Agricultural Hydropower Technical Manual

June 2015

United States Department of Agriculture
NRCS Natural Resources Conservation Service

CO CEO ™ CO CDA ™

Contents

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Common Conversions and Equations Used:

$$1\ pounds\ per\ square\ inch\ (psi) = 2.31\ feet\ of\ head\ (ft)$$

$$1\ cubic\ feet\ per\ second\ (cfs) = 448.83\ gallons\ per\ minute\ (gpm)$$

$$1\ horsepower\ (hp) = 0.746\ kilowatts\ (kW)$$

$$1\ kW = 3412\ British\ thermal\ units/hour\ (BTU/hr)$$

$$Power\ (kW) = \frac{Net\ Head\ (ft) * Required\ Flow\ (cfs) * Turbine\ Efficiency}{11.8}$$

$$Annual\ Energy\ Production\ (kWh/yr) = Power\ (kW) * Operation\ (hr/yr)$$

$$Net\ Simple\ Payback\ (years) = \frac{Total\ Costs - Incentives}{Annual\ Savings}$$

$$Energy\ Generated\ per\ Grant\ Dollar\ Requested\ (Btu/\$) = \frac{Annual\ Energy\ Production\ (kWh) * 3412\ \left(\frac{Btu}{kWh}\right)}{Total\ REAP\ Incentives\ Available\ (\$)}$$

Cover Photo by Travis Harvey ©2014

Background

The *Agricultural Hydropower Technical Manual* was developed as a part of the USDA Regional Conservation Partnership Program (RCPP) Colorado Pressurized Irrigation Small Hydropower Project. This project addresses water quantity, water quality, and energy resource concerns in Colorado by helping farmers upgrade outdated and labor intensive flood irrigation systems to more efficient systems using hydropower. In a 2013 report for the Colorado Department of Agriculture, the Applegate Group identified 5,000 agricultural fields in Colorado with the potential for conversion to hydro-powered, pressurized irrigation, of which 87% are currently flood-irrigated. The map below indicates the locations of these fields.

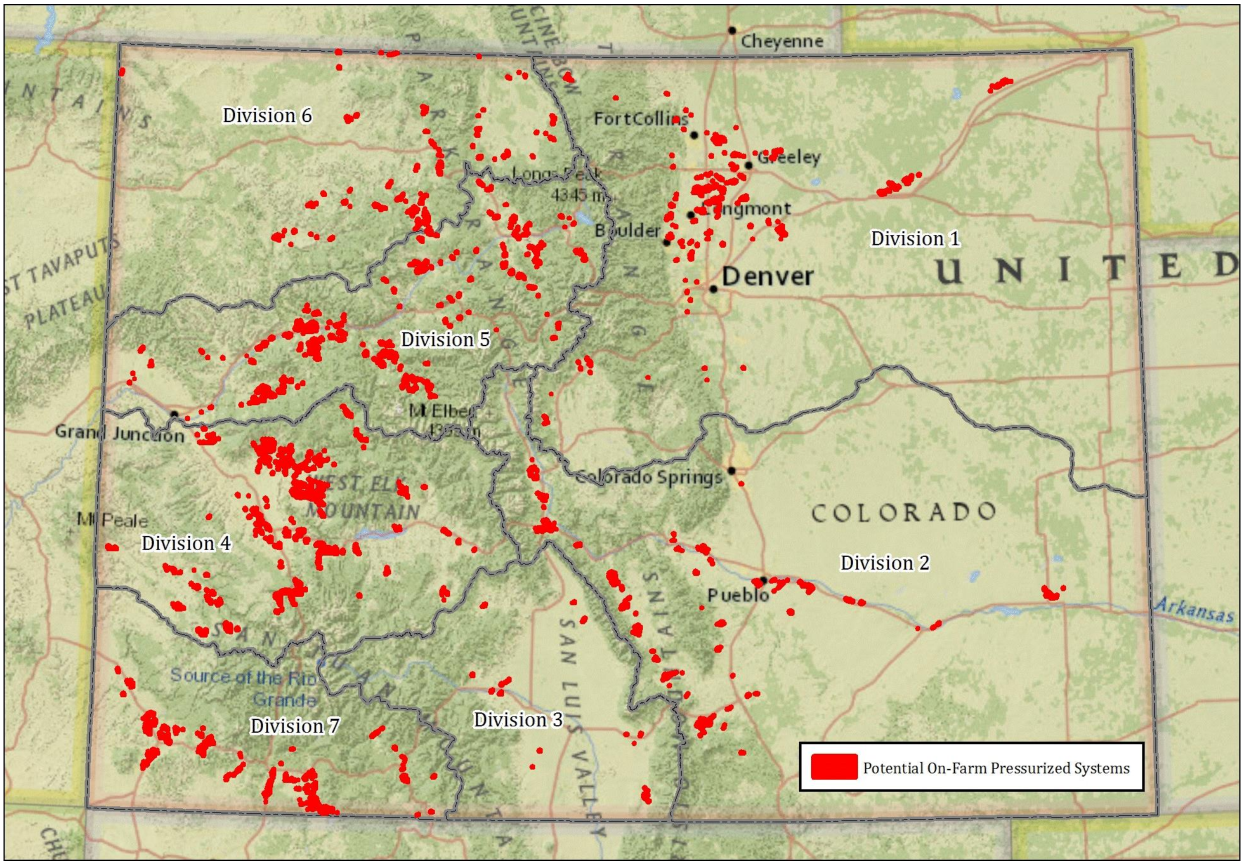


Figure 1: Pressurized Irrigation Hydropower Potential

This *Agricultural Hydropower Technical Manual* was prepared by Applegate Group under a commission from the Colorado Energy Office and the Colorado Department of Agriculture. This manual is a companion to the *Colorado Small Hydro Handbook*, which has additional information about hydropower theory and design concepts.

Introduction to Agricultural Hydropower

Agricultural hydropower projects utilize the infrastructure already in place or being constructed for a pressurized irrigation system. Intake structures and pipelines are system components shared by both pressurized irrigation systems and hydropower systems. By adding some capacity or configuring the layout to facilitate the addition of a turbine, otherwise wasted energy is captured and used to offset or eliminate the electrical consumption of the pressurized irrigation system.

Hydropower is defined as power derived from the energy of falling and running water. For the purposes of this document, the focus is on two specific types of hydropower projects, hydroelectric systems and hydro-mechanical systems. Both systems share many of the main components, but once it comes down to the specifics of how the systems function, the systems differ in many ways.

Hydro-mechanical systems are classified as such because they convert the available head and flow of water into mechanical energy to power machinery, in this case, specifically hydraulically powered center pivot sprinkler systems. Another term used synonymously with a hydro-mechanical system is a “direct-drive” system, because the turbine is connected directly to the drive system of the center pivot sprinkler. Historically hydro-mechanical plants were used to power sawmills, textile mills, or grain mills. These plants produce no electricity; the turbine simply turns the rotating machinery to do mechanical work.

This type of hydro-mechanically driven center pivot is only possible given adequate site conditions and appropriate equipment. The center pivot must be a “hydraulically powered center pivot” or a “hydrostatic drive” meaning that the drive system is powered with a hydraulic pump unit opposed to an electric motor. Traditionally the hydraulic pump unit is powered with either an engine or an electric motor. This manual describes how to power the hydraulic pump unit with a water turbine, otherwise known as a “reverse pump” or “pump-as-turbine.” Sites without cost-effective access to the electrical grid and with access to gravity pressurized water are best suited for this application. Annual operating costs of electricity or fuel are eliminated as a result. Hydro-mechanical projects should be considered when the site is an unreasonable distance from grid interconnection.

The hydroelectric systems are classified as “hydroelectric” because they use the available head and flow of water to convert that energy into electricity. The turbine is used to rotate a generator that produces either DC or AC electricity. A package of electrical equipment and controls is used to safely transfer that electricity to a local electric load or a connection with the grid. Hydroelectric projects should be considered if the project is in close proximity to the grid and there are electrical loads that can be offset.

Hydropower systems require little maintenance and have low operating costs. In general, turbines are very reliable and durable. The systems are becoming more popular in the agriculture community because of their ability to not only save the producer electric power expenses, but also reduce carbon emissions and other greenhouse gases by not burning oil or natural gas to power the irrigation systems. These self-sustaining hydropower systems are not only beneficial to the user, but also for the general community as a whole.

Introduction to Hydropower Systems

Configuration

Hydropower systems require some characteristic infrastructure to gather the energy contained in flowing water. Figure 2 shows a schematic of a typical hydropower system and its components.

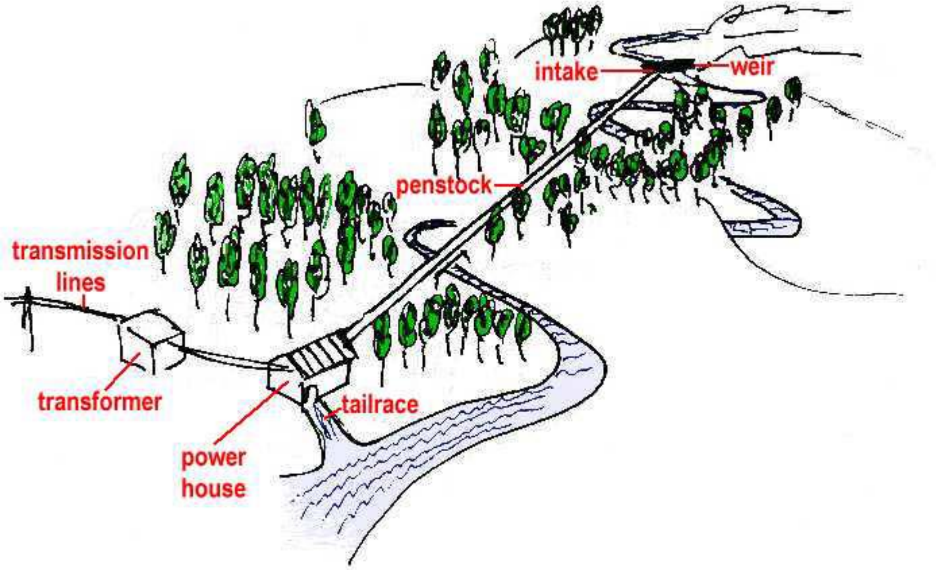


Figure 2: Hydropower Schematic

Hydropower systems begin with an intake or diversion structure to direct flow into the penstock (or pipeline). A diversion structure capable of directing irrigation water into an irrigation pipeline will also serve the same purpose to direct water into a penstock for use at a hydropower facility. The weir acts as a barrier across the water source, altering its flow characteristics and directing flow to the intake as shown in Figure 3. The intake structure is the highest point of the hydropower system and includes a trash rack or screen to remove debris before water enters the system.

Figure 3: Diversion Structure Example

Figure 4: Penstock Example

The pipeline, also known as the penstock, then conveys the water from the intake system to the turbine. Physically, there is no difference between a penstock and a pipeline; penstock is simply the name used for the pipeline that delivers water to the turbine in a hydropower system. Figure 4 shows an example of a penstock during installation.

Downstream of the penstock is where a hydroelectric system differs from a hydro-mechanical system. There, a powerhouse secures and protects the power generating equipment. Hydroelectric systems consist of a turbine, generator, and electrical controls. This equipment must be protected from the weather in an enclosed building or concrete vault. The powerhouse also provides a safe and secure environment for the electrical equipment. On the other hand, a hydro-mechanical system only consists of a turbine and belt connected to the standard equipment for a hydraulically powered center pivot (i.e., the hydraulic pump unit). This equipment does not need to be protected from the elements as there is no electrical equipment (other than a 12-volt controller and battery, housed in a small enclosure). See Figure 5 for an example of a hydroelectric powerhouse under construction and Figure 6 for an example of a hydro-mechanical powerhouse.

Figure 5: Hydroelectric Powerhouse

Figure 6: Hydro-mechanical Powerhouse

A hydroelectric system connects to the grid to transfer electricity to load centers for consumption. A transformer or inverter matches the voltage of the electricity from the hydroelectric generator to the voltage on the grid, and distribution lines feed the electricity to local load centers.

Power Theory

Power is a linear relationship with both the available net head and the available flow. The net head is the available hydraulic pressure represented by the difference in elevation from the intake of the system to the elevation of the turbine, minus any losses including friction loss, entrance loss, etc. The available flow is the amount of volumetric flow that is available at the intake structure. The last factor in the power calculation is the turbine efficiency. See below for the derivation of the basic power equation to calculate the power capacity of a hydropower facility:

$$Power = \rho g Q h$$

Where $\rho = mass\ density\ of\ water = 1.94 \frac{slug}{ft^3}$, where $1\ slug = \frac{1\ lbf}{1\ ft/s^2}$

$g = standard\ gravity\ coefficient = 32.17 \frac{ft}{s^2}$

$\rho g = weight\ density\ of\ water = 62.4 \frac{lbf}{ft^3}$

$Q = volumetric\ flow\ (\frac{ft^3}{s})$

$h = net\ head\ pressure\ (ft)$

Where $1\ horsepower\ (hp) = 550\ (lbf \cdot ft/s)$

$$Power\ (hp) = 62.4 \left(\frac{lbf}{ft^3}\right) * Q \left(\frac{ft^3}{s}\right) * h(ft) * \left(\frac{1\ (hp)}{550\ (lbf \cdot ft/s)}\right)$$

$$= \frac{Q \left(\frac{ft^3}{s}\right) * h(ft)}{8.81 \left(\frac{ft^4/s}{hp}\right)}$$

Where $1\ hp = \ 0.746\ kilowatts\ (kW)$

$$Power\ (kW) = \frac{Q \left(\frac{ft^3}{s}\right) * h(ft)}{8.81 \left(\frac{ft^4/s}{hp}\right)} * 0.746 \left(\frac{kW}{hp}\right)$$

$$= \frac{Q \left(\frac{ft^3}{s}\right) * h(ft)}{11.8 \left(\frac{ft^4/s}{kW}\right)}$$

Please note that this derivation of the power equation does not account for turbine efficiency. Adding the turbine efficiency results in the common power equation.

$$Power\ (kW) = \frac{Net\ Head\ (ft) * Required\ Flow\ (cfs) * Turbine\ Efficiency}{11.8}$$

This equation gives the power capacity of a hydropower plant. The amount of energy produced by this facility is given in kilowatt-hours (kWh). To calculate the amount of energy produced by a hydropower plant over a period of time, the following equation is used:

$$Energy\ (kWh) = Power\ (kW) * Operation\ (hr/yr)$$

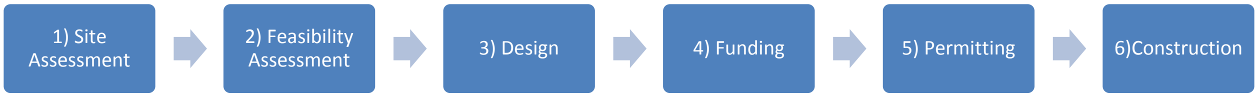
Using this Guidance Document

This document is intended to be used in conjunction with the Toolboxes provided in the appendices and electronically. These assessment tools are a set of Excel worksheets that help the user determine the feasibility of the site, calculate pertinent information for the design of the hydropower project, and help with permitting and funding applications. The Site Assessment worksheet is intended to be printed and used for a field survey during an initial site visit. All other worksheets are intended to be completed within the electronic Toolbox file.

This manual provides the background and a step-by-step process for completing the Hydroelectric or Hydro-mechanical Toolboxes. Use this technical manual as a reference for filling out the Toolboxes and as a resource when questions arise.

Project Development Process

This manual guides the reader through these six project development steps for both hydro-mechanical and hydroelectric projects.



Step 1: Site Assessment

The first step in developing any hydropower project is to complete a Site Assessment. The purpose of a Site Assessment is to determine if a proposed project site appears promising enough to warrant proceeding to a Feasibility Assessment. These questions could be asked over the phone during a preliminary conversation with a prospective applicant or in the field.

The general questions for any agricultural hydropower project, whether hydroelectric or hydro-mechanical, are included in this section. Specific project related questions are explained in Part 1 and Part 2 for hydro-mechanical and hydroelectric projects, respectively.

The description and explanation below each item is specific to hydropower built on a pressurized irrigation system. An interactive site assessment tool for all types of hydropower projects is available at the websites of the Colorado Energy Office and Colorado Department of Agriculture.

A. General Project Types

This technical manual covers two types of projects, 1) Hydro-mechanically driven center pivot sprinkler systems and 2) Hydroelectric plants installed on pressurized irrigation pipelines designed to directly offset electrical loads for agricultural operations in a grid-connected, net-metered system (less than 50 kW, depending on the restrictions of the local utility).

What type of project are you pursuing, hydroelectric or hydro-mechanical?

If the site is an unreasonable distance from the grid for interconnection (i.e. several miles), consider a hydro-mechanical project. Alternatively, if the grid is in close proximity and sufficient electrical loads exist, then consider a hydroelectric project. The economic impacts of extending a power line to the nearest grid connection point typically determine whether a project site is close enough to the grid. A power line extension may cost $30,000 per mile or more. Ask your local utility about typical costs of a power line extension for single- or three-phase power to decide whether to consider a hydroelectric project.

B. Site Location and Ownership

As with installing a pressurized irrigation system, if the agricultural producer does not own all of the land that is associated with the system, the producer must obtain easements or agreements to gain necessary access. The most straightforward approach is to keep all components of the irrigation and hydropower system on the agricultural producer’s property. If that is not possible, appropriate measures must be taken to allow access for construction and operation of the infrastructure.

Do you control the site location through ownership or agreement for construction and continued operation of the project?

If the answer is no, advise the applicant to obtain ownership or permission before considering the project in more detail.

C. Stream or Body of Water

When adding hydropower to a pressurized irrigation system, the hydropower operates using the irrigation water and pressure supplied by the pipelines. The source of irrigation water may be a direct diversion from a natural body of water or a share of the water in a canal or ditch. All projects suggested in this manual assume that adding hydropower, in itself, will not change water diversions or irrigation operations, although upgrades to existing diversion structures may be necessary.

What is the source of water for the project?

D. Water Rights

All projects discussed in this manual use existing irrigation water rights with no change of diversions in timing or quantity due to the addition of hydropower. Because this is the case, there is no need to apply for a new hydropower right, or change an existing right to include hydropower as a beneficial use. The agricultural producer needs to hold the water rights associated with the irrigation system and rely on only that water for hydropower energy production. Applications for assistance for these projects require verification of the water rights that apply to the project.

Do you have rights to the source of water? If yes, what quantity?

If the answer is no, advise the applicant to obtain water rights before pursuing the project in more detail.

E. Road Access

The hydropower facility needs to be accessible for operation and maintenance on a periodic basis. If adequate access needs to be constructed for those activities, the associated cost needs to be considered in the overall cost of the development.

Is there adequate road access to the site?

If the answer is no, advise the applicant to consider the additional costs required to create this access.

F. Community or Environmental Issues

It is important to determine whether there are any concerns that should be addressed with regard to the community or the environment. We do not expect any opposition or impact created by agricultural hydropower projects developed in conjunction with an irrigation pipeline.

Community impacts to consider include, but are not limited to: growth and development impacts, quality of life for adjacent property owners, social environment of the geographical region impacted, safety and general public interest. Environmental impacts to consider include, but are not limited to: endangered species impacts, fish and wildlife impacts, soil and vegetation impacts, etc.

Are there any community or environmental issues that may affect the project?

If the answer to the question is yes, advise the applicant to resolve any potential issues before pursuing the project or consider revising the project concept to avoid potential impacts.

G. Project Specific Questions

The above questions 1-6 apply to any hydropower project. There are additional questions specific to a hydro-mechanical or hydroelectric project, which are covered in Part 1 and Part 2 of this manual, respectively.

Step 2: Feasibility Assessment

A Feasibility Assessment looks at the potential project in more detail than the Site Assessment. The purpose of the Feasibility Assessment is to gather enough information and perform enough design tasks to decide if the potential project is both technically and economically feasible.

The feasibility of a hydro-mechanical project is straightforward. If the appropriate site conditions exist, i.e. enough excess pressure or flow to produce sufficient power for the center pivot, then the project is technically feasible. If the project is technically feasible, it is also likely economically feasible, since installing and operating a hydro-mechanical system costs less than a diesel generator or electrical grid connection, and eliminates annual energy costs.

The feasibility of a hydroelectric project is slightly more complicated. There are many different possible configurations, many turbines, and a number of additional costs to consider. In general, assessing the feasibility of a hydropower project requires investigation, planning, and performance of the following items, as discussed in detail later in this manual.

1. Resource Assessment – The goal of this step is to estimate the power capacity and the annual energy production of the facility based on the available head and flow.
2. Project Layout and Conceptual Design – Enough layout and design must be performed to identify any hindrances to the project with regard to the site conditions, confirm the technical feasibility and estimate the cost of the installation. The following four items should be considered at this stage.
    a. Turbine Selection
    b. Penstock Sizing and Alignment
    c. Powerhouse and Foundation
    d. Interconnection

   For hydroelectric projects, evaluate utility approval as part of the interconnection feasibility.
3. Economic Analysis – Comparing the avoided costs or energy savings to the installation and operating costs will determine the economic feasibility of the facility.
    a. Estimated Project Development Costs
    b. Grants and Incentives
    c. Expected Savings or Avoided Costs

Step 3: Design

The design of a hydro-mechanical system requires the designer to understand how turbines and hydraulic pump units operate. The selection of the turbine and bypass design varies with each design based on the available head and flow, but the remainder of the system is standard for all projects. The hydro-mechanical system design includes the following elements as described in this manual, assuming that the intake and penstock already exist as part of the irrigation system pipeline.

1. Turbine Selection
2. Bypass Design
3. Layout including valves, rotation and fittings

The complete design of a hydroelectric project involves civil, mechanical and electrical engineering. All three disciplines are represented in any project. This manual provides some level of detail about the following components of the design:

1. Intake
2. Penstock
3. Powerhouse and Foundation
4. Turbine and Generator
5. Controls and Interconnection

For additional information about the design of hydropower systems, please see the companion to this manual, *The Colorado Small Hydropower Handbook*.

Step 4: Funding

There are several incentives available for agricultural hydropower projects through the USDA, the Colorado Department of Agriculture, and Colorado Conservation District offices. Some restrictions and limitations apply to each funding program.

EQIP

The USDA-NRCS Environmental Quality Incentives Program (EQIP) provides financial assistance payments to help eligible producers implement approved conservation practices on eligible land. EQIP payments are made through a reimbursement process. Participants may receive EQIP payments to reimburse equipment and technical assistance costs after the approved conservation activity has been certified as complete. Payment rates for conservation practices vary from year to year. The EQIP rates for hydropower equipment (through September 2015) are listed in the table below on a per-unit basis. Contact your local NRCS office to obtain the current payment rates and scenarios as these incentives vary from year to year and may not be available at the rates indicated below.

Table 1: EQIP FY2014 payment rates for hydropower equipment (Practice Code 430 – Irrigation Pipeline)

Component	Unit	Regular EQIP	EQIP Special Initiatives	EQIP Historically Underserved (HU)
Micro Hydroelectric Power Plant	Kilowatt	$1,965.18	$2,679.79	$3,215.74
Micro Hydro-mechanical Power Plant	Horsepower	$897.15	$1,223.38	$1,468.06

REAP

USDA-Rural Development provides guaranteed loan financing and grant funding to agricultural producers and rural small businesses through the Rural Energy for America Program (REAP). REAP grants can be used to purchase or install hydropower systems and are available on a competitive basis for up to 25% of the total project costs. This manual explains how to complete the Technical Report as part of the REAP grant application.

To be eligible for REAP funding; the applicant must be either an agricultural producer or a rural small business. The definition of an agricultural producer is an individual or entity directly engaged in the production of agricultural products, whereby 50 percent or greater of their gross income is derived from those products. A rural small business must be located in a rural area (any area in a state, not within a city or town that has a population of more than 50,000). Consult with the USDA Rural Development office to determine the eligibility of an applicant or project.

ACRE^3

The Colorado Department of Agriculture's (CDA) Advancing Colorado's Renewable Energy and Energy Efficiency program (ACRE^3) provides financial and technical assistance and education to help agricultural producers cut energy costs and develop their own energy resources. A current focus for the program is small hydropower, specifically micro-hydro projects associated with pressurized irrigation systems. Sam Anderson, the CDA energy specialist, is available to assist producers who are interested in pursuing the development of both hydroelectric and hydro-mechanical systems on pressurized irrigation. He can provide agricultural producers with advice, technical support, assistance identifying financial support, and help with other facets of assessing and implementing on-farm small hydropower. Any producer who is interested in small hydropower should contact Sam at 303-869-9044 or sam.anderson@state.co.us.

As CDA develops the ACRE^3 program, it may provide additional funding assistance for hydropower project development and construction costs. At this time, however, CDA continues to evaluate the need for such funding in light of existing federal, state, and utility support for small hydropower. Any financial assistance from ACRE^3 could be combined with assistance from the REAP program and other assistance programs. In addition, producers should also contact their local conservation district office to determine if additional financial support could be available through a Matching Grant from the Colorado State Conservation Board.

RCPP Colorado Ag Hydro Project

Agricultural irrigators eligible for EQIP assistance may also qualify for special funding through a joint program between the NRCS Regional Conservation Partnership Program and CDA. The RCPP Colorado Pressurized Irrigation Small Hydropower Partnership Project provides payments for technical and financial assistance through a special pool of EQIP funds and the CDA's ACRE^3 program. To qualify, irrigators must also engage in an Irrigation Water Management Plan through their local NRCS office.

Projects like those described in this manual may receive funding from NRCS to support resource conservation through water efficiency improvements, such as switching from flood irrigation to sprinkler irrigation, and energy conservation through the development of a renewable energy system. Project owners can receive funding for the implementation of conservation practices such as Conservation Practice Code 430 – Irrigation Pipeline; 442 – Irrigation System-Sprinkler; 447 – Irrigation System-Tailwater Recovery; 449 – Irrigation Water Management, and others that may be applicable to the project. The incentive for hydropower for FY2015 is provided in Conservation Practice Code 430 – Irrigation Pipeline. Please note that these practices may be specific to Colorado.

Step 5: Permitting

Adding a hydro-mechanical system to a pressurized irrigation system does not trigger any additional permits, although adding a hydroelectric system does. For hydroelectric systems, permitting processes are required through the Federal Energy Regulatory Commission, the local utility, and the local jurisdictional electrical inspection authority. This manual explains how to navigate through these permitting processes.

Step 6: Construction, Commissioning and Closeout

Construction, commissioning and closeout of an agricultural project are the final steps of the development process. Construction may begin after the owner gives approval and all permitting and funding is in place. Once the construction begins, inspections will ensure that the construction matches the approved design plans. The appended Toolbox documents contain a checklist to assist in the inspection process.

Following the construction of the system, project commissioning verifies that the system functions properly. When commissioning is complete, the closeout process can begin. Closeout consists of certifying that the following documents and documentation are complete: inspection checklist, any design modifications, construction records, final quantities, progress reporting, and as-built documentation. The NRCS uses form CO-ENG-12 to certify that all closeout items are complete and properly documented.

Part 1: Hydro-mechanical Center Pivot Applications

A less frequently used, but very traditional method of hydropower development is to use water power to turn mechanical machinery. These plants produce no electricity; the turbine simply turns the rotating machinery to do mechanical work. Historically hydro-mechanical plants were used to power sawmills, textile mills, or grain mills. This section explains how to design a hydro-mechanically powered, hydraulically driven center pivot sprinkler.

This type of center pivot drive is only possible given adequate site conditions and appropriate equipment. The major benefit is that the need for electric or diesel motors can be eliminated completely. As a result, annual operational costs of electricity or fuel are eliminated. Sites without access to the electrical grid and with access to gravity-pressurized water are best suited for this application.

The site conditions required to make this application possible include, first, adequate water and pressure to the sprinkler heads, and second, additional water or pressure to generate the power required by the hydraulic pump unit. The pivot must be a hydraulically driven center pivot, currently only available in the United States from T-L Irrigation. It is important to note that the use of a hydraulically driven center pivot may preclude the use of end guns and variable flow through the sprinklers, but the operator may still adjust the irrigation rate by changing the speed of rotation.

The following sections guide the reader through the necessary steps to determine if these conditions are met, if the limitations are acceptable, and how to design and install the system.

Step 1: Site Assessment

Use the Site Assessment worksheet to determine whether a hydro-mechanically driven center pivot system is right for the project site. Once the designer has determined that a hydro-mechanical drive system is the best design for the project, the assessment sheet will indicate whether to move forward with an *excess pressure* design or *excess flow* design.

The ***Excess Pressure System*** utilizes the sprinkler water passing through the turbine before entering the sprinkler and the turbine reduces the pressure to the appropriate level for the sprinklers.

The ***Excess Flow System*** utilizes additional water that is carried through the pipeline to the center pivot, where the excess flow passes through the turbine and discharges to atmospheric pressure for irrigation use downstream.

The Site Assessment worksheet analyzes the project site based on the following criteria: available head (pressure), available flow, and available power capacity. This section walks the reader through the Site Assessment worksheet in the Hydro-Mechanical Toolbox, where each question is shown in bold with a brief discussion. This worksheet documents the answers to the following questions and indicates whether or not to move forward with a full feasibility analysis.

(1) What is the required pressure for the center pivot sprinkler system?

The center pivot sprinkler system requires a certain amount of pressure at the center of the pivot to operate properly. The required amount of pressure is based on the sprinkler head package specified by the irrigation system design as well as the effects of terrain. If a significant elevation change occurs in the span of the sprinkler line as it crosses over the field, the designer must also account for the additional pressure requirements here. For example if the pivot center is at elevation 5,000 feet and the end of the span climbs to an elevation of 5,050 feet, the required pressure will be equal to the sprinkler head pressure (~30 psi) + 50 feet (or 21.5 psi). Therefore the total pressure required is equal to 51.5 psi.

(2) What is the net available pressure for the center pivot sprinkler system?

The project has a certain amount of available pressure that needs to be calculated at the center of the center pivot. The net available pressure can be calculated in a variety of ways. The total or gross head (or elevation change) can be determined using an altimeter, sight level, survey topography, pressure gauge, etc. If head losses through the irrigation piping system are known at this point, deduct those losses from the gross pressure, or estimate the losses for deduction. Head loss is caused by friction, enlargement or contraction of the pipe, pipe bends, as well as pipe fittings and valves; refer to the *Colorado Small Hydro Handbook* for more information on head losses. The net pressure is calculated by subtracting head losses from the gross pressure. If the net pressure is calculated in psi, then the psi can be converted to head using the conversion that 1 psi is equivalent to 2.31 feet of head.

(3) Calculate excess pressure = (2) net available pressure – (1) required pressure

The difference in the net available pressure and required pressure for the center pivot sprinkler system needs to be calculated to determine if the system should be designed using excess pressure. If there is no excess pressure available, excess flow is required to make the site feasible. An excess pressure system uses the excess pressure contained in the water going to the sprinkler heads for energy production. The turbine will act as a pressure reducing valve.

(4) What is the required flow for the center pivot sprinkler system?

The center pivot sprinkler system requires a certain amount of flow through the sprinkler heads to operate properly. The required flow is dependent on the sprinkler head package chosen and the maximum expected irrigation rate, based on the operational conditions of the system.

(5) What is the available flow for the center pivot sprinkler system?

Determine the total available flow for the project site. The available flow can be based on historic flows at the site, or expected flows after conservation improvements are implemented. The available flow can be measured in either gallons per minute or cubic feet per second using the conversion factor of 1 cfs equals 449 gpm.

(6) Calculate Excess Flow = (5) available flow – (4) required flow

Calculate the difference between the total available flow and the required flow of the center pivot sprinkler system to determine whether the system should be designed using excess flow. If there is excess flow, the turbine will be designed to use the excess flow along with all of the available pressure at the pivot. The pipeline to the pivot will carry the excess flow, which then runs though the turbine and is discharged at the center of the pivot.

Power Capacity and Power Requirement Calculations

The next step of the site assessment is to estimate the available power capacity of an excess pressure system or an excess flow system using the calculations from the previous steps. The available power capacity of a hydro-mechanical turbine can be estimated using the power equation:

$$\text{Power (kW)} = \frac{\text{Pressure (ft)} \times \text{Flow (cfs)} \times \text{Efficiency}}{11.8}$$

To estimate the available power capacity for either an excess pressure system or an excess flow system, the same equation is used with the appropriate pressure and flow depending on the system being analyzed. The efficiency is assumed to be 65% for an initial approximation. The actual efficiency of the selected turbine will be determined and used in the design through later steps.

For excess pressure, estimate the available power capacity using the following:

$$\text{Available Power Capacity (kW)} = \frac{\text{(3) Excess Pressure (ft)} \times \text{(4) Required Flow (cfs)} \times 0.65}{11.8}$$

For excess flow, estimate the available power capacity using the following:

$$\text{Available Power Capacity (kW)} = \frac{\text{(2) Available Pressure (ft)} \times \text{(6) Excess Flow (cfs)} \times 0.65}{11.8}$$

The appropriate equation provides the available power capacity based on the available pressure or head.

(7) How many towers does the center pivot sprinkler system require?

The number of towers required on the center pivot sprinkler system determines the required power capacity of the hydro-mechanical turbine. The number of towers is based on the topography and the lateral length of the sprinkler system.

(8) Total required capacity: (7) # of towers x 0.75 hp/tower = ______hp x 0.746 kW/hp = _____kW

Calculation of the total required power capacity assumes that each tower in the center pivot systems require approximately 0.75 hp, although this requirement varies depending on the system configuration and local terrain. The total required capacity is an estimate of how much power the turbine needs to produce in order to meet the electric load of the center pivot drive system. If the required power capacity is greater than the available power capacity estimated previously, then a hydro-mechanically driven pivot is not technically feasible for the project as designed.

Changes could be made to the center pivot system or pipeline design to increase the available power capacity or decrease the required power capacity of the pivot system. Examples of possible changes include increasing the size of the penstock to reduce head loss and/or reducing sprinkler pressure or the number of towers to decrease the required pressure or power capacity. Changes to the available site conditions or the requirements of the system might help with the technical feasibility of the site.

Reevaluate the conditions until the hydro-mechanical system can supply enough power. If sufficient changes are not possible, the site is likely not feasible for a hydro-mechanical system. Consider the possibility of using a hydroelectric system instead.

If it has been determined that a hydro-mechanically driven pivot is technically feasible at the site, the next step is to investigate the economic feasibility. The hydro-mechanical toolbox provides a hydro-mechanical economic feasibility analysis tool, as explained in the next step.

Step 2: Feasibility Assessment

The ***2) Hydro-Mechanical Economics*** worksheet help to determine the total cost for the project, available incentives, savings, and the simple payback for the project. This will help the applicant determine whether or not the project is economically feasible and should move forward or be abandoned.

General Project Information

The first section of the Economic Assessment is to input the required power capacity of the turbine in kilowatts. This was estimated in the Site Assessment worksheet and will be used to calculate the project incentives.

Project Cost Items

The second section of the Economic Assessment is to input the total costs for the project. The project costs are broken down into three items: turbine cost & installation, pipeline costs without EQIP incentive, and design costs (if applicable). At this point in the hydro-mechanical feasibility assessment, the costs are approximated, as the system has not been designed. Based on past projects one can assume that the turbine and installation will cost between $12,000 and $18,000. Other costs will be specific to the project.

Project Incentives

The third section of the Economic Assessment determines which incentives are available for the project. Determine first whether the project will qualify for the Rural Energy for America Program (REAP), and enter a “yes” in the appropriate cell if it is applicable, or “no” if it is not. The available REAP incentive is calculated as 25% of the total project cost. If the REAP incentive is applicable, the worksheet will automatically calculate the *energy generated per grant dollar requested.* This is calculated based upon the annual energy production (converted from kWh to Btu) and the *total REAP incentives requested.* The REAP application requests this value for scoring the merit of the application.

Next, determine if the project qualifies for the Environmental Quality Incentives Program (EQIP). The EQIP incentive is divided into three different payment rates: Regular EQIP, EQIP Special Initiatives, and EQIP Historically Underserved. If the project qualifies for EQIP, then enter a “yes” in the cell for the appropriate payment rate that will be used. The payment rate per kilowatt is then applied to the required power capacity of the turbine to calculate the available EQIP incentive. Please note that the EQIP incentives vary from year to year and the rates reflected within the worksheets may not be the most current payment rates. Irrigation Pipeline Practice 430 currently specifies the EQIP payment rates for hydro-mechanical power plants as used in the worksheet. Contact your local NRCS office to obtain the current payment rates and scenarios.

Avoided Costs and Average Net Savings

The final section of the Economic Assessment is to input the savings that the project is expected to produce. The project savings is broken down into three items: annual energy production, retail rate of electricity, and monthly base charge for electricity. The annual energy production is calculated by multiplying the power capacity in kilowatts by the anticipated yearly hours of operation (also calculated in Site Assessment).

The local electricity providers determine the retail rate of electricity and the monthly base charge. The applicant can use prior similar electricity bills or could contact their local electricity provider in order to determine these rates, as they may not equate with residential rates. Once the data for the savings has been input, the total yearly project savings is calculated.

Simple Payback

The simple payback is calculated and represented in years. The "Simple Payback Before Incentives" is simply the total project costs divided by the total yearly project savings. The "Net Simple Payback After Incentives" is the project incentives total, subtracted from the total project cost, and then divided by the average annual amount of total net savings.

After the Economic Assessment has been completed, and it has been determined that the project will be economically feasible, then the hydro-mechanical system design can begin.

Step 3: Design

Once the project has been found to be both technically and economically feasible, the next step is to design the turbine and associated valves and fittings. The following sections explain the design parameters and the design process. The last section of Step 3 will guide the reader through completing the design worksheets.

A. Head (pressure)

If the site has excess available head (pressure) beyond what is needed to pressurize the sprinklers, a mechanically driven pivot can be powered using the excess available head. In a traditional system, the excess head of the irrigation system would be neglected or burned through a valve or the pressure regulators. A hydro-mechanical turbine takes this otherwise neglected pressure and uses it to directly drive the hydraulic pump unit on the center pivot, eliminating the need for electricity and significantly reducing operating expenses.

The differential or excess pressure is calculated by subtracting the required pressure (head) of the center pivot system from the net available pressure (head) of the irrigation pipeline at the center pivot. The net available pressure is calculated at the center pivot by accounting for irrigation pipeline losses at the maximum expected flow rate (maximum dynamic head losses). The excess pressure is the design pressure of the turbine. If the pipeline carries excess water flow at times, resulting in higher head losses and a lower pressure at the pivot, this will affect the performance of the turbine. By designing the turbine for the lowest expected excess pressure, then the turbine will always provide sufficient power and excess pressure can be dissipated by either valves or the pressure regulators at the sprinkler heads.

If the system uses excess flow, the design pressure available to the turbine is equal to the net available pressure at the center pivot. Again, the design pressure needs to be the lowest pressure expected at the center pivot, accounting for all losses. If the design pressure is calculated in psi, this can be converted to feet of head using the conversion that 1 psi is equivalent to 2.31 feet of head.

B. Flow

If the site has excess flow available at the center pivot, beyond what is needed for the sprinkler system, a mechanically driven pivot can be powered using that excess flow. The irrigation pipeline will bifurcate just upstream of the pivot, directing some flow to the sprinkler heads and the excess to the hydro-mechanical turbine. The excess flow is the design flow of the turbine. The excess flow will be discharged downstream of the turbine to atmospheric pressure and needs to be dealt with after it is discharged. A ditch or additional pipeline will need to be used to take the water away from this irrigated field to another point of use, typically another irrigated field downstream from the discharge point.

If the site uses excess pressure, the available flow to the turbine is limited to the maximum design flow for the sprinkler heads. It may not be necessary to use all of the available flow, but the turbine cannot be designed to use more flow than the sprinkler heads.

It is important in both cases that the flow available to the turbine and the sprinkler system is available for the entire period of operation. The turbine will be sized to operate at one flow rate; if that total flow is not available, the turbine speed will be reduced and the system will not operate properly. All designs should be based on the minimum, reliable flow available to the system. The designer should expect that if insufficient flow is available, the entire system might not be able to operate.

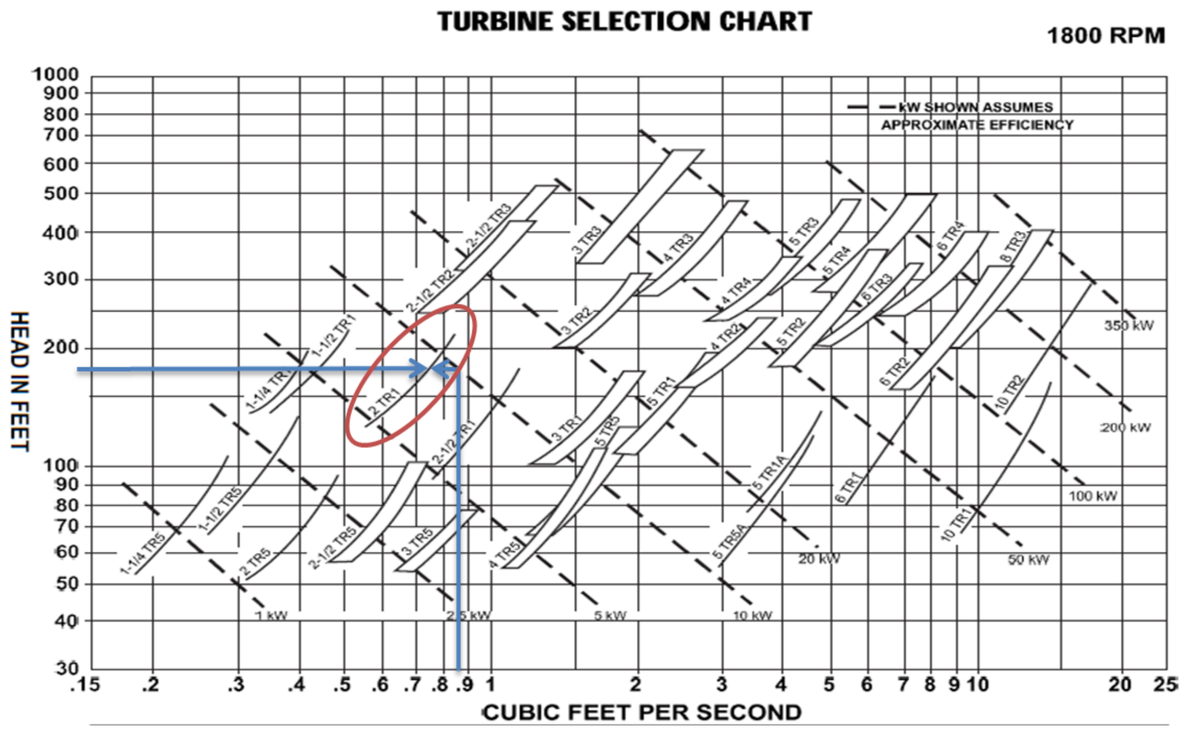
C. Turbine Selection

For hydro-mechanical turbines, reverse running centrifugal pumps are the standard selection to provide power to the hydraulic pump unit of the center pivot sprinkler system. They are also called “pumps as turbines”, meaning they are essentially an inverted pump. The turbine models are the same as the pump models, parts are readily available and maintenance is fairly simple.

Any brand of centrifugal pump can be used; however, Cornell Pump Company has developed turbine curves in order to estimate the power that each turbine/pump model produces. The entire Cornell Catalog is included in Appendix E of this manual. The 1800 rpm selection chart is used to match the power requirements at the same speed of the T-L Hydraulic Pump Unit. Using the 1200 rpm selection chart will misrepresent the power produced at the hydraulic pump unit speed of 1800 rpms.

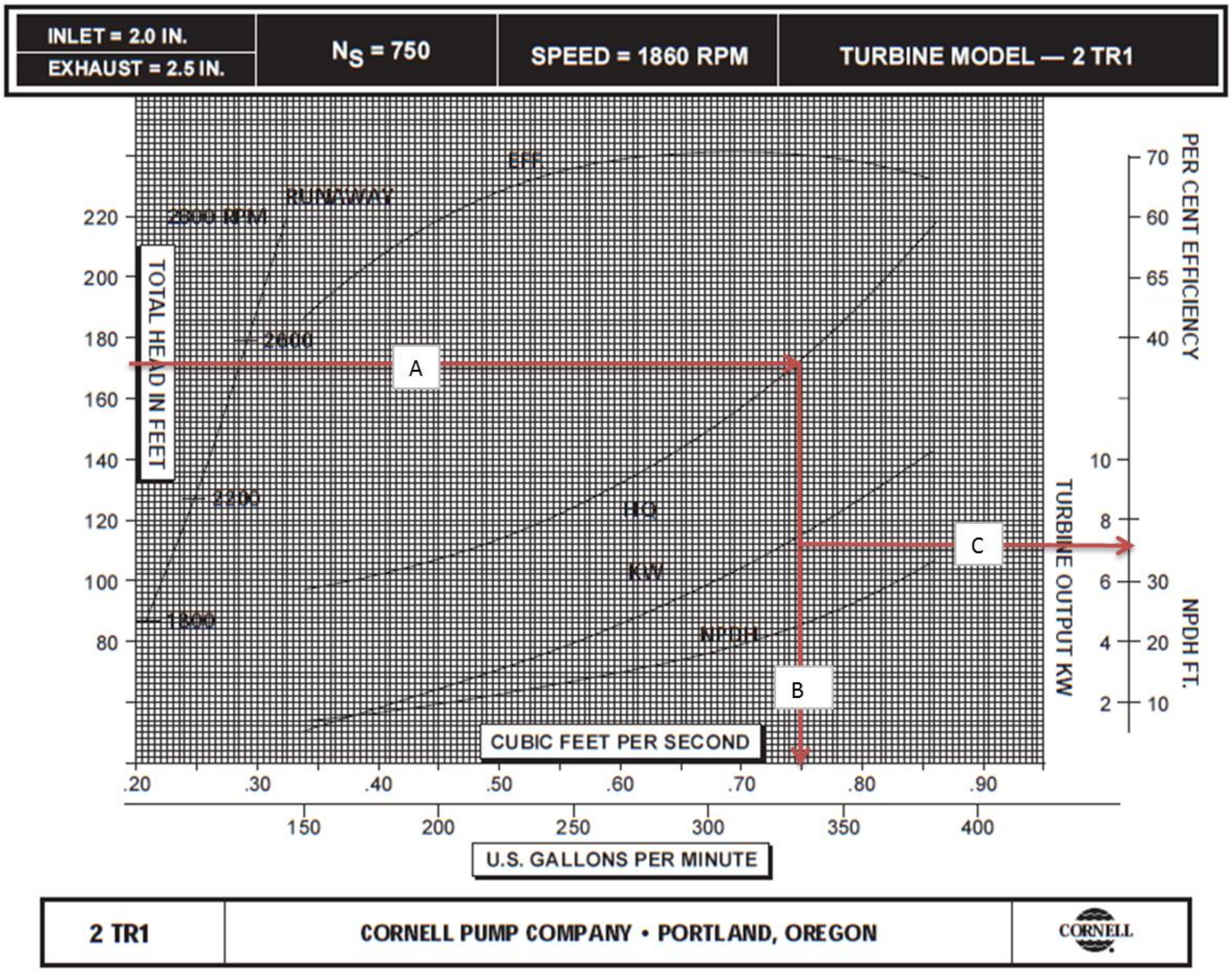
To select the appropriate Cornell Turbine, reference the Cornell Pump Manufacturers Catalog (Page 13) for 1800 RPM Turbine Selection Chart. The pressure differential in feet of head, and the available flow in cfs, is used to find the appropriate turbine model for the project. By following the point along the y-axis for head in feet, and the point along the x-axis for flow in cfs, the point of intersection gives the appropriate turbine model. If the intersection lands in an area without a turbine, reduce the head or flow (but do not increase!) to find the closest match to the site conditions available.

The example used below has 173 feet of available head and 400 gallons per minute (0.89 cfs) of available flow.



Once the turbine model has been selected reference the appropriate turbine model chart (pages 19-52). For the example shown above, the 2TR1 at 1800 rpms is the selected turbine; this turbine model chart is found on page 23.

To find the turbine required flow & kW output, begin by drawing a line from the available head across the page to the “HQ” head-flow line (A). At the intersection, draw a line down to find your required flow (B). Then at the intersection of the line drawn down and the “kW” kilowatt line, draw a line perpendicular to the right side of the page in order to find the turbine output in kilowatts (C).



The flow that will pass through the turbine is based on the amount of head at the turbine. The turbine model curve shown above defines that relationship. Only the combination of head and flow defined by the HQ line is possible. If less head is available at the turbine, the flow that the turbine will pass is reduced and can be found by following the HQ line down. This example using a 2TR1 with 173 feet of head will pass 0.75 cfs of flow and will produce 7.5 kW of power.

D. Power requirement

The power requirement of the system is based upon the number of towers that span the lateral length of the center pivot sprinkler system. The number of towers varies based on the topography and lateral length of the pivot. Each tower is assumed to require approximately 0.75 horsepower, a conservative estimate, and this horsepower is then converted to kilowatts using the conversion that 1 horsepower is equivalent to 0.746 kilowatts.

The available power capacity is based on the turbine selection and the charts shown in the previous section. This available power is then compared to the power requirement to determine if the project is feasible. If the available power is greater than or equal to the required power, then the project can move forward and a turbine can be selected.

E. Bypass Design

If the hydro-mechanical system uses excess flow, a bypass is needed to purge the system of excess flow that neither the turbine nor sprinkler system can utilize. There are several situations where purging excess water is required;

1) In order to move the sprinkler system without applying water to the field, the sprinkler water can be discharged through the bypass instead of through the sprinklers.
2) If excess water is needed downstream, beyond what is discharged by the turbine, the bypass can handle this water.
3) If the center pivot is not operating and water is needed downstream, the bypass can be used to deliver this water.

If the hydro-mechanical system is powered by excess pressure, there are two possible bypasses required. All systems will require a bypass that is installed in parallel with the turbine. This bypass pipeline is sized to convey sprinkler flow in excess of turbine flow. An automatic pressure reducing valve is used to automatically accept any flow above the turbine flow and reduce its pressure to the pressure required by the sprinkler.

The second possible bypass that could be added to an excess pressure design would be located downstream of the turbine before the sprinklers. This bypass would be installed if the producer wishes to move the pivot without applying water to the field. Again, this discharge would need to be managed properly and directed off the field. This bypass would need to be operated manually, and adjusted to allow the flow to pass while maintaining the appropriate back pressure on the turbine in the same amount as the sprinkler pressure.

F. Layout – Valves, Rotation, Example Drawings

The layout of the system will be similar for both excess pressure and excess flow systems. The system begins at the water source using a pipeline to convey the water to the site. Once at the site, if excess flow is available, the pipeline will bifurcate and flow will be apportioned to the turbine and separately to the center pivot sprinklers. When excess pressure is available, the pipeline will bifurcate for a short distance, apportioning flow to the turbine and the bypass valve, downstream of which the pipelines will converge before entering the center pivot sprinkler.

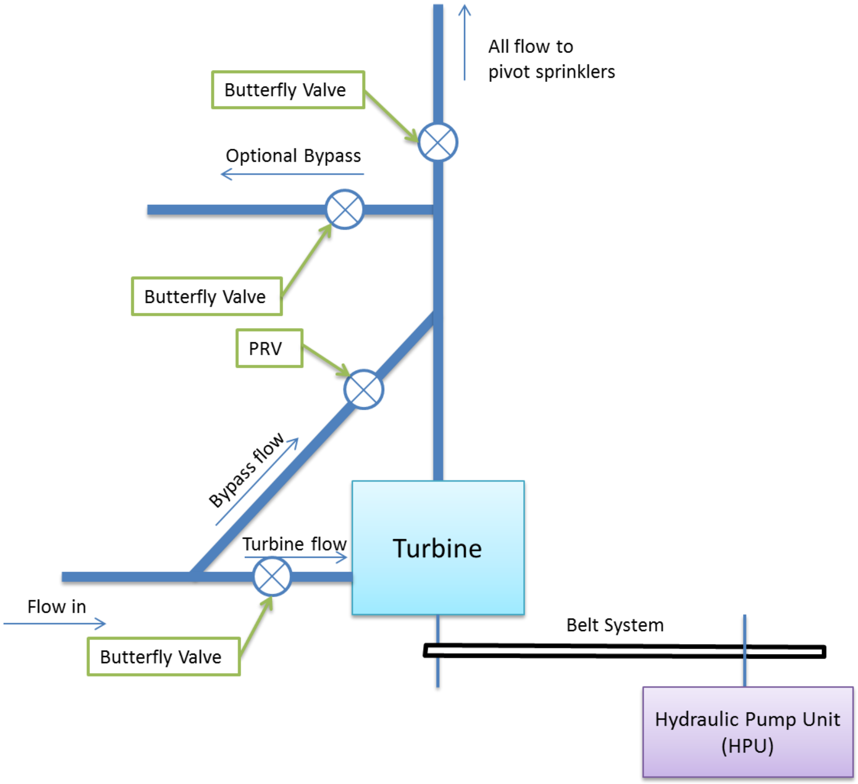


Figure 7: Schematic of Basic Layout for Excess Pressure System Design

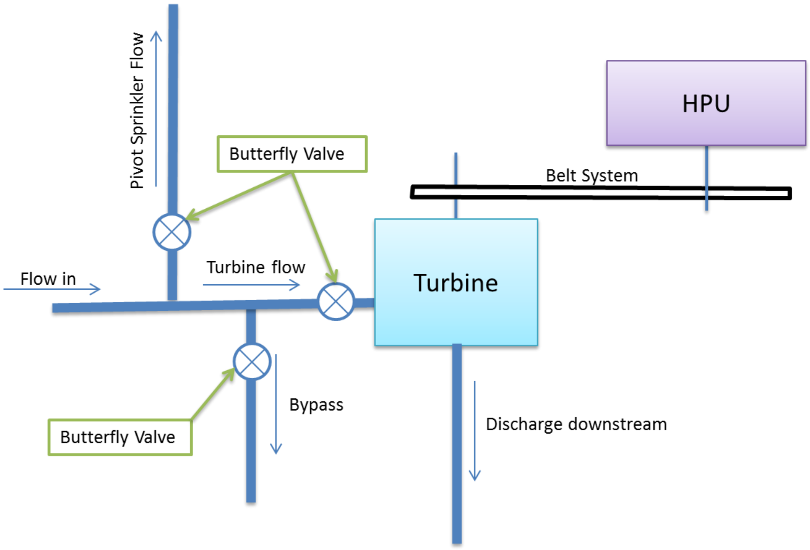


Figure 8: Schematic of Basic Layout for Excess Flow System Design

The system will require manual valves in order to adjust flow and to shut off/turn on water as necessary for maintenance or operation. Butterfly valves are needed upstream and downstream of the turbine, while more valves may be added dependent on operating conditions. In the situation that the pivot must be able to move without conveying water through the sprinkler system, a valve and separate discharge line is added downstream of the turbine but upstream of sprinklers.

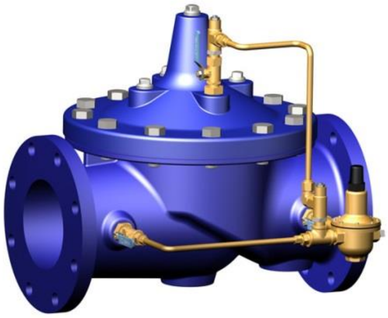


Figure 9: Pressure Reducing Valve (cla-val.com)

An automatic pressure reducing valve (PRV) on a bypass line is required if the system operates on excess pressure. The design of this valve is discussed in the ***3a) Hydro-Mech Pressure Design*** *- Hydro-Mechanical Center Pivot with Excess Pressure Design Sheet, Step 7*. The PRV will adjust the pressure to the determined downstream amount regardless of the amount of flow entering the system. This removes the need to manually adjust the valves upstream in the case that the intake flow is greater than the design flow. *Figure 9* is an example of a CLA-VAL pressure reducing valve.

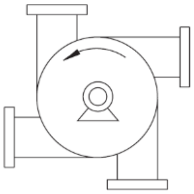


Figure 10: Cornell Pump Rotation

The rotation of the system is controlled by the rotation of the turbine in relation to the rotation of the hydraulic pump unit (HPU). The turbine will rotate in a counterclockwise direction, which is connected to a belt that rotates the HPU in the opposite direction (all T-L Irrigation HPU's are clockwise rotation). Below is a picture of the turbine rotation. In order to match the rotation properly, the turbine and the HPU need to be connected to the belt from opposite directions.

The turbine equipment is mounted on a 6 inch thick concrete pad. The turbine will require a double pulley assembly to the HPU, as well as a pulley system for the alternator. The alternator is a standard vehicle alternator with voltage regulation, wired to a 12 volt battery which connects to the low voltage controls for the HPU driving the center pivot sprinkler system.

Most systems will have flanged connections to the pump, although the smaller Cornell Turbines (up to model 2TR1) will require threaded connections. Flanged connections are recommended whenever possible. The turbine system also requires an automatic control valve to shut down the line when a break is detected.

It may be considered to place a screen filter downstream of the turbine yet upstream of the sprinkler system in order to prevent sediment from entering the sprinkler and while not affecting the turbine performance.

End guns are not permitted with hydro-mechanical systems. The addition of an end gun that operates intermittently will cause the flow rate through the turbine to vary and will affect the head losses in the pipeline. These variations will cause the turbine speed to change and operate outside of its designed range. Do not design a hydro-mechanical drive for a center pivot with an end gun.

The following are a few notes to keep in mind when determining the system parts:

- All fabricated components should be galvanized
- Paint all galvanized nipple threads with galvanized paint following installation
- Enclose battery in supplied plastic battery box
- All concrete anchor bolts should be stainless steel
- The turbine inlet and outlet are at different elevations, piping and fittings need to be laid out correctly both horizontally and vertically.

G. Design Worksheets

What is powering the hydro-mechanically driven turbine will determine which design sheet to use. If the ***1) Site Assessment*** worksheet determined that the best design for the hydro-mechanically driven pivot is an excess pressure design, then the ***3a) Hydro-Mech Pressure Design*** worksheet is referenced. If the ***1) Site Assessment*** worksheet determined that the best design for the hydro-mechanically driven pivot is an excess flow design, then the ***3b) Hydro-Mech Flow Design*** worksheet is referenced.

This section will guide the reader through each of these worksheets. The questions and equations used in the worksheet are individually listed (in bold) with a brief explanation of the required data or calculation.

"3a) Hydro-Mech Pressure Design" *- Hydro-Mechanical Center Pivot with Excess Pressure Design Sheet*

Given Information: **Pipeline pressure at pivot = ______________ psi -or- _______________ ft**
Pressure required at pivot for sprinklers = ________________ psi -or- ________ ft
Required flow through sprinklers = _______________ gpm = _______________ cfs

The given information was calculated during the **"1) Site Assessment"** worksheet and is used to fill in the blanks.

(1a) Compute Pressure Differential: Pipeline pressure at pivot – Pressure required at pivot
= _______________ psi -or- _______________ ft

The pressure differential is calculated simply by subtracting the required pressure at the pivot from the available pressure at the pivot. This information is taken from the **Given Information**.

(1b) Convert psi to feet of head (Optional):
(1 psi=2.31 ft of head) = _______________ ft

If the calculations up to this point have been in units of psi, then the units need to be converted to feet of head before moving to the next step.

(2) Reference Cornell Pump Manufacturers Catalog (Page 13) for 1800 RPM Turbine Selection Chart and select appropriate turbine model given 1a) & 1b).

Page 13 of the Cornell Pump Manufacturers Catalog (see Appendix E) is used to select the appropriate turbine to use in the design. The pressure differential in feet of head, and the required flow through the sprinklers is used to find the appropriate turbine model for the project. By following the point along the y-axis for head in feet, and the point along the x-axis for flow in cfs, the point of intersection gives the appropriate turbine model.

(3) Reference appropriate turbine model chart (pages 19-52)

Using the same Cornell Pump Manufacturers Catalog (see Appendix E), the turbine model chart for the selected turbine in step **(2)** can be found between pages 19 and 52.

(4) Using the appropriate turbine model chart, find the turbine required flow & kW output

(a) Begin by drawing a line from the available head across the page to the "HQ" head-flow line. At the intersection, draw a line down to find your required flow

(b) At the intersection of the line drawn down and the "kW" kilowatt line, draw a line perpendicular to the right side of the page in order to find the turbine output in kilowatts.

The process listed out in step **(4)** describes the process of determining the actual flow that the turbine requires and the kilowatts that it will produce.

(5) Determine the available energy production = 4b) kW * yearly hours of operation

The available annual energy production is calculated in order to determine if the project is technically feasible. The kilowatts from the turbine are multiplied by the yearly hours of operation.

(6) Reference the required annual energy production = ________ kwh from *<u>1) Site Assessment</u>* (9)

The required annual energy production was calculated in the Site Assessment previously and is now used in comparison with **(5).** If the available energy calculated in **(5)** is less than **(6)**, then the project is not technically feasible considering the available capacity of the turbine will not generate enough power as required.

(7) Select appropriately sized pressure reducing valve based on
maximum flow = required flow through sprinklers and
minimum flow = required flow through sprinklers – turbine flow.

With a hydro-mechanical center pivot running off of excess pressure, a pressure reducing valve must be installed in order to reduce excess pressure that is not used by the turbine. The pressure reducing valve selected must automatically take any inlet pressure and reduce it to the desired downstream pressure. By using an automatic valve, compensation is made for varying flow rates if they occur. Sizing the pressure reducing valve is based on the maximum and minimum flow.

There are several manufacturers of pressure reducing valves in this size range, a list of manufacturers is listed in the Additional Resources section at the end of this manual. Engineering data sheets are available from each manufacturer which can be used to appropriately size and specify the pressure reducing valve.

<u>3b) Hydro-Mech Flow Design</u> *<u>- Hydro-Mechanical Center Pivot with Excess Flow Design Sheet</u>*

The design sheet gives a step-by-step process for determining the appropriate turbine model to be used. The design sheet for a hydro-mechanical center pivot with excess flow begins with the following:

Given Information: **Net head available at pivot = ____________ ft**
Total available flow = __________________ gpm = ______________ cfs
Required flow through sprinklers = ______________ gpm = ______________ cfs

The given information was calculated during the initial site assessment and is used to fill in the blanks.

(1) Calculate available flow for turbine = Total available flow – Required flow through sprinklers

The available flow for the turbine is found by subtracting the required flow through the sprinklers from the total available flow. These amounts are found in the **Given Information**.

(2) Reference Cornell Pump Manufacturers Catalog (Page 13) for 1800 RPM Turbine Selection Chart and select appropriate turbine model given 1).

Page 13 of the Cornell Pump Manufacturers Catalog (see Appendix E) is used to select the appropriate turbine to use in the design. The pressure differential in feet of head, and the required flow through the sprinklers is used to find the appropriate turbine model for the project. By following the point along the y-axis for head in feet, and the point along the x-axis for flow in cfs, the point of intersection gives the appropriate turbine model.

(3) Reference appropriate turbine model chart (pages 19-52)

Using the same Cornell Pump Manufacturers Catalog (see Appendix E), the turbine model chart for the selected turbine in step **(2)** can be found between pages 19 and 52.

(4) Using the appropriate turbine model chart, find the turbine required flow & kW output

(a) Begin by drawing a line from the available head across the page to the “HQ” head-flow line. At the intersection, draw a line down to find your required flow

(b) At the intersection of the line drawn down and the “kW” kilowatt line, draw a line perpendicular to the right side of the page in order to find the turbine output in kilowatts.

The process listed out in step **(4)** describes the process of determining the actual flow that the turbine requires and the kilowatts that it will produce.

(5) Determine the available annual energy production = 4b) kW * yearly hours of operation

The available annual energy production needs to be calculated in order to determine if the project is technically feasible. The kilowatts from the turbine are multiplied by the yearly hours of operation to determine the annual energy production.

(6) Reference the required annual energy production = ________ kWh from Site Assessment (9)

The required annual energy production was calculated in the Site Assessment previously and is now used in comparison with **(5).**

If the available energy calculated in **(5)** is less than **(6)**, then the project is not technically feasible considering the available capacity of the turbine will not generate enough power as required.

Step 4: Funding

It is assumed that all projects considered in this manual are receiving some funding from the EQIP program and will apply for a grant through the USDA – Rural Energy for America Program. Grants are available for up to 25% of the project cost and can be stacked with EQIP funding.

This manual does not explain further the EQIP process, but discusses how to complete the Technical Report which is a part of the REAP grant application.

The REAP technical report is found in the ***4) REAP Technical Report*** worksheet of the hydro-mechanical toolbox. Since most of the hydro-mechanical projects are less than $80,000 for total project costs, the report will consist of four subsections.

1) *Project Description*

The project description begins with describing the project – type of turbine, irrigation system, water source, supplier/manufacturer of selected turbine, etc. Include a vicinity map to show the location of the project site. Provide details on the estimated power and energy production and discuss how the turbine will operate. Describe the available flows and head for the site and how these site conditions power the turbine. The number of days the turbine will operate, total number of kilowatts to be generated, as well as the total kilowatt-hours of production per year is included in the descriptions. Also, describe any environmental impacts, as well as how the project potentially enhances the site.

2) *Resource Assessment*

The resource assessment identifies the water source, and delivery from the source to the site. Include the length of pipeline, elevation difference (head), flows, and available days of irrigation water annually. Include a flow duration curve showing the available flow in comparison with the amount of flow to be used for power. Discuss in detail the operation (more than was discussed in the project description), and the amount of energy to be generated.

3) *Project Economic Assessment*

The project economic assessment discusses the incentives that the project qualifies for, and if there are any cost share funds for the project. Give a breakdown of the total project costs that are not covered by the incentive program and discuss the amount of savings that will be produced each year. Also provide the breakdown from ***2) Hydro-Mechanical Economics*** and give an explanation of how these numbers were generated.

4) *Qualifications of Key Service Providers*

List the members of the project team, including the system designer, project manager, equipment supplier, project engineer, construction contractor, system operator, and anyone else that may be applicable. Provide a brief explanation of each member's experience and how it is relevant to the project.

Step 5: Permitting

No additional permits are required for hydro-mechanical projects, beyond what might be required for the installation of the irrigation system.

Step 6: Construction, Project Inspection, Approval and Closeout

Prior to construction of the project, the design documentation should demonstrate that the criteria in the previous steps have been met and are compatible with planned and applied practices. All required permits need to be obtained and the client be ready to begin construction. Once the client has given their approval and all financing has been approved, the construction process can begin.

Prior to installation, a pre-construction meeting with the client and contractor is coordinated. After the pre-construction meeting, it should be determined that the staking and layout is according to plans and specifications, including any layout notes. The utility locate call must be made three days prior to construction. The client should be advised on compliance issues with all federal, state, tribal, and local laws, regulations and NRCS policies during installation. Once construction begins, all design modifications that are required during construction should be documented and coordinated with the client and original designer. The ***5) Project Inspection*** checklist provided within the Hydro-Mechanical Toolbox should be completed during construction.

The project inspection checklist is completed with the certification of completion before the project close-out ends. The inspector will ensure that construction meets all of the design and specification criteria. The checklist will require inspection of the following: staking and layout, excavation, backfill, concrete placement, turbine model/manufacturer, system layout, valves, connections, system functionality and other miscellaneous information that is relevant to construction.

Once the project inspection checklist has been completed, the approval and close-out process can begin. Approval of all documented material (e.g. inspection checklist, design modifications, construction records) is required during the close-out process. As-built documentation is required including drawings, final quantities, and progress reporting. Certification that the installation meets design standards, specifications and all design requirements will have to be completed once all documentation has been received. Form CO-ENG-12 is used for this certification. Once approval and certification is given, then the project close-out is complete.

Part 2: Small Hydroelectric Applications

Agricultural hydroelectric projects utilize the infrastructure already in place or being constructed for a pressurized irrigation system. Intake structures and pipelines are components of a pressurized irrigation system that can also be used to generate electricity. By adding some capacity or configuring the layout to facilitate the addition of a hydroelectric turbine, otherwise wasted energy can be captured and used to offset electric loads of the irrigation system.

Step 1: Site Assessment

In addition to the general hydropower Site Assessment questions, the following questions are specific to the initial assessment of a hydroelectric project.

A. Estimated Head, Flow and Capacity

Using this initial ***1) Site Assessment*** worksheet, an estimate of available head and flow is used to estimate the available power capacity of a hydroelectric system at the site. In the feasibility study stage, these estimates will be refined to take into account system losses and variability in flow.

The preliminary estimate of the available power capacity is calculated with the following equation;

$$Power\ (kW) = \frac{Head(feet)\ \times Flow(cfs) \times efficiency}{11.8}$$

The Head is the available net head expected at the hydropower location accounting for any losses in the pipeline. Head loss is caused by friction, enlargement or contraction of the pipe, pipe bends, as well as pipe fittings and valves; refer to the *Colorado Small Hydro Handbook* for more information on head losses. The flow used in this equation is the maximum expected flow in cubic feet per second (cfs). Efficiency will be evaluated after the configuration is finalized and the turbine selected. At this stage the efficiency can be assumed to be 65% for a conservative estimate.

(1) What flow is available to the site?

(2) What pressure (head) is available to the site?

(3) Approximately how many days during a year will the turbine operate at full capacity?

In general, two possible configurations will be used to take advantage of available head, either in-line pressure reduction or discharging to atmospheric pressure. Installing a hydroelectric generator at the end of a pressurized pipeline and discharging that water to atmospheric pressure is the most straightforward alternative and should be used if possible. If the site conditions do not allow for this approach, certain turbines can reduce pressure within a pipeline. The power capacity of the turbine is estimated using the net pressure reduction.

Using the available flow and the head provided by the applicant, check to see that the combination falls within the range of available turbines in the turbine selection chart. Also, calculate the approximate power capacity using the equation above. The total annual energy production can be estimated by multiplying the available power capacity by the number of hours it will be operating in a year.

B. Irrigation System Electrical Demands

This manual strives to facilitate the development of hydroelectric and hydro-mechanical projects that reduce operating costs for agricultural irrigation systems and support broader irrigation management and resource conservation efforts. If the project is hydroelectric, the goal will be to offset as much of the irrigation system's electric load as possible. If the project is hydro-mechanical, the project will offset both the cost of extending utility power to the center pivot as well as the annual cost of electricity to operate the pivot. In the case of a hydroelectric project, the electric load of the irrigation system must be understood to appropriately size the turbine and evaluate the economics of the project.

(4) What size generator would be required to power the entire irrigation system?

The NRCS EQIP Payment rates for hydroelectric power are based on the needs of the irrigation system, not necessarily the maximum power that could be produced at a site. To determine the EQIP payment that a project will receive, the total power demand of the irrigation system must be estimated. This includes the power required to move the pivot and any associated pumps. The total power capacity required can be calculated in horsepower and converted to kilowatts. Payment will be made on the kilowatts required by the irrigation system.

(5) What is the average annual electric energy consumption that can be offset by the annual electric energy production?

Annual electric energy consumption of the irrigation system can be estimated using historic records, calculated from the power demand multiplied by the operating hours per year, or estimated based on the center pivot manufacturer's recommendations. By comparing this number to the estimated annual energy production of the hydroelectric system, the annual cost savings can be estimated. At this time it is appropriate to engage the local utility to understand net metering policies specific to the utility and the service agreement on the property. Using the utility's net metering policies and rate structure, the annual cost savings can be calculated and used in the economic feasibility assessment.

C. Distance to Utility Connection

This manual covers only net metered hydroelectric projects which supply electricity to the grid to offset the electric loads of the irrigation system. The proximity of the grid to the site, the location of the electrical loads, and the type of service (single phase or three phase) are important in designing the interconnection and will impact the overall project costs.

Some utilities require that the energy production from the hydropower unit be connected directly to the same meter that is supplying the electrical load of the irrigation system. Other utilities allow the energy production to be metered separately from the electrical load, and the offsets to occur through billing. Knowing this information at the site assessment phase is helpful, but this will be discussed again during the feasibility assessment. These questions do not apply to a hydro-mechanical project.

(6) What distance does the utility power line need to be extended to the site?

(7) Is the power line three phase or single phase?

Single phase overhead power extension can cost up to $30,000 per mile and three phase overhead power extension can cost up to $75,000 per mile. This cost must be understood relative to the overall project cost as well as the benefit of extending power. There may be cases where power needs to be extended for the sprinkler system, and will be considered a cost of the irrigation system.

Step 2: Feasibility Assessment

If a project appears viable after the initial Site Assessment worksheet, the next step is to complete a full feasibility study which includes some aspects of preliminary design to be used as the basis for final design. Below is an overview of what a feasibility study will include. The Hydroelectric Toolbox contains worksheets that will walk the user through these feasibility steps.

A. Resource Assessment

Using the Site Assessment worksheet, an estimate of the resources available, head and flow, is made to approximate the plant's available power capacity. During the feasibility phase, a more accurate measurement of available head, calculation of head loss and analysis of flow must be made to calculate the annual energy production and to size the system appropriately.

1. Flow Available

The flow that will be available to a project in the future is generally based on the flows that have been available in the past, with compensations made for any changes to operation expected through the development of the project. If the landowner has kept records of historical diversions at the headgate, or the ditch company has maintained records of orders and deliveries, these can be used to develop a future estimate. We are interested in both the quantity of flow and the variability in flows that are available to the project.

The annual flow data shown in Figure 11 can be transformed into a flow duration curve like that shown in Figure 12 to help visualize both the quantity and variability of flow. Flow Duration Curves depict the relationship between flow and the percentage of time that specific flow rates were met or surpassed. Because these figures are depicting a typical irrigation season, there is no flow occurring more than 50% of the year.

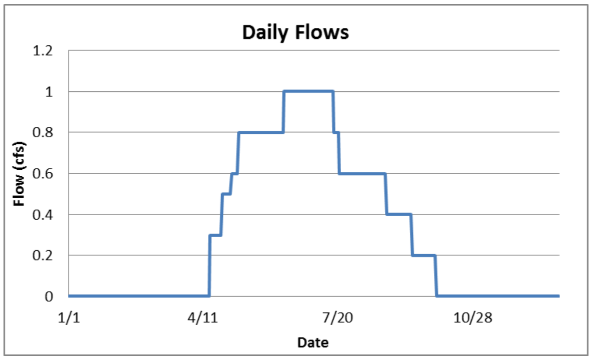


Figure 11: Daily Flow Curve

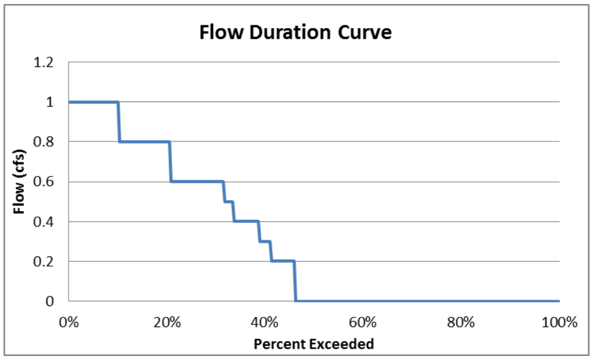


Figure 12: Flow Duration Curve

The Hydroelectric Toolbox contains a worksheet ***2a) Flow Duration Curve*** that can be used to produce the Flow Duration Curve from daily flow data. The worksheet is set up to accept daily data over the period of one year. If additional data is available, the columns can be extended with additional dates and the percentage equations also need to be updated to cover the entire period of available data.

The daily data is entered in Column B of the worksheet, and then copied into Column F. Column F then needs to be sorted from the highest to the lowest to create the flow duration curve.

How to select the design flow using this curve

The Flow Duration Curve enables the assessment of flow variability at the proposed hydro site, and the determination of an initial design flow for the turbine. The design flow is the flow at which the turbine operates most efficiently, and is the maximum flow rate that the small hydro system should operate at for an extended period of time. When looking at a Flow Duration Curve, an initial estimate of the design flow for a small agricultural hydro system will typically be the flow associated with an exceedance value between 25% and 50%. For the example Flow Duration Curve shown in Figure 11, the design flow at 25% exceedance and 50% exceedance would be approximately 0.6 cfs and 0 cfs, respectively. Developing the system for a design flow with an exceedance of 25% means that the system will run at design capacity for approximately 25% of the year, and somewhat less than that value for the remaining operating hours during the year depending on the variability allowed in the selected turbine.

Two factors must be considered from an economic standpoint when designing the power capacity of the agricultural hydroelectric facility. The EQIP program will only provide incentives to cover the power capacity required by the irrigation system; therefore it may be economically beneficial to keep the turbine size at or under the size needed for the irrigation system. Any power capacity above the irrigation system demand is not eligible for the EQIP payment, but the additional energy production could offset other electrical loads of the farm operation. A separate economic analysis may indicate whether energy savings justify the incremental cost of a larger hydroelectric system.

When designing a net-metered hydroelectric system, it may be preferable to select the design flow rate based on achieving a power capacity that can offset all of the electrical loads on that utility meter. This is a trial and error process of adjusting the design flow rate, estimating the electric power and annual energy production and comparing that to the electric load requirements until the load requirements and estimated production match. The ***2c) Energy Production*** worksheet in the Hydroelectric Toolbox can be used to facilitate this analysis.

How to use multiple turbines

Multiple turbines can be combined in a hydro system to achieve a desired design flow, allowing for more flexibility in production. Two of the same type of turbine having different size capacities can be used in conjunction to cover a larger range of discharge at a hydro site. An example situation constituting an appropriate use of multiple turbines is when there is a significant variation in flow seasonally. If winter flows are very low, it may make sense to use a smaller turbine that operates in the winter, and a larger turbine to capture the spring, summer, and/or autumn flows (Figure 13). Another pertinent application of multiple turbines is when a standard turbine size or a fixed flow turbine, such as a pump used as a turbine, cannot accommodate the available flow; several turbines may be used in parallel to compensate, illustrated in Figure 14.

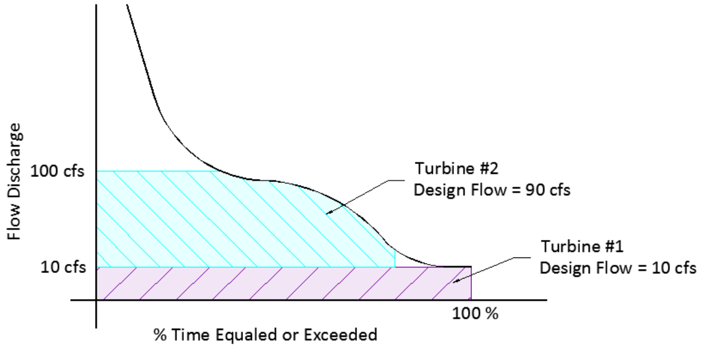


Figure 13: Flow Duration Curve Depicting Two Turbine System

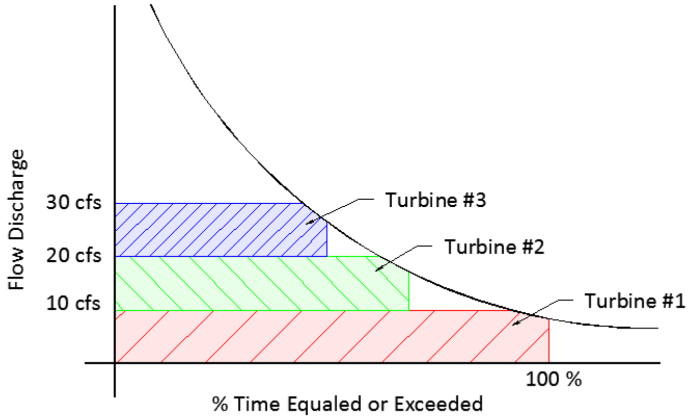


Figure 14: Flow Duration Curve Depicting Three Turbine System

2. Head Available

Head represents the water pressure at a hydro site. Friction losses and other head losses need to be accounted for throughout the system including the intake and penstock. The expected net pressure at the location of the turbine is the operating pressure of the turbine. This pressure will change depending on the flow rate if losses are high in the penstock. The design head is generally calculated at the design flow rate.

$$\begin{matrix} Gross \\ Head \end{matrix} - \begin{matrix} Head \\ Losses \end{matrix} = \begin{matrix} Design \\ Head \end{matrix}$$

Head loss calculations in a penstock are the same as head loss calculations in any pipeline. Losses at fittings, bends, and in the actual pipeline are combined into a total head loss. Factors affecting head losses include flow rate, pipe diameter, roughness of pipe wall, corrosion, length and straightness of pipe.

B. Project Layout and Conceptual Design

At the feasibility level, the project designer should identify project components and complete a conceptual or preliminary design. The goal in completing this work is to determine the technical feasibility of the project. Questions that will be asked and answered during this phase are:

- Is a turbine available that is appropriate for the site conditions?
- Will the hydroelectric system operate in harmony with the irrigation system operations?
- What is the approximate size and configuration of the powerhouse and tailrace?
- Is there sufficient land and area for the powerhouse, intake and penstock?

Answering these questions will also allow for the system cost to be estimated which will be used to determine economic feasibility.

1. Turbine Selection

Hydro turbines are categorized in two groups: impulse turbines and reaction turbines, depending on the way that energy is produced from the inflows. In a reaction turbine, the water flows over the runner blades (see Figure 15), and energy production results from the combined forces of the pressure and moving water. The turbine must be encased in a pressurized housing, and fully submerged in water. Reaction turbines are generally better suited for lower head, higher flow applications. Examples include propeller, Kaplan, Francis turbines and Pumps-as-turbines. An impulse turbine uses the force of a jet of water impacting a runner's curved buckets (see Figure 16) to change the direction of flow, and thus creating momentum to produce mechanical energy. An impulse turbine can be open to the air, and only needs a casing to control splash. Impulse turbines are generally well suited for high head, low flow applications. Examples include Pelton and Turgo turbines.

Figure 15: Reaction Turbine (PAT)

Photo courtesy of Cornell Pumps

Figure 16: Impulse Turbine (Pelton) Runner

Photo courtesy of Canyon Hydro

Each turbine has an associated efficiency curve that may be obtained from the turbine manufacturer. The curve depicts the relationship between the efficiency and the design head and flow under operating conditions. These diagrams allow the analysis of how each turbine will perform under specific conditions. 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. Some turbines may not be flexible enough to operate over a range of available flow rates; these turbines are generally referred to as "fixed-flow turbines." In the case of a fixed-flow turbine, the efficiency at the design head and flow is known and operation outside of those conditions does not allow the generator to produce energy.

For agricultural hydro projects covered by this manual, the turbine selection is divided into two classes of hydroelectric systems: (1) turbines that connect to a low power DC generator and use an inverter to produce AC power, and (2) turbines that connect directly to a high power AC generator.

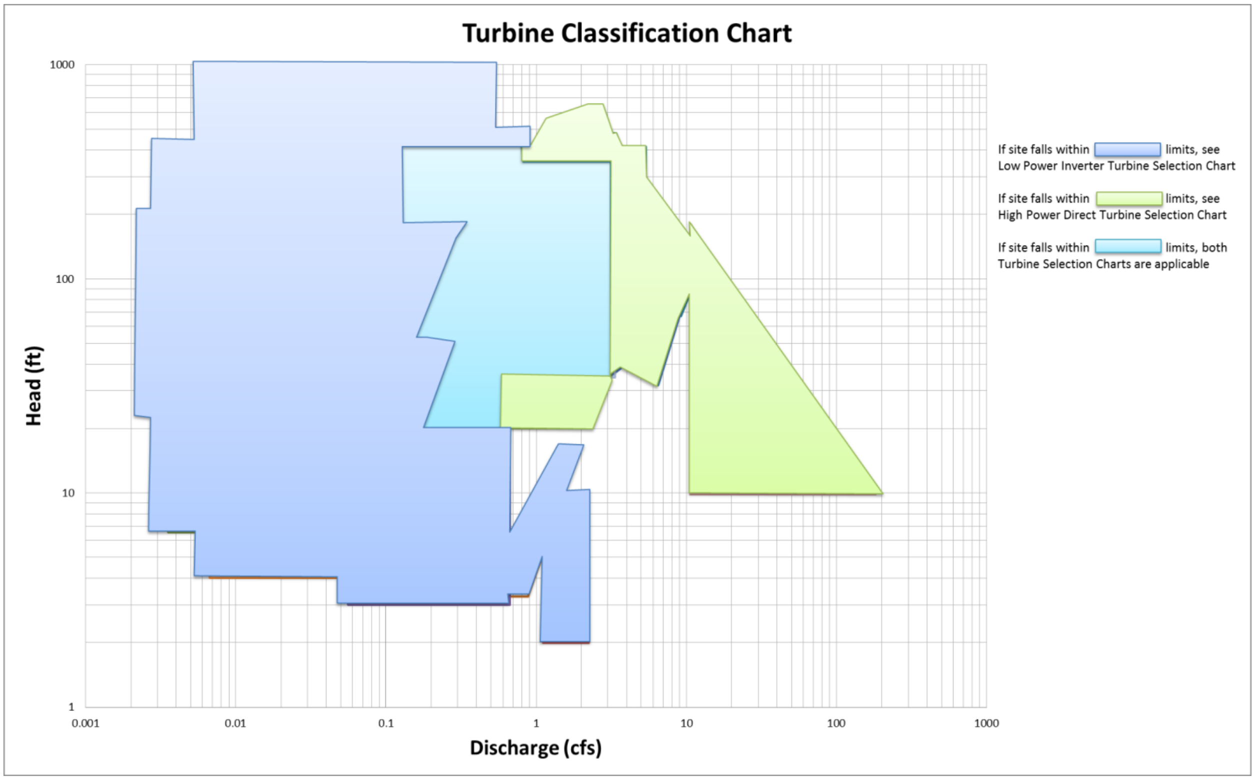
The low power generators produce direct current (DC) or wild alternating current (AC) and then use an inverter to convert to conditioned AC that can be delivered to the grid. The inverter's output is synchronized with the AC waveform of the grid, allowing for interconnection.

A high-powered induction or synchronous generator directly produces synchronized AC and can connect directly to the grid without the need of an inverter. To connect directly to the grid using an induction generator, it is important to know that proper signal synchronization and safeguards must be in place. Grid interconnection controls monitor the grid and ensure your system is generating compatible voltage, frequency, and phase.

These two general types of turbine-generator-controls packages and the design of each require different design approaches, as outlined in the following section. The Hydroelectric Toolbox includes a ***2b) Turbine Selection*** worksheet to help the applicant with turbine selections. The three turbine selection charts are described below:

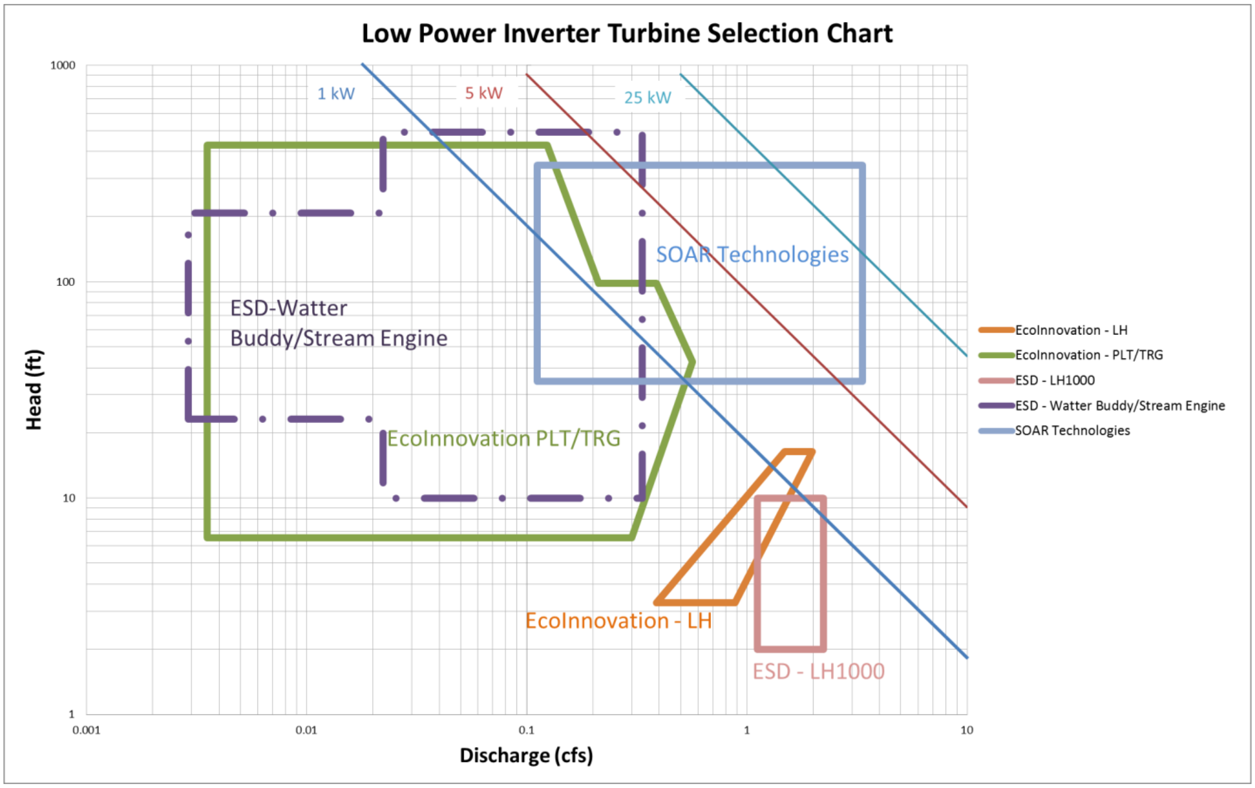
Turbine Classification Chart

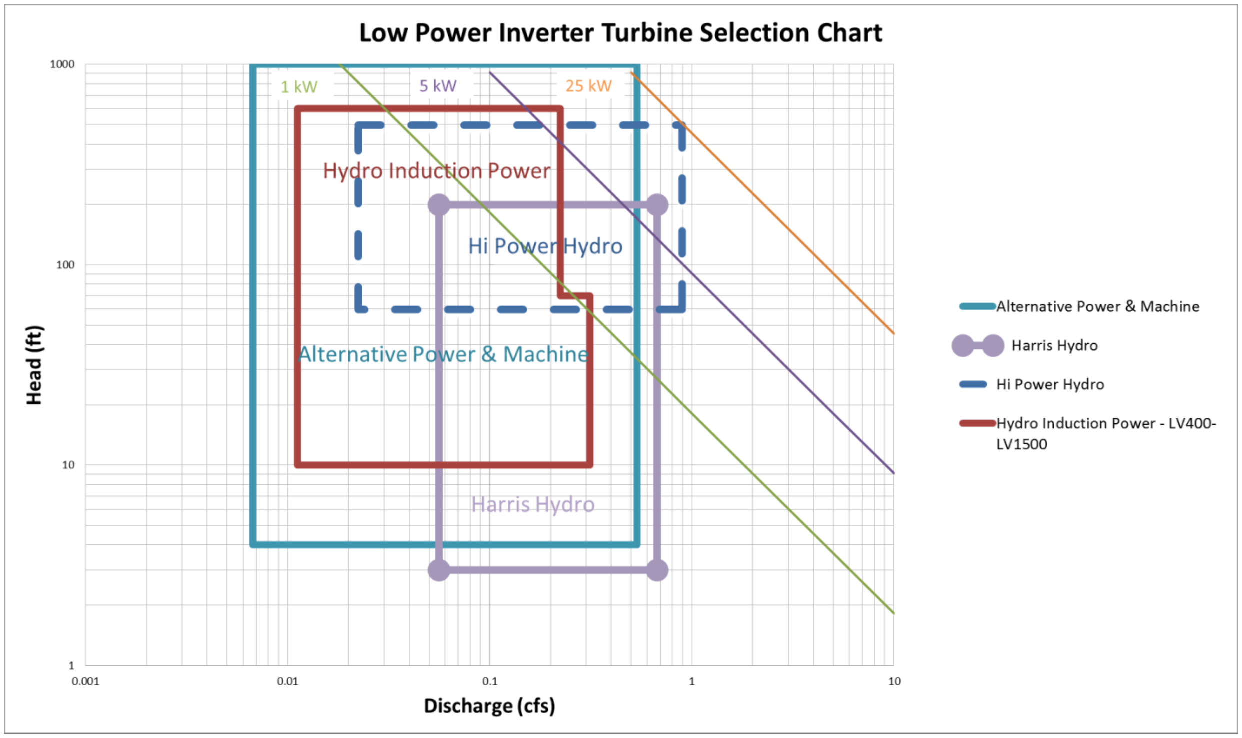
The available flow and head of the site indicates whether a low-power inverter-based system or a high-power direct generator is appropriate. The Turbine Classification Chart will assist in determining which is appropriate. To use the chart, follow the amount of available flow or discharge (gpm) on the x-axis to the intersection of the available head (feet) on the y-axis. If the intersection falls within the limits such that both turbine classifications are applicable, then a decision will have to be made as to which turbine classification best meets the needs of the site.



Low Power Inverter Turbine Selection Chart

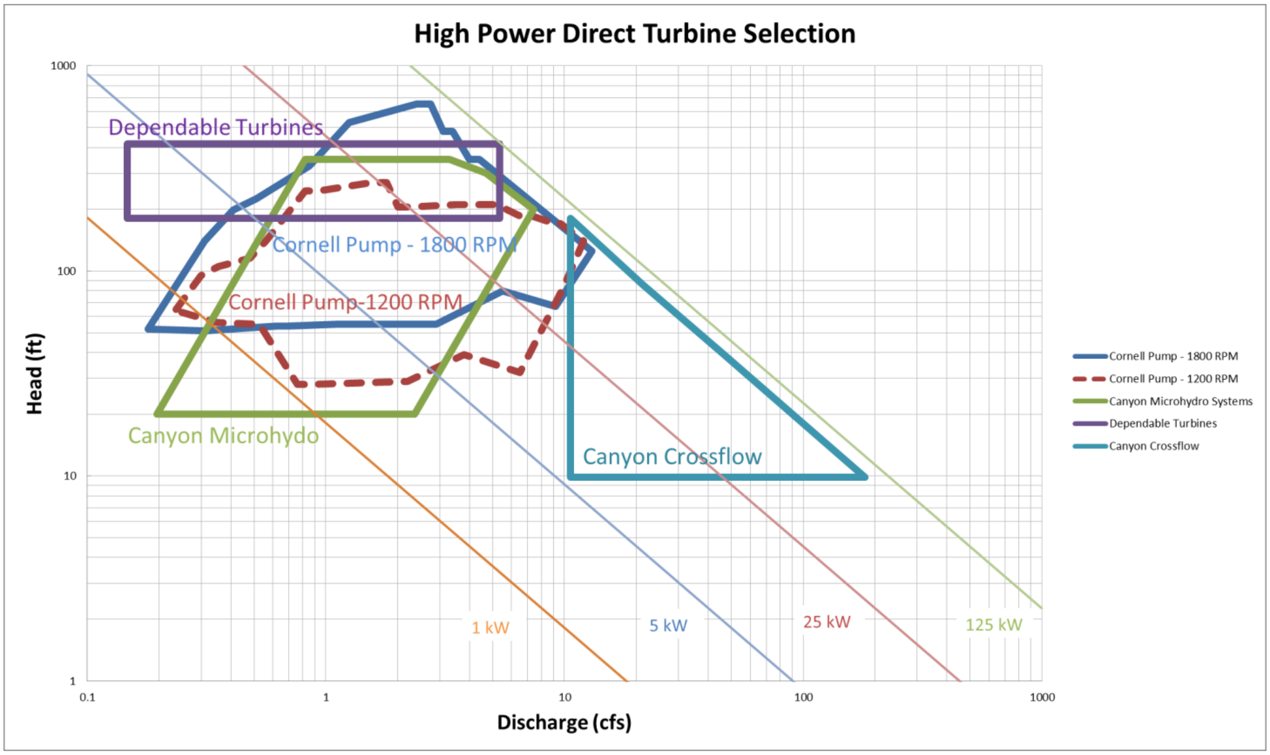
If the given head and flow of the site fall within the limits of a low power inverter turbine, then the Low Power Inverter Turbine Selection Chart suggests some turbine manufacturers and models available to match the site conditions. This chart contains representative turbines, but does not provide an exhaustive list. Other turbines on the market may also be appropriate for the given range of head and flow rates. The same method that was utilized in the Turbine Classification Chart is followed to determine the manufacturer and model. Following the available discharge (gpm) along the x-axis to the intersection with the amount of available head (feet) on the y-axis, the point of intersection indicates the available manufacturers and models. If the intersection suggests several manufacturers and models, then evaluate each turbine model to select the one that provides the best combination of technical and economic performance for the site conditions.





High Power Direct Turbine Selection Chart

If the available head and flow of the site falls within the limits of a high power direct turbine, then the manufacturer and model can be found on the High Power Direct Turbine Selection Chart. The same method that was utilized in the Turbine Classification Chart is followed to determine the manufacturer and model. Follow the available discharge (gpm) along the x-axis to the intersection with the available head (feet) on the y-axis. If the intersection suggests multiple manufacturers and models, then evaluate each turbine model to select the one that provides the best combination of technical and economic performance for the site conditions.



The specific turbine that is selected using these charts is used as the basis for the preliminary design to follow. If there are multiple appropriate turbines, the feasibility analysis considers and compares the options to find the optimal turbine and configuration. Contact the selected manufacturer or a supplier at this stage for a budgetary equipment quote. More details on the individual components of a system are discussed during the final design step. When requesting a quote, it is important to understand that all of the components need to be included: turbine, generator, inverter (if used), controls and interconnection equipment.

A list of manufacturers and suppliers with their websites is included in the Additional Resources section.

2. Penstock Sizing and Alignment

As mentioned in the previous section, the head losses occurring in the penstock have the potential to significantly affect the available power of the turbine. When sizing a penstock, pipe length and diameter, design flow, and gross head must be considered, as they contribute to the head loss in the system. All flows that are carried through the pipeline must be considered including both irrigation flows and flows used for energy production.

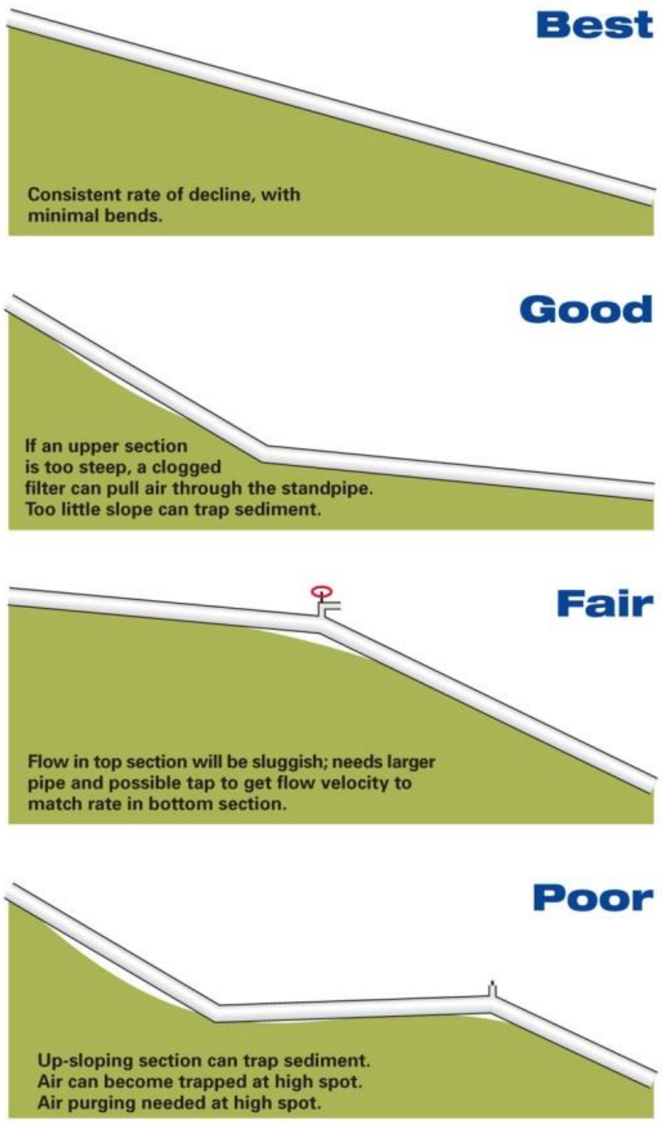


Figure 17: Penstock Slope
Photo courtesy of Home PowerMagazine

In general, the pipe length, design flow and gross head are fixed variables, meaning they are unalterable. As such, the primary alternative to reduce head loss in the system is to adjust the penstock diameter to minimize the velocity in the pipe, and thus, the friction created. However, an increased penstock diameter leads to additional material cost; therefore, an optimum balance should be considered between the two.

Ideally the alignment of a penstock will be as short and straight as possible. In doing so, material and installation costs are reduced and the loss of water power resulting from internal friction is reduced, thereby conserving as much energy as possible. Figure 17 illustrates the preference of slope alignment. Ideally, the penstock will have a consistent rate of decline. A penstock can be either above ground, or below ground. Burying the penstock may facilitate the achievement of an appropriate slope and protect it from damage. Proper anchoring of both buried and above ground penstocks is required to ensure movement does not occur under any conditions, particularly at points of direction change. Each penstock will need to be evaluated individually to determine the need for anchoring and thrust blocks.

During the feasibility assessment step, a preliminary penstock diameter and alignment is determined. Using maps and aerial photographs, complemented with a site visit and walk of the property, any potential issues will be identified. Generally, the penstock will act as both the pressurized irrigation pipeline and the penstock for the hydroelectric turbine. The same design methods used for laying out an irrigation pipeline will be used for a penstock, in fact they may be the same.

3. Powerhouse and Foundation

When building a new powerhouse, it is important to address the size and foundation of the structure. Because the powerhouse provides shelter, and thus protection, to the electromechanical equipment involved in small hydro systems, it is crucial that the powerhouse is large enough to house the necessary componentry such as the turbine, generator and controls. The equipment configuration dictates the size of the powerhouse, type and quantity of turbines, and the landscape of the site. 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, as well as clearances and offsets between equipment.

As the necessary equipment has substantial associated weight, it is also imperative that the foundation be designed to adequately handle the loads to which it will be subjected. The turbine's discharge channel, called a tailrace, is commonly integrated into the foundation as well, and requires placement consideration when designing the powerhouse foundation. Further, any access to the structure must be large enough to accommodate the placement of the equipment it will house.

There are multiple variations for powerhouse configurations based upon the demands of the specific hydro system. The powerhouse can be buried in a water-tight concrete vault or the equipment can be housed above ground. There are two different foundation conditions that are used, a free discharge or a draft tube.

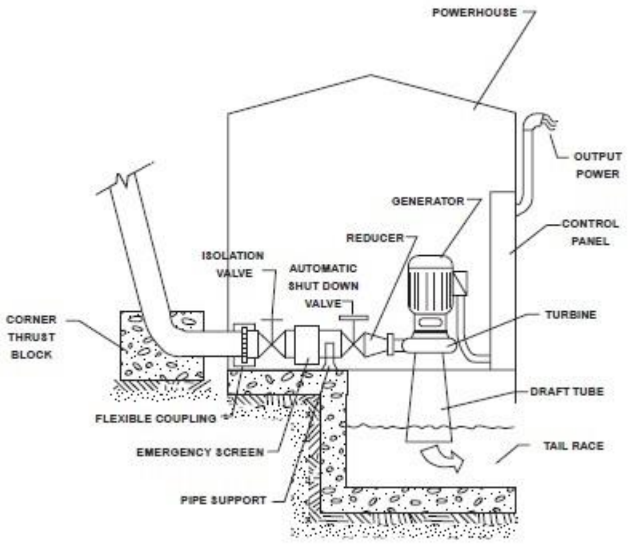


Figure 18: PAT Powerhouse Configuration
Photo courtesy of Cornell Pumps

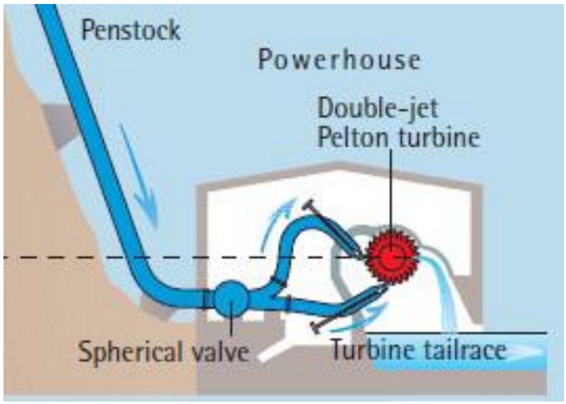


Figure 19: Pelton Powerhouse Configuration

The Tailrace, or discharge structure, is located downstream of the turbine and takes the water discharged from the turbine back to the watercourse. The discharge structure design depends on the type of turbine and the turbine configuration. If the discharge structure is integral to the building foundation, this saves on civil construction costs and space.

Reaction turbines, such as a PAT require a draft tube and tailwater to function properly. These turbines take advantage of the suction provided by the draft tube downstream of the turbine. A draft tube is simply the outlet pipe downstream of the turbine. The draft tube must be submerged in water, which is achieved by maintaining tailwater within the concrete structure, or setting the bottom of the draft tube below the downstream water surface. There also may be instances where a Pump-as-turbine is installed in-line; in this case the discharge continues in a downstream pipeline and a method of bypass must be provided, but a tailrace is not required.

Alternatively, impulse turbines (Pelton, Turgo and Crossflow) do not take advantage of head downstream of the turbine. These turbines discharge into the open air and do not require a set tailwater elevation or a draft tube. It may be necessary to include an energy dissipation structure at the outlet, in the case that water is bypassed around the turbine and released into the discharge structure with full energy.

During the feasibility stage it is important to determine the type and size of the powerhouse in order to estimate the cost. By sketching the configuration of the foundation and powerhouse, the quantity of concrete and the approximate square footage of the powerhouse can be found. Based on those measurements, estimates of cost can be developed based on unit costs and past project costs.

C. Energy Production Estimates

The total annual energy production can be calculated given the design head and flow rates of the site, as well as the efficiency of the turbine. The Hydroelectric Toolbox includes a ***2c) Energy Production*** worksheet to help calculate the annual energy production depending on the turbine that was selected previously.

Turbine Information:

The ***2c) Energy Production*** worksheet contains a dropdown menu that presents the 2 different types of turbines to choose from: a fixed flow turbine model or a variable flow turbine model. If the turbine manufacturer is Canyon Hydro Pelton or Dependable Turbine Pelton, then the correct selection is "variable flow". These turbines have a similar efficiency curve, which is the default when "variable flow" is selected. If an alternative efficiency curve is known, any efficiency curve data can be entered into the worksheet into the greyed boxes to the right side of the worksheet.

If a fixed flow turbine is selected, then "Fixed Flow" is the correct selection in the dropdown box. A fixed flow turbine operates over a very small range of flows at a fixed efficiency. The next step is to input the fixed flow turbine's design efficiency, which can be found in the manufacturer's catalog for the specific turbine, taking into account nozzle size (if applicable), flow and head.

The design head and flow for the project is entered into the worksheet. The design flow that was calculated earlier is recorded in cfs and the design head that was calculated is recorded in feet. Once the turbine model is selected, the design head and flow have been entered, and the efficiency has been calculated, then the worksheet calculates the data in the columns as explained below.

Percent Exceeded

The percent exceeded is copied over from the ***2a) Flow Duration Curve*** worksheet that was calculated earlier.

Flow Available (cfs)

The Flow Available column pulls the flow duration curve information from worksheet ***2a) Flow Duration Curve*** to output the flow that is available at the specific percent exceeded.

Turbine Flow (cfs)

The turbine flow column outputs the max allowable flow for the selected turbine. If a turbine is a "fixed flow" turbine, then the flows will not vary and the turbine will only operate at the design flow that is given. If the turbine is a "variable flow" turbine, then the column uses the provided maximum and minimum flows in comparison with the available flow in order to limit the amount of flow the turbine can accept.

Q/Q_{design} (%)

The Q/Q_{design} column divides the turbine flow by the flow for which it was designed. This column outputs data for a variable flow turbine and is used to determine the efficiency of the selected turbine at each flow rate.

Efficiency

The efficiency column calculates the variable efficiency in the case that the turbine is designed to use variable flows. If the turbine is a fixed flow turbine, then the efficiency column will use the design efficiency that was input previously.

Power Output (kW)

The Power Output column uses the previous columns to calculate the electricity that will be produced in kilowatts. The power is calculated using the basic power equation:

$$Power\ (kW) = \frac{Head\ (ft) * Required\ Flow\ (cfs) * Turbine\ Efficiency}{11.8}$$

Electricity Produced (kWh)

The Electricity Produced column calculates the total electricity produced by multiplying the power output by the number of hours for each available flow. Given that the flows are calculated in 5% increments, each row accounts for 438 hours (equal to 5% of the hours in a year). Multiplying the kilowatts by the 438 hours gives the electricity in kilowatt hours. The kilowatt hours will then be summed and the annual total given at the bottom as “Total Available Energy.”

D. Economic Feasibility

The ***2d) Hydroelectric Economics*** worksheet is used to determine the total cost for the project, incentives that are available, savings, and the simple payback for the project. The worksheet is a key decision point in moving forward with the project. If the savings aren’t sufficient to payback the development cost in a reasonable amount of time, the agricultural producer is not likely to develop the project.

General Project Information

The first section of the Economic Assessment is to input the power capacity of the turbine in kilowatts. Also, for means to calculate the incentives, the power capacity needed for the irrigation system is also entered in this section. The payment rate is then based on the lesser of those two capacities. For example, if the irrigation system needs a 20kW generator to operate and the hydroelectric plant only produces 10 kW, the payment will be based on 10 kW. Also the opposite is true, if the irrigation system only needs 10 kW to operate and the hydroelectric plant produces 20 kW, the payment will be made on the 10 kW need.

Project Cost Items

The second section of the Economic Assessment is to input the total costs for the project. The project costs are broken down into seven items:

1) Turbine, Generator, Controls & Installation: This is an all-inclusive cost provided by a manufacturer or supplier. Commonly known as a water-to-wire package, this includes all equipment necessary from the intake of the turbine to the connection with the grid.
2) Powerhouse Superstructure: Using engineering judgment and knowledge of area construction costs to estimate the cost of the powerhouse structure.
3) Powerhouse Foundation: This cost is based on the configuration found in the preliminary design and knowledge of unit costs and selected materials.

4) Pipeline costs not covered by EQIP: The economic feasibility of the hydropower facility is based on the costs in addition to the irrigation system. Also, a REAP grant is based on this development cost.
5) Miscellaneous Piping and Fittings: Additional piping and fittings, or valves are required to separate or integrate the system with the irrigation system. Those additional costs are considered in the development cost.
6) Electrical Inspection: If the system is a direct generator without the use of an inverter, a certified field inspection must be completed in order to obtain a State Electrical Permit. These costs depend highly on the location of the project.
7) Design costs (if applicable): If an outside consultant is used for the design of this system, include that cost in the total development cost.

Project Incentives

The third section of the Economic Assessment is to determine which incentives are available for the project. Determine whether or not the project qualifies for the Rural Energy for America Program (REAP), and enter a "yes" in the appropriate cell if it is applicable, or "no" if it is not. If the REAP incentive is applicable then it covers up to 25% of the total project cost.

If the REAP incentive is available, then the worksheet automatically calculates the *energy generated per grant dollar requested.* This is calculated is based upon the annual energy production (converted from kWh to Btu) and the *total REAP incentives requested.* This value is needed in the REAP application for scoring the merit of the application.

Next, determine if the project qualifies for the Environmental Quality Incentives Program (EQIP). The EQIP incentive is divided into three different payment rates: Regular EQIP, EQIP Special Initiatives, and EQIP Historically Underserved. If the project qualifies for EQIP, then enter a "yes" in the appropriate cell for the payment rate that is used. The appropriate payment rate is then applied to the minimum power capacity and a total calculated. The total amount of money available through incentives is then calculated based on the payment rates released in January 2015. Please note that the EQIP incentives vary from year to year and the rates reflected within the worksheets may not be the most current payment rates. Irrigation Pipeline Practice 430 currently specifies the EQIP payment rates for hydroelectric power plants as used in the worksheet. Contact your local NRCS office to obtain the current payment rates and scenarios.

Hydroelectric systems are currently only eligible for funding if they are off-grid systems with battery backup. A net metered system may not be eligible for EQIP funding, although net-metered systems may still qualify for technical assistance for activities including initial investigation and evaluation of alternatives, permitting, design, and inspection, while these are not included in the scope of NRCS practices at this time.

Project Savings

The final section of the Economic Assessment is to input the savings that are available for the project. The project savings is broken down into two items: annual energy production and the retail rate of electricity. The annual energy production can be calculated by multiplying *the power capacity in kW x yearly hours of operation* (also calculated in the Design Sheet). The retail rate of electricity and the monthly base charge for electric service are charges that are determined through the local electricity provider. Once the data for the savings has been input, the total yearly project savings is calculated.

If the net meter is placed on a service with a separate demand charge and energy charge for electricity, the calculation of savings is slightly more complicated. Contact the local utility to discuss how they handle the net metering arrangement, and whether the power and energy generated will apply to both the demand charge and the energy charge. Generally, in order to offset the demand charge, the hydropower must be generating at all times during the month when electricity is used.

Net Simple Payback

The simple payback is then calculated and represented in years. The "Simple Payback Before Incentives" is the total project costs divided by the total yearly project savings. The "Net Simple Payback After Incentives" is the project incentives total subtracted from the total project cost, and then divided by the annual savings. This is a simplistic economic measure that does not take into account the rising cost of electricity or any annual operation or maintenance costs associated with the facility. But this is an easy measure to understand, and agricultural producers may be familiar with thinking about investments in this way. This measure allows a producer to decide how long they are willing to wait for the project to payback their initial investment. Producers may have varying opinions on a satisfactory payback period given their particular financial situation.

After the Economic Assessment has been completed, and it has been determined that the project is economically feasible, then the design of the hydroelectric system can begin.

Step 3: Design

Now that the producer has decided to move forward with a hydroelectric project, the final design of the facilities needs to be incorporated into the irrigation system design. The following sections cover the major components of a hydroelectric facility, some of which are common with the irrigation system. Only the design elements specific to the hydroelectric facility are discussed.

A. Intake Structures

Intake Structures are needed to direct the appropriate flow into a penstock or irrigation pipeline and provide for adequate screening. An intake structure for a penstock needs to follow all of the design criteria for an intake structure providing water to an irrigation pipeline.

Several considerations to keep in mind when designing an intake structure for a hydroelectric project;

1) *Screening is necessary to prevent excessive wear on the turbine*

Common to all intake structures is sediment and trash control. Screening the water before it enters the turbine prevents accelerated wear of runners and other components of the turbine. Floating debris may also cause significant damage if allowed to enter the turbine. Screen selection depends on the type of debris and sediment expected. The higher the head on the turbine, the more important is to have sediment free water. Several screen types are shown below with general characteristics of each type.

Table 2: Comparison of Several Screening Options

Screen type	*Screen Size*	*Electricity*	*Turbine Type*	*Flow*	*Head Loss*
Wedge Wire	*Very fine*	*No*	*All*	*Medium*	*High*
Bar Trashrack and Rake	*Coarse*	*Some*	*Low head*	*High*	*Low*
Drum Screens	*Very fine*	*Some*	*All*	*Low*	*High*
Motorized Screens	*Medium*	*Yes*	*Low Head*	*Medium*	*Medium*

Consult with the manufacturer of the selected turbine to determine the maximum particle size that can be passed through the turbine without causing damage. When choosing a screening method, accessibility for maintenance, access to electric service, the size of the debris and sediments, and the selection of the turbine must be considered. The head loss that occurs through the screen must also be considered.

A list of manufactures of screens, trashracks, cleaners and other intake devices can be found in the Additional Resources section.

A settling basin can also be used to trap sediment prior to entering the penstock. Again, these are the same methods employed in an irrigation pipeline design to prevent excessive sediment from entering the pipeline. The sizing, design and location of a settling basin is no different for the penstock and turbine.

2) *Submergence of the penstock is important to prevent trapped air*

Submergence of the penstock inlet is a design consideration for the intake structure. The inlet of the penstock must be sufficiently submerged under water such that air is not drawn into the penstock or vortexes created on the water surface. To prevent this from occurring, a general rule of thumb is to submerge the penstock inlet a full penstock diameter below the water surface. This depth may be reduced through a hydraulic analysis of the structure.

3) Method for bypassing flow

An intake structure provides for a method of bypassing flow if the turbine is shut down for any reason. If the intake structure is taking water off of a ditch or stream, there generally is a way for water to bypass the structure and stay in the original waterway, without causing unintentional flooding. The turbine is installed with a turbine inlet valve that is closed when the generator needs to stop producing power. This valve is located near the turbine, and will shut off the supply to the turbine. When this happens, water needs to bypass the intake.

Alternatively, if this water is needed downstream of the turbine for another purpose, such as irrigation, a bypass valve can be added near the turbine. This allows water to continue to flow in the penstock and arrive at the same delivery point downstream of the turbine. The pressure that was dissipated by the turbine needs to be dissipated at the bypass valve using an energy dissipation structure or appropriate valve.

4) Low head turbine intakes

One low head turbine is included in the turbine selection chart, the LH-1000 from ESD, Inc. This turbine takes advantage of only up to 10 feet of head and does not use a penstock to build pressure. Instead the intake structure directs water into the turbine and the draft tube creates the pressure. A schematic is shown below of the turbine layout and components.

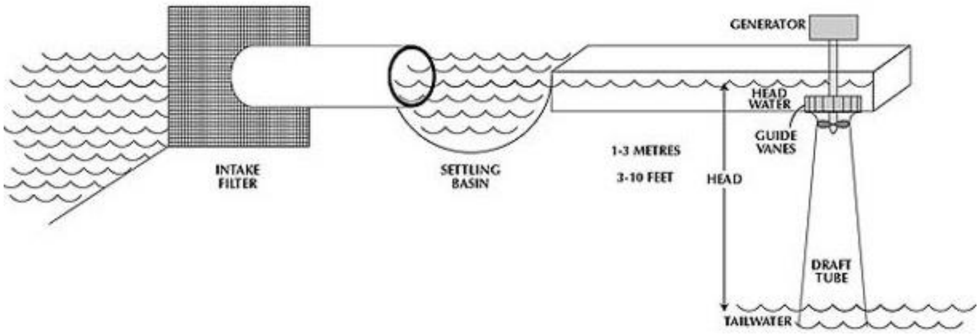


Figure 20: LH1000 schematic (courtesy of Energy Systems Design)

The intake for the low head turbine needs to insure adequate sediment removal through screening or a settling basin. The intake also directs water to the turbine. As shown in Figure 20, this is generally accomplished with a trough that is open above and the turbine is placed through the bottom. This trough must be adequately supported and sized to the site conditions. More specific instructions are available from the manufacturer.

B. Penstock

During the site assessment phase, the penstock size and alignment were chosen. During final design, this preliminary design must be confirmed or altered as necessary. Starting with the preliminary design, additional investigation will further refine the penstock size and alignment.

1) Size the penstock and calculate losses

Most of these projects use the irrigation pipeline to deliver water to the turbine and the irrigation system. The pipeline will need to be sized for both irrigation and turbine flows and head losses need to account for the total flow expected. If variable flows are expected and the head losses change significantly, a flow-pressure relationship can be used in the sizing of the turbine and estimation of energy generated. Alternatively, if high flows are creating unacceptable head losses, the diameter of the penstock may be increased.

2) Design valves and fittings

Using standard pipeline design, provide for adequate air release or vacuum valves as necessary depending on the alignment of the penstock. Also ensure that adequate shutoff valves are included in the design according to planned operations. If there is a low point in the penstock, also include a valve to drain water during the winter when the hydropower unit is not operational and to flush any accumulated sediment.

3) Thrust Blocks

The pipeline needs to be designed with adequate thrust blocks for the expected velocities and forces on the pipeline through its entire length. An additional thrust block or plate is necessary at the entrance to the powerhouse to stabilize the connection to the turbine.

4) Bury Depth

The penstock needs to be buried to a sufficient depth to protect the pipeline from damage, including traffic and icing conditions.

C. Powerhouse

During the feasibility assessment, the powerhouse type and size was determined. At this point the powerhouse and foundation needs to be designed with enough detail for construction.

1) *Type of powerhouse (buried vault, above ground structure).*

During the feasibility assessment phase, the type of powerhouse was considered and selected. Confirm that the selected type will be constructible and functional at the site. If the powerhouse is located near a center pivot, is there adequate clearance if that pivot passes over the powerhouse? Is there shallow bedrock that will prevent excavating for a buried powerhouse? Is there a high water table that will make construction of a buried vault difficult, and difficult to maintain? Is the foundation type selected appropriate for the turbine type?

2) *Size of powerhouse needed to house turbine, generator and controls.*

All of the components of the hydropower system require a certain amount of space within the powerhouse and may require separation from other components. Work with the turbine supplier and electrician to insure that all components are accounted for and clearances are adequate.

3) *How will the equipment be installed in the powerhouse? Ensure adequate space for installation.*

When installing larger equipment, ensure that doorways and access are adequate for the installation of the equipment. If the equipment is very heavy, machinery may be needed to place the equipment. Removable sections of the powerhouse roof or walls may be necessary for the installation.

4) *Foundation requirements to provide adequate support, submergence, capacity and direct discharge water appropriately.*

The powerhouse foundation must be designed to adequately support the expected loads given the soil conditions. For smaller units, a detailed design may not be necessary, but as the equipment size and weight increases or poor soils are encountered, the foundation may need further evaluation.

As mentioned previously, some turbines require submergence of the draft tube while others discharge freely. The turbine manufacturer will generally specify the maximum and minimum tailwater conditions required. The tailwater elevation must be determined under all flow conditions to ensure it will fall within that range.

The flow discharged from the turbine must be directed into an adequately sized conveyance system. If an inline turbine is used and water stays within the pipeline, ensure that the discharge pipeline is sized adequately, and pressure is regulated as needed downstream of the turbine. If the turbine discharges into a ditch or pond, ensure that the hydraulic capacity is adequate.

5) *Is a bypass required, how will it be configured and where will the discharge be directed?*

There are several conditions that will require a bypass structure around the hydroelectric facility. For instance, if irrigation water is needed downstream of the turbine at all times, even when the turbine is not operating, or if the headgate cannot be shut in the case of a turbine shut down when water needs to be directed away from the turbine. Another instance may be when there is more flow than the turbine's capacity needed downstream, and just a portion of the flow must bypass around the turbine. Depending on the situation, the type of bypass can be selected and designed for the conditions. Possibilities include an energy dissipation structure, a pressure reducing valve, a butterfly valve, or a pressure relief valve.

D. Turbine, Generator and Controls

During the feasibility assessment the appropriate turbine was selected for the site conditions. This manual assumes that a turbine manufacturer or supplier will provide all of the equipment required to form a “water-to-wire” package. This is all of the equipment from the intake to the turbine to the interconnection with the grid, including the generator, inverter, diversion load, and controls. The turbine manufacturer/supplier will need to provide a package appropriate for the site conditions, and which complies with the interconnection requirements of the local utility.

The components of both a low power inverter system and a high power direct system will be discussed in this section to insure that the design engineer understands all of the components and their function. However, the actual design of these components will not be covered in this manual.

1. Low Power Inverter System

A low power, inverter based system will be general arranged as shown in Figure 21.

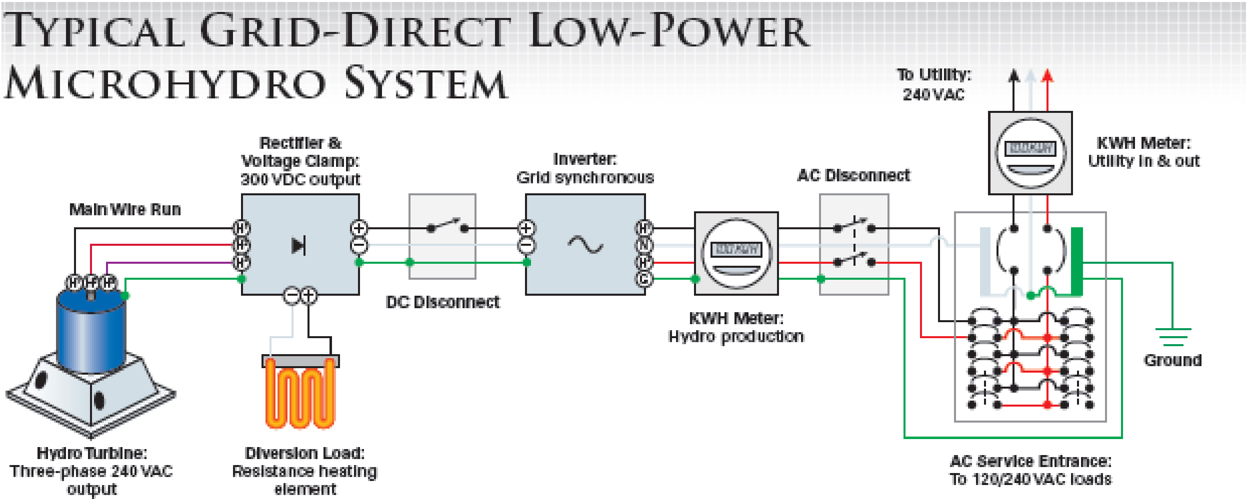


Figure 21: Low Power Inverter System Schematic (courtesy of Home Power Magazine)

The turbine could be any type, a pelton, turgo, propeller, etc. with the purpose of providing rotational energy to the generator. The generator will produce either DC or wild AC power and the inverter rectifies this power before it can be sent to the grid and metered. The voltage of the generator and the voltage of the inverter must be matched for the system to operate properly. Generators are available in a range of voltages, and the selection depends on several factors including the distance of wire required to the grid connection. If a higher voltage is selected, the size and cost of the wire is reduced.

The diversion load is required on this type of system in case of a grid outage. The generator must be loaded at all times in order to regulate the speed of the turbine. The grid loads the generator under normal conditions, but during an outage there must be a backup load: the Diversion Load. A properly sized water or air heating element will act as a Diversion Load.

Battery-less, inverter based systems are relatively new to the market place and aren't widely used. It is important to find a manufacturer or a qualified supplier to provide the appropriate equipment for the conditions of each site.

2. High Power Direct System

A high power, direct system will be comprised of the following components, a Turbine inlet valve, the turbine, generator, and controller and protection system. These components are generally arranged in the manner shown in the following Figure 22.

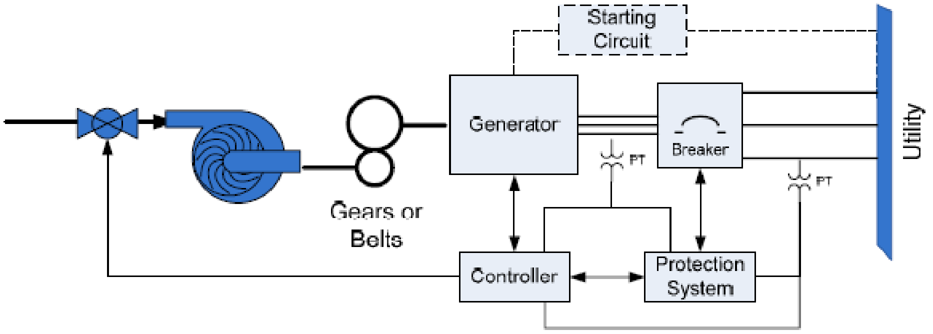


Figure 22: High Power Direct System Schematic

A high powered, direct system is equipped with an emergency shutdown system instead of a diversion load. The ability for the system to disconnect automatically is a fundamental interconnection requirement of the utility. The turbine and generator must stop operating if the connected grid fails. The controller will detect the loss of power and automatically disconnect the generator. This creates an issue where the generator is no longer experiencing a load, and it will tend to increase in speed if the turbine is still passing water and turning the generator. Ultimately, if the turbine is allowed to spin at "runaway speed", there is the potential that it will spin so fast that water will not be able to pass through the turbine. This could cause a catastrophic pressure surge in the pipeline. It will also cause damage to the generator if it is allowed to spin freely.

There are several safeguards that can be included in the system depending on the turbine type. In general, the safeguard is a method to remove water from entering the turbine and spinning the runner. For impulse turbines, a deflector may be used that simply deflects water from the runner in the case of an emergency shutdown. Water will still be traveling through the penstock, but just discharging directly without turning the runner. Subsequently, the turbine inlet valve will be slowly closed. Reaction turbines need the water flow to be stopped through the penstock or directed away from the penstock. This type of control is generally achieved through automatic valves or gates that close slowly to prevent a pressure surge.

The Controller and Protection System are required to insure safe and proper energy production. The main functions of the controller and protection system associated with an induction generator are to:

1) Disconnect and power down the plant when the utility power is disrupted (power outage). This will insure that the plant does not back-feed onto the grid and create a safety hazard for line workers.
2) Protect the equipment from harmful conditions.
3) Allow the turbine to come to normal speed and automatically connect to the grid.
4) Allow for smooth and controlled shut down.

Additional optional controls may be added such as automatic restart of the plant after the grid connection is restored.

3. Transmission and Interconnection

The electrical transmission side of the system must be considered and designed for the site conditions. The location of the turbine relative to the grid and the meter will impact the design and cost of the transmission line. The wire must be appropriately sized given the system voltage, acceptable losses distance, and the number of phases. The turbine manufacturer is able to assist with the design of the transmission and interconnection once provided with the site conditions and utility requirements. Alternatively, a licensed electrician could work with the turbine manufacturer to design and install the appropriate equipment.

Step 4: Funding

It is assumed that all projects considered in this manual are receiving some funding from the EQIP program and will apply for a grant through the USDA – Rural Energy for America Program. Grants are available for up to 25% of the project cost and can be used in conjunction with EQIP funding. This manual will not explain further the EQIP process, but will discuss how to complete the Technical Report which is a part of the REAP grant application.

The REAP technical report can be found in the **"4) REAP Technical Report"** worksheet of the Hydroelectric Toolbox. The REAP Technical Report is dependent on the total project costs. If the project cost is less than $80,000 then the Technical Report will only complete subsections 1) – 4). Whereas if the project cost is more than $80,000, but less than $200,000, then an additional subsection "5) Project Construction and Equipment Information" must be completed as well. Below is a guide to completing each of the subsections.

1) *Project Description*

The project description begins with describing the project – type of turbine, irrigation system, water source, supplier/manufacturer of selected turbine, etc. Include a vicinity map to show the location of the project site. Provide details on the estimated power and annual energy production and discuss how the turbine will operate. Describe the available flows and head for the site and how these site conditions power the turbine. The number of days the turbine will operate, total number of kilowatts to be generated, as well as the total kilowatt-hours of energy production per year is included in the descriptions. Also, describe any environmental impacts, as well as how the project potentially enhances the site.

2) *Resource Assessment*

The resource assessment identifies the water source, and delivery from the source to the site. Include the length of pipeline, elevation difference (head), flows, and available days of irrigation water annually. Include a flow duration curve showing the available flow in comparison with the amount of flow to be used for power. Discuss in detail the operation (more than was discussed in the project description), and the amount of energy to be generated.

3) *Project Economic Assessment*

The project economic assessment discusses the incentives that the project qualifies for, and if there are any cost share funds for the project. Give a breakdown of the total project costs that are not covered by the incentive program and discuss the amount of savings that will be produced each year. Also provide the breakdown from ***2d) Hydroelectric Economics*** and give an explanation of how these numbers were generated.

4) ***Qualifications of Key Service Providers***

List the members of the project team, including the system designer, project manager, equipment supplier, project engineer, construction contractor, system operator, and anyone else that may be applicable. Provide a brief explanation of each member's experience and how it will be relevant to the project.

5) ***Project Construction and Equipment Information (if project is between $80,000 and $200,000)***

This section will describe the design, engineering, testing, and monitoring that are sufficient to show that the design of the project will meet its intended purposes, while also providing adequate safety and adhering to all laws and regulations that apply to the project. A description of the method that will be used to procure the hydroelectric system will be required, including a project development schedule. Also, include component warranties, and availability for spare parts.

Step 5: Permitting

Several permits are required on the local, state and federal level for any hydroelectric installation that is connecting to the grid.

A. FERC Permitting:

The Federal Energy Regulatory Commission (FERC) regulates all hydropower projects in the United States, but has recently made an exception for projects that are constructed on a conduit (canal or pipeline) that is used for another purpose such as irrigation. Although these projects no longer fall under FERC jurisdiction, they do require that a Notice of Intent be filed in order to officially qualify the facility.

A "qualifying conduit hydropower facility" must meet the following provisions:

1) A conduit is any tunnel, canal, pipeline, aqueduct, flume, ditch, or similar manmade water conveyance that is operated for the distribution of water for agricultural, municipal, or industrial consumption, and is not primarily for the production of electricity.
2) The facility generates electric power using only the hydroelectric potential of a non-federally owned conduit.
3) The facility has an installed capacity that does not exceed 5 megawatts (MW).
4) The facility was not licensed or exempted from the licensing requirements of Part I of the FPA on or before August 9, 2013.

It is expected that all of the projects described in this manual fit the above criteria.

The Notice of Intent application is included in the ***5) FERC NOI worksheet*** within the "***Hydroelectric Toolbox***". The Notice of Intent document is approximately four pages and requests general information about the conduit and the hydropower project. Also several drawings must be included with the Notice of Intent: a location map and a plan view of the proposed facility. Specific instructions regarding the content of the drawings are listed in the Notice of Intent worksheet. The last page is a verification form which must be signed and notarized prior to submittal.

The Notice of Intent application form, verification form and necessary drawings can be filed electronically with FERC. Instructions are provided on this website: http://www.ferc.gov/industries/hydropower/indus-act/efficiency-act/qua-conduit.asp. The applicant must sign up on the eRegistration system (http://www.ferc.gov/docsfiling/eregistration.asp), after which all of the files can be uploaded. Email verification will be sent to the applicant within a few business days.

FERC reviews the Notice of Intent application over a 15 day period. If the application is found to meet the qualifying criteria, FERC will issue a letter and request public comments during a 45 day period. If no comments are received, a letter notifying the applicant of acceptance is issued.

B. Interconnection Application:

The local utility will require an interconnection application and a net metering agreement to be completed prior to generating electricity and supplying it to the grid. The requirements of each utility vary slightly, but in general they need to see that the equipment is connected in a safe manner and protection measures are provided. The local utility must be contacted to obtain the forms and provide any specific requirements on equipment, inspections, or fees.

C. Electrical Permit and Inspection:

Electrical inspections are required throughout the State to insure compliance with the National Electric Code. The State of Colorado, State Electrical Board has jurisdiction over the majority of the State except in local jurisdictions that have their own electrical inspection program. The following counties have their own electrical inspection program, while the rest of Colorado falls under State jurisdiction.

- Arapahoe
- Boulder
- Broomfield
- Chaffee
- Denver
- Douglas
- Eagle
- El Paso
- Jefferson
- Mesa
- Pitkin
- Pueblo
- Routt
- Summit
- Teller
- Weld

In general, an electrical permit needs to be obtained prior to the installation of any electrical wiring; this would include the wiring to a center pivot even in the absence of a hydroelectric component. During or after the electrical wiring installation an inspection is made and the permit is approved and closed. Check with the permitting jurisdiction for requirements specific to the area.

Because of the specialized nature of a hydroelectric system the inspector may require additional inspection measures. In the case of an inverter based hydroelectric system less than 100 kW in size, HB 15-1364 outlines that the inverter must be UL listed and any equipment behind the inverter need not be listed. In the case of an induction based system with a control system, the local inspector will require that the installation is certified by a Nationally Recognized Testing Laboratory or by a Professional Engineer certifying that the installation meets design criteria set forth by the Institute of Electrical and Electronics Engineers' (IEEE). A list of firms qualified to perform a field inspection is included in the Additional Resources section.

Step 6: Inspection, Commissioning and Close out

Prior to construction of the project, the design documentation should demonstrate that the criteria in the previous steps have been met and are compatible with planned and applied practices. It should be determined that all required permits have been obtained and that the client is ready to begin construction. Once the client has given their approval, the construction process can begin.

Prior to installation, a pre-construction meeting with the client and contractor should be coordinated. After the pre-construction meeting, it should be determined that the staking and layout is according to plans and specifications, including any layout notes. The client should be advised on compliance issues with all federal, state, tribal, and local laws, regulations and NRCS policies during installation. Once construction begins, all design modifications that are required during construction should be documented and coordinated with the client and original designer. A project inspection checklist is provided within the Hydroelectric Toolbox and should be completed during construction.

The project inspection checklist is required to be completed and certified of completion before the project close-out begins. The inspection checklist will require the inspector to ensure that all construction meets all design and specification criteria. The checklist will require inspection of the following: excavation, backfill, pipeline layout, concrete placement, intake structures, penstock, power house, turbine model and manufacturer, generator, inverter, interconnections, pipe connections, and commission.

Once the project inspection checklist has been completed, the approval and close-out process can begin. Approval of all documented material (e.g. inspection checklist, design modifications, construction records) will be required during the close-out process. As-built documentation will be required including drawings, final quantities, and progress reporting. Certification that the installation meets design standards, specifications and all design requirements will have to be completed once all documentation has been received. Form CO-ENG-12 may be used for this certification. Once approval and certification has been given, then the project close out is complete.

Summary:

This manual has taken the reader step by step through the development of agricultural hydropower projects for pressurized irrigation systems, specifically a hydro-mechanical center pivot installation and a net metered hydroelectric installation. Hydropower projects bring together many disciplines of engineering and will require the combined effort of several professionals. This manual provides an overview of all aspects to help the reader coordinate this effort.

Glossary:

Agricultural Hydropower: Small hydropower projects that are constructed in conjunction with pressurized irrigation systems with direct benefit to the agricultural producer.

Capacity: The peak power that a system can produce. Capacity can be described as what is available for the site, required to power the sprinkler system, or the design capacity of the system.

Draft Tube: Piping that connects the turbine to the tail race, and monitors the influx of water.

Energy: Energy describes the amount of power produced by the hydropower equipment during a period of time in units of kilowatt-hours (kWh) or British thermal units (Btu). Energy can be described as what is available for the site, required to run the sprinkler system, or what the system is designed for.

Flow: Flow is the volume of water passing through an area in a given time period. It is most often measured in cubic feet per second (cfs) or gallons per minute (gpm). Flow can be described as what is available to the site, required for the sprinkler system or the design flow of the system.

Flow Duration Curve: A plot that shows the percentage of time that flow in a stream is likely to equal or exceed some specified value of interest.

Generator: A device that produces electrical power from a rotating shaft.

Grid: Common term for "Electrical Grid": an interconnected network for delivering electricity from suppliers to consumers. It consists of generating stations that produce electrical power, high-voltage transmission lines that carry power from distant sources to electric load centers, and distribution lines that connect individual customers.

Head: The hydraulic pressure in a hydropower system, representing the total vertical distance between the beginning of a pressurized hydro system and the hydro turbine. Net head takes into account losses with the system. Net head is described as what is available to the site, required for the sprinkler system or the design head of the system.

Hydroelectric System: A system that produces electricity using the gravitational energy in falling or flowing water. A micro-hydroelectric system uses small-scale turbines that produce less than 100 kilowatts.

Hydro-mechanical System: A system that produces mechanical power from the gravitational energy in falling or flowing water, and uses a "pump as turbine" (PAT) to power a center pivot sprinkler system.

Impulse turbine: Uses the force of a jet of water striking a runner's curved buckets to change the direction of flow, and thus creating momentum to produce mechanical energy. An impulse turbine can be open to the air, and only needs a casing to control splash. Impulse turbines are generally well suited for high head, low flow applications.

Induction Generator: A type of alternating current (AC) electrical generator that uses the principles of induction motors to produce power. An induction generator operates by mechanically turning its rotors faster than synchronous speed.

Intake: The point at which water is diverted from a river or stream to the hydro turbine via a diversion system.

Inverter: An electronic device or circuitry that changes direct current (DC) to alternating current (AC).

Kilowatt: The kilowatt (kW) is equal to one thousand watts, typically used to state the power output of engines and the power consumption of motors, tools and machines. A kilowatt is approximately equal to 1.34 horsepower.

Kilowatt-hour: A kilowatt-hour (kWh) is a unit of energy equivalent to one kilowatt (1 kW) of power expended for one hour.

Net Metering: A billing mechanism that credits renewable energy system owners for the electricity they add to the grid.

Penstock: A closed pipeline that delivers water to a hydro turbine.

Permanent Magnet Generator: A generator in which the rotor and magnetic field rotate at the same speed, converting the mechanical output power from a hydro turbine into electrical power for the grid.

Power: The rate of energy production or consumption, or the capacity of the hydropower equipment, in units of kilowatts (kW). Power is a measure of energy flow per unit of time.

Reaction turbine: The water flows over the runner blades, and energy production results from the combined forces of the pressure and moving water. The turbine must be encased in a pressurized housing and fully submerged in water.

Water-to-wire package: A turbine generator package that simplifies the planning and development of a project since one vendor looks after a majority of the equipment supply.

Additional Resources:

Pressure Reducing Valves:

CLA-VAL: www.cla-val.com

Flomatic Valves: www.flomatic.com

Watts: www.watts.com

Trashrack and screens:

Atlas Polar Hydro Rake Systems - www.atlaspolar.com

Farmers Screen - www.farmerscreen.org

Hydro Component Systems - www.hydrocomponentsystems.com

Hydrolox – www.hydrolox.com

Hydroscreen, LLC – www.hydroscreen.com

International Water Screen - www.internationalwaterscreens.com

Intake Screens Inc. – www.intakescreensinc.com

Lakeside Equipment Corp – www.lakeside-equipment.com

Norris Screens – www.elginindustries.com

Turbine Manufacturers:

Alternative Power & Machine- www.apmhydro.com

Canyon Hydro – www.canyonhydro.com

Cornell Pump Company – www.cornellpump.com

Dependable Turbines, Inc. – www.dtlhydro.com

EcoInnovation – www.powerspout.com

Energy Systems and Design, Ltd. – www.microhydropower.com

Harris Hydro – www.harrishydro.biz

Hi Power Hydro – www.hipowerhydro.com

Hydro Induction Power – www.homehydro.com

SOAR Technologies – www.soartechinc.com

Qualified Field Inspectors for Electrical Inspection

ASC Engineering Service (ASC); Richmond, CA – www.asceng.net

Canadian Standards Association (CSA); Toronto, Canada – www.csagroup.org

Communication Certification Laboratory; Salt Lake City, UT – www.cclab.com

Curtis-Straus, LLC (CSL); Littleton, MA – 978-486-8880

FM Approvals, LLC; Norwood, MA – www.fmglobal.com

National Technical Systems, Inc. (NTS); Acton, Massachusetts – www.nts.com

NSF International; Ann Arbor, Michigan – www.nsf.org

Intertek Testing Services (ITSNA); Cortland, NY – www.intertek.com

MET Laboratories, Inc. (MET); Baltimore, MD – www.metlabs.com

Underwriters Laboratories Inc. (UL); Northbrook, IL – www.ul.com

NSS Laboratories, Inc.; Fort Collins, CO – www.nsslabs.com

Power Science Engineering (PSE); Auburn, WA – www.power-sci.com

ETI Conformity Services; Pleasanton, CA – www.eticonformity.com

Appendix A – Hydro-mechanical Toolbox

Appendix B – Hydroelectric Toolbox

Appendix C– Hydro-mechanical Toolbox Example:

Appendix D - Hydroelectric Toolbox Example

Appendix E – Cornell Pump-Turbine Catalog

Appendix F – Workshop Presentations