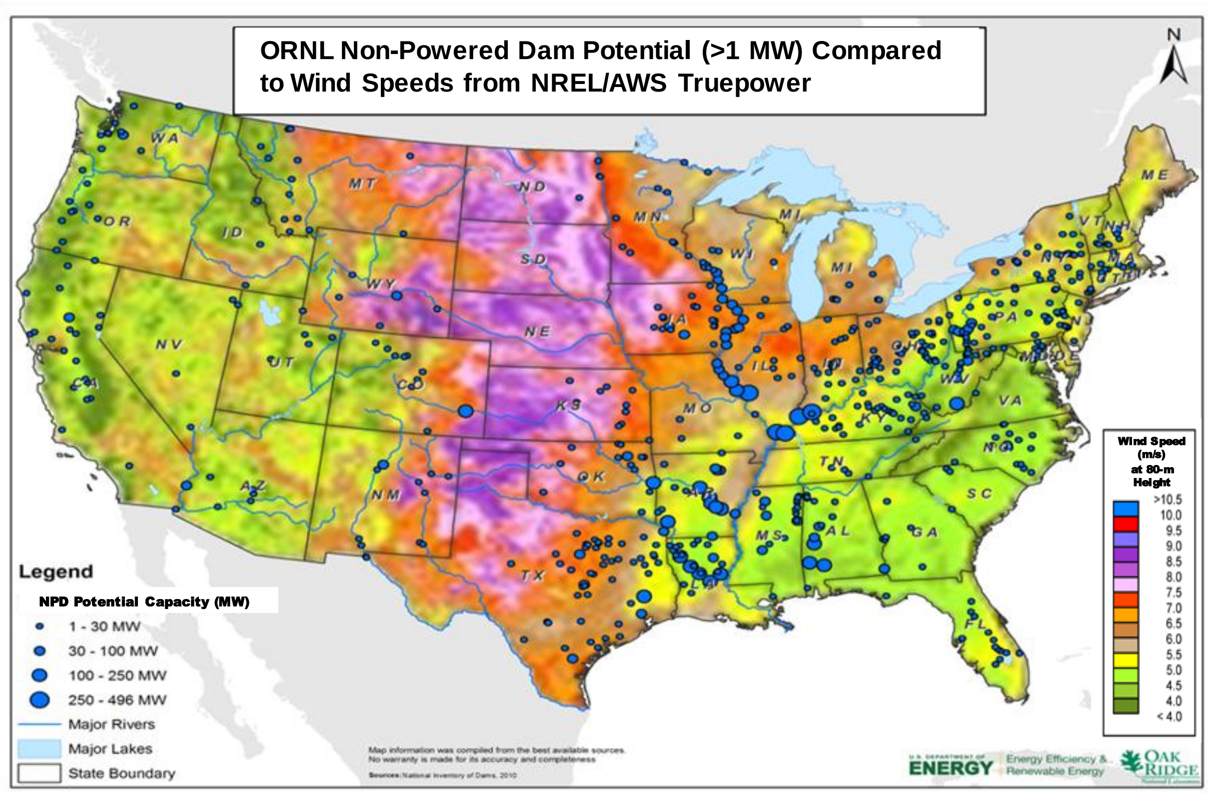


Figure 12. Potential hydropower generation from existing NPDs



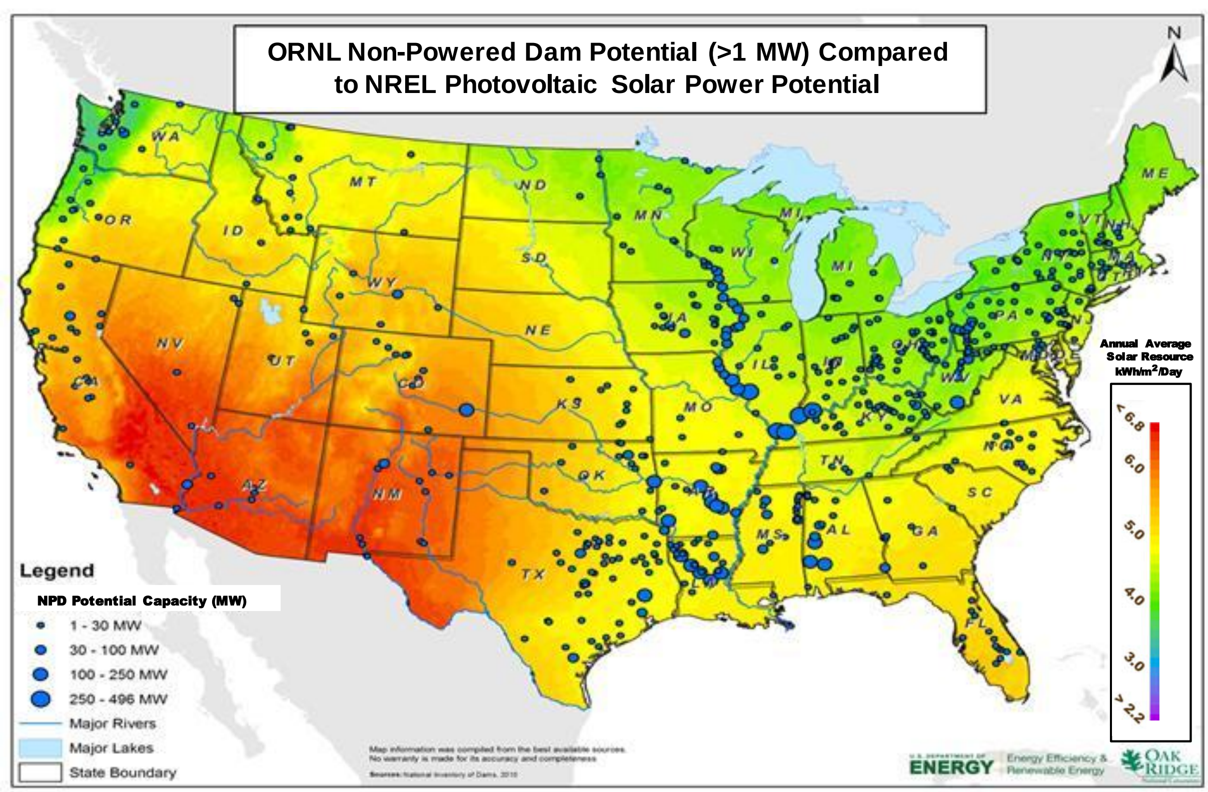


Figure 13. Comparison of top NPD sites with potential capacities greater than 1MW with maps of wind and solar photovoltaic resource potential

3.3 Future Improvement Opportunities

During the execution of the NPD assessment, the study team identified several refinements that were not possible within the current scope of the effort but that may yield improved estimates. Foremost is the application of refined site development models that include economic constraints on turbine and power house capacity based on the frequency of occurrence of daily flows. Such refinement will yield estimates of energy production that are more realistic, but less than the total energy available at a site.

In the context of refined site development modeling, there are dams in high mountain regions where an alternative development scheme with a diversion penstock may yield more hydraulic head—and greater energy production—than the simple dam height or pool elevation difference modeling provides. Enhanced modeling of water availability through collaboration with USGS research efforts will yield more robust estimates that consider long-term climate variability and provide more accurate seasonal statistics and flow-duration relationships for use in energy analysis. Future efforts could examine environmental, socioeconomic, and electric power infrastructure attributes of the NPD population to estimate site feasibility and development cost in addition to potential.

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Appendix A. Top 100 NPD with Hydropower Potential

	Dam Name	**Owner name	City	County	State	River Name	Year completed	Estimated Head (feet)	Estimated Annual Average Flow (cfs)	Estimated Annual Average *Generation (MWh)	Estimated Potential *Capacity (MW)
1	OHIO RIVER LOCKS & DAM 53	CELRL	OLMSTED	PULASKI	KY / IL	OHIO	1929	12.0	276,990	2,084,907	496.0
2	OHIO RIVER LOCKS & DAM 52	CELRL	BROOKPORT	MASSAC	KY / IL	OHIO	1929	12.0	276,133	2,078,454	494.5
3	JOHN T. MYERS LOCKS & DAM	CELRL	UNIONTOWN	UNION	KY / IN	OHIO	1975	18.0	147,134	1,661,216	395.2
4	NEWBURGH LOCKS & DAM	CELRL	SCUFFLETOWN	HENDERSON	KY / IN	OHIO	1975	16.0	133,554	1,340,348	318.9
5	MELVIN PRICE LOCKS & DAM	CEMVS	ALTON	MADISON	IL / MO	MISSISSIPPI	1990	24.0	97,508	1,467,886	299.3
6	COFFEEVILLE LOCK & DAM	CESAM	COFFEEVILLE	CLARK	AL	TOMBIGBEE	1962	34.0	26,470	564,511	241.7
7	DEMOPOLIS LOCK & DAM	CESAM	DEMOPOLIS	MARENGO	AL	TOMBIGBEE	1955	40.0	22,113	554,822	237.6
8	CLAIBORNE LOCK & DAM	CESAM	CLAIBORNE LANDING	MONROE	AL	ALABAMA	1969	30.0	28,340	533,297	228.3
9	RED RIVER W.W. LOCK & DAM 03	CEMVK	COLFAX	NATCHITOCHES	LA	RED	1991	31.0	30,192	587,080	187.0
10	DAVID D. TERRY LOCK & DAM	CESWL	PINE BLUFF	PULASKI	AR	ARKANSAS	1968	18.0	45,857	517,745	164.9
11	JOE HARDIN LOCK & DAM	CESWL	GRADY	LINCOLN	AR	ARKANSAS	1968	20.0	48,420	607,436	161.0
12	COL CHARLES D. MAYNARD LOCK & DAM	CESWL	REDFIELD	JEFFERSON	AR	ARKANSAS	1968	17.0	45,970	490,195	156.1
13	LIVINGSTON DAM	TRINITY RIVER AUTHORITY	LIBERTY	SAN JACINTO	TX	TRINITY RIVER	1969	70.0	7,453	327,233	152.0
14	LOCK & DAM 25	CEMVS	WINFIELD	LINCOLN	MO / IL	MISSISSIPPI	1939	15.0	76,764	722,259	147.3
15	LOCK & DAM 24	CEMVS	CLARKSVILLE	PIKE	MO / IL	MISSISSIPPI	1940	15.0	76,366	718,512	146.5
16	TOAD SUCK FERRY LOCK & DAM	CESWL	CONWAY	FAULKNER	AR	ARKANSAS	1969	16.0	45,336	454,988	144.9
17	RUSSELL B. LONG LOCK & DAM	CEMVK	GRAND ECORE	NATCHITOCHES	LA	RED	1995	25.0	28,663	449,465	143.1
18	W.D.MAYO LOCK & DAM	CESWT	FORT COFFEE	LE FLORE	OK	ARKANSAS	1970	21.0	32,145	423,426	134.9
19	EMMETT SANDERS LOCK & DAM	CESWL	PINE BLUFF	JEFFERSON	AR	ARKANSAS	1968	14.0	46,007	404,007	128.7
20	JOE D. WAGGONNER, JR. LOCK & DAM	CEMVK	SIMMESPORT	CATAHOULA	LA	RED	1985	25.0	25,242	395,825	126.1
21	JOHN OVERTON LOCK & DAM	CEMVK	SIMMESPORT	RAPIDES	LA	RED	1987	24.0	31,322	471,522	125.0
22	JONESVILLE LOCK & DAM	CEMVK	SIMMESPORT	CATAHOULA	LA	BLACK	1972	30.0	24,577	462,472	122.6
23	MILLWOOD DAM	CESWL	ASHDOWN	LITTLE RIVER	AR	LITTLE	1966	74.0	6,818	316,458	100.8
24	MONTGOMERY LOCKS & DAM	CELRP	MONACA	BEAVER	PA	OHIO	1936	18.0	37,166	419,626	99.8
25	MISSISSIPPI RIVER DAM 22	CEMVR	SAVERTON	RALLS	MO / IL	MISSISSIPPI	1938	10.0	74,224	465,570	94.9

*Estimated Generation and Capacity are based on the total energy available at the site.

**Legend for Owner Name column is located in Appendix B.

Appendix A. Top 100 NPD with Hydropower Potential (26 to 50)

	Dam Name	**Owner name	City	County	State	River Name	Year completed	Estimated Head (feet)	Estimated Annual Average Flow (cfs)	Estimated Annual Average *Generation (MWh)	Estimated Potential *Capacity (MW)
26	MISSISSIPPI RIVER DAM 21	CEMVR	QUINCY	ADAMS	MO / IL	MISSISSIPPI	1938	10.0	72,781	456,518	93.1
27	MONTGOMERY POINT LOCK & DAM	CESWL	WATSON	DESHA	AR	WHITE	2004	20.0	27,982	351,041	93.0
28	MISSISSIPPI RIVER DAM 20	CEMVR	CANTON	LEWIS	MO / IL	MISSISSIPPI	1936	10.0	72,126	452,410	92.2
29	LOCK & DAM 15	CEMVR	ROCK ISLAND	ROCK ISLAND	IL / IA	MISSISSIPPI	1934	16.0	42,841	429,950	87.7
30	EMSWORTH LOCKS & DAMS	CELRP	PITTSBURGH	ALLEGHENY	PA	OHIO	1938	18.0	31,424	354,796	84.4
31	JOHN MARTIN DAM & RESERVOIR	CESPA	LAS ANIMAS	BENT	CO	ARKANSAS	1943	78.5	5,027	247,622	78.9
32	LOCK & DAM 18	CEMVR	GLADSTONE	HENDERSON	IL / IA	MISSISSIPPI	1937	10.0	54,831	343,930	70.1
33	DUBUQUE NUMBER 11	DAEN NCR (CORPS OF ENGR)	DUBUQUE	DUBUQUE	IA	MISSISSIPPI	1937	12.0	44,801	337,215	68.8
34	RED ROCK DAM	CEMVR	KNOXVILLE	MARION	IA	DES MOINES	1969	104.0	4,995	325,849	66.4
35	MISSISSIPPI RIVER DAM 13	CEMVR	CLINTON	WHITESIDE	IA / IL	MISSISSIPPI	1939	11.0	46,987	324,201	66.1
36	OOLOGAH LAKE	CESWT	CLAREMORE	ROGERS	OK	VERDIGRIS	1963	86.0	3,502	188,933	60.2
37	MISSISSIPPI RIVER DAM 14	CEMVR	LECLAIRE	SCOTT	IA / IL	MISSISSIPPI	1939	11.0	42,773	295,121	60.2
38	MISSISSIPPI RIVER DAM 16	CEMVR	MUSCATINE	ROCK ISLAND	IA / IL	MISSISSIPPI	1937	9.0	48,050	271,253	55.3
39	GEORGE W ANDREWS LOCK & DAM	CESAM	GORDON	HOUSTON	AL / GA	CHATTAHOOCHEE	1963	25.0	8,203	128,638	55.1
40	PALO VERDE DIVERSION	DOI BR	MAYFLOWER	YUMA,	AZ / CA	COLORADO	1957	46.0	5,603	161,670	54.3
41	WILLIAM BACON OLIVER REPLACEMENT	CESAM	TUSCALOOSA	TUSCALOOSA	AL	BLACK WARRIER	1992	28.0	7,159	125,742	53.8
42	MISSISSIPPI RIVER DAM 12	CEMVR	BELLEVUE	JACKSON	IA / IL	MISSISSIPPI	1938	9.0	45,165	254,971	52.0
43	COLUMBIA LOCK & DAM	CEMVK	RIVERTON	CALDWELL	LA	OUACHITA	1970	18.0	17,301	195,334	51.8
44	A.I.SELDEN	CESAM	EASTPORT	HALE	AL	BLACK WARRIOR	1958	22.0	8,625	119,016	51.0
45	MISSISSIPPI RIVER DAM 17	CEMVR	NEW BOSTON	MERCER	IA / IL	MISSISSIPPI	1939	8.0	48,144	241,588	49.3
46	JOHN C. STENNIS	CESAM	COLUMBUS	LOWNDES	MS	TOMBIGBEE	1978	27.0	6,588	111,567	47.8
47	DASHIELDS LOCKS & DAM	CELRP	CORAPOLIS	ALLEGHENY	PA	OHIO	1929	10.0	31,559	197,956	47.1
48	TYGART DAM	CELRP	GRAFTON	TAYLOR	WV	TYGART	1938	133.5	2,360	197,513	47.0
49	LOCK & DAM 08	CEMVP	GENOA	VERNON	WI / MN	MISSISSIPPI	1937	11.0	32,842	226,599	46.2
50	BLUESTONE DAM	CELRH	HINTON	SUMMERS	WV	NEW	1947	48.0	6,255	188,328	44.8

*Estimated Generation and Capacity are based on the total energy available at the site.

**Legend for Owner Name column is located in Appendix B.

Appendix A. Top 100 NPD with Hydropower Potential (51 to 75)

	Dam Name	**Owner name	City	County	State	River Name	Year completed	Estimated Head (feet)	Estimated Annual Average Flow (cfs)	Estimated Annual Average *Generation (MWh)	Estimated Potential *Capacity (MW)
51	LOCK & DAM 10	CEMVP	GUTTENBERG	CLAYTON	IA	MISSISSIPPI	1937	8.0	43,261	217,083	44.3
52	ROSS BARNETT RESERVOIR DAM	PEARL RIV. VAL. WTR. SUP. DIST	JACKSON	RANKIN	MS	PEARL	1965	44.8	3,678	103,343	44.2
53	ALLEGHENY LOCK & DAM 03	CELRP	HARMAR TOWNSHIP	ALLEGHENY	PA	ALLEGHENY	1934	14.0	20,954	184,003	43.8
54	WESLEY E SEALE DAM	CITY OF CORPUS CHRISTI	CORPUS CHRISTI	JIM WELLS	TX	NUECES	1958	62.3	2,323	90,775	42.2
55	FELSENTHAL LOCK & DAM	CEMVK	STERLINGTON	UNION	AR	OUACHITA	1978	18.0	13,488	152,284	40.4
56	LOCK & DAM 09	CEMVP	HARPERS FERRY	ALLAMAKEE	IA	MISSISSIPPI	1937	9.0	33,817	190,908	38.9
57	DE CORDOVA BEND DAM	BRAZOS RIVER AUTHORITY	PECAN PLANTATION	HOOD	TX	BRAZOS	1969	79.0	1,626	80,558	37.4
58	FISH BARRIER	CDWR	OROVILLE	BUTTE	CA	FEATHER	1964	61.0	3,444	131,765	35.2
59	ALLEGHENY LOCK & DAM 02	CELRP	SHARPSBURG	ALLEGHENY	PA	ALLEGHENY	1934	11.0	21,133	145,812	34.7
60	ALLEGHENY LOCK & DAM 04	CELRP	NATRONA	ALLEGHENY	PA	ALLEGHENY	1927	11.0	20,741	143,111	34.0
61	LOCK & DAM NO 05	DAEN NCS (CORPS OF ENGR)	MINONA	BUFFALO	WI / MN	MISSISSIPPI	1935	9.0	29,155	164,588	33.6
62	LOCK & DAM NO 01	CITY OF BATESVILLE	BATESVILLE	INDEPENDENCE	AR	WHITE	1904	14.0	11,329	99,482	31.7
63	DEWEY DAM	CELRH	AUXIER	FLOYD	KY	JOHNS CREEK OF LEVISA FORK	1949	86.0	2,469	133,165	31.7
64	LOCK & DAM 07	CEMVP	LA CRESCENT	WINONA	MN / WI	MISSISSIPPI	1937	8.0	30,942	155,269	31.7
65	ALLEGHENY LOCK & DAM 07	CELRP	KITTANNING	ARMSTRONG	PA	ALLEGHENY	1931	13.0	16,313	133,017	31.6
66	LOCK & DAM NO 02	ARKANSAS POWER AND LIGHT COMPANY	TICHNOR	ARKANSAS	AR	WHITE	1905	14.0	11,070	97,207	31.0
67	LAKE HOUSTON DAM	CITY OF HOUSTON	MAGNOLIA GARDENS	HARRIS	TX	SAN JACINTO	1954	62.0	1,698	66,021	30.7
68	LOCK & DAM NO 03	ARKANSAS COLLEGE	GRADY	INDEPENDENCE	AR	WHITE	1908	14.0	10,960	96,247	30.7
69	GRAY REEF	USBR	ALCOVA	NATRONA	WY	NORTH PLATE	1961	30.0	5,390	101,423	30.2
70	GRENADA DAM	CEMVK	GRENADA	GRENADA	MS	YALOBUSHA	1954	97.0	1,868	113,654	30.1
71	FRANKLIN FALLS DAM	CENAE	FRANKLIN	MERRIMACK	NH	PEMIGEWAS SET	1943	112.0	1,961	137,757	30.1
72	MAXWELL LOCKS & DAM	CELRP	EAST MILLSBORO	FAYETTE	PA	MONONGAH ELA	1964	20.0	9,815	123,133	29.3
73	ENFIELD DAM	C.H. DEXTER	ENFIELD	HARTFORD	CT	CONNECTIC UT	1825	12.6	16,940	133,884	29.3
74	CHATFIELD DAM	CENWO	DENVER	DOUGLAS	CO	SOUTH PLATTE	1973	124.0	1,257	97,750	29.1
75	RODMAN DAM AND SPILLWAY	FL-DEP	WELAKA	PUTNAM	FL	OKLAWAHA	1968	38.0	2,710	64,598	27.7

*Estimated Generation and Capacity are based on the total energy available at the site.

**Legend for Owner Name column is located at in Appendix B.

Appendix A. Top 100 NPD with Hydropower Potential (76 to 100)

	Dam Name	**Owner name	City	County	State	River Name	Year completed	Estimated Head (feet)	Estimated Annual Average Flow (cfs)	Estimated Annual Average *Generation (MWh)	Estimated Potential *Capacity (MW)
76	BELTON LAKE	CESWF	BELTON	BELL	TX	LEON	1954	117.3	804	59,153	27.5
77	HOWARD A HANSON DAM	CENWS	KANGLEY	KING	WA	GREEN	1962	149.5	1,084	101,620	26.3
78	CHARLEROI LOCKS & DAM	CELRP	MONESSEN	WESTMORELAND	PA	MONONGAHELA	1967	17.0	10,309	109,926	26.2
79	COON RAPIDS	THREE RIVERS PARK DISTRICT	COON RAPIDS	HENNEPIN	MN	MISSISSIPPI	1913	23.0	8,773	126,569	25.8
80	LOCK & DAM 04	CEMVP	ALMA	BUFFALO	WI / MN	MISSISSIPPI	1935	7.0	28,207	123,849	25.3
81	MORELOS DIVERSION	IBWC	YUMA	YUMA	AZ / CA	COLORADO	1950	18.0	6,641	74,985	25.2
82	NEW SAVANNAH BLUFF LOCK & DAM	CESAS	AUGUSTA	RICHMOND	GA	SAVANNAH	1937	15.0	6,127	57,645	24.7
83	SAYLORVILLE DAM	CEMVR	DES MOINES	POLK	IA	DES MOINES	1975	94.2	2,021	119,400	24.3
84	B. EVERETT JORDAN DAM	CESAW	HAYWOOD	CHATHAM	NC	HAW	1974	61.0	1,460	55,846	23.9
85	LOCK C-1 DAM AT WATERFORD	NYS CANAL CORP	WATERFORD	SARATOGA	NY	HUDSON	1912	16.8	9,359	98,625	23.7
86	ADAM T. BOWER MEMORIAL	DCNR	SHAMOKIN DAM	SNYDER	PA	SUSQUEHANNA	1969	5.6	27,692	97,271	23.3
87	LOCK & DAM 06	CEMVP	TREMPEALEAU	TREMPEALEAU	WI / MN	MISSISSIPPI	1936	6.0	29,754	111,980	22.8
88	BARREN RIVER LAKE DAM	CELRL	BOWLING GREEN	BARREN	KY	BARREN	1964	118.0	1,267	93,766	22.3
89	LA GRANGE LOCK & DAM	CEMVR	LA GRANGE	CASS	IL	ILLINOIS	1939	10.0	17,304	108,540	22.1
90	ABERDEEN LOCK & DAM	CESAM	ABERDEEN	MONROE	MS	TOMBIGBEE	1981	27.0	3,037	51,436	22.0
91	EAGLE AND PHENIX MILL LAKE DAM	FIELDCREST MILLS, INC.	COLUMBUS	MUSCOGEE	GA / IL	CHATTAHOOCH EE	1851	9.8	8,309	51,074	21.9
92	LOCK 32 DAM ERIE CANAL	NYS CANAL CORP	PITTSFORD	MONROE	NY	NEW YORK STATE BARGE CANAL	1908	28.0	7,039	123,631	21.3
93	KENTUCKY RIVER LOCK & DAM 05	COMMONWEALTH OF KENTUCKY	LAWRENCEBERG	ANDERSON	KY	KENTUCKY	1844	22.0	6,384	88,093	21.0
94	WISTER LAKE	CESWT	WISTER	LE FLORE	OK	POTEAU	1949	95.0	1,099	65,513	20.9
95	STEVE BOONE	STEVE BOONE	NO TOWN	HENRY	KY	TRIB-KENTUCKY	1992	18.2	7,569	86,412	20.6
96	GOLD RAY DAM	JACKSON COUNTY PARKS & RECREATION	GOLD HILL	JACKSON	OR	ROGUE	1941	35.0	3,589	78,785	20.4
97	SUTTON DAM	CELRH	SUTTON	BRAXTON	WV	ELK	1960	109.9	1,238	85,289	20.3
98	GREEN RIVER LOCK & DAM 02	CELRL	CALHOUN	MCLEAN	KY	GREEN	1956	14.0	9,690	85,091	20.2
99	KENTUCKY RIVER LOCK & DAM 08	COMMONWEALTH OF KENTUCKY	BRYANTSVILLE	GARRARD	KY	KENTUCKY	1900	25.0	5,392	84,553	20.1
100	ARKABUTLA DAM	CEMVK	COLDWATER	CALLOWAY	MS	COLDWATER	1943	84.0	1,433	75,493	20.0

*Estimated Generation and Capacity are based on the total energy available at the site.

**Legend for Owner Name column is located in Appendix B.

Appendix B. Acronyms

CDWR	California Department of Water Resources
CENAB	Corps of Engineers North Atlantic Baltimore District
CENAN	Corps of Engineers North Atlantic New York District
CENAO	Corps of Engineers North Atlantic Norfolk District
CENAP	Corps of Engineers North Atlantic Philadelphia District
CENAE	Corps of Engineers North Atlantic New England District
CENAU	Corps of Engineers North Atlantic Europe District
CENWK	Corps of Engineers Northwestern Kansas District
CENWO	Corps of Engineers Northwestern Omaha District
CENWP	Corps of Engineers Northwestern Portland District
CENWS	Corps of Engineers Northwestern Seattle District
CENWW	Corps of Engineers Northwestern Walla Walla District
CEPOA	Corps of Engineers Pacific Ocean Alaska District
CEPOF	Corps of Engineers Pacific Ocean Far East District
CEPOH	Corps of Engineers Pacific Ocean Honolulu District
CEPOJ	Corps of Engineers Pacific Ocean Japan District
CESAC	Corps of Engineers South Atlantic Charleston District
CESAJ	Corps of Engineers South Atlantic Jacksonville District
CESAM	Corps of Engineers South Atlantic Mobile District
CESAS	Corps of Engineers South Atlantic Savannah District
CESAW	Corps of Engineers South Atlantic Wilmington District
CESPA	Corps of Engineers South Pacific Albuquerque District
CESPL	Corps of Engineers South Pacific Los Angeles District
CESPK	Corps of Engineers South Pacific Sacramento District

CESPN	Corps of Engineers South Pacific San Francisco District
CESWF	Corps of Engineers Southwestern Forth Worth District
CESWG	Corps of Engineers Southwestern Galveston District
CESWL	Corps of Engineers Southwestern Little Rock District
CESWT	Corps of Engineers Southwestern Tulsa District
CELRB	Corps of Engineers Great Lakes and Ohio River Buffalo District
CELRC	Corps of Engineers Great Lakes and Ohio River Chicago District
CELRE	Corps of Engineers Great Lakes and Ohio River Detroit District
CELRH	Corps of Engineers Great Lakes and Ohio River Huntington District
CELRL	Corps of Engineers Great Lakes and Ohio River Louisville District
CELRN	Corps of Engineers Great Lakes and Ohio River Nashville District
CELRP	Corps of Engineers Great Lakes and Ohio River Pittsburgh District
CEGRC	Corps of Engineers Gulf Region Central District
CEGRN	Corps of Engineers Gulf Region North District
CEGRS	Corps of Engineers Gulf Region South District
CEMVM	Corps of Engineers Mississippi Valley Memphis District
CENVN	Corps of Engineers Mississippi Valley New Orleans District
CEMVR	Corps of Engineers Mississippi Valley Rock Island District
CEMVS	Corps of Engineers Mississippi Valley St. Louis District
CEMVP	Corps of Engineers Mississippi Valley St. Paul District
CEMVK	Corps of Engineers Mississippi Valley Vicksburg District
DOE	Department of Energy
DOI	U.S. Department of the Interior
DOI BR	U.S. Department of the Interior Bureau of Reclamation
DWNS	Dams With Negligible Streamflow
ECRE	Eagle Creek Renewable Energy

EIA	Energy Information Administration
FERC	Federal Energy Regulatory Commission
HU	Hydrologic Unit
NED	National Elevation Dataset
NHA	National Hydropower Association
NHAAP	National Hydropower Asset Assessment Project
NHD	National Hydrography Dataset
NID	National Inventory of Dams
NLCD	National Land Cover Dataset
NPD	National Non-Powered Dam
NREL	National Renewable Energy Laboratory
NWIS	National Water Information System
ORNL	Oak Ridge National Laboratory
P	Precipitation
Q	Runoff
TVA	Tennessee Valley Authority
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation (or, Reclamation)
USGS	U.S. Geological Survey
WBD	Watershed Boundary Dataset

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