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Opportunities for Energy Development in Water Conduits

A Report Prepared in Response to Section 7 of the Hydropower Regulatory Efficiency Act of 2013

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Environmental Sciences Division

OPPORTUNITIES FOR ENERGY DEVELOPMENT IN WATER CONDUITS – PREPARED IN RESPONSE TO SECTION 7 OF THE HYDROPOWER REGULATORY EFFICIENCY ACT OF 2013

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CONTENTS

Page

LIST OF FIGURES

Figures **Page**

LIST OF TABLES

Tables **Page**

LIST OF ABBREVIATED TERMS

AF	Acre Feet
ARRA	American Recovery and Reinvestment Act of 2009
BEP	Best Efficiency Point
cfs	Cubic Feet per Second
DMEA	Delta Montrose Electric Association
DOE	Department of Energy
DOI	Department of the Interior
DP	Design Point
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
GIS	Geographic Information Systems
GW	Gigawatt
GWh	Gigawatt Hours
HP	Horsepower
HREA	Hydropower Regulatory Efficiency Act of 2013
kW	Kilowatt
kWh	Kilowatt Hours
MW	Megawatt
MWh	Megawatt Hours
MWRA	Massachusetts Water Resource Authority
NEC	National Electric Code
NEMA	National Electrical Manufacturer's Association
NESC	National Electric Safety Code
O&M	Operations and Maintenance
PPA	Power Purchase Agreement
PRV	Pressure Reducing Valve
PSH	Pumped-storage hydropower
psi	Pounds per Square Inch
PURPA	Public Utility Regulatory Policies Act
REAP	Renewable Energy for America Program
Reclamation	Bureau of Reclamation
SCADA	Supervisory Control and Data Acquisition
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UVWUA	Uncompahgre Valley Water Users Association

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EXECUTIVE SUMMARY

In Section 7 of the Hydropower Regulatory Efficiency Act (HREA) of 2013 (P.L. 113-23), Congress directed the U.S. Department of Energy (DOE) to prepare an analysis of conduit hydropower opportunities available in the United States and to present case studies that describe the potential energy generation from these types of hydropower projects. Those analyses have been included in a new DOE report to Congress, and this ORNL/TM provides additional technical details supporting that report.

Conduit hydropower offers important new ways to enhance renewable energy portfolios in the United States, as well as to increase the energy efficiency of water delivery systems. Conduit hydropower projects are constructed on existing water-conveyance structures, such as irrigation canals or pressurized pipelines that deliver water to municipalities, industry, or agricultural water users. Although water conveyance infrastructures are usually designed for non-power purposes, new renewable energy can often be harvested from them without affecting their original purpose and without the need to construct new dams or diversions. Conduit hydropower differs from more conventional hydropower development in that it is generally not located on natural rivers or waterways and therefore does not involve the types of environmental impacts that are associated with hydropower. The addition of hydropower to existing water conduits can provide valuable new revenue sources from clean, renewable energy. The new energy can be used within the existing water distribution systems to offset other energy demands, or it can be sold into regional transmission systems.

HREA defines the term “conduit” as “any tunnel, canal, pipeline, aqueduct, flume, ditch, or similar manmade water conveyance that is operated for the distribution of water for agricultural, municipal, or industrial consumption and not primarily for the generation of electricity.” There are many thousands of miles of existing, manmade conduits in the United States that are used to transport and distribute water and wastewater. Municipalities, industrial facilities, farmers and ranchers, and other groups of users depend on the water resources in these systems. Energy capture in conduits can be done through two primary mechanisms: (1) conversion of pressure or head differentials within the conduit where there is excess energy available beyond what is required to operate the primary system or (2) capture of the kinetic energy associated with water velocity as it moves along a conduit. Velocity-based generation is referred to as hydrokinetics. Primary considerations in harnessing the energy available in an existing conduit system are how the integrity of the existing infrastructure will be protected and how its priority water use will be preserved. Hydropower manufacturers and developers are now developing new, lower-cost methodologies that will allow conduit owners to more readily harness the available electric energy without jeopardizing water delivery.

Although the Bureau of Reclamation (“Reclamation”) and some states have completed some assessments to estimate the magnitude of new energy from conduits, to date there has been no comprehensive resource assessment conducted at the national level to estimate the undeveloped energy potential of this type of hydropower. It is not useful to aggregate results from individual state and Reclamation studies because of they have used different methods and data. Previous assessments conducted by DOE laboratories examined hydropower opportunities in natural rivers or at existing, nonpowered dams, but they did not study manmade water distributions systems. A number of existing site assessment tools are described in this report; these can be useful in evaluating specific sites, but they also are lacking in several ways, including non-standard methodologies, high cost or high learning curves, or inability to examine systematic effects of new development on an existing water distribution system.

The selection of hydropower equipment for conduit projects can be relatively complex and challenging due to the combinations of heads and flows typically available in the water distribution systems, as well as the physical spaces into which they must fit. By definition, most of the infrastructure for an in-conduit installation already exists. The main purpose of the infrastructure must be maintained throughout the development of the hydropower project (i.e., irrigation, agriculture, municipal use, etc.). A primary design objective, therefore, is to minimize the impact of the hydropower facility on the existing infrastructure and environment, while maximizing total generation. Selecting appropriate equipment for a site is a critical factor in meeting this intent. Often there are also other requirements for hydraulic equipment such as bypass gates and valves and other devices to prevent the interruption of flow or other adverse impacts to the primary water system.

There are many existing hydropower turbine designs that can be used in canals and pielines. These hydraulic turbines are often of custom design and unless offered by a manufacturer in some type of standard package, can be expensive, especially in small sizes. There is an emerging market for hydraulic turbine-generating equipment that is suitable for small hydropower projects on conduit systems. For example, pump manufacturers are offering pumps to be used as turbines. This configuration can be quite cost effective and can be offered using standard pumps. There are also other new and developing small, hydraulic turbine designs that are focused on small hydro applications and low-head hydro applications. The new designs range from modification of traditional hydraulic turbine to original and innovative turbines. One of the most important issues in small hydropower equipment selection is cost. There is a well-documented trend of significantly higher equipment costs per unit energy for smaller capacity machines, which can translate into higher total project costs of development for small projects (1-5 MW or smaller). This type of cost sensitivity is driving innovation, where available research funding is available.

The list of challenges and barriers to conduit hydropower in the United States is long. It includes the lack of comprehensive assessments of undeveloped sites and the tools to evaluate them, complex and uncertain regulatory processes at the federal, state, and local levels of government, difficulties in securing project financing, and technological uncertainties associated with the longer-term performance of newer, more innovative and potentially more cost-efficient technologies.

Nine case studies are presented to illustrate the feasibility of conduit hydropower. Some of these are described in this report, and others are contained in the references cited. Successful examples of conduit deployments of small hydropower are clear for irrigation districts in Colorado, municipal water systems in Massachusetts and Colorado, and individual farmers in Utah and Colorado.

The prospects for future development of hydropower from conduits can be improved with a number of focused actions in applied research, policy analysis, and technology development and testing. In the applied research arena, better, more comprehensive, and consistent resource assessments are needed to guide development. Better analysis tools are also needed for use by small developers to efficiently screen potential sites and to design feasible projects.

Four types of policy analysis would greatly improve understanding of the challenges that developers face and how they may be overcome. In addition to policy analysis, there is a more general need to provide better and more accessible information about the real risks associated with conduit projects and how those risks can be managed. Lack of acceptance of small hydropower projects in water conduit remains a significant barrier at the state and local regulatory levels.

Although DOE and Reclamation have been funding some technology development on small hydropower and hydrokinetic devices in recent years, more such work is needed to reduce the uncertainties associated with precommercial designs and their longer-term performance.

1. INTRODUCTION

1.1 BACKGROUND

The Hydropower Regulatory Efficiency Act of 2013 (HREA; Public Law 113-23) required the U.S. Department of Energy (DOE) to conduct a study of new energy opportunities that exist at pumped storage hydropower facilities and in water conduits, and then to submit a report to Congress that describes the results and recommendations from that study (Table 1.1).

Table 1.1. Text of Section 7 of the Hydropower Regulatory Efficiency Act of 2013(Public Law 113-23), which was approved on August 9, 2013

SECTION 7. DOE STUDY OF PUMPED STORAGE AND POTENTIAL HYDROPOWER FROM CONDUITS.

(a) *IN GENERAL.—The Secretary of Energy shall conduct a study—*

- (1) *(A) of the technical flexibility that existing pumped storage facilities can provide to support intermittent renewable electric energy generation, including the potential for such existing facilities to be upgraded or retrofitted with advanced commercially available technology; and*

  (B) of the technical potential of existing pumped storage facilities and new advanced pumped storage facilities, to provide grid reliability benefits; and

- (2) *(A) to identify the range of opportunities for hydropower that may be obtained from conduits (as defined by the Secretary) in the United States; and*

  (B) through case studies, to assess amounts of potential energy generation from such conduit hydropower projects.

(b) *REPORT.—Not later than 1 year after the date of enactment of this Act, the Secretary of Energy shall submit to the Committee on Energy and Commerce of the House of Representatives and the Committee on Energy and Natural Resources of the Senate a report that describes the results of the study conducted under subsection (a), including any recommendations.*

1.2 PURPOSE

The purpose of this report is to provide a technical analysis of the new energy development opportunities that exist in water conduits in the United States. This report is one of two that support the HREA Report to Congress that DOE will deliver in August 2014. A second technical report prepared by Argonne National Laboratory covers pumped storage hydropower facilities.[1]

1.3 ORGANIZATION OF THE REPORT

This technical report is organized into seven sections. Section 1 explains the background, purpose, and organization of the report. Section 2 defines the various types of energy development in water conduits, as well as the important issues that must be addressed for successful project development. Section 3 reviews the available resource assessments that have been conducted to date, quantifying the magnitude and location of new energy development at these types of sites. Section 4 describes the technologies that are available for deployment in water conduits, including both the gaps among existing technologies and the opportunities for improving the cost performance of these technologies. Considering that almost all of the potential energy resources in water conduits have not yet been developed, Section 5 discusses the challenges and barriers that face developers of these resources. Section 6 presents a few case studies that illustrate the range of sites, technologies, developers, and challenges associated with new energy development in water conduits. Finally, in Section 7, we present our recommendations for science, technology, and policy solutions that may be pursued to accelerate more renewable energy development in water conduits.

A subsequent report to Congress from DOE will summarize the findings presented in this ORNL/TM, as well as those in the Argonne National Laboratory report on pumped-storage hydropower (PSH). The supporting technical reports will be made public via internet sites as soon as DOE delivers the report to Congress.

2. CLASSIFICATION OF CONDUIT RESOURCES

HREA defines the term "conduit" as "any tunnel, canal, pipeline, aqueduct, flume, ditch, or similar manmade water conveyance that is operated for the distribution of water for agricultural, municipal, or industrial consumption and not primarily for the generation of electricity." In this section, that definition is explored more completely.

2.1 EXISTING PURPOSES OF CONDUIT INFRASTRUCTURE

There are many thousands of miles of existing, manmade conduits in the United States that are used to transport and distribute water and wastewater. Municipalities, industrial facilities, farmers and ranchers, and other groups of users depend on the water resources in these systems. Water pipes, canals, and tunnels are the normal means of delivery. Pipes are either buried or installed above ground and canals are typically constructed at the ground surface. Wastewater and stormwater are collected and transported by municipalities and industrial facilities to treatment facilities and/or receiving bodies of water (streams, rivers, lakes, etc.). Water is transported for agricultural uses, such as irrigation or stock watering, typically conveyed to farms or ranches via pipes, ditches, and canals. Larger irrigation schemes—particularly in the West—may have multiple purposes, including municipal and industrial supply, and they may move water long distances, requiring a combination of pipes, canals, tunnels, and siphons. Other types of water conduits include water supply systems to deliver drinking water and gravity-fed systems for industrial process water. All of these may be locations where new conduit hydropower can be developed.

Water conveyance infrastructure is constructed for a specific purpose. In some cases, minor consideration was given to energy production when the infrastructure was built. The owners and operators of the infrastructure have primary responsibility for water delivery without disruption. The ability to move water over terrain requires the conveyance infrastructure to follow the alignment of the topography, which will likely go up and down in elevation. The water may move by gravity—as in a farmer's ditch—or by pumping, both of which product pressure in the distribution system. In conduit infrastructure, there are opportunities to capture energy through two mechanisms:

1. Conversion of pressure or head differentials within the conduit where there is excess energy available beyond what is required to operate the primary system. Some examples of this are where a canal is required to make a steep transition in elevation (e.g., a canal drop), or where there is excess pressure in a pipeline that needs to be dissipated.
2. Capture of the kinetic energy associated with water velocity as it moves along a conduit. Velocity-based generation is referred to as hydrokinetics.

There are many opportunities to utilize locations in the conduit infrastructure to capture electric energy that, historically, have been lost or wasted. Depending upon the specifics of the conduit infrastructure, the electric energy gain could range from kilowatts to megawatts, as determined by the amount of energy that is available.

Primary considerations in harnessing the energy available in an existing conduit system are how the integrity of the existing infrastructure will be protected and how its priority water use will be preserved. Hydropower manufacturers and developers are now developing new, lower-cost methodologies that will allow conduit owners to more readily harness the available electric energy without jeopardizing water delivery. Existing and newer, emerging technologies are described in Section 4, and case studies illustrating successful deployments are presented in Section 6.

Relatively little of the conduit sector has yet been developed for electric generation in the United States. Often, water delivery requires pumping or using other forms of energy to move the water within a larger conduit system, and any electric energy that may be captured with hydropower technology would serve to offset normal energy utilization. The result of this is improved energy efficiency within the overall conduit system. In some cases, this captured electric energy can be utilized in the local area near the conduit infrastructure.

2.2 PROJECT DEVELOPMENT CYCLE

To understand the opportunities and challenges for new energy development in conduits, it is necessary to understand all parts of the project development cycle required in these projects, including the types of developers that propose them (Section 2.2.1). Conduit project types are either pipeline or canal. They are often technically distinguished by the turbine-generating equipment used (Section 4). A description of a representative development cycle is presented below, from identification of a new energy development opportunity (Section 2.2.2) through various project development steps, including planning (Section 2.2.3), screening (Section 2.2.4), permitting (Section 2.2.5), interconnection and power purchase agreements (Section 2.2.6), method of development and construction (Section 2.2.7), and operations and maintenance (Section 2.2.8).

2.2.1 Types of Developers

Different types of developers have different development approaches, financing capabilities, and risk tolerance. Project developers include public and private entities and subcategories within public and private classifications. Public entities include federal, state, and local governmental agencies or counties, cities, and towns, individual or group of municipal utilities, public utility districts (PUDs), and legislated special purpose entities. Private developers can be companies, special interest companies, Indian nations, and individuals.

Many public developers have the ability to use moneys in an annual budgeting process or to raise money through revenue or other types of bonds guaranteed by the entity. Private developers raise money through a combination of equity and debt. The development cycle in which a hydropower addition opportunity at a canal or pipeline is identified, assessed, and licensed is typically funded by a public entity using an annual budget. Once the hydropower addition is fully estimated and license/permits are in hand, the public entity would then issue bonds or fund through an annual budgeting process. The private entity will fund the early development cycle through permitting, licensing, and financial closure using equity. Once financial closure occurs, there is a combination of equity and commercial debt. In some cases, private funding is through insurance companies, or large corporate or financial funds specializing in private project finance. There is limited risk during the early development phases for conduit projects because the basic infrastructure exists and the hydropower addition is smaller in scope and cost than traditional hydropower. In each case, the public and private entity wants to see a satisfactory return on investment and security of existing conduit operations and power revenues from the hydropower addition.

The owner of the existing conduit system where hydropower development is being considered can also be a public or private entity. Typically, these owners are in the business of water delivery for a specific purpose. They often are unfamiliar with electrical generation, although they may have pumping and other hydraulic control structures that require electric service. Traditionally, they have been electrical consumers, and the idea of adding hydropower generation requires a change from their traditional business model. These owners are often the initial entities that know about a location in their canal of pipeline systems that could be a site for addition of hydropower generation. The tradeoff for a business is to become a generation entity or to allow a public or private entity to develop the hydropower generation using the owner’s pipeline or canal. Often these existing owners are not familiar with the hydropower permitting and licensing process and are nervous about working with a new regulator. Many owners of existing conduit infrastructure are reluctant to own or lease the hydropower addition or to allow another to develop hydropower additions, which has become a barrier in this sector for conduit hydropower development. They are reluctant to change their core business or work with what is seen as a new regulator.

Public and private entities are conscious of wasting energy and money and are looking for every opportunity to develop their existing infrastructure to create a new income stream and not waste a resource. But these developers must be confident in the outcome of the development and minimize the risk of capital cost growth and delivery schedule on time completion. Another barrier is often the scheduled path from concept to implementation and commissioning of a hydropower addition is not clear, and the path appears to be risky. These hydropower additions are small in terms of capacity and time delays in licensing, and other non-controllable aspects of development can be seen as risky for a public or private entity with no hydropower development experience. Small change in capital cost can be detrimental to the outcome of a hydropower addition. Because hydropower additions are one of a kind for many canal and pipeline owners, this is also seen as a barrier to be overcome. In some cases the power generated can be used behind the conduit owner's meter, reducing its utility energy use and operating cost.

2.2.2 System Overview

A conduit system overview examines the complete hydraulic system that forms the water conduit, from its source to its discharge point. Whether an initial idea for hydropower generation is technically possible at a specific site is usually determined in an early screening evaluation. As water moves within a pipe or canal and changes elevation, it may gain energy that can be used in hydrokinetic and conventional hydropower applications. In some cases, the available energy may be small and may not be economical to convert to electricity; however, there are cases in which there is a more significant change in canal slope, elevation, or excessive pipeline pressure where energy can be harvested through a financially viable hydropower solution. Other factors that influence a site's feasibility, in addition to available pressure differential, are described below.

If the conduit system of interest is a canal with an open water surface, its key hydraulic characteristics are the flow rate (e.g., cubic feet per second) within the canal and the seasonal variability of this flow rate, and the canal slope or change in elevation from one point to another. Any aspect of the canal that must be maintained to provide the original water delivery purpose of the canal must be defined. These characteristics are needed to develop a schematic or diagram of proposed hydropower development, equipment concept, and energy estimate for the proposed hydropower (conventional or hydrokinetic) addition.

If the conduit system of interest is an enclosed pipeline, the key hydraulic system characteristics are pressure available, plus the flow within the pipe and its time variance. Hydraulic gradients are often employed to recognize where excessive pressure is available within a pipeline. Often in existing pipelines, pressure reducers will be installed at points where there is excessive pressure. These are points in the pipeline system where energy is dissipated and points where the addition of hydropower may be viable. This information is used to prepare a schematic or diagram of proposed hydropower development, select equipment, and estimate energy for the proposed hydropower (conventional or hydrokinetic) addition.

In both cases, it is important to understand how canal or pipeline flow may be interrupted during the hydropower installation or later during the hydropower facility's operation or maintenance and what such interruptions would mean to existing conduit functions. Conversely, project design must plan for prevention of interruptions through bypass structures, and controls that will operate when needed.

Another system overview consideration is how electrical generation equipment can be connected to the electrical system where it can be distributed and sold. In some cases, the conduit owner may be able to use all of the generated energy for its own requirements behind its utility meter. In this case, a power purchase and interconnection agreement may not be needed. In other cases, energy generated will need to be sold to a utility or other entity, and connected to the distribution or transmission system to be able to transmit the electricity. Grid interconnection requirements and other electrical system requirements must be defined, which can be quite simple in a small addition where the electrical energy may be used locally. It becomes more complicated if the new hydropower facility is larger and utility interconnection or transmission is needed. In the latter cases, a power purchase and interconnection agreement will be needed.

2.2.3 Planning

The planning step usually begins soon after the hydropower opportunity is identified and appears to be potentially viable from a technical and financial point of view. Typically, the following steps will be in a project life cycle: conceptual design or assessment, feasibility study, licensing and permitting, financing, detailed engineering, procurement, construction, commissioning and commercial operation and maintenance, and, ultimately, project renewal after the original equipment and structure have completed their projected life.

2.2.4 Screening Sites

Early in the planning process, site screening is an important step. The opportunity is screened for its technical, environmental, social, political, and financial viability. Assessment of the physical opportunity identifies any concerns, problems, issues and barriers that may arise in project development—these are potential fatal flaws or factors that will increase costs. The identification of concerns, problems, issues and barriers must occur as early as possible, and if they cannot be mitigated or resolved, it is necessary to acknowledge a fatal flaw and stop work. Excessive project cost such as the need for significant infrastructure, or high risk of time delays due to limited or restricted construction or installation time windows, are examples of a fatal flaw. If the screening demonstrates sufficient probability for viability, the project can proceed to the next step in the project development cycle.

2.2.5 Permitting Considerations

All hydropower projects, be they in conduits or natural river systems, require project permits and licenses from both federal and state entities.[2] Depending upon the project size and capacity, ownership of the project site, and other political and environmental and social considerations, the developer must determine what licenses and permits will be required. In some cases, exemptions or exclusions from permitting may be possible. All projects are required to comply with the National Environmental Policy Act in one way or another. However, the specific permitting process required, and its difficulty can vary. A licensing and permitting plan is usually developed after screening has been completed. Consultation with the agencies and permitting authorities is typically done as the licensing and permitting plan is developed. For a pipeline and canal hydropower addition, often agencies and permitting authorities cooperate and seek to simplify and expedite the process as there may be little or no ecological effect of the hydropower addition. FERC has excellent guidance available on its website for small hydropower developers.[3]

2.2.6 Interconnection and Power Purchase Agreement

The interconnection agreements and PPAs are also key to project financial viability because they determine the price of electricity that will be received, any other ancillary revenues, future price escalation, and cost of interconnection and wheeling project power to a power purchaser. The cost of the interconnection can vary widely depending upon the modifications required to carry the project power to the power purchaser. For many conduit projects, the interconnection is within the local distribution system, and long distance transmission is not required. Some power purchase agreements encourage renewable energy projects by offering a higher tariff during the debt repayment period or other incentives such as tax holidays and accelerated asset depreciation. In some cases, a conduit owner may be able to use all of the power generated behind the meter for its own use, which may eliminate the need for a power purchase and interconnection agreement.

2.2.7 Methods of Development and Construction

The method of development is often dictated by the project owner (private or public) and the financing methodology. The financer often dictates the methodology for project development. Banks and other financial institutions prefer a low-risk approach to development. They require project development methodologies that seek assurance for repayment of loan and minimize the risk for capital cost growth. They want a power purchase agreement (PPA) and project interconnection agreement. All aspects of project development must be clearly planned, with a clear methodology to achieve each required element of the project and reliable project operation. To achieve a reliable delivery method, the developer is required to assemble a team of experienced professionals and companies. They should be experienced in the specifics of the equipment technology and type of construction required.

For private developers, many financial institutions have required an engineering, procurement, and construction (EPC) approach with a firm capital cost. “Design build” is another approach. At the time of private development financial closure, the financial institution would like to see all licenses, permits, and approvals complete, along with firm prices for all project components with strict contract terms protecting the developer and the financial institution from capital cost growth. In other cases, private developers have been allowed to use an engineering, procurement, and construction management (EPCM) approach. This is another approach, which minimizes risk by having all licenses, permits, and approvals complete and by having firm prices for all equipment and systems and a firm price for the construction contract. The EPCM approach can allow the use of smaller contractors, whereas under the EPC approach, only large contractors may qualify. Like EPC, EPCM also mitigates risks to the developer and to the financial institution. To achieve either EPC or EPCM contracts, engineering and bid documents are prepared that describe the proposed development and the overall requirements and objectives. Firms specializing in EPC and EPCM delivery prepare a firm price estimate. The EPC or EPCM firm performs the detailed engineering and becomes the engineer of record. This firm is responsible for all equipment procurement, construction, and commissioning.

A traditional project delivery method is to engineer and design a project to a 100% complete level, purchase the generating and other electrical equipment, and have one or more contractors performing the construction and installation work. The owner may do construction supervision, have the engineer perform construction supervision, or hire a separate construction manager. Some owners prefer to have complete control throughout the engineering and construction process.

In some cases, the equipment and systems are purchased on a water-to-wire basis, which allows the developer to work with a single equipment supplier. The water-to-wire supplier will take equipment operation risk and provide guarantees for overall efficiency and output. In other cases, equipment is divided into separate supply packages.

Financing considerations for public developers often differ from those of private developers. The ability for the public developer to issue bonds allows them to choose different project delivery. They can hire an engineering company to complete a 100% design and obtain competitive bids for the equipment and construction contracts. This is sometimes referred to a design-bid-build approach. Typically, smaller procurements and construction bids allow for increased competition and lower prices. However, the public developer takes the risk of project delivery and cost overruns. Under the private developer method of delivery, the EPC or EPCM firm takes the risk of project delivery and cost overruns. The public developer typically will hire an environmental and permitting specialty firm, an engineer, and a separate construction manager to manage equipment procurements and construction contracts. The engineer and construction manager will work with the contractor and equipment suppliers during project commissioning.

2.2.8 Operations and Maintenance

Once construction is completed but on-line generation has not begun, a project must be commissioned through a process of step-by-step testing and system-by-system checkout, and then through energized testing and checkout. After these steps, the project is demonstrated to be ready for commercial operation. During this period, project operations and maintenance begins. Operators and maintenance workers become familiar with the local and wider area control, equipment, and systems during the commissioning process. At the time all equipment and systems are determined to be ready for commercial operation, the operators will take over complete operation of the facilities. Maintenance may have begun during the commissioning period but full maintenance responsibility is taken over by the maintenance workers at the time of commercial operation. Typically, there is a warranty period once the equipment and systems are deemed “commercial.” During the warranty period, operations and maintenance are performed by the developer’s operations and maintenance staff. Short shut downs may be scheduled as warranty work is performed, but the project normally remains in control of the operations and maintenance staff. Upon completion of the warranty period, the station enters the normal operations and maintenance period.

Operation and maintenance staff are typically selected based on comprehensive job descriptions and qualifications. They may be available from the consuit owner’s staff if they have experience with mechanical and electrical equipment, such as pumps, motors, and electrical and control equipment. Training is often needed to become familiar with the particulars of the equipment and systems. Frequently they include electricians, technicians, machinists, or mechanics.

3. RESOURCE ASSESSMENTS

Within the past decade, a number of different state and federal entities conducted resource assessments for small hydropower projects. Some of these assessments focused specifically on conduit potential, while others included run-of-river hydropower projects. In addition to these resource assessments, there were several tools that were designed to assist developers with hydropower projects. These tools were also used to simplify the development process for conduit projects. Brief summaries of previous resource assessments and relevant hydropower tools are provided below, after first summarizing the basic factors that go into estimating potential hydropower resources.

3.1 BASIC PRINCIPALS OF HYDROPOWER

The generation potential of a hydropower facility depends on the available head, flow, and equipment efficiency for a specific site.

3.1.1 Head

As used in hydropower engineering, the term head refers to a specific measurement of liquid pressure based on a geodetic datum. Head is equal to the fluid's energy per unit weight of water or other fluid. Typically, gross head is the overall pressure head when the fluid is at rest. When water is flowing in a pipe or canal, there are losses that occur, such as friction along walls, other minor hydraulic losses around intakes, and backpressure from tailwater effects. When the total losses are subtracted from the gross head, the resultant is call "net" head. Net head is a primary variable used to determine power potential.

At a conventional hydropower facility, the elevation of the upstream water reservoir, referred to as "head pond level," is subtracted from the tailwater level to determine gross head. Then net head is determined by calculating all losses in the water passageway to the hydraulic turbine (i.e., entrance, trash rack, friction, and other hydraulic losses) and subtracting the losses from the gross head. In a pressurized system, the net head available for generation will be a function of differences in elevation, water velocity, and losses in the system. In addition, any residual pressure required for continued operation of the primary conveyance system must be considered. Similar factors must be considered to estimate the net head for a conventional hydropower installation on a canal.

3.1.2 Flow

Flow is the volumetric flux of water moving past a given point, usually measured as cubic feet per second (cfs) or cubic meters per second (cms). Since the existing water conduit infrastructure is normally designed and operated for a purpose other than power generation, the flows may have variable temporal patterns, such as a daily fluctuation between high and low flows (day/night water supply) or significant seasonal fluctuations depending on the irrigation needs of crops. To account for these fluctuations, a flow duration curve is developed based on historic flow data. It is important when evaluating the variance in flow to have a good understanding of the primary operations of the system and to design the hydropower system around these operations. Understanding how the flow varies over time and how net head varies over time is essential to selection of the right turbine unit type and size for a given site. Appropriate sizing of equipment is critical to optimizing performance and the cost of development. The use of flow duration curves is discussed further in Section 4.

There may be competing demands for flow at a given site due to issues such as water delivery for irrigation, industrial and public uses, or for environmental needs. These alternative water uses must be accounted for because not all flow will always be available for power generation. To make a proper estimate of generation potential at a site, it is important to investigate other local water uses before determining flow available for generation. Some practitioners refer to this as net flow available for generation.

3.1.3 Energy Conversion Efficiency

Efficiency of hydropower turbine and generator equipment depends on several factors. The overall efficiency of the equipment includes turbine and generator efficiencies. Generator efficiency stays fairly constant over its design range, but turbine efficiency can vary significantly with turbine type, flow, and/or net head. Equipment manufacturers design and test hydropower equipment based on the ranges of net head and flow over time. The equipment is designed to be most efficient at a particular combination of flow and head that is referred to as the Best Efficiency Point (BEP). When the flow rate or net head varies from the BEP, the efficiency decreases. Peak efficiencies of conventional hydropower equipment depend on design, but are typically range between 85-94%.

3.1.4 Power and Energy Generation

The generating capacity of a hydropower facility is a function of the net flow rate available for generation (Q), net head (H_{net}), and turbine-generator efficiency.

The installed power capacity of a hydropower facility in kilowatts is calculated as follows:

$$Power\ (kW) = \dot{Q} \quad \times H_{net} \times \frac{\eta_{system}}{11.8}, where$$

$\dot{Q} \quad = Design\ net\ flow\ rate\ in\ cubic\ feet\ per\ second\ (cfs)$
$H_{net} = Design\ net\ head\ in\ feet\ (ft)$
$\eta_{system} = System\ efficiency$
11.8 = conversion factor for English units

The annual energy generation of a hydropower facility in kilowatt-hours (kWh) is calculated as follows:

$$Average\ annual\ generation\ (kWh) = Power \times Plant\ Factor\ \times 365 \times 24\ , where$$

$Plant\ factor = ratio\ of\ actual\ generation\ to\ theoretical\ maximum$
$365\ = Number\ of\ days\ in\ a\ year$
$24\ = Number\ of\ hours\ in\ a\ day$

The plant factor term, also referred to as capacity factor, is an estimate of the amount of time that the power plant will be operating at its peak capacity. Generally, the annual expected generation is derived by integrating the area under the flow duration curve up to design capacity or by simulating operations in a mathematical model of the proposed plant. This is critical in estimating generation potential, because it accounts for the fact that the water available for generation at a site is usually not constant over an annual period.

3.1.5 Hydrokinetic Principals

The calculation for power potential for hydrokinetic projects is significantly different than conventional hydropower. It begins with the following equation for power flux in moving water (stream power):

$$Power\ Density\ \left(\frac{W}{m^2}\right) = \frac{1}{2} \times\ \rho\ \times\ V^3, where$$

$$V = Water\ velocity\ (m^2/s)$$
$$\rho\ =\ Water\ density$$

To estimate the energy potential of a hydrokinetic project, the theoretical power density of a given site must be adjusted by the area of energy extraction for a given hydrokinetic machine (which will be significantly less than the cross-sectional area of a conduit) and other technology specific efficiency factors. The appropriate methods for estimating technically recoverable energy from hydrokinetic developments is an active area of research within the DOE Water Power Program and is beyond the scope of this current report.[4,5]

3.2 OPEN-CHANNEL SITE ASSESSMENTS

There has been little development of hydropower in water conduits in the United States relative to international development, in part due to low investments in development of the low-head technology needed at these types of sites.[6,7,8] To date, there have been no comprehensive national assessments of the undeveloped energy potential from either canal or pipeline sites. There have, however, been several more limited assessments performed at either state or regional levels.

Previous assessments of undeveloped hydropower resources in the United States, such as those by Idaho National Laboratory in 2006[9] and Oak Ridge National Laboratory in 2014,[10] did not address the conduit opportunities described herein; rather, they focused on natural streams. Similarly, hydropower assessments at existing, non-powered dams[11] examined dams on natural rivers but omitted man-made canals or water distribution systems.

Some of the more geographically limited assessments of undeveloped hydropower and conduit resources are describe below. These estimates typically do not include hydrokinetic potential and likely underestimate the conduit resources available due to lack of a consistent methodology and baseline data. It is also not useful to aggregate results from these different studies because of the inconsistent methods and data.

3.2.1 Idaho National Laboratory Study

In 2006, Idaho National Laboratory published a combined study and geographic information system (GIS) tool on the feasibility of developing small hydro projects throughout the United States.[12] This study relies on FERC licensing data from the 1990s and only considers hydropower projects on existing stream reaches. When determining analysis factors for these opportunities, researchers did not consider existing conduit projects, meaning that a potential development site would have little resemblance to a conduit project. Nevertheless, the study is useful for outlining the development challenges (i.e., transmission and generation issues) that small hydro projects face because these same challenges may also apply to conduit hydro projects. This Idaho National Laboratory study is also one of the few national assessments that had been completed to date; therefore, it may provide valuable insights into the methodology for such a project. For example, in order to be considered for development, the hydro sites had to be located within one mile of a road, and their existing power infrastructure had to be in place. In total, researchers identified 5,400 small, conventional hydro sites that met the preset conditions for development feasibility. These sites represented a total gross energy potential of about 18,000 megawatt hours (MWh).

3.2.2 Bureau of Reclamation Conduit Study

The U.S. Bureau of Reclamation ("Reclamation") conducted a study in 2012 on Reclamation-owned conduits and found that 191 of the 530 conduits that were analyzed had at least some level of hydropower potential.[13] Additionally, the study found that 70 of those sites could be economically viable for development. The study used Reclamation's Hydropower Assessment Tool, an Excel model developed in 2011 that uses hydrologic data and local site characteristics to estimate potential energy generation and economic benefits (note the basic cost equations in this model come directly from the Idaho National Laboratory 2006 report). Producing hydropower at sites that have a development benefit/cost ratio of greater than 0.75 could yield as much as 225 megawatts (MW) and 1 million MWh of energy annually. To calculate hydropower potential, only conduits that were in operation for at least 4 months of the year with a minimum head level of 5 ft were considered. The maximum flow capacity (design flow) of any conduit meeting these specifications was then calculated using the formula of power (kilowatts) = head (ft) * flow (cubic ft/s) / 11.8. Conduit sites with flows producing less than 50 kilowatts (kW) were dismissed from further consideration.

Reclamation-owned conduits may include check structures, vertical drops, chutes, drops series, pipelines, and check drops that may present opportunities for power generation due to excess energy. Historic data, along with data from U.S. Geological Survey (USGS) and Reclamation stream gauges, were used to calculate the flow in each identified conduit where gauging data was available. Some conduits had no available flow data, and, thus, were dismissed from further consideration. Reclamation used its own hydropower assessment tool to combine data on site location, head, flow, and access to distribution lines to determine the final economic potential of a hydro site. This tool is generally used for sites that experience year-round flows and require a larger power facility, which means that it may either overrepresent or underrepresent the economic benefits of smaller seasonal conduit facilities. For this analysis, the tool was set to use a 15% flow exceedance over average flows to account for any extreme flow events when determining the most economical size of a potential hydropower plant.

Information was broken down by geography so that it may correspond with the regions in which Reclamation works. The Great Plains, Upper Colorado, and Pacific Northwest regions were found to have the greatest available hydropower potential. Tables 3.1 and 3.2 below show a breakdown of the calculated resource potential in each Reclamation region as well as the top 25 states that were analyzed.

The large number of Reclamation-owned canals in remote locations means that accurate and current data collection is neither possible nor available for each conduit location. Due to this disadvantage, the assessment's results are not final estimates of feasible energy potential. There were conduits for which there was no existing head or flow data available, as well as conduits for which data was not provided at a fine-enough scale to appropriately determine their hydropower potential. The full report provides a breakdown of each conduit and the source of data that was used for each calculation. While many of the analyzed sites in this assessment would be developed under the Bureau of Reclamation Lease of Power Privilege process rather than FERC licensing, the study adequately outlines an analysis process that could be used further for a national assessment.

3.2.3 State of California

In 2006, the State of California published a small hydro resource assessment that considered the total hydro potential in "manmade water conveyance conduits," which includes canals, irrigation ditches, aqueducts, and pipelines.[14] Due to a lack of comprehensive data on current conduit infrastructure throughout the state, the study was restricted to only conduits that were owned by water purveyors who had entitlements amounting to 20,000 acre-feet (AF) or more. It was easier to obtain data from these larger purveyors, because their conduit infrastructure was more extensive and thereby deemed more likely to produce projects that met the 100 kW minimum capacity thresholds that were set for the analysis.

Table 3.1. Conduit hydropower development in each of the Reclamation regions based on the Bureau of Reclamation's existing conduit assessment

Region	Canal sites	Potential installed capacity (kW)	Potential annual energy (kWh)
Great Plains	175	38,525	122,204,196
Lower Colorado	28	5,239	29,283,867
Mid Pacific	39	4,392	17,550,289
Pacific Northwest	74	22,755	85,385,703
Upper Colorado	57	32,717	110,794,792
Total	**373**	**103,628**	**365,218,846**

Table 3.2. Examples of statewide data for Reclamation conduit hydropower development based on the Bureau of Reclamation's existing conduit assessment

State	Canal sites	Potential installed capacity (kW)	Potential annual energy (kWh)
AZ	26	5,061	28,464,753
CA	20	1,570	4,802,925
CO	28	27,286	100,230,315
ID	9	2,771	11,451,814
MT	32	9,885	26,316,565
NE	30	5,501	13,793,995
NM	8	1,427	3,573,029
NV	16	1,533	8,671,966
OR	68	20,404	75,943,044
SD	1	131	572,000
UT	12	3,552	5,965,031
WA	2	1,047	2,885,357
WY	121	23,460	82,548,053

Note: This table contains all assessed sites rather than simply those with a benefit/cost ratio higher than 0.75.

Water purveyors were further broken down into small, medium, and large categories, depending on the amount of acre-feet (AF) in which they were entitled. Out of 12 large water purveyors (with entitlements greater than 500,000 AF) that were examined during the study, 8 were found to have the potential for small hydro development in their conduits. The total estimated potential for these purveyors was 81,393 kW across 75 total sites. Out of 31 small and medium water purveyors (entitlements from 20,000 to 500,000 AF), 24 were found to have potential for small hydro development, totaling an additional 64,212 kW across 53 sites. The minimum head measurement for conduits that were considered was 9 ft. The economic feasibility of their development was not taken into account. The results were extrapolated to include water districts that were not surveyed by the team and which offered a total undeveloped conduit hydro potential of 255 MW. This potential was split evenly between irrigation districts and municipal water delivery systems.

To perform this assessment, state data, including historic hydrologic flows and USGS topographic maps, were used in combination with site visits and phone interviews to determine an estimate for monthly energy production from each conduit. The Public Interest Energy Research "Strategic Value Analysis" GIS database, which contains information about transmission potential and local energy supplies, was used to offer a better estimate of the ability to realistically use a conduit as a power-generation site. The authors of the report acknowledge that due to conduit hydro barriers—including seasonality of flows and the high fixed costs related to development—this potential capacity estimate is probably much higher than the actual realized capacity would be.

3.2.4 State of Colorado

After combining results from the Bureau of Reclamation report mentioned above, along with an Oak Ridge National Laboratory hydropower potential study, the State of Colorado estimates in a 2013 report that it has approximately 41 potential sites with undeveloped hydro. The total capacity of these sites is estimated to be 737,975 MWh per year. These figures are reported in the Colorado Energy Office Small Hydro Handbook; however, Colorado completed no additional assessments at the time of publication. [15] These sites represent a mix of conduit and non-conduit facilities.

In late 2013, the Colorado Department of Agriculture published a report looking at the development potential for hydropower in agricultural irrigation.[16] This study was able to identify 200 distinct drops in statewide open agricultural canals that had hydropower potential. Sites were required to either have a flow of 100 cfs or more than 150 ft of head. Detailed data from Delta County allowed for additional analysis, which determined that the county's 77 drops had the potential to provide approximately 3.0 MW of electricity (12,100 MWh per year); however, the final report determined that only 9 sites representing 0.8 MW of this capacity were economically feasible for development (in this case, "economically feasible" is defined as projects with a payback period of 20 years or less, based on given assumptions for the value of energy generated).

3.2.5 State of Oregon

The Energy Trust of Oregon commissioned a 2010 study in which it specifically investigated the hydropower potential of irrigation water providers in the state.[17] Out of an initial list of 108 irrigation water suppliers, 29 were identified as having the potential to develop projects of 0.5 MW or larger, "according to diversion, flow, and priority date analysis of existing records." Further evaluation on the likelihood of development was used to narrow this pool to a field of 30 sites that were owned by 14 water suppliers. An on-site analysis of flow rates, seasonality of flow rate, head, interconnection potential, equipment requirements, potential conduit size, and consistency of reservoir withdrawals was used to better gauge development potential. Potential power generation at these sites ranged from 0.03 MW to 2.6 MW.

A more detailed complementary study that was performed at the same time in Wallowa County found that 1,020 kW of potential capacity capable of producing more than 3.3 million kWh of power per year could be generated from the county's irrigation conduits.[18] Using data on water rights and topography, analysts were able to identify 19 sites within the county with conduit hydropower potential greater than 20,000 kWh—the baseline for an applicable project. Following this, analysts visited each site in person to obtain additional data on existing infrastructure, distance to transmission, detailed water rights information, and energy/water efficiency use information. The assumptions of this analysis include that land with a significant elevation change adjacent to a known conduit location was representative of an elevation change within the conduit itself; that water rights identified through state databases were reflective of actual water use in the conduit; and that water flowing in the conduit could be accurately represented by the maximum legally allocated flows. The final capacity estimate for the 19 projects ranged from 5.0 kW to 390.9 kW. While this analysis was resource intensive and required significant on-site data collection from analysts, it has the benefit of providing one of the more thorough estimates of capacity potential that is available to date. It also suggests that obtaining a national study with a similar degree of detail for irrigation canals and other open-channel systems could be difficult due to the remote nature of many conduit locations, as well as the wide variance in record-keeping systems related to the operation of conduits.

3.3 PRESSURIZED PIPELINE SITE ASSESSMENTS

Broad resource assessments for pressurized pipeline opportunities are less common due to the highly individual nature of each project and because they cannot be completed using the typical GIS-based methodology that is applied in most hydropower assessments. Power that is generated from a pressurized pipeline project may either be used within the existing water system to offset other electricity demands or transmitted into the local electricity grid. Design of new energy projects must account for the possibility that if energy extraction is too great, it may require additional pumping and energy inputs elsewhere in the system—a situation that will most likely make projects infeasible. A 2013 U.S. Environmental Protection Agency report on obtaining power from pressurized wastewater treatment systems found that in comparison to the United States, most of the operating experience with hydropower turbines is concentrated in Europe and Asia.[19]

Conduit hydropower in existing water delivery systems also provides system administrators with an additional source of revenue that can then be applied to system upkeep and maintenance. An American Society of Civil Engineers report from 2013 on the state of America's drinking water infrastructure found that most of this infrastructure is aged and expected to need either maintenance or full replacement by 2030.[20] Typically, the repairs are costly; local governments pay the largest share of these costs. Power sales revenue from conduit projects installed in new pipeline can help reduce the taxpayer burden associated with these costs without disrupting water deliveries.

3.3.1 State of Colorado

The abovementioned Colorado Department of Agriculture study that was completed in 2013 contained an analysis of the hydropower potential of pressurized irrigation systems. Based on a GIS analysis that estimated 7% (175,000 acres) of Colorado's farmland is suitable for pressurized irrigation sprinklers, researchers determined that as much as 30 MW of power could be generated from these systems.

3.3.2 State of Massachusetts

In partnership with Alden Research Laboratory, the State of Massachusetts (Executive Office of Energy & Environmental Affairs Department of Environmental Protection) developed a screening tool that helps identify pressurized pipeline opportunities in water supply and wastewater treatment facilities.[21] Infrastructure that is maintained by either municipalities or districts is the primary focus for additional hydropower development. This tool is described in more detail in Section 3.4. Ten projects representing a wide variety of capacities and technologies were chosen as examples. Additionally, the state has made available the detailed case study material from the In-Conduit Hydropower Project – Phase I Report from August 2013.[22] A Phase II report that focuses specifically on applicable technologies for conduit hydropower in water distribution and treatment facilities was published in November 2013.[23]

The Phase II report covers both the replacement of an existing pressure reducing valve (PRV) or similar device with a turbine and the installation of a new turbine that is designed to take advantage of water transport between two storage locations with varying elevations. This report identified approximately 130 sites across the state with the potential for conduit hydropower systems based on both state census data (which helped determine areas with a population significant enough to support a water system capable of providing power) and the capacities of projects examined in Phase I. The report estimates that these sites—which include both water transport and wastewater treatment systems—would be able to generate between 10.3 million kWh and 42.5 million kWh of energy in a given year based on both low-head and high-head systems. This range is fairly wide due to uncertainties in available data. The majority of this energy (39.5 million kWh) would be generated from high-head projects (heads estimated to be between 52 ft to 163 ft) in water transport systems. The head values that were used for the estimates were based on average head values from data that was generated in Phase I of the report. Along with this report, the state also produced a corresponding analysis tool that would help those who are interested in generating power from pressurized systems make project-related decisions. This tool is described in more detail in Section 3.4.3.

3.4 TOOLS FOR IDENTIFYING FEASBILE PROJECTS

There are a number of engineering screening and design tools that can be used by prospective developers in the evaluation of prospective conduit energy projects. It is important to understand the limitations and assumptions associated with each tool prior to utilization so as the meaning of the results are understood. There are many tools available within the industry from simple spreadsheets to more sophisticated analytical tools. We discuss some of the commonly used tools in the following subsections of Section 3.4. Section 3.5 discusses gaps in present available tools.

3.4.1 RETScreen

RETScreen, which can be used for hydro projects of any size, is a tool that is used to predict "the energy production and savings, costs, emission reductions, financial viability, and risk for central-grid, isolated-grid, and off-grid hydropower projects."[24] The RETScreen Small Hydro Project Model exists specifically to help developers of small hydro projects estimate the likelihood of success for their projects before moving forward. While the tool may be used on pumped-storage projects, it is optimally designed for run-of-river projects that may be either off grid or in an isolated grid area. Due to similarities in the projects' designs, the tool should also work for conduit hydro projects. To use RETScreen, developers need to provide information in seven categories about the prospective project, including information on technology use and financing/cost. Depending on the intent of the analysis, users may also provide information on financial sensitivity for long-term projects and greenhouse gas inputs.

When estimating project costs with the RETScreen Small Hydro Project Model, developers may use one of two methods: (1) the "formula method," which is based on historic cost data or (2) the "design method," which is based on estimated quantities and unit costs. The design method requires additional knowledge about material needs and costs; it is generally completed in addition to the formula method, rather than alone. Predicting the energy production of the project requires developers to have detailed knowledge of site information regarding head and flow inputs, which are used in a series of in-tool algorithms. Detailed information on these calculations can be found in the RETScreen Small Hydro Project Model manual.

One limitation of this tool is that it uses a year-round flat energy demand model to predict the amount of energy a project can deliver. In areas where this is not the case, developers will need to make adjustments. The small hydro version—as well as other versions of the tool for other types of hydro projects—can be downloaded for free from the RETScreen website, along with instructions and examples.

- *Sample Tool Inputs*: Turbine efficiency, interest rates, number of turbines, access road length, and transmission line voltage (a full list of inputs can be obtained from the RETScreen website).
- *Tool Returns*: Annual energy production, project costs, and greenhouse gas reduction potential.

3.4.2 HydroHelp

HydroHelp is a Microsoft Excel-based tool produced by OEL-HydroSys (a Canadian consulting company) and that is designed to assist developers with turbine selection for hydropower projects. [25] Four separate versions of HydroHelp exist; the first is for helping developers with turbine selection, and the remaining three are for determining site specifications once a Francis, impulse, or Kaplan turbine has been selected.

Developers using the first version of the tool are required to input 12 pieces of site information—including head, water levels, flow, and water temperature—to receive a recommendation on potential project turbine types. Based on these inputs, the program will suggest applicable turbine types, starting with the least costly option. If necessary, the program may also suggest alternative turbines, depending on the specifications of the proposed powerhouse. After the user selects a turbine, the program will generate an efficiency curve for potential flow levels based on the American Society of Mechanical Engineers definition of efficiency. This version (which can be used on turbines starting at 1 MW) along with corresponding tutorials can be downloaded for free from the HydroHelp website.

The turbine-specific versions of HydroHelp are pay services that can be purchased from the HydroHelp website. These programs use location specifics for the proposed hydro project to produce basic structure dimensions and cost estimates. As might be expected, information generated from one of the pay versions of the software is more detailed than information generated from the free version. Each version of the program has embedded constraints based on known technology capabilities in order to prevent a user from designing a project that would be technologically unfeasible given the suggested turbine capacity.

- *Sample Tool Inputs*: High and low headpond elevations, head loss to turbine, normal tailwater level, flood tailwater level, design power plant flow, desired number of units, summer water temperature, system frequency, generator power factor, maximum allowable gearbox power, design standard and generator quality, and inflation ratio since 2008.
- *Tool Returns*: Suggested turbine type and efficiency curve.

3.4.3 Massachusetts Screening Tool

In partnership with Alden Research Laboratory, the State of Massachusetts (Executive Office of Energy & Environmental Affairs Department of Environmental Protection) developed a screening tool that helps identify pressurized pipeline opportunities in water supply and wastewater treatment facilities.[26] Infrastructure maintained by either municipalities or districts is the primary focus for additional hydropower development. This Microsoft Excel-based tool can be downloaded for free from the State of Massachusetts website along with a corresponding user manual. Users may select one of three project types (“conventional hydropower,” “simplified conventional hydropower,” or “simplified hydrokinetic”), depending on the project specifications and amount of information a developer has available. In some cases, if the developer is missing project information, the tool may be able to auto-fill the field with an estimated parameter based on data from existing projects. Based on a number of project inputs, the tool will offer estimates for project power, energy generation, costs, and financial viability.

The tool was developed from research on existing projects in Massachusetts that had previously received a conduit exemption. Researchers used information on these projects— including "equipment manufacturer, installation contractor, capital cost, operation, and maintenance (O&M) costs, incentives utilized, O&M level of effort, general performance, and challenges faced," as well as how each project was integrated into the water treatment or water distribution system— to develop common parameters for other Massachusetts projects.

- *Sample Tool Inputs*: Flow units, hydrology type, turbine design flow, flow duration, head, turbine flow maximum/minimum, turbine selection, and generator efficiency. A full list of inputs can be found in the tool's manual, located on the project website.
- *Tool Returns*: Power generation, energy generation, costs, and project financial viability.

3.4.4 Other Geographic Information System Tools

In addition to these assessment tools for engineering and economic feasibility analysis, some new GIS tools are now available to evaluate the environmental sensitivity of potential conduit sites. The U.S. Department of the Interior released a GIS tool in the spring of 2014 designed to help with landscape-scale management of public lands.[27] This tool is the product of a larger five-part strategy that the department has implemented to mitigate potential damage resulting from development of all types of renewable energy, disseminate information more efficiently to the public, increase resource resilience, ensure that conservation efforts are well planned and complement one another, and improve processes that provide federal compensation for mitigation. DOE has also supported development of a GIS database that provides environmental attributes to new hydropower sites.

3.5 GAPS IN ANALYSIS TOOLS

As owners and developers initially identify a site and complete a feasibility report of conduit hydropower opportunities, they are hampered by their inability to use standard tools to conduct reliable assessment and feasibility studies. Projects are generally very small (microhydro, under 500 kW) or small (less than 10 MW). These smaller opportunities for harvesting conduit energy typically have limited financial budgets for early, custom engineering studies. These limited financial budgets are often the initial barrier in the increased development of conduit hydropower opportunities. There is a natural reluctance to authorize a budget without a real and reliable understanding of the opportunity. Providing the owners and developers with engineering and assessment tools for use in these initial assessments would help break down this barrier. These tools would allow a manager to have an early understanding of the hydroelectric resource capacity and an estimate of annual energy and to have an idea of the project features required, type of equipment, fatal flaw checklist, list of typical development steps and requirements, indicative cost estimate, and project schedule. This approach would allow for a minimum engineering cost until the manager agrees that the opportunity is worth further study.

Another gap that owners and developers confront is the lack of tools to establish a standard methodology for determining the feasibility of a conduit opportunity. Conduit opportunities often have little or no environmental impact. The canal or pipeline already exists and is operated and maintained. Typically, there are no aquatic resources or fish present at the conduit location because they have been excluded where water first enters the canal or pipeline. Often the construction and operation disturbance is minimal. Tools that standardize feasibility; study technical, environmental, social, construction, economic, and financial aspects; and streamline acceptable characterization, mitigation, and project delivery would be worthwhile. These tools would potentially save time and money, thereby avoiding the customary one-project-by-one-project approach. Custom engineering not only increases engineering costs, but also increases construction costs because it does not encourage standardization and modularization. Conduit hydroelectric projects in canals and pipelines often have common geometry and physical attributes, which can minimize the need for custom engineering. Therefore, off-the-shelf, pre-engineered solutions that satisfy technical, environmental, and economic suitability tests may be more cost effective. Web-based, intelligent tools would be ideal for overcoming this gap. Project examples, as well as lessons learned from past projects, would enhance the tool and keep it up-to-date with the latest advances in technology.

The final gap is in standard design tools. Although there are a variety of commercially-available design tools (Section 3.4), more custom or more sophisticated analytical tools are often expensive in cost and learning time. Available design evaluation tools are also not integrated with GIS data, nor are they programmed on a platform that is dedicated and customized to canal or pipeline projects. Each can be adapted or customized to suit the particulars of a canal or pipeline project. Customization has been a barrier to the harvesting of conduit hydropower. Furthermore, design tools that are dedicated to canal and pipeline hydropower installations would drive down installation costs and eliminate unnecessary optimization through standardizing and modularizing design approach, criteria, equipment, and systems and configurations. The approach would maximize off-the-shelf equipment, along with non-customized components and structures. Web-based, intelligent tools would be ideal for overcoming this design tool gap. Customization and optimization are not necessary for these micro and small projects, and, in fact, they increase project risk, installation cost, and schedule length. The installation should work reliably, harvesting the energy that is available in a reasonable manner at a reasonable cost within a rational schedule with little or no impact on the environment. Project examples, as well as lessons learned from past projects, would enhance the tool and allow it to keep up-to-date with the latest advances in technology.

4. AVAILABLE TECHNOLOGIES AND PERFORMANCE

The selection of hydropower equipment for conduit projects can be relatively complex and challenging due to the combinations of heads and flows typically available in the water distribution systems, as well as the geometry and physical spaces into which they must fit. By definition, most of the infrastructure for an in-conduit installation already exists. The main purpose of the infrastructure must be maintained throughout the development of the hydropower project, i.e., irrigation, agriculture, municipal use, etc. A primary design consideration is to minimize the impact of the hydropower facility on the existing infrastructure and environment, while maximizing total generation. Selecting appropriate equipment for a site is a critical factor in meeting this intent. Often there are also other requirements for hydraulic equipment such as bypass gates and valves and other devices to prevent the interruption of flow or other adverse impacts to the primary water conduit system.

Hydropower equipment is designed to operate within a specific range of flow and head combinations. The chart below shows the typical range of design parameter for conventional types of turbines (Fig. 4.1). More vendor-specific versions of this type of turbine application chart can be found in Colorado’s 2011 Department of Agriculture report on low-head hydropower,[28] in hydropower engineering text books, and from manufacturers.

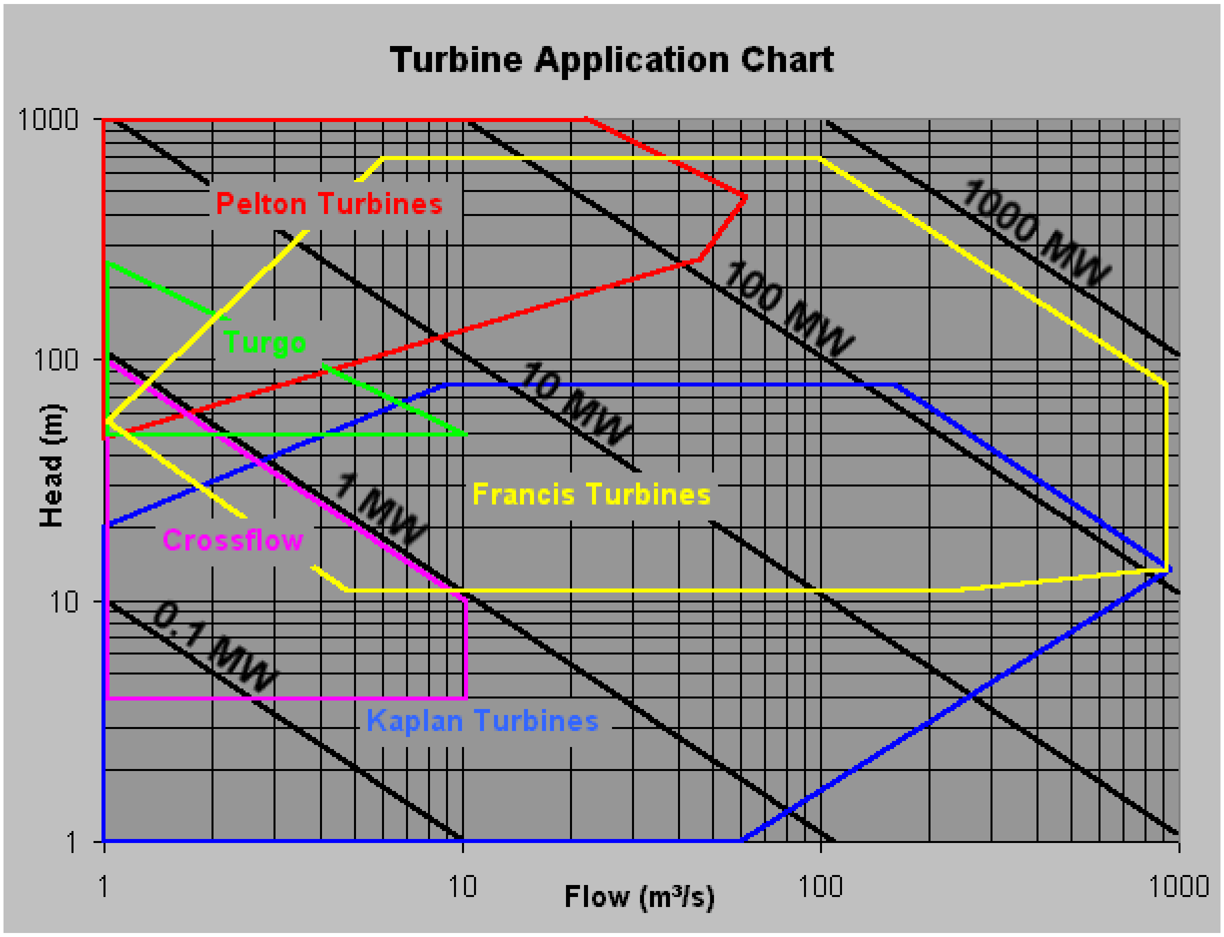


Fig. 4.1. Turbine application chart. (Source: www.jcmiras.net/wiki/hydropower-turbine-application-chart-12.htm)

The flow rate available for in-conduit hydropower systems is a function of the flow rates associated with the primary purpose of the water conveyance system. For conduit projects that have relatively constant or predictable head, selection of turbine size can focus on flow frequency and variability, as represented graphically on a flow duration curve (Fig. 4.2). Figure 4.2 shows a sample flow duration curve and demonstrates how the design flow rate and operating range are selected based on the flow data.

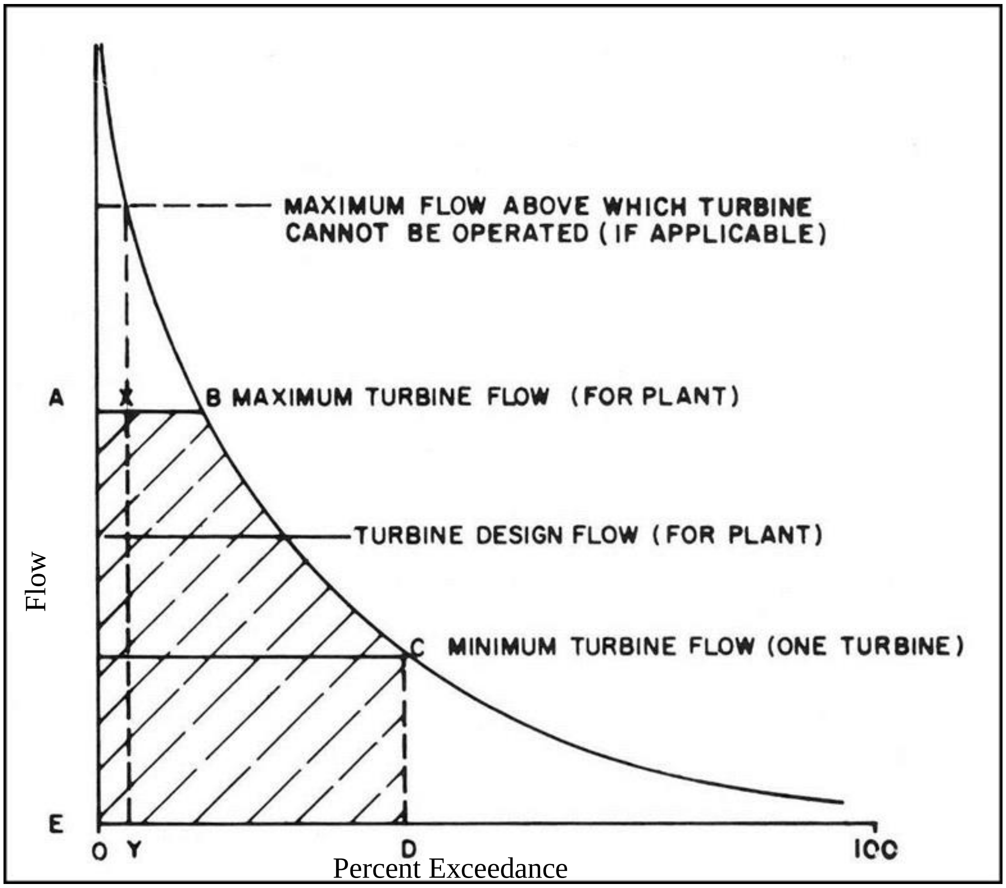


Fig. 4.2. Sample flow duration curve. (Source: Electric Power Research Institute, 1985)

Once the design flow rate is selected, the corresponding design head is estimated. For a hydropower facility, efforts are made to maximize the amount of net head available for hydropower generation. In a conduit system, the prime purpose is water delivery, and this purpose must be considered when determining the net head available for power production. The following net head equation considers the static head (elevation difference) that is reduced by system losses:

$$H_{net} = H_{gross} - H_{loss}$$

There are several ways to maximize the net head that is available. Some of these may not be available depending upon the conduit configuration. A few methods are listed below:

- Increase the difference in static head between the inlet and discharge water levels
- Use large trash rack openings
- Increase the trash rack size to lower approach velocity of the water
- Use a large diameter penstock
- Use a short (length) penstock

- Optimize the geometry of the penstock by reducing abrupt bends and other appurtenances
- Use smooth surface coating
- Use a full-ported inlet valve.

Another method of increasing the potential energy generation of a hydropower facility is to optimize the generating equipment's efficiency. The overall efficiency of a facility depends on the type, size, number of units, and frequency of operation of the unit(s) at the design point. When a piece of hydraulic generation equipment does not operate within its design range, poor performance, premature wear and tear on the equipment can occur. Typically most engineers will work closely with turbine and generator manufacturers who will guide the correct selection of the appropriate turbine generation equipment. In some cases, more than one type of hydraulic turbine could be appropriate for a particular site. Each type of hydraulic turbine has advantages and disadvantages that should be carefully considered during the turbine selection.

4.1 CONVENTIONAL TURBINES

As discussed above and shown in Fig. 4.1, specific turbines are applicable for ranges of head and flow combinations. Proper equipment selection is an important part of hydropower project development. This section outlines the applicability of hydropower turbines for various conditions.

For the purposes of this report, the technical parameters are defined as follows:

- **Reaction turbine:** Generation is a function of the change in pressure of the water; reaction turbines must be fully submerged in a continuous water column.
- **Impulse turbine:** Generation is a function of a change in velocity of the water; free jets of water hit the turbine blades, causing rotation.
- **Turndown:** Turndown is related to the range of flow at which a turbine operates most efficiently; for example, with a 2:1 turndown, the flow range is x to 2x, where x is the minimum flow rate.
- **Head classification:**
  - Low head: 0–20m (66ft)
  - Medium: 20–200m (656ft)
  - High: > 200m
- **Costs:** Project costs of different types of turbines depend on many factors that have been evaluated in other DOE-supported reports.

There is a well-documented trend in the costs of conventional hydropower turbines in which smaller-sized machines (measured as capacity) have much higher costs per unit energy output ($/kW).[29] For example, the illustration in Fig. 4.3 shows the cost of Francis turbine-generator sets for units larger than 1 MW are generally do not exceed $1,000/kW, while units smaller than 1 MW can have costs ranging up to $3,000/kW and above (Fig. 4.3). This trend also exists for other types of turbines. Turbine costs comprise approximately half of project development costs, depending on the site. There are, however, significant opportunities to push down development costs through aggressive research and development. The following areas for potential cost reductions in small hydropower projects have been identified by Oak Ridge National Laboratory:

- New manufacturing strategies for less expensive, modular systems and advanced materials applied to turbines and generators
- Improved controls and instrumentation
- Innovative design and construction of powerhouses, dams/spillways, and penstocks
- More efficient engineering and permitting.

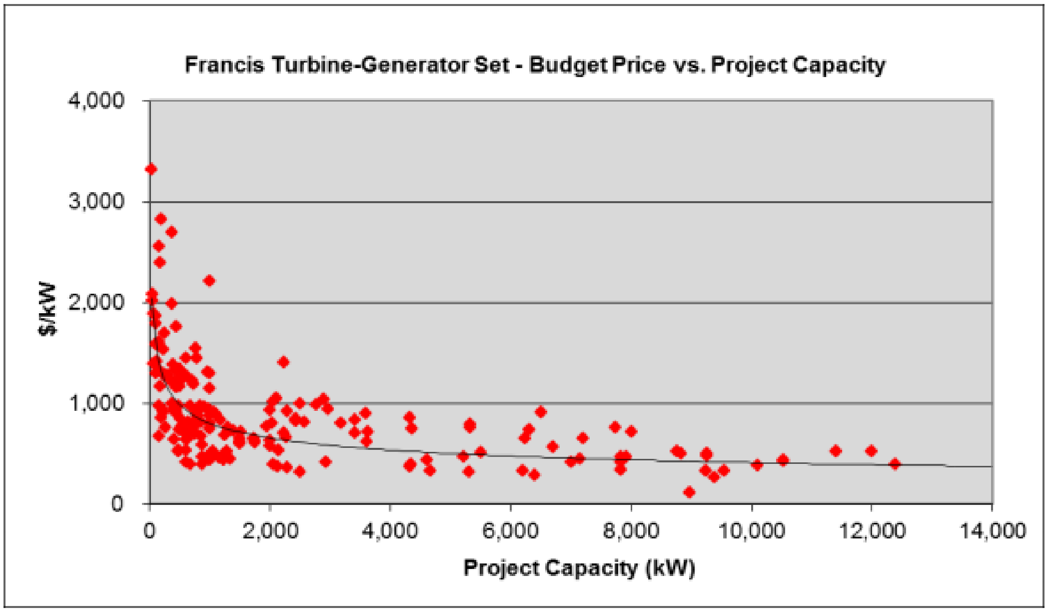


Fig. 4.3. Typical cost relationship of small hydropower turbines. Shows an inverse relation between cost per kW and capacity. (Source: Zhang et al., 2012)

Tables 4.1 and 4.2 illustrate more of the characteristics and differences in design among the available conventional turbine tyes that are available for conduit project applications.

Table 4.1. Characteristics of different reaction turbines available for hydropower applications

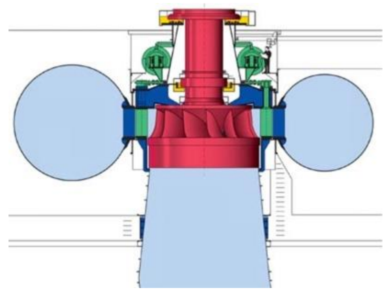
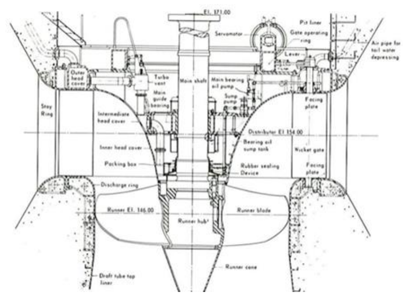
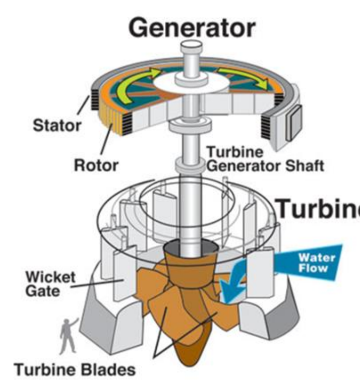
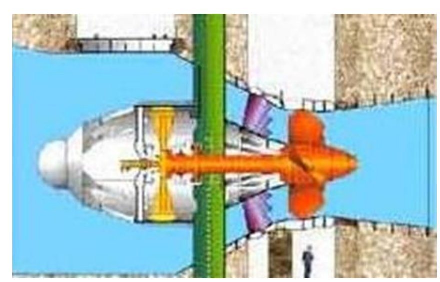
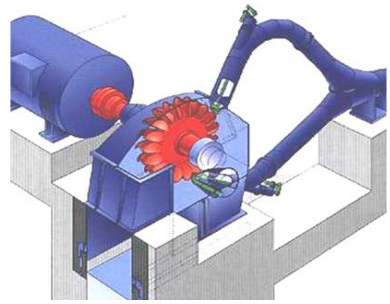
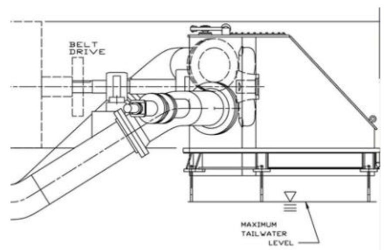
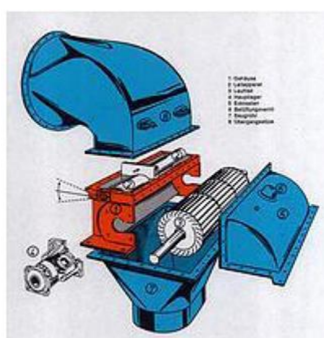
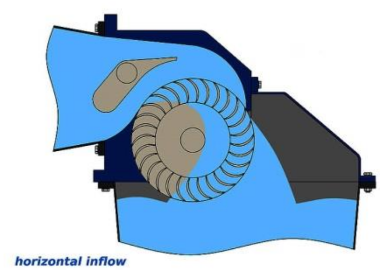
Type/characteristics	Grapic illustrations of concepts	
Francis • Moderate to high head (80 ft to 2000 ft) • Limited turndown (4:1) • Good efficiency, but limited flow range • May require a surge tank or reactive bypass system • Will require a draft tube • High civil costs	 Francis unit	
Propeller • Fixed Kaplan blades with adjustable wicket gates • Low to moderate head (30 ft to 200 ft) • Limited turndown (~3:1) • Great efficiency at the design point, but very limited flow range due to fixed blades • Require a draft tube • High civil costs		
Kaplan • Adjustable blades • Low to moderate head (20 ft to 200 ft) • Good turndown (5:1, maybe) • Great efficiency at design point (DP), greater flow range, and blades will adjust to the flow, moving the DP • Will require a draft tube • High mechanical and civil costs	 Source: Mavel	
Bulb • Low head (6 ft to 30 ft) • In-line flow (horizontal units) • Offer the same performance feature as the Kaplan • Good efficiency on and around the DP • Can deal with extreme flows • Moderate civil costs • High mechanical costs	 Source: Andritz	

Table 4.2. Examples of impulse turbines available for hydropower applications

Type/characteristics	Graphic illustration of concepts	
Pelton • High head (900 ft plus) • High turndown (5:1 per nozzle) • Good efficiency, but great flexibility in flow ranges • Low mass, generally requiring a fly wheel to add stability • May not require a surge tank with the use of deflectors during a load rejection • No draft tube requirement • Minimal civil costs	 Three-jet Pelton turbine Source: Andritz	
Turgo • Low to moderate head (50 ft to 200 ft) • No turndown on basic unit (1:1) • Low efficiency • No governor; requires a ballast system to address changing loads • Will not require a draft tube • Low initial costs • Low civil costs • A variable nozzle and governor can be used with increased cost	 Source: Varspeedhydro	 Micro Turgo Water Wheel in Housing
Cross-Flow • Low to moderate head (10 ft to 500 ft) • High turndown (10:1) • Lower efficiency • Will not require a draft tube	 Source: Ossberger	

4.2 NEWER DESIGNS

There are many traditional hydraulic turbine installations in canals and pielines. These hydraulic turbines are often of custom design and can be expensive unless offered by a manufacturer in some type of standard package. There is an emerging market for hydraulic turbine generating equipment that is suitable for small hydropower projects on conduit systems. Pump manufacturers are offering pumps to be used as turbines. This configuration can be quite cost effective and can be offered using standard pumps. There is a loss of overall efficiency using a pump as a turbine, but the capital cost can offset this efficiency loss.

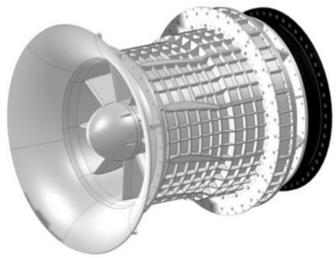
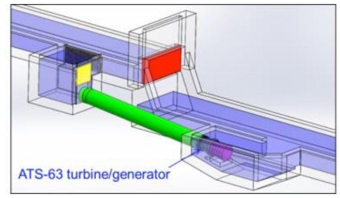
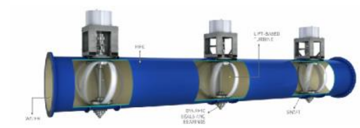
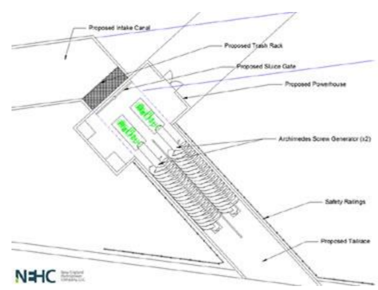
There are other new and developing, small hydraulic turbine designs that are focused on small hydro applications and low-head hydro applications. The factors driving innovation include the following:

- **Demonstrated need.** A focus on small hydropower in the United States is driven by the recognized need for clean energy. In the case of hydropower, this means low impact by adding projects at existing infrastructure locations.
- **Research Dollars**. Innovation is encouraged as money becomes available to investigate newer designs.
- **U.S. Inventors.** More inventors in the United States are comfortable presenting their ideas based on the recent studies that show a need for newer technologies for small hydropower projects.
- **Repeatability.** Many small hydropower projects on conduits can be repeated in somewhat of a "cookie-cutter" design due to similarity in design head, design flow, and configuration. Repeatability can help reduce the capital cost, scope of work for construction, and complexity of permitting and licensing.

The new designs range from modification of traditional hydraulic turbine to original and innovative turbines. The manufacturers that are developing new pressure flow technologies for pipeline or canal projects include Voith, Andritz, and Mavel. The Archimedes Screw is an example of a low-head turbine. Manufacturers working on new designs for in-pipe applications include Cleanpower Norway, Obermeyer, VLH, Amjet, and Natel. Some of the hydrokinetic turbine manufacturers who are developing hydrokinetic technology applicable to canals or pipelines are Lucid, HydroVolts, Verdant, RER Hydrokinetic/TREK Technologies, and Instream Energy. Examples of some of these innovations are shown in Table 4.3. Additional examples can be found in the reports from Masssachusetts and Colorado cited in Section 3.3, as well as in the New Pathways Report and the Technology Catalog that will be coming out soon from the Hydropower Research Foundation.[30]

Many of these technologies are still in the research or prototype phases of development, so they must be considered pre-commercial products. Developers and inventors are pursuing collaboration with DOE and its national laboratories, universities, and hydraulic laboratories. Innovation promises to reduce cost and improve efficiency for a variety of applications, from hydrokinetics to high-head installations. However, more prototype testing is needed to build up operational experience to define long-term energy performance and operation and maintenance costs.

Table 4.3. Selected examples of newer, emerging technologies potentially applicable to conduit projects

Manufacturer	Graphic illustration of concepts	
Amjet Integrated axial turbine-generator for in-pipe installations www.amjethydro.com/	 ATS-63 TURBINE/GENERATOR WITH 63-INCH DIAMETER INTAKE	
Lucid Lift-based, vertical axis spherical turbine for in-pipe applications www.lucidenergy.com		
Natel Energy Two-stage, modular impulse turbine www.natelenergy.com		
Archemedies screw For example, The Archimedes Screw Co. (TASC) www.tasc.co www.nehydropower.com		

4.3 MODULAR EQUIPMENT

An important trend in hydropower technology is the growing emphasis on off-the-shelf or packaged units. Off-the-shelf or packaged units are based on a fixed design for specific head and flow conditions. The units are offered as a package that includes turbines, generators, governor, and intake or inlet valve. The approach is to manufacturer more than a single unit of the standard configuration and be able to replicate by using a single turbine and generator design. The intent of this trend is to reduce the capital costs associated with equipment design. By eliminating custom design and manufacturing, the unit cost can be more competitive and take advantage of non-custom manufacturing techniques.

Established hydropower equipment manufacturers are recognizing the industry need for low-cost equipment and are marketing pre-designed equipment for specific applications. Manufacturers such as Canadian Hydropower Components, Ossberger, Obermeyer, Mavel, Toshiba, Andritz, Voith, Canyon Industries, EEG Canada Power System, Hydro Works (New Zealand) are marketing packaged units more in recent years. Manufacturers in China, Brazil, and Turkey have offered standard packages in small and micro hydro equipment for some time. These manufacturers have chosen to use lower cost materials and manufacturing techniques to lower production cost. This equipment may not be manufactured to a North American standard, and performance over a complete life cycle may be less well known. The technical requirements for modular or packaged units in the North American market must be balanced to obtain a desired level of equipment and manufacturing quality and durability at competitive cost.

New entries into the hydraulic turbine manufacturing are also seeking to standardize on certain sizes and on head and flow criteria. In-line turbines that can eliminate traditional powerhouse structures are well suited to modular construction. AMJET and Clean Power Norway offer an axial flow-combined turbine/generator unit with limited moving parts. These axial flow units can be placed into a pipeline or used in combination with a penstock or canal without pipeline. Obermeyer offers an off-the-shelf turbine generator that is offered in standard sizes for application at existing dams and canal drops. Canadian Hydro Components, Canyon Industries, Andritz, and Voith also have standard lines of small turbine generator systems and have new product offerings.

Several manufacturers are offering pre-assembled turbine generator systems. The components are assembled in the shop and transported to the site; then they are aligned and leveled, concreted, and grouted or otherwise mechanically attached to the foundation or substructure. Pre-assembling minimizes the field erection work of the generation equipment. The limitation is economical shipping size and weight. For a typical canal installation, the turbine can be preassembled and shipped as a single component. The generator would be a single component. The electrical panels and switchgear could be largely preassembled with a similar objective. Factory pre-assembled electrical and hydraulic systems are available from such companies as PCX. The transformer would be a single component. Modularizing allows preassembly before generating equipment is delivered to the project site. By planning the modularization, the owner, engineer, supplier, and contractor can not only save cost but also installation time. Commissioning time is also reduced, thereby speeding the time to revenue generation.

Modular construction not only involves the generation equipment but also the structure within which the equipment housed. Typical small hydro projects have had the generation equipment configured within a powerhouse with reinforced concrete substructures and foundations. The powerhouse superstructure could be of many architectural configurations, from reinforced concrete, masonry, or wood or steel frame construction, or a combination. The concept of modular construction seeks to reduce cost through use of modular and standardization. Canadian Hydro Components has a product line of small hydro-generating equipment that does not have to be embedded in concrete but that is self-supporting through the equipment steel frames and housings. There are some limitations related to turbine size and hydraulic and mechanical forces, but this innovation allows for new types of modularization and simplification of reinforced concrete substructures.

Other modular construction involves many possible solutions, including cofferdams, steel support structures for hydraulic turbines and generators, and intake to discharge prefabricated units. Modular construction solutions are only limited to the vision of the engineers, owners, and construction contractors.

Fig. 4.4. Example of a modular powerhouse for a small, conduit project (concrete box in left photo) installed at a canal drop. (Source: Natel)

4.4 HYDROMECHANICAL SYSTEMS

There is one other, non-traditional method for using the energy that can be harnessed from water conduits without conversion of that energy to electricity. That method is to use hydraulic pressure directly in a gravity-pressurized irrigation system to spin a center pivot sprinkler. Such an approach can avoid the need for grid electricity or a diesel generation that would otherwise be used the spin the center pivot. All that is required is excess head. Although these types of systems do not generate electricity directly, they can represent significant energy savings for individual farms and ranches, which also translates into financial savings. The Colorado Department of Agriculture is currently developing a program aimed at accelerating installation of these type of systems. Example projects have recently been developed in Colorado and Utah. Case studies illustrating these types of hydromechanical applications are presented at the end of Section 6.

5. CHALLENGES AND BARRIERS TO DEVELOPMENT

FERC and the Bureau of Reclamation have regulatory control over non-federal hydropower development in water conduits; one or the other is the lead agency for regulatory approval depending on congressional authorization for federal power development at the site. In response to the HREA 2013 legislation, FERC has implemented policies that allow more conduit projects to either become exempt from its licensing or be excluded from FERC jurisdiction. Only one new FERC-permitted conduit project was placed into service during 2013.[31] As of June 2, 2014, there have been 27 applications from conduit projects requesting exemption from FERC licensing pursuant to HREA 2013; 20 of these were deemed eligible for exemption, 5 were rejected, and 2 had not been decided yet. This recent record indicates that not many developers are taking advantage of new federal regulations, and it suggests that perhaps the overall regulatory environment for small conduit projects still involves costs or other risks that are prohibitive. This section describes the remaining types of challenges and barriers that face developers of small conduit projects.

5.1 RESOURCE ASSESSMENTS AND FEASIBILITY ANALYSIS

The identification and evaluation of potential conduit projects share some of the challenges of conventional hydropower; however, they also pose unique challenges. High-level resource assessments to identify potential sites or to quantify hydropower potential are challenging because of the man-made, or artificial, nature of conduit systems. This makes estimating site potential, even at the highest levels, difficult if not impossible without site-specific information. When completing an evaluation at either the site assessment or feasibility analysis level, understanding the resource characteristics available (temporally variable head and flow) have the additional challenge of considering other system operations and resource needs. Equipment selection also continues to be an issue as the available flow and head typically vary from the typical design specifications of conventional generation equipment.

5.1.1 Resource Assessments

It is important to understand the overall generation potential of in-conduit hydropower at both the state and national level for planning purposes. This information will provide policy makers, developers, and consultants details on which geographical areas and technical locations (irrigation canal, water supply conduits, etc.) are most suited for development.

Conventional resource assessments are completed by identifying existing dams or topography with sufficient drop for hydropower potential. A hydrologic analysis can be completed (typically using a USGS gauge) to understand the typical stream flows and ultimately power and energy estimates can be completed at a high level. This approach estimates power potential based on the natural features and publically available data and may be suitable for a canal site. However, this approach can not be used for pressurized pipelines due to their artificial, engineered characteristics. To estimate the head and flow available for generation within a pipeline, site-specific information must be available for analysis. The information required to complete estimates of potential include the following:

- Historical flow data
- Historical pressure/elevation data
- Detailed understanding of the entire conveyance system to ensure that sufficient resources remain after generation for the primary system to function properly
- Existing system drawings to physically identify if a suitable installation location exists.

Typically, the information listed above is not readily available for review. Sometimes, the information is considered critical infrastructure data and can be challenging to obtain. Finally, the level of effort to achieve even high-level estimates is greater than conventional hydropower.

5.1.2 Site Assessments and Feasibility Studies

Site assessments and feasibility studies are similar in nature; however, the level of detail can vary significantly. When a conduit hydropower opportunity is identified, the owner or developer will want to do a low-cost, high-level site assessment of the hydropower opportunity. An early site assessment is valuable to an owner or developer because it provides an understanding of what the site potential is and it begins to identify challenges and/or fatal flaws associated with development. It also gives prospective developers an understanding of any potential impact that it may have on the existing flow conveyance structures. Efforts are made to identify challenges, such as those involved in permitting or in protecting any existing environmental resources, earlier in project development to minimize risk to the developer. Items typically addressed in a site assessment include the following:

- Site layout, including accessibility of transmission interconnection
- Estimated capacity (kW)
- Estimated average annual energy generation (kWh) and the variability of generation year-to-year and month-to-month
- Estimated annual revenue expected from energy sales and renewable energy certificates
- Estimated initial capital investment.

The level of effort associated with a site assessment can vary widely; however, there are generally early studies to determine if an addition of hydropower at a conduit should be pursued or not, and if pursued, at what risk and cost. Often, a site assessment is completed on multiple locations in an attempt to find the most viable site for development. Typically, there is limited information available at this stage, and the assessment is made based on incomplete information. In some cases, assessments can be an early opinion of viability with an identification of additional study or information needs and requirements. Topography, geologic, and hydrologic information can be missing for example. Some topography may be available, but it may not be at a scale where it is useful.

The following examples illustrate the types of information required to make an assessment and how reliable they tend to be. Due to the differences between conventional and hydrokinetic based generation systems, information required for site assessments differ.

Conventional hydropower assessment. Whether pipe or canal, the assessor must determine the amount of flow and the net head that is available to generate electricity. Flow often varies over time, and a flow duration curve is prepared to show how the flow varies over time. In some cases, head will also vary over time and with different levels of flow, and a head duration curve is prepared. The timing of head and flow should coincide timewise when estimating energy production. Energy production can be estimated at any point on the flow duration curve and head duration curve by multiplying net head times flow.

For example, in a situation in which there is an upper and lower canal that have an elevation change of 10 meters (32.8 feet) and a flow of 2 cms (70.63 cfs), using a turbine efficiency of 0.88 and a generator efficiency of 0.96, production can reach 165.8 kW. If the head is increased 10 times with the same flow, the amount of power produced can be increased 10 times. If the amount of flow is increased 10 times with the same head, the amount of power produced can be increased 10 times.

Water pressure is typically expressed in pounds per square inch (psi), and 50 psi (3.447 bar) is equivalent to a water head of 35.15 meters. In the previous example, 10 meters of water head would be equivalent to about 14.2 psi (0.981 bar) water pressure.

In our canal example, if the canal is operational for 300 days per year and has a constant flow of 2 cms (70.63 cfs), then the canal can produce 1.19 million kWh of annual energy.

With an energy tariff $0.10 per kWh, this canal example could produce annual revenue of $119,376. Based on this annual revenue, an owner or developer can make an indicative business decision if it is worthwhile or not to study this further.

In a pipeline example, if there is a 50 psi (3.447 bar) pressure reduction and a flow of 2 cms (70.63 cfs) using a turbine efficiency of 0.88 and a generator efficiency of 0.96, you can produce 582.61 kW. If you increase the pressure 10 times with the same flow, you increase the amount of power produced 10 times. If you increase the amount of flow 10 times with the same pressure, you increase the amount of power produced 10 times.

If the pipeline is operational for 365 days per year and has a constant flow of 2 cms (70.63 cfs), then the pipeline pressure reduction can produce 5.1 million kW-hrs annual energy.

With an energy tariff of $0.10 kWh, this pipeline pressure reduction example could produce annual revenue of $510,000. Based on this indicative annual revenue, an owner or developer can make a business decision if it is worthwhile or not to study this further.

These are simplified examples, but illustrate very simple early assessments. Typically assessments are conducted in more detail, but with a preliminary estimate of flow and head. Then based on the head and flow, power, energy, and revenue can be estimated. Most engineers will select an appropriate type of turbine generator machinery to more accurately estimate the turbine and generator efficiencies. However, for the purpose of an early assessment, general estimates of efficiency can be used. This is not to say that the consideration of equipment is not important and that further refinement is appropriate in later study. Also, there has been no attempt to make engineering adjustments that may improve head and flow; this can also be refined with more study.

Most owners and developers want to have more reliability than the simplified early indicative assessment illustrated above, and they would prefer to do some early engineering in the assessment, and outline in more detail a schematic of the proposed hydropower concept. They would like to know if there are any apparent fatal flaws in addition to project economics that would prevent the addition of the hydroelectric option being considered. Fatal flaws are barriers or challenges to a proposed development that are unlikely or expensive to overcome. Examples could include geological issues, environmental and social issues, and ownership issues.

Most practitioners would start with a review and examination of topographic maps and geological maps, satellite photographs, and any aerial photography that may be available. For canals, the entity that originally engineered and built the canal will likely have much of this information already in their archives. It may be from the original construction period and may not be in digital form, but it is quite valuable and useful. Ownership surveys showing boundaries and right of ways are also quite useful. In some cases, as-built or as-constructed information may be available as well. Often in the case of pipelines, detailed engineering drawings and fabrication drawings available. Often, there are actual flow gages on the existing canals and pipelines, which accurately regulate and record the flow at all times. Flow records are often available for many years of record. What is equally important is to understand if there has been a flow regime or operational change and the reason for the change. Reasons could be related to a change in water right, a sale or transfer of a water right or legislative change, increased water demand by a municipality, or another reason. An understanding of the reasons for flow change can be used to interpret past flows and predict future flows.

Typically, the canal water levels and pipeline pressures are closely regulated. Heads and pressures can be accurately calculated without significant engineering work required. For municipal water delivery systems and wastewater systems, more engineering work may be needed to accurately understand the hydraulics and available net heads and flows, and how they vary over time.

The features required for a hydroelectric addition at a canal would typically include a head works, water conveyance structure, turbines, generators, unit control, protection, switchgear, transformers, and a powerhouse. New and developing axial-flow turbine-generator equipment are now available that does not require a traditional powerhouse. If the generator is a direct current type, there is an inverter to convert the direct current to alternating current. It is quite straightforward for an experienced hydroelectric engineer to develop a schematic drawing for the assessment. Once the features are understood as to size and length, a fatal flaw analysis can be completed.

Hydrokinetic assessment. Whether pipe or canal, the assessor must first determine the water velocity available to generate electricity from a hydrokinetic turbine/generator. Flow often varies over time and with flow change there may be different physical water levels, flow levels, and water velocity variation. Engineers will prepare a velocity duration curve for use in the assessment of hydrokinetic resource.

The actual power generated by a hydrokinetic device will be less than its theoretical potential due to the efficiency of the turbine and generators and the device's hydraulic effects on the surrounding channel flows. Hydraulic losses include wake affects and associated head losses. When a turbine's cross-sectional area is significant compared with the area of the canal or pipeline, head loss can develop raising the upstream water surface elevation. The Electric Power Research Institute developed an enhanced bottom roughness for use in a standard hydraulic calculation procedure and model to determine the hydrokinetic device impact. Rigorous analysis using an enhanced Manning roughness is present in Appendix B: Hydraulic Impacts of Hydrokinetic Devices in the Electric Power Research Institute's 2012 Technical Report, "Assessment and Mapping of Riverine Hydrokinetic Resource in the Continental United States."[32] For an early efficiency estimate when calculating hydrokinetic power, practitioners will use 0.30 to 0.35. It is always appropriate to contact an equipment manufacturer or supplier for specific unit information when preparing a more detailed assessment. Some hydrokinetic turbines are more suitable to a particular site location than others.

There are many scientific and engineering questions that remain unresolved in the development of hydrokinetic turbine technologies. These include the following:

1. What happens during a hydraulic transient event in a conduit to the hydrokinetic turbine? Does the installation of the hydrokinetic turbine increase the magnitude of the hydraulic transient condition? Does the hydraulic transient condition potentially damage the hydrokinetic turbine?
2. What will the hydraulic interactions among multiple machines be? How would the implementation of multiple machines affect a canal or pipeline operation?
3. How can the deployment of multiple hydrokinetic turbines be achieved without interfering with the existing conduit's operation?
4. Does the deployment of single and multiple hydrokinetic turbine contribute to additional energy losses in conduits? If so, how much and can this be modeled and predicted?

These and other technical questions should be considered in future applied research. As hydrokinetic turbine prototypes are being deployed, the goal should be to instrument, monitor and collect precise scientific and engineering data, pose and answer questions, and develop new questions and answers through applied research. These initial installations and prototypes offer exceptional opportunities to learn, create a database of knowledge, and identify possible turbine improvements and demonstrate hydrokinetic turbine reliability.

Whether hydrokinetic devices are deployed in a series in a pipeline or canal, enough distance between turbines should be allowed to minimize hydraulic interactions and possible wake affects between units. Such interctions are dependent upon the specific design of hydrokinetic turbines and the configuration of the turbine blades and their orientation.

Cost estimates and project schedules are more difficult at the assessment stage for hydrokinetic installations, as there have not been many of these types of projects completed to date. Most information is based on prototypes and is closely held by the equipment manufacturers. As more deployment takes place and operation experience is gained, better cost estimates and construction schedules will be possible.

5.1.3 Feasibility Studies

Should the results of the initial site assessment indicate that the site may be viable and no fatal flaws have been identified, a feasibility study can be commissioned and conducted. These studies involve an order of magnitude more effort than an assessment. This type of study thoroughly looks at each technical facet of project equipment and works to develop reliable, bankable energy projections, capital cost estimates, schedules, cash flows, and analysis to demonstrate financial viability. Typically, financing and financial terms are addressed as well. A typical feasibility study will address the following in detail:

- Site survey, topography, and land ownership
- Hydrology
- Geology and soils
- Layout of key project features
- Initial turbine/generator selection
- Power studies
- Environmental and social assessment
- Project permitting
- Cost estimates
- Preliminary schedules
- Financing and financial considerations
- Project report.

5.1.4 Barriers to Site Assessment

- **Standard assessment methodologies.** The industry has not adopted a standard methodology for conduit assessments. Without a standard assessment methodology, the method of assessment and the results of assessment will vary widely. Having a consistent approach in assessment methodology will allow owners and developers to obtain consistency in approach and the end result of the assessment. It will also allow the industry to have a systematic approach in harvesting the energy wasted in existing conduits. Step-by-step approaches with tools will allow this process to be standardized and improve the reliability and consistency of the assessment results. In some cases, there is not enough data or the data is costly to obtain, which can be an added complexity to conducting the assessment.

- **Equipment.** There is inadequate information cataloged on conventional hydropower and hydrokinetic equipment. Hydrokinetic equipment is new and still being proven. There is inadequate cataloged arrangements of both canal and pipeline hydro. The installations to date have been custom, and there is no process or methodology that has been developed that can allow owners and developers to have a roadmap and step-by-step approach to developing canal and pipeline hydropower. This results in expensive arrangements and inefficient selection of equipment and construction methodologies. There has been little opportunity to date for standardization and modularization. These ideas must begin in the assessment and feasibility phases where they can be most cost effective in the harvesting of the energy that would have otherwise been wasted.

5.2 PERMITTING

Permitting requirements have been a barrier to small hydro development for decades, although requirements have recently been simplified through federal and state hydro permitting reform legislation. In August 2013, President Obama signed into law two pieces of legislation aimed at making the regulatory process more efficient for small hydro: H.R. 267, the Hydropower Regulatory Efficiency Act (HREA), and H.R. 678, the Bureau of Reclamation Small Conduit Hydropower Development and Rural Jobs Act.

HREA created a “regulatory off-ramp” from FERC permitting requirements for non-controversial hydro projects on existing conduits that are less than 5 MW in capacity, provided that there are no public objections to the project during a 45-day public notice period administered by FERC. The bill also increased the FERC conduit exemption to 40 MW, directed FERC to explore a 2-year licensing process for hydropower development at existing non-powered dams and closed-loop pumped storage projects, increased the FERC small hydro exemption from 5 MW to 10 MW, authorized FERC to grant developers 2-year preliminary permit extensions; and directed DOE to prepare reports regarding pumped storage and conduit project opportunities.

The Bureau of Reclamation Small Conduit Hydropower Development and Rural Jobs Act authorized small conduit (under 5 MW) power projects on Reclamation-owned infrastructure, while providing irrigation districts and water user associations the first right to develop hydropower projects. The bill also directed the Bureau of Reclamation to use its National Environmental Policy Act categorical exclusion process for small conduit applications.

In addition to federal reform efforts, some states have started developing efforts to simplify permitting for small hydropower. In May 2014, Colorado Governor John Hickenlooper signed into law HB14-1030, legislation that directs the Colorado Energy Office to facilitate hydropower project review by Colorado state agencies in a timely manner commensurate with FERC timelines, making it possible for a project applicant to simultaneously clear federal and state review as quickly as 60 days for non-controversial projects (Fig. 5.1). The bill also streamlines the electrical inspection process for small hydropower, directing the State Electrical Board to provide small hydro with the same exemption from product listing requirements that apply to small wind, as contained in the 2011 National Electric Code.

Fig. 5.1. Photograph of Governor John Hickenlooper of Colorado on May 31, 2014, and others, at the signing of a bipartisan Small Hydropower Reform Bill. The bill will help accelerate conduit hydropower development and promote job creation in rural communities by coordinating the regulatory processes. (Source: Colorado Small Hydropower Association, 2014)

In November 2013, the California Water Resources Control Board and FERC executed a memorandum of understanding that covers coordination of pre-application activities associated with proposed non-federal hydropower projects in California.[33]

In 2012, the governor of Vermont signed S. 148, "An act relating to expanding development of small and micro hydroelectric projects," legislation that sought to expedite procedures for FERC's granting approvals for small hydro projects in Vermont. Vermont state agencies have entered into a multiagency memorandum of understanding that outlines the assistance and support Vermont will provide to small hydro developers. Vermont is also developing a small hydropower developer guidebook and a project intake form to help make the state approval process easier.

Notwithstanding the significance of recent federal and state permitting reforms, significant challenges remain. A review of the applications processed by FERC to date pursuant to the HREA indicates that few projects have applied to FERC seeking exemption, suggesting that perhaps the new FERC process is still not perceived as simple. According to FERC data,[34] as of September 3, 2014, 30 conduit application projects have applied to FERC requesting exemption pursuant to HREA—of which, 24 have been deemed eligible for exemption, 4 have been rejected, and 2 are pending.

The regulatory barrier of having to secure an exemption from FERC pursuant to HREA could be perceived as a barrier for the smallest projects, including net-metered small projects in rural areas. The costs of regulatory processes are especially burdensome for small projects, because the regulatory processes involve fixed costs that translate into higher costs per unit energy for smaller projects. For example, in 2001, FERC analyzed regulatory costs to hydropower developers in its "603 Report to Congress."[35] The FERC study showed that licensing costs (based on Year-2000 dollars) are around $900/kW for projects < 1 MW, $200/kW for those in the 1–5 MW size range, and $100 for larger projects 5–25 MW in size. The average licensing process takes many years, which means large carrying costs on capital raised for project development. In addition, the capital for project development necessarily comes at a higher cost give the additional layers of risk associated with the time-consuming, lengthy, and uncertain permitting process.

5.3 PROJECT FINANCING

Small hydropower has substantial financing challenges that are due primarily to lengthy and unpredictable permitting processes. Potential lenders will evaluate a hydropower project just like any other potential investment, considering factors that include project completion risk, operation risk, revenue risk, debt structure, and counterparty risk. The uncertainties and duration of regulatory requirements for small hydropower can prevent securing financing until all regulatory processes have been completed and a power purchase agreement (PPA) is in place.

The biggest problem in financing hydropower is revenue uncertainty. Lenders typically will not finance projects without a long-term PPA with a creditworthy counterparty, yielding a revenue stream with an acceptable debt-coverage ratio and a PPA term length that is equal to or greater than the term of the debt.

Current wholesale market conditions with low electricity prices and uncertainties in Renewable Energy Credit (REC) and capacity markets make financing difficult. REC contracts are typically short-term (three years), and future REC market pricing is subject to future changes in Renewable Portfolio Standard requirements, which can make REC values unreliable for long-term financing.

The Public Utility Regulatory Policies Act of 1978 (PURPA) helped encourage small project development, including hydropower, by requiring utilities to purchase energy from Qualifying Facilities. FERC issued regulations requiring utilities to purchase energy and capacity from Qualifying Facilities at rates equal to the utility's avoided cost, defined as the incremental cost the utility would have incurred if not supplied by the qualifying facility. In the past, PURPA rates have been set at a level sufficient to spur new small hydro development. Recent PURPA rates, however, have typically been too low to incentivize new development.

Federal tax incentives, the Investment Tax Credit, and the Production Tax Credit have been helpful to project financing, but the tax credits for hydropower are currently expired. Even if they are extended, ongoing political uncertainty regarding future availability of the credits will add risk to any financial projection based upon future tax credit availability. The net value to a developer of the tax credits can vary based upon whether they can be used internally by the developer or need to be sold. Many small hydropower developers are startups or small companies that do not have a corporate tax burden to offset with tax credits. In addition, many small hydro developers are public entities and thus are unable to benefit from tax credits unless they create a financial structure in partnership with a private-sector entity.

For fiscal year 2014, Congress provided $3.6 million in appropriations to fund Section 242 of the Energy Policy Act of 2005, which authorized payment of production incentives for new hydroelectric generation. If the program's authorization is extended and appropriations continue into the future with long-term certainty, the Section 242 incentives could become an important driver for new development of small hydropower.

The U.S. Department of Agriculture's (USDA's) Rural Energy for America Program (REAP) can provide financial assistance for small hydropower projects. Under REAP, grants and guaranteed loans are available to install renewable energy systems, including small hydropower. In addition, in December 2013, USDA announced a new loan program that could potentially help support development of small hydropower systems. USDA plans to provide rural electric cooperatives with funding to lend to business and residential customers for energy efficiency improvements and renewable energy systems, potentially including small hydropower. Some utilities have already developed effective on-bill financing programs that make it possible to pay back borrowed funds for project construction through a regular monthly bill payment—a program model that could potentially be applied to small, net-metered hydropower.

In order to help address financing challenges in hydropower in general, DOE recently announced a new loan program that would available to some types of hydropower. The program includes application fees, annual maintenance fee, and other administrative fees that are high relative to small hydro developers' ability to pay, including most developers of conduit projects.

Some states have developed loan programs that can be helpful to small hydro developers. Massachusetts and other Northeastern states have had programs to provide funding for small hydro feasibility assessment as well as construction. The Colorado Water Conservation Board has a hydropower loan program that can finance the engineering and construction of hydro projects with loan terms of 30 years at an interest rate of 2%—a program that has been successfully used to finance development of new small hydropower in Colorado (Fig. 5.2).

Fig. 5.2. The 8 MW hydro project at Ridgway Dam in Western Colorado. Completed in June 2014, it was made possible by $15 million in 2% loan funding provided by the Colorado Water Resources and Power Development Authority and the Colorado Water Conservation Board. (Soure: Tri-County Water Conservancy District)

5.4 FINAL DESIGN AND CONSTRUCTION

Design and construction challenges that may arise at conduit projects tend to be unique and different from more conventional hydropower development. These also differ by the type of site that is being developed, as illustrated in the following sections.

5.4.1 Conventional Hydro Installation in a Pipeline

To avoid any interruption of the flow conveyance flow, a pipeline is typically divided into two parallel pipe routes. One route can bypass flow around the new hydroelectric equipment, and one houses the new hydroelectric turbine/generator equipment. Typically, there is a shutoff valve in the entrance and exit of each parallel pipe route. When the hydroelectric equipment is operating, the bypass pipeline entrance and exit valves are closed. When the hydroelectric equipment is not operating, these bypass valves are open and the entrance and exit valves in the pipeline containing the hydroelectric equipment are closed. The entrance and exit valves can be partially open or closed depending upon the design.

Typically in pipeline installations, there is no need to remove trash or to protect for aquatic life because this has been already accomplished at the entrance or intake of the pipeline. In some cases, the water in the pipeline will be raw water, and in other cases, it will be treated water. The hydroelectric equipment and system are designed in accordance with the required water standard. In some cases, the pipeline installation can be associated with raw or potable water; or greywater or wastewater. Potable water installations are designed to comply with potable water standards or requirements. Greywater or wastewater can have some particulate matter and variations in chemical pH and other active chemicals. In these cases, care is required in the specifications and design details to assure long-term, low-maintenance operations. Mitigation could include specification of stainless steels and industrial-grade coatings and linings. In some cases, cathodic protection may be required.

The design requires development of a hydraulic grade line, which defines the gross water pressure, net water pressure, and transient and water hammer water pressures. These pressure characteristics are developed for each operating and non-operating case. The gross water pressure and the net water pressure are used to calculate the energy produced based on the variation of flow to the hydroelectric equipment. Pipelines can have a variety of flow variations, and this must be understood. In all cases, the new hydroelectric installation can use well-proven, time-tested equipment and design concepts. The equipment must be suitable for the particular installation. The construction is often conventional and straightforward, and limitations (if any) are based more on space available than the design or operation limitations. In some cases, the new hydroelectric installation can be placed in a new vault or small structure, and in other cases, it can be in an existing structure. Typically, the new structures are made of reinforced concrete below grade and a reinforced concrete slab and prefabricated metal or masonry building above grade.

The balance-of-plant equipment is conventional unless the electrical equipment must also be located in vault. Special electrical provisions are applicable to vault installations that must be considered. Special ventilation and sump pumps may be needed if the installation of the new hydroelectric equipment is in a vault.

5.4.2 Conventional Hydro Installation in a Canal

The existing canal is typically divided into two parallel water routes: the existing canal and the path through the new hydroelectric turbine/generator equipment. The waterway associated with the new hydroelectric equipment can be a small canal, a penstock, or both. Typically, there is a shutoff gate at the entrance of the canal section in parallel with the new hydroelectric equipment water route, and one in the intake or entrance for the water route to the new hydroelectric equipment. When the hydroelectric equipment is operating, the bypass shutoff gate at the canal section is closed. When the hydroelectric equipment is not operating, the shutoff gate to the canal section is opened. The entrance gates can be partially open or closed depending upon the design.

Typically in canal installations, there is a need to remove trash, and a trashrack is required at the intake. The need for fish protection features will depend on the presence of aquatic life in the canal. In some cases, the water in the canal will be raw water for irrigation or other public water use. The new hydroelectric works design must be in accordance with the required water standard. In some cases, the canal installation can be associated with greywater or wastewater and can have some particulate matter and variations in chemical pH and other active chemicals. Care is required in the specifications and design details to assure long-term, low-maintenance operations. Mitigation could include specification of stainless steels and industrial-grade coatings and linings. In some cases, cathodic protection may be required.

The canal design requires development of a hydraulic grade line, which defines the open-channel water levels, gross water pressure, net water pressure, and transient and water hammer water pressures. These are developed for each operating and non-operating case. The gross water pressure and the net water pressure are used to calculate the energy produced based on the variation of flow to the hydroelectric equipment. Due to the flow of most canals being quite steady with little flow variation, this is hydraulically straightforward. Occasionally, a canal will be encountered with more significant flow variation; these installations are more complicated hydraulically and their analysis may be more sophisticated for a trouble-free installation. In all cases, the new hydroelectric installation can use well-proven, time-tested equipment and design concepts. The construction is conventional and very straightforward, and limitations (if any) are based more on space available than the design or operation limitations. In some cases, the new hydroelectric equipment can be placed in a small powerhouse structure. A small substation is located adjacent to the powerhouse structure. Typically, the new structures are made of reinforced concrete below grade and a reinforced concrete slab and prefabricated metal or masonry building above grade. The submergence of the turbine sets the powerhouse floor level and depth of powerhouse and tailrace excavation, and interconnection details back to the canal downstream of the powerhouse. The balance-of-plant equipment is conventional. Minor servicing can be accommodated while the turbine is deployed and operational—if the hydrokinetic turbine/generators are accessible.

5.4.3 Hydrokinetic Installation in a Pipeline

The hydrokinetic design requires development of the velocity of water variation in the pipeline. Due to the flow of most pipelines being quite steady with little flow variation, this is hydraulically straightforward. Occasionally, one will encounter pipelines with more significant flow variation; these installations are more complicated and the range of water velocities should be understood. Hydrokinetic equipment is in prototype development stages, and new installations are being proposed. Typically, the generator is located on the outside of the pipe containing the hydrokinetic turbine. The generator can be supported from the pipeline or on a concrete pad adjacent to the pipe and hydrokinetic turbine. The installation of hydrokinetic turbines in a section of pipe is similar to the installation of a section of pipe except for the consideration of the generator. The construction is conventional and very straightforward, and limitations (if any) are based more on space available than the design or operation limitations. In some cases, the new hydrokinetic installations can be placed above ground or in a new vault or small structure, and in other cases, they can be in an existing structure. Typically, the new structures are made of reinforced concrete below grade. It is not necessary to construct a powerhouse for the hydrokinetic equipment if installed above ground. A small electric/control building is located near the hydrokinetic cluster of turbines. The small substation is located near the electrical/control building. Smaller-capacity installations may not require a building and may simply have an electrical/control panel and small switchgear and transformer. If the generator is of the direct current type, an inverter is required, and these can also be placed in a National Electric Manufacturer's Association (NEMA)-4 weather proof metal enclosure rather than requiring a building.

There is no significant balance-of-plant equipment required unless the electrical equipment must be located in a vault. Special electrical provisions that are applicable to vault installations must be considered. Special ventilation and sump pumps may be needed if installation of the new hydrokinetic equipment is in a vault. Minor servicing can be accommodated while the turbine is deployed and operational—if the hydrokinetic turbine/generators are accessible.

5.4.4 Hydrokinetic Installation in a Canal

Hydrokinetic turbines must be sited and deployed based on flow variation, water level, geometry, and orientation of a canal. The hydrokinetic turbine/generators can be supported above the canal, floating on the canal, or located within the canal. In all cases, the hydrokinetic turbine/generators can be lifted or rotated out of the canal flow for maintenance and servicing. Minor servicing can be accommodated while the turbine is deployed and operational—if the hydrokinetic turbine/generators are accessible. There are three different ways that a hydrokinetic turbine can be deployed in canals:

- Case I: Supported aerially from above the canal
- Case II: Floating on the water surface
- Case III: Located within the canal.

Where the hydrokinetic turbine/generator is supported from above the canal (Case I), there are usually foundations on either bank of the canal. A support structure bridges the canal and supports the hydrokinetic equipment. The generating equipment can be lifted or rotated out of the water into a maintenance position. There are access walkways. A small building or NEMA-4 electrical enclosure is located on one bank with a pad mounted or pole mounted switchgear and transformer in a small substation to connect to the electrical distribution system. The design and construction is conventional, and the installation can be modularized for a multiple hydrokinetic turbine/generator installation.

Where a hydrokinetic turbine/generator is supported from a floating platform (Case II), the platform and the hydrokinetic equipment are usually a single module delivered to the site and deployed. The floating platform is anchored to the canal banks using cables to “deadmen” or other foundations. The generating equipment may be lifted or rotated out of the water into a maintenance position from the floating platform. Access would be by small boat from the canal bank. An electrical cable connects the equipment to the bank. A small building or NEMA-4 electrical enclosure is located on one bank with a pad mounted or pole mounted switchgear and transformer in a small substation to connect to the electrical distribution system. The design and construction is conventional, and the installation can be modularized for a multiple hydrokinetic turbine/generator installation.

Where hydrokinetic installations are entirely located in the canal and within the canal water (Case III), these are self-contained devices that are lowered to the canal floor and rest on the canal floor. The devices are self-supporting, but they may need a concrete base if deployed in soil-lined canal. To access these hydrokinetic equipment for operations and maintenance purposes, they must be lifted out of the water to the canal bank. An electrical cable connects the equipment to the bank. A small building or NEMA-4 electrical enclosure is located on one bank with a pad mounted or pole mounted switchgear and transformer in a small substation to connect to the electrical distribution system. The design and construction is conventional, and the installation is modularized for a multiple hydrokinetic turbine/generator installation.

5.4.5 Barriers to Final Design and Construction

Deployments. The opportunity for harvesting conduit energy is not well defined at the state or national level by actual locations, sites, and similarity of individual sites. Often, past site installations have been a custom design. The past installations have not be cataloged, and information is often limited to technical papers, company experience, and personal knowledge. It is necessary to carefully record the past installations, and develop a resource database to use as a basis for new installations while avoiding custom designs, if possible. Having standard designs and equipment arrangements will allow an owner or developer to start from a standard arrangement or frame of reference. This will also provide a single frame of reference for design and construction costs and schedule. Lessons learned from existing projects will also improve the delivery with a category or project group.

Standardization and modularization. There is significant opportunity for standardization and modularization of conduit hydroelectric designs and construction. The projects to date have been looked at as one-of-a-kind or custom projects. There has been no active work done to date to standardize design and modularize for lower construction cost.

Web-based concept design. Owners and developers should be able to obtain information and concept design using a Web-based tool that will guide based on historical design and new design concepts to lower-cost equipment, systems, and components. The Web-based tool would allow a conduit owner or developer to actually size the components for the addition of hydroelectric to harvest the energy that would have been otherwise wasted. The Web-based tool would calculate an early cost estimate based on selected equipment and provide an early financial analysis based on inputs such as energy tariff, cost of money, and other considerations.

5.5 ELECTRICAL INTERCONNECTION AND TRANSMISSION

Electrical interconnection rules address the technical requirements and the application process for requesting electrical connection. Uncertainty in the cost, timing, and technical requirements of grid interconnection process can be a barrier to small hydro or any other distributed energy resources. Independent System Operator (ISO) interconnection application processes are typically expensive and time-consuming with their own timetables and priorities, which are not necessarily consistent with the timeline needs of small hydro developers.

In order to promote interconnection success for small hydro generators, rules are needed that obligate utilities to review applications in a timely manner and provide detailed cost estimates to interconnection applicants. There also needs to be simplified processes for very small generators that are net metered, and interconnection study and metering requirements that are commensurate with the size of the generator, building on efforts already underway in some states.

Various industry groups, including the Interstate Renewable Energy Council, have been working with state public utility commissions to improve interconnection procedures by identifying and promulgating procedural best practices. One best practice is to make available a pre-application report, which can enable project developers to better choose appropriate project locations.

Related recent federal efforts include FERC Order 792, issued November 22, 2013. The order establishes new rules for small generator interconnection agreements and procedures. In California, that state's "Rule 21" describes the interconnection, operating, and metering requirements for generation facilities to be connected to a utility's distribution system.

Because electrical interconnection requirements can differ by state and utility, there is substantial variation in the degree to which interconnection rules pose a barrier to small hydro development.

5.5.1 Electrical Inspection

For electrical inspection, larger hydro systems will typically be inspected pursuant to the National Electric Safety Code (NESC).

For small net-metered hydro systems, the relevant electrical inspection code is the National Electric Code (NEC). The NEC requires that all products be UL listed and used in a manner commensurate with their nameplate.

Because the U.S. small hydro industry is so small, many small hydro manufacturers do not sell enough products annually to have standardized products that are UL listed. Frequently, the turbine is custom-manufactured for a particular site configuration of head and flow, the generator is an off-the-shelf motor configured for use as a generator, and the controls are custom-engineered.

Local electrical inspectors working according to the NEC can be unwilling to approve small hydro systems—even systems built by reputable U.S. manufacturers that have been in business for decades. This problem is compounded by the fact that, unlike photovoltaic and small wind, small hydro is not currently covered in the NEC.

One option to address this problem is UL field verification, requiring a visit to the project site. However, field verification can be time-consuming and expensive, potentially exceeding the cost of the hydropower equipment for very small hydro systems.

The most logical process addressing these electrical inspection issues would be to explicitly include small hydro in the next version of the NEC, which will be updated by 2017.

5.6 TECHNOLOGY UNCERTAINTIES

Often the head and flow resources available at conduit hydropower sites vary from conventional hydropower sites. Commonly available hydropower equipment has not been configured or optimized to operate in typical conduit applications. This means there must be careful equipment selection and customization to the requirements of a conduit site. Often practitioners must seek out a suitable equipment manufacturer with equipment suitable for the installation. Some innovative and cost-competitive technologies exist or are advancing through later stages of research and development. Most new technology does not have long-term track records, which can be seen as a risk during project finance. Generally, small hydropower technology developers cannot afford to fund applied research, development, and demonstration. More demonstration and testing of new and advance technologies are needed to build a performance record and gain industry-wide acceptance.

Due to the fact that relatively few conduit energy projects having been developed, there are few standard designs available. Typically, there are few existing standard designs to start from, and some aspects must be custom engineered, with associated high engineering costs. A custom turbine and engineering configuration will match the conditions at a site and extract an optimal amount of energy from a site, but typically the cost will be higher than a standardized turbine and system design. Typically these are small installations which cannot afford customization.

6. CASE STUDIES

The case studies presented in this section illustrate the range of conduit energy projects that have been developed to date in the United States. Additional case studies can be found in other recent publications, including those reviewed in Section 3. The case studies presented here use best available information to characterize project designs, development experience, financing, and lessons learned.

6.1 SOUTH CANAL, DELTA-MONTROSE, COLORADO

Project Design and Overview. The South Canal project (Fig. 6.1), located in southwestern Colorado and brought online in summer 2013, came about as the result of collaboration between the Delta-Montrose Electric Association (DMEA) and the Uncompahgre Valley Water Users Association (UVWUA).[36] The South Canal is part of the Uncompahgre Irrigation Project, one of several large-scale Reclamation-owned irrigation projects in the West. When the Bureau of Reclamation finished construction on the canal in 1909, engineers indicated that it had the potential to be used for hydropower. It took until 2012 for construction on two separate powerhouses to begin. At Site 1, water is diverted for one-quarter of a mile, dropping a total of 55 feet. The Site 1 generator has a 4-MW capacity. Site 3's design is identical to that of Site 1, but its generator has a 3.5-MW capacity. Site 2 was scoped but not initially developed. In total, the two sites (Site 1 and Site 3) are producing 27 million kWh of electricity per year, which is enough to power 3,000 average homes in the DMEA service territory. The power generated is consumed locally by DMEA. Vertical shaft double regulated Kaplan Turbines are installed at both sites.[37] Electricity is only produced during the seven-month-long irrigation season when there is water flow in the canal.

Fig. 6.1. Photographs of the South Canal Project. (Source: DMEA)

Enough fish swim through the canal that it was necessary, as part of the power station construction, to place electric fish gates at the canal source water entrance. These electric fish gates have been successful at keeping fish from swimming into the canal and into the turbines. One of the key public concerns was that fishing access not be lost. This problem was avoided by an agreement whereby DMEA purchased nearby land for fishing along the Uncompahgre River to substitute for areas along the canal that are now closed for recreational use.

Project Permitting and Funding. The project was permitted through a Lease of Power Privilege from the Bureau of Reclamation. The project cost $22 million, which DMEA was able to finance through a 21-year, low-interest Clean Renewable Energy Bond. Based on estimates that hydropower will provide DMEA a total of $2 million in savings every year, the loan should be paid off after about 10 years. However, DMEA has indicated that this is a conservative estimate due to likely increases in wholesale rates.

6.2 DEER ISLAND WASTEWATER TREATMENT PLANT, MASSACHUSETTS

Project Design and Overview. The Deer Island Wastewater Treatment Plant (Fig. 6.2), located outside of Boston, Massachusetts, and operated by the Massachusetts Water Resources Authority (MWRA), has installed two 1-MW hydropower Kaplan turbines at the plant's outfall.[38] Estimates put the yearly savings at $600,000 from the generators, each of which is capable of generating about 6 million kWh annually. Under Massachusetts' Renewable Portfolio Standard, this hydropower plant, along with the additional renewables in use on the island, qualifies as "green." As a result, MWRA receives approximately

Fig. 6.2. Photograph of energy improvements made on Deer Island. Includes conduit hydropower that was added to the treatment plant outfall; STG = "steam to gas." (Source: MWRA)

$500,000 in additional annual revenue. Conduit hydropower is just one part of Deer Island's efforts to offset energy costs, and in total, the facility is able to produce roughly 26% of its required electricity onsite, with about 5% of that coming from the hydropower system. Additional energy-generation projects include offshore wind turbines, photovoltaic installations, and methane recapture from digester gas. The hydropower equipment has been in operation since 2001, and it received a conduit exemption from FERC at the time of its construction.

The outfall where the generators are located carries treated and disinfected wastewater out of the treatment facility into the Massachusetts Bay, which provides an average head of approximately 29 feet. Water is separated at the base of what is known as "channel #1" into two separate "rectangular concrete conduits" that measure approximately 11 feet by 11 feet, each containing a single turbine. Each turbine can handle flows of up to 500 cfs, and the combined capacity of the two generators is enough to handle the typical maximum outflow from the treatment plant. Each turbine and corresponding system can be operated independently to adjust to available flow conditions. Electric output also varies based on tides and ocean level, which change the total head available in the outfall canal from around 13 feet to around 33 feet.

Project Permitting and Funding. The project received an initial FERC conduit exemption in 1993. In total, the original cost of construction was $36.2 million; although, this price includes some additional pieces of equipment specific to the operation of the treatment plant. Part of construction required electrical modifications at the facility's pumping station to allow for immediate use of generated electricity. Exempting these costs, the installation cost of solely the hydropower-generating materials was $7.4 million. Neither of these costs includes costs for the outfall chute where generation takes place and which was constructed at the same time. Construction of the outfall chute was required for continued facility operation even without the addition of hydropower. Original calculations estimated the payback period for the hydropower system to be around 12 years, but this estimation was based on an overly optimistic generation potential. Follow-up estimates in 2010 place the actual payback period around 25 years. Annual maintenance costs vary depending on conditions throughout the year; they totaled $134,000, $140,000, and $256,000 in 2009, 2010, and 2011, respectively. The facility was certified by the Low Impact Hydropower Institute in 2009, as all discharges from the plant, including discharges from the hydropower outfall, meet State of Massachusetts standards and have received EPA National Pollutant Discharge Elimination System permits.

Lessons Learned. MWRA's commitment to offsetting energy costs at Deer Island has helped to move the conduit project forward due to an increased familiarity with permitting and funding requirements. The plant currently generates 26% of its own electricity needs, helping to cut operation costs. In-pipe conduit projects in existing water and wastewater treatment plants can contribute to energy generation efforts without requiring significant infrastructure updates. Only a small number of plants in the United States are currently making use of this potential energy source, leaving room for large gains in generation capacity.

6.3 CITY OF BOULDER, COLORADO

Project Design and Overview. The City of Boulder ("the City") currently owns and operates a system of eight pressurized pipeline hydroelectric power stations, seven of which were constructed within the last 30 years.[39,40] The eighth project, the Boulder Canyon Hydroelectric Plant (Fig. 6.3), was built in 1910 by the Eastern Colorado Power Company for the sole purpose of hydroelectric power production. The City purchased the plant from the Public Service Company of Colorado in 2001. This plant underwent a modernization project in 2012 that should allow it to continue power production for 50 years. The City, which stores water in high-elevation mountain reservoirs, has positioned each plant where a mechanical PRV would traditionally be required to reduce water pressure before water enters the City's municipal delivery system. Three of the plants are located for delivering a raw water source to the City’s Betasso Water Treatment Plant, four are located below the plant before treated water enters the City’s delivery system, and the Boulder Canyon Plant is located at a system outfall where excess water is returned to Boulder Creek. As water travels more than 9,000 feet down to the City’s elevation of 5,430 feet, pressures may be in excess of 800 pounds psi. The hydroelectric system helps reduce these pressures to those required for municipal water delivery.

Fig. 6.3. Installation of a new runner in the modernization of the Boulder Canyon plant (left) and treated water moving through the system at the Sunshine hydro plant (right). (Source: City of Boulder, Colorado)

As of 2011, annual generation values for each of the eight plants range from about 0.390 gigawatt hours (GWh) to 18.400 GWh with a total system electrical generation of 50.700 GWh. Both Pelton and Francis turbines are used at the plants, depending on site characteristics. Pelton turbines ranging in size from 3.1 MW to 5 MW are used at the 3 plants above Betasso (where heads may be as high as 1,800 feet) as well as at the Boulder Canyon Plant. These turbines remove all residual pressure from the water and then rely on gravity flow to further transport the water, as no additional pressure is necessary when the water enters the treatment plant or is returned to the environment. Francis turbines, which allow exiting water pressure to remain higher than the Pelton turbines, are used at the four plants between Betasso and the City’s delivery system, where heads are typically between 100 feet and 800 feet and range in size from 90 kW to 800 kW. The total system average for hydraulic energy to electrical power conversion is 85%. All stations may be operated both locally and remotely to quickly adapt to changes in demand or irregular conditions. Stations are operated remotely by a supervisory control and data acquisition (SCADA) system. This system links to the local water treatment facility where operators are available 24 hours/day, seven days a week.

Table 6.1. Annual generation from each of the City of Boulder’s power plants in 2011 (Source: City of Boulder, Colorado)

Plant name	Generation in 2011 (GWh)
Maxwell Hydro	0.575
Kohler Hydro	0.754
Orodell Hydro	0.39
Sunshine Hydro	3.84
Betasso and Lakewood Hydro	18.4
Silverlake Hydro	14.8
Boulder Hydro	12

Project Permitting and Funding. All eight plants have received conduit exemptions from FERC. Capital costs for the seven City-constructed projects ranged from about $300,000 for the Maxwell Hydro Plant constructed in 1985 to about $4.43 million for the Silverlake Hydro Plant constructed in 1999. The update of the Boulder Canyon Plant cost about $5.90 million, $1.18 million of which was provided by DOE through an American Recovery and Reinvestment Act of 2009 (ARRA) grant, the remainder of which came from an existing reserve fund. The payback period for the project is estimated to be less than 20 years subject to future power purchase agreements. Electricity generated by the seven constructed plants is sold to the local utility, Xcel Energy, and the total system has generated more than $30 million for the City since the construction of the first plant in 1985. Following the recent update of the Boulder Canyon Plant, energy from the plant will be sold to the Tri-State Generation and Transmission Association. Under this five-year agreement, energy will be sold under varying rates depending on peak energy demand, with the highest payments accordingly expected in the summer months. During 2013, the eight plants together generated more than $1.96 million in revenue which helps pay for maintenance costs of the system, personnel salaries, and lowers ratepayer costs. This revenue stream from these projects is part of the reason why the system has grown throughout the years. Knowing the projects will generate consistent funds has made it easy to obtain City Council approval for updates or additions. In total, all eight projects have paid for themselves.

Lessons Learned. Project developers stress the importance of adequate preparation when developing a project or series of projects of this magnitude. Having a strong relationship with outside contractors and understanding each step in the process are important for ensuring a project progresses smoothly. Small hydropower like the City's series of stations, which work within existing infrastructure, are a good way to generate clean energy without having to undergo the more stringent permitting that comes with larger projects.

The City of Boulder system is a successful example of developing a series of projects that functions as a larger system. These larger projects help provide payback to the developer in the form of more energy and revenue production, while also engaging stakeholders regularly with the development process. This leads to more local interest in projects and provides a source for troubleshooting roadblocks to future development in the area.

6.4 LORING ROAD PROJECT, MASSACHUSETTS

Project Design and Overview. The Loring Road facility (Fig. 6.4), located in Weston Massachusetts at the Loring Road Covered Storage Facility, contains a 200-kW compact-design horizontal Francis hydropower turbine, which is used in place of a PRV.[41,42] The storage facility is part of a larger water transport system maintained by MWRA that brings water from the Quabbin Reservoir, located about 65 miles west of Boston, and the Wachusett Reservoir, located about 35 miles west of Boston. MWRA has constructed a series of holding tanks where excess water leaving these reservoirs can be stored after treatment, one of which is the Loring Road facility. At the facility, a portion of water entering from another local storage tank is passed on to high-elevation areas in MWRA's service territory. The remaining water is delivered to low-elevation areas (known as the Low-Service Area) and has a much higher water pressure than the municipal delivery system can handle. The hydropower turbine reduces that pressure to a constant useable level while also generating energy. The turbine was manufactured by James Leffel & Company out of Springfield, Ohio, and was chosen based on size and on specifications set forth by the grant funding that the project received. Construction on the hydropower facility was completed in 2010, and it was certified by the Low Impact Hydropower Institute that same year.

Flow through the turbine is kept at a constant flow rate of 31 cfs, and the turbine operates year round. Estimates put the amount of energy generated by the hydropower facility annually at 1,207,000 kWh. Energy not used onsite is sold back to the grid. Project organizers did significant research on state power purchase policies prior to applying for a PPA for the project. The relatively small size of the Loring Road facility meant it had the potential to take a backseat to other larger projects throughout the regulatory process. Having a strong awareness of exactly what PPA policies the project qualified for ahead of time meant that it was able to move through the process efficiently with no major holdups. Due to State of Massachusetts specifications, hydropower projects of this size do not qualify for net metering.

Fig. 6.4. Photographs of the Loring Road project. Shows the original water pipeline on the lower portion of the left side, and new penstock running up and over to new Francis turbine on right. (Source: M.J. Sale, Low Impact Hydropower Institute)

Project Permitting and Funding. The original cost of the project was $1.88 million; MWRA, however, was able to finance a significant portion of construction costs through $1.252 in ARRA funding and a $275,000 grant from the Mass Clean Energy Center. Remaining costs were covered through rate-payer generated funds, but use of this source was minimal. Additional grants from the Massachusetts Clean Energy Center (formerly the Massachusetts Technology Center) also helped cover costs related to design and feasibility studies. While planning for the Loring Road facility had been in place prior to the announcement of ARRA funding, project organizers were quick to take advantage of funds through this source as they became available. Having several sources of funding assistance was key to the project's success.

The large size and altitude gradient of the MWRA service area makes it an ideal location for similar small hydro projects, and beyond Loring Road and Deer Island the agency has a number of additional projects either installed or in the planning stages. MWRA project officials acknowledge that water delivery and management are always the primary function of their system, but see small hydro projects as an efficient way to offset energy costs as long as they are managed with respect to this primary goal.

Lessons Learned. Understanding how a project qualifies for different incentives and energy policies throughout the development process before starting work on the initial phases can help developers avoid some of the difficulties traditionally associated with small hydro projects. Some of what makes a project successful is simply timing, but Loring Road project developers also advocate reaching out to local resources and taking advantage of anyone who has prior hydropower development or energy policy experience.

6.5 TOWN OF BASALT, COLORADO

Project Design and Overview. The Town of Basalt ("the Town") is a small mountain community located between Carbondale and Aspen.[43] Basalt began looking into its hydro potential due to its environmentally conscious citizenry with a long-standing desire to develop the area's rich hydro potential. Basalt's Green Team, a committee of residents and elected officials, started exploring the idea of small hydro, eventually leading to the decision to install a small hydropower project utilizing flow from two nearby springs being piped down to the town's water treatment plant (Fig. 6.5).

Fig. 6.5. Turbine in use at Town of Basalt facility. (Source: Colorado Energy Office)

The project has a generating capacity of 40kW, generating an estimated 300,000 kWh annually at full capacity. The project utilizes water from two springs—Basalt Springs and Luchsinger Springs—and does not affect any stream flow. Through pipeline improvements, including slip-lining, valving, and installations of ductile iron piping, the springs provide the needed flow for a small hydro project totaling approximately 2.0 cfs. The piping provides approximately 345 feet of head, yielding net pressure at the turbine of 140 to 160 psi. Based on the head and flow, a constant flow variable speed generator was selected. The project construction timeline was approximately one year.

Two different factors drove decisions regarding the siting of the project: a desire to minimize the visual impact of the structure and powerhouse placement to ensure maximum generating capacity. The expected lifetime of the powerhouse building is 100 years and 20 years for the mechanical equipment and controls equipment.

The Town enlisted the assistance of an outside consulting firm with experience in the design and development of similar projects. The manufacturer of the turbine, generator, and controls for the project was Canyon Hydro.

The Town installed equipment at the powerhouse to provide warning notification of problems. Project monitoring is tied into some of the same monitoring equipment as is used for the water filtration plant.

Project Permitting and Funding. The hydro project cost was approximately $207,000 which included ancillary work. This cost does not include pipeline work to accommodate the pressures necessary to support the hydropower plant, although the pipeline work would probably need to have been done anyway related to the Town's water supply needs. The total cost of the project—including both the pipeline work (much of which was necessary regardless of hydro generation) as well as the hydro equipment—was approximately $394,000. Financing for the project was provided by Holy Cross Energy and the Colorado Energy Office.

The Colorado Energy Office supplied the project with $119,000 in ARRA (federal stimulus) grant funds. Holy Cross agreed to finance up to $300,000, which was scheduled to be repaid through the electrical generation of the plant, estimated at 6,000,000 kWh (for a Holy Cross Energy loan of $300,000). Electricity generated by the project is being used to pay down what is effectively a no-interest loan provided by Holy Cross Energy. By having Holy Cross supply the needed money for the project's upfront construction costs, the Town avoided taking out a loan, avoiding years of loan interest payments, ultimately saving approximately $60,000 in interest payments (assuming a 20 year loan at 2%). The project's generated electricity will be provided to Holy Cross until the initial $300,000 is paid off, after which point the Town will retain the revenue from electricity generated by the project.

The expected payback period involved several varying factors, including annual operations and maintenance costs of approximately $1500 annually. At maximum production, the plant is expected to generate 300,000 kilowatt hours annually. At a power purchase rate of $.08 per kilowatt hour, revenue is approximately $24,000 per year, yielding a payback of about 11.4 years—a best-case scenario based upon maximum annual generation. The Town anticipates that the actual payback period may be closer 20 years based upon annual generation of 175,000 kWh.

Lessons Learned: Perhaps the most important part of the success of the project was the Town's partnership with Holy Cross Energy, without whose assistance the Town probably could not have completed the project. The role of Holy Cross Energy underscores the importance of effective partnerships to project success. The biggest challenge to the project has been related to water rights, which have inhibited the project from operating at full capacity, yielding the reduced annual estimated generation of 175,000 kWh. The Town is pursuing additional water rights.

6.6 LUCID ENERGY, VARIOUS LOCATIONS: CALIFORNIA, OREGON, TEXAS

Project Design and Overview. Lucid Energy ("Lucid") was formed in 2007 with the goal of increasing the use of water pipeline infrastructure as an energy source.[44,45] In 2008, the company formed a partnership with the Northwest Pipe Company, which is the largest manufacturer of steel water transmission pipe in the United States. Lucid turbines are installed in the pipe to create the LucidPipe technology, which then replaces existing pipe in a water delivery system. In 2009, DOE awarded Lucid a Small Business Innovation Research grant totaling $1 million for the development and field testing of its LucidPipe technology. After installation in existing water pipelines (Fig. 6.6), LucidPipe turbines are powered by the energy of water moving through the pipe system. If the pipe is flowing at capacity immediately upstream of the turbines, they function as conventional (head-based) turbines. After installation, the turbine can be used without disrupting existing operations. The LucidPipe turbine is designed to operate in 24–96 inch diameter pipes that are designed for large-scale municipal or agricultural uses. Each LucidPipe turbine retails for $150,000 and has an individual capacity of 50 kW. A number of turbines are typically used in sequence to form a system in a single pipe.

Fig. 6.6. Installation of a Lucid Pipe system (left) and internal view of runner (right). (Source: Lucid Energy Systems)

Lucid systems have been installed in municipalities in cities across the United States, including Riverside, California; Portland, Oregon; and San Antonio, Texas. The Riverside project, which was installed in early 2012, is the first commercial-scale use of the LucidPipe system. The project uses a 4-turbine system installed in a 42-inch diameter pipeline and generated more than 8,000 kWh in the first four months after installation.

The Portland pilot-scale project was approved in fall 2013 and will involve the installation of a 172 kW four-turbine system, which is expected to generate 1,000 MWh of energy annually—enough energy to power up to 150 homes. The project is funded primarily by private investment, and the Portland Water Bureau will share in the revenue that is estimated at $55,000 in the first year. Lucid continues to move forward on additional projects and has recently reported securing new funds from private investors in fall 2013.

Lessons Learned. Lucid has been able to take advantage of available DOE funding to fill a technology gap in hydropower generation. As municipalities look for ways to both offset energy costs and update older infrastructure, in-pipe hydropower generation may become more prominent. This growing role for conduit hydropower is supported by the early successes of pilot projects across the country.

6.7 INSTREAM ENERGY SYSTEMS, ROZA CANAL, WASHINGTON

Project Design and Overview. In the State of Washington near the town of Yakima, the Bureau of Reclamation owns and operates the Roza Canal, which delivers more than 136,000 AF of water annually to farmland in the region.[46,47] The canal also provides optimal conditions as a test site for no-head, hydrokinetic water power technologies. These optimal conditions include the canal's fast water flow (concerte-lined), accessible location for vehicles and other equipment, proximity to a local load (within a half mile) and nearby transmission lines, and water flow occurring a high percentage of the year.

The canal has a trapezoidal shape with a 14-ft width at the bottom, 11-ft depth, and 1.5 to 1.0 side ratio. Water flows through the canal for 11 months of the year with the “power-generation window” running from primarily from March to September. During the period of operation, the maximum flow is 2,100 cfs, with a speed of 6.9 feet per second.

In 2013, Instream Energy Systems (“Instream Energy”) began testing hydrokinetic power-generating units directly in the existing open-channel system without construction of additional diversions. In August 2013, Instream deployed a single hydrokinetic turbine in Roza Canal with a nameplate capacity of 25 kW.

Instream Energy has worked with BAE Systems on the design of a turbine that is low cost, modular, and scalable to capture the energy of moving water in manmade structures. There is growing international interest in developing distributed energy as a secondary purpose of existing facilities used for conventional hydropower, water supply, and flood control. This approach is intended to minimize the environmental impact of new energy sources.

Instream Energy kicked off their 2-1/2-year pilot project evaluating BAE Systems rotor and generation system and its impacts on the hydrokinetics of the canal. Roza Canal was chosen because it is similar to many irrigation canals, is easier to work in than rivers and tidal bodies, and it operates for a greater part of the year than many irrigation canals. Continued research is showing that many canals do operate most of the year and would provide more energy generated than the Roza Canal application. The Instream Energy testing program could be expanded to multiple turbine systems deployed using additional spanning structures that extend over the Roza Canal. The 2013 installation initiated Phase One of the testing, characterizing the performance of a single turbine (Fig. 6.7). Phase Two is now underway and is focused on assessing impacts to existing operations. The scope of Phase Three is to be determined but may include the use of multiple hydrokinetic units in groupings or arrays.

Fig. 6.7. Photographs of the 2013 installation of the spanning beam on the Roza Canal for hydrokinetic testing (left) and the fully deployed, 25 kW Instream Energy hydrokinetic turbine, with the canal running full (right). In this deployment, the spanning beam is structurally independent of the canal. (**Source: Instream Energy Systems)**

Technology. The vertical axis hydrokinetic turbine has “egg beater”-style turbine blades designed to operate at zero head and low flow velocities of 5–10 feet per second. The minimum canal requirements are 7 ft of depth and bottom width of 13 ft. The turbine is mounted on a rotating spanning beam that is structurally independent of the canal and designed to maintain operational submergence as the water level of the canal changes and to lift the turbine out of the water during canal maintenance or when water levels drop below minimum operating levels.

Permitting and Partnership. The passage of US HB 678 (113th Congress), Bureau of Reclamation Small Conduit Hydropower Development and Rural Jobs Act, has further facilitated a cooperative relationship between USBR and Instream Energy in the development of this pilot study.[48] Likewise, Sandia National Laboratory is collaborating with Reclamation and Instream Energy to characterize the effect of hydrokinetic turbine operation on the Roza Canal flow regimes using field measurements and numerical modeling. It is known that the turbine slows water in the vicinity of the turbine blades, but water that goes around the turbine speeds up slightly, and that the flow of water returns to initial conditions shortly downstream of the turbine. Additionally, large-enough turbine arrays may raise the water level slightly upstream of the turbine. The Sandia study is intended to extrapolate conditions such as water level and flow from one turbine to an array of similar turbines and begin to understand the impacts of widely deployed hydrokinetic turbines on water ways.[49]

Lessons Learned. Instream Energy has taken advantage of R&D funding from DOE, water resource planning, and engineering partnerships with Reclamation and SNL to help with project design and siting. The project also highlights its ability to use existing infrastructure in a low-impact environmentally sustainable manner without interrupting existing water deliveries.

6.8 BARTON RANCH PROJECT, UTAH

Project Design and Overview. Roger and Shelley Barton own and operate Barton Farm in Ferron, Utah.[50] The Bartons farm 120 acres of alfalfa and mixed grasses used for horse hay. They irrigate with a center-pivot irrigation system. Diesel fuel is a large expense in operating a center pivot. The Bartons needed to reduce fuel costs and still follow their irrigation schedule.

The Barton's hay fields are located a half-mile from the nearest overhead power line. After considering the cost to have single-phase power run to the field, the Barton's selected a T-L diesel-powered hydraulic center-pivot irrigation system and had it installed in 1998. This T-L hydraulic center pivot is powered by a diesel motor and uses gravity flow to pressurize the irrigation system. A small, direct current (DC) alternator operates the control panel. At the time the irrigation system was installed, the national average cost for diesel hovered at around $1 a gallon. In 2008, the Bartons paid $4.25 a gallon. Fuel costs for the irrigation system were about $4,000 a year and rising.

The Bartons met with Ken Gardner, a civil engineer and hydropower specialist with Gardner Engineering, to consider alternative energy options to power their system. They determined that the irrigation system required only about 53 percent of the available water pressure. The additional pressure could be used to power the turbine. The Bartons could keep their existing irrigation system and reduce their fuel costs to zero.

Technology. The combination of a hydraulic center pivot and hydro turbine are generally a good match when available pressure exceeds the requirements of the irrigation system by 40 psi or more. The Bartons receive irrigation water by gravity feed from a reservoir several miles away, which provided 80 psi of operating pressure at the pivot point, 37 psi more than required to operate 1,220 feet of pivot and the end gun. The T-L hydraulic pivot installed at the Bartons requires 15 horsepower (HP) to operate correctly.

The Bartons hired Redmond Irrigation in Redmond, Utah, to design and install the system (Fig. 6.8). A Cornell turbine from Centex Fluid Products was selected. Centex designs and sells custom hydro turbines, made by Cornell Pump Company, that work with a range of heads, flows, and pressures. The basic method of sizing this system included assessing the flow (the volume of water passing through the pipe), determining the residual (additional) pressure available, calculating any pipe or other head and flow losses, and evaluating the technical requirements of the irrigation system. These data were provided to Centex to design the turbine.

Fig. 6.8. Photos of the hydromechanical system that was developed at the Barton Ranch in Utah. (Source: Roger Barton)

The Cornell hydro turbine was coupled with the T-L variable-displacement hydraulic pump using a belt drive. The system is monitored by the T-L control system. A filter was installed before the turbine to remove sand, gravel, and other water debris that can damage the turbine impeller. Auto valves with a trip switch automatically shut down flow to the turbine if there is a problem in the system. An integrated 12-volt alternator provides the DC voltage required by the control panel.

The cost for design, equipment and installation of this system was $17,000. The Bartons received a $4,000 cost share under the NRCS Conservation Innovation Grant program. The estimated simple payback on the hydro turbine system is 2.5–3 years. In Utah, NRCS is currently offering a 65% cost share for this type of system under the Environmental Quality Incentives Program (EQIP). The specifications for the Barton Ranch system were the following:

- Hydro resource: Gravity flow from reservoir
- Total pressure: 80 psi
- Additional pressure: 37 psi
- Head: 162 ft
- Flow: 888 gallons/minute
- Irrigation system: T-L hydrostatic center pivot
- Hydro turbine: Cornell Turbine (5TR5-F16)
- Runner type: Francis
- Pipe: 10-inch steel with compression fittings
- Total system cost: $17,000 (before cost share)
- Incentives: $4,000
- Cost savings estimate: $4,000 annually.

Lessons Learned. Roger Barton has eliminated all irrigation fuel costs by integrating a hydro turbine into his existing center pivot. One disadvantage that was discovered is that water must be running through the turbine to move the pivot. The T-L hydraulic pivot continuously “walks” as long as the turbine is operating. If the system is crossing ground that is not to be irrigated, then it may be necessary to install a backup diesel motor in addition to the hydraulic system. Re-nozzling of the pivot may also be necessary to compensate for the reduction in pressure throughout the system.

6.9 BEAR RIVER RANCH HYDROMECHANICAL PROJECT, COLORADO

Project Design and Overview. The Natural Resource Conservation Service (NRCS) encourages water conservation by supporting the conversion of flood irrigation to sprinklers and also supports renewable energy for on-farm applications. By working with the NRCS for project design and financial assistance, Bear River Ranch was able to achieve both NRCS goals.[51] A center pivot sprinkler was chosen as the water conservation measure, which uses significantly less water than the previous method of flood irrigation. A hydro-mechanical system was installed to eliminate the energy required to power the center pivot.

Technology. The photograph below (Fig. 6.9) shows the key components of the system: a turbine that powers the hydraulic pump through use of a connecting belt, and water supply lines to power the turbine and provide water to the sprinklers. A single, supply pipeline originates from a settling pond at a point 150 feet higher in elevation. This elevation difference pressurizes the water in the pipeline. Just before reaching the center pivot, the pipeline splits into two smaller supply pipes, and the pressurized water powers the turbine and supplies the sprinklers. The turbine is attached to a shaft that drives a belt connected to the hydraulic pump. The hydraulic pump powers the drive system that moves the center pivot wheels and turns the sprinkler system.

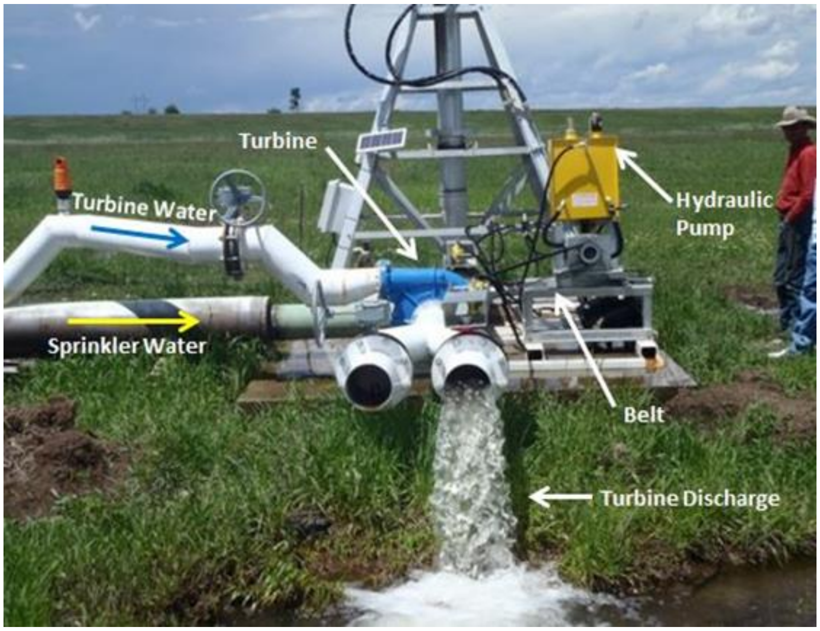


Fig. 6.9. Hydromechanical system used to drive an irrigation system at the Bear River Ranch. (Source: Colorado Energy Office, 2013)

The Bear River Ranch turbine produces an equivalent of 5.2 kW or 7 HP to power the hydraulic pump on the center pivot sprinkler system. The hydraulic pump powers the drive system that turns the sprinkler, and the sprinkler is pressurized through gravity. No pumps, motors, or electrical connections are required, resulting in very low annual operational expenses and minimal maintenance.

The center pivot is operated only during irrigation season, with operation dictated by the crop's water demand. A T-L Irrigation hydrostatic center pivot with manual speed control was selected for the sprinkler system, and a Cornell Pump (5TR5) was selected as the turbine. Cornell pumps are easily obtainable due to their dual purpose. Most pumps can be used for both pumping and as a turbine without any modification.

Construction of the hydro-mechanical system was a fast and simple process, spanning only one non-irrigation season. The center pivot distributor, B&B Irrigation, consulted with Jordan Whittaker of Two Dot Irrigation to select the turbine and design the connection. Because the turbine and hydraulic pump are belted together, their power outputs are essentially equivalent. As such, the turbine was sized to provide 7 HP or 5.2 kW, which corresponds to the power needed for proper operation of the hydraulic pump. The turbine uses a flow of 560 gpm at the available 126 feet of working head to provide the 7 HP to the hydraulic pump.

Maintenance of the system is very simple. The turbine will need to be maintained as a pump would, with occasional bearing greasing. The center pivot machinery and turbine are generally given a useful lifetime of 20 years, although with proper operation and maintenance, they can last much longer. Premature wear due to debris and sediment in the water is possible and could reduce the expected lifespan of the turbine. Therefore, care must be taken to adequately filter the water prior to its entry into the system.

NRCS supported the project in both the design of the irrigation system and partial funding of the entire project through the Environmental Quality Incentives Program (EQIP) program. EQIP provides financial and technical assistance to farmers and ranchers for the planning and implementation of natural resource conservation efforts. During 2011, EQIP allocated more than $26 million for nearly 800 projects in Colorado. For Bear River Ranch, the NRCS grant lowered installation costs enough to make NRCS the only outside source of funding needed.

Permitting. Because the project is not on a navigable waterway and does not produce electricity, it is not regulated by the Federal Energy Regulatory Commission.

Lessons Learned. The only cost incurred that varied from that of a traditional, electricity-driven center pivot is that of the turbine; the center pivot sprinkler and pipeline costs were equivalent to traditional, center pivot installations. The purchase of the turbine amounted to $13,000. Of this, the NRCS contributed $6,000, making the out-of-pocket expense for the system $7,000. The system saves estimated annual energy costs of approximately $2,100. Power to spin to the center pivot could alternatively have been obtained through either a diesel generator or grid interconnection if Bear River Ranch had opted for a traditional center pivot irrigation system, but this would result in annual fuel/electricity expenses. If electricity had been extended to the center pivot location, it would have cost $22,000. Center pivot systems using diesel or electricity would have higher installation costs and would have resulted in higher annual expenses. With the hydro-mechanical system, the initial investment by the ranch of $7,000 will be recaptured in 3.3 years of energy savings, a success which can potentially be replicated at additional agricultural sites across the country.

7. RECOMMENDATIONS FOR FUTURE WORK

There are several actions that could improve the prospects for future development of hydropower projects in water conduits, including applied research, policy analysis, and technology development and testing. Additional research needs related to small hydropower development, including conduit projects, can be found in the Small Hydropower Technology Summit report sponsored by DOE.[52] Although the report was published in 2010, its findings and recommendations are still relevant.

7.1 APPLIED RESEARCH AND DEVELOPMENT

Three new areas of applied research needed to better understand opportunities for energy development in water conduits are the following:

- A comprehensive, nationwide assessment of undeveloped energy resources in both open-channel and pipeline conduits, conducted in partnership with industry organizations such as the American Water Works Association and irrigation engineering societies
- Improved site-specific feasibility analysis tools that are appropriate for small developers to estimate the effects of new conduit projects on existing water distribution characteristics (e.g., water pressures throughout a piped distribution system or timing of downstream flows); these tools should be made publicly available and should include access to the best available, most current economic data
- Continued development of more cost-competitive technologies and site development strategies for small hydropower in water conduits, both for conventional hydropower and hydrokinetic equipment.

7.2 POLICY ANALYSIS AND INFORMATION EXCHANGE

Four types of policy analysis would greatly improve understanding of the challenges that developers face and how they may be overcome.

- Investigation of ways in which existing Federal and state financial incentive programs could be designed to better fit the needs and capabilities of smaller projects and to equalize the treatment of small hydropower relative to other renewable energy sources;[73,74]
- Identification of ways to further streamline the regulatory processes at state and Federal levels, including tracking of the success, or lack thereof, of these efforts; this should define types of non-controversial, low-impact conduit projects that can be built within existing infrastructure and implement procedures to exclude these from Federal jurisdiction under the Federal Power Act; where regulatory improvement efforts are not successful, studies should be conducted to identify the remaining obstacles to new development and to find more effective solutions;
- Investigation of innovative market structures and policies, addressing potential new drivers such as offtake pricing and purchasing, a possible surcharge for conduit energy to be paid at the utility level nationally, or renewable energy offsets for federal agencies; and
- Support for development of standardized, simple interconnection rules and new, hydropower-specific electrical codes that are approved by the Institute of Electrical and Electronics Engineers for inclusion in future updates of the National Electrical Code.

In addition to policy analysis, there is a more general need to provide better and more accessible information about the real risks associated with conduit projects and how those risks can be managed.

Lack of acceptance of small hydropower projects in water conduit remains a significant barrier at the state and local regulatory levels.

7.3 TECHNOLODY DEMONSTRATIONS AND TESTING

Although DOE and Reclamation have been funding some technology development on small hydropower and hydrokinetic devices in recent years, more such work is needed to reduce the uncertainties associated with precommercial designs. These would include the following:

- A continuation and expansion of technology demonstration and testing of new conduit projects, especially for newer, more innovative and cost-competitive technologies, including hydrokinetic technologies; establishing one or more test sites for new technologies that would be pre-permitted/licensed and have power off-takes or surrogate loads would be very useful to new technology developers.
- Conduct more technology development, demonstration, and full-scale testing to reduce uncertainties in costs and performance of new designs, specifically for small conduit applications.

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