# E3A: Micro-hydropower for the Home, Farm, or Ranch

Author: Geiger, Milton; Sarah Hamlen and Mike Vogel, eds. E3A Program

## Steps in the Micro-hydro Series

1. Understand Micro-hydro
2. Site Assessment
3. Equipment/Installer Selection and Costs
4. Regulations


Hydropower station.
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## Introduction

Ever-expanding interest in renewable energy systems, from small wind to solar, has led to a renewed interest in one of the oldest and most established types of renewable energy: hydropower. When most people think of hydropower, they imagine the Hoover Dam or other large-scale installations. Hydroelectricity can also work on a much smaller scale. This module focuses on micro-hydroelectricity (micro-hydro), designed for homeowners and agricultural operators to reduce purchased electricity use, much like a small wind or solar electric system

### 1. Do you have access to flowing water on your property?

Although a total drop (head) of as little as three feet can be utilized for a micro-hydropower system, generally a high volume of flow or a head of at least 10 feet are required for a viable system.

☐ Yes — Move to question #2

☐ No — Consider other renewable energy technologies such as wind energy or photovoltaics (PV) for your property. If you are not sure about how much head your resource has, consult the “Site Assessment” module.

☐ Uncertain — Read on to learn more!

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**2. Does the water resource have adequate flow?**

Although low and seasonal (e.g. irrigation) flows can be utilized, the greater the flow the better.

- ☐ Yes — Move to question #3
- ☐ No — Consult the "Site assessment" module to help better estimate your resources, and if it is too small, then consider other renewable energy sources.
- ☐ Uncertain — Read on to learn more!

**3. Do you have the legal right to utilize the water?**

Under strong Western water laws, simply having water crossing your property does not give the landowner the right to utilize it.

- ☐ Yes — Move to question #4
- ☐ No — You still may be able to proceed, but you will need to consult your state engineer's office about obtaining a "non-consumptive" use permit.
- ☐ Uncertain — Read on to learn more!

**4. Do you have an electric load within one mile of the resource?**

The closer the electric load, such as a home or irrigation system, to the hydroelectric resource, the lower the cost and greater the efficiency.

- ☐ Yes — Move to question #5
- ☐ No — You still may be able to proceed, but you will need to more closely evaluate economic feasibility.
- ☐ Uncertain — Read on to learn more!

**5. Are you willing to invest money and some maintenance time into a system to generate electricity for your home, farm, or ranch?**

Although many micro-hydro systems may present an attractive financial return, especially where they use existing infrastructure such as irrigation civil works, micro-hydropower receives relatively few financial incentives and does require some maintenance.

- ☐ Yes — Let's get started learning more.
- ☐ No — Consider lower cost projects such as energy efficiency improvements.
- ☐ Uncertain — Read on to learn more!

## Notes

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STEP 1

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## Steps in the Micro-hydro Series



## Understanding Micro-hydro

The generation of electricity from falling water is generally divided into three broad categories:

- Large hydro – Greater than 20 megawatts (MW) of capacity
- Small hydro – From 100 kilowatts (kKW) to 20 MW capacity
- Micro-hydro – Under 100 kKW capacity

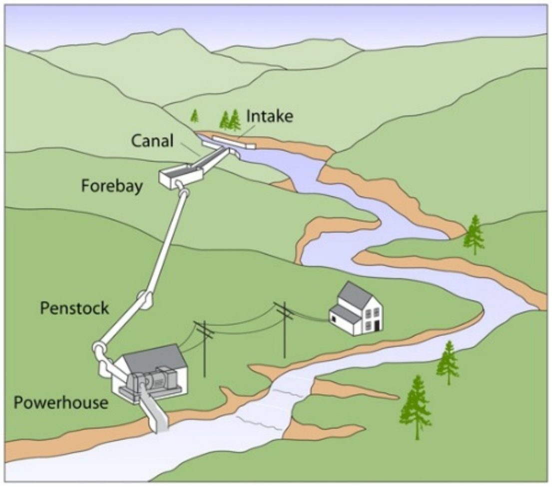
It is important to note that micro-hydro involves a large range of system sizes, from a 50 watt system powering an electric fence to a 100 kW system selling significant quantities of electricity to a utility. Like other renewable energy technologies, micro-hydro can be used as either a grid-connected or a battery-based, off-grid system. This module focuses on micro-hydro systems that are designed to offset home or farm/ranch energy consumption, not the sale of electricity for profit. If you have an interest in larger systems designed to sell electricity for enhanced revenue, please contact your Montana or Wyoming Cooperative Extension Service.

Micro-hydropower resources are also divided into two categories: low-head and high-head systems. Head is a measure of the vertical distance that water falls. Low-head is generally considered anything between 3-40 feet. Obviously, the higher the head, the greater the available energy, so low-head systems generally require more available water (flow) than high-head systems to generate the same amount of energy. The difference will be further discussed in Section 2.

All hydroelectric electric systems are further categorized as impoundment or run-of-the-river systems. Impoundment systems store water for the hydroelectric system. Larger systems typically use this method, as flow can be regulated and maintained at a more consistent level throughout the year. Unless an impoundment already exists for activities such as irrigation, most micro-hydro systems will be run-of-the-river where water is simply diverted from a stream or canal. Run-of-the-river systems typically have much less impact on wildlife habitat, fish passage, water flow, and water quality than impoundment hydroelectric systems.

## Components of a Micro-hydro System

All hydroelectric systems are designed to extract energy from falling water, regardless of the size of the installation. The figure on the right shows the basic components of a system. The intake is typically shielded




A typical hydroelectric system. Courtesy of US DOE EERE
http://energy.gov/energysaver/microhydropower-systems

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with a trash rack, weir, or forebay to prevent debris from entering the pipeline. The pipeline (penstock) carries water under pressure to the turbine (powerhouse), where the energy of the flowing water is converted to electricity. The turbine for a micro-hydro system operates in much the same manner as a wind generator. The “wild” AC power is sent to an inverter, from which standard 110/220 volt, 60 hertz electricity emerges that would commonly be used in homes or other electrical loads.

In essence, a micro hydro systems works just like a wind turbine, except it extracts energy from a denser fluid (water) than a wind turbine (air)!

## Applications of Micro-hydropower

Only a lucky few farmers, ranchers, or homeowners will have access to a quality, micro-hydro resource. Hydroelectric resources are much more site specific and concentrated than solar or even wind energy. Naturally flowing streams, irrigation ditches, and existing pipelines are the most likely locations for a micro-hydro system. Obviously, if you do not have flowing water on your property, then micro-hydro is not for you. For those who have access to the resource flowing water, micro-hydropower can often be the lowest cost source of renewable energy available, so it should not be overlooked. More information on site assessment, selecting equipment, regulatory considerations, cost, and incentives is presented in the following sections.

## References:

Several important resources were heavily used to develop this module, including:


Davis, Scott. *Microhydro: Clean Power from Water*. New Society Publishing. Canada: 2003.

Idaho National Laboratory. Hydropower Program. Available at < http://hydropower.inel.gov/>.

Kindberg, Leif. *Micro-Hydro Power: A Beginners Guide to Design and Installation*. National Sustainable Agriculture Information Service. February 2011. Available at < http://attra.ncat.org/attra-pub/farm_energy/hydropower.html>.

Northeast Regional Agricultural Engineering Service – University of West Virginia Cooperative Extension Service. *Small Hydroelectric Plants*. EPP-13.ON: FS 13: 1978. Available at <http://www.wvu.edu/~exten/infores/pubs/ageng/epp13.pdf>.

United States Department of Energy: Energy Efficiency and Renewable Energy. *Small Hydropower Systems*. DOE/GO-102001-1173: July 2001.


## Notes

STEP 2

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## Steps in the Micro-hydro Series



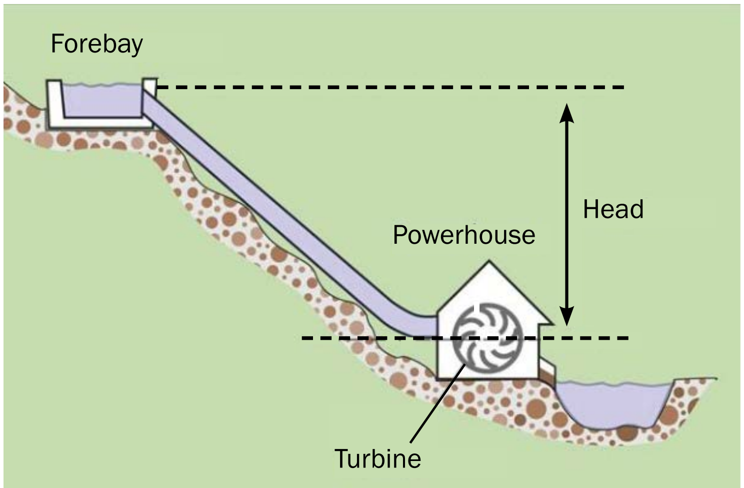


## Site Assessment

Montana and Wyoming are fortunate to possess the two important pieces of a viable hydropower resource: water and elevation. Although both states often suffer from drought, many of our water resource come from perennial high elevation resources, which creates an opportunity to harvest clean energy from falling water. The scarce nature of developable hydropower resources means that landowners need to understand the two important characteristics of a hydropower resources: head (elevation) and flow (water).

## Determining Head

Basically, head is the vertical distance that water falls. It is important to note that head is not a measure of the horizontal length of a pipeline (penstock). Only the vertical distance influences available energy. (Longer pipelines can actually reduce available energy through friction loss). The greater the head, the more energy available. The figure on the right illustrates the importance of vertical drop.




Determining head: the vertical distance between the intake and the powerhouse.
Source: US DOE http://energy.gov/energysaver/planning-microhydropower-system

It is also important to understand the difference between gross head and net head. Gross head is the total vertical distance between the intake and turbine. The gross head is reduced over the length of the penstock by friction and turbulence loss. Standard friction loss tables, often used for irrigation calculations, can provide more precise calculations. Friction loss is often 20 percent of gross head.[1]

Measuring head can be a difficult task for landowners. The services of a professional surveyor or engineer may be required. A U.S. Geologic Survey topographic map can be used to approximate the available head, as can an altimeter or GPS unit. These will provide rough estimates of available head. Several more precise methods can also be used by the more intrepid landowner seeking to estimate head, including attaching

1 A friction loss table is provided in the referenced Northeast Regional Agricultural Engineering Service – University of West Virginia Cooperative Extension Service publication.

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a graduated pressure gauge to a temporary hose or using a surveyors transit or laser level to estimate head. These methods are described in detail in *Micro-Hydro Power: A Beginners Guide to Design and Installation* from the National Sustainable Agriculture Information Service.


Photo: USDA https://commons.wikimedia.org/wiki/File:GatedPipe.JPG

**Do you know the pressure on an existing pipeline?**

If you know the available pressure on an existing pipeline, such as a household water or irrigation pipeline, then you also know the head. To covert pounds per square inch (psi) to feet of head, simply multiply by 2.31. For example, 40 psi of pressure would be calculated: 40 x 2.31 = 92.4 feet of head.

## Determining Flow

The other vital component of available energy is the amount of water that is available to be diverted to the penstock. It is important to remember that stream water flows, especially in Montana and Wyoming, are highly regulated and can be quite seasonal. More water is often available in spring and early summer during snowmelt than in late summer. This variation can impact your expected energy production, and it is important to remember that an average flow with great seasonal variation may not be the most accurate measure on which to base the sizing of a micro-hydro system.

Some landowners already know how much water is in an existing canal or pipeline is available to them based upon documents provided as part of a water right. Simple methods can be used to estimate the amount of water available for a micro-hydro system. For example, contact your local irrigation district, water supply, or USDA Natural Resource Conservation Service office to see if they have the flows for the waterway. If these are unavailable, several do-it-yourself methods are possible, including the bucket-and-weir and float methods. The bucket measure is simply diverting the waterway into a bucket of known volume and timing how long it takes to fill. The weir method involves a temporary structure that diverts the water through an opening of known size and depth. A float is then used to measure the velocity of the water that flows through the opening. Once again, the *Micro-Hydro Power: A Beginners Guide to Design and Installation* from the National Sustainable Agriculture Information Service is an excellent resource for a detailed description of these methods

## Calculating Available Energy

Once the head and flow are known, the power available for a micro-hydropower system can be calculated. There are some losses converting the kinetic energy of flowing water into electricity because the efficiency of micro-hydropower turbines is not 100 percent. Accurate calculations need to consider this loss. For most micro-hydropower systems, a rough estimate of 50 percent efficiency is accurate. Therefore for a 53 percent efficient turbine simply multiply net head (feet) by flow (gallons per minute) divided by 10 (a constant that serves as a correction factor). This will provide output in Watts. As an equation:

**(Net head (feet) × Flow (gallons per minute))/10**
**= Power (Watts)**

This equation will give a landowner a good estimate of the amount of power that can be extracted from a hydropower resource.[2]

## Characteristics of a Viable Location

Although any places with flowing water and adequate head can be a viable location for a micro-hydropower system, the following characteristics help to identify some of the "better" locations:

- Adequate head – Although heads as low as three feet can be viably harnessed, sites with at least 10 feet are generally needed to be economically viable.
- Existing civil works – Locations that have existing infrastructure, such as diversions, dams, or penstocks, will often have lower development costs.
- Proximity to a load – Many good micro-hydro locations are located far from buildings or other electric loads. Just like other renewable energy systems, transporting electricity over long distances increases cost and reduces efficiency.

2 If you want more detailed calculations, with known efficiencies, the following equation can be used:
Where: Q = water flow, cubic feet per second
H = Net head, feet
E = efficiency of the micro-hydroelectric plant, percent divided by 100

- Minimal environmental disturbance – Although regulatory constraints will be discussed further in Section 4, it is useful to consider the environmental impacts of your system
- Clearly identified water rights – In both Montana and Wyoming, access to water is controlled by strictly defined water rights. Water flowing across your property does not necessarily give you access to the resource, even for non-consumptive use in a hydroelectric plant.

## "Hydro Prospecting"

In addition to simply knowing the characteristics of waterways and canals on your property, other methods exist that help you identify potential locations for hydroelectric facilities. One of the best is Idaho National Laboratory's Virtual Hydro Prospector. This web-based geographic information system (GIS) resource will let you examine micro-hydropower potential on all naturally flowing waterways across Montana and Wyoming. Please visit http://hydropower.inel.gov to access the tool. You can also contact either Montana or Wyoming Cooperative Extension Service for help using the tool.

## References


Davis, Scott. *Microhydro: Clean Power from Water*. New Society Publishing. Canada: 2003.

Idaho National Laboratory. *Hydropower Program*. Available at http://hydropower.inel.gov.

Kindberg, Leif. *Micro-Hydro Power: A Beginners Guide to Design and Installation*. National Sustainable Agriculture Information Service. February 2011. Available at http://attra.ncat.org/attra-pub/farm_energy/hydropower.html.

Northeast Regional Agricultural Engineering Service – University of West Virginia Cooperative Extension Service. *Small Hydroelectric Plants*. EPP-13.ON: FS 13: 1978. Available at http://www.wvu.edu/~exten/infores/pubs/ageng/epp13.pdf.

United States Department of Energy: Energy Efficiency and Renewable Energy. *Small Hydropower Systems*. DOE/GO-102001-1173: July 2001.


## Notes

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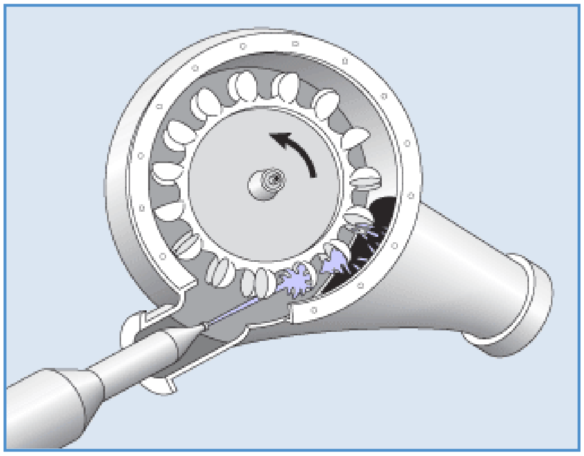
## Selecting Equipment and Installers

Now that you have determined your available resource and the rough viability of a system, it is vital to select the right equipment for your location. Although waterwheels are still available today, almost all micro-hydropower systems use turbines. Turbines turn when moving water strikes turbine blades, which in turn spin a shaft connected to a generator. There are two primary types of turbines used for micro-hydro systems: impulse and reaction. Impulse and reaction turbines have different designs that make them better suited to either high-head or low-head applications.

### Impulse Turbines

Impulse turbines are the most commonly used design for high head systems. This relatively simply design uses the velocity of flowing water to turn a wheel, which is called a runner. The Pelton and Turgo wheel are the most common types of impulse turbines. The photo on the left shows a common Pelton wheel.



A single nozzle Pelton wheel.
Courtesy of DOE http://energy.gov/eere/energybasics/articles/microhydropower-turbine-pump-and-waterwheel-basics

The Turgo is an upgraded version of the Pelton wheel that operates more efficiently under certain conditions, particularly medium heads (50-150 feet). The Turgo wheel is also often less expensive to manufacture than a Pelton wheel. Generally, impulse turbines can operate under low-flow conditions but require a high head.

### Reaction Turbines

Reaction turbines utilize pressure as opposed to velocity to produce energy, and they often have very high efficiencies. Most large-scale hydroelectric projects use reaction turbines, but they can be used in low-head micro-hydro applications. Due to cost, reaction turbines are less commonly utilized than impulse turbines for micro-hydro installations.

## Micro-hydro – Cost and Incentives

In the right location, micro-hydro has the potential to be a low cost source of renewable energy. The unique nature of each individual hydroelectric resource means that it is difficult to provide estimates for the cost of systems. For example, low-head systems are generally more expensive than more common high-head systems. Also, some landowners may already have the civil works, such as a diversion or penstock already installed for other purposes. A rough estimate of costs is provided in the Table 1.

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### Micro-hydro system costs

| Table 1: AC-Direct system installed by a contractor | | | |
|---|---|---|---|
| System Size | 100 Watt (flow rate of 63 gpm; head of 16 ft.) | 400 Watt (flow rate of 63 gpm; head of 80 ft.) | 3.5 kW (flow rate of 222 gpm; head of 163 feet) |
| Component | | | |
| Intake | $1,200 | $1,200 | $1,500 |
| Penstock | $2,000 | $2,00 | $4,000 |
| Turbine-generator | $2,300 | $1,500 | $2,500 |
| Controller | $350 | $350 | $650 |
| Transmission line | $300 | $400 | $1,500 |
| Powerhouse | $1,500 | $1,500 | $2,500 |
| Miscellaneous | $4,400 | $4,500 | $4,800 |
| Total cost of equipment | $12,050 | $11,450 | $17,450 |
| Installation cost | $3,000 | $3,000 | $4,000 |
| Cost/Watt | $150.50 | $36.13 | $6.13 |
| **Total Cost** | **$15,050** | **$14,450** | **$21, 450** |

Estimates provided by Ken Gardner, Gardner Engineering from Kindberg, Leif. Micro-Hydro Power: A Beginners Guide to Design and Installation. National Sustainable Agriculture Information Service. February 2011. Available at http://attra.ncat.org/attra-pub/farm_energy/hydropower.html.

### Incentives

Unfortunately, micro-hydroelectric systems are not eligible for many of the same financial incentives as other renewable energy systems. The federal government provides relatively few incentives for micro-hydro, but local utilities and states may have some incentives. In Montana and Wyoming, state incentives can include property tax and/or sales tax exemptions.

Federal incentives as of 2011 include the following:

- Renewable Electricity Production Tax Credit – Available to qualified hydroelectric facilities that offer electricity for sale. Under current law, systems need to be in-service by December 31, 2013 to receive a 1.1¢/kWh tax credit for the first 10 years of production. Generally most practical for larger micro-hydro or small hydro installations.
- USDA Rural Development Rural Energy for America Program (REAP) – Offers 25% grants up to $500,000 and options for guaranteed loans for hydroelectric projects. The program is only available to agricultural producers and small businesses when electricity is not supplied to a residence.

## References:

Davis, Scott. *Microhydro: Clean Power from Water*. New Society Publishing. Canada: 2003.

Kindberg, Leif. *Micro-Hydro Power: A Beginners Guide to Design and Installation*. National Sustainable Agriculture Information Service. February 2011. Available at http://attra.ncat.org/attra-pub/farm_energy/hydropower.html.

Northeast Regional Agricultural Engineering Service – University of West Virginia Cooperative Extension Service. *Small Hydroelectric Plants*. EPP-13.ON: FS 13: 1978. Available at http://www.wvu.edu/~exten/infores/pubs/ageng/epp13.pdf.

United States Department of Energy: Energy Efficiency and Renewable Energy. *Small Hydropower Systems*. DOE/GO-102001-1173: July 2001.

STEP 4

## Steps in the Micro-hydro Series



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Photo: Digitalpilgrim (Own work) CC BY-SA 3.0 https://commons.wikimedia.org/wiki/File:Occum_Hydroelectric_Plant_and_Dam.JPG, via Wikimedia Commons

## Regulatory Considerations

The use of water in the West is often a contentious issue. The installation of micro-hydro systems reflects this concern through a heavy regulatory burden relative to other renewable energy technologies. Any new micro-hydropower facility is subject regulatory approval concerning surface water rights and quality in both Wyoming and Montana. Efforts are ongoing to reduce the regulatory burden, but there are several important steps to licensing.

- **Establish water right** – Simply having water flowing through your property does not necessarily mean that you have the right to use it, even for a non-consumptive use such as hydropower. Contact your state or county engineer, to verify your right to use the water without altering the benefits for users with more senior access rights.
- **Federal Energy Regulatory Commission (FERC)** – All grid-connected non-federal hydroelectric facilities, regardless of size, must receive the approval of FERC. In an effort to reduce regulatory burden, FERC's Small/Low-Impact Hydropower Program allows micro-hydro facilities to apply for an exemption. The exemption is available to projects under 5 MW that use an existing dam or conduit. As opposed

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to receiving a license, which must be renewed every 30-50 years, an exemption is generally issued in perpetuity. The FERC process may also require you to seek approval from other agencies, such as fish and wildlife, historic preservation, and U.S. Corps of Engineers.

In addition, you will need to complete other steps associated with the installation of electricity generating renewable energy systems, such as utility interconnection, inspections, and county construction permits. Although there are many variables, the entire process can take from 3-24 or more months, so it is important to start early in the project development process.

## Reference

For additional licensing information, visit FERC's website at http://www.ferc.gov/industries/hydropower.asp.

## Notes