Pacific Northwest NATIONAL LABORATORY

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Small Hydropower Interconnections: Small Hydropower in the United States

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1.0 Introduction

Small hydropower projects, which we define as generators below 20 MW in capacity have been the predominant source of hydropower growth over the past decade and create the most cost-effective and environmentally permissible avenues for new hydropower installation in the United States (DOE 2016; Johnson et al. 2018). Small hydropower developers across the United States have found that interconnecting these projects with the grid can be challenging due to unexpected costs and schedule overruns. Understanding the interconnection challenges and improving the process may allow more small hydropower projects to be successful.

Noting these challenges, the U.S. Department of Energy Water Power Technologies Office enlisted Pacific Northwest National Laboratory (PNNL) and Oak Ridge National Laboratory (ORNL) to investigate the small hydropower interconnection landscape across the United States. To begin to analyze the existing interconnection processes and challenges facing small hydropower, the state of small hydropower development in the U.S. must first be described to understand the characteristics of the industry. The first in a series, this paper presents the state of small hydropower projects in the U.S. to describe their type, location, and size based on data extracted from the HydroSource database (ORNL 2020).

The following papers in the series will detail the variety of state interconnection processes to connect power generators with the grid (“Small Hydropower Interconnections: State Interconnection Processes”), analyze these interconnection processes (“Small Hydropower Interconnections: Analysis of Interconnection Processes”), and present best practices in interconnection processes (“Small Hydropower Interconnections: Best Practices”) that will help overcome barriers to future small hydropower development.

2.0 Status of Small Hydropower in the U.S.

Small hydropower is commonly divided into four subsectors:

1. **Non-powered dams (NPDs)**, which could be retrofitted with power generating equipment. Past estimations of small hydropower resource potential suggest that NPDs provide a significant opportunity for growth. Hadjerioua et al. (2012) estimated 12 gigawatts (GW) of capacity across 54,391 dams. Filtering to individual NPDs of less than 10 megawatts (MW) in capacity, Johnson et al. (2018) estimated the potential for 2,500 MW across 397 projects.
2. **In-conduit hydropower**, which can be inserted in water conveyance, distribution, or collection infrastructure. Though a federal assessment of in-conduit hydropower is lacking, 104 MW of potential capacity was estimated over 373 Bureau of Reclamation canals (Bureau of Reclamation 2012). More recently, in-conduit potential in California was estimated at 414 MW (Badruzzaman 2020).
3. **Pumped storage hydropower (PSH)**, in which water is pumped uphill to store as potential energy, then released through a hydropower facility to create electricity when needed. PSH could be sited in many locations, though the development to date has been concentrated on larger systems due to economies of scale for this technology.
4. **New stream reach development (NSD)**, in which completely new infrastructure is constructed to harness potential energy gradients of a waterway. Of the three million streams in the United States inspected by Kao et al. (2014), technical potential for NSD capacity is 65.5 GW. A small NSD potential capacity of 4,321 MW across 1,035 sites was estimated by Johnson et al. (2018) for projects under 10 MW capacity.

The status of small hydropower in the U.S. was evaluated using information from the HydroSource database (ORNL 2020) by searching for projects between 0 to 30 MW nameplate capacity (the rated power output of the generator). The capacity and number of projects in operation and under development were analyzed by capacity, type, geographic distribution, and state.

2.1 Small Hydropower Nameplate Capacity

The majority of small hydropower projects are concentrated below 5 MW, both for currently operational facilities and projects under development (Figure 1). This trend holds true for all project types, even after removing in-conduit projects, which tend to be smaller in capacity. Relatively few projects are in operation or under development between 15 to 30 MW. In addition to containing the largest number of projects, the 0 to 5 MW capacity group also contains more hydropower capacity than other groups (Figure 2).

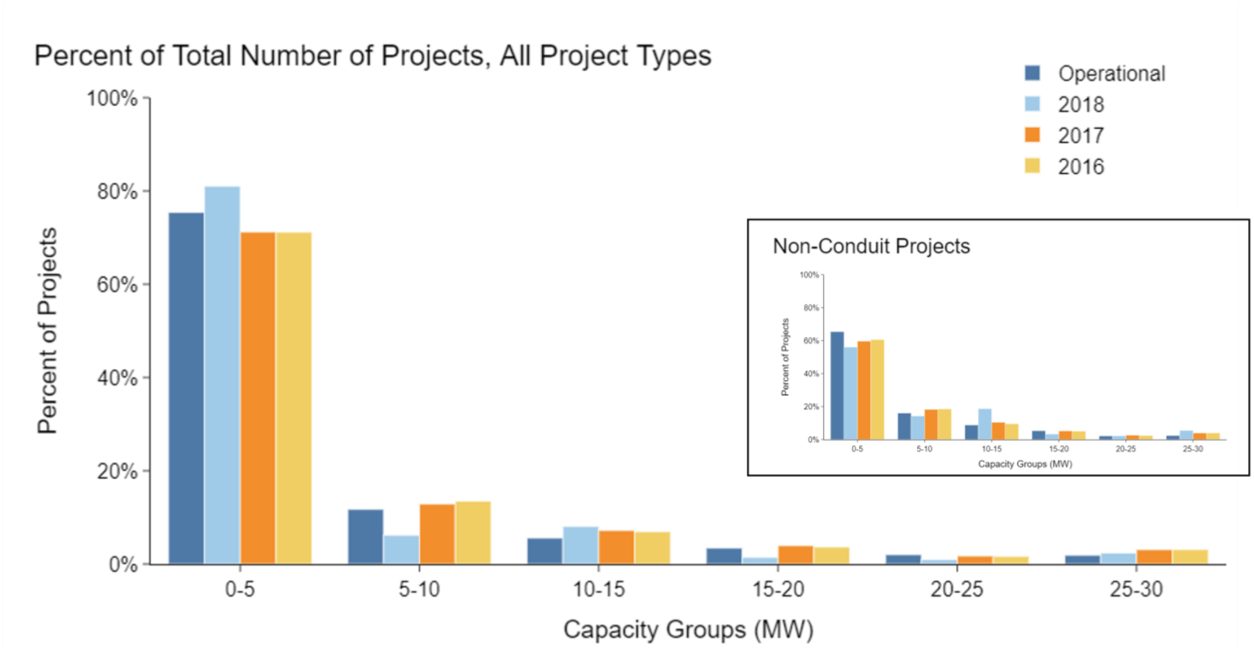

Figure 1. Small Hydropower Capacity Distributions for All Projects (main figure) and Non-Conduit Projects Only (inset)

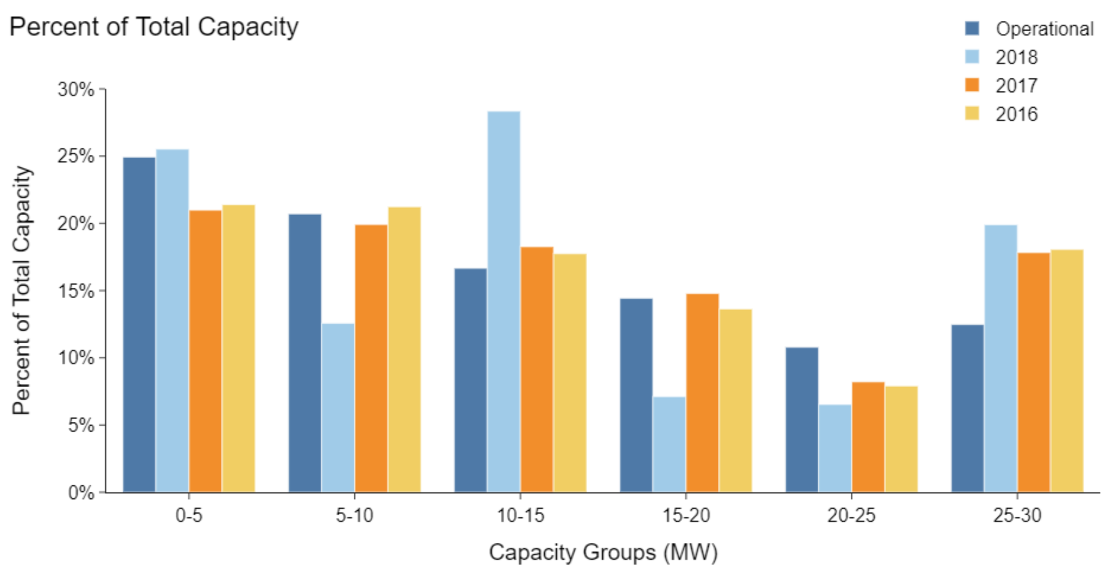

Figure 2. Small Hydropower Capacity Distributions by Proportion of (summed) Capacity

Based on these distributions, 20 MW will be considered the upper capacity limit for small hydropower projects. The 20 MW upper bound refers to the total output of a hydropower plant (e.g. four 5 MW generators at a single plant would be 20 MW total output). This boundary was confirmed through consultation with the small hydropower industry representatives on the technical advisory group, and because it matches the limit imposed by the Federal Energy Regulatory Commission's (FERC's) delineation between small versus large generator interconnection procedures. A 20 MW upper bound was applied to the HydroSource data for the remainder of the analysis.

2.2 Small Hydropower Type

Small hydropower projects below 20 MW are separated into different categories based on type of hydropower project. The categories include NPD, conduit, NSD, PSH, capacity uprate, or re-licensing (Figure 3). Table 1 and Table 2 provide the breakdown of projects by type, in terms of project number and total capacity, respectively. NPD contained the majority of projects and overall capacities, followed by conduit, and then NSD. PSH projects were extremely limited below 20 MW, primarily because PSH competes on cost-based economies of scale. Only larger projects justify the risk-reward of navigating the extended FERC licensing process. Similarly, NSD requires a full environmental review through FERC licensing, without exemption, which presents an elevated risk profile over other types of development.

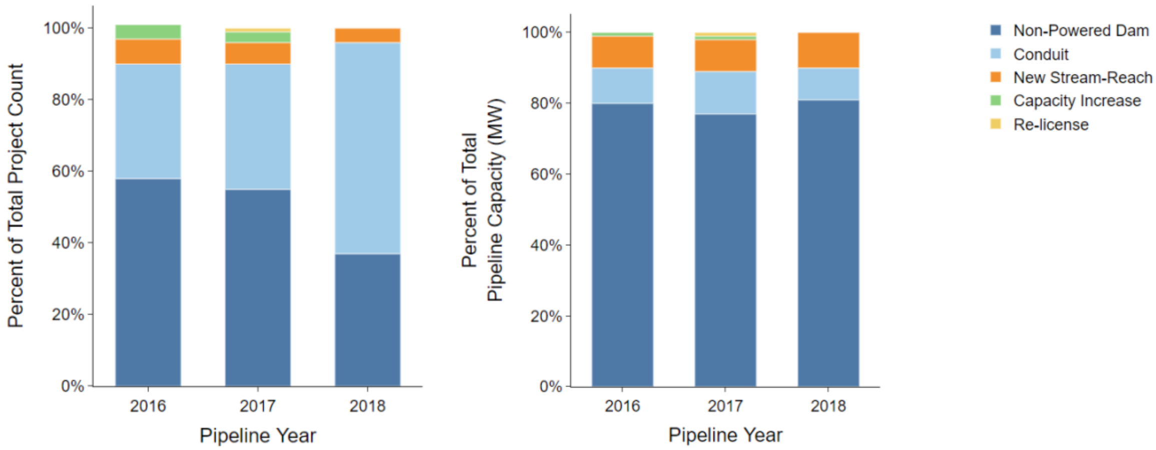

Figure 3. Small Hydropower (< 20 MW) Segmentation by Project Count (left) and Capacity (right)

Table 1. Small Hydropower Project Counts by Type

Project Type	2016 Pipeline	2017 Pipeline	2018 Pipeline	Count Total
Capacity Uprate/Increase	20	18	--	38
Conduit	168	194	120	482
New Stream Reach	35	34	9	78
Non-Powered Dam	293	295	75	663
Pumped Storage Hydropower	--	--	1	1

Table 2. Small Hydropower Project Capacities (MW) by Type

Project Type	2016 Pipeline (MW)	2017 Pipeline (MW)	2018 Pipeline (MW)	Capacity Total (MW)
Capacity Uprate/Increase	28	31	--	59
Conduit	195	218	51	464
New Stream Reach	157	163	52	372
Non-Powered Dam	1,468	1,527	437	3,432

Pumped Storage Hydropower	--	--	5	5

2.3 Geographic Distribution

Hydropower projects are strongly tied to the location of water resources and the precise location of pressure head. Geographic location of small hydropower NPD and in-conduit projects are described in this section. HydroSource data did not indicate significant PSH or NSD pipeline activity, so these market segments are not shown.

2.3.1 Small Non-Powered Dams

Leveraging the database compiled by Hadjerioua et al. (2012), clear groupings of NPD potential are shown aligning with topography along the Cascade, Sierra Nevada, Bitterroot, and Appalachian mountain ranges (Figure 4). There is also significant NPD potential in locations that are not traditional hubs for hydropower generation, such as eastern Texas and central Florida.

Many of the small NPD projects under development in 2018 (Figure 5) are located in the Appalachian and southern Rust Belt region running from the Southeast to the Northeast. Many of these locations correspond to locks and dams actively or formerly used for navigation along large rivers such as the Kentucky, Muskingum, Monogahela, Ohio, or Allegheny. There is similar activity on the Illinois and upper Mississippi rivers. Other NPDs currently under consideration for small hydropower retrofit were originally developed for irrigation, flood control, and recreational benefits in Mississippi, Kansas, Montana, Oregon, and California.

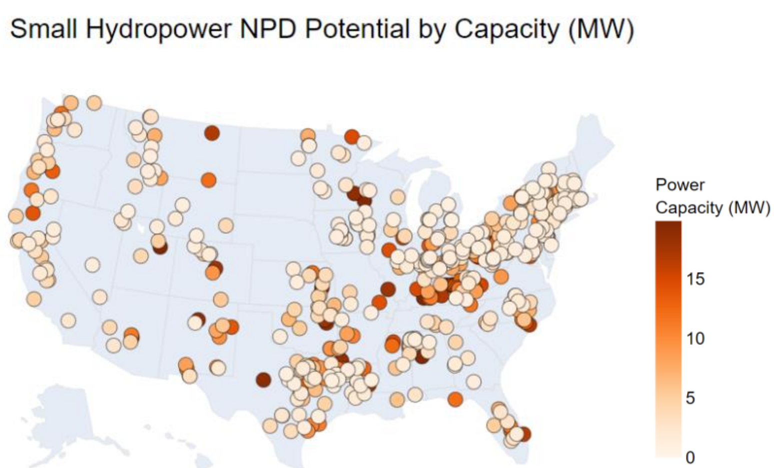

Figure 4. Small Hydropower NPD Potential. Symbol shading correlated with nameplate capacity to 20 MW.

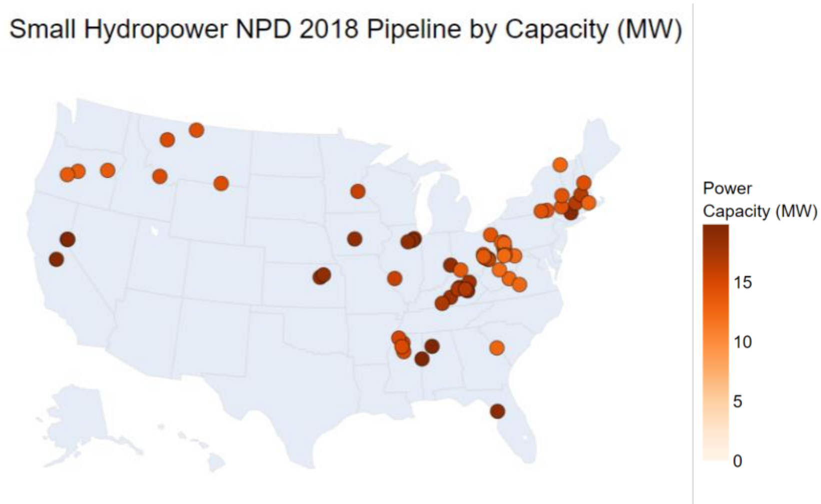

Figure 5. Small Hydropower NPD 2018 Pipeline. Symbol shading correlated with nameplate capacity to 20 MW.

2.3.2 Small Conduit Hydropower

In-conduit hydropower opportunities are typically found at the overlap of population centers requiring developed water conveyance infrastructure and topography that results in excess pressure head across water collection, processing, and distribution networks. Operational small conduit hydropower projects and those under development are located predominantly in the western and northeastern U.S. (Figure 7 and 6). Projects in the 2018 pipeline are concentrated in the arid West where broad water conveyance is found. Regions of the most projects in development are found across California, Colorado, Oregon, Idaho, and Utah. The largest of these projects in development are approximately 5 MW in scale.

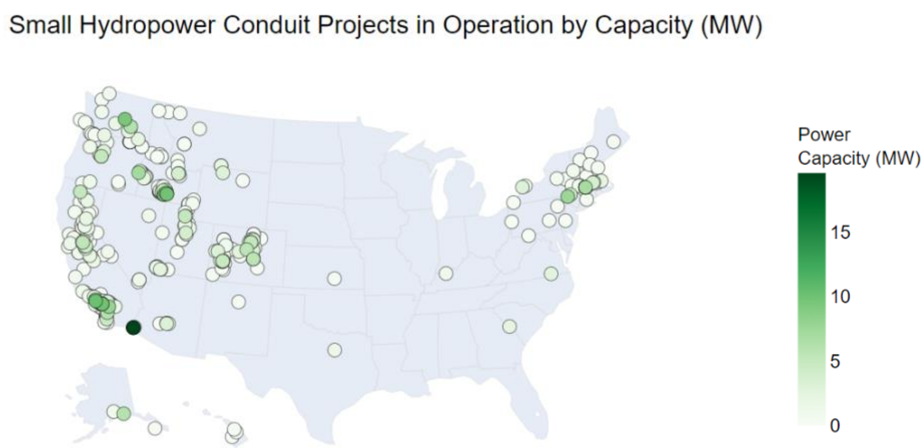

Figure 6. Small Hydropower Conduit Projects in Operation. Symbol color shading is correlated with nameplate capacity to 20 MW.

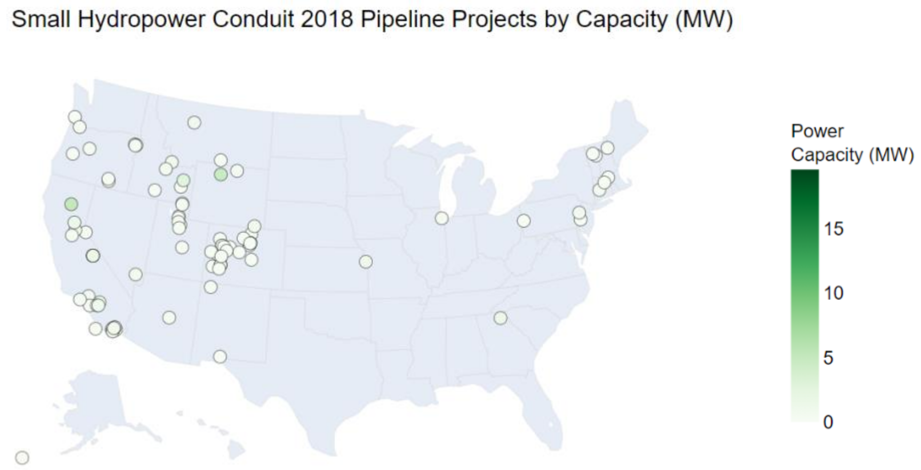

Figure 7. Small Hydropower Conduit Projects in the 2018 Development Pipeline. Symbol color shading is correlated with nameplate capacity to 20 MW.

2.4 Distribution by States

While all regions of the U.S. have some potential for small hydropower development, some states have more projects in development or already in operation. California, New York, and Maine have the most existing small hydropower capacity (Figure 8). Colorado, Oregon, Pennsylvania, Kentucky, and Ohio may be poised for the most growth, as these states have seen more projects in the pipeline between 2016 and 2018 compared to the scale of their operational fleet. These states may need more consideration for interconnection processes that meets the needs of new small hydropower projects.

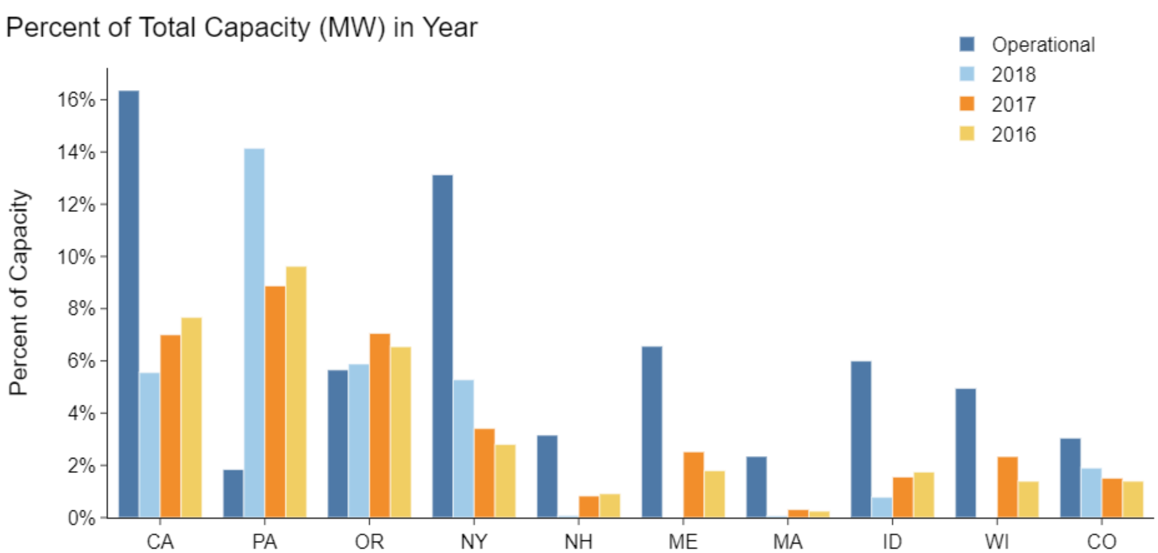

Figure 8. Cumulative capacity of small hydropower projects in top 10 states for both operational projects and 2016 - 2018 development pipelines.

3.0 Summary

The small hydropower segment in the U.S. includes generators between 0 to 20 MW. Within this segment, most projects and installed capacity are less than 5 MW nameplate capacity. Small hydropower consists of different types of projects, including NPD, in-conduit hydropower, NSH, and PSH. Most new capacity in the development pipeline between 2016 and 2018 were NPD projects, followed by in-conduit and NSD. Small hydropower non-powered dam potential is spread across the U.S., but development has been focused in the Appalachian Mountains and southern Rust Belt regions with some projects in the West and Midwest. In-conduit small hydropower development has primarily been located in western and northeastern U.S. California, New York, and Maine have the most existing small hydropower capacity, but the most growth was evident in Colorado, Oregon, Pennsylvania, Kentucky, and Ohio. Overall, the status of small hydropower in the U.S. shows an industry with a wide distribution of geographies and technology types filled primarily on generators less than 5 MW.

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