Hydropower in the Land of Ten Thousand Lakes

An analysis of the socio-economic and environmental feasibility of powering Army Corps dams in the St. Paul District.

National Hydropower Association, Summer 2020 Fellowship
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Abstract

How feasible is the construction of hydropower facilities on non-powered dams? A 2013 study by the US Department of Energy's Oak Ridge National Laboratory estimated that non-powered dams (NPDs) in the United States contain a total of 12 GW of potential energy.[1] Yet, as of 2016, only 3% of the approximately 87,000 NPDs in the US generate electricity. [2] Why is this the case? Existing energy potential and reduced construction needs suggest greater economic feasibility for projects on NPDs. On the other hand, feasibility must also be examined in cost-benefit analyses of community and environmental impacts. For a given region, how beneficial will an added hydropower plant be in comparison to other waterfront operations? Does the generation of energy outweigh disturbances to the surrounding community and environment? While it has been proven that potential energy on NPDs exists, economic and community feasibility analyses remain integral to understanding which existing dams should be powered.

This paper focuses on the qualitative impacts of hydropower on NPDs in Minnesota, briefly discussing quantified data from previous studies. The dams examined in the paper are all US Army Corps of Engineers (USACE) dams in the USACE St. Paul District. Each section addresses one part of the process of proposing, constructing, and operating a hydropower plant on a non-powered dam. Topics include the hydrology of the region, historical and community sites, and conservation programs. Upon close examination of these factors, this report predicts that, while there is regional potential for hydroelectric expansion, water flow and usage constraints contribute to a high cost-benefit ratio relative to other regions of the country. The paper concludes that further research is merited to determine site-specific feasibility, especially given the potential effects of future climate change. This research is particularly urgent given the important role that hydropower can play in balancing the electric grid as regional solar and wind energy markets expand.

[1] Hadjerioua, et al. "An Assessment of Energy Potential at NPDs in the United States," vii.
[2] US Department of Energy, "Hydropower Vision", 11.

Table of Contents

Background on Federal Hydropower

Hydropower is one of the oldest sources of electric energy in the United States, originating in the late 1800s, a few decades after engineer James Francis invented the modern water turbine. In 1882, the world's first hydroelectric power plant started operations in Appleton, WI. The hydropower market grew quickly throughout the 20th century, and the capacity of conventional hydropower in the nation peaked from 1997-2002.[3] Although hydropower no longer makes up as large a share of the country's electricity generation as it did 100 years ago, it remains a staple of the United States' renewable energy market today.[4] According to the US Energy Information Administration, in 2019 hydropower made up 6.6% of total US electricity generation and 28% of renewable US electricity generation. This makes hydropower the largest source of US renewable electric power.[5]

Lock & Dam 8 on the Mississippi River, photo courtesy of the USACE St. Paul District website

[3] US Army Corps of Engineers, "Outlook for the US Army Corps of Engineers Hydropower Program," 4.
[4] National Hydropower Association, "History."
[5] US Energy Information Administration, "Hydropower Explained."

Hydroelectric generation remains popular because its grid reliability and operational flexibility make it a stable energy source, and one which can be used to supplement more irregular sources of energy, such as wind and solar power. Yet, despite its reliability and flexibility, some other benefits of hydroelectric power are matched with drawbacks: while projects may provide additional recreational opportunities, they can also disrupt existing activities. Similarly, while they can help ease inland navigation, project-related shoreline erosion poses a significant threat to shipping vessels. The same is true of the environmental impacts of hydropower projects: they at once provide opportunities for environmental protection, while also posing a significant threat to those same ecosystems. These community and environmental impacts will be discussed in a later section.

This paper will focus on Army Corps dams, however, hydroelectric projects can be owned by private entities, non-utility companies, private utility companies, municipalities, electric cooperatives, or state or federal entities. While not all hydropower projects utilize dams, many rely on them to regulate water flow and energy generation. In 2016, the DOE reported that 49% of hydropower ownership was federal, while 51% was non-federal.[6] Of the federally owned projects, 78% are owned by the US Army Corps of Engineers (USACE) and the Bureau of Reclamation, accounting for 91% of federally owned hydroelectric capacity.[7] The Tennessee Valley Authority, Bureau of Indian Affairs, and the International Boundary and Water Commission account for the rest.

Indeed, the Army Corps is the largest owner and operator of hydroelectric plants in the United States and one of the largest in the world, with a 2011 report estimating that USACE

projects generate 68 billion kWh a year.[8] The same 2011 report highlighted new pressures on the agency, including aging infrastructure, federal funding deficiencies, and outside pressure to dispose of some dams.[9] In response to these concerns, the USACE report outlined plans to update infrastructure, introduced the potential of further dam privatization, and restated a desire to make the licensing process more efficient for private developers.

Currently, for outside developers to operate a hydropower plant on USACE property, they must involve the Army Corps as a key stakeholder throughout the FERC licensing process and complete separate 404 and 408 reviews for Corps. Despite a 2011 Memorandum of Understanding between FERC and USACE, the process remains inefficient.[10] While USACE does not predict significant privatization of its dams in the near future, it remains open to private development.[11] The FERC and USACE joint licensing procedure will be discussed in future sections, as will the terms of site-sharing between private developers and the Corps.

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[6] US Department of Energy, "Hydropower Vision", 11.
[7] US Federal Energy Regulatory Commission, "Hydropower Primer", 1.
[8] US Army Corps of Engineers, "Outlook for the US Army Corps of Engineers Hydropower Program," 4.
[9] US Army Corps of Engineers, "Outlook for the US Army Corps of Engineers Hydropower Program," 8, 37, 12.
[10] US Army Corps of Engineers, "Outlook for the US Army Corps of Engineers Hydropower Program," 44.
[11] US Army Corps of Engineers, "Outlook for the US Army Corps of Engineers Hydropower Program," 43, 42.

Legislative and Regulatory Processes

Hydroelectric projects on USACE dams must go through two licensing procedures: one through FERC and another through USACE. Although some measures exist to merge the processes, both agencies remain heavily involved in the procedure and reserve the right to request various amendments to the terms of the application. As is such, while developers traditionally complete FERC licensing before the USACE requirements, many also communicate with USACE during the pre-filing process to make sure that the agency is on board with their proposed project.

Developers can apply for a preliminary permit for a potential hydroelectric project site. The preliminary permit gives that developer a three year period to examine the feasibility of the site. During that time, they hold priority over other potential license applicants. At the end of the three years, the developer may file for a two-year extension, or choose whether or not to apply for a license. As with other FERC license processes, once an application for a permit has been filed with FERC, the agency releases a public notice of that application. Stakeholders are invited to comment on the proposal, which has the potential to change the terms or outcome of the application.

FERC's hydropower licensing procedures include a pre-filing procedure as well as one of three licensing processes. Projects that propose to use USACE unpowered dams are not eligible for FERC licensing exemptions. The pre-filing process usually begins with applicants filing a formal Notice of Intent (NOI) and a Pre-application Document (PAD) with the commission, the latter of which includes a description of the project and its potential environmental impacts. During pre-filing, developers will gather information and conduct studies to determine the environmental impacts and feasibility of their project, dependent on stakeholder and FERC requirements. The pre-filing process engages relevant stakeholders to ensure they are fully aware of the proposal and to allow them to voice concerns. These stakeholders include state and federal agencies, tribal authorities, local businesses, and local community members. These stakeholders must be consulted with before the license application can be filed.

The pre-filing requirements are also dependent on which of the three licensing processes the developer applies for. The three processes are the Integrated Licensing Process (ILP), Alternative Licensing Process (ALP), and the Traditional Licensing Process (TLP). The ILP is the default process and requires the most intensive studies and stakeholder coordination in the pre-filing process. The ALP is less intensive, with very little formal FERC involvement in the pre-filing process. The TLP is the least intensive of the three processes and is meant for projects that require very few studies and stakeholder cooperation. There is no formal FERC involvement in the TLP pre-filing process. Developers must request and obtain FERC approval to utilize the ALP and TLP.

Once the license application has been filed at the end of the pre-filing process, the post filing procedure is similar across the three licensing processes. Firstly, FERC formally requests stakeholder comments on the application and prepares an environmental document. The environmental document is prepared under the guidelines of the National Environmental Policy Act (NEPA). For projects that are likely to have a significant environmental impact, an Environmental Impact Statement is prepared. For projects that are expected to have a more minor environmental impact, an Environmental Assessment is prepared. The completed NEPA documents must be provided to USACE for review and comments and may be used by USACE in their own review process. Following the completion of stakeholder consultations and the NEPA document, FERC makes their final decision on the license application. If the license is granted, any terms that the FERC or mandatory conditioning agencies–stakeholders whose requests must be accepted–require are incorporated into the license conditions.

Typically once the FERC licensing procedures are complete, USACE requires the license applicant to undergo section a 408 analysis and issue a section 404 permit before the license can be finalized and construction may begin. The section 408 analysis is required under section 14 of the Rivers and Harbors Act of 1899.[12] The review considers the technical design and the environmental impact of the project. A 2011 Memorandum of Understanding (MOU) between FERC and USACE, meant to integrate their hydropower licensing processes, attempts to merge FERC's NEPA study with the 408 review.[13] If the MOU's suggestions are utilized in licensing, the 408 becomes a purely technical analysis.[14] The section 404 permit allows USACE to regulate the project's effect on the surrounding aquatic resources. The permit is required under Section 404 of the Clean Water Act and Sections 9 and 10 of the Rivers and Harbors Act of 1899. USACE may require more than one permit pursuant to these sections. The reviews are carried out by USACE, independent of FERC. The satisfactory completion of both the 408 and 404 reviews are necessary before an applicant may begin construction on a project.

Energy Capacity

The potential energy available at a non-powered dam depends on the head height–the vertical distance between intake and discharge of the water–, the flow rate of the water, and the density and gravity of the water's acceleration. In addition, the plant's infrastructure, most notably the turbine design, will affect the energy generated at any given site.[15] Lastly, the design of the dam will affect at what percentage of total capacity the plant is allowed to operate. Run-of-river plants generate energy according to available water inflow, so that output varies

[12] License and regulatory information hitherto from: US Federal Energy Regulatory Commission, "Hydropower Primer," "Hydro Vision."
[13] US Federal Energy Regulatory Commission and the US Army Corps of Engineers, "Memorandum of Understanding."
[14] Spaulding, Doug. Discussion with Lillie Horton. June 2020.
[15] Belyakov, Nikolay. "Sustainable Power Generation," 335-337.

depending on water flow and quantity. Peaking dams, on the other hand, regulate energy production by filling reservoir storage during low load demand periods to be used in generating electricity during peak demand.[16] All of the USACE dams discussed in this paper are operated as run-of-river dams, meaning hydroelectricity generated is less adaptable to short-term market needs.

Below is a table that synthesizes the findings from two reports on the power potential of ten unpowered USACE dams in the St. Paul District regulatory boundary. These dams are currently unpowered, but represent the dams within the St. Paul district regulatory boundary with the greatest energy potential, according to a 2013 Oak Ridge National Laboratory (ORNL) study. [17] The other report is a USACE study of their own dams, also from 2013.[18] Both reviews examined the potential generating capacity of non-powered dams (NPDs) in megawatts (MW). The results are organized from greatest to least potential, according to the ORNL findings. There is a significant difference between the two study's energy potential estimates, due to the methods used to calculate potential power. These discrepancies will be discussed below.

Dam	**Nearest City or Town / Waterway**	**ORNL Study: Potential Capacity (MW)**	**USACE Study: Potential Capacity (MW)**
Lock & Dam 8	Genoa / Mississippi River	46.2	14.35
Lock & Dam 5	Minnesota City / Mississippi River	33.6	24.62
Lock & Dam 7	La Crescent / Mississippi River	31.7	14.68
Lock & Dam 4	Alma / Mississippi River	25.3	14.73
Lock & Dam 6	Trempealeau / Mississippi River	22.8	10.90
Lock & Dam 5A	Fountain City / Mississippi River	19.5	7.51
Pokegama Lake Dam	Grand Rapids / Mississippi River	3.2	<1

[16] Rosemore, Nora. Discussion with Lillie Horton. July 2020.
[17] Hadjerioua, Boualem, et al, "An Assessment of Energy Potential at NPDs in the United States."
[18] US Army Corps of Engineers, "Hydropower Resource Assessment at Non-powered USACE Sites."

Winnibigoshish Dam	Deer River / Mississippi River	2.3	<1
Orwell Reservoir and Dam	Fergus Falls / Otter Tail River	1.8	4.45
Lac Qui Parle Dam	Watson / Minnesota River	1.6	4

Both of the studies listed above calculate potential generation in megawatt-hours (MWh), using the same equation: $E = Q \times H \times e \times T / 11800$. This equation has been used in earlier DOE and Bureau of Reclamation reports. "E" represents total hydroelectric power generated in MW per hour, "Q" (ft^3/s) is average flow during total generation period "T" (hrs.). "H" (ft.) equals hydraulic head height and "e" is generating efficiency, which is assumed as .85. In converting potential hourly generation to potential capacity in MW, the ORNL study incorporates a capacity factor, whereas the USACE study does not. The capacity factor is the measurement of actual energy produced over the hypothetical maximum and depends on regional hydrology records, dam type, operational constraints, and power demand. The ORNL study the capacity factor equation:
$Cf = annual\ generation / installed\ capacity\ (MWh) \times 365 \times 24$for each dam. Using these variables, the study generated the following equation for potential dam capacity in MW: $Potential\ Capacity = E\ (MWh) / (Cf \times 365 \times 24)$.[19] The USACE report, however, does not add capacity factor into its calculation of potential capacity in MW. Instead, the report uses the equation $Potential\ Capacity = Q \times H \times e / 11800$.[20] While the report does consider capacity factors, they are not included in the initial potential capacity estimate. Instead, the report demonstrates how capacity exceedance can be used to measure the range of energy generation the project could feasibility produce. While both approaches towards calculating potential capacity have their advantages, this paper will use the ORNL estimates since they are already adjusted for the capacity factor. It is worth noting, however, that in addition to the discrepancies between power estimates, the USACE study's potential capacity findings also contain a different order of greatest potential between the ten dams.

To make the above potential capacity estimates more palatable, consider their potential in terms of powering a single household. According to the Energy Information Administration, the average US household in 2018 used 10,972 kWh in electricity.[21] The potential capacity of the ten dams above is equal to 2,371,332,000 kWh. Therefore, if all of the dams above were powered, they could contribute to the necessary annual electricity for 216,125 American households. This

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[19]Hadjerioua, Boualem, et al., An Assessment of Energy Potential at NPDs in the United States," 8-10.
[20]US Army Corps of Engineers, "Hydropower Resource Assessment at Non-powered USACE Sites," 6-10
[21] US Energy Information Administration, "How Much Electricity Does an American Home Use?"

means that, if all ten of the above dams were powered at the estimated capacity, they would meet the annual electricity demands for close to 10% of the state of Minnesota.

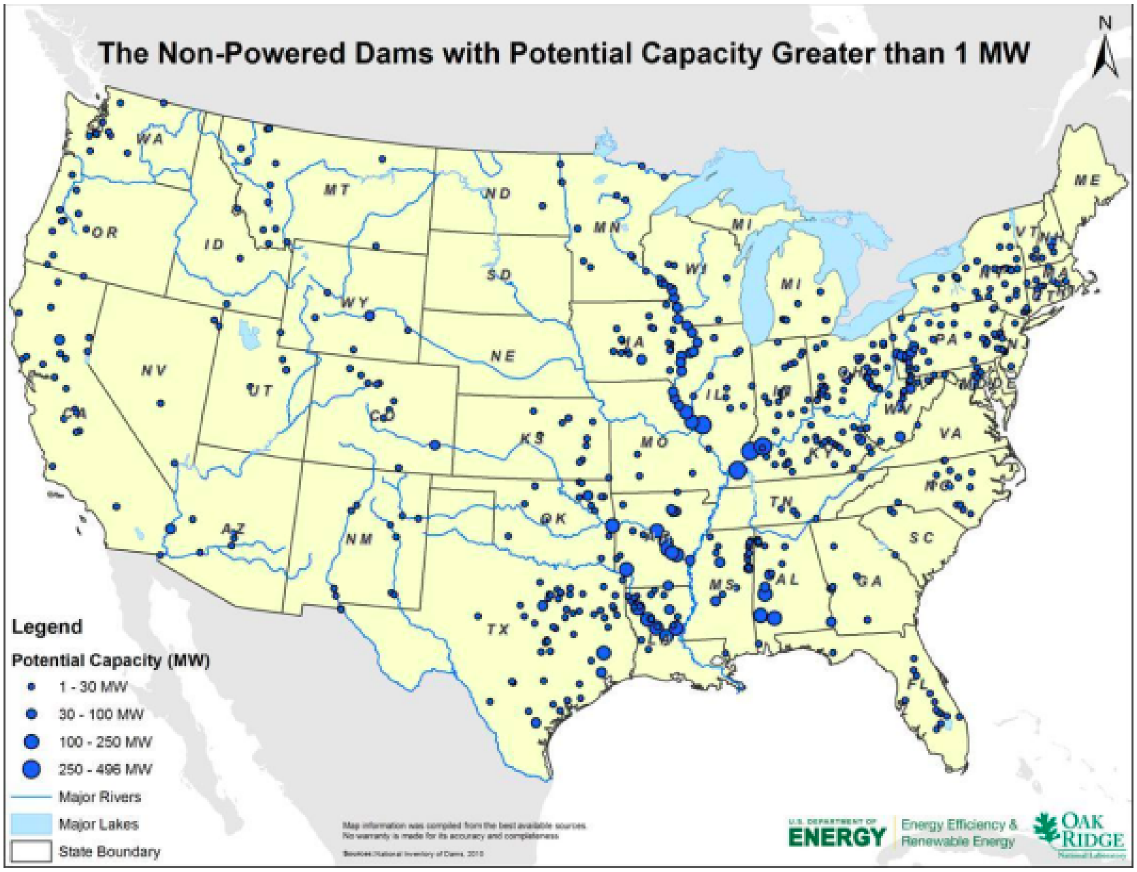
Compared to existing hydropower plants on Army Corps sites, the ten dams above offer a greater or a similar amount of potential energy, depending on whether they are compared to the ORNL study or USACE study estimates. Currently, five USACE dams in Minnesota have private hydropower plants on them, and their location, operator, most recent license year, purpose, and power capacity are listed below.[22]

Dam / Site	**Nearest City or Town / Waterway**	**Operator**	**Most Recent License Year**	**Purpose**	**Power Capacity (MW)**
Lock & Dam 1	Twin Cities / Mississippi River	Twin Cities Hydro LLC	2004	Wholesale power marketer	18
Lower St. Anthony Falls	Twin Cities / Mississippi River	SAF Hydroelectric LLC	2006	Wholesale power marketer	9.6
St. Anthony Falls Hennepin Island	Twin Cities / Mississippi River	Northern States Power Co. MN	2004	Investor-owned utility	13.7
Lock & Dam 2	Hastings / Mississippi River	City of Hastings	1983	Private, non-utility	4.4
Upper St. Anthony Falls	Twin Cities / Mississippi River	A-Mill Artist Lofts	2015	Private, non-utility	0.6

To contextualize the operating and potential energy of Minnesota dams, consider energy estimates from other regions of the United States. According to the 2013 ORNL study, 40% of the national energy potential is concentrated at 25 NPDs, highlighting significant variability nationwide. The states with the greatest potential capacity are Illinois (1269 MW), Kentucky (1253 MW), and Arizona (1136 MW). The hydrologic regions with the greatest potential are Ohio (3236 MW), Upper Mississippi (2027 MW), the Arkansas-White-Red (1898 MW), and the South Atlantic-Gulf (1618 MW). It is worth clarifying that while Minnesota is part of the Upper Mississippi basin, its capacity is smaller than other states in the region, notably Iowa, Illinois,

[22] Oak Ridge National Laboratory, "SMH Explorer."

and Missouri.[23] As depicted in the map below, Minnesota–while host to multiple small-capacity projects–is not among the states with the greatest energy potential. Given the resources required to license, construct, and operate a hydropower facility, even on a non-powered dam, this map suggests that projects in Minnesota may not be as economically feasible as those in other states. This will be explored further in the next section.



Hadjerioua, Boualem, et al, "An Assessment of Energy Potential at NPDs in the United States," 24.

Economic Feasibility

To analyze the economic feasibility of hydropower projects, past studies have used two metrics: the benefit-cost ratio (BCR) and the internal rate of return (IRR). The BCR is equal to the net present value of benefits over the net present value of cost while the IRR is the discount rate at which the net present value of cost will equal the net present value of benefits. In other words, the IRR measures the rate of return at which project costs and benefits are at equilibrium. The BCR and IRR consider construction costs and operation and maintenance (O&M) costs, as well as energy capacity and the levelized cost of energy (LCOE). The LCOE is the minimum

23 Hadjerioua, Boualem, et al, "An Assessment of Energy Potential at NPDs in the United States," 22-25.

price that a project must sell its generated electricity at in order to make the project economically feasible. It is worth noting, though, that even if a project does not make the LCOE, it does not mean that it will fail. Other forms of revenue, such as environmental incentives, can provide additional financial benefits.[24]

The USACE 2013 study on NPDs estimated the economic feasibility of their dams using the BCR and IRR metrics. Of the ten unlicensed dams in the St. Paul District regulatory boundary, only one was estimated to be economically feasible. The Orwell Reservoir and Dam is expected to have a maximum feasible capacity of 1.6 MW, allowing it a BCR of 1.03 with an IRR of 4%. The other nine dams in the region were deemed to be economically unfeasible given the costs of production in relation to their potential energy output and LCOE.[25] That being said, this study utilized the energy capacity estimates that, while included in the table in the previous section, this paper chose not to use in favor of the ORNL energy estimates. The USACE study's calculations for power potential did not initially figure in capacity factor. While the Corps did use measures of capacity in their estimates,[26] it is also possible that calculating economic feasibility with the ORNL study's energy potential data would yield different results. However, the ORNL study does not contain economic feasibility estimates. While this paper does not calculate the BCR, IRR, and LCOE of the above dams itself, these metrics would be useful for anyone who wishes to further quantify the feasibility of powering NPDs.

The USACE study compares the feasibility of NPDs across Corps districts and divisions, not hydrologic regions. The St. Paul District belongs to the Mississippi Valley division, which actually ranks first in terms of feasible capacity estimates, followed closely by the Great Lakes and Ohio River Division.[27] Similar to the ORNL study's energy potential estimates, however, the St. Paul district contributes significantly less to that feasibility estimate than the other districts in the division. The Vickburg, Rock Island, and St. Louis districts contribute a combined 938 MW of maximum feasible capacity, while the North Atlantic, Baltimore, and St. Paul districts only contribute an additional 78 MW. Two dams in Vicksburg and St. Louis districts contain over 100 MW of maximum feasible energy, more than all of the dams these three districts combined[28] Therefore, it can be said that when compared to other states, Minnesota's hydropower potential on NPDs is not only smaller, but also less economically feasible.

[24] Zhang, Qin Fe, et al., "Technical and Economics Feasibility Assessment of Small Hydropower Development in the Deschutes River Basin," 24, 21.

[25] US Army Corps of Engineers, "Hydropower Resource Assessment at Non-powered USACE Sites," 36,37.

[26] US Army Corps of Engineers, "Hydropower Resource Assessment at Non-powered USACE Sites," 21.

[27] US Army Corps of Engineers, "Hydropower Resource Assessment at Non-powered USACE Sites," ES-3.

[28] US Army Corps of Engineers, "Hydropower Resource Assessment at Non-powered USACE Sites," 32-42.

Orwell Reservoir & Dam, photo courtesy of the USACE St. Paul District website

Stakeholders

As mentioned above, stakeholder coordination is integral to the licensing process. Depending on the nature of the project, its location, and affected officials, tribes, and organizations, additional reviews may be required of the developer, primarily during the pre-filing process. According to the FERC's Code of Regulations 18, section 5.5, relevant stakeholders include the county, political subdivision, irrigation or drainage district, and Indian tribal authority that may be impacted by the project, whether or not the development site is located within the stakeholder's boundaries. The developer must provide the contact information for these entities, as well as any additional stakeholders they believe may be affected by the project. Stakeholders are notified during the pre-filing process, and often formally identified by the applicant in the Notice of Intent (NOI) that they file with the FERC. Applicants must send a copy of the NOI to listed stakeholders for review and comment.[29]

[29] US Federal Energy Regulatory Commission, "Title 18–Conservation of Power and Water Resources," 143-144.

Non-governmental organizations (NGOs), who may be affected by or interested in the proposed project, are also listed on the NOI application to FERC. These may include other hydropower developers, hydropower regulatory organizations, environmental consulting or conservation entities, and recreational organizations that operate near the proposed project site. In addition, the NOI is made public as part of the pre-licensing process, allowing entities that are not listed as stakeholders–including community members–to comment.[30]

In addition to the stakeholders listed on the NOI, the state in which the project is located may also make requests of the applicant. This includes reviews that are required by federal regulations but that involve or are delegated to state agencies. Under section 401 of the Clean Water Act, the appropriate state pollution control or tribal agency must grant a water quality certification to the proposed project. Under the Fish and Wildlife Coordination Act, federal and state officials coordinate and must grant a license or permit to the developer. The Coastal Zone Management Act (CZMA) states that if a project is within a state coastal zone or will have an effect on one, the state CZMA agency must be consulted with.[31] Lastly, the National Historic Preservation Act typically involves state and federal officials in ensuring that no historic sites are adversely affected by the proposed project. For USACE sites, a historical review is undertaken by the district office prior to them issuing a section 404 permit.[32] The rest of this section, as well as future sections, will explore the relevant stakeholders specific to the USACE St. Paul District, tailored to the locations of the dams listed in this paper.

Several branches of the Minnesota Department of Natural Resources (DNR) and the Minnesota Pollution Control Agency (MCPA) undertake review consistent with the federal regulations listed above. Within the DNR, several sections, including Fisheries and the Trails and Waterways Unit, are involved in studies under the Fish and Wildlife Coordination Act. The MPCA oversees the water quality certification under section 401 of the Clean Water Act. Lastly, the DNR's Lake Superior Coastal Program oversees construction that will affect state coastal areas.

Another important stakeholder is local Native American tribes. Within Minnesota, there are 11 sovereign Native American communities living on distinct reservations. One reservation in particular–the Leech Lake Indian Reservation–is near to the Winnibigoshish Dam mentioned in this paper, making this community a clear stakeholder in any activity on the dam. Again, a proposed hydropower project does not have to be located on reservation land for a tribe to become a stakeholder in the licensing process. Those tribes that may be affected by project construction or operation near them are also to be notified of the developer's intent and should be involved in the pre-licensing procedures.[33] This means that tribes outside of Minnesota could

[30] US Federal Energy Regulatory Commission, "Title 18–Conservation of Power and Water Resources," 143-144.
[31] US Federal Energy Regulatory Commission, "Energy Primer," 21, 22.
[32] US Army Corps of Engineers, "Guidelines for Compliance with Section 106 of the National Historic Preservation Act" 1.
[33] US Federal Regulatory Commission, "Hydropower Primer," 15.

become stakeholders to a hydropower project within state boundaries, as long as they are affected by changes to the water source that the dam will operate on. More information on Minnesota-specific stakeholders will be included in the following two sections.

Environmental Impact

The most common environmental concerns about hydropower include soil erosion, diminished water quality, wildlife disturbance, and greenhouse gas emissions. Hydropower projects on dams rely on water that is diverted from the main waterway path to run through the project's turbines and generate energy. Projects can therefore cause fluctuations in water quantity and flow. Depending on the type of bedrock that the river runs along, hydropower projects may also contribute to changes in soil and sediment discharge and waterway hydrodynamics, which can negatively affect local habitats and the structural integrity of downstream infrastructure. By changing water quantity and flow patterns, projects may also affect navigation, recreation, and the aesthetics of the waterway, which will be discussed in the next section. The Upper Mississippi River Basin (UMB), in which the St. Paul District is situated, contains limestone above soft shale and poorly cemented sandstone, making this an especially relevant concern for proposed hydropower projects on the river.[34]

Projects that are built on dams have the potential to disrupt wildlife health and migration, which is especially detrimental when it affects threatened or endangered species. Certain fish species reproduce in upstream river or stream beds, necessitating migration. The construction of artificial structures called fish ladders is one solution to this issue, allowing fish to move around the dam structure. Another common concern is that turbines increase fish mortality. While this is true, the proportion of fish killed is relatively small and new turbine research hopes to decrease fish mortality even further. Lastly, terrestrial animals and vegetation may be affected by changes to their habitat resulting from sediment erosion or changes to water quantity or quality. Plant growth can also be adversely affected by project construction and operation.[35]

Wildlife concerns stem not only from plant infrastructure but also from water quality disruption. Hydropower projects produce colder water with a greater dissolved oxygen content, which can affect the surrounding ecological environment. One solution is to use aerating turbines, which utilize a multi-level water intake system to release water from all areas of a reservoir, mitigating temperature and chemical changes to the water composition. Environmental impacts extend to the surrounding landscape, including concerns about shoreline erosion and downstream changes to water flow. In addition, water quality concerns have the potential to

[34] US Federal Energy Regulatory Commission, “Crown Hydro LLC Project No. 11175–025 Minnesota, Notice of Availability for Draft Environmental Assessment,” 15.
[35] US Federal Energy Regulatory Commission, “Hydropower Primer,” 12-14.

extend beyond the immediate vicinity of the project, depending on the magnitude of its effects and the body of water on which it is situated.[36]

Lastly, while its status as a renewable energy source suggests that hydropower projects are emission-free, studies have shown that hydropower may be a greater pollutant than expected. Greenhouse gas emissions have historically been tied to hydropower construction, which is expected to be offset by the long-term positive effects of hydroelectric generation. For NPDs, construction-related pollution is an even smaller problem, since most projects would require little additional building. However, more recent research suggests that the decomposition of biomass under the surface of the water releases carbon dioxide and methane into the air.[37] The extent to which this occurs is not yet clear and is a major topic in the hydropower industry currently.

Lock & Dam 5A, photo courtesy of the USACE St. Paul District website

In the UMB region specifically, there are at least 150 different fish species and almost 50 species of freshwater mussels. Nearly 300 species of birds migrate through the area. In addition, there are 22 reptile species, 45 mammal species and 13 amphibian species in the Mississippi River area around the Twin Cities.[38] A small number of species are designated as either

[36] Union of Concerned Scientists, "Environmental Impacts of Hydroelectric Power."
[37] US Energy Information Administration, "Hydropower Explained."
[38] US Army Corps of Engineers, "2014 Upper Mississippi Basin Report," ES-IV, ESV.

endangered, threatened, or of special status. These include the mudpuppy salamander, the Northern long-eared bat, the Higgins eye pearlymussel, and the Snuffbox mussel.[39] There are also a number of invasive species, whose further spread can be mitigated through diminished lock and dam usage. In the UMB, zebra mussels and Asian carp are especially subject to environmental monitoring.[40]

While eight of the ten NPDs in the St. Paul District are on the Mississippi River, the Orwell Reservoir and Dam and the Lac Qui Parle Dam are not. The Orwell Dam is situated on Otter Tail River near Fergus Falls, Minnesota, while the Lac Qui Parle Dam is on the Minnesota River near Watson, Minnesota. Both river and lake systems contain similar geological and biological characteristics as the UMB.[41] Of note, however, is that a recent study of the Lac Qui Parle region found several poorly maintained biological habitats in the area.[42] Already diminished water quality and wildlife habitats could discourage future hydropower proposals on the Lac Qui Parle Dam.

Community Impact

Environmental concerns often overlap with community concerns, especially for those who live or work in the vicinity of the proposed project. Other community impacts include effects on recreation, the local economy, shoreline management, and cultural resources. A major issue for stakeholders is that of recreation: if a hydro project is to be built in an area already containing recreational resources such as swimming, hiking, or canoeing, will that project obstruct the recreational experience? Through the licensing procedure, hydropower developers may also be asked to assess how their projects can create new recreational opportunities for the area. In doing so, projects can have a positive effect on the surrounding socio-economic community by boosting employment and tourism. At the same time, proposed projects can pose a threat to existing shoreline homes, businesses, and other public or private development projects. Some of these areas may be considered of historic or cultural value, including archaeological or historic sites, or tribal lands. As with environmental impacts, community effects can extend beyond the immediate vicinity of the project, are site-specific, and must be addressed during licensing procedures.

In past hydropower licensing procedures, Minnesota community stakeholders have included the Minnesota Historical Society, the Minnesota Department of Transportation, city-level parks and recreation boards, NGOs, and private residents.[43] Minnesota's lakes and rivers house many recreational activities, and some contain designated state historical sites. For a

[39] US Federal Energy Regulatory Commission, "Crown Hydro LLC Project No. 11175–025 Minnesota, Notice of Availability for Draft Environmental Assessment," 5.
[40] US Army Corps of Engineers, "2014 Upper Mississippi Basin Report," 67-70.
[41] Dollinger, Dave, et al,. "Otter Tail River Monitoring and Assessment Report."
[42] Minnesota Pollution Control Agency, "Minnesota River Basin Lac Qui Parle Watershed," 2-3, 1.
[43] US Federal Regulatory Commission, E-library.

new hydropower plant to be accepted into these communities, the developers must demonstrate that their project will not disrupt pre-existing activity. In many cases, developers are asked to provide further recreational activities, aesthetic additions, and tourist opportunities to the site they are operating on.

Navigation on the Mississippi River is especially relevant for projects proposed in the St. Paul USACE District. The District sees 17 million tons of cargo pass through annually, and the USACE Inland Navigation system saves the country an estimated $1 billion in transportation costs each year.[44] Therefore, any additions to dams along the river cannot disrupt water quantity and flow to the extent that navigation is affected. Hydropower developers on USACE dams must be mindful not to obstruct the dam's primary purposes in their project designs.[45] This will be discussed further in the next section. It is also worth noting that three St. Paul District dams–Upper St. Anthony Falls, Lower St. Anthony Falls, and Lock & Dam 1– are currently subject to Corps disposition study.[46] However, the outcome of those studies will not change the feasibility of new development projects on the dams listed in this paper.

Lastly, when considering community impact, hydropower developers must take state and federal waterway development and conservation plans into account. Within the St. Paul District, recreational parks, fisheries, and historic sites are especially applicable to proposed hydropower projects. In addition to small, local parks, the US National Park Service has designated a 72-mile area along the Mississippi River as the Mississippi National River and Recreation Area. Local recreational activities include fishing, hunting, canoeing, and hiking. The Upper Mississippi River basin also contains a number of Minnesota state historical sites.[47] Of particular note is the Winnibigoshish Dam, which is listed on the National Register of Historic Places, making it especially susceptible to state and federal protective regulation.[48]

Dam Safety and Infrastructure

To ensure the physical safety and cybersecurity of hydropower projects, FERC regulations stipulate that all projects keep records of safety incidents and continually revise emergency action plans. Projects must also have a dam safety performance monitoring program, and most must develop public safety plans. Larger or more hazardous projects are subject to inspection by independent consultants and must conduct potential failure mode analyses. All dams must conduct a full-scale practice of their emergency action plan every five years. A regional engineer is responsible for safety protocol oversight and has the authority to require

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[44] US Army Corps of Engineers, "Upper Mississippi River Periodic Basin Management Report," 15, ES-II.
[45] Spaulding, Doug. Discussion with Lillie Horton. June 2020.
[46] US Army Corps of Engineers. "Minneapolis Locks Disposition Study."
[47] US Federal Energy Regulatory Commission, "Crown Hydro LLC Project No. 11175–025 Minnesota, Notice of Availability for Draft Environmental Assessment," 13, 56-58.
[48] US Army Corps of Engineers, "Lake Winnibigoshish."

safety device implementation, including signage, warning devices, restraining devices, escape devices, and project operating procedures.[49]

For hydropower developers on USACE dams, safety protocol is especially relevant right now. The median age of Corps dams nationwide was 47 years in 2011, with 90% older than 34 years. Older dams have higher rates of equipment failure, necessitating infrastructural updates and–in extreme cases–dam disposition.[50] As mentioned previously, private developers must be mindful not to obstruct the primary purposes of USACE dams. On the Mississippi River, this is the navigation of shipping cargo,[51] for which the Corps attempts to maintain a 9-foot channel.[52] Beyond the Mississippi River in Minnesota, USACE dams have flood control and recreational purposes.[53] To allow dam-specific Army Corps activity to continue unimpeded, hydropower facilities cannot have too large an impact on nearby hydrology. During the licensing procedures, the Corps may ask developers to conduct hydraulic studies and can request design modifications when necessary.[54] In addition to coordinating shared water use with USACE, developers should also be mindful of how their water usage will affect the nearby communities, as mentioned above. At times, shared water use with USACE and other entities may require hydropower plants to change their operation schedule.[55]

Operation and Electric Grid Integration

In addition to recording safety incidents, licensed facilities must also file license deviation reports to the Hydropower Administration and Compliance (DHAC) department in FERC. These reports notify DHAC of any events in which the plant's water usage level strayed from license stipulations. The facility must also present DHAC with the impacts of that license deviation. Upon receiving such a report, DHAC determines whether the facility was in violation of the license or whether the event was outside of their control. This determination is recorded on the facility's compliance record and may become relevant in future relicensing procedures.[56]

An operator's continued cooperation with USACE is integral to plant operation post-licensing. Private operators pay a fee to use Army Corps property, and also provide electricity to the site in return for basic space maintenance that the Corps provides. For the most part, however, the operator is responsible for the upkeep of their own facility. The terms of this

[49] US Federal Energy Regulatory Commission, "Hydropower Primer," 45-51.
[50] US Army Corps of Engineers, "Outlook for the US Army Corps of Engineers Hydropower Program," 9.
[51] Bischoff, Nanette. Discussion with Lillie Horton. July 2020.
[52] US Army Corps of Engineers St. Paul District, "District Project Home."
[53] US Army Corps of Engineers, "National Inventory of Dams."
[54] Bischoff, Nanette. Discussion with Lillie Horton. July 2020.
[55] Rosemore, Nora. Discussion with Lillie Horton. July 2020.
[56] Rosemore, Nora. Discussion with Lillie Horton. July 2020.

coexistence are outlined in a series of cooperative agreements which speak to the design and construction phase of the project, as well as to regular operations.[57]

A fundamental part of hydropower plant operation is electric grid integration, whereby the plant interconnects with its regional grid system. Minnesota is part of the Eastern Interconnection Grid, with an unregulated wholesale market balanced by the Midcontinent Independent System Operations (MISO).[58] Operators must gain an interconnection agreement with MISO in order to connect their energy to the grid. The terms of the interconnection agreement will vary depending on what impacts the hydropower plant's interconnection will have on the rest of the grid. For instance, if MISO is required to upgrade their system to accommodate the plant's power, the interconnection agreement will cost the operator more money.

Lastly, for a private hydropower facility to integrate into the electric grid, they need a power purchase agreement (PPA). A PPA is a contract between an electric utility and the hydropower operator stipulating the terms of the sale of electricity between them. For private operators, obtaining a 20-30 year PPA can be essential to get external funding for their project. Despite increasing rates of development in the wind and solar energy sectors–especially in the Minnesota region–hydropower remains a necessary component of the electric grid, providing a reliable source to balance less predictable sources of renewable energy.[59][60]

Conclusion

In summation, Minnesota Army Corps' dams contain the potential for private hydroelectric development, but significant constraints on water quantity and usage merit a further examination of the economic feasibility of each site. The low head height and multiple competing water usages along the Mississippi River suggest a low ratio of generated electricity to invested resources, especially when compared to other regions of the country where NPDs either have larger energy potential or can operate at greater capacity year-round. That being said, the five hydropower plants currently operating on USACE sites along the river offer a hopeful precedent. If those projects are able to operate despite regional hydraulic, environmental, and community constraints, it seems that future projects may also be feasible. Further research is necessary to determine whether Minnesota would benefit from hydropower development on the dams included in this paper, and on other NPDs throughout the state.

The research in this paper demonstrates the variability in hydropower feasibility not just across the state, but also within individual watershed environments. The ORNL data suggests that the sites along the Mississippi–containing greater energy potential than elsewhere in the

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[57] Bischoff, Nanette. Discussion with Lillie Horton. July 2020.
[58] Minnesota Electric Transmission Planning, "Minnesota Biennial Transmission Planning."
[59] Spaulding, Doug. Discussion with Lillie Horton. June 2020.
[60] Bischoff, Nanette. Discussion with Lillie Horton. July 2020.

Lower St. Anthony Falls Dam, photo courtesy of the USACE St. Paul District website

state–would provide the most feasible NPDs for hydropower development. It is also true that the poor health of the Lac Qui Parle Dam watershed and the historical and tribal significance of the Winnibigoshish Dam could create significant stakeholder resistance towards new development. Yet hydropower facilities on the Mississippi River are susceptible to greater water usage competition than in other watershed environments. Navigation, alongside intense recreational and conservation activities along the Mississippi, could decrease the operational capacity of hydropower on the river. Therefore, this paper urges future research to incorporate metrics for community and environmental impact into a site-specific, quantified analysis of feasibility.

Future research will also have to consider how climate change will affect hydropower development. Recent studies examine the regional hydraulic impact of extreme weather patterns. A 2016 study of reservoir dams found that, while water inflow may increase in the future, its variability will also rise. Increased hydraulic variability will decrease the reliability of hydropower generation. This research suggests greater variability could lead to greater greenhouse gas emissions as electric grids are forced to rely on natural gas to balance the system.[61] If this is true, more regulated forms of hydropower plants–for example, pumped storage and

[61] Tarroja, Brian, et al., "Quantifying Climate Change Impacts on Hydropower Generation and Implications on Electric Grid Greenhouse Gas Emissions and Operation."

peaking dams–could prove essential in maintaining the stability that hydropower brings to the renewable energy sector. The reliability of conventional dams, such as those discussed in these papers, is called into question in the face of this new research. Further study is needed to determine whether climate change trends prove a significant enough threat to regional dams and hydropower projects to dissuade future investments in existing NPDs.

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