Microhydropower

[STRATEGY]

Brief Description

Hydropower presents a means of producing electricity without the use of fossil fuels. In any flow of fluid, energy is present in the form of pressure and flowrate. Hydropower relies upon turbines that have been hydraulically designed to respond to the pressure (referred to as 'head') and flowrate of a stream of water. Microhydropower refers to hydropower installations with capacity of less than 100 kW. Such installations, if applied under the right conditions, offer a clean alternative energy source.

Design Notes

COMMON TERMINOLOGY

- Flow(rate) – flowrate refers to the volumetric flow of water in a given stream or through a given conduit. Flowrates for a given waterway may be found from a variety of sources, such as the United States Geologic Survey (USGS) and the Corps Water Management System (CWMS).

- Head - the pressure aspect of hydropower is commonly referred to in terms of feet of water ('head'), or the difference in free surface elevation between the upstream (forebay) and downstream (tailwater) sides of a dam or small pond.

- Energy – the capacity to perform work. Energy comes in several forms – potential, kinetic, chemical, nuclear, electrical; in the case of microhydro, the goal is to use turbines to extract the potential and kinetic energy of the water and convert it to electrical energy for consumption. The most commonly used unit of energy for this application is kilowatt-hours (kWh).

- Power – the rate of energy flow or the quantity of energy produced per unit-time. The most common unit of power for this application is kilowatts (kW). A 50-kW microhydropower turbine is capable of producing energy at a rate of 50 kWh per hour.

CATEGORIES OF HYDROTURBINES

There are two basic categories of hydro installation: closed conduit and open channel.

OPEN CHANNEL microhydro turbines include the following types and would be applicable under the following generalized site characteristics:

- Hydrokinetic turbines – turbines arranged in open streams, driven only by the velocity of the stream.

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- Archimedes screw turbines – unlike hydrokinetic turbines, Archimedes screws are designed to utilize a site with some change in head. Archimedes screws, as shown in image (a) on the following page, rely on the installation of an open chute. In operation, they rotate slowly and require a gear box to step up the rotational speed of the generator.

(a) Archimedes Screw[1]

(b) Hydrokinetic free-flowing river application[2]

(c) Hydrokinetic canal application[2]

CLOSED CONDUIT hydroturbines are those that feature a pressurized passageway to deliver flow to the turbine. These passageways or conduits are commonly known as penstocks, but for small scale applications, common diameters of piping may suffice. Closed conduit turbines would be applicable under the following generalized site characteristics: a dam with a discharge pipe, a pipe with a pressure reducing valve, or a pipe with an elevation drop, such as near a waterfall or at an outfall from a water treatment facility. Closed conduit hydroturbines may be subcategorized into reaction and impulse turbines:

- Reaction turbines – Francis, Kaplan, fixed-blade axial flow (propeller) turbines, crossflow, pumps-as-turbines, and various novel designs for microhydro applications. Reaction turbines are subjected to pressurized flow.
- Impulse turbines – Pelton, Turgo wheels. Impulse turbines utilize nozzles which convert the pressure (potential) component of the energy of a stream into velocity

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(kinetic) energy. An impulse turbine then captures the kinetic energy of the stream emerging from the nozzle(s).

(d) Ossberger Crossflow[3]

(e) Voith StreamDiver[4]

SITE SCREENING

These design notes address the considerations necessary to evaluate a site's suitability for microhydro. These 'site evaluation considerations' may be employed as the initial step of a feasibility analysis. The following subsections will detail the necessary site evaluations, but as a general roadmap to the evaluation process, consider the following:

1. Army or USACE installation identifies and screens a potential site
2. Installation contacts relevant USACE District for scoping discussion
3. Scoping discussion and additional screening determine the next steps
    - At this point, the USACE District may consider engaging the USACE Hydroelectric Design Center (HDC). HDC is the mandatory center of expertise performing planning, engineering and design, maintaining expertise, and developing standards for USACE hydroelectric facilities and large pumping plants. In regards to microhydro, HDC can advise on generation capability, economic analysis, hydropower planning, engineering and design, powerhouse equipment selection, data acquisition and control systems, support for construction and operations, and development of plans and specifications.
4. If the potential site continues to show merit for microhydro potential, move forward with the project process, including management by a team that is:
    - Lead by a District Project Manager
    - Staffed by a multi-disciplined team
    - Guided by multiple points of 'go/no-go' decisions

The following sub-sections address the additional considerations necessary for site screening.

RULE-OF-THUMB SITE ATTRIBUTES

There are many factors that may determine the suitability of a site for the installation of microhydro. The initial screening for site suitability must include an analysis of both technical feasibility (does the site have flow and head characteristics conducive to development?) and installation feasibility (does the site have existing infrastructure to facilitate the addition of microhydro, or would extensive civil work be necessary to make it possible?). Without a complementary combination of head, flow, constructability, and operability, a microhydro inquiry should not proceed to the scoping stage.

GENERAL ATTRIBUTES OF A GOOD SITE

- High head – high head sites (particularly those with significant elevation change in a short distance) provide the opportunity for hydro generation that requires very minimal amounts of flow
- Minimal disruption or intrusion on flowing stream/river – some portion of the flow can be diverted without significantly altering the existing waterway
- An existing dam – existing dams that do not already feature hydro facilities may offer possibilities for microhydro. Of particular note are dams that include an outlet conduit or other auxiliary pipe that is pressurized. Note that the outlet works of dams typically use lined tunnels not designed for pressurized flow. An unused connection for a municipal water system is one example of a pressurized auxiliary pipe sometimes present as an existing feature of a dam
- Close to grid connection point or proximity to load
- Reliable flows – consistent flowrates are a positive attribute, as excessive variation in flow necessitates more complex control mechanisms
- An irrigation canal with sufficient flow – hydrokinetic turbine installations require a minimum cross-section, as well as a minimum water velocity

GENERAL ATTRIBUTES OF A DIFFICULT SITE

- Requires impoundment of a free-flowing stream – redirecting or altering a free-flowing stream requires review by Federal, State, and local environmental authorities, and may not be allowable depending on the nature of the installation
- Requires diverting a substantial amount of flow from a stream – see above
- Large distance to grid connection point or load – the cost of transmission line installation
- Endangered species or migratory fish in the water
- Access is difficult or site is remote
- Dam has existing hydropower or a pending FERC license

THE IDEAL FLUID POWER EQUATION

If a site meets some of the above qualitative criteria, its generation potential can be approximated as a next step. The following equations are expressions of the *ideal* power, *P*, available in a flowing stream of water. The power captured by a hydroturbine generating unit would then be a fraction of these calculated ideals, reflective of the efficiency. 70% is a reasonable assumption, but some microhydro units in the sub-10 kW range may have efficiency values as low as 50%.

$$P = \frac{HQ}{11.8} \qquad P = \frac{Hq}{5305}$$

$$P = \frac{pQ}{5.12} \qquad P = \frac{pq}{2299}$$

Where: P = power in kW *p = pressure in PSI*
H = head in feet (ft) *Q = flowrate in cubic feet per second (CFS)*
q = flowrate in gallons per minute (GPM)

The above equations can be employed as an early screening step in assessing a site's suitability for microhydro, while remaining aware of the additional qualitative assessment factors. For instance, if an existing dam has a pressurized outlet pipe without a designated function, one of the above equations can be used to estimate the possible power available via that pipe.

Conversely, if one were to apply the above equations to a dam that does not feature a pressurized outlet (or some other means of utilizing the gross head differential), the economics of the civil construction will likely overwhelm the benefit of the added generation.

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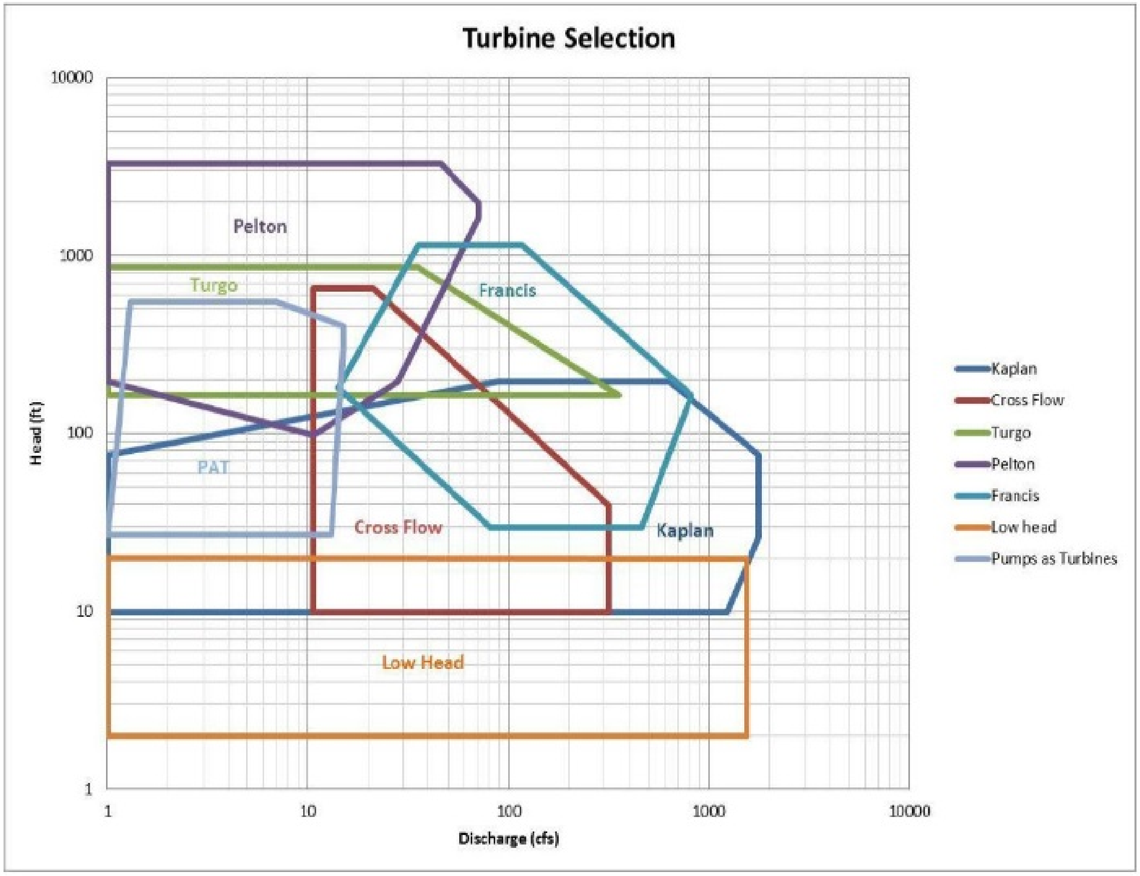
The following figure, "Turbine Selection," shows a variety of common turbine types, and plots the envelopes (ranges) of head and flow across which those turbines are typically applied. For instance, if a site has an average flow of 5 cfs at an average head of 50 ft, a pump-as-turbine (PAT) may be an option. Cornell Pumps is one manufacturer of PAT's. Refer to 'Vendors' under the 'Product and Economics' section, below. Manufacturers create performance curves (power output based on combination of head and flow) for their turbines; these can be found online or requested from the manufacturer.



(f) Turbine application ranges by type, as a function of flow and head range. "Low Head" refers to the novel range of turbines developed specifically for microhydro and employed in conditions with less than 10 feet of head. Note that, in general for the more common turbine types, Kaplan turbines are applied at the lower range of head but across a broad range of flow; Francis turbines utilize slightly higher head and high flow; and Pelton wheels utilize very high head and low flow conditions.

GENERATION AND LOAD

In conjunction with the turbine-specific considerations, site screening (and more in-depth feasibility analyses) must consider how the generation is connected and applied to a load.

One of the simplest arrangements for low power outputs (0-10 kW) is to utilize a DC generator that charges a battery bank. The battery bank in turn could provide DC power or be inverted to AC depending on the desired connection and load.

In general, the generation may be applied in one of the following scenarios:

- Isolated generation supplying isolated load
- Generation connected to the distribution grid
- Generation connected to the grid, plus serving as back-up to an isolated system when the grid goes down

Large scale hydro installations typically utilize direct-drive synchronous generators. For a microhydro installation, direct-drive synchronous generators are expensive and technically complex to install due to the large machine size necessary to achieve operation at synchronous speed given turbine speed requirements. For microhydro, DC, induction, and PMG generators are better suited. Depending upon the speed characteristics of the turbine required and the intended load, some means of modifying the speed of the generator may be necessary. Speed increasers, power electronic converters, and variable speed generators may be options in these cases. In the end, the decision on the type of generator to be used will be a result of analysis of the resource available (amount of power, speed, etc.), the intended load (isolated load, battery charging, grid connected, etc.), and the budget allocated for the project.

ELECTRICAL CONTROLS

Electrical controls are necessary for safe and reliable operation of hydropower units. These control functions may include control of the mechanical operation, control of breakers to properly connect and disconnect the unit from its load or grid connection, monitoring diagnostics for unit function and performance, and ensuring the unit can shut itself off during abnormal conditions via protective controls.

Traditional hydropower features governors that control the supply side of the generation/load system. With microhydro, it is possible to include controls or governors that address the demand side of the equation. In other words, it is possible to either limit

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the load (to batteries, for instance) or introduce a load that dissipates any un-utilizable generation. There are manufacturers of control systems with a focus on microhydro. Beyond balance of the generation and/or load, the following considerations may be included in the control scoping for a microhydro units:

- Protection systems for overspeed events or overheating
- Controls for remote monitoring and operation
- Evaluation of complexity and cost in relation to the extent of control mechanisms
- Analysis of the potential for cybersecurity risks related to the connectivity of control systems

TRANSMISSION AND SWITCHING

Transmission and switching are features that must be evaluated in conjunction with the target load, control mechanism, and turbine unit sizing. If the microhydro generating unit is located at a significant distance from its load or grid connection, site and application conditions may require transformers and transmission lines. To avoid costly transmission equipment, the optimal set of conditions would include:

- The placement of the generating unit adjacent to its load
- Utilizing the generated electricity to charge a battery bank, which in turn supplies electricity to a relatively constant load

NON-TECHNICAL HURDLES TO HYDROPOWER

In addition to the technical aspects of site screening, the following items require consideration:

- Legal authorities for environmental considerations, water usage, property rights, and endangered species protection
- Authorized purposes of facility:
    - Local water rights
    - Flood control
    - Power production – note that in circumstances wherein USACE-owned dams do not already feature grid-connected electrical generation, USACE is prohibited from installing grid-connected generation capacity
    - Navigation
- Permitting:
    - Environmental Protection Agency (EPA)
    - National Environmental Policy Act (NEPA)

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    - Endangered Species Act (ESA)
- Costs of operation and maintenance

IMPLEMENTATION SCHEDULES

- Highly variable depending on site
    - Possibly as short as 6 months
    - More likely 1-3 years; longer if NEPA and EPA permitting is required
- Equipment may be either pre-engineered or custom made
    - For very small (1-3 kW) units, complete off-the-shelf equipment packages are readily available
    - For larger units, very little is off-the-shelf; that equipment which is available off-the-shelf would need to be adaptable to the unique characteristics of a site, and without being optimized to a given site, would be subject to lower efficiencies than a custom-engineered unit

References

1. Source: Western Renewable Energy http://www.westernrenew.co.uk/wre/home
2. Source: Instream Energy Systems https://www.instreamenergy.com/
3. Source: Ossberger http://www.ossberger.de/cms/en/hydro/the-ossberger-turbine-for-asynchronous-and-synchronous-water-plants/
4. Source: Voith http://voith.com/en/products-services/hydropower/streamdiver-55362.html

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Energy Savings

ENERGY SAVINGS

Generation capacity determines energy savings; refer to the power equation presented on page 4. The scale of the installed hydropower capacity contributes directly to reduced consumption of non-renewable energy and to reduced expenditures for commercial electricity consumption (assuming the installation functions in an energy independence role for its parent facility). Site suitability and sizing of a microhydro installation determine the potential for a return on investment (ROI). Where an ROI is not the primary concern, other ancillary benefits may be considered.

THE BENEFIT EQUATION

Total Benefits = Energy Generated – Construction Costs – O&M Costs + Ancillary Benefits

- Engineers can provide analyses of Energy Generated and Construction Costs

- The value of Ancillary Benefits must be identified and quantified with the customer
    - National and Army policy objectives, such as energy security, energy use reduction, and greenhouse gas emission reductions are examples of ancillary benefits

Energy and Environmental Impact

The addition of microhydro generation is beneficial in terms of the pursuit of energy independence and reduced reliance on fossil fuel-based energy sources. However, in the majority of arrangements, hydropower does require some extent of manipulation or redirection of waterways. A hydropower installation's environmental impact must be considered with regards to various federal policy, including the Clean Water Act and Endangered Species Act, as well as state and local policy.

Guideline Principles

NetZero

- The Department of the Army introduced the Net Zero strategy in 2010, laying forth a goal of achieving energy security and sustainability.

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- A "Net Zero Energy Installation" is an installation that produces as much renewable energy onsite as it uses over the course of a year

Low Impact Hydropower Institute (LIHI)

- The Low Impact Hydropower Institute is a non-profit organization that promotes and certifies small scale hydropower installations that have been implemented with an approach that reduces environmental impacts
- Criteria for LIHI certification include:
    - Ecological flow management
    - Water quality protection
    - Fish passage
    - Threatened and endangered species protection
    - Watershed and shoreline protection

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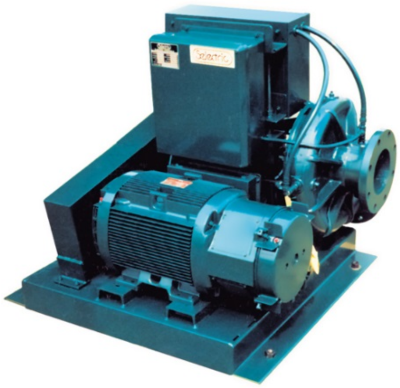
Product images



(i) Cornell skid-mounted pump-as-turbine unit. Cornell PAT's are but one example of small, ready-for-install turbine and generator packages available for less than $20,000. However, costs for the remaining features of an installation may cause the total price to vary widely.

Payback

- It is not common to find a microhydro site that would offer a traditional financial payback; up-front engineering and construction can be expensive – refer to the general characteristics of good sites and bad sites, above
- The cost of engineering, construction, and maintenance of a microhydro system should be compared to the cost of other energy sources:
    - The cost per installed kilowatt capacity of microhydro may vary significantly depending on the site conditions. In instances where microhydro installation is difficult and expensive, solar arrays or wind turbines may offer a more feasible and affordable renewable energy source
- Payback must factor in the contribution of maintenance costs, for both replacement, consumable, and spare parts, as well as labor hours for the staff performing maintenance work.
- The amount of power generated by a microhydro installation contributes to the return on investment calculation by determining the equivalent cost of that electrical energy if simply purchased from the local utility

Vendors

MICROHYDRO SITE SERVICES CONTRACTORS

- Andritz Hydro
- Canyon Hydro
- Mecamidi

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- Toshiba
- Voith
- Western Renewable Energy

MICROHYDRO EQUIPMENT MANUFACTURERS

- Andritz Hydro
- Canyon Hydro
- Cornell Pump
- Gilkes
- Hydrovolts
- Instream Energy Systems
- Lucid Energy
- Mavel
- Mecamidi
- Natel
- Nautilus Water Turbines
- Obermeyer Hydro
- Ossberger
- PowerSpout
- Scott Hydroelectric
- Seabell
- Toshiba
- Voith

Cost Range

Cost is variable depending on the complexity of the site and size of the microhydro turbine generator to be installed. Civil construction work contributes significantly to this variability. For sites that do not require extensive work, a variety of turbine and generator systems in the sub-25 kW range are available for less than $20,000. However, note the overall cost must factor in the installation efforts along with the auxiliary components listed below.

Components

As described in the Design Notes Section, the major subsystems of a microhydro system include:

- Water intake conduit with associated valves
- Turbine
- Generator
- Control system

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- Switchgear and transmission lines, inverters, energy storage systems, and transformers – note that these are expensive components; for example, battery storage equipment with an inverter on the order of 10 kW could $20,000 by itself, while transformers in the 10 kW range may be a few thousand dollars
- Shed or containment (powerhouse) for the generation unit and control panel
- Trash rack and other intake exclusion components - note that the amount of debris present in a stream also contributes to O&M costs and considerations

Microhydropower

[Case Study**]**

Project Location	Neosho River, Burlington, KS
Project Name	John Redmond Dam
Year Built / Time Period of Study	2014 (Study; unbuilt)

Description of Microhydro Project

USACE's Tulsa District (SWT) commissioned a study for the feasibility of a hydropower installation at John Redmond Dam. John Redmond Dam was built as a flood control facility on the Neosho River in southeast Kansas.

John Redmond Dam features three separate discharge conduits capable of handling pressurized flow. Mead and Hunt analyzed John Redmond from the perspective of maximizing electrical output, and providing said output to the local utility. The study indicated that 106 kW was achievable, and an installation of that scale could be installed at John Redmond for $2.3 million. However, two key considerations prevented this project from proceeding:

- USACE is prohibited from adding generation to contribute to the grid from currently non-powered dams
- 106 kW greatly exceeds the onsite electrical power requirements for John Redmond Dam's existing project operations

Technologies Used

Assuming that John Redmond Dam is assessed from the perspective of electrical self-sufficiency versus commercial power production, the project has the capacity to be outfitted with a hydropower unit sized to the onsite needs and installed at a fraction of the $2.3 million estimated for the higher output facility. The following considerations make John Redmond Dam a viable option for the addition of hydropower:

- The existence of unused, pressurized outlet conduits
- The potential powerhouse site is close to a target load to which the generation can be applied
- The downstream end of the pressurized conduits are well situated for the addition of a small powerhouse and its ancillary components
- The site features a minimum sustained flow of 40 cfs

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(j) John Redmond Dam

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Microhydropower

[Case Study**]**

Project Location	Air Force Academy
Project Name	U.S. Air Force Academy – Site Investigation for Potential Hydropower Opportunities
Year Built/ Time Period of Study	2009 (Study; unbuilt)
Description of Microhydro Project	In 2009, Hydropower Specialists from the Corps of Engineers Hydroelectric Design Center met with representatives of the Air Force Academy to investigate and discuss the options for installing Hydroelectric Generating capability at the Air Force Academy. Six different schemes for installing hydropower were discussed, including:

(1) Energy recovery from the potable water supply to the Cadet area (classrooms/dorms/school administrative area)

(2) Energy recovery from the grounds irrigation system

(3) Energy recovery from the Cadet Area wastewater systems

(4) Development of conventional Hydropower generation using water from the Stanley Canyon Dam and Stanley Canyon watershed

(5) Use of non-treated water from Colorado Springs Utility's Tesla Hydropower facility as irrigation water for Academy Grounds

(6) Recovery of energy from the 48 inch and 90 inch potable water mains originating at the McCulloch and Pine Valley water treatment plants.

Most of the proposed schemes were deemed not viable. The basis for this determination included:

- Diversion of water
- Insufficient flowrate

- No available/net pressure available for hydropower generation

Item (5) above, the use of non-treated water from the Tesla Hydropower facility as irrigation water for Academy Ground was the only option deemed a possibility.

The use of the non-treated water from the Tesla facility required further study to address the following:

(1) Cost of obtaining the water from Colorado Springs Utilities

(2) Is there sufficient elevation drop from the Tesla Tailrace to the Academy's irrigation system to make this possible without pumping

(3) Cost of building a pipeline from Tesla to an appropriate termination location on Academy ground

(4) Visual impact of a pipeline

(5) The possibility of assigning the water rights to the Academy's Irrigation Wells over to Colorado Springs Utilities

(6) What to do with the wastewater that is no longer disposed of by irrigation.

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Microhydropower

[Case Study**]**

Project Location	Arden Hills Army Training Site, MN (AHATS)
Project Name	Minnesota Arden Hills Army Training Site Micro-Hydro Groundwater Recovery System – 30% Preliminary Design
Year Built / Time Period of Study	2016 (Study; unbuilt)

Description of Microhydro Project

AHATS is a National Guard facility in Minnesota that features a groundwater treatment facility. The effluent from the treatment process is pumped out from the facility over the course of approximately one mile. The final run of the discharge lines are gravity fed. A study was undertaken by ERDC/CERL, HDC, and others to determine the viability of using that final gravity-fed run to produce approximately 25-30 kW of electrical power.

Following analysis, the plan was suspended based on the following assessments:

- Existing pipes on the gravity-fed run of the discharge are not designed to be pressurized
- Adapting the turbine to handle the cycling of the discharge pumps requires a periodic electrical load demand or complex control and valve scheme
- Electrical transmission will be more costly than other generation sources
- Cost per installed kW of generation capacity exceeds other generation sources
- Requirements for design, construction, and maintenance exceed such requirements for other alternative energy sources of similar capacity

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Photo(s)

(k) The final run of the discharge pipes at the Arden Hills Army Training Site in Minnesota. The proposal was to use the existing pipes, shown above, as penstocks feeding a 25-30 kW hydro turbine.

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