The Montana Consumer Guide to Micro-hydro Systems

- Micro-hydro Overview
- Head and Flow Components
- Physical and Mechanical Components
- Water Rights

The Montana Consumer Guide to Micro-hydro Systems

Understanding and Incorporating Micro-hydro for Residential and Small-Business Consumers

Thank you for your interest in micro-hydro generation and for taking the time to read this publication. It has been developed as a basic resource and practical guide for consumers who have a water resource they may want to develop to generate electricity.

The publication highlights the basics of micro-hydro technologies, as well as the installation requirements and legal factors involved with a system. It is not intended to be a technical manual, and consumers will need to conduct additional research prior to purchasing and installing a system.

There are a limited number of renewable energy contractors in Montana with knowledge and experience relative to micro-hydro. For larger systems, there is a broader scope of contractors in the northwestern United States and Canada. An internet search is a good place to locate micro-hydro resources.

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Micro-Hydro Overview

Introduction

Montana is fortunate to have the water resources and diverse topography to support the scope of hydroelectric installations. This includes micro-hydro, which is defined by the United States Department of Energy as having the capacity "to produce 100 kilowatts (kW) of electricity or less." This document is targeted to micro-hydro systems, and more specifically towards "run-of-the-river" applications that are under 50 kW.

Run-of-the-river, or diversion systems, were a significant contributor to the development of Montana, especially in the early 20th century, and the technologies they utilize have continuously improved. Advanced turbine types and components have entered the market and have proven to increase production and reliability.

Other systems are viable, including installations with a powerhouse located at a dam base or those integrated into a canal, but these are beyond the scope of the needs of most individual consumers.

Run-of-the-river systems generate electricity when the water source is available and flowing. When the water source is not supplying the system, generation ceases. Run-of-the-river systems usually include components such as a weir (a small dam) and a forebay to optimize and "prepare" the water to enter the conveyance system. However, unlike a dam, these components are not responsible for holding and regulating the flow of an entire water source.

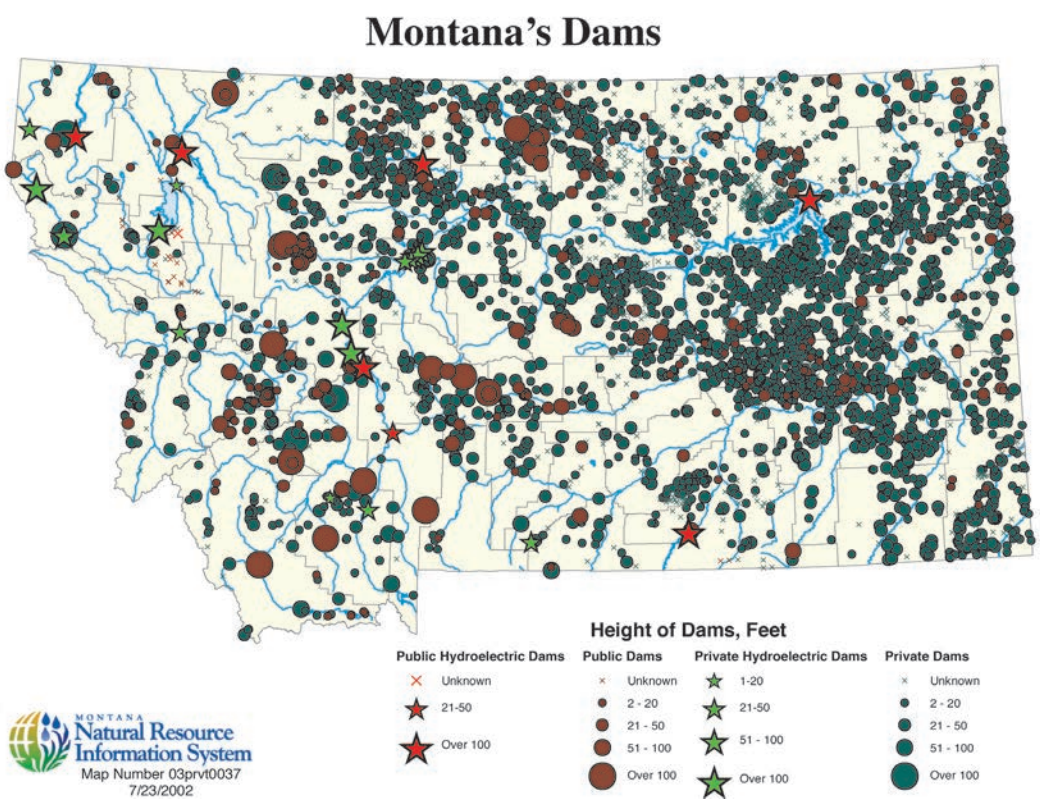
Although most micro-hydro installations do not have the same potential for environmental impact that larger facilities do, there are concerns with installations of any size. The primary consideration is hydroelectric generation's impact on water flow and quality. Hydropower can cause changes in water oxygen levels, which in turn can be harmful to aquatic life, stream integrity, and riparian habitats.

Micro-hydro installations can also be impacted by drought. Installations are especially susceptible when the water source is dependent on seasonal rains and snow pack or runoff. Dependency on runoff can affect production as well as cause environmental problems. For year round production, a reliable water source is required. Necessary safeguards need to be put in place to protect the system from both low water and extreme freezing conditions.

Individuals who have installed micro-hydro systems in Montana and other western states advise that water quality, from a production and maintenance perspective, is the primary issue they have encountered. The primary problems with water quality are excessively turbid flow, debris, and ice. This can lead to excessive maintenance time and expenses.

Scope of the Publication

The type of micro-hydro system, as well as specific components and installation requirements, are matched to the characteristics of the water resource, electricity demand, and other variables at a given location. As noted in the introduction, Montana's diverse topography supports the scope of micro-hydro applications.



Montana's Dams

As the above map illustrates, there are numerous existing impoundments in the State. Many are currently used for livestock and agricultural purposes, but indicate a water resources that could incorporate micro-hydro production. Not included are small streams and springs that are free flowing on an individual's property.

This publication is intended to provide an introduction of the processes, principles and considerations for a basic comprehension of micro-hydro. This knowledge is applicable to the spectrum of potential customer sites in Montana. The contained material is intended as a "first step" for consumers, and further research, planning and development are warranted and necessary to complete a successful micro-hydro project.

Head and Flow - Micro-Hydro's Essential Components

The essential components to any micro-hydro system are the ability of the water resource to provide adequate head and flow that is compatible to the designed components of the system and the consumer's power requirements.

An understanding of the head and flow characteristics of a specific site are essential – from planning and design choices, to selection of components, to matching production to electricity demand

"Head" – The Vertical Drop of the Water Source

"Head" in micro-hydro applications is the vertical (not linear) distance the water falls from the source to the point of generation. Because water has weight, the farther it falls, the more impact it has on the source it contacts. In the case of micro-hydro applications, the impact is on the turbine.

Head is usually measured in feet. Micro-hydro installations are labeled in reference to their head potential as high head, medium head, or low head. As a general rule, the higher (i.e. greater) the head of the water resource, the better. Head classifications vary. A general classification of "low head" is two to twenty feet, and above twenty five feet is considered "high head." "Medium head" is usually regarded in the fifteen to thirty foot range.

When selecting a turbine, it will be labeled with a minimum head rating and a power curve for different head and flow measurements. For marketing purposes, some manufacturers include advertising descriptions such as "ultra-low" or "ultra-high," but it is the specific numerical head and flow ratings and power curves that are important.

Head ratings on turbine units are usually what are termed "gross head" ratings. Gross head is the vertical distance from the source to the turbine. "Net head," the actual head realized at the turbine, is influenced by the design and construction of the conveyance mechanism, including the piping. Friction and turbulence losses can be significant and should be accounted for in the design and installation.

Output in Watts

Head (Ft.).	Flow Rate - Gallons Per Minute (GPM)									
	79	159	238	317	634	951	1268	1585	2378	3170
3	25	49	74	98	196	294	392	490	735	980
7	49	98	147	196	392	588	784	980	1470	1960
13	98	196	294	392	784	1176	1568	1960	2940	3920
26	196	392	588	744	1568	2352	3136	3920	5880	7350
33	245	490	735	980	1960	2940	3920	4900	7350	9800
49	368	735	1103	1470	2940	4410	5880	7350	13230	17640
66	490	980	1470	1960	3920	5880	7840	9800	17640	23520
98	735	1470	2205	2940	5880	8820	14113	17640	26460	35280
131	980	1960	2940	3920	7840	14112	18816	23520	35280	47040
197	1470	2940	4410	5880	14112	21168	28224	35280	52290	70560
262	1960	3920	5880	7840	18816	28224	37632	47040	70560	94080
295	2205	4410	6615	8820	21168	31752	42336	59920	79830	105840
328	2450	4900	7350	9800	23520	35280	47040	58800	88200	117600

US DOE Sample Head/Flow Chart for a Micro-hydro System

Head Losses in a System

Micro-hydro professionals warn that a primary culprit of poor performance in systems not designed and installed by a knowledgeable contractor are due to the failure to account for head losses.

Professionals cite improperly sized pipe, abrupt bends in the conveyance system, and excessive turbulence as the primary factors in head loss. Once these factors create heat energy on the way from the water resource to the turbine (i.e. through friction), it cannot be recovered back to the required "pressure energy" necessary to power the turbine.

It is important to remember that in a non-horizontal pipe, the weight of the water is the contributing factor in the energy formula. Energy resulting from “flow” or the motion of the water is a separate component of the power equation.

“Flow” - The Volume of the Water Resource

Flow is the volume of water provided to the turbine by the water resource. Flow volume is measured in gallons per minute (gpm) or cubic feet per second (ft3/s). In addition to the head rating, turbine manufacturers list the flow ratings of turbines and related components.

Just as “net head” is the critical factor to the performance of a system, the “design flow” is the important and practical measurement relative to the volume of water the resource will provide to the turbine.

For the vast majority of water resources, flow is seasonal and is impacted by environmental events such as rain and snow. Design flow (which is always less than maximum flow) is the planned volume that the turbine and components can handle and are optimally sized for. It accounts for variables and prevents either over or under sizing that can lead to both production problems and equipment failure.

Montana Flow Duration Curves

Seasonal Stream Flow

Hydrologists use what are termed flow duration curves to assess the minimum and maximum flow of a water source throughout the year. For the majority of Montana, the pattern of the curves is similar.

As a general rule, the greatest amount of flow is available in early spring, and flow is at its lowest levels in late summer or early fall, as well as mid-winter.

In some cases only a percentage of the water source will be used for generation, and flow levels may not be as important. However, as the system size increases, the importance of seasonal flow becomes more critical.

Besides stream flow measurements and historical data, a close examination of the water source can be key to determining flow patterns. High water marks can be determined by examining the stream vegetation and topography.

Evaluating The Site for Head and Flow

Evaluating the site and performing basic measurements and data collection are requisite process steps for a successful project. They are essential before beginning detailed research on specific micro-hydro applications and/or contacting a micro-hydro manufacturer or contractor. At a minimum, the following information is important:

1. **General overview and assessment of the water resource. This includes the type of resource (i.e. stream, spring, impoundment), as well as an approximate idea of the seasonal characteristics of the resource.**
2. **The proximity of the water resource to the structure(s) it will serve and existing electrical service.**
3. **The existing and planned electrical demand (i.e. what the micro-hydro project is proposed to service).**
4. **The approximate head and flow of the water resource relative to the proposed generation site.**

Gathering this information will not only help with approximating the system type and size, but also ensure quality dialogue and service with manufacturers and contractors.

Head Measurements

Evaluating head is an important part of the site evaluation process. Depending on the potential and purpose of the proposed micro-hydro application, the consumer may wish to have the site professionally surveyed. This is especially important in lower head installations, where a 10% error may be critical, as opposed to sites with very high head, where small errors may not impact system performance.

There are numerous ways to measure head besides hiring a surveyor. These include measuring pressure when existing pipe is available or using DIY (do it yourself) methods such as the “Carpenter Level Technique.” An internet search for “hydro head measurement” will provide web resources with both instructions and graphics for DIY techniques.

For the purposes of this publication, we will focus on using available maps, topographic data, and global positioning systems (GPS) data. Usually at least one of these resources is available to assist in approximating head at a given site.

Using Topographic Maps, Altimeters, and Global Positioning Systems

For high-head systems, topographical maps can be a useful tool for a preliminary estimation of head. It is also worth the time to consult supporting property documentation at a proposed site. There may be aerial photos, historical measurements, property maps, or surveyor notes that illustrate elevations within the property.

Topographic Map Analysis

There are also a variety of handheld altimeters that can provide a general estimate regarding the distance between a water source and potential turbine site. Some are incorporated into watches and smart phones. Although these devices are not accurate enough for engineering or equipment sizing, the majority of quality altimeters can provide a workable approximation of elevation differences.

Elevation markings can also be obtained through the use of a portable Global Positioning System (GPS). GPS units provide fairly accurate data, but general consumer designed instruments are estimated to only be accurate within 15 meters on average (point on a map).

Measuring Vertical Drop With a GPS

Not all GPS instruments are the same. “Mapping grade” instruments employed by surveyors and engineers are accurate to within one meter or less.

GPS experts recommend several simple practices to improve accuracy in measurements. These include holding the device at shoulder height when taking readings, as well as leaving the unit on while completing the survey.

It is also not a good idea to put the unit in an enclosed space, such as a jacket pocket or backpack, while completing the elevation survey. Getting a signal while in the middle of trees or near other obstructions may lead to erroneous results. Because the unit receives readings from different angles for the most accurate results, errors in obstructed areas are likely. Make sure the device is being held property to take advantage of its built-in antenna.

When taking elevation readings, it is best to survey the site more than once and at different times of the day. This will also help to eliminate sporadic errors resulting from issues such as satellite shading, number of satellites visible to the unit, and atmospheric influences.

It is also a good idea when physically measuring water resource and site altitude to evaluate proposed routes for the delivery system and note terrain types and possible obstacles. This is good information to include when contacting and providing preliminary information to a contractor.

Micro-hydro contractors can provide more accurate preliminary estimates and advice with viable data input. Pictures of the water source, delivery route to the turbine, and the turbine site are easy to take and send to contractors. Especially for sites where travel by the contractor is costly, considerable money and resources can be saved.

Geocache Clubs

There are a number of geocache clubs in Montana, as well as individuals who participate in on-line geocaching forums. Geocache members use GPS instruments to find caches that are hidden by other members, and some participants invest in and use state-of-the-art, professional instrumentation. For micro-hydro site evaluation, geocache “volunteers” are an option for site owners seeking a preliminary evaluation.

The Practicality and Accessibility of the Water Resource

Some water resources can have a number of possible intake points at different elevations relative to the proposed turbine site. “High head” is almost always considered a positive, however the intake site and delivery path to the turbine site need to be practical from both a construction and maintenance perspective.

Excessively steep ground and terrain immediately adjacent to streams are susceptible to erosion and excessive soil run-off. This makes burying pipe at a depth to prevent freezing or environmental damage more difficult.

Flow Measurements - Measuring Flow

Depending on the type of water resource the site has, flow estimations can be made using several methods.

For high volume resources with a uniform contour, the best method is to contact a hydrology professional and contract them to estimate the flow using a device such as a contact meter or electronic flow measuring device. Although there are DIY (do it yourself) methods including measuring stream volume (width x average depth x speed) or constructing a portable weir across the stream, experts suggest it is more cost effective and accurate to obtain preliminary measurements using instrumentation.

Steep Penstock Drop

For lower volume sources including springs or small streams, the bucket method (used by well drillers) is both simple and accurate. The procedure requires the bucket to be kept as vertical as possible in order to ensure reliable results.

Controlled diversions and using PVC or sprinkler pipe as the “spout” for the diverted flow is a common tactic.

To measure the flow with a five gallon bucket, use the following method:

Materials Needed:

1. Five-gallon bucket
2. Watch with second hand or timer
3. Calculator and notepad

Process:

1. Channel the source by damming (if necessary) to accurately be able to discharge the water into the 5 gallon bucket.
2. Place the bucket under the source and record the fill time. Do this several times to ensure accuracy.
3. To calculate the flow in gallons per minute (gpm), use the time measurement it took to fill the bucket (i.e. 20 seconds) and use the factor required to determine the time at 60 seconds (one minute). In this example, the factor would be three (20 x 3) = 60.
4. Apply the factor to the 5 gallon measurement. (In this case, 5 gallons x 3 = 15 gpm). This will provide the gallons per minute (gpm) measurement.
5. If the bucket takes longer than 60 seconds to fill, the factor would be less than one [i.e. - 120 seconds (2 minutes) would provide a factor of .5].

Portable Weir on a Small Stream

With the majority of micro-hydro water resources, there is no single month or season to measure flow and then determine the remaining yearly flow amounts based on the single measurement. Physical data for all seasons is valuable.

The Physical and Mechanical Components of a System

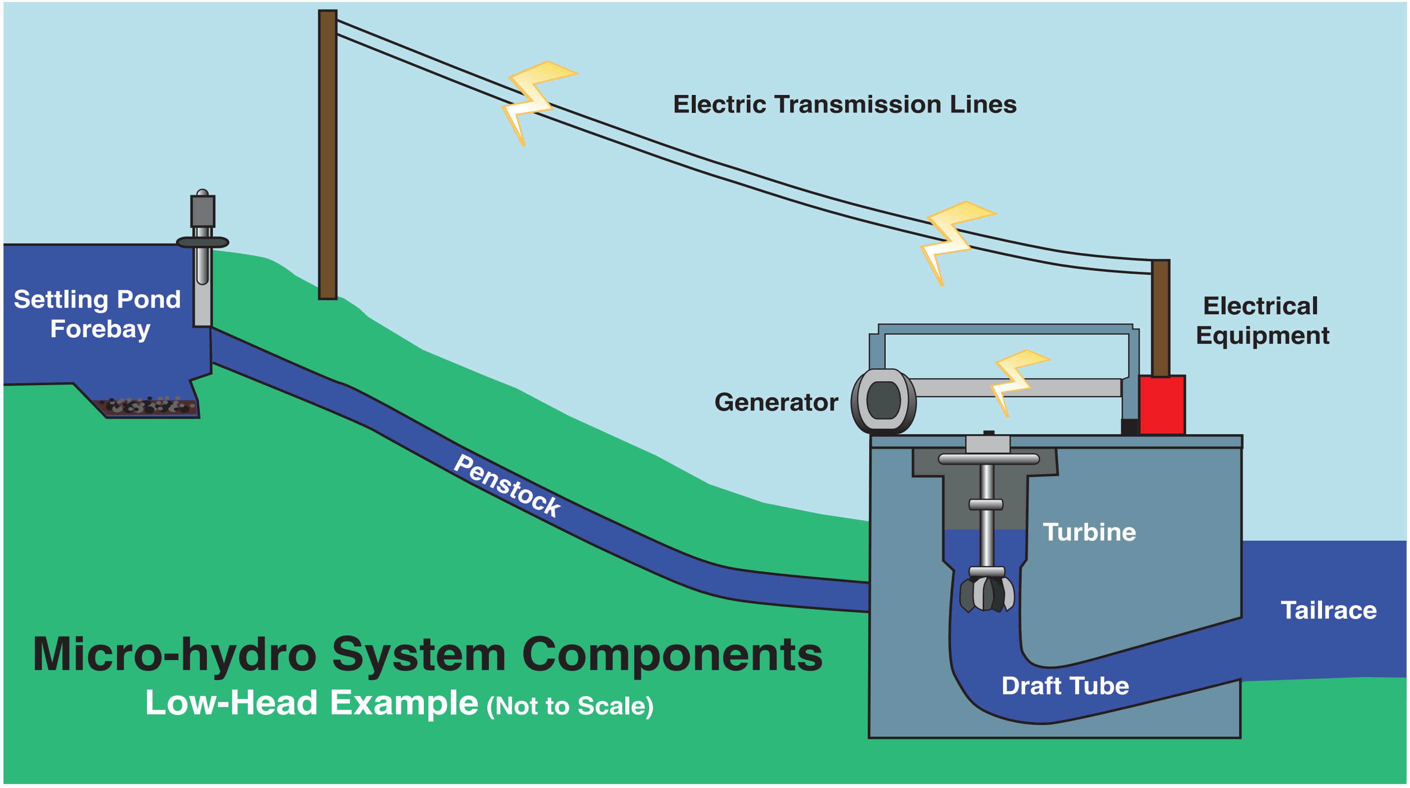
Micro-hydro systems, excluding portable “in stream” turbines used in small remote locations such as temporary hunting or fishing camps, can be divided into three primary segments: the water resource intake, the delivery system to the generator, and the generator and electrical components. An overview of each is included in the following sections of this publication.

Micro-hydro Intake Systems

In nearly all micro-hydro installations, the water servicing the turbine will contain both small particles (silt), and larger materials (rocks, leaves, branches). Without an intake system, problems ranging from restricted flow to damaged turbines can result. Intake systems consist of several physical components.

Due to Montana’s seasonal and “ever changing “ weather, for most locations, sediment and larger particle loads can be expected. These loads consist of seasonal type particulates, such as silt-laden or muddy water from snow melt or rain. Unexpected particle loads including wind-blown debris also need to be accounted for.

To allow for clear, non-abrasive water to enter the micro-hydro system, variations of the “two S’s” are employed in a micro-hydro intake. The S’s represent “settling” and “screening,” and both are necessary for effective micro-hydro system performance.



For an effective micro-hydro intake system, the settling basin and screening mechanisms need to work synergistically to ensure the following characteristics:

1. **The intake must be large enough to sufficiently handle the required amount of water needed by the turbine. In times of peak flow, the excess water must be able to pass through the intake without causing damage.**
2. **There must be a method in place for removing accumulated sediment and larger debris from the bottom of the settling basin. This can be accomplished manually or through a "flushing" type of mechanism.**
3. **Routine and emergency maintenance of the settling basin and forebay area needs to include safety provisions for access and entry. The combination of water and suction can be hazardous, even with smaller systems.**
4. **The design of the settling basin should prevent both turbulence and flow separation. Excess turbulence caused by either improper design (size) or sharp bends can prevent smaller silt particles from settling, and it may damage turbine components. Improper flow separation, sometimes called slipstreaming, occurs when the design of the settling basin coupled with the water flow prevents the sediment from settling, as the water is moving too quickly through the basin.**
5. **In systems where a portion of the water source is diverted and stream flow changes are common, the overflow in times of peak water must be directed away from the intake system to avoid erosion and damage. Erosion problems are also common in systems that have an integrated sediment flushing mechanism. Depending on the installation, an engineered "spillway" type drain may be necessary to prevent damage to the intake and penstock.**
6. **Air entering the penstock, whether caused by excessive turbulence or intake placement, can be as problematic and destructive as silt or debris. Both the settling basin design and intake need to minimize air entering the turbine delivery system.**

Settling Basin Design

Because micro-hydro water sources in Montana vary considerably, a standard settling basin design is not practical. In some installations, an in-stream intake settling basin consisting of sandbags may be adequate, while other systems require engineered settling basins that can include excavation and construction.

The rule-of-thumb for settling basins suggests that the larger the amount of water being directed to the turbines, the larger the settling basin. Velocity is also a factor in settling basin size and design, as silt particles will remain suspended if the water velocity is not adequately reduced.

Settling Basin and Trash Rack

The majority of Montana water sources will at some time contain sediment particles that need to be separated. Even clear spring-fed streams carry rock and sand particles, especially in times of snow melt, high water and run-off. A trade-off of reduced head due to placing the intake below the water source (where a better settling basin can be developed) might make sense, due to easier maintenance and separation capacity.

Settling Basin Maintenance

In most installations, periodic clean-outs of sediment in the settling basin and forebay will be required. Depending on the size and water/silt loads, this may include conditions ranging from the removal of a few shovels of material to a complete shutdown requiring water diversion and specialized equipment.

Some experts suggest an engineered clean-out pipe that is shut off with a cap or valve when the system is operating. Using hand tools and the available water pressure from the source, silt is channeled through the clean-out pipe and away from the basin and forebay.

When using a clean-out, it is important to consider erosion that might undermine the settling basin and/or penstock supports. One idea is to build a rock channel at the clean-out pipe outlet in order to ensure that water is moved sufficiently away from critical components or structural supports.

Below Settling Basin Before Cleanout - USDA Photo

Below Settling Basin After Cleanout - USDA Photo

Professionals also caution that "all sand is not the same." For example, in some areas of the state, there is a preponderance of decomposed granite sand that is larger than typical "beach" sand.

Decomposed granite sand can fill up a settling basin quickly. It is light and sometimes unpredictable relative to how easily and fast it will run off. Because of its large size and mineral composition, it is quite abrasive and can plug smaller penstocks and cause damage to the turbine.

The Forebay

The water enters the micro-hydro delivery system (penstock) at the end of the settling basin through what is termed the forebay. The entrance to the penstock is submerged in the forebay tank. A protective screen covers the intake to the penstock.

The accepted procedure is to ensure the penstock entrance is submerged at least four times its width below the water surface. This prevents a "vortex effect," caused by air entering the penstock if the opening is placed closer to the surface.

There are a number of forebay designs and screening methods available for micro-hydro systems, but they should include the following provisions:

Forebay and Submerged Penstock Entry

1. **The screen mesh size should be small enough to prevent large debris from entering the system, as it could clog the pipe or nozzle. However, a mesh size that is too small will cause frequent clogging and require frequent maintenance. Quarter-inch mesh is the recommended choice for most applications.**
2. **It is recommended to allow one square yard of screen area for each cfm of water flow.**
3. **Screens should be as vertical as possible and include some type of slope to the sides. The slope enable self-cleaning. Horizontal screens are usually not effective.**

4. **In some cases, it is necessary to place a trash rack before the screen. This trash rack prevents large debris from damaging the screen and/or "damming" the intake. Trash racks are usually placed between 60 and 80 degrees and may include a raking mechanism for debris removal.**
5. **Screens are usually made of brass or stainless steel. Stainless steel screen, widely used in agriculture, is readily available in different weights and mesh sizes.**

Poorly designed intakes can cause problems throughout the micro-hydro system. Depending on the specific installation, redesign and/or repair costs can be excessive. It is worth the effort to take the time to observe the water source characteristics and plan, design and build the intake system accordingly. Many hydro experts caution that poorly designed and constructed intakes are sometimes overlooked and end up being the most problematic component of a micro-hydro system.

Penstock (Delivery System)

Micro-hydro systems require a delivery mechanism from the intake to the turbine. Even low-head systems that operate directly from a dam require a short flume or pipeline. Except in rare cases, the conveyance of the water from the intake to the turbine is accomplished using pipe, which is termed the penstock in micro-hydro applications.

Penstocks in higher head systems can account for nearly one-half the cost of the installation. Improper sizing and material selection can lead to reduced production, increased maintenance, and excessive costs. A basic understanding of the physics involved with the penstock system, as well as characteristics of material types, is necessary when planning the system.

Basic Physics of Water

Unlike gas, water is not compressible. Therefore, reducing or tapering the size of the pipe through the penstock system does not increase the pressure or power of the system. Instead, reduced pipe diameter leads to friction loss and reduced power.

The general rule is to minimize pipe diameter reductions. When it is necessary to use undersized pipe, it should be done in short increments. Friction losses are cumulative. Water pressure is also impacted by the inside surface of the pipe. Polyvinyl Chloride (PVC) and Polyethylene (PE) pipe both have fairly low inside surface friction, followed by mild steel and cast iron.

Consumers should never use light gauge irrigation pipe for a penstock. It is designed for its ability to be moved and handled and does not support the dynamics of micro-hydro insulations. Most used irrigation pipe is also thin walled and has varying degrees of damage that will lead to failure in a micro-hydro installation.

PVC Pipe

PVC is one of the most common penstock materials used in micro-hydro systems. It is reasonably priced, can be purchased with different pressure ratings, and comes in a multitude of dimensions. PVC pipe is also lightweight, resilient, and has high elasticity (which is necessary for preventing damage from pressure surges). PVC's most significant drawback is that it deteriorates due to ultraviolet light from the sun.

PVC Pipe Ready for Joining and Burying

PVC pipe must be covered, painted or buried to protect it from the sun. In most cases in Montana, the preferred option is to bury the pipe to prevent freezing.

PVC pipe should also be supported, even when buried. If it is not supported, constant vibrations caused by water flow may lead to the pipe's fatigue and failure. When buried, a sand or fine gravel bed is the best choice. Pipe placed on sharp rocks will eventually fail because of the continuous water vibration causing fatigue in "contact spots."

Efforts should also be made to avoid sharp bends or acute changes in direction with PVC. Such changes in direction not only cause significant bending stresses, but also contribute to friction losses.

It should be noted that PVC pipe loses its flexibility and strength as the temperature decreases. Pipes must be buried below the frost line. Even though water may remain flowing in pipe buried above the frost line, the exterior surface of the pipe is exposed to potentially damaging temperatures and freeze/thaw cycles.

Polyethylene Pipe

Polyethylene (PE) Pipe

The common alternative to PVC pipe is polyethylene (PE). It comes in several densities that can be matched for the pressure characteristics of specific systems. PE pipe is resistant to ultra-violet light and has excellent characteristics to prevent friction and corrosion. PE pipe also comes in large rolls, which can simplify a small-scale installation.

PE pipe is more freeze resistant than PVC. It also can absorb mild bends, however, when bent too abruptly, the pipe has a tendency to fold/collapse. PE pipe has slightly more friction loss than PVC (2” PE has a friction head loss of 1.77 ft. per 100 ft. at 30 gpm. Comparatively, 2” PVC loses 1.17 feet of head due to friction per 100 ft. at 30 gpm.)

Generally speaking, for the quality of PE pipe needed for most micro-hydro installations, PE is slightly more expensive than PVC.

Steel Pipe

New or slightly used steel pipe, which may be available as either construction over run or at surplus auctions, is sometimes a viable choice. Depending on the installation, mild steel can be used. Its biggest drawback is that fact that it will corrode rapidly when buried. Steel has a moderate friction loss, but higher than PE or PVC.

Penstock Expansion and Contraction

In the majority of situations, where the penstock descends directly from the forebay to the turbine, several safeguards for expansion and contraction of the penstock can be implemented.

The first is to allow some flexibility in the pipe resting within the forebay (where it can move back in forth inside a socket). This is usually sufficient, especially with smaller diameter pipe.

The second is to permit for expansion by ensuring a bended part of the penstock take up the expansion and contraction forces. To allow for this, there has to be room designed for movement integrated into a part of the penstock, even if the pipe is buried.

If using PVC pipe, joint gaskets can service the expansion and contraction of the penstock. Pipes and fittings installed in cold weather will expand in cold weather, and hot weather joints will contract in freezing temperatures. For underground installations (below the frost line), ambient temperature fluctuations do not usually create significant problems.

Necessary Valves and Gauges

Pressure Gauge Above Turbine Stop Valve

Below the forebay exit (at the top end of the penstock), a stop valve is installed to prevent water from entering the penstock. This is usually a design that can be adjusted for maintenance, operational and testing purposes. Below the forebay stop valve, a vacuum breaker is included.

Vacuum breakers are necessary in the event of an intake clog where water is quickly emptied from the penstock. In such an event, the pipe changes from being under pressure to being in a vacuum. Vacuum breakers can prevent severe damage to the pipe. For most micro-hydro systems, the vacuum breaker is a simple, smaller diameter pipe that extends above the water level at the intake and allows air into the penstock in an emergency.

At the turbine end of the system, engineers suggest that a valve or valves be installed above the turbine in order to turn it off. Sometimes in multi-jet turbine systems, a stop valve is assigned for each jet. These valves allow for maintenance of a specific jet and function as a manual method to handle variable water flow conditions.

Often there is also a bypass where water delivered from the penstock is channeled away from or around the turbine. This bypass can be useful for repairs, to purge air, or to address unusual water or freezing temperature conditions.

It is also useful to include a pressure gauge upstream of the turbine-end stop valve. This allows for measurement of static head and dynamic head. Pressure gauge readings can help detect clogs and leaks, as well as problems with component sizing.

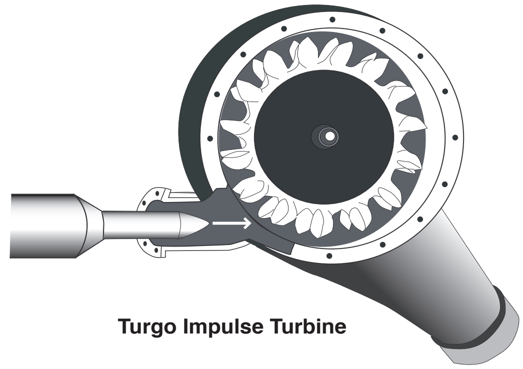
Turbines

The penstock or water conveyance system delivers the water to the micro-hydro turbine, where the turbine transforms the energy of the water into rotational energy, which is then transformed into electricity by the generator.

Modern micro-hydro turbines are designed and manufactured for specific water resources and head/flow variables. The following information details the primary types and uses for small-scale applications.

Impulse Turbine Overview

Impulse turbines are the choice for high-head, low-volume water sources. Sometimes the term “high head” is substituted for “impulse,” but they are the same. The name “impulse” refers to the momentum that is achieved when the water strikes the turbine wheel or runners.



Turgo Impulse Turbine

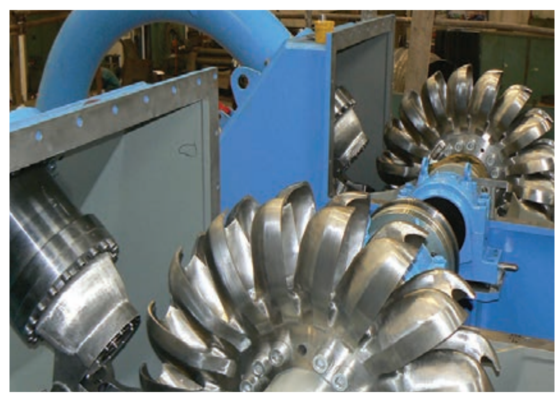
A basic comparison of the action of an impulse turbine is to relate it to that of a child’s pinwheel. Although the momentum source is different (air rather than water), the action of pushing the wheel in a circle is very similar. In an impulse system, the water is diverted upstream of the turbine and delivered through the penstock. The flow is then constricted to a narrow jet of “pressurized” water immediately before hitting the turbine.

Many of the recent technological improvements in micro-hydro have been directed towards impulse turbine systems. This is partially driven by the fact that there is usually more access for consumers to smaller streams and/or developed wells.

Most experts suggest that sites with 25 feet of head or more use an impulse turbine. Advantages include the cost and the relatively simple design. Impulse turbines can also be designed with adjustable or “easy change” nozzle sizes to allow for seasonal stream flow. The most common impulse turbines are the Pelton and Turgo designs.

Two Types of Impulse Turbines – The Pelton and Turgo

The Pelton turbine uses the physical principle of jet force to create energy. The water is directed through a pipeline system to an outlet nozzle, which constricts the flow and builds pressure. The Pelton design, which has “double cupped” runners attached to a wheel, rotates continuously.



Dual Pelton Turbines

While similar to the Pelton turbine, the Turgo turbine differs with respect to several design and operating characteristics. The first difference is that the Turgo jet is angled to allow the spray to hit three buckets at once, causing the turbine wheel to move faster than on the Pelton.

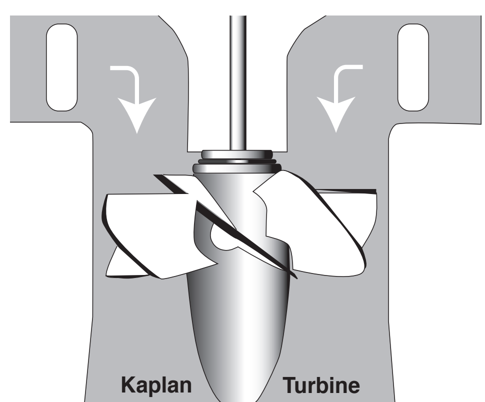
The second difference is the Turgo jet is approximately one-half the size of the Pelton. “Off the shelf” units are available with up to four one-inch jets per unit, which allows for handling higher water flows.

Both the Pelton and Turgo turbines have proven performance and reliability. Specific manufacturers will advertise their particular turbine type as an “upgraded” or “improved” version of the other. Depending on the site, the characteristics of either design may prove to be advantageous for production and reliability.

Reaction Turbine Overview

Reaction Turbines are the choice for low-head, high flow water sources. They are often labeled “low head” turbines in manufacturer’s literature. Most large-scale hydropower sites utilize reaction turbines. Reaction turbines are highly efficient, but they are more complex than impulse turbines.

Reaction turbines generate power through pressure, rather than velocity. The turbine runners are designed to be placed in the water source. Power is achieved by water flowing over the turbine, as opposed to striking each blade individually.



Kaplan Turbine

For reaction turbines to work efficiently, they must take advantage of what is termed “pressure head.” Pressure head can be understood as the pressure created by the weight of water above or directed towards an object. Water has a specific weight, and it has the potential energy to create a reaction, such as moving a rock or turning a wheel. There is water pressure even in “still” water environments. This pressure is the reason divers have to take extra precautions when diving deep, or why a person experiences popping ears when going underwater. Water pressure is measured in pounds per square inch (PSI).

“Suction head” can also play a significant role in the power production of many reaction turbines. Designs that have a discharge, or “draft tube,” can increase the system’s head from the vacuum created between the turbine blades and water discharge level. Estimates from manufacturers suggest up to a 20% power increase with a properly designed discharge system. The draft tube must be completely submersed in the discharge, or “tail” water, with no air leaks, thus maintaining the vacuum suction.

Reaction Turbine Types - Propeller Turbines

The most popular reaction turbines for micro-hydro applications are propeller turbines. Propeller turbines come in designs that closely model a boat propeller, where the blades maintain constant contact with the water. These model types do not have nozzles, and the units are fitted inside the penstock tubing.

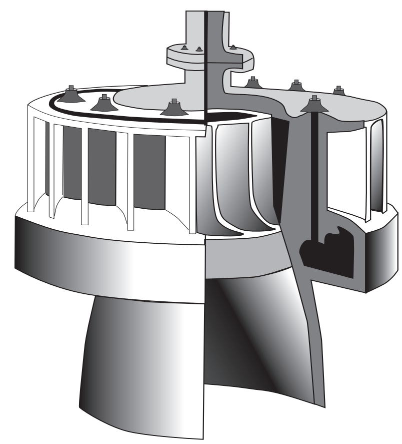
Propeller designs include bulb turbines and tube turbines. In bulb turbines, the turbine and generator perform as a sealed unit placed directly in the stream. Tube turbines have a design where the penstock bends before or after turbine runners and has a straight connection to the generator. The generator is located outside of the pipe.

The Kaplan turbine is the most popular small reaction turbine. It is a hybrid bulb and tube design. Kaplan turbines utilize a propeller-type device with adjustable blades, which allows for variations in flow rates. They can be modified for use in as little as two feet of head.

Frances Turbines

“True” Frances turbines are typically not used in micro-hydro applications. The design involves a tapered spiral casing, complex blade profiles, and adjustable guide vanes. Frances turbines are primarily used in large-scale hydro facilities, however there are “Frances type” turbines now available and being marketed for micro-hydro applications.

A brief overview of the smaller “Frances type” turbines points out that they can operate efficiently in as little as 4 feet of head and use both a closed water diversion system and draft tube to produce power. The units require bearing and seal replacement on a periodic basis; however, the other components of the turbine are rated at 50 years.



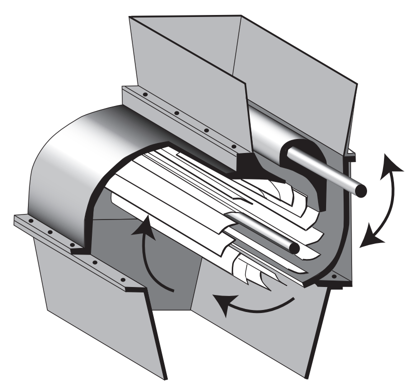
Frances Turbine

Cross Flow turbines

The cross flow turbine is usually considered a high head unit, but there are models that have been designed for heads from 3 to 10 feet.

Cross flow turbines are often mistaken as a cross between an impulse and reaction turbine. However, this is not the case. Cross flow turbines employ a sheet of water that crosses the turbine and turns the turbine blades, then exits from the other side from which it entered. (This method is in contrast to using channeled water from a nozzle to provide the energy.)

Viewed from the end, the process could be explained as water entering at the 9:00 o’clock area, crossing the center of the turbine, then exiting at 4:00 o’clock. This method of entry and escape is what gives the turbine the name of “cross flow.”



Crossflow Turbine

Using Converted Pumps as Turbines (PATs)

There are finished turbines, kits, and home plans designed on reversing the action of a conventional pump and using it to produce energy. In fact, a centrifugal pump closely resembles a Frances Turbine in appearance. However, the efficiency of a converted pump is suspect, especially since the components are not designed to adjust to variations in head and flow. There is significant guesswork in determining output based on the pump and its design variables, and often the decrease in performance is higher than any initial cost savings.

Using Converted Water Wheels as Turbines

Montana's mining and agricultural past utilized water wheels for a variety of mechanical operations. Some consumers entertain transforming these units into electrical turbines, and DIY sources have a number of plans to either facilitate conversion or build an electricity generating waterwheel "from scratch."

Although they are much more inefficient than turbines designed specifically for electricity production, they can be modified to produce power for domestic use.

In order to generate electricity, water wheels need to incorporate a high-ratio gear box and specialized controls to increase speed. This is mechanically possible, but micro-hydro experts agree that necessary modifications are usually not "do it yourself." Consumers should also consider that water wheels cannot be operated when ice and freezing conditions are present. This causes both operational problems and potential damage to turbine components.

It is also important to consider that for the vast majority of applications, plans that use water wheels made from components such as wooden cable spools and car parts might work for simple "off-the-grid" purposes, but are not suitable for most consumer applications. They also can be very unsafe.

Portable Turbines

Although the intent of this manual is not micro-hydro generation at remote, off-grid locations, consumers often want to include hydro generation at a cabin or recreation site. There are a variety of portable, in-stream units which are suitable for charging batteries and small loads.

Some portable units can operate on flow as small as 3 gpm. At 120 feet of head, these units will produce between 25 and 75 watts of continuous power. Output on these units can be ordered in 12V, 24V, or 48V DC. Other portable turbines are "ultra" low-head units that can operate on heads from 2-5 feet. These are self-contained systems rated up to one kW. They are lightweight and can be removed in winter or during flood conditions.

Submersible propeller turbines (much like those used to produce power on some ocean vessels) are also available. Models can be purchased that will produce up to 100 watts of power. Water speed of at least 2-4 mph is required.

Micro-hydro Generators

Every micro-hydro system must be able to convert the rotational energy of the turbine into electrical energy. This conversion is accomplished through a connection to a generator. Micro-hydro generators work much like the alternator in an automobile. The terms generator and alternator are interchanged when referring to Alternating Current (AC) electricity.

The process of generator operation is quite basic. When a coil of wire is directed past a magnetic field, electrical voltage is induced. Depending on the AC generator type and size, varying voltages that "alternate" above the zero voltage point are generated, creating the electrical wave patterns required for AC usage.

Synchronous Generators

In commercial hydroelectric operations, synchronous generators are the standard. The name synchronous refers to the fact that the generated frequency is directly related to the shaft speed. In the majority of cases, the turbine unit and generator are factory matched, as the operating characteristics (constant, intermittent) and operating rpm must be compatible and designed for the specific parameters of the system.

Generators used for diesel and other motor generating sets can be used for micro-hydro applications as well. However, common risks include over-speed damage to the motor windings, bearing failure, and inadequate voltage adjustment.

Off-the shelf synchronous generators intended for other uses are not recommended for micro-hydro applications unless significant modifications and engineering controls are in place to prevent common failure points.

Asynchronous Generators

Asynchronous generators (frequently called induction generators) are the most common generators used for micro-hydro systems. They have the advantage of being more durable and less expensive than synchronous generators. They also can withstand 100% over-speed.

In a grid-connected system, induction generators work well. In stand-alone systems, there are sometimes issues with their ability to supply the high start-up load required by motors and appliances. The addition of voltage and frequency controllers can help solve the induction type loads. Systems up to 50 kW have been successfully installed, and they perform well as an AC supply source with the use of an induction generator/controller.

Efficiency Factors

Generator efficiency losses can be significant in a micro-hydro system. As a general rule, larger generators are more efficient, and three-phase units are more efficient than single-phase. Synchronous generators are typically 75-90% efficient at full-load. Efficiency is reduced by several points at part-load. Induction generators are approximately 75-95% efficient at full-load and efficiency can drop to 65-85% at part-load.

Drive Systems

To transform the power from the generator into usable electrical power, the turbine must be connected to the generator. This connection is termed the drive system. It typically contains the turbine and generator shafts, couplings, bearings, pulleys, belts and other components. The function of the drive system is to provide the correct directional power (at the optimal speed) from the turbine to the generator.

Most packaged micro-hydro systems have engineered and matched turbines, drive systems, and generators; however, especially in custom or larger systems, the drive system and generator may be of a design and construction not included or often used with the turbine. The design and construction of drive systems are varied. For the purposes of the manual, a basic overview of the common drive systems will be included.

Direct Drive Systems

Direct coupled drives are compact, low cost and nearly 100% efficient if engineered and matched correctly. In a direct coupled system, the turbine and generator are mounted on a common base and the shaft is adjusted to the same height using flexible couplings and packing.

In some cases, a gearbox is added to optimize the speed required by the generator. In other designs, the generator is designed to run at the same speed as the turbine. Direct drives are quite easy to service, and they do not need excessive maintenance or adjustment when installed properly.

The most common problem with direct drive couplings is angular or positional misalignments, or a combination of both. To help alleviate these problems, flexible couplings, preferably “two-piece,” are used.

Belt Drive Systems

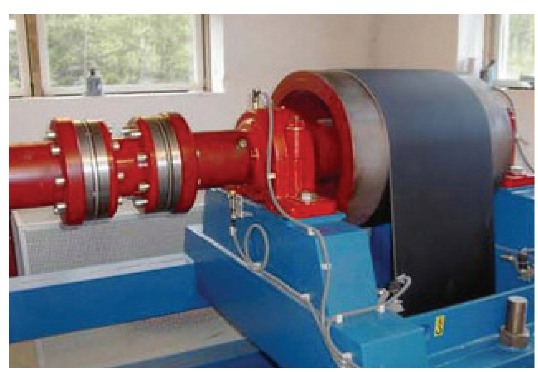
Belt drives allow for the turbine and generator to run at different speeds, optimizing the performance of both through the use of proper design and components. A common practice is to use a belt drive system to connect a less expensive turbine with a smaller diameter to a larger generator. Also, belt drive systems are sometimes used to “gear” older, recycled turbines, (originally designed for lower speed “mechanical” tasks), to instead generate electricity.

Direct Drive Coupling

Micro-hydro manufacturers rate the efficiency of engineered, packaged belt drive systems at up to 98%. It is important to consider that belt drives work by friction. The belt is gripped by the driving pulley on the turbine and then turns the driven pulley. The “grip” on the belt is a combination of the tension of the belt and the coefficient of friction between the belt and pulleys. In order for the grip to be optimum, several factors must be present.

The first factor for optimal efficiency is arranging the shafts to be parallel, although they may be mounted at different heights. Though there are some systems that have a “quarter turn” design where the turbine shaft is mounted vertically, there is increased potential for maintenance problems and efficiency loss.

The second consideration for maximum efficiency is that the belts must be aligned and tensioned properly, and a formal maintenance schedule must be in place. Pulleys and bearings must also be sized correctly and maintained.



Belt Drive Coupling

Electronic Load Controllers

One of the breakthroughs in the micro-hydro industry has been the introduction of electronic load controllers (ELCs) for synchronous generators. ELCs prevent variations in generator frequency due to changing loads. Before ELCs, mechanical governors were required; however, they were costly and led to premature generator failure in many cases.

The basic concept of ELCs is to use electronic components and switching to maintain a consistent load on the turbine, which, in turn, assures stable frequency. The ELCs monitor the load on the system for variations, and when necessary, dissipate or "dump" excess load into a ballast device such as a water heater.

With the use of ELCs, the flow through the turbine is set at a predetermined level to meet expected electricity requirements. When the load varies, the generator operating characteristics do not change. ELCs can be programmed to handle up to five times the output of the micro-hydro system. In some cases, the "dump" sequence can be pre-determined to provide space heating, pumping, or other functions in a prioritized schematic.

For induction generators, induction generator controllers (IGCs) are utilized. The primary difference between an ELC and an IGC is that an IGC serves as both a load controller and voltage regulator. There are also distributed intelligence load controllers (DILCs) being introduced. These DILCs are attached directly to large loads such as refrigerators and water heaters and function similar to ELCs placed before the main load circuit.

Water Rights

Prior to initiating extensive design and construction, prospective micro-hydro owners should know the Montana Water Rights Laws and take steps to ensure that their planned installation does not violate the statutes. The repercussions for breaking the law are quite clear. Regulatory approval "before construction" in both surface and ground water applications is absolutely necessary.

It is also important to consider that the installation of micro-hydro systems is considered, under the Montana Water Use Act of 1973, as a "beneficial" use of either surface or ground water. Therefore, depending on the specifics and size of the installation, either a permit to appropriate water or the filing of a Notice of Completion of Ground Water Development (for wells under 35 gpm) must be in place for the issuance of a Certificate of Water Right. Without one of these, installation and operation of the system is illegal.

What are Water Rights?

The Montana Constitution states in Article IX, section 3(3) that "all surface, underground, flood, and atmospheric waters within the boundaries of the state are the property of the state for the use of its people."

A water right is considered a "property right." However, just because a stream or aquifer exists on a property, does NOT guarantee the owner has permission to use the water. Rather, the State grants that owner the privilege through water rights which are derived from laws, regulations and history for specific water sources.

Prior Appropriation

Like most western states, Montana water rights are guided by the doctrine of "prior appropriation." Prior appropriation dictates that the "senior" holder on a specific source has the right to use their complete appropriation before the next person "in line." In times of drought or low water, there is no system in place for proportioning water among all rights holders on a specific source.

Some water rights in Montana have been in existence for nearly 150 years. Prospective micro-hydro owners should understand that a right for a determined amount of flow can be impacted by use of a source by more senior holders.

"First in Time, First in Line" is a valid concern given the source's upstream uses in conjunction with weather patterns and seasonal conditions.

Water Rights Laws Help Prevent
Adverse Impacts During Drought Conditions

Beneficial Use

Prior to 1973, "beneficial use" of water sources in Montana included agriculture, mining, industry, and municipal rights. The Montana Water Quality Act of 1973 expanded the definition of beneficial use to include water quality, recreation and the protection of fisheries and habitat. For those wishing to install micro-hydro, these expanded "beneficial uses" are important to consider.

It is also critical to understand that for the issued water right to remain valid, the system must be in use. The water cannot simply be diverted without being put to its intended use. There have also been recent claims and court proceedings where land owners challenge upstream users regarding diversion in agricultural applications. With micro-hydro installations, the potential for similar challenges is possible.

Use Changes for Existing Water Rights

Prior to 1973, landowners did not need approval from the Montana Department of Natural Resources and Conservation (DNRC) for changes on existing water rights including the place of diversion, purpose of the use, or place of the use. This resulted in lawsuits from other users who were adversely impacted by the changes. The issue was addressed by State lawmakers in the early 1970s.

The Montana Water Quality Act of 1973 now demands prior approval before construction if an existing water rights holder wants to change any of the following: the point of diversion, the place of use, the purpose of use, or the place of storage.


Unused Water Resource/Right

Applicants may make these approved changes on the amount of water historically diverted; however, there are additional responsibilities. It is up to the holder seeking modification to prove that the proposed changes will not impact other users. This process may become complicated, possibly requiring hydrological studies. There is a chance that downstream users may challenge the application, based on predictions of more water usage with the modification compared to what was historically used.

Micro-hydro installations may also require changes to the diversion point on an existing structure. The extent of the changes and legal ramifications should be included when contacting the DNRC. There are some circumstances where a "Change in Water Use" application may not be required, and instead a "Replacement Point of Diversion" is warranted, which does not require prior DNRC approval. However, it is always a good idea to contact the DNRC first.

Changes in water use and navigating water rights can be tricky. Micro-hydro contractors and realtors are usually not water rights experts. No matter the potential and practicality of a planned system, the initial considerations should always involve the proper research, permitting and adherence to Montana Code.

Does Diversion Require a Water Right?

A common misconception by consumers is that water removed from a source like a river or creek and then returned downstream does not require a water right.

Montana law considers water used for consumption, diversion, or impoundment as requiring legal water rights, even if it is returned directly into the source. This is especially critical when considering water quality and environmental impacts in reducing stream flows (even temporarily).


Popular DIY "In-stream" Design

A somewhat related misconception is that a portable or temporary micro-hydro system placed "in-stream" is exempt from State statutes and regulation. There are several DIY "in-stream" designs (usually from 3-10 kW) that are popular in areas outside of Montana, but would constitute both water rights and possible water quality violations if placed within the State.

Contacting the DNRC

There are a variety of useful water rights resources, searches and forms available at the Montana DNRC website. Phone numbers for regional offices are also listed on the site. It can be accessed at dnrc.mt.gov/divisions. The division link is labeled "Water Resources."

Notes

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The Montana Consumer Guide to Micro-hydro Systems