Interim Report - Low Head Turbines

# Exploring the Viability of Low Head Hydro in Colorado's Existing Irrigation Infrastructure

<u>*Interim Report*</u>

*Summary of Available Low Head Turbine Technologies*

***September 2010***

*AG File No. 10-101*


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# INTRODUCTION

Applegate Group, Inc. was awarded a Colorado Department of Agriculture ACRE grant to perform a research study entitled "Exploring the Viability of Low Head Hydro in Colorado's Irrigation Infrastructure". The study will be performed by taking a state-wide look at existing infrastructure and current technologies. This report summarizes the progress of this research study which is approximately 50% complete with a final report anticipated in Spring 2011. The main goals of this study are to research low head hydro turbine technologies, explore interconnection issues, and to quantify the potential of Colorado's irrigation infrastructure to produce low head hydroelectricity. To complete these goals five tasks were identified;

Task 1: Research low head hydropower technologies
Task 2: Inventory the infrastructure available in Colorado for low head hydropower generation
Task 3: Investigate interconnection issues
Task 4: Compare the technologies to the hydraulic structures
Task 5: Estimate a statewide potential

Task 1 has been completed and the result of this research is included in this report. A preliminary overview of interconnection issues is also included. Task 2 is currently in progress; surveys are in the process of being distributed to irrigation providers, and results are being collected. Once the results of Task 2 are compiled, the technologies in this report will be compared with the hydraulic structures described in the surveys. Two "project location" sites will be chosen from the surveys and investigated in more detail. The interconnection issues associated with those sites will be explored, as well as specific turbines and power production estimates. More specifics regarding the applicability of these turbines to site conditions will be included in the final report.

A total of sixteen turbine manufacturers have been identified and are listed in this report. These turbines are either impulse or reaction turbines, including propeller type, a hydroengine, screw type turbines, hydrokinetic turbines and waterwheels. The head and flow ranges of each turbine are mentioned and visually displayed in the attached chart. Contact information including websites and telephone numbers are included for each manufacturer. All of the manufacturers listed in this report have either been responsive to inquiry or have information on their websites.

# GENERAL TURBINE TECHNOLOGIES

## LOW HEAD TURBINES

Generally low head turbines are going to be of the reaction type. The water passing through a *reaction turbine* loses its energy, or pressure, as it passes the turbine blades. The turbine must be encased in a pressurized housing, and fully submerged in water. This is different from an *impulse turbine* which changes the velocity of the water. Water is directed at the blades of an impulse turbine with a high velocity nozzle, and the velocity of the water turns the blades. An impulse turbine can be open to the air, and only needs a casing to control splash. All turbine types can be classified into one of these two groups.

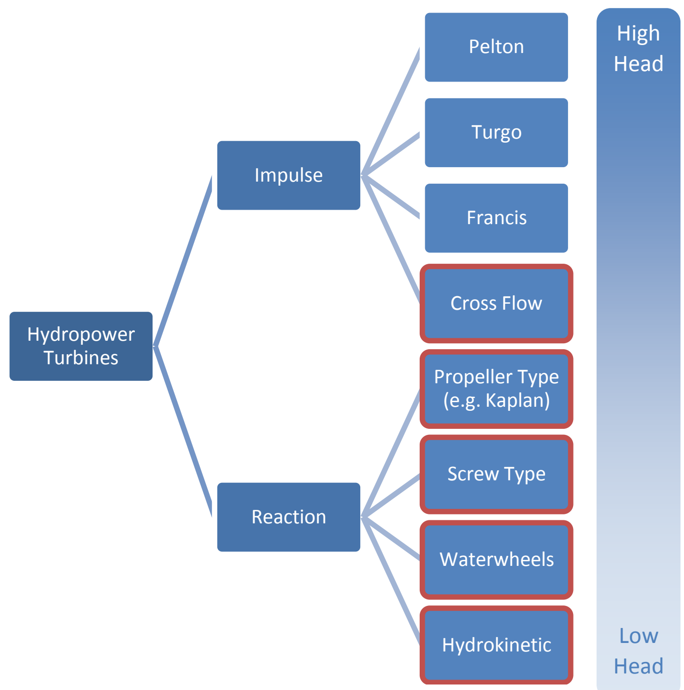



FIGURE 1: TYPES OF HYDROPOWER TURBINES

The turbines are listed from higher head to lower head. The turbines highlighted with red are considered low head turbines, and examples of these turbines are discussed in this report.

## SITE CONDITIONS

The two conditions that are used to choose the appropriate turbine for a site are head and flow rate. The head is measured as the vertical distance between the highest and lowest water surface, minus any losses that occur through that drop (such as pipe friction). The flow rate is a measure of all of the water that will be passing through the turbine. Turbines can generally operate through a range of flow rates, but the size of that range varies with turbine type. Also the efficiency of the turbine lowers as the flow rate varies from the designed flow rate. This is something to consider when choosing a turbine for a site. It is possible that the best turbine may not utilize all of the flow available at high flow, so that the range can also cover the low flow periods. A detailed analysis of the flow over time will need to be performed to choose a turbine that is best suited for a site. The power produced by a site can be estimated using the following equation, where head is in feet and flow is in cubic feet per second.

$$Power = \frac{Head \times Flow}{11.8} \times efficiency$$

This equation can provide an estimate of the power available at a site, either high or low head, but the turbine manufacturer should be contacted regarding the efficiency of a particular turbine, and how that efficiency may vary with flow rate.

## TURBINE SELECTION CHARTS

Turbine selection charts can be used as a starting point to determine which turbine may be applicable to a particular site. The ranges shown are approximate, and the turbine manufacturer should be contacted to verify that the turbine is appropriate for the site's specific conditions. The turbines may operate within the whole range shown, but the efficiency may decrease as you approach the corners or edges of the range. Please use these charts as a starting point and a visual approximatation of the range of turbine applicability. This is also not an exhaustive listing of all turbines available. These are the turbines that we believe will be appropriate in Colorado's irrigation infrastructure for sites in the low head range, between 5 and 30 feet. For clarity the charts have been divided into two subranges.

Details on each of the turbines displayed in the chart are listed in the following section. Also the ranges for individual turbines are explained or displayed in the description.

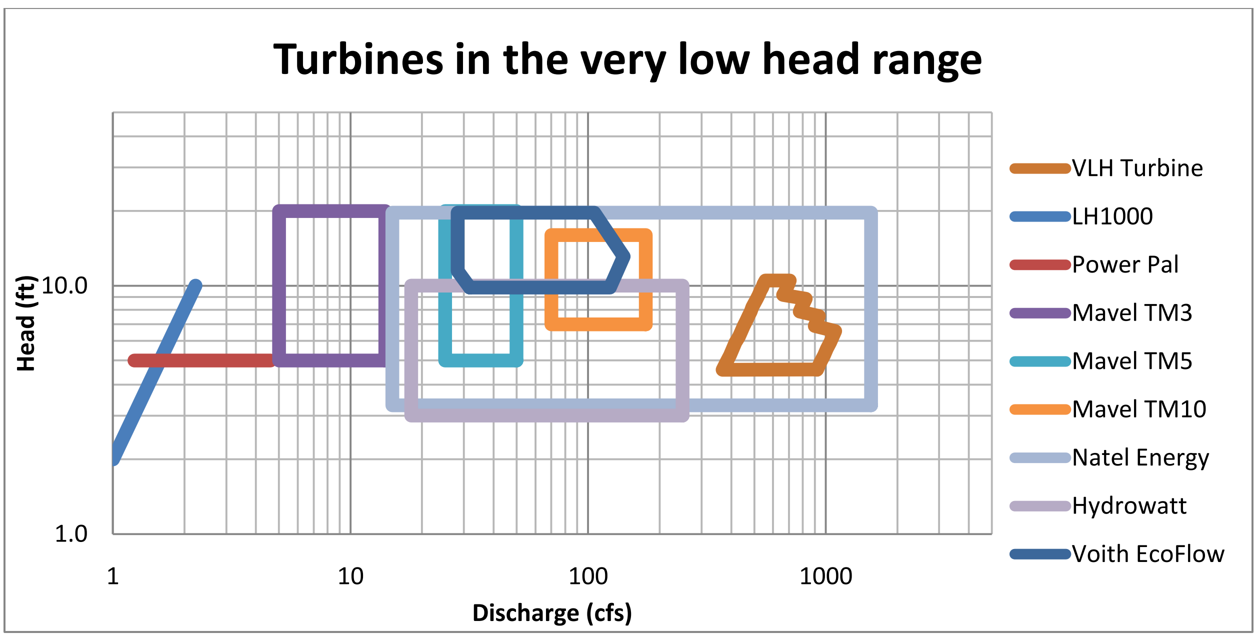



FIGURE 2: VERY LOW HEAD RANGE TURBINE SELECTION CHART

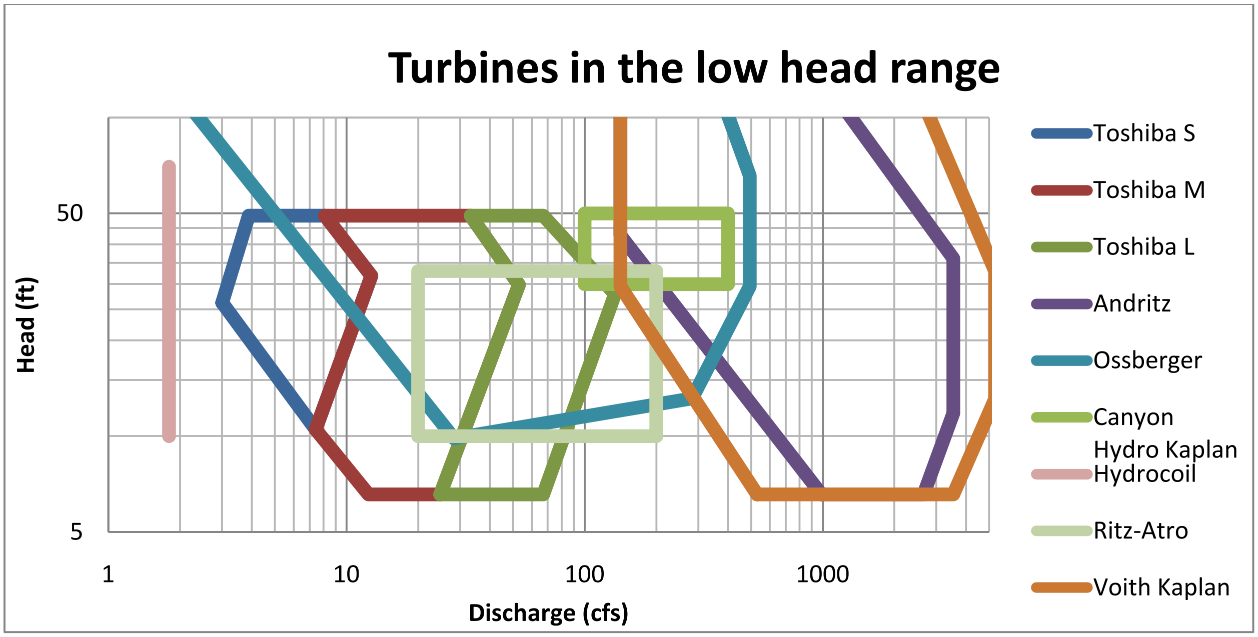



FIGURE 3: LOW HEAD RANGE TURBINE SELECTION CHART

# INTERCONNECTION ISSUES

Pending completion of the project specific site surveys, the project team has not approached Colorado utilities to inventory interconnect challenges for small hydroelectric plants. However, the research on available turbines, coupled with existing knowledge of utility interconnect issues, can highlight interconnect challenges. Interconnection of small generation stations is well understood; there are few significant technical issues. Instead, issues are primarily economic, with technical hurdles tending to increase implementation costs. The following techno-economic topics are discussed in this section:

1) Impact of generator size and type on interconnect process and equipment.
2) Interconnecting to utility service
3) Electricity sales arrangements

## TYPES AND SIZES OF GENERATORS

Figure 4 illustrates the range of possible power outputs for the turbines identified in this report. Each red square represents the lowest quoted size for one turbine type. Each blue diamond represents the largest quoted size. Sizes have been restricted to the size range of likely installations – 5-30 ft of head and 100-1500 cfs of flow. Turbine types outside of this range are not plotted. Since turbine efficiencies are not generally quoted in preliminary information, efficiencies of 70-75% were assumed for all turbine types. Considering these factors, output power is expected to lie between approximately 0.2 KW and 3000 KW in size.

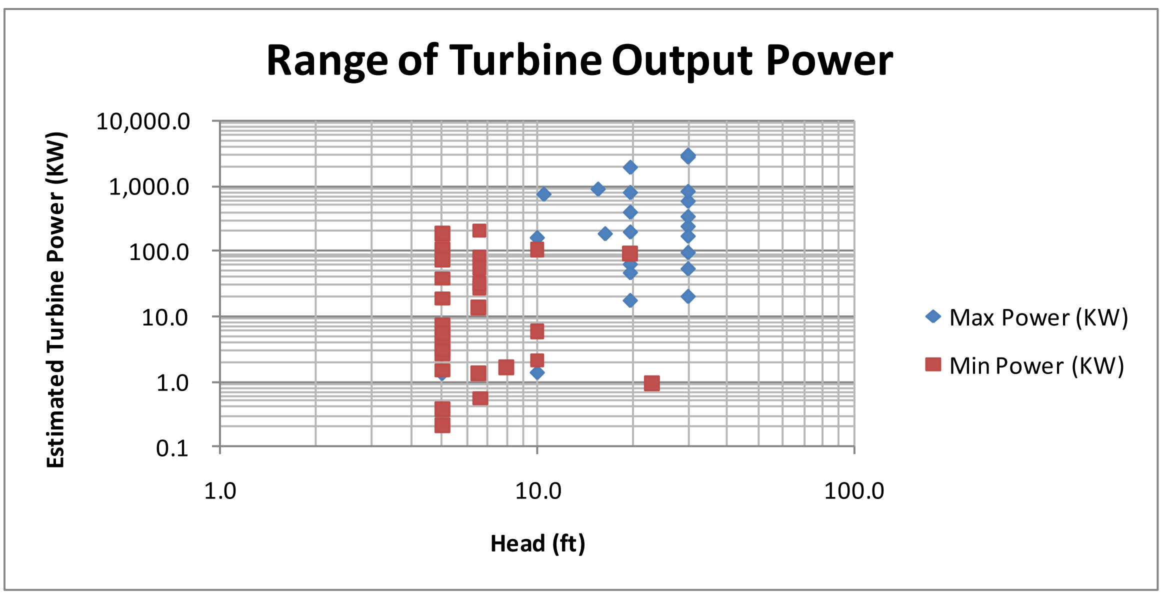



FIGURE 4: ESTIMATED OUTPUT SIZE RESTRICTED TO LIKELY INSTALLATION LOCATIONS

Similar to wind energy, smaller turbines tend to utilize power electronics – typically an inverter or variable-frequency drive – to interconnect with the electrical power system as shown in Figure 5. The inverter/drive provides synchronization with the utility and controls power production. The system controller computes the correct loading on the turbine and generator to maximize power production. While shown as a single-phase connection, power electronics systems can connect to three-phase circuits as well.

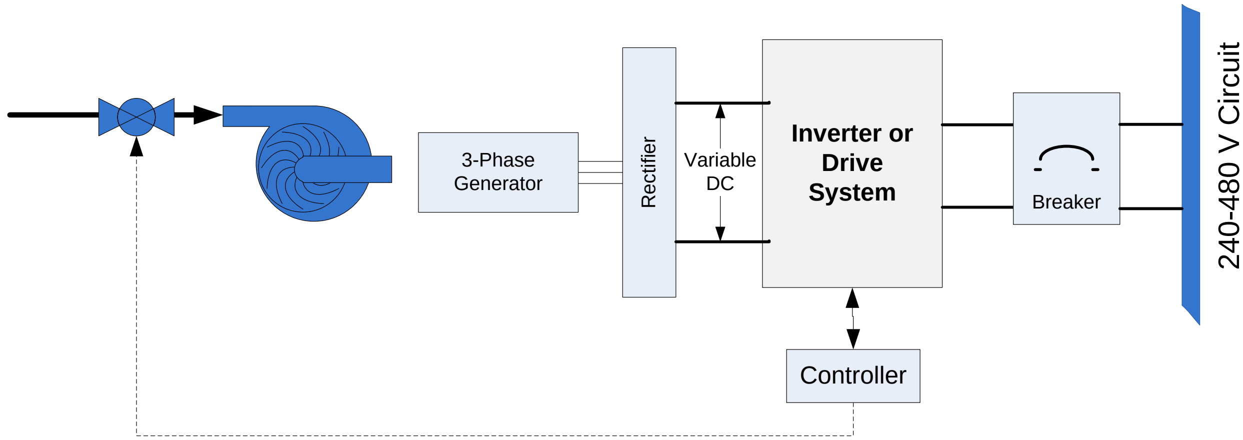



FIGURE 5: TYPICAL INTERCONNECT FOR SMALL TURBINES

Since turbine loading can be controlled electrically through the generator, water flow can, to some extent, be controlled indirectly by adjusting turbine speed. As a result, some designs do not require automatic control of the water flow rate (dotted line in figure), while other designs will require traditional gate control. Most inverter-based systems can operate the turbine at variable speeds, which can provide higher efficiencies at variable flow rates.

Larger turbines typically couple directly to three-phase electrical generators, most often through fixed-ratio shaft couplings, belts or gears. The generators connect directly to the electrical grid, as shown in Figure 6. Direct connection benefits from higher efficiency than the inverter system, but suffers from fewer control options. Since the generator speed is effectively locked to the fixed frequency of the grid, the turbine typically rotates at a constant speed, governed by the gears or belts coupling the generator and turbine. Since speed is fixed, flow control must be provided externally in most cases, either through automatic or manual adjustment of intake gates.

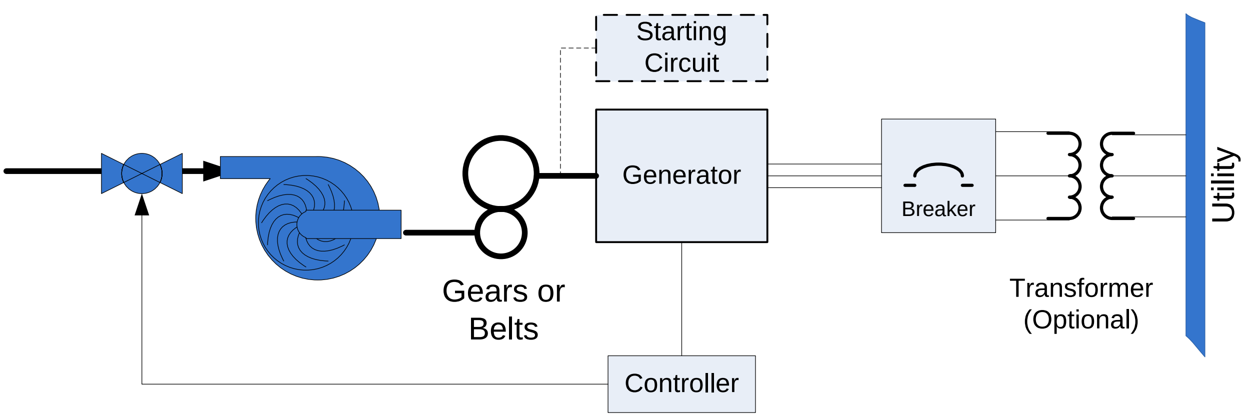



FIGURE 6: TYPICAL INTERCONNECT FOR LARGER TURBINES

Directly coupled systems must also be synchronized to the utility before closing the interconnect breaker. In some cases, a “starting circuit” or starting motor is required. Other systems utilize flow control to adjust the generator speed, bringing the system in synchronization with the utility.

## INTERCONNECT APPROVAL PROCESS

Interconnection processes are governed by two primary factors – size and the type of generator. From a regulatory standpoint, most generator sizes anticipated in this study slot most projects into the "expedited approval" categories currently recognized by the Federal Energy Regulatory Commission [1](FERC) and the Colorado Public Utilities Commission[2] (C-PUC). This should reduce the engineering costs and complexity of generation projects. Two key factors are considered to classify a project for expedited approval – the size of the new project, and the total amount of generation connected on a single feeder (i.e. distribution line from the nearest substation). Given the relatively low penetration of distributed generation in Colorado, it is likely that the project size will be the most important classification criteria. This topic will be further investigated in future stages of this project.

Most distribution utilities (i.e. retail electric utilities) in Colorado have exclusive power purchase agreements with a single generation or generation & transmission (G&T) operator. For example, many rural cooperatives have exclusive provider agreements with Tri-State Transmission and Generation. These agreements often limit the size of individual projects and total amount of power the utilities can purchase from other sources, such as hydroelectric projects. Larger units, e.g. those ≥ 1000 KW, may require "power purchase agreements" directly with the G&T operator. The impact of existing power purchase agreements on small hydroelectric projects will be assessed later in this project, in general for the entire state, and in detail for specific study sites.

The type of generator also impacts certain technical interconnect requirements. The primary driver behind this difference is the "fault current contribution" of the generation system. "Fault current" can be casually described as how much instantaneous current a device produces if there is a fault (e.g. a short circuit) between the device and another part of the grid. Power electronic systems, like inverters, tend to have low fault current contributions. Rotating machines tend to have higher fault current contributions. Therefore, inverter-based systems (Figure 5) typically require limited engineering work prior to interconnect, while rotating machine systems (Figure 6) may require more extensive and expensive simulation studies before the project will be approved. In addition, many utilities now have extensive experience with photovoltaic inverters, leading to additional comfort with inverter-based generation. Therefore, inverter-based systems may reduce interconnection complexity.

Generation equipment must meet applicable standards before utilities will allow interconnection. UL approval is typically required for most systems, although larger, engineered systems may only require UL approval for components, and not on the entire installation. In addition, generation equipment must typically meet additional standards, including:

- IEEE 1547 – governs how generators synchronize with the grid and how they respond if electrical service is lost.

[1] FERC Order No. 2006, *Standardization of Small Generator Interconnection Agreements and Procedures*, USA Federal Energy Regulatory Commission, May 12, 2005.

[2] Colorado Public Utilities Commission, *Code of Colorado Regulations (CCR) 723-3, Part 3, Rules Regulating Electric Utilities,* March 30, 2010.

- IEEE 519 – specifies how "clean" the power output must be from generation equipment. It particularly impacts power electronic systems, such as inverters and variable-frequency drives.

## INTERCONNECTION COST

With few exceptions, the total cost of interconnection must be borne by the generation project. Costs include bringing electric service to the project location, transformers, service entrance, meters and other electrical components, and application and inspection fees. Depending upon the generation type and size, some engineering costs (e.g. fault or protection studies) may also be incurred. Of these costs, extending distribution lines to remote sites is frequently the largest single cost. Generation projects larger than a few kilowatts typically require a new or upgraded connection to a distribution line. Most often, residential or farm service is insufficient for units larger than 20 KW in size, and may be insufficient for generators as small as 5 KW. Extending distribution lines is expensive, and may render remote projects uneconomical, especially for smaller projects. Therefore, ideal projects exist at the intersection of "sites with good hydropower resources" and "sites near sufficient electrical service."

## REVENUE

The value of generated electricity is ultimately governed by where it is used. As a first-level analysis, three cases exist:

1) Electricity utilized where it is generated – i.e. "net metering"
2) Generation facilities smaller than 100KW
3) Generation facilities larger than 100 KW

If the electricity is generated at a facility where electric loads are larger than the generated power, then the power can be utilized locally. Many utilities support the concept of "net metering," where the customer pays only for the "net" of consumption and production. For example, if a 50KW hydropower project is installed at a plant that has an electricity load of 80 KW, then the customer would pay for 30KW – the "net" of 80 KW of usage and 50 KW of production – plus distribution service fees, typically based upon the size of the service or peak demand.

When electricity is "exported" to the grid it is effectively sold to the local utility for re-distribution to other customers. For generation facilities smaller than 100 KW, utilities pay for exported electricity at "avoided cost." The C-PUC defines avoided cost as:

> *"Avoided cost" means the incremental or marginal cost to an electrical utility of electrical energy … [that] the utility would generate itself or would purchase from another source.*

It is important to note that avoided cost does *not* include the capital cost of the utility's or T&G operator's generation equipment. It includes *only* the incremental costs – fuel, operation and maintenance – and does not include capital cost recovery for the construction of the utility's plant and equipment. As a result, avoided costs are often dominated by the fuel costs of the largest, least-expensive power plants, typically coal-fired thermal plants, and can be quite low as a result.

Utilities are obligated to publish fixed tariffs applicable to all generation facilities ≤ 100 KW, reducing the uncertainty in financial calculations. For generation facilities larger than 100 KW, power purchase rates are governed by other contractual vehicles, such as a bid or auction procedure to set power and capacity purchase prices. While utilities are obligated to buy power from projects ≤ 100 KW, they are not obligated to purchase from projects larger than 100 KW; power purchase agreements are a matter for negotiation.

In many cases, hydroelectric projects will also qualify for "renewable energy credits," or other green power incentives, which can contribute substantially to revenue.

## ADDITIONAL COMMENTS

No set rules can be stated at this time regarding the economics of any specific hydropower project. Further investigation during this project will highlight opportunities and issues. However, a few general observations can be made.

First, net metering typically provides the best financial return, since electricity utilized locally represents a direct offset to the owner's utility bill, that is, it is closer to the "total cost" of electricity, versus the "avoided cost" offset paid when exporting power to the utility. However, it is currently unclear if many attractive hydropower sites are properly situated to make net metering effective.

Substantial regulatory changes have recently occurred or are under discussion. These changes generally favor the introduction of small and distributed generation, and are likely to positively impact small renewable power sources, such as hydroelectric power. In addition, renewable portfolio standards, which require utilities to produce energy from renewable resources, are increasing utility interest in, and payments for, renewable energy projects. Many utilities are aggressively pursuing small projects in an effort to meet these standards.

Regarding technical interconnect topics, power electronics continue to fall in price, driven by the rapid growth in photovoltaic systems and use of power electronics for motor drives. Well understood implementations of interconnect standards have also reduced utility concerns about how these systems will behave during power outages. Given reduced prices and simplified interconnect requirements, small power systems are increasingly moving to inverter-based systems. These systems are often easier to operate and remotely monitor than synchronous or induction generators; key attributes for remote sites.

Unfortunately, no similar cost reductions are likely for distribution extensions, transformers or service upgrades. Indeed, copper prices remain high – and highly variable. As a result, service upgrades will likely remain the key cost driver behind electrical interconnection for remote sites.

# IMPULSE TYPE TURBINES

## OSSBERGER - CROSS FLOW TURBINE

PO Box 736
Hayes, VA 23072
1-804-360-7992
hts-inc@hts-inc.com
www.hts-inc.com/ossbergerturbines.html

The Ossberger turbine is a Cross Flow turbine with a patented design that was first manufactured in the 1920's. There are over 9,000 power plants using the Ossberger Turbine. The turbines can be supplied in a varitey of configurations including one or two cells, and horitzonal or vertical. A cross flow turbine is designed to maintain efficiency over a wide range of flow rates. This turbine is supplied by a Hydropower Turbine Systems, Inc. of Virginia.

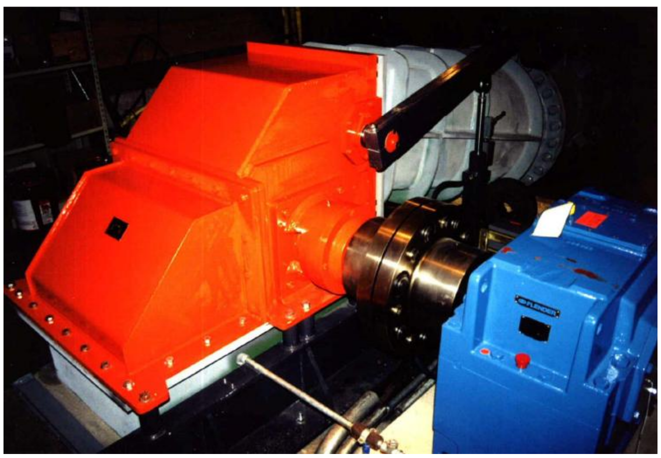


FIGURE 7: OSSBERGER CROSS FLOW TURBINE AT THE MAROON CREEK POWER PLANT, CITY OF ASPEN

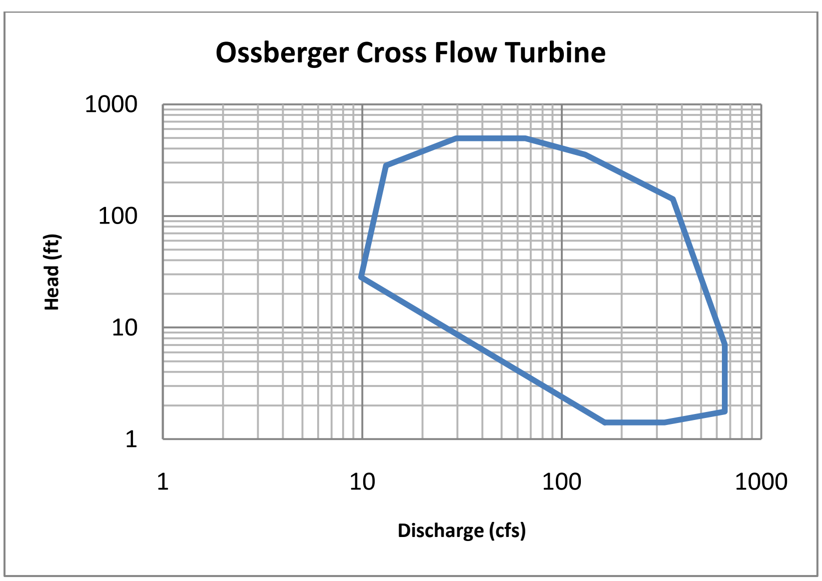



FIGURE 8: RANGE OF SITE CONDITIONS

# REACTION PROPELLER TYPE TURBINES (SMALL)

## ENERGY SYSTEMS AND DESIGN – LH1000

PO Box 4557
Sussex, NB E4E 5L7
506-433-3151
hydropow@nbnet.nb.ca
http://www.microhydropower.com/

The LH1000 is a small propellor type turbine suitable for sites with about 2 cfs, and 10 feet of head. In these conditions one unit will produce 1 kW of DC electricity. The LH1000 uses a permanent magenet alternator. An inverter is utilized for AC systems, and the turbine can be also be used to directly to charge batteries using a charge controller. This turbine can be purchased for between $3,000 and $4,000.

FIGURE 9: TWO LH1000 TURBINES INSTALLED IN A VAULT (ES&D, 2010)

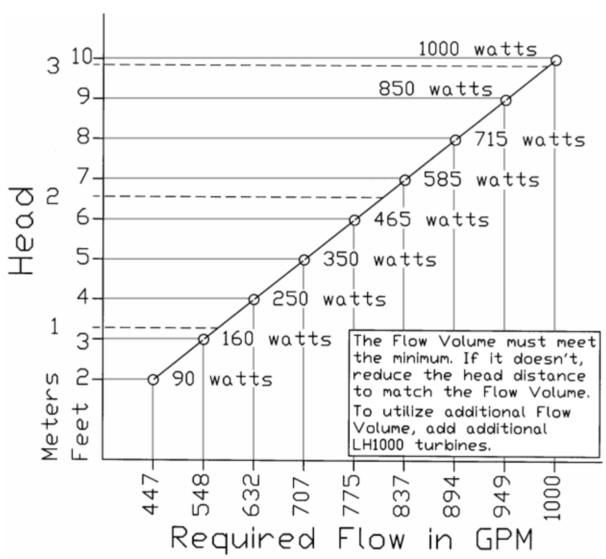



FIGURE 10: RANGE OF OPERATION (WWW.ABSAK.COM)

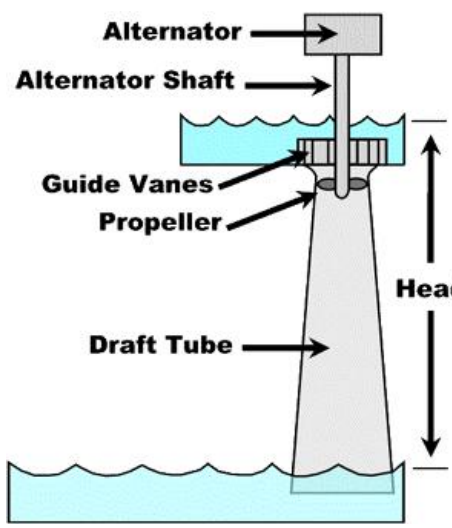



FIGURE 11: BASIC COMPONENTS (WWW.ABSAK.COM)

## POWER PAL

2-416 Dallas Road
Victoria, BC V8V 1A9
CANADA
1-250-361-4348
info@powerpal.com
http://www.powerpal.com

The Power Pal turbine is a very small, low head propellor type tubine that can produce up to 1 kW of electricity. Three models are offered, producing 200, 500 and 1,000 Watts. The turbine is set at the elevation of the incoming water and a draft tube extending below the turbine creates the head differential with suction. At the combination of head and flow shown in the table below, each model will produce the amount of power listed. This turbine is generally used for a stand alone application, either a direct load or a battery charge. Grid connection of this type of turbine would require additional equipment.

| **Power Pal** | **MGH-200LH** | **MGH-500LH** | **MHG-1000LH** |
|---|---|---|---|
| **Flow (cfs)** | 1.23 | 2.47 | 4.6 |
| **Head (ft)** | 5 | 5 | 5 |
| **Power (KW)** | 0.2 | 0.5 | 1 |

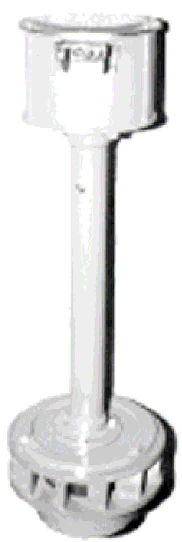


FIGURE 12: POWER PAL

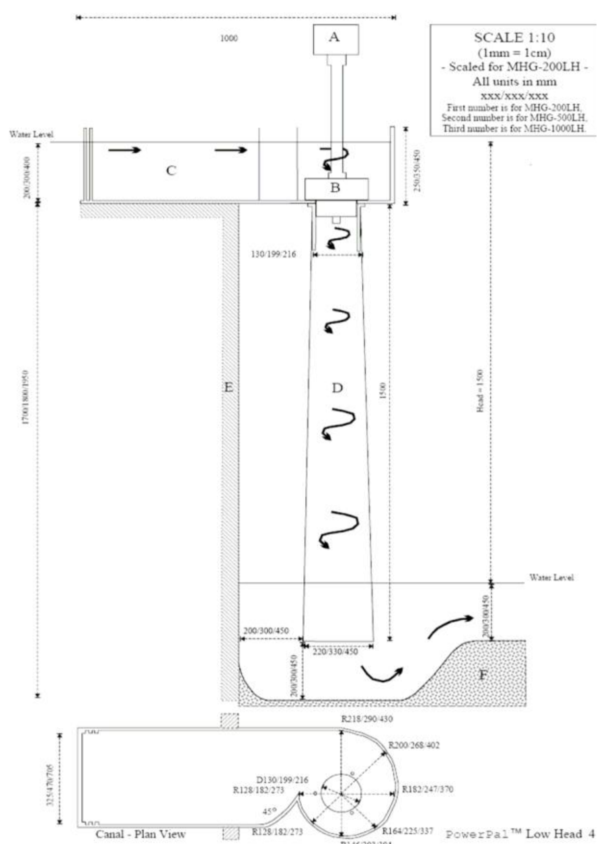



FIGURE 13: POWER PAL SCHEMATIC

# REACTION PROPELLER TYPE TURBINES (MEDIUM)

## CANYON HYDRO – KAPLAN TURBINE

5500 Blue Heron Lane
Demming, WA 98244
1-360-592-5552
info@canyonhydro.com
www.canyonhydro.com

Canyon Hydro is located in Washington State and has been in business for over 30 years. Canyon Hydro builds custom hydroelectric systems, including design and manufacturing the turbine, and assembling the system to provide a "Water-to-Wire" package. A wide range of turbines are available for both high and low head, large and small projects. For low head applications Canyon Hydro suggests their Kaplan turbine based equipment package. The Kaplan turbine design adjusts to varying head and varying flow using adjustable pitch runner blades and wicket gates. The efficiency of the turbine is maintained down to about 35% of the design flow. This turbine is recommended for sites with between 30 and 50 feet and flows ranging from 100 to 400 cfs. The turbine package would be custom designed to the site conditions including the alignment of the intake and discharge.

FIGURE 14: 300 KW KAPLAN TURBINE INSTALLED IN LOGAN, UTAH

FIGURE 15: CANYON HYDRO KAPLAN TURBINE

## TOSHIBA INTERNATIONAL – HYDRO-EKIDS

18 Bayberry Drive
East Hampton, MA 01027
303-568-3881
[www.tic.toshiba.com.au/hydro-ekids__8482_](www.tic.toshiba.com.au/hydro-ekids__8482_)

The Hydro-eKIDS are manufactured in three standard sizes, S, M and L. The runners can be chosen from three alternatives to match the site conditions. The runner vane angle will also be adjusted to match site conditions. These turbines can be installed in series or in parallel to accomidate a range of head and flow conditions.

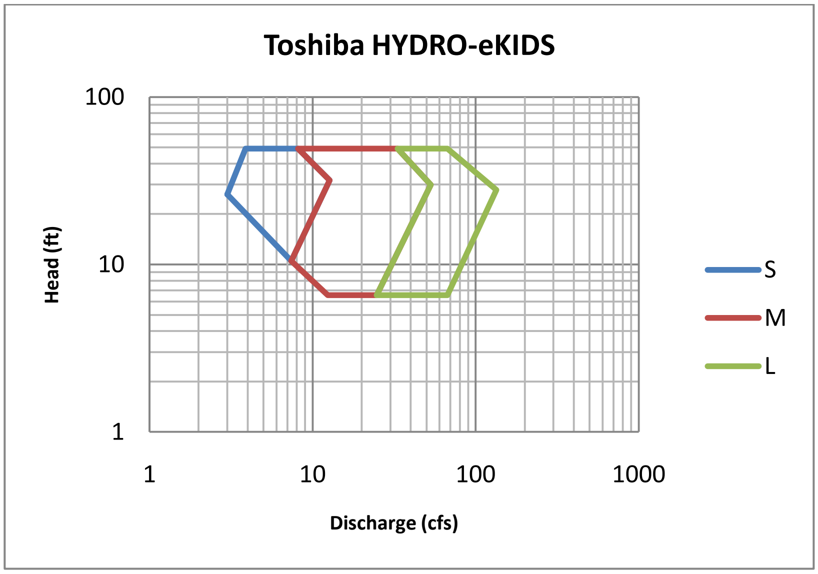



FIGURE 16: RANGE OF SITE CONDITIONS

These are propellor type turbines and would be best suited for installation in an existing pipe or in an outlet of a reservoir. The Type S produces between 5 and 35 kW, the Type M between 5 and 100 kW, and the Type L between 10 and 200 kW. Toshiba provides the turbine, generator and controls in one package for this type of turbine. As seen in Figure 17, the turbine can be installed with a siphon intake so not to distrurb the existing dam.

FIGURE 17: EXAMPLE INSTALLATION WITH SIPHON INTAKE

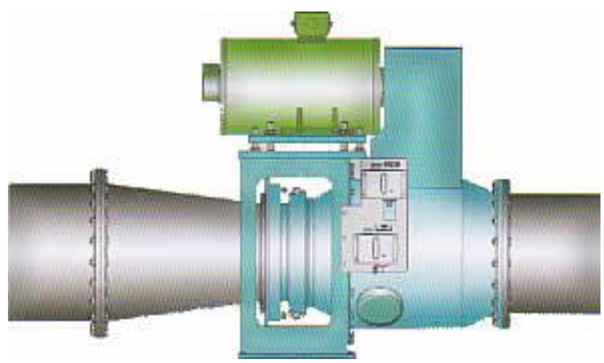


FIGURE 18: TYPE M (WWW.TIC.TOSHIBA.COM.AU)

## VERY LOW HEAD TURBINE

4 rue de la Megisserie
12100 Millau (France)
00 33 565-599-946
www.vlh-turbine.com

This turbine is in the pilot project stage of development. A turbine has been installed in a site in France. The company is eager to expand its buisiness into the United States. The turbine will be offered in five sizes to accomidate a range of site conditions. This turbine is intended to be installed in an open channel, and a head differential will be created across the turbine. This turbine would probably be best suited for the larger canals in Colorado, and in an existing structure to reduce the infrastructure costs. At the maximum discharge rate shown below this turbine operates at almost 80% efficiency.

FIGURE 19: VLH TURBINE INSTALLATION (WWW.VLH-TURBINE.COM)

**Maximum discharge through the turbine at the specified head**

| Net Head (feet) | Runner Diameter (feet): 11.6 | 13.1 | 14.8 | 16.4 | 18.4 |
|---|---|---|---|---|---|
| **4.6** | 367 | 470 | 593 | 731 | 918 |
| **4.9** | 381 | 484 | 614 | 756 | 950 |
| **5.2** | 396 | 501 | 632 | 780 | 982 |
| **5.6** | 406 | 516 | 653 | 805 | 1010 |
| **5.9** | 417 | 530 | 671 | 830 | 1042 |
| **6.2** | 431 | 544 | 689 | 851 | 1070 |
| **6.6** | 441 | 558 | 706 | 872 | 1095 |
| **6.9** | 452 | 572 | 720 | 897 | |
| **7.2** | 463 | 586 | 742 | 918 | |
| **7.5** | 473 | 600 | 759 | 936 | |
| **7.9** | 484 | 614 | 777 | | |
| **8.2** | 491 | 625 | 791 | | |
| **8.5** | 501 | 639 | 809 | | |
| **8.9** | 512 | 650 | 823 | | |
| **9.2** | 523 | 660 | | | |
| **9.5** | 530 | 675 | | | |
| **9.8** | 540 | 685 | | | |
| **10.2** | 547 | 696 | | | |
| **10.5** | 558 | 706 | | | |

**Power Produced (kW)**

| Net Head (feet) | Runner Diameter (feet): 11.6 | 13.1 | 14.8 | 16.4 | 18.4 |
|---|---|---|---|---|---|
| **4.6** | 113 | 144 | 182 | 226 | 284 |
| **4.9** | 125 | 159 | 202 | 251 | 315 |
| **5.2** | 138 | 175 | 223 | 276 | 347 |
| **5.6** | 151 | 192 | 244 | 302 | 380 |
| **5.9** | 164 | 209 | 266 | 329 | 415 |
| **6.2** | 178 | 227 | 288 | 357 | 450 |
| **6.6** | 192 | 245 | 311 | 386 | 486 |
| **6.9** | 207 | 264 | 335 | 415 | |
| **7.2** | 222 | 283 | 359 | 445 | |
| **7.5** | 237 | 302 | 384 | 476 | |
| **7.9** | 253 | 322 | 409 | | |
| **8.2** | 269 | 343 | 435 | | |
| **8.5** | 285 | 363 | 462 | | |
| **8.9** | 302 | 385 | 488 | | |
| **9.2** | 318 | 406 | | | |
| **9.5** | 336 | 428 | | | |
| **9.8** | 353 | 450 | | | |
| **10.2** | 371 | 473 | | | |
| **10.5** | 387 | 496 | | | |

## GILKES – KAPLAN TURBINE

2103 – 4464 Markham Street
Victoria, BC V8Z 7X8
250-483-3883
b.sellars@gilkes.com
www.gilkes.com

Gilkes is a British company with a distributor in Canada. They manufacter both high and low head turbines, for small and large hydro applications. The company has been in existance since 1856. Gilkes manufactuers a small scale Kaplan turbine that may be installed in a drop structure. More details about this turbine were unavailable at the time this report was published. We suggest contacting the distributor to see if this turbine would be appropriate for a site. This turbine is supplied with a head level sensor to optimize power production at a range of flow rates. A hydraulically managed control system together with PLC controls enables the turbine to start-up, synchronise and shut down automatically.

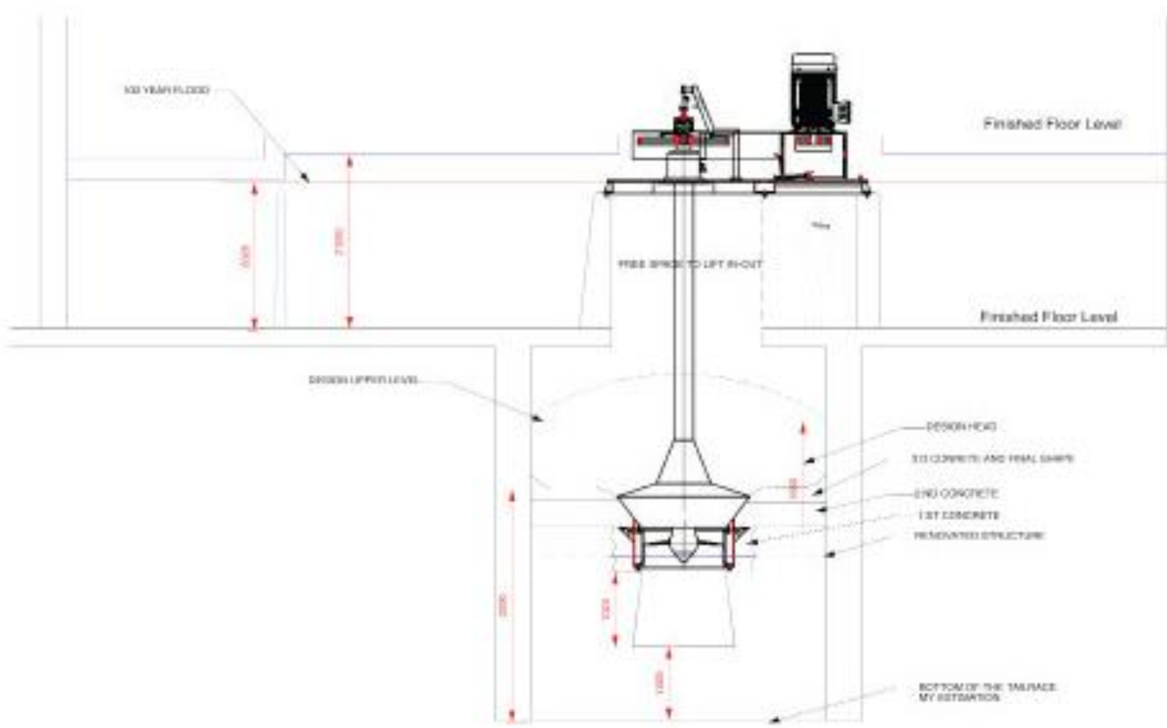



FIGURE 20: GILKES SMALL KAPLAN TURBINE

## MAVEL

121 Mount Vernon Street
Boston, MA 02108
617-242-2204
jeanne@mavel.cz
www.mavel.cz

Mavel is a turbine manufacturer located in the Czech Republic, with a distributor in Massachusetts. The company recently announced a Micro Line of turbines for low head projects. They have successfully installed these turbines in Poland, Japan, and Latvia. Mavel has installed turbines in the United States, but not turbines from the Micro Line. The Mavel Micro Turbines are a propellor type turbine designed for low head, low flow site conditions. Currently three sizes of the turbine is offered, the TM3, TM5 and TM10. The range of site conditions suitable for each turbine is listed in the table below. These turbines can be installed in parallel if there is more flow available than a single turbine can handle, as shown in the photograph below.

| | TM3 | TM5 | TM10 |
|---|---|---|---|
| Head (ft) | 5-20 | 5-20 | 7-16 |
| Flow (cfs) | 5-14 | 25-50 | 70-175 |
| Power Output (kW) | 0.7-13 | 2-50 | 30-180 |

The siphon outlet on these turbines may be beneficial if there is an exisitng structure that needs to be bridged. Installing the siphon outlet may decrease installation costs if modifying the existing structure is not feasible.

FIGURE 21: TM10 INSTALLATION (WWW.MAVEL.CZ)

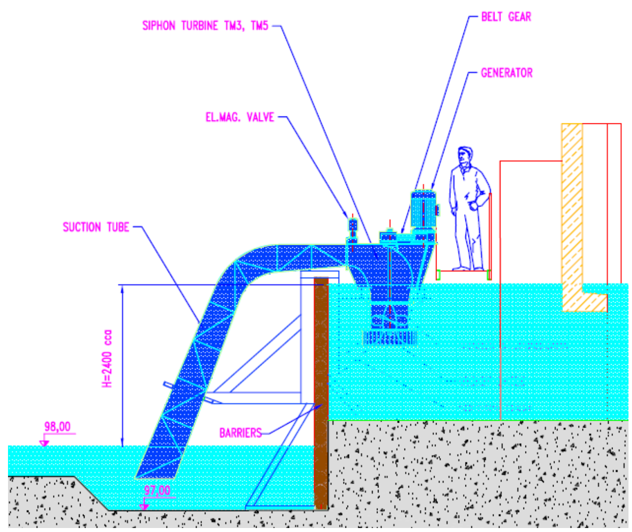



FIGURE 22: EXAMPLE INSTALLATION

## REACTION PROPELLER TYPE TURBINES (LARGE)

### VOITH HYDRO

760 East Berlin Road
York, PA 17408-8701
717-792-7000
Info.voithhydro@voith.com
www.us.voithhydro.com/vh_en_pas_small_hydro.htm

Voith Hydro is one of the major manufacturers of large hydro turbines in the world. They also manufacturer a line of small hydro turbines including a low head Kaplan turbine. The Kaplan turbines can be manufactured with 3 to 7 blade runners of any diameter, in vertical full or semi spiral arrangements. Voith offers multiple configurations including pit turbines, S-turbines, bulb turbines, and tubular axial turbines.

Voith also offers an "Ecoflow" turbine with much lower head and flow requirements. These turbines can produce between 25 and 175kW and are designed to integrate into existing structures.

FIGURE 23: ECOFLOW TURBINE (WWW.KOESSLER.COM)

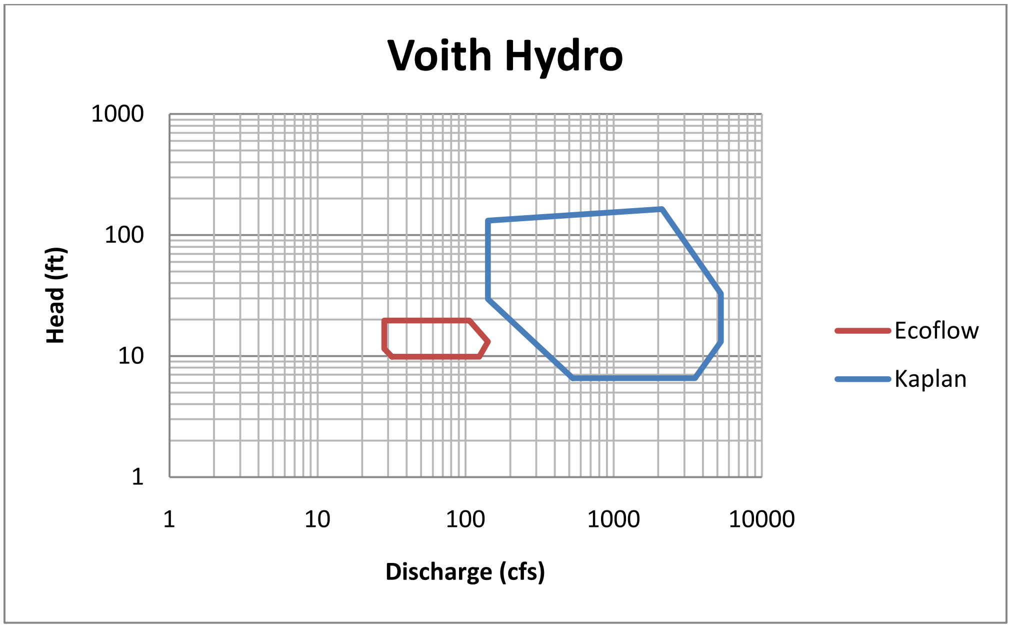



FIGURE 24: RANGE OF SITE CONDITIONS

## ANDRITZ HYDRO

Jeans Pautz
ANDRITZ HYDRO GmbH
Penzinger Strasse 76
1141 Vienna, Austria
+43 (1)891 00 0
Contact-hydro@andritz.com
www.andritz.com

Andritz Hydro is an Austrian company that has installations worldwide, including in the United States. They have a compact turbine line that would be suitable for Colorado's irrigation canals. These turbines require less infrastructure than Andritz's larger traditional turbines. The head and flow range of the low head Axial turbine is shown in the chart below. In the low head range of 5-30 feet this turbine would require at least 200 cfs to operate. These turbines would be best suited for the largest canals in Colorado, with the ability to utilize up to 3,500 cfs at 20-40 feet of head. Andritz also has a large line of hydro turbines, generally using more than 3,500 cfs.

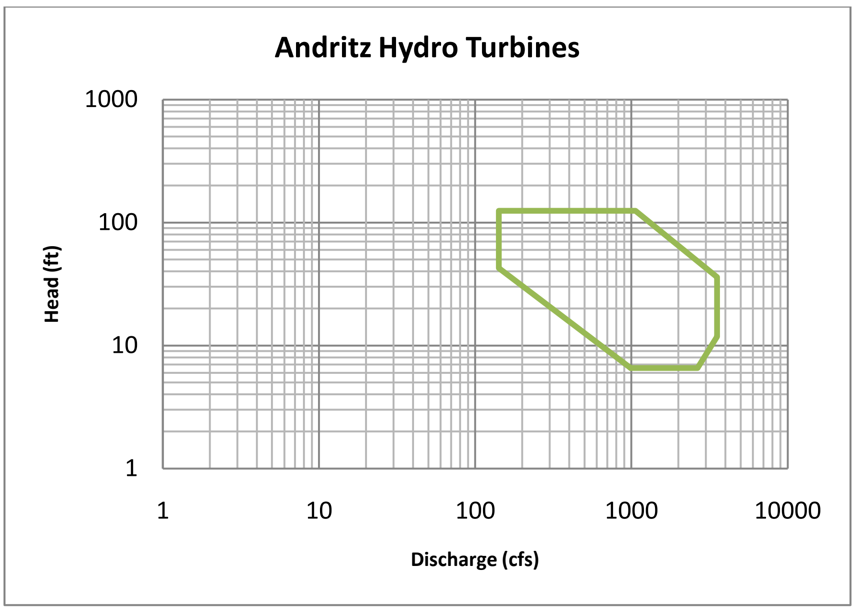



FIGURE 25: RANGE OF SITE CONDITIONS

The specific turbines can operate in the following ranges.

| Turbine Type | Head (ft) | | Flow (cfs) | |
|---|---|---|---|---|
| Belt Drive Bulb | 6.6 | 15.6 | 212 | 883 |
| Bevel Gear Bulb | 6.6 | 39.4 | 80 | 1625 |
| Axial | 19.7 | 98.4 | 80 | 2295 |
| Kaplan | 6.6 | 39.4 | 141 | 2119 |
| Eco-bulb | 6.6 | 49.2 | 529 | 3531 |

## HYDROENGINE

### NATEL ENERGY

2175 Monarch Street
Alameda, CA 94501
501-984-3639
gia@natelenergy.com
www.natelenergy.com

Natel Energy's hydroengine is a unique design using the uplift created as water passes by curved blades. This turbine is in the pilot project stage, and is ready for commercial development. A 10 kW turbine was recently installed in an irrigation canal in Buckeye, Arizona. The turbine was installed in an aging check structure that needed repair. These turbines will be offered in 5 sizes with the following site conditions and power productions. The power produced is at the high end of the flow range and at 13 feet of head.

| Model | Head (ft) | | Flow (cfs) | | Power (kW) |
|---|---|---|---|---|---|
| SLH-10 | 3.3 | 19.7 | 15 | 37 | 32 |
| SLH-50 | 3.3 | 19.7 | 63 | 155 | 133 |
| SLH-100 | 3.3 | 19.7 | 127 | 310 | 266 |
| SLH-200 | 3.3 | 19.7 | 253 | 620 | 533 |
| SLH-500 | 3.3 | 19.7 | 633 | 1550 | 1332 |

The turbine is offered as a water-to-wire package including the turbine and draft tube, generator, switchgear, SCADA compliant controls, as well as installation and maintenance support. This system is intended to be installed in an existing drop or structure, requiring little civil improvements. This system is referred to as a hydraulic engine instead of a hydraulic turbine, because of the unique design, claimed to be the first fully flooded two-stage water impulse engine. This design is fish friendly, allowing fish and debris to pass through the engine without damage.

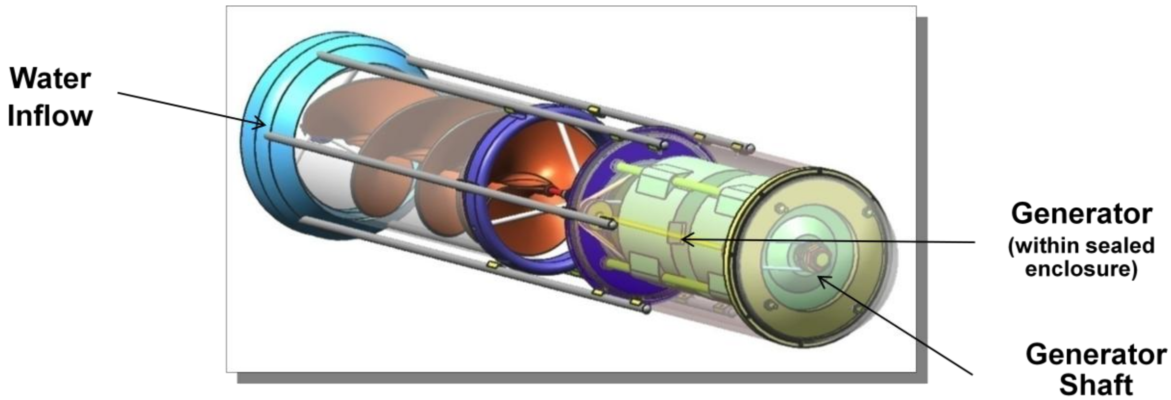
FIGURE 26: CROSS SECTION OF THE HYDROENGINE (WWW.NATELENERGY.COM)

FIGURE 27: PILOT INSTALLATION IN BUCKEYE, AZ (WWW.NATELENERGY.COM)

# SCREW TYPE TURBINES

## HYDROCOIL POWER

1359 Arbordale Road, 3rd floor
Wynnewood, PA 19041
862-397-4363
richdeluca@hotmail.com
www.hydrocoilpower.com




The HydroCoil Turbine is a very small turbine that can utilize heads between 10 and 70 feet of head, and produce up to 2 kW of electricity. The turbine is in the funding stage and ready for commercialization. Certified testing occurred on a prototype and using 12 feet of head generated approximately 1.5 kW using 1.8 cfs. These turbines could be installed in "clusters" utilizing higher flow rates, or in series to utilize longer drops. Although this turbine is not yet commercially available, the manufacturer could be contacted to discuss your project and application for the turbine.

FIGURE 28: HYDROCOIL IN USE
(WWW.HYDROCOILPOWER.COM)

## RITZ-ATRO – HYDRODYNAMIC SCREW TURBINE

Ritz-Atro GmbH
Max – Brod – Strabe 2
D-90471 Nurnberg, Germany
+49 911 998 12 -0
info@ritz-atro.de
www.ritz-atro.de

Ritz-Atro is a German Company that supplies pumps to the water and wastewater community, specializing in Archimedean screw pumps. As a result they also manufacturer “hydrodynamic screws”, which are turbines based on the Archimedean screw principle. These turbines are fish friendly and do not require fine screening. These turbines also maintain their efficiency over varying heads and flow rates. Eighty percent of peak efficiency is maintained down to 30% of the design flow rate, and it can operate at as low as 5% of the design flow rate. Turbines are supplied in many sizes and custom designed for each site. They can produce up to 300 kW of power, using up to 200 cfs, and heads up to 33 feet.

There are a number of distributers and installation in the United Kingdom. It appears that some of these distributers are also interested in entering the U.S. market. This turbine could be used in existing concrete structures with a unique geometry, as seen in the photograph below.

FIGURE 29: HYDRODYNAMIC SCREW (WWW.RITZ-ATRO.DE)

## WATERWHEELS

### HYDROWATT

Am Hafen 5
76189 Karlsruhe, Germany
+49 (0)721-831 86-0
http://www.hydrowatt.de/sites/english/home.html

Hydrowatt of Germany, manufacturers both overshot and breastshot waterwheels. The water enters an overshot waterwheel at the 12 o'clock position, and can be used at sites with heads between 8 and 32 feet, and flows between 3.5 and 88 cfs. The water enters a breastshot waterwheel below the axis, and can use between 3 and 10 feet of head and between 18 and 250 cfs of flow. These traditional waterwheels could be used in a location where a waterwheel was once installed, to recreate the historic site while producing electricity with a modern wheel and generator. These turbines have an efficiency around 60% which is much lower than a Kaplan turbine, but the site conditions may make these types of turbines an economical alternative.

FIGURE 30: BREASTSHOT WATERWHEEL (WWW.HYDROWATT.DE)

FIGURE 31: OVERSHOT WATERWHEEL (WWW.HYDROWATT.DE)

## HYDROKINETIC

### ALTERNATIVE HYDRO SOLUTIONS – DARRIEUS WATER TURBINE

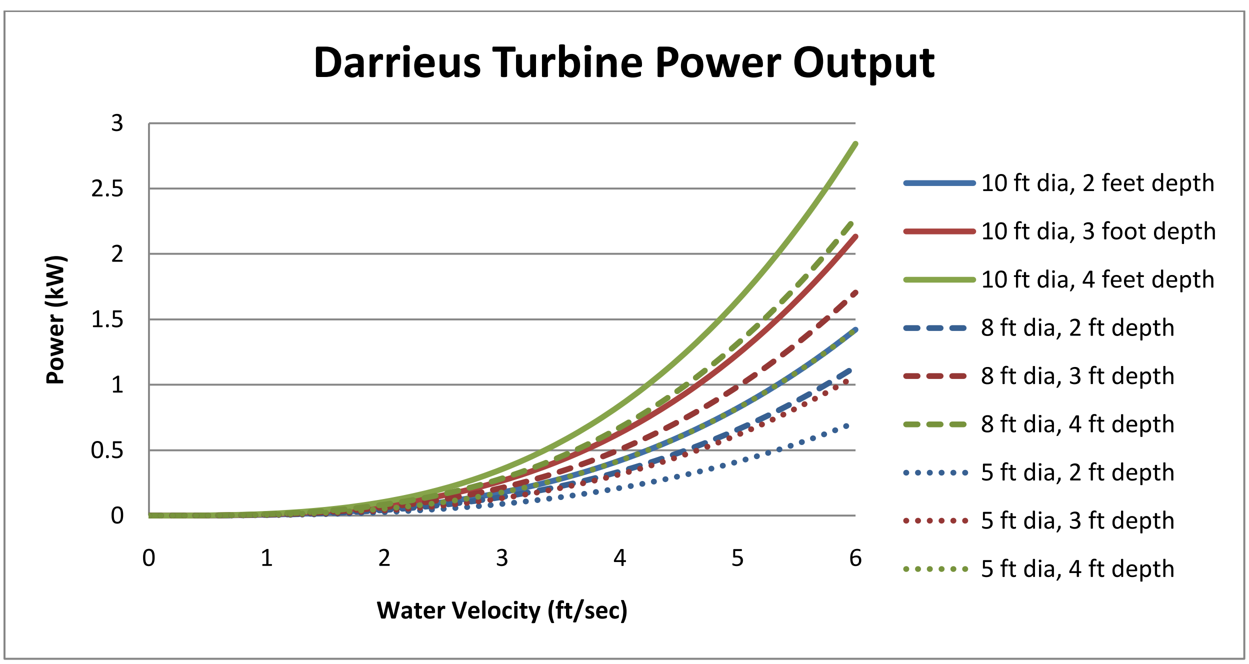
Stephen Gregory
Suite 421 323 Richmond Street East
Toronto, Ontario M5A 4S7
416-368-5813
sdgregory@althydrosolutions.com
www.althydrosolutions.com

FIGURE 32: DARRIUS WATER TURBINE

These Darrieus Water Turbines are manufactured in Canada, with one installation in the United States. This turbine is considered a hydrokinetic turbine that uses the velocity of the passing water to produce power and requires no head differential. Generally speaking this turbine can be installed in a canal with a water depth of over 2 feet and with water velocity of more than 2.5 feet per second. Each turbine is custom designed to the site's conditions and can produce between 1 and 4 kW of electricity.

The turbine is suspended in the water with a barge or a structure crossing the canal. The turbine rotates on a vertical axis to turn a generator located above the water surface. Below is a curve of expected power given the turbine's diameter and the depth of water the turbine is submerged in.

Colorado's irrigation canals generally would not meet the criteria of depth and velocity that is needed to produce power with these turbines, although conditions may exist at drop structures or areas where the canal width is narrower. Trash accumulation may be an issue with these turbines, therefore screening upstream may be required.



## HYDROVOLTS

210 South Hudson Street #330
Seattle, WA 98134
206-658-4380
www.hydrovolts.com

The Hydrovolts turbine is in the pre development stage. They have tested one turbine in an irrigation canal in Oregon. This turbine is "dropped in" to the canal and suspended using cables attached to either bank. The turbine rotates on a horizontal axis with the generator located on the ends of the turbine underwater. No modifications to the canal or additional structures are required to deploy this technology. The company will be producing three sizes of turbines, the middle size is rated at 5kW and will cost about $20,000, the larger size is 25kW and will cost about $50,000. Both models are rated for 6.5 feet/second water velocity. At this velocity the water holds about 0.4 kW per square foot; to produce 5 kW the turbine will need to cover at least 12.5 square feet of flow area. This 5kW turbine may be approximately 7 feet wide and 2 feet in diameter.

Velocities over 6.5 feet/second will only be seen in an irrigation canal in certain situations, such as below drops or chutes. Hydrokinetic technologies like this are feasible in canals with high velocities, but they will only be able to produce a small amount of power. They will likely be useful in situations where the power can be consumed at the turbine site, such as powering automation equipment or remote pumping locations.

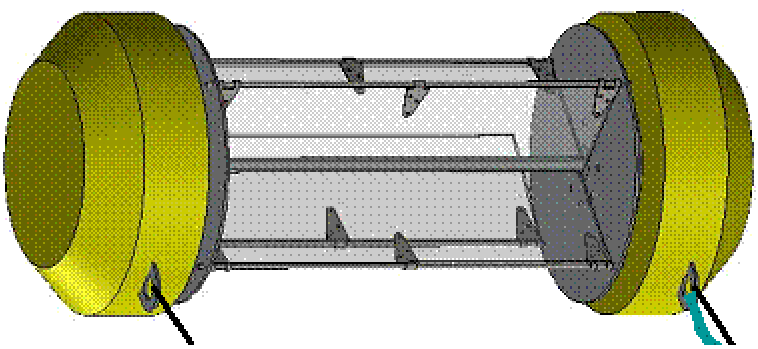


FIGURE 33: SCHEMATIC OF HYDROVOLTS TURBINE (WWW.HYDROVOLTS.COM)

# DO-IT-YOURSELF TURBINES

## ELEPHANT BUTTE IRRIGATION DISTRICT

Las Cruses, NM

The staff of the Elephant Butte Irrigation district designed, manufactured and installed a turbine in a drain off of their canal with 8 feet of head and about 20 cfs of flow. The irrigation district designed and tested four turbine configurations before finalizing the design. They started with a paddlewheel style turbine, moved on to an axial flow propeller type, and modified the blades to optimize the power production. The final turbine design is shown in the photograph below. They also have optimized their generator choice and are now producing about 6 kW of electricity.

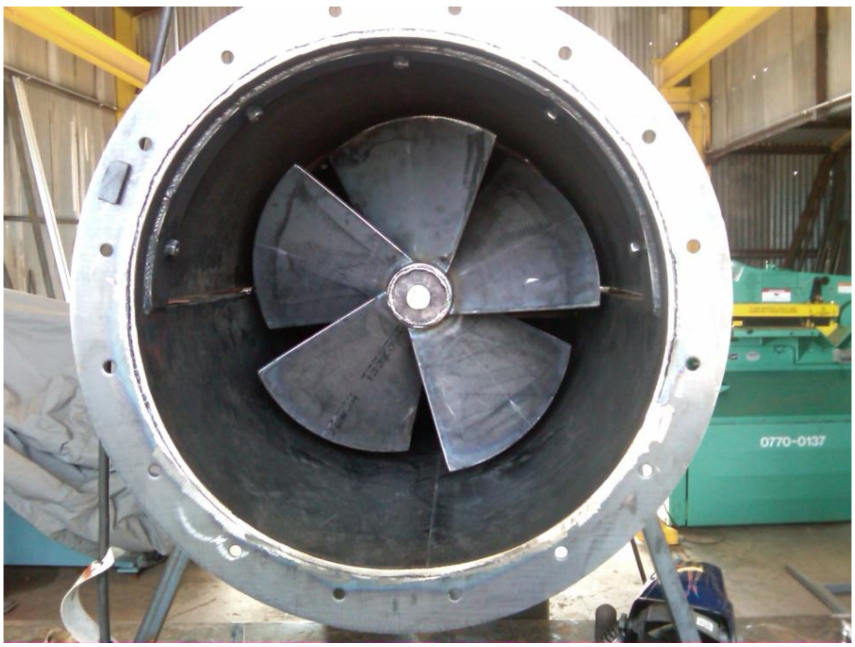



FIGURE 34: EBID KAPLAN STYLE TURBINE

The District has identified over 100 sites on the system where this type of turbine could be installed. By designing and manufacturing their own turbines, they are able to save a significant amount of cost. The efficiency of the turbine is not as high as the other turbines presented in this report, but the cost is much lower and with multiple sites the total power produced could be as high as 1.5 MW.

## WATER VORTEX POWER PLANT

A-3200 Obergrafendorf
Wildgansstraße 5
AUSTRIA
Telephone: 0043-(0)2747-3106
**office@zotloeterer.com**
http://www.zotloeterer.com/our_company.php

The gravitational water vortex power plant was invented by an Austrian engineer, Franz Zotlöterer. This power plant uses the rotational energy at the center of a vortex to turn a paddle type turbine. There have been installations in Switzerland, Indonesia, and currently an installation is in progress here in Colorado. The plant requires a very small head difference, and the configuration is very unique. The turbine is set in the center of the vortex with the axis of rotation vertical, and the generator is mounted above the water. The diameter of the spinning pool, quantity of flow and head drop is used to determine the amount of power that can be produced at a site. For example, the power plant shown in the figure below utilizes 4.6' of head, 30 cfs of flow, and the spinning pool is 18 feet in diameter. This plant can produce 7.5 kW of electricity.

FIGURE 35: INSTALLATION IN SWITZERLAND (WWW.ZOTLOETERER.COM)