Feature Article

NICHOLAS MORGAN, KELLY KIRVEN, AND MICHAEL PARKER

Hydroelectric Energy: Sustainable and Economical Solutions for Water Systems

WATER UTILITIES MIGHT WANT TO CONSIDER USING HYDROELECTRIC POWER TO COMPENSATE FOR INCREASED INFRASTRUCTURE COSTS AND FINANCIAL SHORTFALLS RESULTING FROM DECREASED DEMAND.

While every utility seeks to improve the sustainability and resiliency of its systems, many water suppliers now face the challenge of balancing the cost of infrastructure renewal and replacement with declining demand and subsequent revenue. A potential solution is to adapt hydroelectric generating capacity to existing water resources and infrastructure. Developing hydroelectric power requires careful planning and design; the guidelines provided in this article are intended to help water utilities understand the potential benefits and pitfalls associated with this approach, which provides reliable power with a reasonably quick return on investment.

BACKGROUND

The top two challenges facing the water industry, identified in the AWWA *2018 State of the Water Industry* report, relate directly to the costs of maintaining infrastructure, and, further, over half of all water utilities report declining or "flat" water demand as their cost to maintain infrastructure increases (AWWA 2018).

Over the past several decades, water conservation efforts have reduced the overall demand for potable water in many areas, decreasing cash flow and exacerbating the problem of keeping up with the rising cost of maintaining and improving drinking water and wastewater infrastructure (Beecher 2010). In fact, the US Environmental Protection Agency's *Drinking Water Infrastructure Needs*

Survey and Assessment estimates that $472.6 billion will be needed to upgrade drinking water infrastructure over the next 20 years (USEPA 2018).

Problems with declining revenue may be solved by increasing rates, which can be unpopular, especially if rate changes are large and unexpected. Declining revenue may also be solved by lowering operating costs with a more efficient water treatment and transport system. Energy demands and associated costs rank among the most important issues facing water companies (AWWA 2018), and energy consumption is one of the largest operation and maintenance costs for water utilities, second only to the cost of labor (Biehl & Inman 2010). Achieving energy efficiency can be a primary focus for reducing costs and one that is broadly popular with boards, customers, and stakeholders.

Utilities may improve energy efficiency by upgrading older equipment or changing operations, but these changes only partially address what the US Government Accountability Office (GAO) has found to be the largest energy draws required for water distribution (GAO 2011). Water is relatively heavy, and pumping it over great distances or across significant changes in elevation is energy-intensive. In both pumped and gravity-fed water delivery systems, pressure-reducing valves (PRVs) are regularly used to dissipate energy in the system; the GAO recommends that utilities recover that potential energy using technologies such as micro-hydroelectric generators (GAO 2011). Depending on the physical and hydrologic characteristics of their water systems, water utilities may be able to generate a significant amount of energy simply by exploiting potential energy that is currently being wasted.

BENEFITS OF HYDROELECTRIC ASSETS

Water utilities can use the energy produced by hydroelectric generation to become energy-neutral or net-energy producers as well as provide emergency back-up power during outages (Angers 2001). Financial benefits from hydroelectric generation include offsetting power usage, selling any net power produced, and selling renewable energy credits. Offsetting power includes connecting the generation source to a load such as a pumping station to offset power demand from the grid in real time. Net metering is when the utility generates power that it exports to the grid at times when instantaneous demand is lower than generation. The water company receives credits for this exported power that offset or partially offset future power usage. The value of these credits varies on the basis of local conditions, including state laws and local power company policy.

Small hydroelectric producers can sell power in the wholesale market in most places, but this is often the least beneficial option because prices on the wholesale power market are lower than other options—$20 to $40/MW·h, depending on the region. Since the retail price of power is much higher than the wholesale price, it is better to offset internal demand or net meter in areas where that option is available. Typical retail power prices in some regions are $70/MW·h without transmission and distribution or $140/MW·h with transmission and distribution. These rates vary regionally and by the customer pricing the water company receives from the local power company.

In the United States, utilities that produce hydroelectric energy may be able to apply for renewable energy credits (RECs). RECs capture the value of the renewable attribute of the power above and beyond the value of the electricity. For example, RECs in the northeastern United States can be worth an additional $15 to $55/MW·h. State laws that set standards for renewable energy portfolios require power companies to purchase RECs for a set percentage of the power they deliver. The price of RECs varies from state to state and year to year on the basis of the supply of available credits and the power companies' demand for them. Since the REC value is variable, REC values are best considered an additional incentive for developing hydroelectric capability rather than a primary economic benefit. Some states require Low Impact Hydropower Institute certification to qualify for RECs, which carries both process costs to obtain certification and annual costs based on generating capacity. These costs are generally a small fraction of the overall REC value.

Water utility leaders and managers have become increasingly aware of public interest in environmentally sustainable water sources (Mercer 2013, Smith 2007), and water systems must balance issues of quality and supply with other demands such as aquatic ecosystems and electric generation (Grigg 2012). Utilities that want to promote the fact that they operate sustainably to protect public resources can use a hydroelectric project to showcase their efforts while offsetting their energy requirements.

A few basic planning and design considerations will help utility decision-makers determine whether

Depending on the physical and hydrologic characteristics of their water systems, water utilities may be able to generate a significant amount of energy simply by exploiting potential energy that is currently being wasted.

a hydroelectric project is right for their water system. The following sections summarize the primary concerns in each area.

REGULATIONS

Some water utilities may be reluctant to develop hydroelectric power in their systems because of confusion over regulations, planning, and design. In the United States, there may be concerns that the Federal Energy Regulatory Commission (FERC) will become a burdensome additional layer of regulatory oversight; however, FERC has streamlined the regulatory process, making it easier to develop small hydroelectric installations like those commonly developed by water companies.

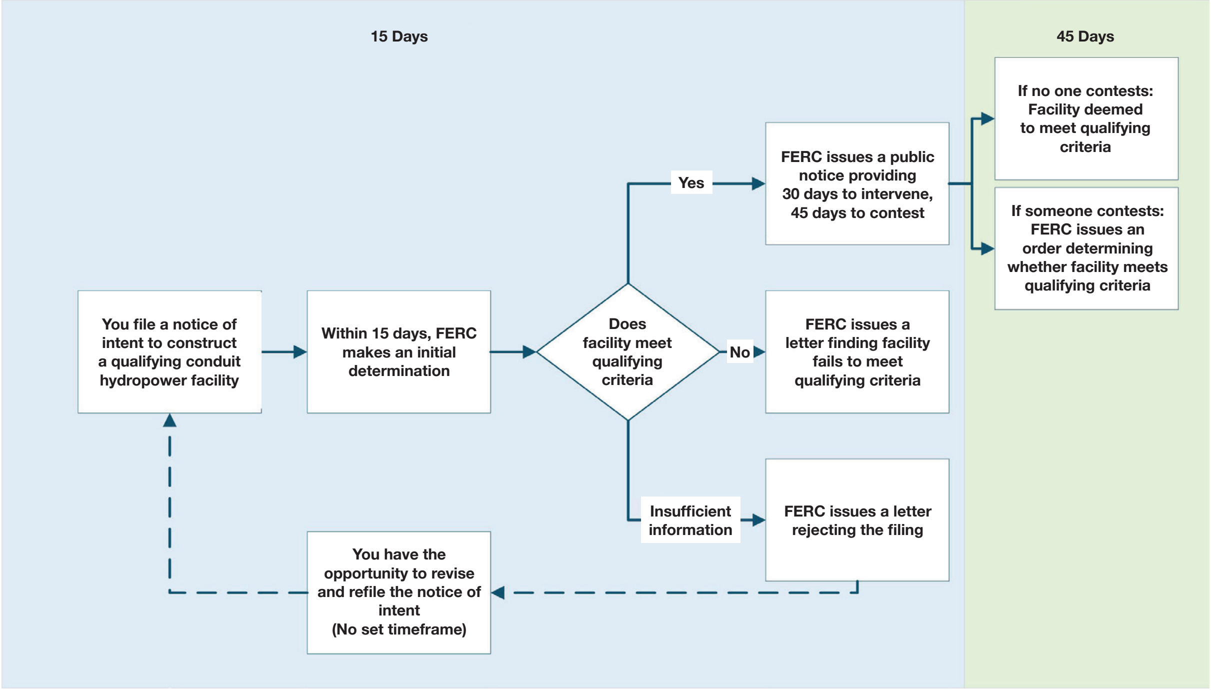
Under a provision of the Hydropower Regulatory Efficiency Act of 2013, FERC is required to determine whether proposed projects meet the criteria to be considered "qualifying conduit hydropower facilities." Qualified projects are not required to be licensed or exempted by FERC. These projects are on engineered conduits that are not owned by the federal government and are operated primarily for non-hydroelectric purposes. The following provisions are required for a project to be deemed a qualifying conduit hydropower facility (FERC 2018a):

- The facility must be a conduit, which is any tunnel, canal, pipeline, aqueduct, flume, ditch, or similar man-made water conveyance that is operated for the distribution of water for agricultural, municipal, or industrial consumption and is not primarily for the generation of electricity.
- Electric power generated at the facility must use only the hydroelectric potential of a non-federally owned conduit.
- Installed capacity at the facility must not exceed 5 MW.
- The facility must not be licensed or exempted from the licensing requirements of Part I of the Federal Power Act on or before Aug. 9, 2013.

FERC regulations under 18 CFR §4.400 (2018) implement the procedures of the act such that any person, state, or municipality proposing to construct a facility that meets the criteria must file a Notice of Intent to Construct a Qualifying Conduit Hydropower Facility, along with project drawings, with FERC. A template for the notice can be found on FERC's website, and content requirements are provided in 18 CFR §4.401 (2018). Generally, the notice must include

- the location of the project;
- applicant information;
- project information, such as detailed descriptions of the

FIGURE 1 FERC process for qualifying conduit hydropower approval



Source: www.ferc.gov/industries/hydropower/indus-act/efficiency-act/qua-conduit/qual-conduit.asp?csrt=14089384244854242979

FERC—Federal Energy Regulatory Commission conduit and water supply facilities, intake facilities, powerhouses, purposes for which the conduit is used, and the number, type, and generating capacity; and

- estimated average annual generation of the proposed generating units.

If a dam or impoundment is associated with the project, a description of the nature and extent of the dam and impoundment must be included. Submitted drawings must include a plan view of the proposed hydropower facilities, a location map showing the facilities and their relationship to the nearest town, and a profile drawing of the conduit.

Once a Notice of Intent to Construct a Qualifying Conduit Hydropower Facility is filed, the FERC will make an initial determination within 15 days (Figure 1). If FERC determines that the facility meets the qualifying criteria, a public notice will be issued, providing 30 days for members of the public to file motions to intervene and 45 days to provide comments contesting whether the facility meets the qualifying criteria. If no one files comments contesting the facility's qualification, the facility is deemed a qualifying conduit hydropower facility, and FERC will issue a letter stating such. If comments are filed contesting the facility's qualification, FERC will review the comments and issue an order determining whether the facility qualifies.

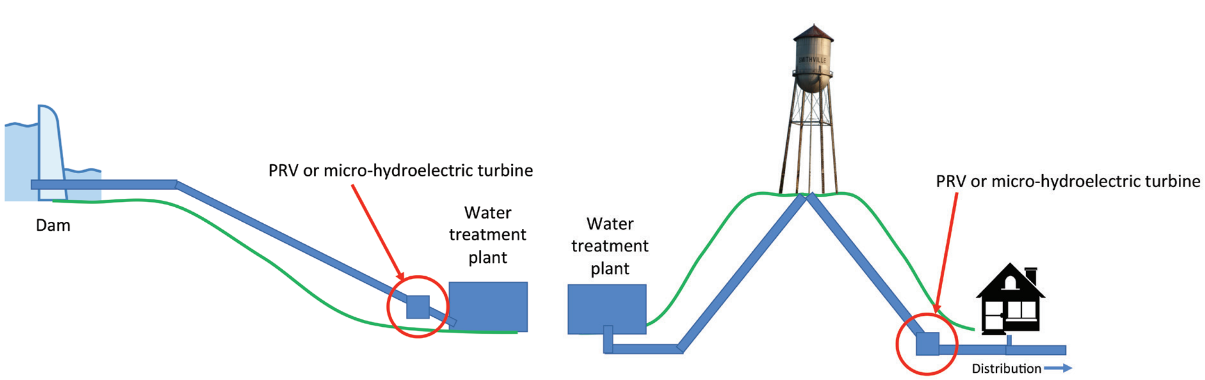
Since implementation of the Hydropower Act, 99 projects have been allowed non-jurisdictional status, 17 have been rejected, one is pending determination, and one application has been withdrawn (FERC 2018b). The cost and operational restrictions associated with FERC licensing have been major hurdles for micro-scale hydroelectric projects to overcome in the past, and although bureaucratic red tape remains, the recent improvements have minimized the upfront cost of applying for non-jurisdictional status.

The Hydropower Act also amended Section 405 of the Public Utility Regulatory Policies Act of 1978 to allow FERC to grant exemptions from licensing projects of 10 MW or less, increasing the previous qualifier to 5 MW or less. Additionally, conduits with a capacity of 40 MW or less may be granted conduit exemption through the traditional licensing process. Previously, only state or local governments could receive an exemption for 40 MW projects; other applicants qualified only if the project was 15 MW or less (FERC 2018a).

Interest in renewable energy has resulted in increased research and development, and new options are available for a variety of applications, including distribution lines and dams.

The Hydropower Act also directed FERC to investigate the feasibility of a two-year licensing process for hydropower development at nonpowered dams and closed-loop, pumped storage projects to drastically reduce the cost and process time of project licensing. In a report to Congress in May 2017, FERC staff concluded that a two-year process is feasible without statutory changes to the Federal Power Act. Previously, licensing would have

FIGURE 2 Two scenarios showing where a micro-hydroelectric turbine could replace a PRV



PRV—pressure-reducing valve

This is an example of a small conventional hydroelectric system. *Photo courtesy of Canyon Hydro*

This is an example of a pump-as-turbine unit. *Photo courtesy of Canyon Hydro*

taken approximately five to seven years to complete. All of these provisions can result in significant savings in time and money for the applicant.

PLANNING

A good time for utilities to consider adding hydroelectric capability may be when a dam or PRV is being rehabilitated or replaced. Once a water utility is familiar with the regulatory process, it should develop tools to identify the best locations for installation of a micro-hydroelectric turbine. A geographic information system (GIS) is a valuable tool for evaluating the hydroelectric potential of a site, organizing information about the water system to identify the areas of greatest hydroelectric potential, such as PRVs and dams where potential energy is being wasted (Figure 2). The following site-specific criteria are critical to consider when evaluating a site's potential hydroelectric capability.

Available head. Generating hydropower reduces the pressure in the pipeline such that a micro-hydroelectric turbine often replaces a PRV (Figure 2). Available head needs to be evaluated over the course of a year because seasonal changes in reservoir levels or pressure changes in the distribution line will affect the ultimate annual revenue. High-head sites traditionally have been the most economical because the size and cost of the equipment is less for the same power output. However, recent technological developments have made low-head sites in the range of 10 to 20 ft of head potentially economical.

Flow. The range of flows through the pipeline at the site needs to be evaluated throughout the year. If the flow and head are constant, a pump can be modified to be used as a hydroelectric unit. This is an economical option but requires head and flow conditions that vary by no more than a couple of percentage points. For more variable head sites, compact Francis turbines are often a good solution.

Existing infrastructure. Infrastructure must be evaluated for its ability to support installation of hydroelectric equipment, including determining whether a local distribution line is available to connect the turbine with the existing power transmission system. The easier it is to connect the new hydroelectric turbine and house its equipment, the more economical the project will be.

GIS can track potential locations with suitable head, flow, and infrastructure to support the hydroelectric project. The economics of developing hydroelectric capability improve if a water system can use the produced power to offset its need for power. Analysis of GIS data can further refine search results for sites that are located within a certain distance of the areas of greatest demand for power, such as pumps. Once initial areas with hydroelectric potential are identified, they should be thoroughly assessed, and any site-specific constraints should be documented.

DESIGN

Once ideal locations for hydroelectric generation are identified, the appropriate technology fit at these sites must be determined. Although hydroelectric technology is well developed, there is no one-size-fits-all approach to maximize the energy potential at every location. Interest in renewable energy has resulted in increased research and development, and new options are available for a variety of applications, including distribution lines and dams. The three main micro-scale hydropower technologies currently available are small conventional hydroelectric systems, pumps as turbines, and low-head hydroelectric turbines.

Small conventional hydroelectric systems offer the advantage of large operating ranges in both head and flow and are well-developed, proven technologies (see the top photograph on page 40). The main disadvantage of small conventional hydroelectric systems is that they are relatively expensive for each kilowatt of energy produced. These technologies are best considered for applications with high head.

Pump-as-turbine units use production pumps with a generator instead of a motor (see the bottom photograph on page 40). The benefit of these units is that they are less expensive than small conventional hydroelectric units for the same head and flow. This technology is most applicable where head and flow vary by no more than a couple percentage points over the course of a year.

> Interest in renewable energy has resulted in increased research and development, and new options are available for a variety of applications, including distribution lines and dams.

New low-head technologies use lighter construction and new arrangements to produce hydropower economically at heads between 10 and 20 ft. These technologies can be preferred over conventional hydroelectric turbines, which are very expensive at these heads, and pump-as-turbine units, which are generally not feasible.

Power estimates. The following example demonstrates the potential value of a typical hydroelectric asset that might be owned by a water utility. If flow in a distribution line is approximately 9.3 ft3/s (6 mgd), with approximately 100 ft of available head (43.3 psi), the following results:

Available Power
= Head × Flow × Efficiency/11.8
= 100 ft × 9.3 cfs × 0.85/11.8
= 50 kW

Today, the cost of equipment in this range would vary from approximately \$100,000 for a pump-as-turbine unit to \$200,000 for a small conventional unit. Installation would cost between \$100,000 and \$400,000, depending on how much of the existing infrastructure would need modification and what other work would be needed to install the unit. Assuming constant head and flow and that the turbine runs at capacity for 90% of the year, this system would produce 390 MW·h annually.

Table 1 presents a range of hydroelectric scenarios for various power prices and equipment costs. The current price for power at the low end of the wholesale market can be taken as \$20/MW·h, while the upper limit price, associated with net metering with transmission and distribution with RECs, could be as much as \$195/MW·h. In the middle range is net meter without transmission and

TABLE 1 Potential straight payback time for three hydroelectric development scenarios

Scenario[a]	Price for Power (per MW·h) $	Cost of Equipment and Installation $	Straight Payback *years*
Net metering, transmission, and distribution included, renewable energy credits, ideal installation cost	195	200,000	3
Net metering, transmission, and distribution not included, mid-range installation cost	70	400,000	15
Sell energy at wholesale price and major installation cost	20	600,000	77

[a]All scenarios assume production of 390 MW·h annually.

distribution, estimated at approximately \$70/MW·h. As Table 1 shows, the payback in terms of years is highly variable. In the best-case scenario, a utility would recoup its investment within three years. In the worst case, the water company would break even on the investment within approximately 77 years. A favorable net metering arrangement with an opportunity to install a unit with few modifications to existing facilities would likely provide a favorable payback within 10 to 15 years, less if RECs are available.

CONCLUSION

Using these guidelines, water utilities can evaluate the potential value for hydroelectric power generation within their system and make an initial estimate of the return on investment. Depending on the site conditions, there is a wide range of potential payback scenarios, so utilities should carefully consider whether these systems are appropriate. Generally, the easiest payback for a water utility is to use hydroelectric power to supply energy for its own pumps and facilities. As more hydroelectric systems are implemented, the overall sustainability and resiliency of the water industry will improve.

ACKNOWLEDGMENT

The authors thank Andy Qua, regulatory technical advisor, and Paul Williams, engineering technical advisor, both of Kleinschmidt Associates, for reviewing this article and providing technical advice as this article was prepared for publication.

ABOUT THE AUTHORS

Nicholas Morgan *(to whom correspondence may be addressed) is project manager with Kleinschmidt Associates, 204 Caughman Farm Ln., Ste. 30, Lexington, SC 29072 USA; Nicholas.Morgan@KleinschmidtGroup.com. He provides strategic advice to assist clients with planning and evaluating projects that provide sustainable and cost-effective energy solutions. Morgan was recently elected to a three-year term on the Kleinschmidt board of directors and currently serves as secretary.* ***Kelly Kirven*** *is regulatory coordinator and* ***Michael Parker*** *is senior engineer with Kleinschmidt Associates.*

https://doi.org/10.1002/awwa.1195

REFERENCES

18 CFR (Code of Federal Regulations), 2018. Conservation of Power and Water Resources. Office of the Federal Register, Washington.

Angers, J., 2001. The Power Puzzle. *Journal AWWA,* 93:6:54. https://doi.org/10.1002/j.1551-8833.2001.tb09224.x.

AWWA, 2018. 2018 *State of the Water Industry Report.* AWWA, Denver. www.awwa.org/resources-tools/water-and-wastewater-utility-management/state-of-the-water-industry.aspx (accessed Aug. 18, 2018).

Beecher, J.A., 2010. The Conservation Conundrum: How Declining Demand Affects Water Utilities. *Journal AWWA,* 102:2:78. https://doi.org/10.1002/j.1551-8833.2010.tb10051.x.

Biehl, W.H. & Inman, J.A., 2010. Energy Optimization for Water Systems. *Journal AWWA,* 102:6:50. https://doi.org/10.1002/j.1551-8833.2010.tb10129.x.

FERC (Federal Energy Regulatory Commission), 2018a. Hydropower Regulatory Efficiency Act of 2013. www.ferc.gov/industries/hydropower/indus-act/efficiency-act.asp (accessed Sept. 24, 2018).

FERC, 2018b. Notices of Intent to Construct Qualifying Conduit Hydropower Facilities. www.ferc.gov/industries/hydropower/indus-act/efficiency-act/qua-conduit/soi.xls (accessed Sept. 24, 2018).

Grigg, N.S., 2012. Water Utility Leadership and Its Key Role in Protecting Aquatic Ecosystems. *Journal AWWA,* 104:10:50. https://doi.org/10.5942/jawwa.2012.104.0136.

GAO (US Government Accountability Office), 2011. Energy-Water Nexus: Amount of Energy Needed to Supply, Use, and Treat Water Is Location-Specific and Can Be Reduced by Certain Technologies and Approaches. www.gao.gov/new.items/d11225.pdf (accessed Sept. 24, 2018).

Mercer, K., 2013. 2013 State of the Water Industry: Exploring the Water Sector's Renewed Focus. *Journal AWWA,* 105:9:46. https://doi.org/10.5942/jawwa.2013.105.0135.

Smith, M.P., 2007. Defining Sustainability: New Tools for Water Management. *Journal AWWA*, 99:10:20. https://doi.org/10.1002/j.1551-8833.2007.tb08043.x.

USEPA (US Environmental Protection Agency), 2018. *Drinking Water Infrastructure Needs Survey and Assessment: Sixth Report to Congress.* EPA 816-K-17-002. www.epa.gov/sites/production/files/2018-03/documents/sixth_drinking_water_infrastructure_needs_survey_and_assessment.pdf (accessed Sept. 24, 2018).

AWWA RESOURCES

- Sustainability Strategies at the Water–Energy Nexus: Renewable Energy and Decentralized Infrastructure. Lee, J. & Younos, T., 2018. *Journal AWWA,* 110:2:32. https://doi.org/10.1002/awwa.1001.
- Energy Storage at Groundwater Banks. House, L.W.; Beuhler, M.; Ahinga, Z.; Iqbal, N.; & Ta, T., 2018. *Journal AWWA,* 110:8:E17. https://doi.org/10.1002/awwa.1072.
- Survey of Energy Requirements for Public Water Supply in the United States. Sowby, R.B. & Burian, S.J., 2017. *Journal AWWA,* 109:7:E320. https://doi.org/10.5942/jawwa.2017.109.0080.

These resources have been supplied by *Journal AWWA* staff. For information on these and other AWWA resources, visit www.awwa.org.