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Wyoming Small Hydropower Handbook





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WYOMING SMALL HYDROPOWER HANDBOOK

Prepared for:

UNIVERSITY OF WYOMING

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Authors' Note

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This guide provides water users, such as irrigators and municipal water users, a detailed understanding of hydropower. The handbook identifies the tools and procedures necessary to complete a preliminary site assessment, initiate the permitting and licensing requirements, and locate potential funding opportunities. This guide can be used to assess whether a full feasibility study is warranted. The flow chart in Figure 1 provides a general understanding of the process of hydropower development. A glossary of terms is available at the end of the document.

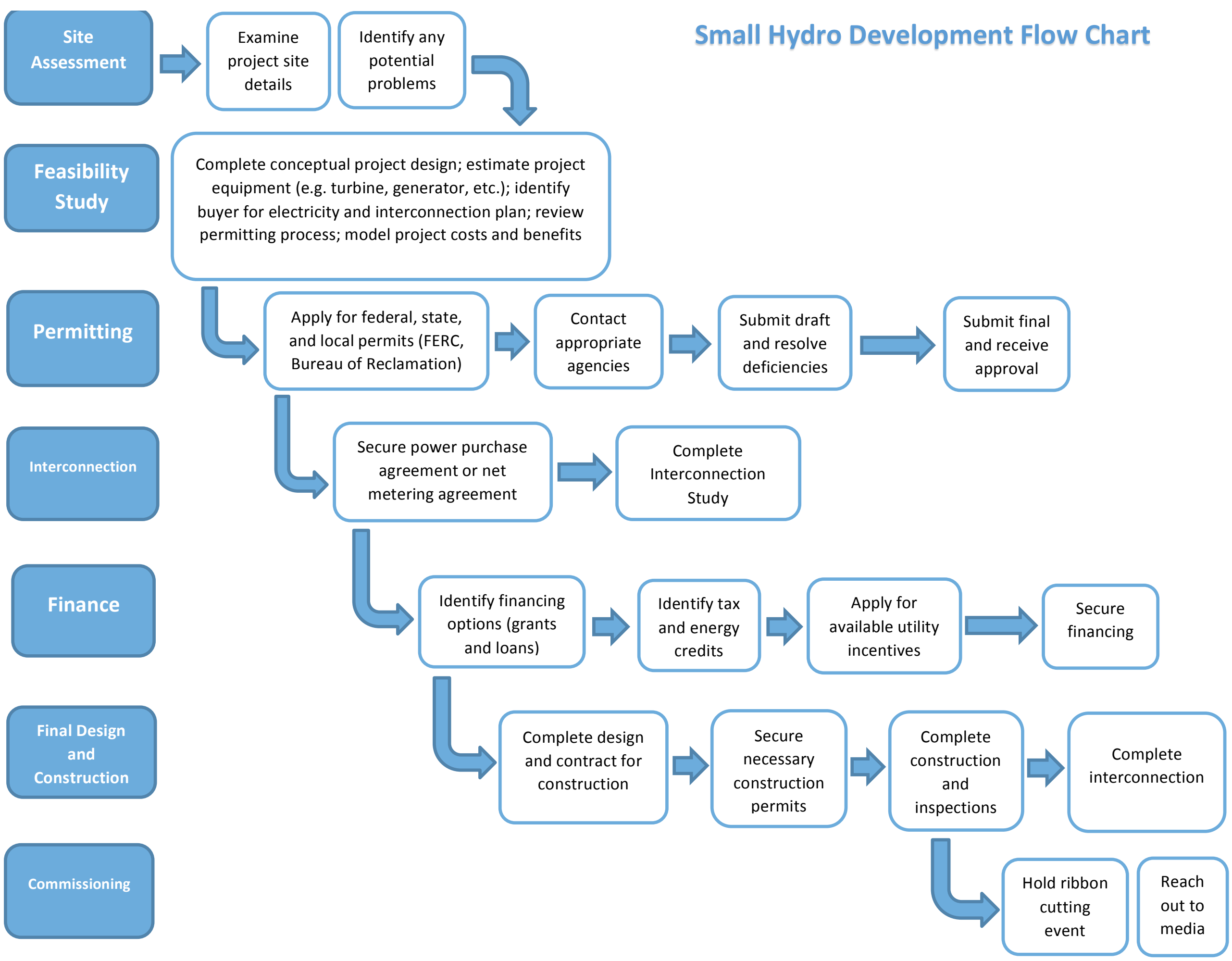

Figure 1: Small Hydro Development Flow Chart

Source: Colorado Energy Office "Small Hydropower Handbook"

HYDROPOWER BASICS

Hydropower systems, also known as hydroelectric power, harness the energy of flowing water to produce electric or mechanical energy. Hydroelectric installations are the most common and often least expensive sources of renewable electricity in the United States today. According to the Department of Energy, Energy Information Administration, in 2013 more than 6 percent of the country's electricity was produced from hydropower resources and nearly 52 percent of all renewable electricity generated in the United States comes from hydropower resources, mostly at large dams. Hydropower, especially large-scale hydropower, is valued for its reliability, with many facilities operating for over 100 years, and low-cost provision of base load electricity. Although few, if any, new large dams are under consideration in Wyoming, the opportunity for installing small hydropower is now more feasible with recent changes in federal policy.

What is Small Hydropower?

While the definition of "small hydropower" varies, this handbook considers a facility that has a generating capacity up to five Megawatts (MW) to be a small hydropower facility. Although termed "small," small hydropower can generate significant quantities of electricity, which is often sold into utility power markets. For example, a one MW system operating year-round can produce enough electricity for nearly 850 standard Wyoming homes. New small hydropower is also considered to have a low environmental impact and typically utilizes existing facilities, such as already-constructed dams, irrigation canals, and pipelines. According to the Low Impact Hydropower Institute[i], a hydropower facility is deemed low impact when multiple ecosystem qualities are protected, including river flows, water quality, fish and wildlife, and other environmental indicators of a healthy ecosystem around hydropower facilities, as well as meeting recreational and cultural preservation needs.

Micro-hydropower

Micro-hydropower is a smaller class of hydropower. Micro-hydropower systems are small hydroelectric power systems of less than 100 kW used to produce mechanical energy or electricity for farms, ranches, and homes and are often designed to offset personal consumption. Micro-hydropower systems range in size and can be as small as a few watts. In Wyoming, micro-hydropower systems are typically non-commercial installations less than 25 kW due to net metering agreements (explained in later sections) for grid-tied systems.

How Hydropower Works

Water power is the product of head (vertical drop) and flow. In a typical small hydropower system, water is diverted from a channel into a pipeline or penstock and conveyed downhill to a turbine; this constitutes the flow portion of hydropower. Flow is the volumetric quantity of available water, often expressed in cubic feet per second (cfs) or gallons per minute (gpm). The vertical drop creates pressure at the bottom of the pipeline creating the force that drives the turbine; this constitutes the head portion of hydropower. Head is water pressure created by the difference in elevation between the intake and turbine and is expressed as vertical drop, often expressed in feet, or as pressure, such as pounds per square inch (psi). Head and flow are the two most important components to hydropower generation. A detailed description on how to measure head and flow is described in later sections of this guide.

Wyoming's Hydropower Potential

In 2012, Wyoming had 16 operating hydropower facilities with a combined installed capacity of 303 megawatts, producing approximately 800,000 megawatt-hours (MWh) of electricity annually. This amounts to 2 percent of all electricity generated in Wyoming. Existing hydropower plants range in size from 12 kW to 66.8 MW.[ii]

There is significant potential for additional small hydropower generation in Wyoming. In 2011, the United States Department of the Interior, Bureau of Reclamation, Power Resources Office conducted an extensive nationwide assessment of hydropower resources at existing U.S. Bureau of Reclamation (Reclamation) facilities[iii]. This resource assessment evaluated the feasibility of additional hydropower development at existing Reclamation facilities. The assessment was targeted towards water users and private developers that could further evaluate the potential to increase hydropower production at Reclamation sites. The study identified 17 potential hydropower sites in Wyoming that included reservoir dams, diversion dams, and canals with a potential to generate 47,187 MWh of electricity annually at existing Reclamation facilities. Of the 17 potential sites, three had a benefit-to-cost ratio greater than 1.0, indicating a potentially cost-effective location for hydropower development. These three sites are listed in the table below.

Table 1: Potential Bureau of Reclamation Hydropower Sites with Benefit-to-Cost Ratios Greater than 1.0

Facility Name	Installed Capacity (kW)	Annual Production (MWh)	Benefit-to-cost Ratio
Willwood Diversion Dam	1,062	6,337	1.1
Gray Reef Dam	2,067	13,059	1.58
Pathfinder Dam	743	5,508	1.23

In 2012, Reclamation conducted an additional study to supplement the 2011 study.[iv] The 2011 study did not fully capture the hydropower potential of all Reclamation conduits. The supplemental assessment report builds off of the 2011 study and identifies potential hydropower sites on Reclamation -owned conduits and determined those sites' capacity and energy potential. The majority of sites identified are at drops on irrigation canals. Due to the seasonal flows in irrigation canals, and limitations in Reclamation's assessment tool, the supplemental assessment report focused on identifying the technical potential of hydropower development based on each site's available head, flow, and proximity to electrical transmission lines, but does not provide an economic benefit-to-cost analysis. The report identified capacity and generation potential, as well as site maps, the number of months of potential generation for each site, and their proximity to electrical transmission or distribution lines. Sites were identified in 13 western states, and Wyoming had the most identified sites. The study identified 121 canal sites in Wyoming with a potential installed capacity of 23,460 kW and annual energy generation of 82,548 MWh. Between the two Reclamation studies, Wyoming's untapped hydropower potential at Reclamation facilities is over 129,000 MWh. If Wyoming were to utilize this full potential, the new development could supply enough energy to support the average electricity consumption of over 12,000 homes.[v]

Another report by the Idaho National Engineering and Environmental Laboratory for the U.S. Department of Energy, Energy Efficiency and Renewable Energy Office in 2004 assessed the water energy resources of stream reaches throughout the United States.[vi] The principal focus of the study was on low-head (less than 30 feet)/low power (less than 1 MW) resources. The assessments were made by estimating the power potential of all the stream segments in a region, which averaged 2 miles in length. Figure 2 shows the results of this study for Wyoming.

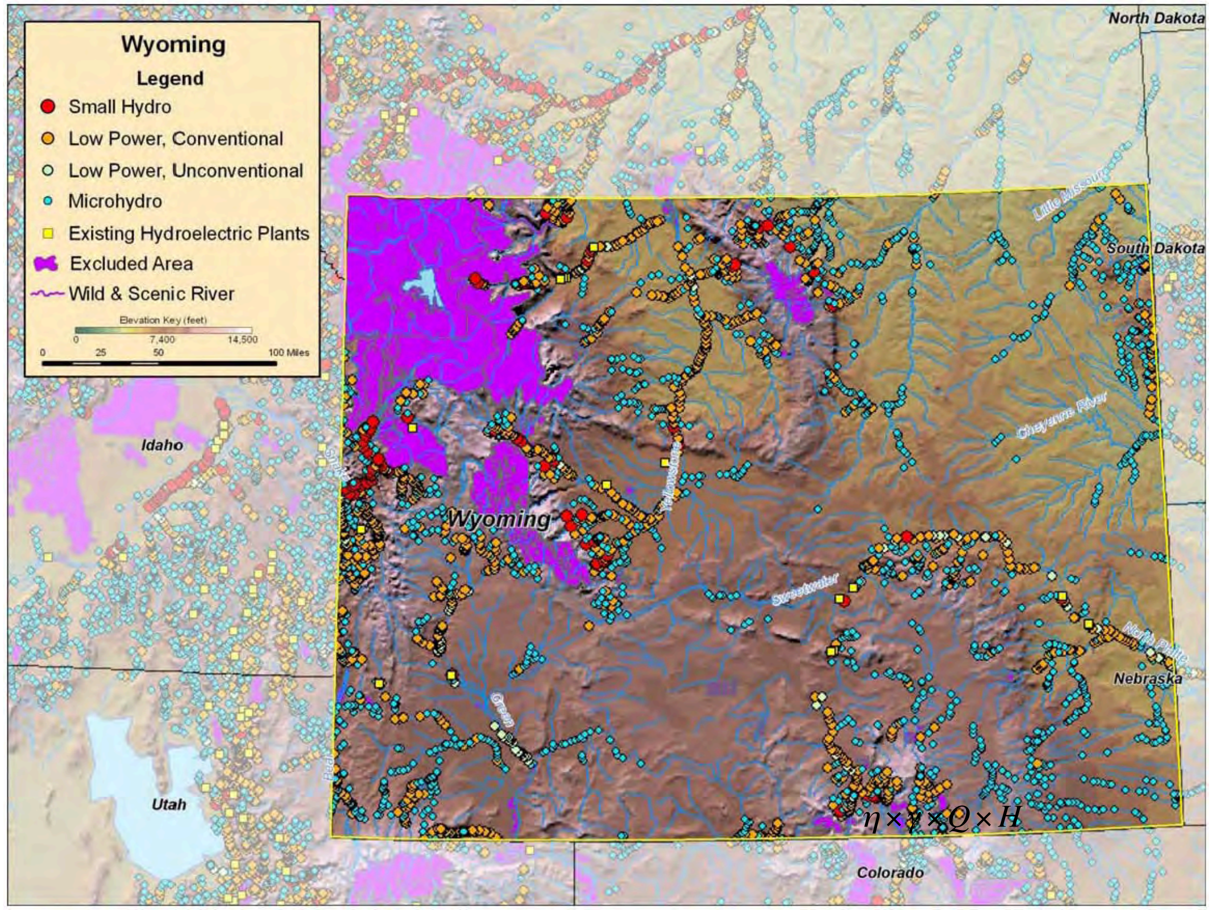

Figure 2: Small Hydro Feasible Projects and Existing Hydroelectric Plants in Wyoming
Source: U.S. Department of Energy. Water Energy Resources of the United States with Emphasis on Low Head/ Low Power Resources. April, 2004.

The total available power potential was subdivided into small hydro (one MW or more), low power conventional (less than one MW and heads greater than 8 feet), low power, unconventional (less than one MW and heads less than e8 feet), and micro-hydro (less than 100 kW). This study concluded Wyoming had 2,840 potentially feasible small hydropower projects with 507 MW of potential capacity. Sixty-five percent were classified as micro-hydro projects. Between these three studies, Wyoming's estimated untapped hydropower potential is over 540 MW of generation capacity. The assessment considers technical feasibility, thus the amount of truly viable new development is much lower.

There is potential for hydropower development on municipal water systems, non-federal irrigation districts, and private dams, in addition to the potential sites identified in these three studies. The power potential from these types of installations has not been quantified, but several examples of these types of installations are described in the following sections.

EVALUATING RESOURCES

Site Assessment

When evaluating a potential site for hydropower development a preliminary site assessment should be completed to determine if further investigation is warranted. The most important consideration is the head and flow conditions. Still, the assessment is broader than the mere existence of a resource; it should include site location, ownership, access, preliminary estimate of head and flow, location of utility connection, water rights, and political or environmental concerns.

Site Location, Ownership, and Access

Ownership and control of the small hydropower development site, and surrounding areas potentially affected through development, is a vital component of site assessment. A developer must have legal access to either a private or public hydropower resource to even proceed with a full assessment. Consideration should be made to ownership and property rights of the intake, pipeline, and outlet as well since these components could be on separate properties. If some components to the facility are existing, such as a dam or pipeline, previous ownership (if applicable) could be helpful to determine what rehabilitation or alterations have been made and may be able to provide as-built drawings of the facility.

Site access, for both construction and maintenance, must be secured. The use of existing roads, especially private and service roads, needs to be confirmed for all components of the system, including intake, penstock, and powerhouse. The access may also need to accommodate the passage of heavy construction equipment. If there is no suitable access, estimating road construction and maintenance costs will need to be part of the assessment.

Estimated Head and Flow

Head and flow are the two most important factors in a site assessment. A preliminary estimate of head and flow provides an estimate of the power generation capacity at the site. Head and flow also determines engineering parameters, including pipeline size, turbine type and size, rotational speed, generator size and output, and even rough cost estimates. Accuracy of head and flow measurements are critical to determining final feasibility; however, at an early stage of development head and flow can be estimated. Determining head at a site requires the measurement of the elevation difference between the intake and water turbine. For a basic, early assessment, this can be measured with a hand-held Global Position Satellite (GPS) unit, approximated from U.S. Geologic Survey (USGS) topographic maps, or even a mapping service such as Google Earth. Flow can be estimated from historic measurements or stream gauges. Measuring head and flow is discussed in more detail in later sections of this guide. Once the head and flow are estimated, the capacity of a hydropower plant can be estimated by the power formula[vii]:

$$P = \frac{\eta \times \gamma \times Q \times H}{737}$$

Where P = generator power production in kW

η = overall plant efficiency

γ = pecific weight of water, 62.4 lb/ft^3

Q = turbine discharge in ft^3/sec

H = net head in feet

The overall plant efficiency varies between turbine type and system designs; a site-specific turbine performance curve should be used when determining the efficiency under different loads. More accurate efficiency assessments are possible after the plant configuration is finalized and turbine selected; however, for a preliminary estimate, the efficiency can be assumed to be 80 percent. The power formula is then reduced to:

$$\text{Power (kW)} = \text{Head (feet)} \times \text{Flow (cfs)} \times 0.068$$

Location of Suitable Utility Connection

The distance to and types of utility connections is also a vital piece of the site assessment. Electricity generated by the project needs to be delivered to an electric load, either on-site, such as a house or irrigation motor, or through the local grid using electrical switchgear and step-up transformers. The distance to the nearest utility distribution or transmission line, and what type of line it is (e.g., single phase or three phase), must also be determined. If the hydropower site is remote, installing new distribution lines can add significant costs to the project. It may also be cost prohibitive if existing nearby distribution lines need to be upgraded to handle the additional capacity.

In rare applications, hydropower facilities can operate without connecting to the grid and only serve an adjacent on-site electric load. This method is often referred to as a stand-alone, or island, system. Hydropower turbines have difficulty reacting quickly to a sudden change in electric demand without the use of expensive electrical storage equipment (called balance-of-system) and is the reason island generation facilities are uncommon. Balance-of-system equipment is used to condition the electricity, safely transmit the electricity to the load that will use it, and/or store the electricity for future use. This equipment usually includes batteries, charge controller, power conditioning equipment, safety equipment and meters and instrumentation, and depending on the needs of the system, can account for half of the total system costs.

Water Rights

Wyoming water law is based on the "doctrine of prior appropriation." The first person to put the water to beneficial use has the first right, and is often referred to as "first in time, first in right." All water in Wyoming is property of the state and the right to use the water is regulated by priority. A permit is required to use water. Water rights are obtained by applying to the Wyoming State Engineer's Office and obtaining a permit for a specified amount, location, and use. Any water right must be for a beneficial use, which is the overt act of diverting water from a water source and applying it to a specified purpose. Common beneficial uses include irrigation, domestic, municipal, industrial, and power generation. The most senior water right holders (those obtained at the earliest date) are entitled to water prior to junior water right holders, independent of their location along the river. For example, if a junior water right holder is upstream of a senior water right holder, the water must pass the point of diversion of the junior water right to satisfy the senior right if there is not sufficient water to satisfy both needs. Although water rights can be much more complicated than this basic scenario, generally, the more senior a water right, the more certainty there will be water available for use in years of low water supply.

Power generation is generally considered a non-consumptive use, since the same quantity of water diverted is returned to the river. There may be an exemption if a reservoir is constructed to store water or a new canal is constructed to convey water to the hydropower plant, as evaporation may consume a portion of the water. However, since this guide is geared toward low-impact hydropower facilities installing the hydropower plant at existing facilities is assumed.

The Wyoming Water Development Commission also holds in-stream flow water rights in some rivers to maintain a minimum flow to protect aquatic species. These in-stream flow rights may be junior to a senior water right holder, but new hydropower junior rights need to consider their impact even if the water right is non-consumptive. There may be a portion of the river between the intake of the hydropower plant and the discharge where in-stream flows cannot be reduced.

A water right must include power generation or hydropower as a beneficial use before the right can be used in a small hydropower installation. Hydropower can be added as a beneficial use to existing rights by filing for an enlargement of the right that includes hydropower as a beneficial use. If a hydropower facility is added to an existing irrigation system and a new point of diversion is added, or more diversions will be made throughout the year to supply the facility, a new water right application or an enlargement application needs to be filed. This additional application allows the diversion of water outside of the irrigation season.

An individual who owns an adjudicated water right and wishes to change the current use or change the place of use must file a petition with the Wyoming State Engineer's Office Board of Control requesting permission. A petition for change of use should only occur when changing the beneficial use. When requesting a change in place of use, all pertinent information about existing use and proposed place of use should be specified in the petition. If a change in place of use or change in use is granted, the quantity of water transferred cannot exceed the amount of water historically diverted under the existing use. Furthermore, the amount consumed cannot exceed that under existing use. Finally, such a petition, if granted, cannot decrease the historic amount of return flow or in any manner injure other existing lawful appropriators.

The Wyoming State Engineer's Office is a useful primary resource for information and assistance on filing new water right applications and petitions, but a professional well versed in Wyoming water law is recommended when applying for a new right or filing any type of petition.

Political or Environmental Concerns

In addition to the technical characteristics of a site, other environmental, cultural, and political factors can influence feasibility. Identifying potentially contentious issues early is important before significant resources are spent studying the feasibility of the project. Potential political or cultural concerns may include nearby historic sites or commercial/recreational activities, such as boating, occurring in the impacted area. In addition, some hydropower turbines can be fairly noisy, so identifying any nearby neighbors that may be impacted is vital. Local zoning laws may also impact where hydropower development may occur.

Although small hydropower is considered a clean, low-impact energy source, potential environmental impacts exist. Specifically, diminished water flows in a waterway could impact aquatic and riparian zone species. Although less likely on existing water projects, evaluating the likelihood of environmental impacts early in the process is critical.

General Project Types

There are several different configurations of small hydropower installations. Examples of the most common types of configurations are described below.

Dam Installations

The majority of existing hydropower capacity in Wyoming are dam installations owned and operated by the U.S. Department of the Interior, Bureau of Reclamation. Dams in Wyoming were primarily constructed for multiple uses, including water supply, flood control, hydropower, and recreation. Hydropower facilities at Reclamation dams are typically large scale; however, there are potential applications at unpowered dams for small hydropower. Depending on the type of dam and outlet configuration, several alternatives are available for hydropower development. A general schematic of hydropower on a dam is shown below in Figure 3.

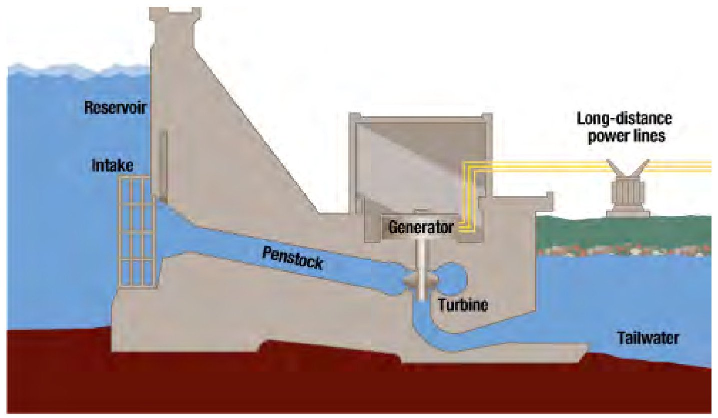

Figure 3: Schematic of a Hydroelectric Dam
Source: Tennessee Valley Authority

i) Guernsey Powerplant

Although slightly larger than the five MW small hydropower limit, the Guernsey Powerplant at the Guernsey Dam is owned and operated by Reclamation. The Guernsey Dam controls North Platte River flows for varying irrigation demands. The original powerplant was constructed in 1928 and updated in 1994 and consists of two Francis turbines with 3,200 kilowatt (kW) generators each for a combined capacity of 6,400 kW. The turbines utilize 70 feet of head and 700 cfs each. The project was constructed on a secondary outlet from the reservoir, and the powerhouse is at the toe of the dam along the right abutment. The primary outlet works is a concrete chute along the left side of the embankment.

Figure 4: Guernsey Dam and Powerplant
Source: Bureau of Reclamation

ii) Siphon Penstock

An alternative to using an outlet through the dam is to use a siphon penstock over the dam. Siphons may be preferred if the existing outlet works are not suitable for hydropower. There is a limit to the height of the siphon above the reservoir level that would need to be considered in the design. There are no examples of a siphon penstock in Wyoming; however, The Colorado Energy Office describes the Humphreys Hydroelectric project near Creede, Colorado, in The Small Hydropower Handbook. The Humphreys Hydroelectric project was constructed by a private landowner and consists of one 310 kW Cross Flow turbine using 91 feet of head and 60 cfs of flow.

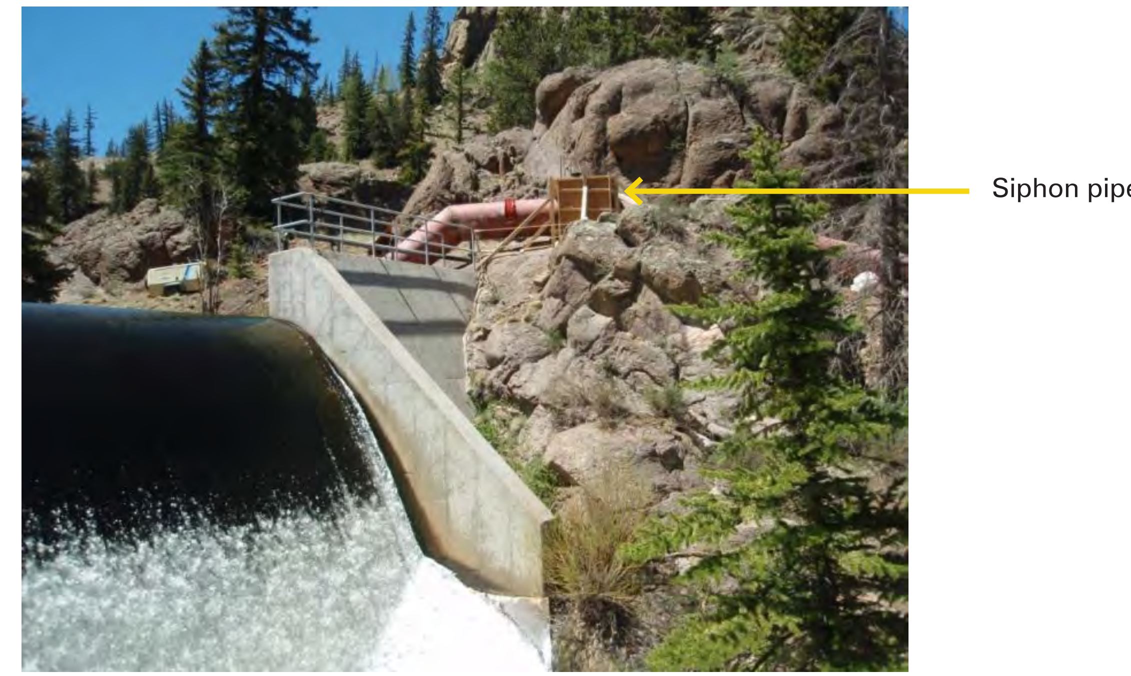

Figure 5: Humphreys Hydro Siphon Intake
Source: Colorado Energy Office "The Small Hydropower Handbook"

Run-of-River Hydropower

Run-of-river hydropower installations do not require large storage reservoirs and are commonly used for small hydropower systems. Run-of-river hydropower systems divert and convey a portion of a river's water and convey the water through a channel or pressurized pipeline (penstock). The pressurized penstock then delivers the water to the hydropower turbine and is discharged back into the river. A schematic of a run-of-river hydropower installation is shown in Figure 6

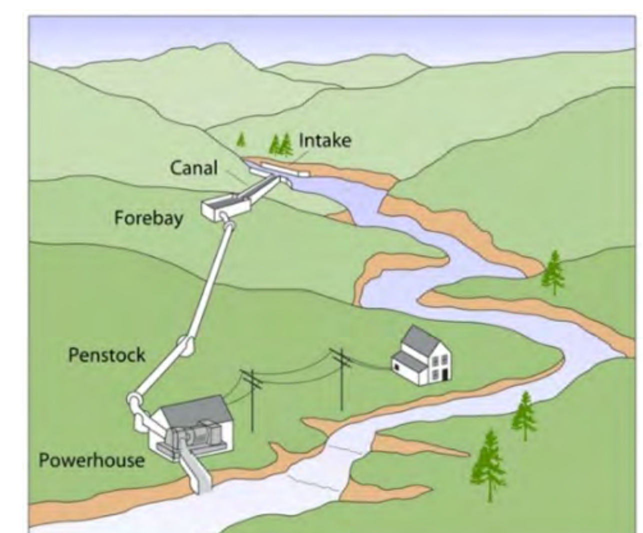

Figure 6: Schematic of Run-of-River Hydropower
Source: U.S. Department of Energy

i) Strawberry Creek

The Strawberry Creek facility is a certified low-impact, run-of-river hydroelectric facility owned and operated by Lower Valley Energy on federal land in the Bridger-Teton National Forest near Bedford, Wyoming.

The project consists of a concrete gravity dam 22 feet high and 110 feet long with a 40-foot long overflow spillway in the channel of Strawberry Creek. The dam diverts flows into a 2.3-mile long penstock and can supply up to 48 cfs for power generation. The powerhouse consists of three 500 kW Pelton turbines for a combined capacity of 1,500 kW. The turbines utilize 500 feet of head and 16 cfs each.

Conduit Hydropower

Conduit hydropower uses an already existing conduit (pipe or canal) that supplies water for purpose other than hydropower. Conduit hydropower systems are found in municipal water pipelines and irrigation distribution systems, where power can be generated from excess pressure that otherwise would have to be mechanically reduced by a pressure reducing valve. This type of hydropower plant is often very low impact and cost-effective, as they utilize existing infrastructure.

i) Garland Canal Power Plant

The Garland Canal Power Plant is owned and operated by the Shoshone Irrigation District near Ralston, Wyoming. The powerplant utilizes irrigation flows in the Garland Canal to generate power and consists of one semi-Kaplan turbine with a 2,900 kW generator. The powerplant was constructed in 1983 and utilizes 52 feet of head and 800 cfs.

Figure 7: Semi-Kaplan Turbine

Photos courtesy of Shoshone Irrigation District

Figure 8: Folding Weir and Intake

ii) Pilot Butte Powerplant

The Pilot Butte Powerplant is owned and operated by Reclamation and is part of the Riverton Unit. In 1951, Reclamation transferred the operation and maintenance of portions of the Riverton Unit to the Midvale Irrigation District but retained ownership and operation of the Pilot Butte Powerplant. The powerplant was constructed in 1925 at the drop from the Wyoming Canal to Pilot Butte Reservoir. The plant has two Francis turbines and generating units, which operate under a maximum head of 105 feet with a total capacity of 1,600 kW. The plant was shut down in 1973 because of high operation and maintenance costs and penstock problems. The penstock was replaced in 1990 and was placed back online until 2007 when shut down again due to high operation and maintenance costs. The high maintenance costs are a result of the age of the facility, as the powerplant and much of the other equipment is nearly 90 years old.

Figure 9: Pilot Butte Powerplant

Photos courtesy of U.S. Bureau of Reclemation

iii) Purvis Drop – Cody Canal Irrigation District

A study funded by the Wyoming Water Development Commission was recently completed assessing the feasibility of a hydropower facility at the Purvis Drop on the Cody Canal near Cody, Wyoming. The study concluded hydropower is potentially feasible. A new diversion structure in the canal at the top of the drop would divert water into the penstock. The penstock would run parallel to the existing canal drop and supply water to a Francis turbine at the bottom of the drop. The turbine would utilize 144 feet of head and up to 200 cfs to generate 1,660 kW. The turbine would then discharge water back into the canal at the bottom of the drop. The canal drop would handle overflows or flows when the turbine is offline.

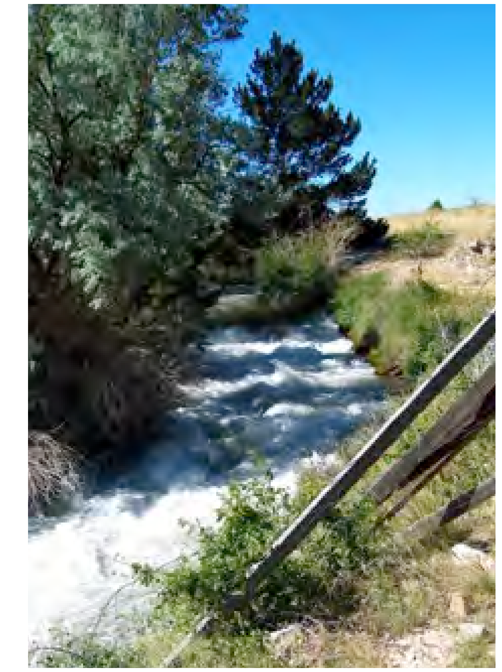

Figure 10: Purvis Drop

iv) Buffalo Hydropower Plant

The City of Buffalo owns and operates a 200 kW Pelton impulse type hydropower facility. The unit is inline with their existing 14-inch municipal raw water supply pipeline to the water treatment plant. The city diverts water from Clear Creek and pipes it 3.6 miles to the water treatment plant. In 1995, the diversion and pipeline were reconstructed in conjunction with the Tie Hack Reservoir. The hydropower facility was constructed in parallel with the existing pressure reducing station on the pipeline. This pipeline provides 6 cfs with 492 feet of net head to the hydro turbine. The hydropower facility is typically operated year-round. During snowmelt runoff and times when stream flows are adequate, the city uses its direct flow water rights to provide water to the turbine and water treatment plant. When stream flows are reduced and city direct flow water rights are out of priority, the City makes releases from storage in Tie Hack reservoir to provide water to the turbine and water treatment plant. During the non-irrigation season the municipal demand on the water treatment plant is reduced, and excess water from the hydro turbine is returned to Clear Creek.

Figure 11: Buffalo Hydropower Plant

v) Afton Culinary Water System Hydroelectric Facility [ix]

The Town of Afton and Lower Valley Energy co-own a 225 kW Pelton impulse type hydropower facility on Swift Creek in western Wyoming. The hydropower system was installed on their municipal water system, which is supplied by Periodic Spring. The pulsing flow from the spring can vary from no flow up to approximately 90 cfs during spring runoff. The existing municipal water supply system collects a portion of the flow and pipes it to a surge tank to help buffer the fluctuations. From the surge tank, flows enter an existing 3.2-mile long, 18-inch pipeline to the water treatment facility. The small hydro turbine was constructed in 2010 at the end of the pipeline and discharges to the water treatment facility storage tank. The hydro turbine makes use of 12 cfs and 310 feet of head to generate power.

vi) Sherard Hydroelectric Generation Project

The City of Cheyenne Board of Public Utilities is evaluating adding a hydropower unit in parallel with its existing pressure reducing station at the head of the water treatment plant. The water treatment plant is supplied from Crystal Lake Reservoir via a 15 mile long pipeline. Head and flow conditions vary based on the demand of the water treatment plant. Flows can range as high as 35 cfs during peak demand and averages 10 cfs during the non-irrigation months. Available head varies due to head loss in the existing pipeline and ranges from 440 feet at 35 cfs to 500 feet at 10 cfs. At 20 cfs there is 490 feet of net head available. Preliminary turbine selection indicates either a single impulse type turbine or single Francis type turbine would be appropriate. Rated capacity would likely be approximately 700 kW at 20 cfs.

Hydrokinetic

Recent innovations are driving new interest in an old technology – hydrokinetic power. Systems use the kinetic energy, or velocity head, of a flow by placing the turbine in a river or canal. Hydrokinetic power differs from conventional hydropower, which uses the potential energy or pressure head of the water to generate energy. Hydrokinetic systems require relatively high flow velocities and sufficient water depth to maintain submergence of the turbine. The potential to extract energy from the flow is related to the swept area of the turbine and the velocity cubed, much like a wind turbine. Hydrokinetic systems can only extract a fraction of the power from the water compared to conventional hydropower systems; hydrokinetic turbines are based on the kinetic energy of the flow only and not the potential energy from pressure head. The majority of hydrokinetic turbines are still in the prototype phase, with a small number of companies offering commercial products. Commercial hydrokinetic turbines range in size from 5 kW to 250 kW and cost around $4,000 per installed kW. Compared to other forms of hydropower generation, hydrokinetic turbines are relatively expensive. Typically, conventional hydropower systems cost around $2,000 per installed kW. Hydrokinetic systems often appear simple to deploy, but low production relative to installed cost leads to a less cost-effective system than many conventional hydropower installations. Environmental issues can still impact the feasibility of hydrokinetic systems and can include impacts to aquatic life, erosion, and flow alteration.

Figure 12: EnCurrent Hydrokinetic Turbine
Source: New Energy Corporation

The canal installation shown below is a Hydrovolts turbine installed for six weeks as a test program in the Roza Canal in Oregon. The turbine produces 5 kW with 6.5 ft/sec of water velocity. The canal is cement lined and 14 feet wide at the bottom with a maximum water depth of 11 feet. The canal flows between 1,100 and 2,100 cfs. The installation of this turbine requires little civil infrastructure, although the canal must have adequate geometry and freeboard to handle the resulting rise in water surface elevation upstream of the turbine (6-8 inches).[xii]

Figure 13: Hydrovolts - Roza Canal
Source: The Colorado Energy Office "The Small Hydropower Handbook"

Hydro-mechanical

Hydro-mechanical systems use hydro turbines to supply mechanical work to machinery instead of electric generators. Historic uses include sawmills, textile mills, and grain mills. In the present day, hydro-mechanical energy can be used to drive sprinkler irrigation systems. Most center pivot sprinklers use hydraulic or electric motors to drive the wheels. In cases where excess head is available, a hydro-mechanical turbine can power a hydraulic pump, which in turn drives the hydraulic motors that propel the sprinkler. These systems are not feasible where water is pumped to the sprinkler. Since the hydro-mechanical turbine does not generate electricity, installations are not regulated by the Federal Energy Regulatory Commission (FERC). These installations can replace diesel/propane generators or eliminate the need to have electrical service provided to the center pivot. Performance of the sprinkler system may also be increased, as center pivot manufacturers claim hydrostatic drive pivots move more smoothly and do not leave dry areas associated with the start-and-stop electric motor driven units.[x]

The Bear River Ranch near Steamboat Springs, Colorado, installed a hydro-mechanical system to power its center pivot irrigation system. The system uses the power of falling water to directly drive and pressurize the center pivot and eliminated the need for electricity and significantly reduced operating expenses. The turbine uses 126 feet of head and 560 gallons per minute to produce the equivalent of 5.2 kW of power, which drives the center pivot. A case study at the end of this handbook describes the system in more detail.[xii]

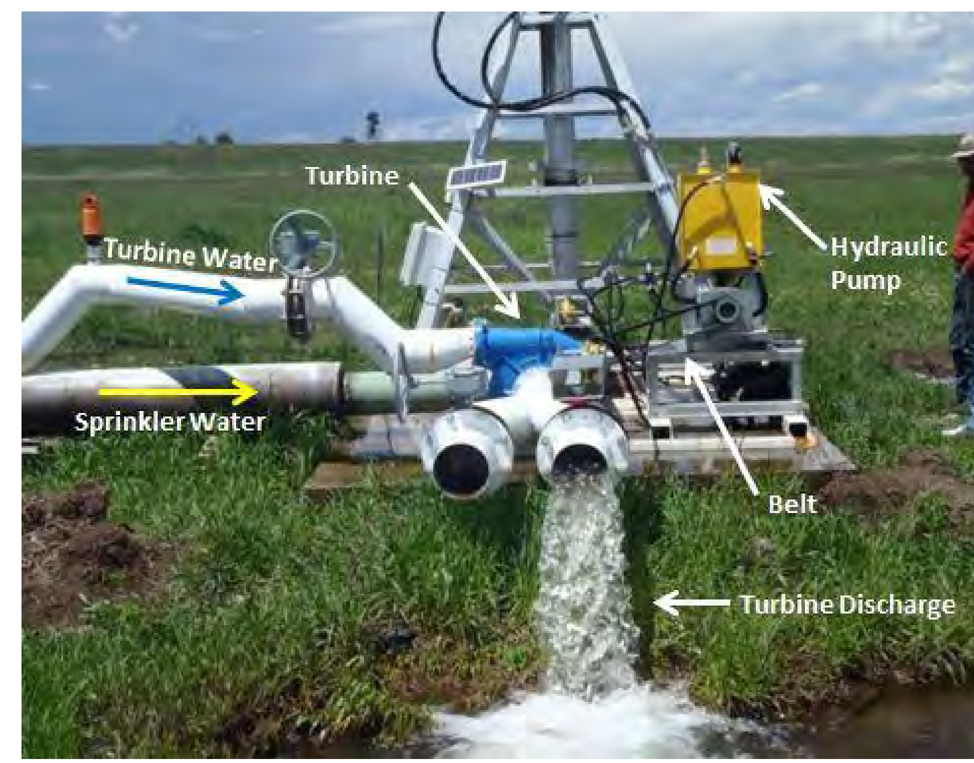

Figure 14: Bear River Ranch Center Pivot
Source: The Colorado Energy Office "The Small Hydropower Handbook"

Measurement of Head and Flow

A preliminary estimate of head and flow, as described in the previous section, is adequate for estimating the hydropower plant's generating capacity in early stages of project development; however, as the project progresses, detailed and accurate measurements of head and flow are critical when determining the type of turbine and energy output of the generator.

Hydrology and Flow[xi]

Flows available to a hydropower plant can either be estimated using the hydrologic conditions of the site or physically measured. The preferred method will depend on available data. Methods and resources are described below to estimate the flow conditions of a site. When using these methods, keep in mind available flows can change due to meteorological conditions. Forecasting future available flow requires careful consideration of past drought conditions and predicted climatic trends.

i) Historic Hydrology Data

Historic records of diversions may be available in instances where water is already diverted from a stream for agricultural, municipal or industrial uses under an existing water right. The Wyoming State Engineer's Office maintains a public record of diversions by geographic area (see appendix for additional information). In cases when the hydropower facility will utilize a new diversion, water availability may be approximated by using flows from a nearby stream gauge. Real-time stream flow, through a GIS-based map and data portal, can also be accessed on the Wyoming State Engineer's Office website (see appendix for additional information). Other stream gauges and data are kept by the United States Geologic Survey and can be downloaded from their website (see appendix). Average flows over multiple time periods can typically be accessed through the USGS database.

ii) Measurement of Flow

Measuring flow for a period during the planning stages of a hydropower plant may be necessary if historic records do not exist. There are structures to measure the flow rate in a channel. Reclamation provides guidance through its *Water Measurement Manual*.[xii] By using the structure's dimensions, in conjunction with flow depths, a flow rate can be determined by referencing tabulate flow discharge values. The Reclamation manual has tabulated data in its appendices for three, commonly used flow measurement structures: the Parshall Flume, the weir, and the flow meter.

a) Parshall Flume

The Parshall Flume is one of the most common types of flumes in Wyoming, depicted in Figure 15. Canals are commonly measured using this type of flume. Use of a flume is likely the best alternative for flow measurement when water depth is low. For this particular type of measurement structure, a flume of known geometry is installed perpendicular to the flow in a channel. Using the measured water depth and throat width in the flume, an associated flow discharge can be calculated or obtained through reference to flow discharge tables (located in Appendix A8 of the *Reclamation's Water Measurement Manual*).

b) Weir

A weir is an overflow structure of known dimensions installed perpendicularly in the channel to measure the flow rate. Weirs are one of the most common measuring devices and are designed with various shapes and sizes, as shown in Figure 16, 17 and 18. Sharp-crested weirs have a center notch of varying shapes through which water is directed, while broad-crested weirs have a horizontal crest over which water flows. Using the upstream pool depth, weir dimensions, and depth of water flowing over the weir, the discharge flow rate can be calculated or obtained from a table. Guidance is provided in the aforementioned Reclamation manual.

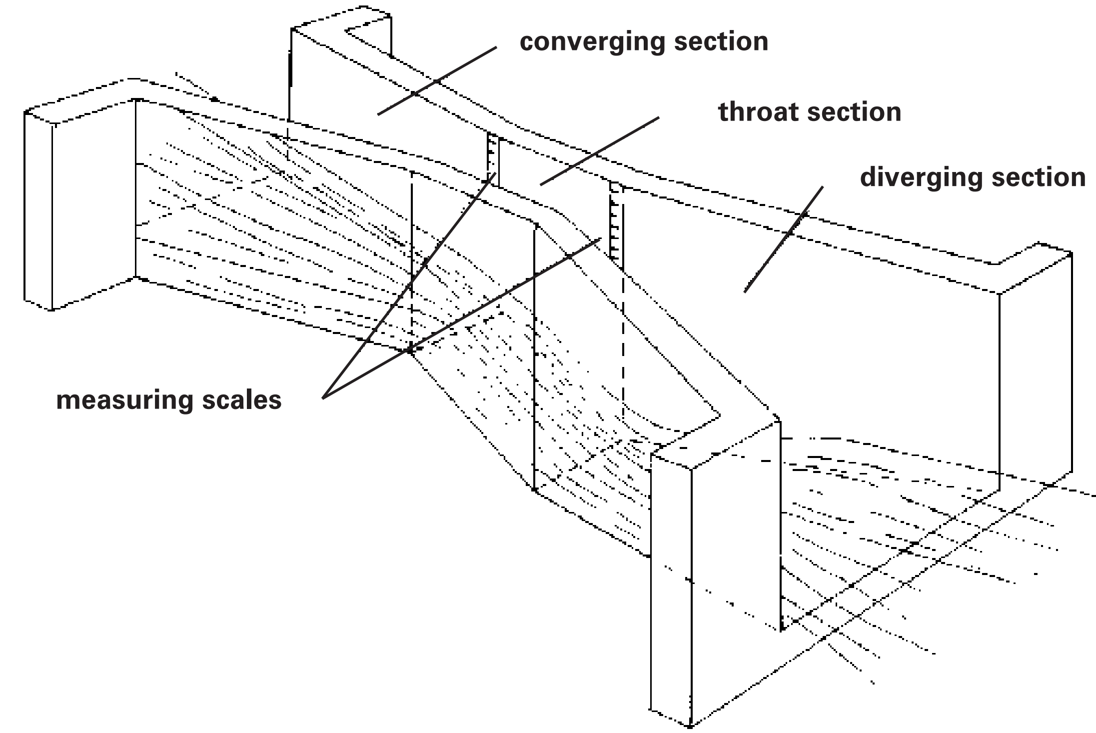

Figure 15: Parshall Flume
Source: Food and Agricultural Organization of the United Nations

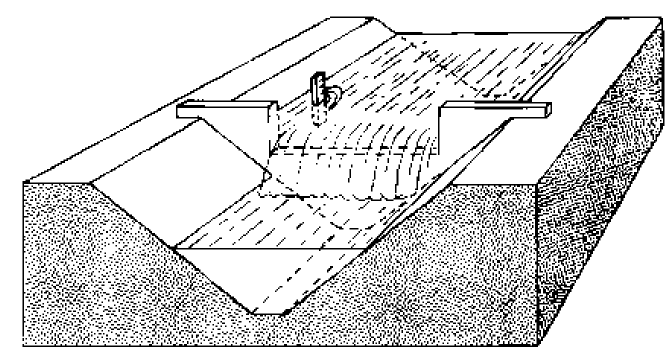

Figure 16: Rectangular Weir

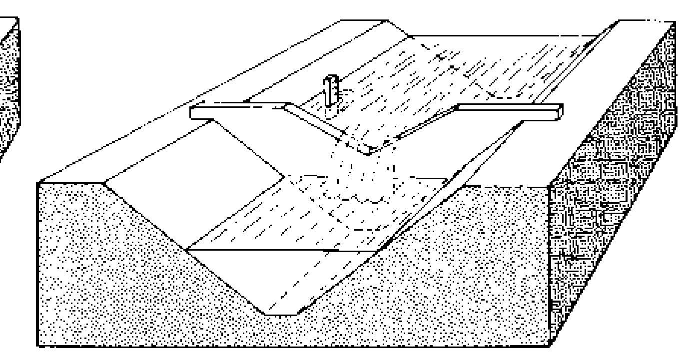

Figure 17: Triangular Weir

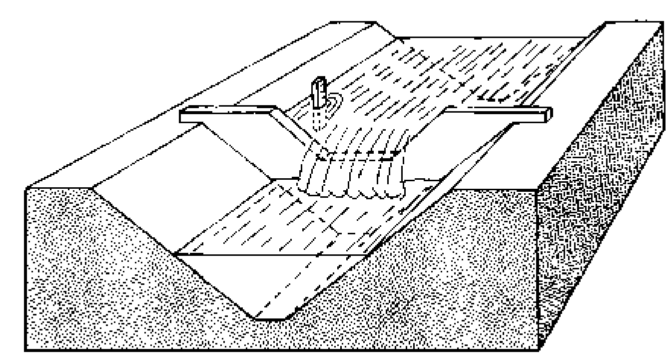

Figure 18: Trapezoidal Weir

Source: Food and Agriculture Organization of the United Nations

c) Flow Meter

There are multiple types of flow meters. The most commonly used is the submerged orifice flow meter. This consists of a precisely designed, sharp-edged opening placed perpendicularly to the channel flow, through which all water passes. As small changes in the orifice's construction can have a large impact on the accuracy of its associated flow values, the orifice must be well-machined and dimensioned as accurately as possible. By measuring the water depth immediately upstream and downstream of the orifice, flow rate can be obtained through the use of discharge tables. Guidance is provided in the aforementioned Reclamation manual.

d) Current Meter/Velocity Meter

Flow measurement with a velocity meter measures the velocity of the channel flow. To measure flow, the current meter is placed at specific cross-section intervals along a reach of channel and records an average flow and water depth over those sections. The flow rate can then be calculated using the following equation:

$$Q_i = V_i(A_i)$$

Where Q_i = Flowrate in cubic feet per second at each cross-section interval
V_i = Velocity in feet per second at each cross-section interval
A_i = Cross-sectional area in square feet at each cross-section interval

The flow rate, Q_i, at each interval is summed to obtain a total flow rate through the cross-section of the channel.

Optimally, current meters should be used in straight, uniform sections of the channel reach to minimize flow disturbances. Additionally, the flow velocity should be greater than 0.5 feet per second, and the meter should be kept as still as possible. This type of flow measurement is ideal for investigation of larger flows or for flows containing larger amounts of sediment. There are multiple types of current meters to measure the velocity of the channel flow:

1) The Price Type AA meter is shown in Figure 19. This type of current meter is commonly used for irrigation and watershed applications. Velocity is measured by dragging anemometer cup wheels or propellers through calm waters.

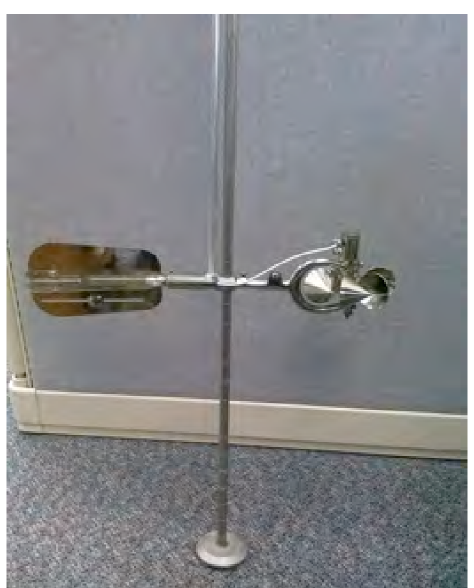

Figure 19: Price Type AA Current Meter

Figure 20: Stream Gauging a River Cross-section

Figure 21: Portable Magnetic Flow Meter
Source: Hach Company

Figure 22: Acoustic Doppler Current Profiler

Figure 23: Pressure Transducer Used to Measure Water Level in Streams

Figure 24: Temporary Stream Gauge

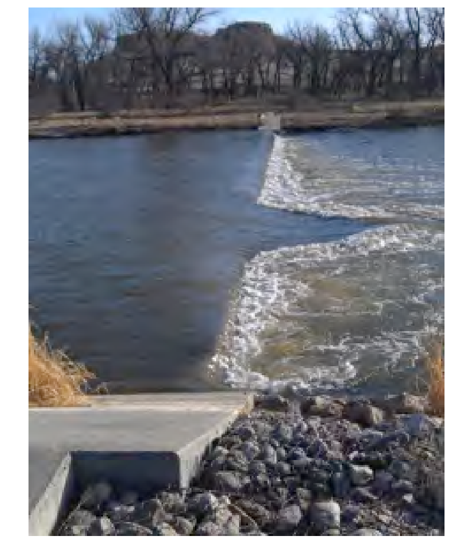

Figure 25: USGS Orin Gauge on the North Platte River

2) The electromagnetic velocity meter is shown in Figure 21. This type of current meter produces voltage proportionately to the stream velocity and has an easily read analog display. The measuring accounts for directional velocities and measure cross flows but is not as accurate as anemometer-propeller current meters.

3) The Acoustic Doppler Current Profiler is shown in Figure 22. These meters measure the change in source light or sound frequency to measure velocity. Doppler meters are versatile, providing measurement in a wide range of water body sizes and types. They are able to measure multiple directions of flow velocity simultaneously.

Multiple measurements throughout the planning period from the devices described above are needed to accurately determine the flow rate available for hydropower generation. Stream gauges that have continuous recording capabilities can be installed at weirs, flumes or channel reaches. The gauges generally consist of a water level sensor (pressure transducer), which logs the elevation of the water on a daily, hourly, or sub-hourly basis. The section of stream is then rated by measuring the flow from one of the methods described above to provide a relationship between the water surface elevation and the total flow. Stream gauges can be temporarily installed as shown in Figure 24 or permanent installations such as the USGS gauge shown in Figure 25.

Flow Duration Curve

Flow may be very high at some points throughout the year, especially during peak run-off periods or after exceptionally rainy periods, so measuring flow multiple times throughout the planning period is vital. Designing a hydropower system to handle peak flows that only occur just a few days a year is unlikely to be cost-effective. Sizing a system that uses flows that are available for a majority of the water season is more cost-effective. The variance in annual flow can be depicted graphically through a flow duration curve, such as Figure 26. Use of a flow duration curve can allow for more accurate small hydro planning by considering maximum and minimum flows and observing trends in consecutive yearly data. Flow duration curves graphically depict the relationship between channel flow and the percentage of time that specific flow is exceeded.

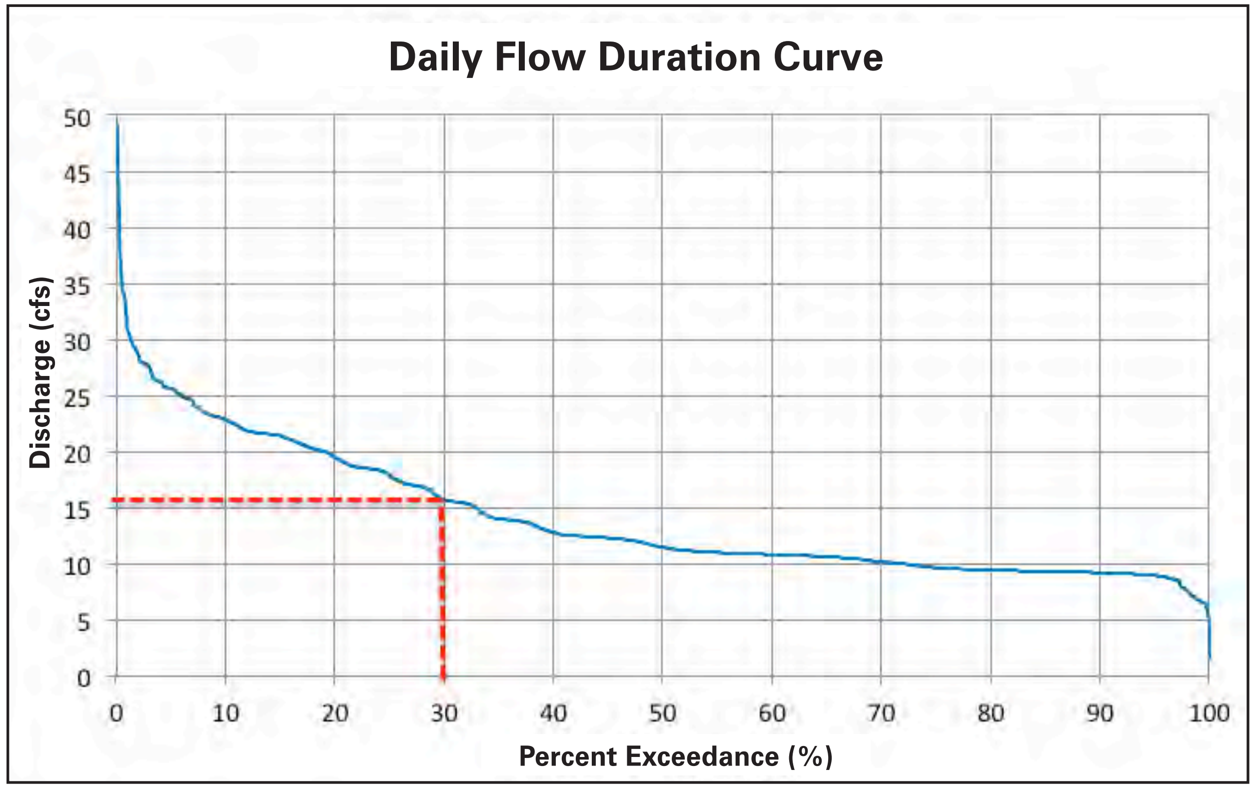

Figure 26: Flow Duration Curve with 30 percent Exceedance Indication

Design Flow

The design flow is the flow at which the turbine operates most efficiently and is the maximum flow rate the hydro system should operate at for an extended period of time. When looking at the flow duration curve, an initial estimate of the design flow for a small hydro system will typically be the flow associated with an exceedance value of 30 percent. For the example in Figure 28, the design flow at 30 percent exceedance would be approximately 15 cubic feet per second (cfs). This is a general rule-of-thumb and can vary depending on the shape of the flow duration curve. To size the system more accurately, each system will have to be analyzed individually and the costs and benefits compared among potential turbines. Generally, the design flow can be exceeded by approximately 10 percent; however, running the turbine at this higher flow rate should not be a frequent occurrence as turbine efficiency will decrease and excessive wear or damage to the turbine or components may result.

Measuring Head

Head is representative of the water pressure created by the difference in elevation between the intake of the penstock and the hydro turbine discharge. Head can be applicable to two different values, gross head and net head. The gross head is quantified by the change in water elevation prior to the commencement of any water flow. Energy is lost due to friction of water flowing through the penstock. The available head for hydropower generation is less than the gross head. After the energy loss has been accounted for, the resulting adjusted head, called net head, represents the pressure at the bottom of the pipeline during water flow. Head loss can vary depending on the penstock size and material; however, for a well-designed system the net head will generally be 85-90 percent of the gross head.[viii] The net head represents the actual amount of head available for use in the turbine. The relationship between gross head and net head is as follows:

Gross Head – Head Loss = Net Head

Calculating head loss in a pipeline can be complicated, and seeking help from a professional is recommended; however, in general terms a larger diameter penstock will reduce head loss, as shown in Figure 27. Energy losses in a penstock result from friction losses and minor losses. Friction loss in the penstock is a function of penstock diameter, length, flow rate, and pipe material. An increase in penstock diameter will reduce friction loss; whereas, an increase in flow rate and/or penstock length, will increase friction losses. Minor losses in the penstock are attributed to any bends, fittings, valves, and pipe entrance and exits. The total energy loss in the pipeline is the sum of the friction losses and minor losses. Even though head losses are less in larger penstocks and can deliver more power to the turbine, larger penstocks are also more expensive. There is a tradeoff between head loss and system cost. A good place to start when sizing a penstock is to keep the flow velocity in the pipe less than 10 feet per second (fps). The flow velocity can be calculated by dividing the flow rate by the cross-sectional area of the pipe. According to Canyon Hydro, which is a prominent U.S.-based manufacturer of small hydropower systems, a good rule of thumb is to size the pipe such that no more than 10 to 15 percent of the gross head is lost due to pipe friction.[xiv]

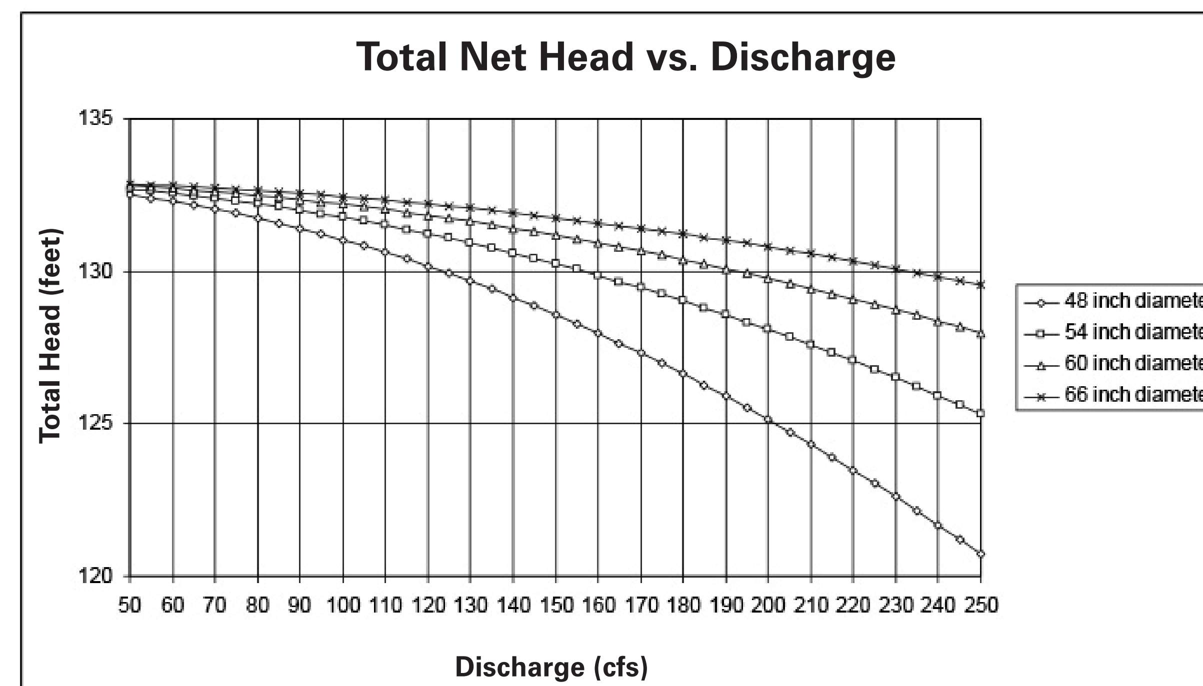

Figure 27: Net Head vs. Discharge for Various Penstock Diameters

There are two accurate methods for measuring head – direct distance measurement and water pressure.

i) Direct Distance Measurement[xiii]

The most accurate direct distance measurement is a topographic survey conducted by a professional land surveyor. A similar method is to use a surveyor's transit, a contractor's level on a tripod, or a level taped to a straight board to measure gross head. A surveyor's rod or a pole with graduated measurements is also required (measuring tape affixed to a 20-foot section of PVC pipe works well). Direct measurement requires an assistant. Make a series of vertical measurements using the transit level and the vertical measuring pole. Make sure each transit setup is exactly level, and ensure the measuring pole is vertical. Keep detailed notes at each step and then add up the series of measurements (A, B, C, D, etc.) to find the gross head. This method may not be practical if the pipeline is long.

ii) Water Pressure Measurement

Head can also be calculated using some type of pressure meter, such as a piezometer or pressure gage. By utilizing a pipe or tube completely filled with water that spans the full elevation drop, pressure can be measured at the bottom or the outlet. One pound per square inch (psi) of pressure accounts for approximately 2.31 feet of vertical head. When using this method, use a continuous pipe or tube although segments can be used if care is taken to eliminate any leakage at the connections. If a single span of tubing is unavailable, multiple readings can be taken along the elevation drop; however, this method will greatly increase chances for error. Since there is no water flowing out of the pipe when this pressure measurement is taken, this is a measurement of the gross head.[xii]

As an alternative, pressure readings across a pressure reducing valve (PRV), say on a municipal pipeline, can be used to determine the net head available for hydropower. If the PRV is on a penstock that will supply the turbine and the upstream and downstream pressure readings are recorded at the design flow in the pipeline, then the difference between the two pressure readings can be correlated to an accurate measurement of the net head.

Electromechanical Equipment

Hydropower facilities consist of electromechanical equipment that converts the potential energy of the water into electricity. Typical electromechanical equipment includes inlet gate or valve, penstock, powerhouse, turbine, drive system, generator, governors and control system, switch gear, protection system, and power and current transformers. Many small hydropower systems, particularly micro hydropower, are sold as "water-to-wire" packages. For water-to-wire packages, the manufacturer/supplier will supply all of the equipment – turbine, generator, controls and low voltage switchgear – as a package according to the specifications and interconnection requirements. The civil infrastructure such as intake, penstock, and powerhouse are not included in the water-to-wire package.

Intake Structures

The intake is typically the highest point of the hydro system, where water is diverted from the waterway into the pipeline that feeds the turbine. In many cases, a small dam is used to divert the water. The dam, in most large hydro projects, also creates the head necessary to drive the turbine. A water diversion system serves two primary purposes. The first is to provide a deep enough pool of water to create a smooth, air-free inlet to the pipeline. Air reduces power and can cause damage to the turbine. The second is to remove dirt and debris. Screens or trashracks can help stop larger debris such as leaves and limbs, while a settling zone will allow dirt and sediment to settle to the bottom before entering the pipeline. This helps reduce abrasive wear on the turbine

Penstock

The pipeline, typically called the penstock, is responsible for conveying water to the turbine and serving as the enclosure that creates pressure with increasing vertical drop. In effect, the penstock focusses all the water power at the bottom of the pipe where the turbine is typically located. Pipeline diameter, length, and routing all affect efficiency, and there are guidelines for matching the size of the pipeline to the design flow of the turbine.viii As described in the previous section, a small diameter pipeline can considerably reduce the available power output, even though it can carry all available water.

Powerhouse

The powerhouse is simply a building that houses the turbine, generator, and controls. The size and configuration of the powerhouse is dictated by the equipment configuration and landscape of the site. For example, a micro-hydropower system may not need any type of enclosure. Generally, the larger the system, the more civil infrastructure is required. The necessary equipment needs to be configured in an efficient manner with adequate clearance for installation and maintenance. Turbine manufacturers can give recommendations about powerhouse size requirements clearances and offsets between equipment.

Since hydro turbine and generator equipment has substantial weight, properly designing the powerhouse foundation and structure to handle the loads to which it will be subjected must be considered. Thrust blocks to support the penstock and turbine assembly should be designed to handle the loads and vibrations caused by the turbine. The turbine's discharge channel (tailrace) is commonly integrated into the foundation and requires placement consideration when designing the powerhouse foundation. Access to the equipment must also be considered when designing the powerhouse. A permanent crane may be necessary to lift and place the equipment within the powerhouse.

Reaction turbines discharge water through a tailrace incorporated directly into the powerhouse foundation; whereas, an impulse turbine powerhouse discharges the tailwater directly into an open air excavation rather than a tailrace.

Turbine Selection

The type and size of hydropower turbine can be selected, once the available head and flow conditions are determined. This guide describes the most common turbines used in small hydropower applications and provides a general understanding of how the turbines operate. There may be applications where multiple turbine types will work with the given site conditions, and a turbine manufacturer or supplier (listed in the Appendix) can help in selecting an appropriate turbine.

Hydro turbines are categorized into two groups: impulse turbines and reaction turbines, whose difference relates to the way energy is produced from the inflow. In a reaction turbine, the water pressure can apply a force on the face of the turbine runner blades, which decreases as it proceeds through the turbine. The turbine runner blades are fully immersed in water flow and must be encased in a pressurized housing. Reaction turbines are generally suited for lower head, higher flow applications. Francis and Kaplan turbines fall under the reaction turbine category. Impulse turbines convert the water pressure into kinetic energy before entering the runner, and use the force of a jet of water impacting curved buckets mounted on the periphery of the runner to change the direction of flow and thus creating momentum to produce mechanical energy. An impulse turbine can be open to the atmosphere and only needs a casing to control splash. Impulse turbines are generally well suited for high head, low flow applications. Pelton or Turgo turbines fall under the impulse turbine category. Impulse and reaction turbine runners are shown in Figure 28 and Figure 29.

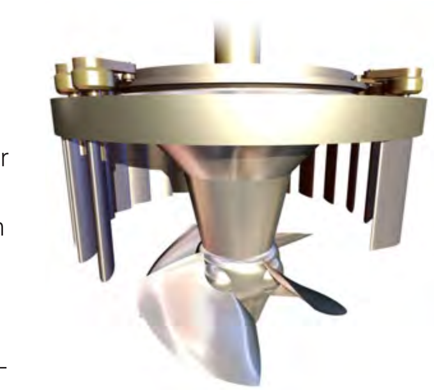

Figure 28: Reaction (Kaplan) Turbine Runner
Source: Alstom

There may be several turbines capable of operating under the given site conditions although they will likely differ in efficiency or range. Consulting with a turbine manufacturer from the beginning of the project can be very beneficial in determining the most efficient turbine for site conditions. The design flow for smaller systems, such as a pump-as-turbine, may also be dictated by standard, "off-the-shelf" turbine sizes. The chart below shows seven major types of turbines and their recommended range of head and flow. This chart can be used to identify potential turbine types suitable for a given design head and flow. For example, for a design flow of 100 cfs and 100 feet of head, three turbines may be appropriate for the site: a Francis, Kaplan, or a cross flow. Each turbine has certain advantages and disadvantages that may dictate selection. The turbines listed in the chart are described in more detail in the next section.

Figure 29: Impulse (Pelton) Turbine Runner
Source: Gilkes Hydropower Systems

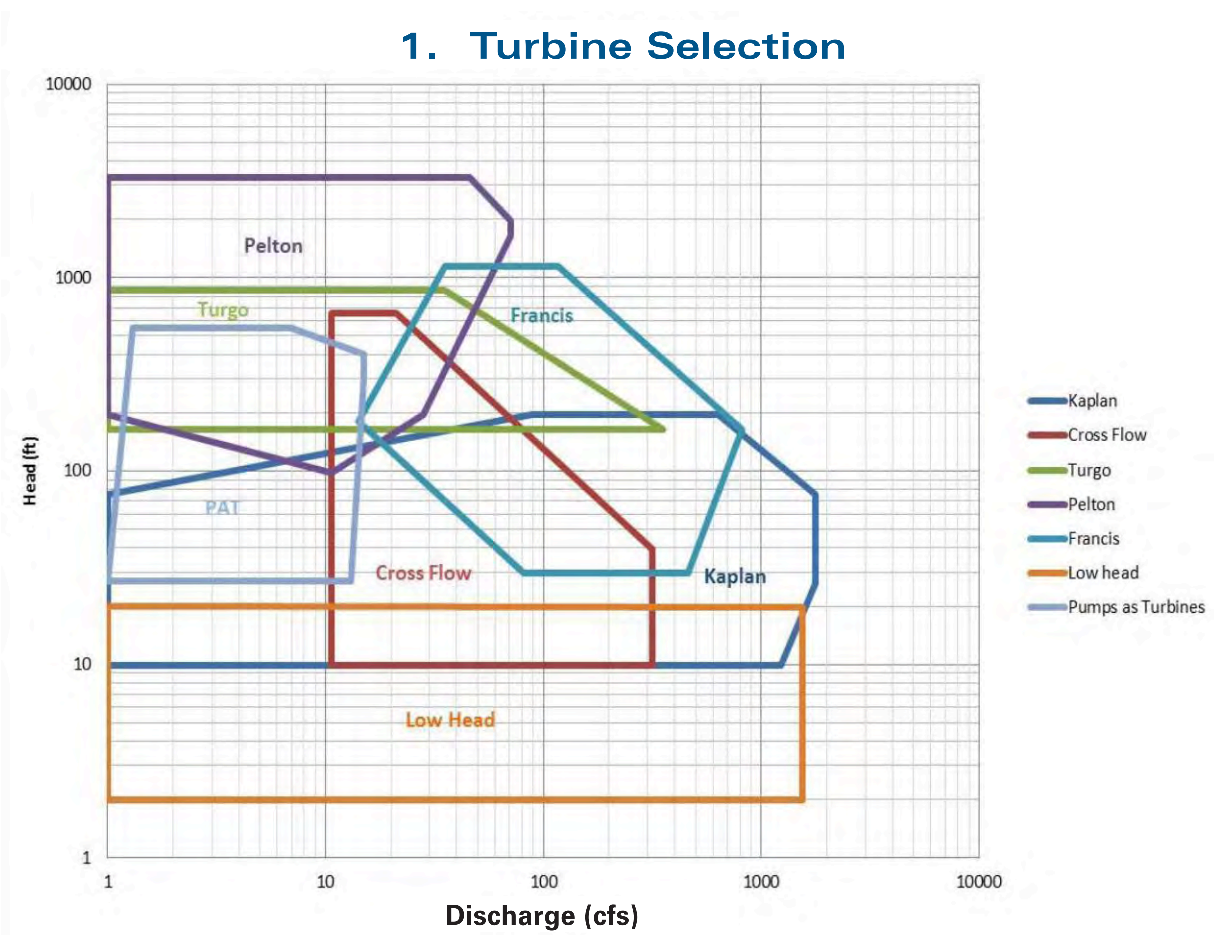

Figure 30: Turbine Selection Chart
Source: The Colorado Energy Office "The Small Hydropower Handbook"

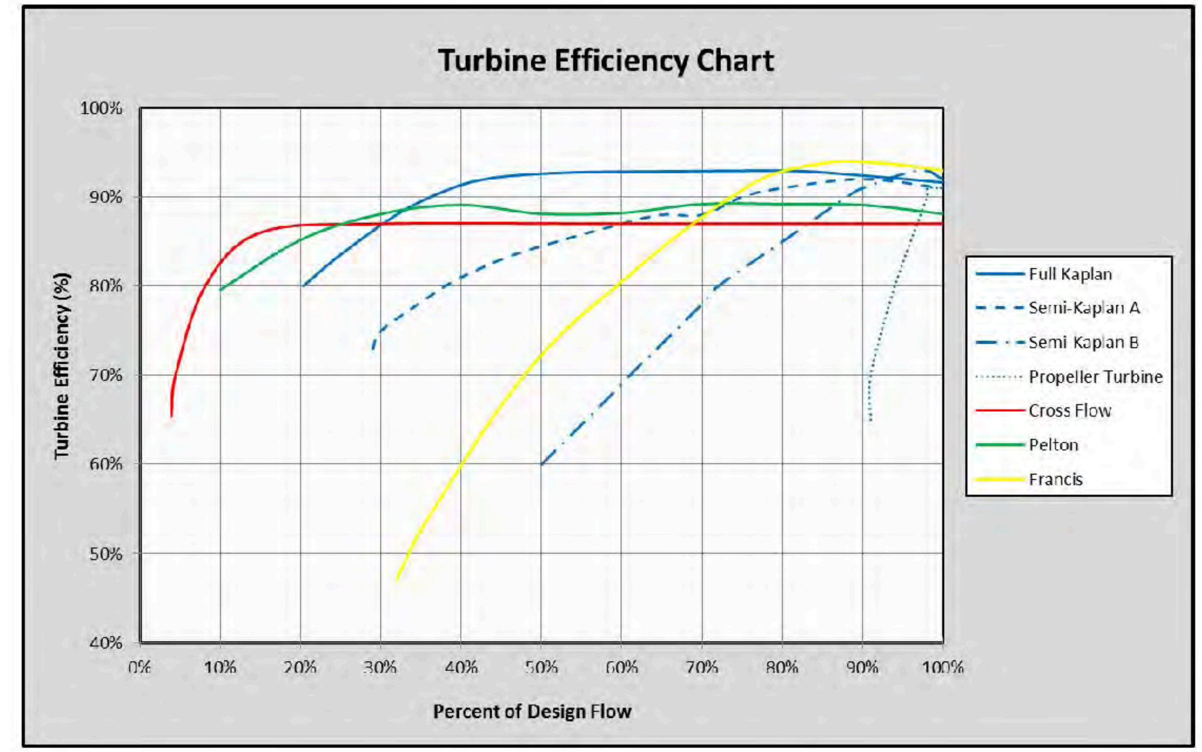

Figure 31: Turbine Efficiency Chart for Various Turbine Types
Source: The Colorado Energy Office "The Small Hydropower Handbook"

Both reaction and impulse turbines can operate over a wide range of flows as shown in Figure 31 and will generally have an operating range of 30 to 110 percent of the design flow. Generally, a flatter efficiency curve represents a turbine that can operate under broad ranges of head and flow. Curves that are steeper and narrower are indicative of a turbine designed for more focused ranges of operation. Efficiency curves specific to the type of turbine and design head and flow can be obtained from a manufacturer. These curves depict the relationship between the flow, head, and turbine efficiency under specific conditions. Use of these curves can be used to analyze how each turbine will perform under specific conditions. Turbine performance curves along with a flow duration curve can be used in the analysis of annual electric generation from the hydropower system.

Figure 32: Two Jet Pelton Turbine
Source: Gilkes Hydropower Systems

Turbine Types

As previously discussed, two broad turbine types exist – impulse and reaction. The following section addresses the style of turbine that can be installed at small hydropower sites in Wyoming.

i) Pelton Turbine

Pelton turbines, as shown in Figure 32 and Figure 33, are impulse turbines where one or more jets focus the water flow controlled by needle valves into buckets attached peripherally on the turbine runner. Pelton turbines are best suited in high head applications. Since the head is typically high, the flow rate tends to be low and can be as little as 0.2 cfs. The turbine requires the flow through the inlet to be

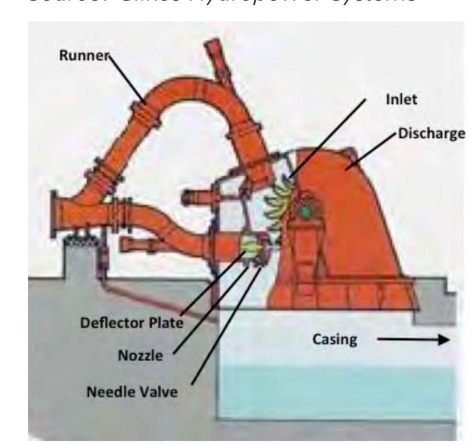

Figure 33: Pelton Turbine Schematic
Source: "Guide on How to Develop a Small Hydropower Plant" European Small Hydropower Association 2004

highly pressurized; as a result the penstock design is crucial and should be designed to handle the high pressures. In case of an emergency stop of the turbine, the jet may be diverted by a deflector so that it does not impinge on the buckets and the runner cannot reach runaway speed. In this way the needle valve can be closed very slowly, so that overpressure surge in the pipeline is kept to an acceptable level. A Pelton turbine can have multiple jets, up to six, that can maintain high efficiencies and greater power production under variable flows. The jets and buckets are designed to create minimal loss and to keep exit velocities to a minimum; this leads to a potential efficiency of 90 percent, even in small hydro applications. Multi-jet turbines can operate very efficiently at flows as low as 10 percent of the design flow as shown in Figure 31. Since Pelton turbines discharge to atmosphere they are not well suited if downstream pipeline pressures are required, such as a municipal system installation.

ii) Turgo Turbine

The Turgo turbine, as shown in Figure 34 and Figure 35, is an impulse turbine developed from the Pelton turbine and utilizes much of the same technology. Turgo turbines are typically utilized for lower heads and higher flows than Pelton turbines. The efficiency of a Turgo is lower than the Pelton, but retains the ability to support a broad flow range. The main physical differences between the two relate to the flow path of water through the turbines and the cup shape on the runners.

Figure 34: Turgo Turbine Runner
Source: Gilkes Hydropower Systems

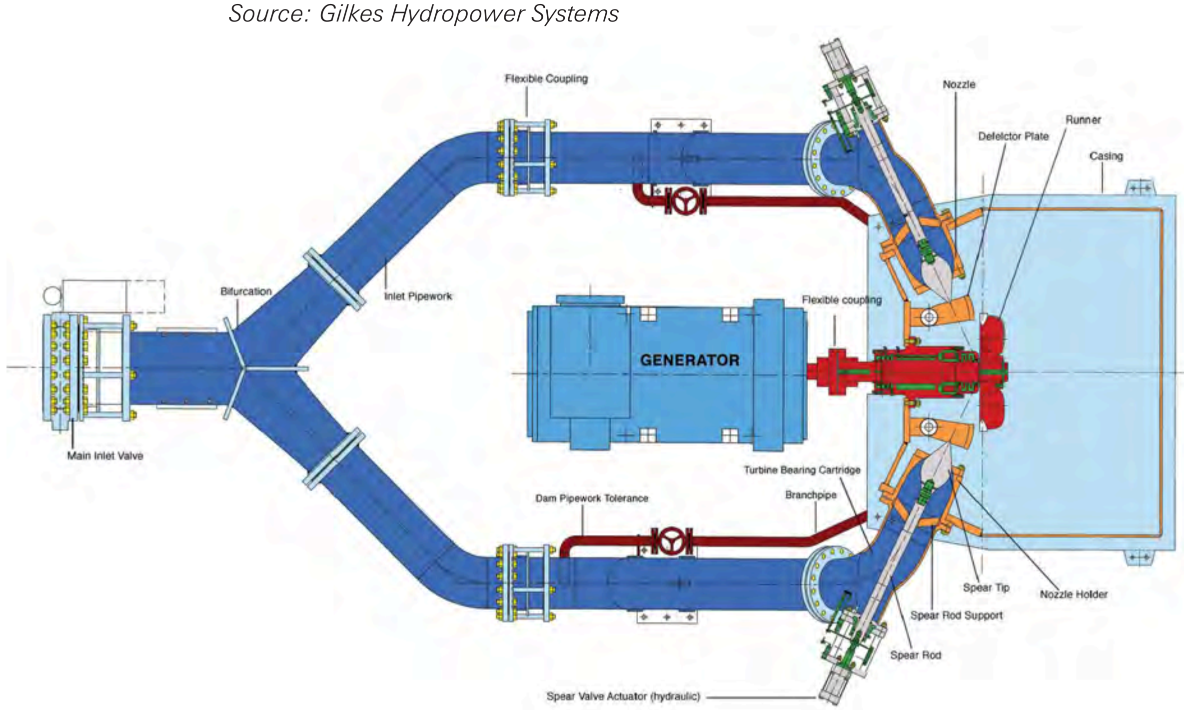

Figure 35: Turgo Turbine Schematic
Source: Gilkes Hydropower Systems

iii) Cross Flow Turbine

The cross Flow turbine, as shown in Figure 36 and Figure 37, is an impulse turbine named for the way the water flows across the runner. Most cross flows have two or more inlet guide vanes and can maintain a high efficiency over a wide range of flow rates. By altering the operation of the inlet guide vanes to better suit flow conditions, flow can be directed at just a portion of the runner during low inflow, or the entire runner when higher flows dictate. As evident from the efficiency curve, the Cross Flow is able to maintain a consistent efficiency. Cross flow turbines can operate under a wide range of head, spanning from approximately 6 feet to 650 feet, although it becomes less effective for heads greater than 130 feet. The major advantage of a cross flow turbine is it can operate efficiently over a wide range of flows, as little as 1.5 cfs, up to 175 cfs, making it well-suited for seasonal flows. The self-cleaning design and standardized componentry lends to very little maintenance and prolonged life. Typical power outputs range from 5 kW to 100 kW, though they can actually be up to 3 MW on the very largest systems; however, there are generally better turbine choices for these higher power outputs.

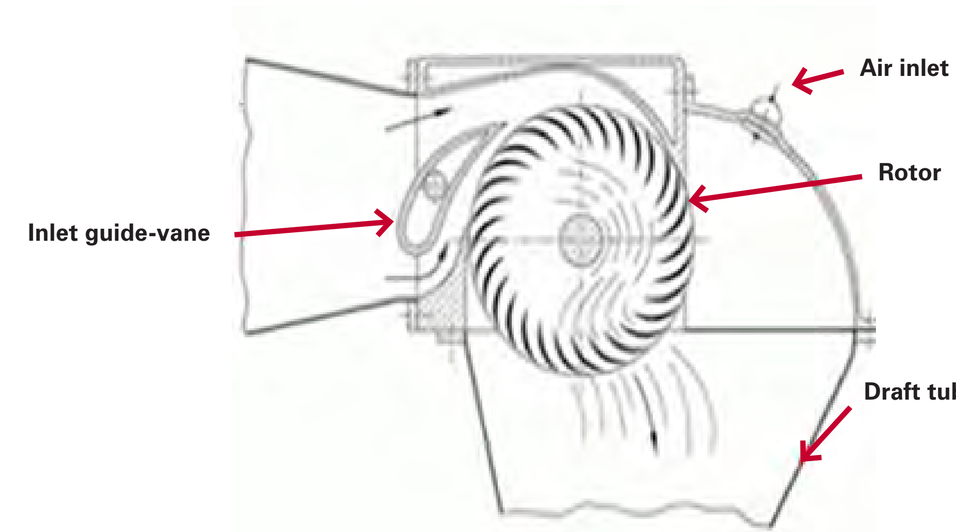

Figure 36: Cross Flow Turbine in Cross-section
Source: Renewables First

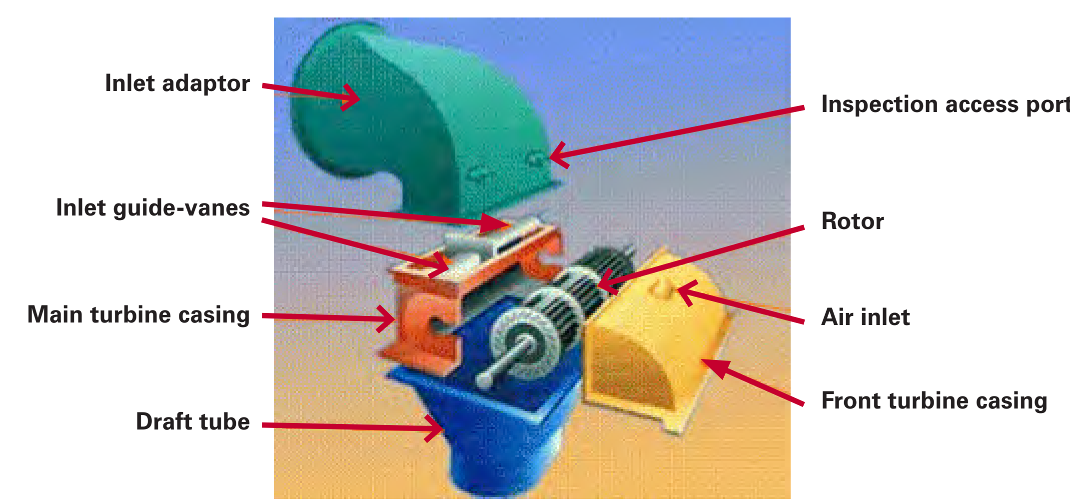

Figure 37: Cross Flow Exploded Schematic
Source: Renewables First

Figure 38: Francis Turbines at Carter Lake, CO
Source: Gilkes Hydropower Systems

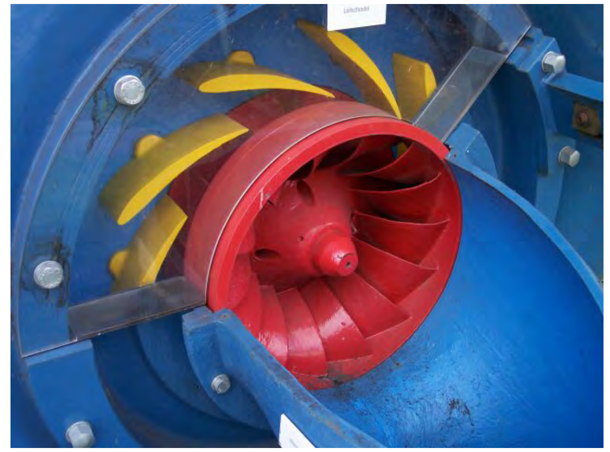

Figure 39: Francis Turbine Runner and Guide Vanes
Photo courtesy of Stahlkocher

iv) Francis Turbine

The Francis turbine, as shown in Figure 38 and Figure 39, is a reaction turbine and the traditional turbine for standard, medium head. It has a reliable, simple construction with adjustable guide vanes and fixed runner blades. The efficiency curve shows the Francis turbine has a higher peak efficiency than other turbines but has a narrow operating range. The inlet water flow is always radial, and the outlet is axial through a draft tube. The water enters the turbine by the spiral scroll case and flows through adjustable guide vanes or wicket gates, whose function is to control the water flow into the runner and adapt the inlet angle of the flow to the runner blades angle. Guide vanes can be used to shut off the flow to the turbine in emergency situations. A butterfly valve on the turbine inlet is also an emergency means to shut off the flow to the turbine. The runner blades on a Francis turbine are designed to throttle the flow during a run-away event; however, the sudden reduction of flow and thus velocity will create a transient surge and cause water hammer in the pipeline. The amount of increased pressure would depend on the change in the water velocity, and an extensive transient surge analysis is required to determine the pressure increase and design of surge protection tanks or other design measures. The Francis turbine can typically operate in run-away mode for a limited amount of time. This allows for the slow closure of the wicket gates or turbine inlet valve and turbine shut down. The Francis turbine can be used in-line with an existing pipeline and has the ability to maintain downstream pressure requirements. This application is useful in municipal installations where pipeline distribution pressures are required.

v) Kaplan Turbine

The Kaplan turbine, as shown in the figures below, is a reaction turbine that is highly adjustable in both the pitch and the runner blades as well as the inlet guide vanes. This adjustability increases efficiency and allows for a larger flow operating range. Figure 40 shows the varied positions of the runner blades to accommodate changing flows. A Kaplan is ideal for low head sites with net head ranging from 10 feet to 65 feet. Since Kaplan turbines can operate under low heads, optimally the turbine will have large flows through the turbine. The peak discharge for which the Kaplan operates ranges from approximately 100 cfs to 1,050 cfs.

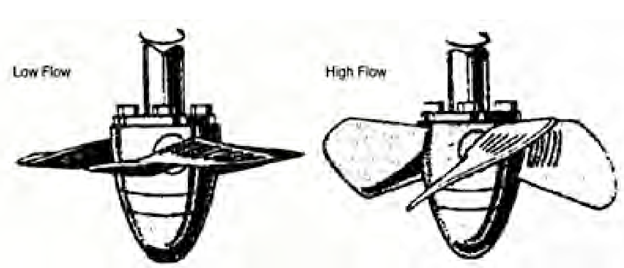

Figure 40: Kaplan Turbine Rotor Blade Positions
Source: Renewables First

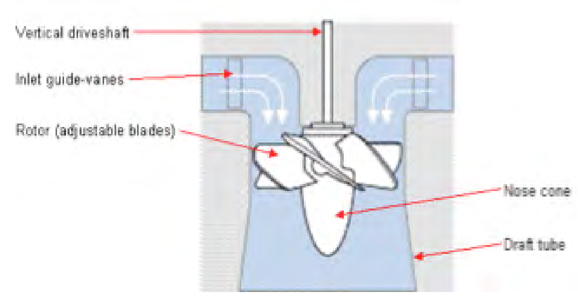

Figure 41: Basic Layout of a Kaplan Turbine
Source: Renewables First

The turbine works by utilizing flow through the inlet guide vanes that acts upon the propeller-like blades to create shaft power. While the Kaplan is relatively expensive compared to other turbine types, its adjustability and higher efficiency adds to its appeal. Different versions of the Kaplan are available for varying conditions, which can reduce the price of the turbine. Kaplan turbines that have both adjustable inlet guide-vanes and adjustable rotor blades are known as being "double regulated" or full-Kaplan turbines. The variant of Kaplan turbines that only have adjustable inlet guide-vanes or adjustable rotor blades are known as semi-Kaplans. Although the performance of semi-Kaplans is compromised when operating across a wide flow range, for applications where the flow does not vary greatly, they can be a more cost-effective choice. Figure 43 shows how the efficiency varies across the operating flow range for a full-Kaplan (curve A), a semi-Kaplan with adjustable blades (curve B) and a semi-Kaplan with adjustable inlet guide-vanes (curve D). It also shows the efficiency curve for a propeller turbine, a Kaplan with both fixed blades and fixed inlet guide-vanes (curve C), and an impulse turbine, such as a Pelton (curve E).

vi) Pump-as-Turbine

The pump-as-turbines, as shown in Figure 44, are reaction turbines that utilize a standard centrifugal pump running in reverse. Instead of using an electric motor to drive the pump, a pump-as-turbine operates by moving the flow through them in reverse, which causes the motor to become a generator. In most cases, it is more reasonable to have a direct drive, in which the pump shaft is connected directly to the generator, rather than fitting the system with a belt drive. Pump-as-turbines are generally fixed flow, and multiple turbines can be installed to account for varying flows. Pump vendors (e.g. Cornell Pump) have tested a range of pumps running as turbines and can provide a standardized product often less expensive than a custom Francis or Pelton turbine. Several different sizes and

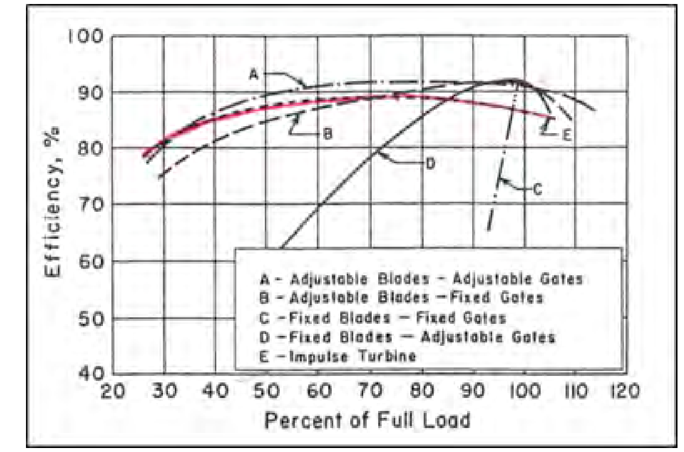

Figure 42: Kaplan Turbine Efficiency Comparison
Source: Hydropower Engineering Handbook Arndt and Gulliver 1991

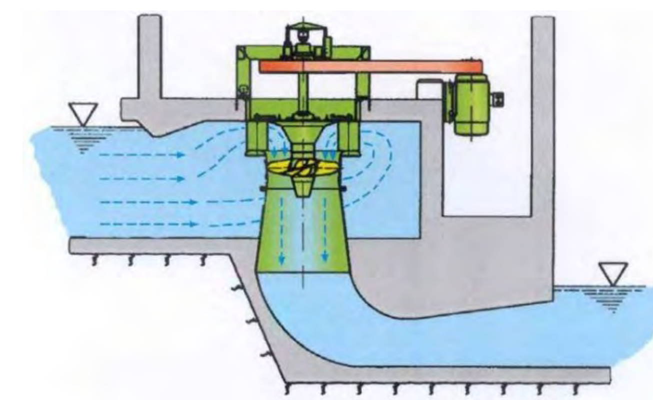

Figure 43: Cross-section of a Typical Vertical Axis Kaplan System
Source: Renewables First

Figure 44: Centrifugal Pumps Acting as Pump-as-Turbines
Source: Cornell Pump Company

configurations are available and can operate under a large range of head and flow. Since pump-as-turbines are fixed flow, they operate in "on/off." When the flows exceed the design flow of the turbine they are switched on, and any flows greater than the design flow of the turbine would be bypassed. When the flow rate is less than the design flow of the turbine, the unit is switched off, and power is not generated. Pump-as-turbines are not well-suited for variable flow conditions. If flow rates are variable, the pump-as-turbines could start up and shut down multiple times causing stress on the turbine, generator, and piping, which could reduce the overall life of the equipment. Since pump-as-turbines are reaction turbines, surge pressures in the pipeline must be considered when the turbines shut down. Pump-as-turbines are well-suited for agricultural installations at the base of a center pivot where flow rate is consistent.

Generator

The generator converts the rotational power from the turbine shaft into electrical power. Efficiency is important at this stage as well, but most modern well-built generators deliver high efficiencies. There can be big differences in the type of power generated, however. Direct current (DC) generators can be used with very small systems but typically are augmented with batteries and inverters for converting the power into the alternating current (AC) power required by most appliances. AC generators are normally used in all but the smallest systems. Common household units generate 120 VAC (volts AC) and 240 VAC, which can be used directly for appliances, heaters, lights, etc. AC voltage is easily changed using transformers, which makes it relatively simple to drive other types of devices or transmit over long distances. Depending on power requirements, either single-phase or three-phase AC generators are chosen in a variety of voltages. Larger generators are typically three-phase and 480 volts. There are two main types of generators: induction and synchronous. Induction generators rely on the electric grid to control the speed and frequency; synchronous generators monitor grid frequency and voltage and automatically adjust generation to match. If the electric grid goes down, induction generators have to be shut-down to prevent "free-wheel" and will not operate; synchronous generators can be designed to continue to operate if the grid goes down. Induction generators are more common in micro-hydro applications and are generally less expensive than synchronous generators. Synchronous generators are necessary in larger hydropower installations and off-grid applications.

Controls

Turbine and generator controls are typically supplied with the water-to-water package, but there are different types of controls that can be used for different applications.

i) Grid Interconnection Controls

Grid interconnection controls, including switchgear, synchronize frequency and voltage to enable coupling with the grid. It will also safeguard both equipment and the grid in case of failure. The system will monitor the grid frequency and voltage to automatically adjust generation to match. This is a fundamental interconnection requirement for all utilities. Additional capabilities may be included in customized controls including water level monitoring and operation of flow control valves. Switchgear and transformers are used to step-up the generated voltage to line voltage for distribution to the grid.

ii) Emergency Shutdown System

The ability of the system to disconnect automatically is also a fundamental interconnection requirement. If the grid goes down, the generator must disconnect from the grid within two seconds to prevent additional power from feeding back into the grid for the safety of line workers and general public. The controls will detect the loss of power and automatically disconnect the generator. Once the generator is no longer experiencing a load, it will tend to increase speed if the turbine is still passing water and turning the generator. If the turbine is allowed to spin at runaway speed, there is potential it will spin too fast and water will not be able to pass through the turbine. The sudden reduction of velocity in the pipeline can cause a catastrophic pressure surge and can also damage the generator if allowed to spin freely. The emergency shutdown system will protect the system from overspeed. There are several safeguards that can be included in the system depending upon turbine type. As described above, different types of turbines are better suited to remove water from entering the turbine and spinning the runner. Impulse turbines use deflectors to simply deflect the water from the runner in case of emergency shutdown. The control valves can then be closed slowly to minimize pressure surges in the pipeline. Reaction turbines need to shut down slowly and water flow stopped through the penstock or directed away from the penstock. This can be controlled by automatic valves that close at a controlled rate to prevent an excessive pressure surge. Surge tanks are often commonly installed with reaction turbine systems.

iii) Off Grid Applications

As discussed previously, the majority of small hydro applications are interconnected with the grid and use the grid to control and regulate the frequency and voltage of the generator. Without the grid to regulate the generator, a much more site-specific assessment is needed to determine equipment needs to ensure safe, effective operation. Generally, a governor or load management system is needed (also called balance-of-system). A load management system can distribute generation to loads according to preset priorities and includes one load to shed excess generation. The system is used to condition the electricity, safely transmit the electricity to the load that will use it, and store or shed the electricity. Loads to shed excess generation can include battery charging or heat sinks such as water or ground heaters. A governor is necessary to balance varying loads and generation that do not have the benefit of the grid. Depending on the needs of the system, load management systems can account for half of total system costs.

System Costs

Generalizing the cost for turbines is difficult, as they often are designed specifically to accommodate individual site conditions. This is particularly true for units above 100 kW. Significant cost savings can be achieved if the hydroelectric system is installed at a site with existing civil infrastructure, such as a pipeline or other conveyance method and diversion structure. The appendix contains a list of turbine manufacturers, and when contacted directly with detailed site conditions (head and flow) of the proposed hydro site, an appropriate quote can be obtained.

The Electric Power Research Institute (EPRI) published a report, Quantifying the Value of Hydropower in the Electric Grid Plant Cost Elements in 2011.1 This report includes cost estimate formulas for reconnisence level hydropower development projects and is useful to estimate development costs of a hydropower facility. These cost formulas are generalized and adequate for reconisence level studies; however, more detailed cost estimates should be used when designing and analyzing project feasibility. Table 2 lists the cost elements typically associated with the development of small hydropower installations.xv

According to the EPRI, the supply costs for the turbine, generator (lesss than 100 kW), and controls package can range from $1,000 to $2,000 per kW depending on unit type and operation, and installation costs can range approximately 50 percent of the equipment costs. As a rule of thumb, the civil works costs are less than or equal to the equipment costs (turbine, generator, and controls), and the total capital costs can range from $2,000 to $8,000 per kW of installed capacity, depending on the system's capacity and location.[xv]

Table 2: Probable Cost Elements for Small Hydropower Facilities

Project Site: TBD	
Typical Equipment Alternative: TBD	
Typical Installed Capacity: TBD kW	
Preparation of Final E/M Design	$
Permitting/Mitigation	$
FERC Small Conduit License Exemption	$
FERC Qualifying Facility Self Certification	$
Interconnection Application	$
FERC Small Conduit License Exemption	$
Other Permits and Miscellaneous Fees	$
Legal Fees	$
Acquisition of Access and Rights of Way	$
Cost of Project Components	
Power Transmission	
Interconnection Costs	$
Service Transformer	$
Secondary Service, Disconnect and Metering	$
Hydropower Plant	
Turbine Generator & Controls Supply	$ See Comment 1
T/G Installation and Other E/M Modifications	$ See Comment 2
SCADA Input	$ See Comment 3
Structural and Site Work Allocation	$ See Comment 4
Mobilization and Demobilization	$
Temporary Facilities and Equipment Rental	$
Miscellaneous	$
Subtotal Project Components	$
Field & Technical Support @ 10% of Above Subtotal	$
Profit, Insurance, Bonds, etc. @ 15% of Above Subtotal	$
Subtotal	$
Contingency @ 20% of Above Subtotal	
Total Construction Costs	$
Total Project Costs ($)	$
	$ See Comment 5

Comment 1: The supply costs for the turbine, generator, and controls package can range from $1,000/kW to $2,000/kW depending on the unit type, operating head/flow range, and required protections. Turbines are assumed to be Cornell type, in-line horizontal direct drive configuration. Generators are assumed to be induction type.
Comment 2: Equipment installation can range approximately 50% (+/-) of the equipment supply costs.
Comment 3: SCADA input can range approximately $10,000 to $15,000.
Comment 4: As a rule of thumb, the civil works costs should be less than or equal to the equipment costs.
Comment 5: The total project costs can range approximately $2,000/kW to $8,000/kW depending on specific site characteristics and impacts to existing infrastructure.

PERMITTING AND LICENSING

The regulatory and permitting requirements for hydropower systems can be extensive, however, recent federal legislation aims to simplify the permitting process for small hydropower projects. The following section describes the regulatory and permitting process and requirements for implementing small hydropower projects.

Federal Energy Regulatory Commission

The Federal Energy Regulatory Commission (FERC), through section 23(b)(1) of the Federal Power Act (FPA), requires hydropower projects to be licensed or granted an exemption from licensing. FERC provides two possible exemptions, the Conduit Exemption and the 10-MW Exemption. FERC also allows certain Qualifying Conduit Hydropower Facilities up to 5-MW to not require a license or an exemption.

Qualifying Conduit Hydropower Facility

FERC may not require certain hydropower facilities on non-federally owned conduits with installed capacities up to 5-MW to be licensed or exempted. The applicant must file a Notice of Intent to Construct a Qualifying Conduit Hydropower Facility with FERC and show the conduit is not primarily for the generation of electricity and was not licensed or exempted on or before August 9, 2013. The project cannot be located at an impoundment. There are no consultation requirements and are categorically exempt from preparing a NEPA document

Conduit Exemption

FERC allows for a small hydroelectric facility up to 40 MW using a man-made conduit operated primarily for non-hydroelectric purposes to potentially be eligible for the conduit exemption. Under the conduit exemption, FERC requires the applicant to have all real property interests necessary to develop and operate the hydropower project, and the facility cannot occupy federal lands. The conduit on which the project is located must already exist and cannot be included as project work associated with the development of the hydropower facility. The conduit must be used for existing agricultural, municipal, or industrial consumption. The project also cannot be located at an impoundment (e.g., dam). Applications for exemptions of small hydroelectric conduits are categorically exempt from the requirement for an Environmental Assessment (EA) or Environmental Impact Statement (EIS); however, FERC can require an EA or EIS to be prepared if the project appears to have adverse environmental impacts.

The first step to obtaining a conduit exemption is to file preliminary information to FERC and stakeholders (defined below) so these entities can understand the proposed project, identify any environmental issues, identify any information needs, and provide comments and recommendations for the project. The information to be provided to FERC is called an "Initial Consultation Document" and includes the following

- Proof of land ownership,
- Descriptions of the conduit,
- Water source and destination description,
- Head and flow characteristics,
- Turbine description and drawings,
- Turbine site boundary, and
- Turbine site environmental and cultural information.

The next step is to identify and consult with project stakeholders. Project stakeholders include relevant federal and state agencies, Indian tribes, non-governmental organizations, and interested parties. The consultation provides agencies and public an opportunity to voice any concerns or request any studies that may be relevant to the project. The consultation is a three-stage process. The first stage is to hold at least one joint meeting with stakeholders to explain the project and to discuss the projects potential environmental effects, and to find out if there are any needed studies. The second stage is to conduct any studies necessary and to prepare and receive comment on the draft exemption application. The third stage is to prepare and file the final exemption application with FERC and stakeholders. The three stages of the consultation process must be documented per 18 C.F.R. § 4.38. There is no filing fee required for application. There is no term limitation with conduit exemptions; therefore, the exemption is issued in perpetuity.1

In most cases, a FERC conduit exemption can be obtained within one year of initial development of application materials. FERC has issued conduit exemptions for other some projects in as little as two months.

10 MW Exemption

FERC allows for a small hydroelectric project up to 10 MW to potentially be eligible for the 10 MW exemption. The applicant can propose to install or add capacity to a project at a non-federal, pre-July 22, 2005, dam or at a natural water feature. The project can be on federal lands but cannot be located at a federal dam. FERC requires the applicant to have all real property interests necessary to develop and operate the hydropower project. Unlike the conduit exemption, a NEPA document must be prepared. The consultation requirements are the same as for the conduit exemption as described above. There is no filing fee required for application. There is no term limitation with 10 MW exemptions; therefore, the exemption is issued in perpetuity.

Certification as a Qualifying Facility

FERC certifies small power production facilities as qualifying facilities under the Public Utility Regulatory Policies Act of 1978 (PURPA) to provide certain benefits to the facility under federal, state and local laws. The benefits include 1) the right to sell energy or capacity to a utility, 2) the right to purchase certain services from utilities, and 3) relief from certain regulatory burdens. A qualifying small power production facility is a generating facility of 80 MW or less whose primary energy source is a renewable resource and is certified pursuant to 18 C.F.R. § 292.207.

Bureau of Reclamation – Lease of Power Privilege[1]

The development of non-federal hydroelectric powerplants on existing Reclamation facilities (e.g., dams or conduits) requires either a Lease of Power Privilege (LOPP) issued by the Reclamation or a License or License Exemption from FERC as previously described. Permitting authority is mutually exclusive; a Reclamation facility is either within the Reclamation's or FERC's permitting jurisdiction. Accordingly, development proceeds through either a LOPP or FERC License/Exemption, but not both. Hydropower developers are free to choose which agency to contact, and it is up to the Reclamation or FERC to determine the lead permitting authority[1].

An LOPP is a contractual right given to a non-federal entity to use a Reclamation facility for electric power generation consistent with Reclamation project purposes. Reclamation's main concern in awarding a LOPP is that the integrity of Reclamation facilities are not impaired. A new hydropower facility must not interfere with existing operations, jeopardize existing water rights, or create any safety issues.

Under an LOPP, the lessee is responsible for compliance with NEPA and the Endangered Species Act (ESA). Reclamation is responsible for lease development, as well as review and approval of designs, plans, and specifications and NEPA documentation.

Under an LOPP, title of the federal facility remains with Reclamation. Title of the hydropower facility is with the lessee unless contracted otherwise. Reclamation has the first right to take over the hydro plant in the event of a sale or default.

1 This section was taken from The Colorado Energy Office *The Small Hydropower Handbook*, 2013

Once selected for development of an LOPP, the potential lessee must develop a cost recovery agreement with Reclamation for Reclamation costs related to the development of the lease including but not limited to NEPA, review of designs, administrative costs, construction, operation, maintenance, and security.

Initiation of an LOPP application starts with an application letter to Reclamation requesting an LOPP. In response, Reclamation posts a formal solicitation in the Federal Register asking for LOPP applications. After selection of the lessee, the LOPP process cannot be finalized until after completion of the NEPA process. Assuming the environmental process does not uncover any problematic issues resulting in a "Finding of No Significant Impact," the process moves to final negotiation of the LOPP. Once signed, the typical LOPP length is 40 years. Additional information regarding the LOPP process is available on Reclamation's Lease of Privilege website.[viii]

Army Corps of Engineers[2]

The Army Corps of Engineers regulates all construction activities occurring in "waters of the U.S." by authority of the Clean Water Act, Section 404. Construction activities include the removal or placement of fill below the ordinary high water mark. This can include any natural waterway or wetland. There are three levels of Army Corps involvement in a hydropower project, 1) if the project is on a canal or conduit with no wetland impacts, the Army Corps may have no involvement, 2) if the construction activity is minor and/or the project qualifies for a FERC exemption, the project may qualify for a nationwide permit, or 3) if the amount of disturbance or quantity of dredge or fill is more than what qualifies for a nationwide permit, an individual permit is required.

Nationwide Permits

Nationwide permits are designed for specific activities that will have little impact on the water or environmental quality. These permits are subject to fewer requirements than an individual permit and are meant to expedite the permitting process. There are several nationwide permits that could apply to hydropower construction activities.

i. Nationwide permit #17 for Hydropower

For discharges or dredge or fill material associated with hydropower projects having (a) less than 5 MW of total generating capacity at existing reservoirs, where the project, including the fill, is either licensed or exempted by FERC. (Section 404)

ii. Nationwide permit #18 for minor discharges

For minor discharges of dredged or fill material into all waters of the United States, provided the activity meets all of the following criteria: (a) the quantity of discharged material and the volume of area excavated do no exceed 25 cubic yards below the plane of the ordinary high water mark; (b) the discharge will not cause the loss of more than 1/10-acre of waters of the United States; and (c) the discharge is not placed for the purpose of a stream diversion. (Sections 10 and 404)

iii. Nationwide Permit #19 for minor dredging

For dredging of no more than 25 cubic yards below the plane of the ordinary high water mark or the mean high water mark from navigable waters of the United States (i.e., section 10 waters). This NWP does not authorize the dredging or degradation through siltation of coral reefs, sites that support submerged aquatic vegetation (including sites where submerged aquatic vegetation is documented to exist but may not be present in a given year), anadromous fish spawning areas, or wetlands, or the connection of canals or other artificial waterways to navigable waters of the United States (see 33 CFR 322.5(g)). (Sections 10 and 404)

2 This section was taken from The Colorado Energy Office The Small Hydropower Handbook, 2013

Individual Permit

An individual permit must be obtained, if a project does not fit into the requirements of one of the nationwide permits. These permits will take more time to obtain and have more requirements than a nationwide permit. Most small hydropower installations would likely qualify for a nationwide permit; however, to ensure adequate compliance with the Clean Water Act, the local U.S. Army Corps of Engineers office should be contacted and consulted regarding specific projects.

Wyoming Department of Environmental Quality Water Quality Division

The Wyoming Environmental Quality Act mandates permits are required for construction or modification of public water supplies. Plan review by the Wyoming Department of Environmental Quality – Water Quality Division (WDEQ-WQD) is required prior to bidding or constructing a project to obtain a permit to construct.

In addition, the WDEQ-WQD will complete a Section 401 certification to ensure activities authorized under a FERC exemption or Section 404 Army Corps of Engineers permit meet state water quality standards and do not degrade water quality. These certifications are required if a federal permit is issued for the facility. Wyoming Pollution Discharge Elimination System (WYPDES) permits are required for the discharge of stormwater pollutants associated with construction and also any construction dewatering.

Wyoming State Engineer's Office

The Wyoming State Engineer's Office (SEO) regulates and permits the beneficial use of water in the state. Development of a hydropower project will require the water right to list hydropower as a permitted use. Hydropower can be added to a water right as a permitted use by petitioning the State Board of Control (see prior discussion in "Site Assessment" for additional information).

Wyoming Game and Fish Department

The Wyoming Game and Fish Department would be considered a stakeholder during the FERC permitting process and would provide comment during the FERC licensing process. Usually, the U.S. Fish and Wildlife Service and the Wyoming Game and Fish Department work in conjunction with one another as stakeholders during the FERC licensing process

State of Wyoming Department of Fire Prevention and Electrical Safety

The Electrical Safety Division of the Department of Fire Prevention and Electrical Safety is responsible for issuing electrical wiring permits and performing inspections of electrical installations. An electrical wiring permit is required anytime the electric utility needs to connect, disconnect, and restore electrical power. A wiring permit is required before work is started, and the person or contractor installing electrical wiring is responsible for obtaining the wiring permit. State versus local jurisdiction varies by county and municipality.[xvii]

City/County Planning and Development Office

A city or county building permit may be required for the development of hydropower projects. Prior to the issuance of a building permit, a plan review is required to ensure all proposed construction is in accordance with Wyoming Public Works standard specifications and city/county standard specifications.

POWER MARKET

Once the potential energy generation from a project has been determined, based upon head, flow, and turbine type, the next step is to determine the value of the electricity generated. Initial discussions with the local electric utility can determine the value energy can be sold to the electric utility and identify interconnection requirements. Interconnection requirements and the value of the energy can vary considerably depending on the electric utility and size of the hydroelectric generation facility. The most likely purchaser of the generated electricity for a given project is the local electric utility. Most of Wyoming's electric utilities, including investor-owned electric utilities, rural electric cooperatives, and municipally owned utilities, are regulated by the Wyoming Public Service Commission (PSC). Figure 45 shows the service areas for electric utilities in Wyoming.

Power Purchase Agreement

Energy is typically sold in kilowatt-hour (kWh) increments through a power purchase agreement (PPA) for systems larger than 25 kW. A PPA is a contract between the owner of the electric generation facility and the purchaser of the electricity. The PPA defines the conditions of the sale of electricity between the two parties and can include delivery of electricity, penalties for under-delivery, payment terms, and rates and termination. In addition to purchasing energy, a utility will typically pay a firm capacity price if a minimum capacity measured in kilowatts (kW) can be guaranteed. The firm capacity price could potentially increase the power revenue approximately 30 to 50 percent.

Utilities typically purchase energy at an avoided cost less than the retail rate. Avoided costs are essentially the marginal cost for a public utility to produce one more unit of power. Since purchasing energy from a qualified facility will reduce the utilities need to produce this additional energy themselves, the price utilities pay a qualified facility's generated energy has been set to an avoided, or marginal cost. These prices are designed to simulate a "market price" for energy. Some utilities in Wyoming, such as investor-owned utilities, have avoided costs on file with the PSC.[xviii] Utilities that have avoided costs on file with the PSC provide a straightforward way to assess the value of power. Due to regulatory structure, most rural electric cooperatives do not have avoided costs on file with the PSC. In a case where a utility has not established an avoided cost, negotiations are held on a case-by-case basis. This process can be time-consuming and would need to be approved by the PSC prior to execution of a power purchase agreement

Interconnection Requirements

Interconnection requirements and costs vary depending on the electric utility, size, complexity, and type of interconnection of the project. Most project interconnections will also require approval by a state electrical inspector.

For a smaller, residential scale project, a simple net metering agreement and interconnection agreement can usually be arranged with the local utility without difficulty. Most Wyoming utilities (only municipally owned utilities are excluded) are obligated to provide net metering for systems up to 25 kW. Generally, the interconnection requirements under net metering require the use of switching equipment capable of isolating the system from the grid. Net metering is described in more detail below.

For larger "small" hydropower systems (greater than 25 kW), the local utility will likely require an interconnection study to determine whether or not the project would cause any adverse impacts on utility infrastructure or operations. This study is typically completed by the utility and paid for by the owner of the facility. Results identify the interconnection requirements the customer must fulfill to connect the unit to the utility grid. Some utilities have specific interconnection requirements while others may simply follow or comply with the nationally recognized IEEE Standard 1547.

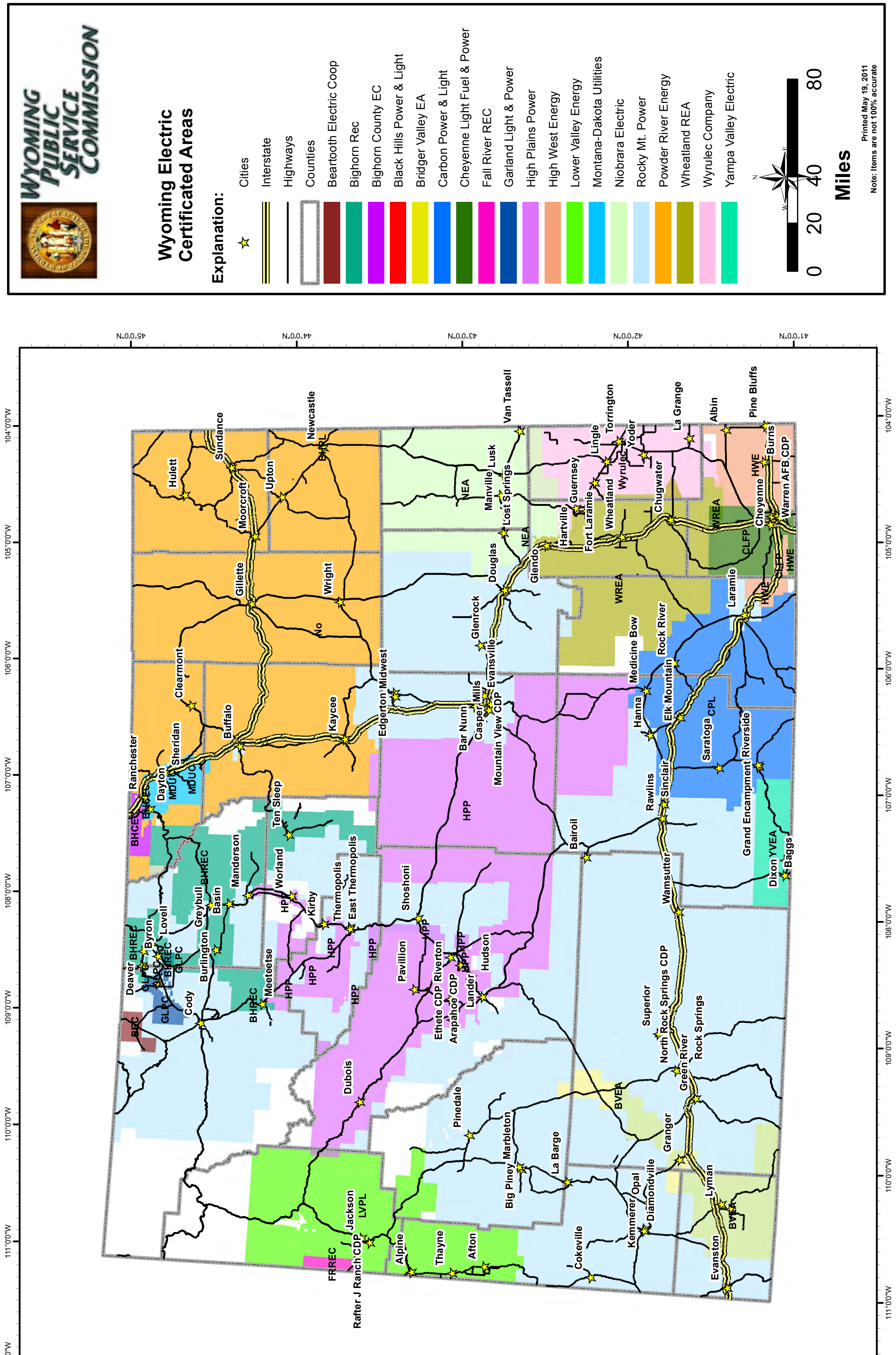

Figure 45: Wyoming's Electric Utility Service Areas

Source: Wyoming Public Service Commission

Net Metering

Net metering is an electricity sales arrangement for consumers who develop small scale energy facilities. Under a net metering agreement, electricity from an eligible consumer-owned generation facility is used directly by the consumer. Generation in excess of the consumer's use is exported to the utility (grid). Consumer needs in excess of the self-generation is obtained from the utility. Meters record the energy generated (kWh) by the generating facility and the energy consumed from the electric utilities grid. If more energy is generated than consumed, the excess energy can be exported back into the grid, and the consumer receives a credit. The credits are usually carried over every month and at the end of the year, any credits remaining are paid at the avoided cost.

When load (electricity usage) is sufficient to use a large fraction of the electricity generated, then a net metering agreement is generally the most financially advantageous arrangement for a small hydropower facility (under 25 kW). Instead of selling the energy at an avoided rate, which is much less than the retail rate, the consumer can use the generated energy from the small hydropower facility to offset the retail rate purchased from the utility. This is the primary advantage to net metering. This is a typical scenario; however, net metering policies vary by each utility. Some utilities limit the amount of energy that can be generated, size of the generation facility (typically 25 kW or less), and how much the credits are worth. Net metering programs are adopted on a state level of legislation, and in Wyoming, investor-owned utilities are required to make net metering available for systems 25 kW or less.[xix]

When considering net metering, knowing the local utilities policy on net metering and how the excess generation will be sold or credited is important. In addition, knowing how far the generating facility is from the adjacent load and whether the annual electric load of the adjacent facility matches that of the proposed generation facility is also vital. Under Wyoming law, electricity cannot be sold to another entity in the franchised service area; it must be used by the generator, sold to a utility, or sold to a distant entity through a wheeling agreement with the intervening utility

Renewable Energy Certificates

A Renewable Energy Certificate (REC) represents the property rights to the environmental, social, and other non-power attributes of renewable electricity generation. An REC, and its associated attributes and benefits, can be sold separately from the underlying physical electricity associated with a renewable-based generation source. RECs are tradable instruments that can be used to meet voluntary renewable energy targets as well as meet compliance requirements for renewable portfolio standards. This allows organizations to support renewable energy development and protect the environment when green power products are not locally available. As renewable generators produce electricity, they typically create one REC certificate for every 1,000 kilowatt-hours (1 megawatt-hour) of electricity placed on the grid. Each REC denotes the underlying generation energy source, location of the generation, and year of generation, environmental emissions, and other characteristics associated with the generator. Unlike electricity, RECs do not need to be scheduled on a transmission system, and they can be used at a different time and location than the moment of generation. The generation source has to be certified by an independent certification process and then RECs can be tracked and sold through various tracking systems.

The Western Renewable Energy Generation Information System (WREGIS) is an independent renewable energy tracking system for the Western Interconnection, the geographic area of the Western Electricity Coordination Council (WECC) that includes parts or all of the western states, including all of Wyoming, Colorado, and Montana. WREGIS tracks renewable energy generation from units that register in the system and creates RECs for this generation. WREGIS users have private accounts similar to bank accounts in which certificates are deposited upon creation. Once a certificate is created, it can be transferred, retired, or exported to a compatible tracking system according to the needs of the certificate owner. For example, if a hydropower facility in Wyoming generates

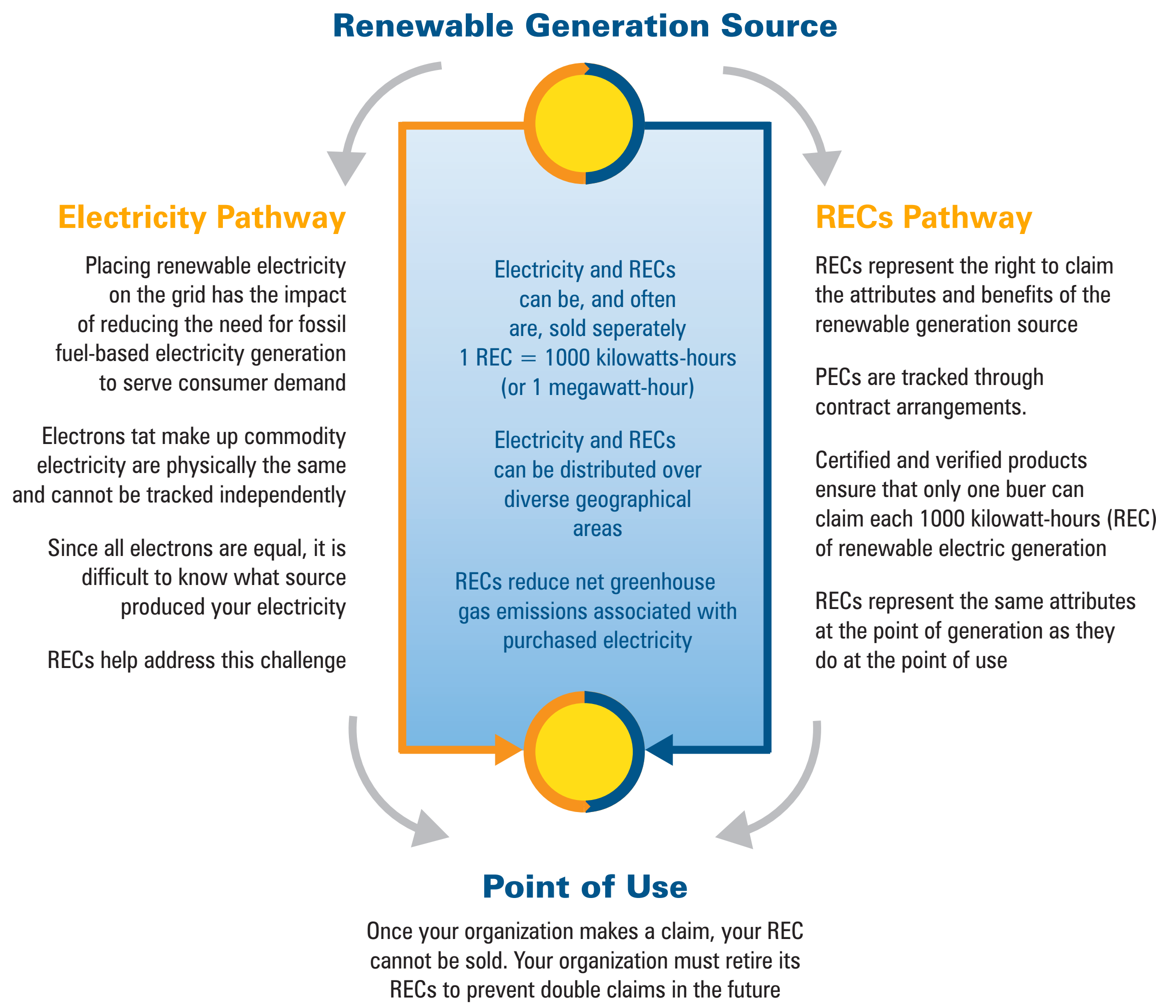

Figure 46: Renewable Energy Certificate Flow Chart
Source: United States Environmental Protection Agency

4,000 megawatt-hours (MWH) a year, the owner of the facility reports the generation to WREGIS and 4,000 RECs are created and deposited into their account. An electric utility located in California, which has a Renewable Portfolio Standard (RPS) and is required to provide a specific percentage of renewable energy, can then purchase the RECs generated by the Wyoming hydropower facility. The RECs are transferred from one account to the other and then retired so no other users can claim the REC. REC prices vary according to the market trends in the voluntary and compliance market.

Renewable Portfolio Standards (RPS) require electric utilities to provide specific percentages of renewable energy by certain dates, helping to support development of new renewable energy, including hydropower. Wyoming does not have a Renewable Portfolio Standard (RPS) so the local market is purely voluntary, and REC pricing is low. Adjacent states such as Colorado and Montana do have RPS, and RECs can be sold to utilities or other parties in these states.

AVAILABLE INCENTIVES, GRANTS AND LOANS

State Incentives

There are several state agencies that promote the development of water projects in Wyoming and provide funding in the form of grants and loans, some of which can be used to fund small hydropower projects. Important sources of potential financial assistance include:

- Wyoming Water Development Commission (WWDC) – Feasibility studies,
- Office of State Lands State Loan and Investment Board (SLIB) – Project financing,
- Wyoming State Revolving Funds Program (SRF) – Project financing.

Each provides services to distinct entities (e.g., municipalities or irrigation districts).

The WWDC receives general fund appropriations, as approved by the Wyoming State Legislature and passed in the omnibus planning bill, to fund planning studies and cost share in construction projects. The WWDC funds hydropower feasibility studies throughout Wyoming as part of planning. At this time, hydropower studies do not qualify for construction funding through the WWDC. Planning studies are 100 percent funded through the WWDC – meaning there is no cost to the project applicant. Eligible WWDC funding applicants shall be a legal entity, such as a municipality or irrigation district that can legally receive state funds, incur debt, and generate revenues to repay a state loan. The Water Development Program's Operating Criteria outlines requirements for new applications to the program such as a $1,000 application fee and a certified original of a resolution passed by the council or governing body of the sponsoring entity. There are other requirements such as the proposed projects must serve 20 or more municipal/domestic water taps with individual meters for each tap or 2,000 or more water righted acres. The applicant can apply for a Level II feasibility study if there is potential for hydropower development within their system. All applications for Level II projects new to the Wyoming Water Development Program must be submitted no later than August 15 of each year. There are different applications for municipal/joint powers water board water systems, agricultural water projects, and rural domestic water systems, so applicants should read the "Information for Applicants" link under Project Application Information on the WWDC website. The applicant will have to explain various details about their system and likelihood of hydropower development in the application. After all applications are received, the WWDC approves projects based on priority and type of project. Typically, hydropower projects are not a very high priority, but the WWDC has completed several hydropower feasibility studies in the past. Once a project is approved for funding, the WWDC is responsible for developing the scope of work in the contract and selecting consultants to complete the study and fund the project. Consultant selection occurs in early May each year and hydropower feasibility projects typically take one year to complete.

Once the feasibility study is completed, the results of the study are available for the project applicant so they can make an informed decision whether or not to pursue the construction of a project. The project owner can then apply to the Wyoming SLIB for a loan to construct the hydropower facility.

SLIB may provide loans to municipalities, irrigation districts, and special districts duly organized in the state to finance construction of hydropower development projects. All loan applications shall be accompanied by the feasibility study completed by the WWDC. If approved, the term of the loan cannot exceed 30 years and may be for a shorter term as determined by financial strength, repayment ability, security, and other factors. Typical terms of a loan from SLIB are 20 to 30 years at a 4 percent interest rate. SLIB also has a grant program, Chapter 3 – Mineral Royalty Grants, for which an application can be submitted for hydropower projects. The Office of State Lands website describes the application process in more detail.

Another potential funding opportunity for municipalities is the Wyoming State Revolving Funds Program (SRF). The Wyoming SRF consists of two separate but similar funds: the Drinking Water State Revolving Fund (DWSRF) and the Clean Water State Revolving Fund (CWSRF). Both funds are administered by the Wyoming Department of Environmental Quality, WWDC, and SLIB. Both funds make loans to public entities for infrastructure improvements and allocate a portion of the fund to green projects, including hydropower. SRF loans are normally at 2.5 percent interest rate up to 20-year term; however, at times SRF loans have even lower interest rates and/or include forgiveness of a portion of the principal when congressional appropriation bills contain special requirements. A municipality in Wyoming has recently acquired a 0 percent interest loan and 25 percent loan forgiveness from the DWSRF for the design and construction of a hydroelectric generation facility at the head of a water treatment plant. More detailed description of the funds and how to apply can be found on State Revolving Funds website.

Federal Incentives

Federal incentives include the Bureau of Reclamations' WaterSMART grant program, the U.S. Department of Agriculture's (USDA) Rural Energy for America Program (REAP), and the National Resources Conservation Service Environmental Quality Incentives Program (EQIP).

The Bureau's WaterSMART grant program can help fund hydro project development. Eligible WaterSMART grant applicants include states, Indian tribes, irrigation districts, water districts, or other organizations with water or power delivery authority in the western United States. Successful WaterSMART hydro grant recipients typically include not only a hydropower project but also some type of additional public benefit such as water conservation or in-stream flows.

The USDA's REAP can provide loan guarantees up to $25 million, project feasibility grants up to $50,000 covering 25 percent of study costs, and renewable energy project grants up to 25 percent of project costs with a maximum of $500,000. Hydropower is an eligible project type for REAP grants. Eligible REAP grant applicants are typically rural small businesses, including rural electric cooperatives, but not irrigation districts. Rural areas are generally considered those outside of Cheyenne and Casper.

The NRCS's EQIP provides financial and technical assistance to agricultural producers to address natural resource concerns and deliver environmental benefits. Agricultural producers and owners of non-industrial private forestland and tribes are eligible to apply for EQIP. Eligible land includes cropland, rangeland, pastureland, non-industrial private forestland, and other farm or ranch lands. The applicants must control or own eligible land, comply with adjusted gross income limitation provisions, be in compliance with the highly erodible land and wetland conservation requirements, and develop an NRCS EQIP plan of operations prior to receiving funding. Irrigation districts, ditch companies, municipalities, or other entities do not qualify.

The Internal Revenue Service (IRS) has established an energy investment tax credit program that allows taxpayers to take advantage of federal tax incentives. Hydro projects greater than 150 kW are eligible for either the Investment Tax Credit (ITC) or the Production Tax Credit (PDC); the taxpayer is free to choose one or the other. The ITC can be claimed in year one of a project for 30 percent of depreciable capital costs and reduces the project's depreciable basis by 15 percent. The PDC is worth 1.1¢/kWh for the first ten years of the project's operations (with the PDC value escalating with inflation). Only private sector entities are able to take advantage of these tax credit incentives, and the eligible systems must be placed in service on or before December 31, 2016. In general, the original use of the equipment must begin with the taxpayer, or the system must be constructed by the taxpayer. Businesses that receive other incentives are advised to consult with a tax professional regarding how to calculate this federal tax credit.

Utility Incentives

Some Wyoming utilities offer incentives in the form of low-interest loans or grants to qualified renewable energy generating facilities.

Rocky Mountain Power's Blue Sky Program allows customers to purchase renewable energy to supply their home or business for a flat rate per 100 kWh per month. Rocky Mountain Power (RMP) buys RECs on the customer's behalf to equal their Blue Sky purchases. Annually, RMP teams up with Blue Sky customers to help support the installation of community-based, non-residential renewable energy projects in the RMP service area. Low-impact hydro projects are eligible to receive Blue Sky funds. The project has to be locally owned, commercial-scale with a capacity less than 10 MW and completed by the end of the year the funding is secured. The level of funding available is determined on a case-by-case basis; however, RMP is interested in providing enough funding to selected projects such that they will be economically feasible. All applicants are expected to pursue all other applicable forms of funding and must secure at least 40 percent of the project's total costs from sources other than Blue Sky. RMP does not provide funding for project development assistance, only portions of the construction costs.

The North Carolina Solar Center at North Carolina State University, with support from the Interstate Renewable Energy Council, Inc. and funded by the U.S. Department of Energy, operates a Database of State Incentives for Renewables & Efficiency (DSIRE). DSIRE is the most comprehensive source of information on incentives and policies that support renewables and energy efficiency.

EXAMPLES OF PROCESS

Detailed Case Studies

Buffalo Hydropower Project

Summary

The city of Buffalo owns and operates a 200 kW Pelton impulse-type hydropower facility. The unit is in-line with their existing 14-inch municipal raw water supply pipeline to the water treatment plant. The project was funded with a loan from the Wyoming Water Development Commission. The WWDC deferred payment of principal for five years to take advantage of escalating avoided rates. A power purchase agreement was administered between the city of Buffalo and PacifiCorp (Rocky Mountain Power). The project is in year 18 of a PPA and sells the generated energy to Rocky Mountain Power at a rate of 10.65¢/kWh.

Figure 47: Tie Hack Dam

Project Design and Technical Details

The city of Buffalo is located at the base of the Bighorn Mountain Range. The city diverts water from Clear Creek and pipes it 3.6 miles to the water treatment plant. In 1995, the diversion and pipeline were reconstructed and Tie Hack Reservoir was constructed. At this time, the hydropower facility was constructed in parallel with the existing pressure reducing station on the pipeline and was online in 1998. This pipeline provides 6 cfs with 492 feet of net head to the hydro turbine. The hydropower facility is typically operated year-round. During snowmelt runoff and times when stream flows are adequate, the city uses its direct flow water rights to provide water to the turbine and water treatment plant. When stream flows are reduced and their direct flow water rights are out of priority, the city makes releases from storage in Tie Hack Reservoir to provide water to the turbine and water treatment plant. During the non-irrigation season, the municipal demand on the water treatment plant is reduced and excess water from the hydro turbine is returned to Clear Creek.

Figure 48: Buffalo Hydropower Facility

The Pelton turbine utilizes approximately 213 psi and discharges into a stilling basin at the head of the water treatment plant. The turbine reduces the head into the water treatment plant instead of a pressure reducing valve. The powerhouse consists of a concrete vault buried underground and was designed to last for more than 100 years. The hydroelectric equipment is in its seventeenth year of operation and has had minimal maintenance issues. Bearings were replaced twice. The PPA allows 30 days per year of turbine downtime, but the full allotment is rarely used.

The city enlisted an outside consulting firm with experience in the design and development of similar projects. The turbine, generator, and controls were manufactured by Sulzer Canada and were supplied as a water-to-wire package. The equipment has been operating without difficulty since project commissioning in 1998.

Challenges

Permitting and licensing of the facility were the biggest challenge to the project. The city obtained a 5 MW license exemption from FERC and a PPA from PacifiCorp (Rocky Mountain Power). This process took over two years. Part of the reason for the long timeline was due to the permitting and construction of Tie Hack Reservoir.

Project Economics

The hydropower portion of the project cost was approximately $860,000, which included the procurement of the hydroelectric equipment and construction of the powerhouse and modification to the diversion structure and a portion of the pipeline. Financing for the project was provided by the Wyoming Water Development Commission.

Payment on the principal of the loan was deferred five years to take advantage of escalating avoided rates. Money from the sale of energy was put into a slush fund during the deferment period and was used to pay off the loan completely within a few years.

Lessons Learned

Perhaps the most important part of the success of the project was the financing and loan terms. The project would not have been able to cash flow without the deferred payments, and the city would have had to invest in the project through other financing arrangements.

One of the principal project barriers was federal permitting. It took nearly two years to obtain a FERC license exemption and power purchase agreement; however, recent federal hydropower reform legislation has streamlined the federal permitting process. The FERC permitting process can take as little as three months now..

Sherard Water Treatment Plant Hydroelectric Generation Project

Summary

The city of Cheyenne Board of Public Utilities (BOPU) manages, operates, maintains, and controls the municipal water works for the city of Cheyenne, Wyoming. The BOPU's primary function is to provide potable water and water reclamation service to the city and other industrial and wholesale customers. Water treatment services are provided at the Sherard Water Treatment Plant. The BOPU has been interested in hydropower generation at the Sherard Water Treatment Plant for many years and has hired a consultant as part of the Sherard Hydroelectric Generation Facility Project to evaluate the technical and economic feasibility of installing a new hydroelectric generation facility at Sherard. The feasibility study recommended selection of either a single Francis turbine or a single Pelton turbine. The turbine would be rated at 700 kW and was estimated to generate 4,000 MWh annually. The feasibility study was completed in 2013, and the BOPU is holding negotiations with Cheyenne Light Fuel and Power in an effort to secure a power purchase agreement.

Project Design and Technical Details

The project would have a generating capacity of 700 kW, generating an estimated 4,000 MWh annually. The project would be at the head of the Sherard Water Treatment Plant west of Cheyenne and would operate parallel to the existing pressure reducing station. The turbine would be supplied by water stored in Crystal Reservoir and conveyed through a 15-mile pipeline utilizing approximately 212 psi at a rated flow of 20 cfs. Either a Francis or Pelton turbine was recommended, each having advantages and disadvantages.

Several factors drove the recommendations of the turbine configurations. One being the water treatment plant requires 10 psi to operate, making it difficult for an impulse turbine to operate. Second, the integrity of the pipeline must remain, and pressure surges in the pipeline associated with the Francis turbine warrants the use of expensive surge protection equipment.

Challenges

If a hydropower facility is constructed, the biggest challenges will be in the design of the civil infrastructure necessary for the different turbine types. If a Francis turbine is chosen, extensive surge tanks and bypass controls are required to maintain the integrity of the supply pipeline. If a Pelton turbine is selected, maintaining the downstream pressure requirement to operate the water treatment plant will be a challenge. To address this challenge, the consultant recommended installing the Pelton in a powerhouse approximately 20 feet above the water treatment plant. The optimal location for siting the turbine was adjacent to the water treatment plant. This would allow the energy generated by the hydropower facility to be consumed at the water treatment plant.

Project Economics

At this point in the project, only the total project costs and avoided costs from the electric utility have been estimated. The hydro project was estimated to cost $2.3 million. The cost estimate was nearly identical for both turbine types. Initial discussions with the local electric utility indicated the avoided costs would be 4¢/kWh. The energy generated from the hydropower facility would be directly consumed at the water treatment plant and would offset all of the energy purchased from the utility. Any excess energy the water treatment plant does not consume would be sold to the utility. This arrangement is similar to net metering, except it is anticipated the utility will charge to reserve the capacity the water treatment plant would use should the hydropower facility go offline. This type of agreement is fairly complicated, and the details have not yet been decided. Based on the initial negotiations with the electric utility, it is anticipated the project will have a payback period of 8 to 10 years and have an internal rate of return approaching 10 percent. The project is funded by the Wyoming Drinking Water State Revolving Fund.

Lessons Learned

IIncluding all the affected parties early in the development of a hydropower project is important. This case was unique to the local electric utility and working through the details of the power purchase agreement takes time. Involving the affected parties early on can help the permitting and licensing process move forward efficiently and smoothly.

Bear River Ranch Hydro-Mechanical Center Pivot Irrigation Project[xx]

Summary

When confronted with rising water costs and low crop yields, Bear River Ranch, near Steamboat Springs, Colorado, installed a hydro-mechanical system to power its center-pivot irrigation system. This system uses the power of falling water to directly drive and pressurize the center pivot; this eliminates the need for electricity and significantly reduces operating expenses. The turbine uses 126 feet of head and 560 gpm to produce the equivalent of 5.2 kW of power which drives the center pivot. The $13,000 project was funded through $6,000 in support from NRCS, yielding out-of-pocket cost to the ranch of $7,000, and an expected payback of slightly over three years.

Background

The Natural Resources 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. 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.

Design and Technical Details

The photograph at right 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; the pressurized water powers the turbine (via the pipe denoted with a blue arrow) and supplies the sprinklers (via the pipe denoted with a yellow arrow). 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.

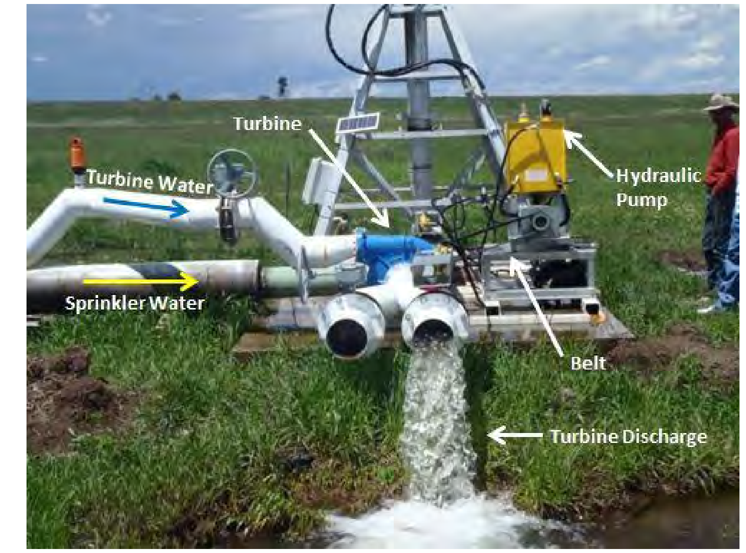

Figure 49: Hydro-mechanical Center Pivot


Figure 50: Bear River Ranch

Hydro-mechanical systems are relatively simple, so complex safety and operational procedures are typically not necessary. Because the use of hydro-mechanical systems is relatively rare, a lack of institutional knowledge has prevented their widespread use to date.

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. Because it does not produce electricity, the project is not regulated by the Federal Energy Regulatory Commission.

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 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, so care must be taken to adequately filter the water prior to its entry into the system.

Economics

NRCS supported the project in 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 over $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.

The only cost incurred that varied from 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 to which 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 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.

Lessons Learned

The project ran successfully through the 2012 irrigation season with no problems reported and increased crop yields using less water than had historically been used with flood irrigation. Many of the ranchers in the area are expressing an interest in installing the same type of system. Some have submitted applications to the local NRCS office, which is hoping to offer design services for this type of system. Such a system can potentially be replicated throughout Colorado in areas where sufficient pressure can be generated using at least 100 to 150 feet of fall.

APENDIX A

SITE ASSESSMENTS

A preliminary site assessment was conducted on two potential sites to determine the viability of hydropower development and if further feasibility studies are warranted. Both sites are on the Wheatland Irrigation District's system: one on the outlet of Wheatland Reservoir No. 1 and the other on a drop structure in a canal. The available flows were estimated and obtained from the Wheatland Irrigation District (WID). The net head was estimated from the gross head obtained from the WID. Cost estimates are generalized based on the generator output and Bureau of Reclamation cost index formulas, Electric Power Research Institute Plant Cost Elements, and experience with similar projects. It was assumed a loan would be secured to finance 100 percent of the project capital costs (4 percent over 30 years). The Bureau of Reclamation's Hydropower Assessment Tool was used to estimate the power generation potential at each site.

Joe Drop

Site Location, Ownership and Access

The Joe Drop is on a lateral owned and operated by the Wheatland Irrigation District (WID). Joe Drop is near the intersection of Highway 34 and Sybille Creek Road approximately 7 miles southwest of Wheatland. The lateral supplies water to agricultural producers within the boundaries of the Wheatland Irrigation District. The WID has an easement to access and maintain the drop structure, and the existing access roads are adequate.

Water Rights

The Wheatland Irrigation District owns the water rights that would be used for hydropower production; however, the beneficial use is permitted as irrigation. WID would have to file for an enlargement to add power generation as a beneficial use to the water rights. The water right for power generation would be non-consumptive and secondary to irrigation. The need for any additional water rights is not anticipated, as the hydropower facility would utilize existing rights.

Estimated Head and Flow

The elevation difference across the drop is approximately 20 feet. Water levels upstream of the drop can vary slightly depending on the flow rate in the canal; however, for the level of this analysis, the variation in elevation was assumed to be insignificant. The length of the penstock will be very short and assumed sized to minimize friction loss; therefore, the gross head of 20 feet was also assumed to be the net head available. A more detailed analysis is required to properly determine the net head and is beyond the scope of this assessment.

The available flows in the canal were obtained from the WID. The available flow for hydropower generation is seasonal and occurs during the irrigation season assumed to be from May 15 to September 15. The minimum flow is 80 cfs, and the maximum flow is 240 cfs. The minimum flows occur early and late in the irrigation season, and the maximum flows occur during July and August. The design flow was estimated to be the maximum flow or 240 cfs, since the turbine can handle the variable flow rates fairly efficiently. Daily flow data should be obtained in future studies to accurately assess the energy generation of the hydropower facility. For this analysis, the following flow characteristics were assumed:

Month	Average Monthly Flow
May	80 cfs
June	150 cfs
July	240 cfs
August	240 cfs
September	100 cfs

Utility Connection

The proposed hydropower facility is in a rural but fairly developed area. Several residences are within close proximity to the proposed site, and a major electrical transmission line is approximately 4,000 feet away. Smaller distribution electrical lines are along Sybille Creek Road, approximately 500 feet away. The capacity of the distribution line is unknown but was assumed to be the location of interconnect.

Political and Environmental Concerns

The proposed site is in a rural area where agriculture is the driving industry. The nearest residence is approximately one-eighth of a mile away. Noise from the turbine is not anticipated to impact the nearby residences. Since the hydro turbine would be on an existing canal and flows are already seasonal, the environmental impact associated with hydro would be very minimal. Fish and wildlife mitigation would not be required, and the federal permitting process would be streamlined and take minimal effort.

Generation and Turbine Selection

The Bureau of Reclamation's Hydropower Assessment Tool was used to estimate capacity and energy generation of the proposed hydropower facility. Based on a rated flow of 240 cfs and a net head of 20 feet, the plant would have a design capacity of 343 kW and generate 795 MWh of energy annually. The head and flow conditions indicate the turbine would likely be a Kaplan. A cross flow turbine may be an option; however, the design flow would be on the high end of a cross-flow turbine. The following tables show the plant generation summary.

Plant Generation Summary	
Plant Design Capacity (kW)	343
Number of Days	365
Data Years	1.00
Total Data Period Energy (kWh)	795,000
Average Plant Capacity (kW)	93
Plant Peak Capacity (kW)	343
Plant Factor	0.270

Plant Monthly Generation			
Month	Days with Data	Average Capacity (kW)	Average Energy (MWH)
January	31	0	0
February	28	0	0
March	31	0	0
April	30	0	0
May	32	61	44
June	30	242	174
July	31	337	243
August	31	343	247
September	30	121	87
October	31	0	0
November	30	0	0
December	31	0	0
Annual			**795**

Economics

Plant costs were generalized and based on the generator output, Bureau of Reclamation's Cost Index, Energy Electric Power Research Institute "Quantifying the Value of Hydropower in the Electric Grid: Plant Cost Elements" and experience with similar projects. The cost estimate is conservative and should be estimated with more detail in future studies. For small, low-head hydro installations, the Electric Power Research Institute indicates the range of turbine, generator, and controls could cost $1,200 to $1,400 per kW of output. This assessment assumed a cost of $1,400/kW or $480,000 for the turbine, generator and controls. The civil infrastructure would consist of an intake, short penstock, powerhouse, and tailrace and was estimated to be 40 percent of the turbine and generator costs or $193,000. A summary of the total plant costs is shown below.

Site Information	
Unit Capacity (MW)	0.34
Number of Units	1
Plant Capacity (MW)	0.34
Turbine Type	Kaplan
Design Head (ft)	20
Unit Speed (RPM)	600
Estimated Generation Voltage (KV)	0.48
Transmission Voltage (KV- 69,115)	115
T-Line Length (miles)	0.10
New Transformer	YES
Fish and Wildlife Mitigation	No
Recreation Mitigation	No
Historical & Archeological	No
Water Quality Monitoring	No
Fish Passage Required	No
State Sales Tax Rate (percent)	4.00
Construction Year	2014

Total Direct Construction Cost	995,575
Civil Works	193,436
Turbine(s)	210,455
Generator(s)	171,144
Balance of Plant Mechanical	42,091
Balance of Plant Electrical	59,901
Transformer	24,404
T-Line	20,000
Contingency (20 percent)	144,286
Sales Taxes	0
Engineering and CM (15 percent)	129,858

Total Development Costs	1,152,565
Cost Escalation factor from 2010	1.1
Licensing Cost	50,000
Total Direct Construction Cost	1,098,929
T-Line Right-of-Way	3,636
Fish & Wildlife Mitigation	0
Recreation Mitigation	0
Historical & Archeological	0
Water Quality Monitoring	0
Fish Passage	0

Annual O&M Expense	15,508
Fixed Annual O&M	5,000
Variable O&M	5,000
FERC Charges	526
Transmission / Interconnection	1,000
Insurance	2,987
Taxes	0
Management / Office / Overhead	0
Major Repairs Fund	996

It was assumed a loan would be secured for the total development costs of $1,152,000. This amount was amortized at 4 percent interest over 30 years resulting in an annual loan payment of $66,620. Including annual operation and maintenance costs of $15,500, the total annual expenses were estimated to be $82,120. Irrigation districts typically are not able to subsidize hydropower projects; therefore, the revenue from power generation should nearly cash flow the project from year one of operation. For this proposed project, the energy would need to be sold at $0.10/kWh in order to cash flow the project from the first year of operation. At this rate, the project would have a simple payback period of 17.6 years.

Conclusions and Recommendations

Based on the assumptions listed above, this project does not appear to be very economically feasible. An avoided rate of $0.10/kWh is not out of the realm of possibility but is higher than current typical rates. Current avoided rates are typically around $0.04/kWh. This does not mean a more detailed analysis should not be completed. Without too much effort, more detailed flow rates can be estimated and cost estimates could be specific to the project area instead of using generalized costs. The cost index used for this analysis tends to be conservative, and actual quotes from suppliers should be used to better estimate construction costs. It is recommended to use daily average flow rates throughout a typical irrigation season and investigate whether supplemental flows can be sent through the turbine to increase energy generation. A field survey of the available head should also be completed. This information can then be used to obtain specific turbine efficiency curves, and a better estimate of plant capacity and energy generation can be completed. The following table shows the results of the preliminary analysis.

Results – Joe Drop – Wheatland Irrigation District		
Data Set	1	years
Max Head	20	ft
Min Head	20	ft
Max Flow	240	cfs
Min Flow	80	cfs

Turbine Selection Analysis

Selected Turbine Type	Kaplan	
Selected Design Head	20	ft
Maximum Turbine Flow	240	cfs
Generator Speed	600	rpm
Max Head Limit	25.0	ft
Min Head Limit	13.0	ft
Max Flow Limit	240	cfs
Min Flow Limit	48	cfs

Power Generation Analysis

Installed Capacity	343	kW
Plant Factor	0.27	

Projected Monthly Production:

January	0	MWH
February	0	MWH
March	0	MWH
April	0	MWH
May	44	MWH
June	174	MWH
July	243	MWH
August	247	MWH
September	87	MWH
October	0	MWH
November	0	MWH
December	0	MWH
Annual production	795	MWH

Benefit/Cost Analysis

Projected expenditure to implement project

Total Construction Cost	$ 1,152,565	
Annual O&M Cost	$ 15,508	
Projected Total Cost over 50-year period (present worth)	$ 1,328,691	

Projected revenue after implementation of project

Power generation income for 2014 to 2060	$ 2,936,219	
Projected Total Revenue over 50- year period	$ 1,042,542	
Benefit/Cost Ratio	0.78	
Internal Rate of Return	2.8 percent	

Installed Cost $ per kW	**$ 3,360**	

Wheatland Reservoir Number 1

Site Location, Ownership, and Access

The Wheatland Reservoir Number 1 is a re-regulation reservoir owned and operated by the Wheatland Irrigation District (WID). The reservoir is on Reservoir Road approximately 4 miles southwest of Wheatland. The reservoir supplies water to agricultural producers within the boundaries of the Wheatland Irrigation District. The WID has an easement to access and maintain the reservoir and the existing access roads are adequate.

Water Rights

WID owns the water rights that would be used for hydropower production; however, the beneficial use is permitted as irrigation. WID would have to file for an enlargement to add power generation as a beneficial use to the water rights. The water right for power generation would be non-consumptive and secondary to irrigation. The need for any additional water rights is not anticipated and the hydropower facility would utilize existing rights.

Estimated Head and Flow

Since Wheatland Number 1 serves as a re-regulation reservoir, the water level can vary significantly. The elevation difference between the spillway and outlet is approximately 40 feet. When the reservoir is full, the elevation difference is approximately 39 feet. On average the reservoir operates half full, and the elevation difference is approximately 27 feet. This elevation difference was used to estimate the net head available for hydropower generation. A more detailed analysis is required to properly determine the net head and is beyond the scope of this assessment. The turbine would utilize the existing outlet works of the reservoir and would be installed on the existing outlet pipe. The condition of the existing pipe is unknown and would have to be determined if the pipe is suitable for a hydropower installation in future studies.

The available flows released through the outlet of the reservoir were obtained from the WID. The available flow for hydropower generation is seasonal and occurs during the irrigation season assumed to be from May 15 to September 15. The minimum flow is 75 cfs, and the maximum flow is 250 cfs. The minimum flows occur early and late in the irrigation season, and the maximum flows occur during July and August. On average, 200 cfs is released throughout the irrigation season. The design flow was estimated to be the average flow or 200 cfs. The turbine can handle the variable flow rates fairly efficiently. Daily flow data should be obtained in future studies to accurately assess the energy generation of the hydropower facility. For this analysis, the following flow characteristics were assumed:

Month	Average Monthly Flow
May	75 cfs
June	175 cfs
July	225 cfs
August	225 cfs
September	100 cfs

Utility Connection

The proposed hydropower facility is in a rural but fairly developed area. Several residences are within close proximity to the proposed site, and a major electrical transmission line is approximately 1 ¼ miles away. Smaller distribution electrical lines cross the proposed project site. The capacity of the distribution line is unknown but was assumed to be the location of interconnect.

Political and Environmental Concerns

The proposed site is on the outlet of the Wheatland Reservoir Number 1 in a rural area where agriculture is the driving industry. The reservoir is primarily used for irrigation but also provides recreation use. The nearest residence is approximately one-half of a mile away. Noise from the turbine is not anticipated to would impact nearby residences. The primary purpose of the reservoir is for irrigation, and the WID would continue to operate the reservoir as they historically have. Since the hydro turbine would be at an existing embankment and flows are already seasonal, the environmental impact associated with hydro would be very minimal. Fish and wildlife mitigation would not be required, and the federal permitting process would be streamlined and take minimal effort.

Generation and Turbine Selection

The Bureau of Reclamation's Hydropower Assessment Tool was used to estimate capacity and energy generation of the proposed hydropower facility. Based on an average flow of 200 cfs and an average net head of 27 feet, the plant would have a design capacity of 482 kW and generate 1,018 MWh of energy annually. The head and flow conditions indicate the turbine would likely be a Kaplan. A cross flow turbine may be an option; however, the design flow would be on the high end of a cross flow turbine. The following tables show the plant generation summary.

Plant Generation Summary	
Plant Design Capacity (kW)	482
Number of Data	365
Data Years	1.00
Total Data Period Energy (kWh)	1,018,000
Average Plant Capacity (kW)	119
Plant Peak Capacity (kW)	482
Plant Factor	0.246

Plant Monthly Generation			
Month	**Days with Data**	**Average Capacity (kW)**	**Average Energy (MWH)**
January	31	0	0
February	28	0	0
March	31	0	0
April	30	0	0
May	31	79	57
June	30	351	253
July	31	445	320
August	31	439	316
September	30	99	71
October	31	0	0
November	30	0	0
December	31	0	0
Annual			**1,018**

Economics

Plant costs were generalized and based on the generator output, Bureau of Reclamation's cost index, Energy Electric Power Research Institute "Quantifying the Value of Hydropower in the Electric Grid: Plant Cost Elements," and experience with similar projects. The cost estimate is conservative and should be estimated with more detail in future studies. For small, low-head hydro installations the Electric Power Research Institute indicates the range of turbine, generator, and controls could cost $1,200 to $1,400 per kW of output. This assessment assumed a cost of $1,400/kW or $675,000 for the turbine, generator, and controls. The civil infrastructure would consist of a pipeline bifurcation, short penstock, powerhouse and tailrace and was estimated to be 40 percent of the turbine and generator costs or $203,000. A summary of the total plant costs is shown below.

Site Information	
Unit Capacity (MW)	0.48
Number of Units	1
Plant Capacity (MW)	0.48
Turbine Type	Kaplan
Design Head (ft)	27
Unit Speed (RPM)	600
Estimated Generation Voltage (KV)	4.16
Transmission Voltage (KV- 69,115)	115
T-Line Length (miles)	0.00
New Transformer	YES
Fish and Wildlife Mitigation (Yes/No)	0.00
Recreation Mitigation (Yes/No)	0.00
Historical & Archaeological (Yes/No)	0.00
Water Quality Monitoring (Yes/No)	0.00
Fish Passage Required (Yes/No)	0.00
State Sales Tax Rate (percent)	4.00
Construction Year	2014

Total Direct Construction Cost	1,206,724
Civil Works	203,550
Turbine(s)	295,275
Generator(s)	213,601
Balance of Plant Mechanical	59,055
Balance of Plant Electrical	74,760
Transformer	28,196
T-Line	0
Contingency (20 percent)	174,887
Sales Taxes	0
Engineering and CM (15 percent)	157,399
Total Development Costs	**1,256,724**

Cost Escalation factor from 2010	1.1
Licensing Cost	50,000
Total Direct Construction Cost	1,206,724
T-Line Right-of-Way	0
Fish & Wildlife Mitigation	0
Recreation Mitigation	0
Historical & Archeological	0
Water Quality Monitoring	0
Fish Passage	0

Annual O&M Expense	16,566
Fixed Annual O&M	5,000
Variable O&M	5,000
FERC Charges	739
Transmission / Interconnection	1,000
Insurance	3,620
Taxes	0
Management / Office / Overhead	0
Major Repairs Fund	1,207
Reclamation / Federal Admin	0

It was assumed a loan would be secured for the total development costs of $1,256,724. This amount was amortized at 4 percent interest over 30 years resulting in an annual loan payment of $72,638. Including O&M costs of $16,566, the total annual expenses was estimated to be $89,204. Irrigation districts typically are not able to subsidize hydropower projects; therefore, the revenue from power generation should nearly cash flow the project from year one of operation. For this proposed project the energy would need to be sold at $0.085/kWh to cash flow the project from the first year of operation. At this rate, the project would have a simple payback period of 18 years.

Conclusions and Recommendations

Based on the assumptions listed above, the project feasibility is marginal. An avoided rate of $0.085/kWh is not out of the realm of possibility but is higher than current typical rates. Current avoided rates are typically around $0.04/kWh. This does not mean a more detailed analysis should not be completed. Without too much effort, more detailed head and flow rates can be estimated, and cost estimates could be specific to the project area instead of using generalized costs. The cost index used for this analysis tends to be conservative, and actual quotes from suppliers should be used to better estimate construction costs. It is recommended to use daily average flow rates throughout a typical irrigation season and investigate whether supplemental flows can be sent through the turbine to increase energy generation. A field survey of the available head should also be completed. This information can then be used to obtain specific turbine efficiency curves and a better estimate of plant capacity, and energy generation can be completed. It is recommended that a more detailed study be completed to assess the feasibility of this project. The following table shows the results of the preliminary analysis.

Results – Wheatland Res No. 1 – Wheatland Irrigation District		
Data Set	1	years
Max Head	39	ft
Min Head	20	ft
Max Flow	250	cfs
Min Flow	75	cfs

Turbine Selection Analysis

Selected Turbine Type	Kaplan	
Selected Design Head	27	ft
Maximum Turbine Flow	250	cfs
Generator Speed	600	rpm
Max Head Limit	33.8	ft
Min Head Limit	17.5	ft
Max Flow Limit	250	cfs
Min Flow Limit	50	cfs

Power Generation Analysis

Installed Capacity	482	kW
Plant Factor	0.25	

Projected Monthly Production

January	0	MWH
February	0	MWH
March	0	MWH
April	0	MWH
May	57	MWH
June	253	MWH
July	320	MWH
August	316	MWH
September	71	MWH
October	0	MWH
November	0	MWH
December	0	MWH
Annual production	**1,018**	**MWH**

Benefit/Cost Analysis

Projected expenditure to implement project

Total Construction Cost	**$ 1,256,724**	
Annual O&M Cost	**$ 16,566**	
Projected Total Cost over 50-year period (present worth)	**$ 1,442,788**	

Projected revenue after implementation of project

Power generation income for 2014 to 2060	$ 3,762,126	
Projected Total Revenue over 50-year period	$ 1,335,893	
Benefit/Cost Ratio	0.93	
Internal Rate of Return	3.9 percent	

Installed Cost $ per kW	**$ 2,605**	

APPENDIX B – HYDROPOWER RESOURCES

All links provided at: http://bit.ly/1saqi3W (or University of Wyoming Renewables - Hydroelectric)

1. Wyoming Water Rights information

I. Wyoming Water Law a Summary, UW Extension
II. Wyoming Water Rights Database – login required

2. Hydrology Resources

I. Bureau of Reclamation - Water Measurement Manual
II. Wyoming SEO - Historic Diversion & Stream flow Records
III. Wyoming SEO - Real-time Stream flow Data
IV. National Weather Service - Stream flows
V. USGS - Wyoming-Montana Water Science Center - Stream flows

3. Topography and Mapping Resources

I. USGS Topographical Maps – The National Map
II. USDA Geospatial Data Gateway – National Elevation Data & Aerial Photography – GIS capabilities required
III. Wyoming Geographic Information Science Center – GIS data, Imagery, Online mapping application

4. Head Loss Resources

I. Calculator for head loss in pipes using Hazen-Williams Equation
II. Calculator for head loss in pipes using Darcy-Weisbach Equation

5. Turbine Manufacturers[viii]

I. Very small hydropower turbine and generators appropriate for net metering or off-the-grid applications.

Manufacturer	Website	Name	Turbine Type
Cla-Val	www.cla-val.com/x143hp-hydro-powered-generator-p-63-l-en.html	X143HP	Pump-as-turbine
Energy Systems and Design	www.micro-hydropowerMicro-hydropowermicro-hydropowermicro-hydropowerMicro-hydropower.com	LH1000 Stream Engine	Propeller, Turgo
Asian Phoenix Resources	www.powerpal.com	PowerPal Low Head PowerPal High Head	Propeller, Turgo
Harris Hydroelectric	www.thesolar.biz/harris_hydro.htm	Harris Turbine	Pelton
Scott	www.absak.com/catalog/product_info.php/cPath/33_89_91/products_id/1370	Scott Cross Flow Turbine	Cross flow
Power Spout	www.powerspout.com	PowerSpout PowerSpout Low Head	Pelton, Propeller

II. Small Turbine Distributors:
ABS Alaskan
www.absak.com/
Energy Alternatives
www.energyalternatives.ca

III. Hydro-mechanical Resources:

Two Dot Irrigation and Supply LLC
Leadore, Idaho
208-768-2058

IV. Traditional turbines and generators, offering "water to wire" packages

Manufacturer	Website	Turbine Type
Small		
Cornell Pump Company	www.cornellpump.com/products/hydroturbine.html	Pump as turbine
Canyon Hydro	www.canyonhydro.com	Pelton Francis Cross Flow Kaplan
Rentricity	www.rentricity.com	Pump as turbine
Medium		
Canadian Hydro Components	www.canadianhydro.com	Kaplan Propeller Francis
Dependable Turbines LTD	www.dtlhydro.com	Kaplan Propeller Francis Turgo Pelton Pump as turbine
Toshiba International	www3.toshiba.co.jp/power/english/hydro/products/equipment/turbine.htm	Kaplan Francis
Pentair Tamar	www.southerncross.pentair.com/	Kaplan Francis Pelton
Ossberger	http://hts-inc.com/ossberger.html	Kaplan Movable Powerhouse (Kaplan) Cross flow
Gilkes	www.gilkes.com/	Francis Turgo Pelton
Mavel	www.mavel.cz	Microturbines (propeller) Kaplan Francis Pelton

Manufacturer	Website	Turbine Type
Large		
Voith Hydro	http://voith.com/en/products-services/hydro-power/small-hydro-power-plants-552.html	Kaplan Francis Pelton Ecoflow
Andritz	www.andritz.com/hydro/hy-small-hydropower-standard.htm	Propeller Francis Pelton
Alstom Power	www.alstom.com/power/renewables/hydro/turnkey-power-plants/small/	Kaplan Francis Pelton

V. Emerging technologies that are new to the market or not yet commercially available or implemented in the U.S.

Manufacturer	Website	Turbine Type
Hydrokinetics		
Alternative Hydro Solutions	www.althydrosolutions.com	Darrieus Water Turbine
Hydrovolts	www.hydrovolts.com	Canal turbine
New Energy Corp	www.newenergycorp.ca	EnCurrent
Hydro Green Energy	www.hgenergy.com	Lock+ and Dam+
Hydrodynamic Screws		
Ritz-Atro	www.ritz-atro.de/2006/index_neu.html	Archimedean Screw
Andritz	www.andritz.com/products-andservices/pf-detail.htm?productid=8775	Archimedean Screw
ReHart	www.rehart.de	Archimedean Screw
HydroCoil Power	www.hydrocoilpower.com	Small screw type turbine
Low Head Turbines		
Natel America	www.natelenergy.com	Hydroengine
MJ2 Technologies SAS (VLH Turbine)	www.vlh-turbine.com	Low Head (Kaplan)
Propeller Turbines		
Amjet	http://amjethydro.com/	Propeller
Clean Power	www.cleanpower.no/Home.aspx	Propeller
In-Pipe Turbines		
Lucid Energy	www.lucidenergy.com/lucidpipe/	Vertical Axis

6. Civil Works Resources[viii]

I. Gates and Checks:

Fresno Valves & Casting
Golden Harvest, Inc.
Obermeyer Hydro
Safety Gates LLC
Waterman Industries

II. Screens and Trashracks:

Atlas Polar Hydro Rake Systems
Farmers Screen
Hydro Component Systems
Hydrolox
Hydroscreen, LLC
International Water Screen
Intake Screens Inc.
Lakeside Equipment Corp
Norris Screens

7. Controls Resources[viii]

Powerbase Automation Systems Inc.
Thomson and Howe Energy Systems Inc.

8. Permitting Resources

Federal Energy Regulatory Commission
USACE Wyoming Office
Wyoming DEQ-WQD – Clean Water Act Section 401 Certification
WYPDES & Construction Dewatering permits
Department of Fire Prevention & Electrical Safety

9. Construction Cost Resources[viii]

EPRI, 2011, "Quantifying the value of Hydropower in the Electrical Grid: Plant Cost Elements", Final Report 1023140, Palo Alta, CA

10. Small Hydropower Consultants in Wyoming (inconclusive list)

Baccari and Associates, LLC
Sheridan, WY
larry@baccari.biz
307-672-5885

HDR
Cheyenne, Gillette & Riverton, WY
http://www.hdrinc.com/markets/power/renewable-energy/project-types/hydropower

Sunrise Engineering
Cheyenne & Afton, WY
www.sunrise-eng.com

Wenck Associates, Inc.
Cheyenne & Sheridan, WY
www.wenck.com

11. Technical Resources

The Small Hydropower Handbook – Colorado Energy Office

Micro Hydropower Handbook, Part 1 - DOE, Idaho Operations Office

Micro Hydropower Handbook, Part 2 - DOE, Idaho Operations Office

Water Energy Resources of the U.S. with Emphasis on Low Head/Low Power Resources - DOE

New Stream-reach Development Resource Assessment – National Hydropower Asset Assessment Program

Guide on How to Develop a Small Hydropower Plant – European Small Hydropower Association

An Introduction to Hydropower Concepts and Planning – Canyon Hydro

Low Impact Hydropower Institute – Certification Handbook

Micro-Hydropower: Oregon Development Guide – Oregon State University Extension Service

Small Hydropower Technology and Market Assessment – Energy Trust of Oregon

Micro-Hydropower Systems: A Buyer's Guide – Natural Resources Canada

Endnotes

[i] For more information see www.lowimpacthydro.org

[ii] Based on the U.S. Energy Information Administration's data, *Net Generation by State by Type of Producer by Energy Source* (EIA-906, EIA-920, and EIA-923) and *Existing Nameplate and Net Summer Capacity by Energy Source, Producer Type and State* (EIA-860). (http://www.eia.gov/electricity/data/state)

[iii] United States Department of the Interior, Bureau of Reclamation, Power Resources Office. *Hydropower Resource Assessment at Existing Reclamation Facilities.* March 2011.

[iv] United States Department of the Interior, Bureau of Reclamation, Power Resources Office, *Site Inventory and Hydropower Energy Assessment of Reclamation Owned Conduits: Supplement to the "Hydropower Resource Assessment at Existing Reclamation Facilities Report"*, March 2012.

[v] Based on the Public Service Commission's estimate the average home consumes 850 kWh/month.

[vi] United States Department of Energy, Energy Efficiency and Renewable Energy Wind and Hydropower Technologies. *Water Energy Resources of the United States with Emphasis on Low Head/Low Power Resources.* DOE/ID-11111. April 2004.

[vii] Source: Gulliver, J. S. & Arndt, R.E.A., Hydropower Engineering Handbook. New York, NY: McGraw-Hill, Inc. 1991.

[viii] Source: *Report Supporting Endorsement as a Low-Impact Hydroelectric Power Facility for the Strawberry Hydroelectric Project FERC Project* #2032, Northwest Power Services, Inc. December 2002 (http://www.lowimpacthydro.org/assets/files/lihi-cert-app-files/DraftGreenPowerApp.pdf)

[ix] Source: *Afton Culinary Water System Hydroelectric Project FERC No. 13301 Soil and Erosion Control Plan*, Symbiotics, LLC. June 2010

[x] Source: T-L Irrigation (www.tlirr.com/difference/continous_movement_hydraulic-drive)

[xi] Source: The Colorado Energy Office. *The Small Hydropower Handbook*, August 2013 (www.colorado.gov/energy)

[xii] United States Department of the Interior, Bureau of Reclamation, *Water Measurement Manual*. 2001. (http://www.usbr.gov/pmts/hydraulics_lab/pubs/PAP/PAP-1058.pdf)

[xiii] Source: *Guide to Hydropower An Introduction to Hydropower Concepts and Planning*, Canyon Hydro (www.canyonhydro.com)

[xiv] *Quantifying the Value of Hydropower in the Electric Grid: Plant Cost Elements.* EPRI, Palo Alto, CA: 2011

[xv] Source: *Hydroelectric Project Handbook for Filings Other Than License Exemptions,* Federal Energy Regulatory Commission, April 2001.

[xvi] For more information see www.usbr.gov/power/LOPP

[xvii] For more information see http://wyofire.state.wy.us/%5C%5C/pdf/localandstatejurisdictions.pdf

[xviii] For more information see http://psc.state.wy.us/

[xix] Source: U.S. Department of Energy, Energy Efficiency and Renewable Energy, Green Power Markets, Net Metering, *Map of State Net Metering Rules* (http://apps3.eere.energy.gov/greenpower/markets/netmetering.shtml)

[xx] Source: The Colorado Energy Office. Case Study: *Bear River Ranch Hydro-Mechanical Center Pivot Irrigation Project (http://www.colorado.gov/cs/Satellite?blobcol=urldata&blobheadername1=Content-Disposition&blobheadername2=Content-Type&blobheadervalue1=inline%3B+filename%3D%22Hydro+CS_Bear+River.pdf%22&blobheadervalue2=application%2Fpdf&blobkey=id&blobtable=MungoBlobs&blobwhere=1251856801677&ssbinary=true)*