

Low Head Hydro - Final Report

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

Final Report



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EXECUTIVE SUMMARY

In Colorado, about 5% of electricity is currently provided by hydropower. Since the settlement of Colorado in the 1800's Coloradan's have been utilizing the geography and hydrology to exploit this renewable resource. Traditionally, most hydropower has been developed on large, on channel dams and related structures; few small dams, canals and conduits have been utilized. Recently, there has been a significant public push toward clean and renewable energy sources. Colorado House Bill 10-1001 increases the Renewable Energy Standard from 20 to 30% for Investor Owned Utilities by 2020. This includes a requirement for one-tenth of that renewable electricity to come from distributed generation. The Governor's Energy Office of Colorado (GEO) has been leading a renewed effort to increase small hydro production. Small hydropower has been recognized as a desirable source of renewable energy, particularly since it is less variable than other renewable resources such as wind and solar. In many cases, much of the base infrastructure already exists which reduced impact. If no changes in operations of existing water delivery systems are required, then the result is very environmentally friendly. Small hydro also has disadvantages, including the site-specific nature of projects, high capital cost and extensive permitting requirements. The GEO has introduced programs to address these issues, including a Renewable Energy Development Team and a FERC streamlining pilot project. In addition, the Colorado Department of Agriculture offers research grants through their Advancing Colorado's Renewable Energy (ACRE) program to promote energy-related projects beneficial to Colorado's agriculture industry.

Applegate Group and Colorado State University teamed together to study development of agriculturally related small hydro in existing irrigation infrastructure. The study intends to provide information on small hydro development, state-wide, to agricultural water users and policy makers, including guidance on site types, equipment and utility interconnection. Applegate Group is a water resources engineering firm that specializes in raw water conveyance and storage infrastructure as well as water rights, planning and development. Applegate's clients are both public and private entities who own and operate irrigation and municipal water supply systems. A number of these clients have expressed an interest in producing hydroelectric power, but were generally hesitant to invest without more information. Agricultural water systems have a primary purpose of delivering water to their project beneficiaries. The addition of other components such as generating electricity can be a distraction to the original purpose and it is incumbent on any renewable energy effort to demonstrate that it will enhance existing operations. Building trust with the system owners is the key factor for any project to move to development. Colorado State University's *Engines and Energy Conversion Laboratory* (<http://eecl.colostate.edu>) supports an extensive power engineering education and research program. CSU researchers are actively studying the integration of distributed renewable energy resources into regional and island power systems.

THE STUDY

The study, "Exploring the Viability of Low Head Hydro in Colorado's Existing Irrigation Infrastructure," focuses on low head technologies which can be productively installed in existing constrained waterways that were originally intended for delivering irrigation water – a hydropower area that appears to be lacking in overall knowledge. A number of low cost, low head turbines have recently been introduced to the market, but are unknown to Colorado's water users. There is limited knowledge of the viability of these low head turbines in typical irrigation structures, which are often both low-flow and low-head. There has also been no systematic identification of attractive sites within irrigation systems, and no developed process to easily

classify and assess sites for development. The study also focuses on sites within existing infrastructure, due to the ease of permitting and developing projects within an existing canal or conduit. It is important to note that this study investigates only a portion of the hydropower potential in Colorado. Sources that do not meet the constraints of this study were not assessed, nor were efficiency enhancements at existing hydropower facilities – even low-head facilities.

The purpose of this study is to provide relevant information to agriculturally-related water users on the opportunities that may exist to implement low head hydropower on their systems. The study has three goals; 1) Research available low head technologies, 2) Match those technologies with typical irrigation structures by studying two project canals, 3) Estimate a state wide potential for low head hydropower. The results of this study will be conveyed through a final report submitted to the Colorado Department of Agriculture, and posted on a website dedicated to low head hydropower in Colorado. The project team has also held a number of workshops, and presentations and has written a number of conference papers and articles to disseminate this information. This effort is intended to provide a roadmap for agricultural water systems to develop their existing resources and with an end goal to provide a reliable secondary revenue stream to help support those systems.

There are almost 3.5 million acres¹ of irrigated land in Colorado, supplied with water by canals, ditches and pipelines. This extensive statewide water supply system is fragmented geographically and operationally. The Ditch and Reservoir Company Alliance (DARCA) of Colorado is an organization whose mission is “to become the definitive resource for networking, education and advocacy” for their members. Membership includes all types of irrigation enterprises - ditch companies, reservoir companies, laterals, private ditches, and irrigation districts. DARCA provides a platform for the transfer of information and is a strong supporter of this study. The project team led an all day workshop prior to the 2010 annual DARCA convention, focused on low head hydropower. The workshop was very well attended and well received, highlighting the interest that exists in Colorado’s irrigation community. Attendants heard from engineers, turbine manufacturers, regulators and developers of low head hydropower.

CHALLENGES AND OPPORTUNITIES

There are many challenges related to successfully implementing a hydroelectric facility in a Colorado irrigation canal, including the seasonality of irrigation diversions, seniority of water rights, locations remote from power service, and the variable nature of the flow and reservoir releases. There are also opportunities afforded by the existing, engineered infrastructure of irrigation systems. Pipelines and drop structures are already in place, and many are in need of modernization. Hydropower could be incorporated into the structure during heavy maintenance work. Irrigation operators are generally interested in finding additional revenue sources to augment their finances and reduce shareholders’ annual assessments or fund system improvements. These physical opportunities joined with the interest of the organizations may support the development these projects.

¹ Colorado Water Conservation Board. 2010. State of Colorado Current and 2050 Agricultural Demands. Draft Technical Memorandum, July 16, 2010. Prepared by Camp Dresser & McKee, Inc., AECOM, and Harvey Economics.

Permitting delays and regulatory complexity have long retarded new hydropower development. Most irrigation system sites are quite small. Permitting costs do not scale well to small sites, creating disproportionately high up-front costs that often kill economic viability or dissuade potential investors from seriously considering small hydropower projects. There is also an inherent distrust of the Federal permitting process and a real fear that exposing an existing irrigation system to the federal nexus could result in negative consequences. To address this issue, Colorado, acting through the Governor's Energy Office (GEO), signed a memorandum of understanding with the Federal Energy Regulatory Commission (FERC) to "Streamline and Simplify the Authorization of Small Scale Hydropower Projects"² – particularly targeted at existing structures and man-made waterways. This trial rule change may significantly lower permitting barriers for small hydropower.

Electrical interconnection also presents both challenges and opportunities. Ideal hydropower sites – like ideal wind or photovoltaic sites – are those with ready access to electrical service. Pulling new electrical service over any distance is often cost-prohibitive for small renewable systems. Conversations with one utility indicate that systems as large as 500 KW can be connected at the distribution level in modern distribution systems. However, on remote, rural feeders, sizes may be more restricted. Many utilities limit distributed generation to 10-15% of the peak load on a feeder line.

Traditionally, hydropower systems have utilized synchronous generators, or occasionally induction generators, coupled directly to the power system. While more efficient than inverter-based systems, such generators are more difficult control and produce larger "fault currents" – surge currents during shorts or other system issues. Therefore, the study authors expect utilities to steer small hydropower systems toward inverter-based generation. Inverters are generally equipped with solid-state synchronization, remove control capabilities and produce far less fault current than similarly sized generators – all of which ease interconnection complexity.

RESULTS

An interim report was published in September 2010. The report addresses the project's first goal, researching available turbine technologies. This report is publically available on Applegate Group's website³ and on the Colorado Department of Agriculture's website⁴. The report identifies over 20 low head turbines that may be appropriate for sites in Colorado, with required conditions and contact information. Additional turbines and manufacturers are included in this final report. Estimating the potential of all of the irrigation infrastructure within the state has proven problematic. The intent of this study was to obtain a realistic estimation of hydropower potential by gathering information on actual irrigation systems, rather than using GIS data, as has been done in other studies. Mailed, emailed and hand delivered surveys were provided to over 250 irrigation entities with decreed diversion flow rates over 100 cfs. Only about 10% of those surveys have been returned, and those that were returned required some level of persuasion by the study authors. Reasons for the low return rate are hard to identify. Clearly, the survey requests specific, technical, information from operators who may not be comfortable with technical requests. Face-to-face interviews proved to be the most fruitful in gathering information, but is very time consuming.

² Retrieved at: <http://www.ferc.gov/legal/maj-ord-reg/mou/mou-co.pdf>

³ <http://www.applegategroup.com/news/turbine-report-available>

⁴ <http://www.colorado.gov/cs/Satellite/Agriculture-Main/CDAG/1238508031938>

Hydropower workshops proved to be a good opportunity to talk to irrigation operations that had specific interest in learning more about hydropower. These entities are also thinly staffed, and often overloaded with other concerns. The low return rate is ironic, given the high interest in hydropower expressed by many irrigation entities.

The team has learned that, to truly assess small hydropower potential state-wide, a researcher will need to travel the state and visit each canal that has promising overall characteristics such as flow rate and duration. This approach, or perhaps another approach of mid-level detail, should be explored further. Overall, the project has been a success in raising awareness and educating irrigation entities about the opportunities that exist in small hydro. This final report provides practical resources for those considering development. Estimating the overall state-wide potential has proven more difficult than expected, but the study indicates that potential does exist in a number of irrigation systems. These sites can be developed with minimal impact and the project will benefit a number of agricultural producers. Existing irrigation infrastructure deserves focused attention in the future development of low head hydropower in Colorado.

STUDY TASKS, GOALS AND DELIVERABLES

The intent of this study was to achieve three main goals; 1) Explore available technologies 2) Expose interconnection issues and 3) Investigate and quantify the statewide potential to produce low head hydropower. To accomplish these goals five tasks were outlined in the project proposal. These tasks are outlined and summarized below, and the results of the goals and tasks are detailed in later sections of the report.

TASK 1: RESEARCH LOW HEAD HYDROPOWER TECHNOLOGIES

Available low head hydropower technologies were researched. Over 20 turbines were found in varying stages of development and commercialization. These technologies are included in the appendix to this report with a description of the technology, including flow rates and heads necessary to economically produce power, and unique installation or operational requirements. Contact information for each manufacturer or distributor is also included.

TASK 2: INVENTORY THE INFRASTRUCTURE AVAILABLE IN COLORADO FOR HYDROPOWER GENERATION

A two step approach was used to inventory the infrastructure in Colorado that has the potential of producing low head hydropower. First, agricultural ditches and canals across the state were identified using the Colorado Decision Support System (CDSS) and the collective knowledge of the Applegate staff. Paper surveys were sent to these organizations requesting information about low head drops on their systems. Second, two project canals were chosen to identify and investigate typical irrigation structures and the opportunity to add hydropower.

TASK 3: INVESTIGATE INTERCONNECTION ISSUES

This analysis focused on the two “project locations” identified in Task 2. After structures were identified, CSU personnel made contact with the appropriate local utilities to estimate the costs of interconnection, value of a power purchase agreement, and equipment requirements. The results

have been translated into set of decision guidelines that can be applied to locations statewide to estimate the best candidates' development.

TASK 4: COMPARE THE TECHNOLOGIES TO THE HYDRAULIC STRUCTURES

In order to determine the hydropower generation potential of the irrigation systems in Colorado, the technologies researched in Task 1 are compared to the physical characteristics of the structures identified in Task 2 to consider the technical feasibility of applying the researched technologies to the selected structures on the project canals.

TASK 5: ESTIMATE A STATE WIDE POTENTIAL

The potential of low head power generation for all of the canals identified in Task 2 has been estimated. We hoped that these surveys would provide sufficient information to determine an overall potential of Colorado's irrigation canals to produce low head hydropower. Unfortunately, the survey response was low, and to infer a statewide potential from this limited information would be very difficult. However, based on the information that we were able to collect, it is apparent that there is a significant amount of hydropower potential in Colorado and that it warrants evaluating approaches to develop it.

DELIVERABLES

Three products have been completed as a result of this project; this final report, a website, along with presentations and public outreach. These products are intended to disseminate the findings of this study in three different forms in order to reach the target audience. The information contained in these products is meant to educate agricultural producers on the available technology and specific applications on their property.

TASK 1: 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.

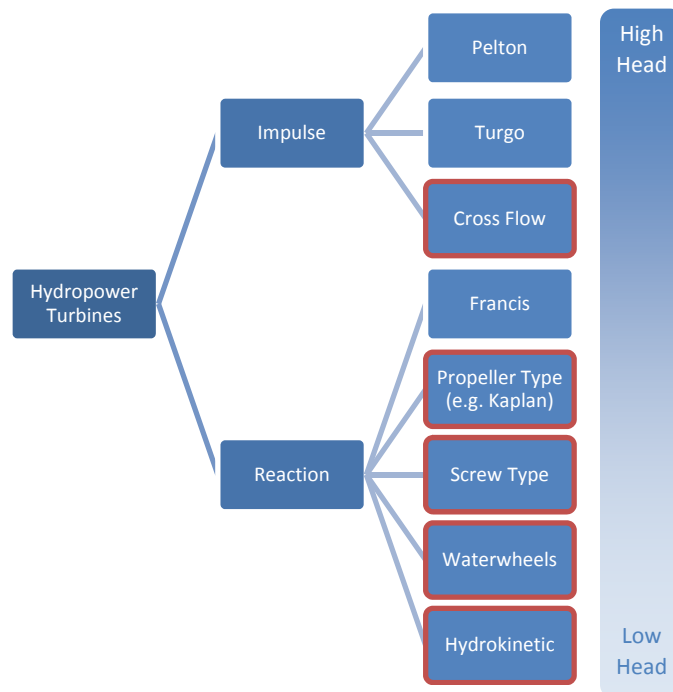


FIGURE 1: TYPES OF HYDROPOWER TURBINES

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 approximation 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 included in the appendix. The ranges for individual turbines are explained or displayed in the description.

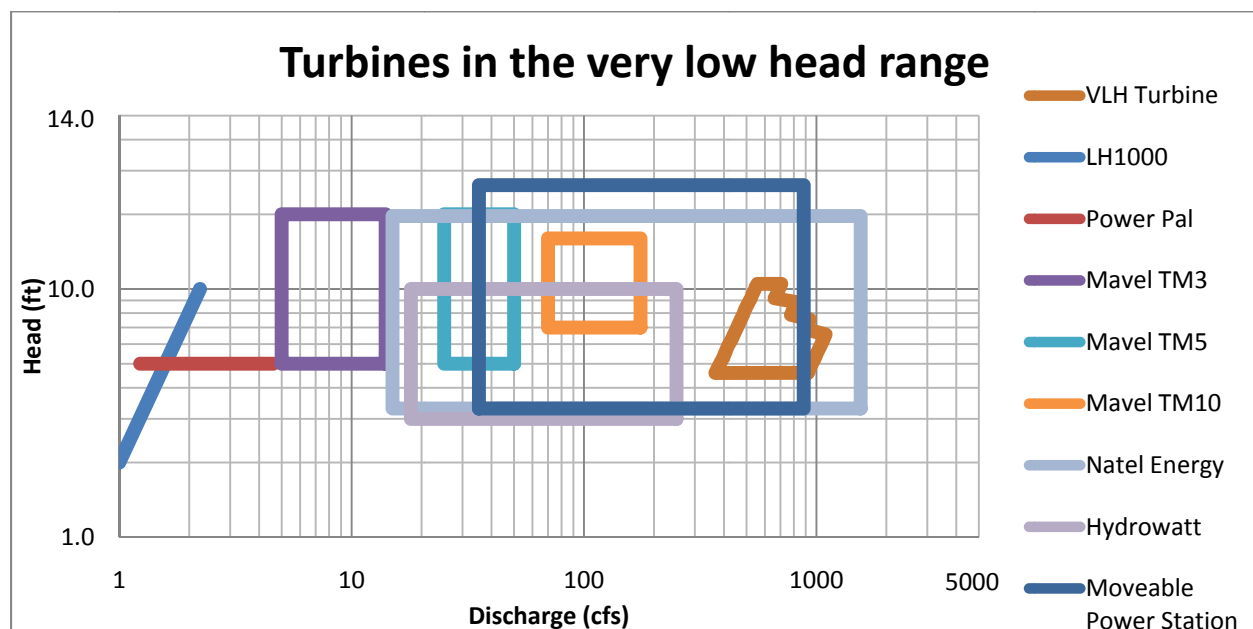


FIGURE 2: VERY LOW HEAD RANGE TURBINE SELECTION CHART

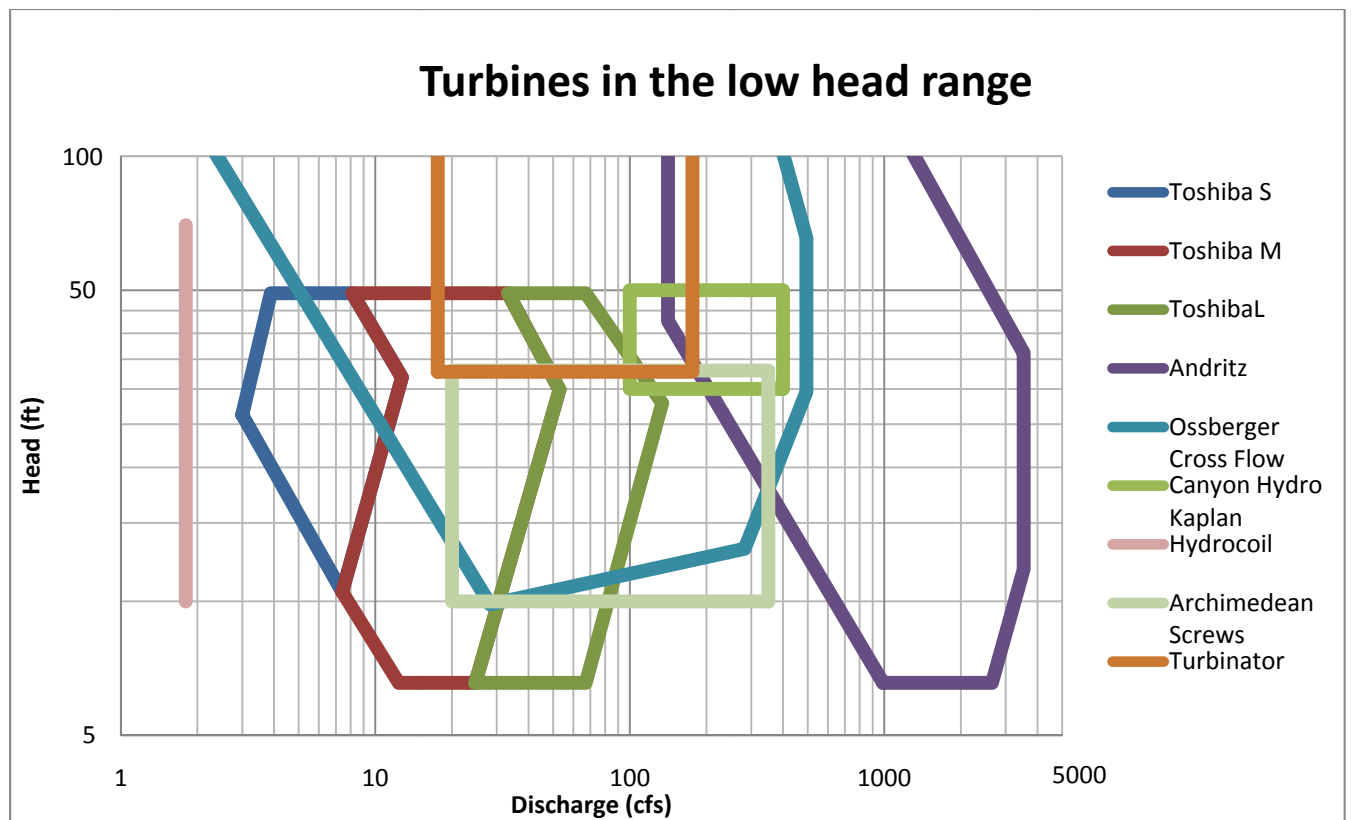


FIGURE 3: LOW HEAD RANGE TURBINE SELECTION CHART

TASK 2: INVENTORY INFRASTRUCTURE

APPROACH

In order to identify irrigation canals and ditches in the State of Colorado, the Colorado Decision Support System (CDSS) was used. The CDSS is a water management system that contains historic records of water use in the State of Colorado. The search was limited to those water rights that have absolute decrees for diversion rates 100 cfs or more. This value was chosen to narrow the scope of this study, not necessarily to indicate that flows less than 100 cfs don't have the potential to produce hydropower. The number of canals in Colorado with lower flow rates would be unmanageable for a study of this scope, for example there are over 500 canals with less than 5 cfs of decreed capacity. Over 250 canals were identified with a decreed flow rate above 100 cfs and used in this study, the distribution of flow rates are shown in the graph below.

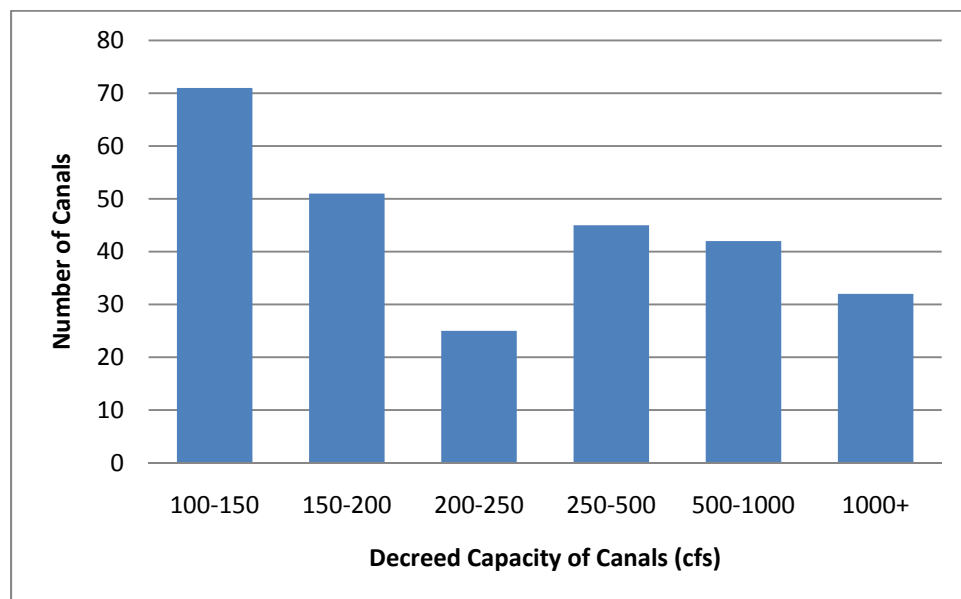


FIGURE 4: IRRIGATION CANALS IN COLORADO

The CDSS system does have gaps in the ownership data. Owner's information and contact information was collected from multiple sources to ultimately send out surveys to 237 irrigation entities. Surveys were also distributed via email to the DARCA email distribution list and hand delivered to multiple companies at various functions and meetings.

CHALLENGES

Identification of the canals of interest was achievable, but obtaining information from all of the organizations involved proved challenging. There is an immense interest in hydropower in irrigation canals, but that interest did not translate into returned surveys. We made the surveys available in paper copies, electronically, and on a web based survey, hoping that the multi-media choices would promote completion and return. We also offered the incentive of being chosen as a project canal for this study which would include a no-cost hydropower analysis of the system, if the survey was returned. Even with those measures only 10% of the surveys were returned. Survey

responses of the general public are between 1 and 20%, according to those statistics our return rate was average, all though much lower than we had hoped.

Irrigation companies and other districts are generally lightly staffed and rely heavily on volunteer participation. There are also a number of people involved in the organization, generally a board of appointed or elected members, and decisions are made collectively. These could be factors that contributed to the low return rate. We also learned that irrigation companies receive a number of surveys each year.

RESULTS

There were 59 structures identified in the 23 surveys that were returned. While this information will not be sufficient to estimate a statewide potential, it does give us valuable information about the typical structures that are used at elevation drops in Colorado's canals. The distribution of the types of structures is shown in the chart below.

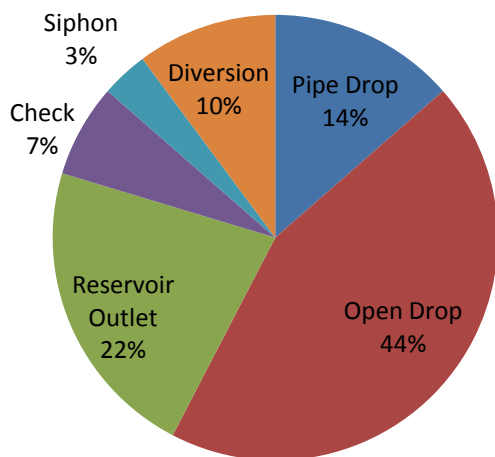


FIGURE 5: DISTRIBUTION OF STRUCTURES

According to the data that we collected, the most common occurring structure is the open drop. This includes concrete lined chutes, vertical drops, and other similar structures. These structures were seen in almost all of the systems surveyed. This result is not surprising as an open channel drop would be the least expensive and easiest way to change elevation in these larger open canals.

We are seeing an increase in pipe drops as systems convert from open channel to piped or pressurized systems. In the Colorado River Basin this conversion is partially supported by the Salinity Control Projects supported by the Bureau of Reclamation.

Those systems that do utilize storage in a reservoir, identify potential related with the outlet works of the reservoir. This can be a challenging structure to develop when the storage is only used for late season demands and it is not located on a stream with substantial year round flow. This limits the length of the year hydropower can generate and thus decreases the capacity factor of the plant.

The Diversion Dam was identified by 5 of the 23 respondents. Depending on the natural river geometry and the topography of the area, the size and shape of diversion dams can vary. Diversion dams can be an ideal place to implement low head hydropower since the full flow of the river can be utilized instead of just the diversion. Using the river flow can also extend the season beyond irrigation season, and increase the capacity factor of the plant.

All of these typical structures will be matched with appropriate low head turbines in the discussion of Task 4 below.

PROJECT CANALS

We visited four project canals to compile the more detailed information on typical structures. One project canal system was investigated in detail, the Grand Valley Irrigation Canal. A detailed description of each site on the canal along with interconnection issues is included in Appendix B. This detailed information should provide irrigation companies with a starting point to evaluate a site however, the information contained in this report cannot be used to determine a site's feasibility with absolute certainty. There are many site specific factors that must be considered. We hope that the information in this report will help irrigation companies ask the right questions and decide whether or not to proceed with a detailed feasibility study.

RECOMMENDATIONS

Attempting to inventory infrastructure throughout the state by survey proved to be challenging. It appears that the only way to obtain a realistic accounting of structures is to conduct an in person interview and site visit. We recommend using this method in the future if a quantification of potential is desired.

TASK 3: INTERCONNECTION ISSUES

The development of successful hydropower production depends upon constraining the costs of interconnection and acquiring a power purchase agreement – be it net metering or wholesale power purchase – that supports the project development and ongoing costs. This chapter discusses the current situations and issues related to electrical interconnection, with particular emphasis on the Grand Valley Irrigation Company sites, where significant interaction with Xcel Energy allowed an estimation of the costs and complexity of interconnecting the survey sites.

INTERCONNECTION TECHNOLOGY

Before discussing electrical interconnect methods, it is useful to review of several technical topics which impact the choice of power conversion technology. Utilities are frequently concerned about the ‘fault current’ produced by distributed generation. Fault current is a current surge caused by a device when a fault occurs in the power system. Typical faults include ground faults – an energized line contacting the ground – and phase-to-phase faults – two energized lines contacting each other. Since all devices respond when a fault occurs, fault currents of all connected devices tend to add up, exacerbating the fault. Generally, larger inertias cause larger fault currents, as do larger inductive or capacitive electrical components. For example, a large induction motor driving a heavy turbine (large inductive load, large inertia) produces substantially more fault current than a small motor driving a pump (smaller inductive load, lower inertia).

In addition to fault current, utilities are also concerned about starting and stopping transients caused when a generator connects to the grid. Before interconnecting a generator, the generator must be “brought into synchronization” with the grid – i.e. generator voltage must be at the same frequency as the grid, in-phase, and at the same magnitude as the grid. Starting certain components – such as induction generators – can also cause current spikes, which may cause significant voltage fluctuations, or “flicker.”

Most utilities base their interconnect requirements upon the combination of several standards:

- IEEE 1547.x, which specifies the behavior of an interconnected generation devices. Inverters (power electronics) are additionally standardized by the related UL 1741 standard.
- IEEE 519, which specifies allowable power distortion caused by an interconnected generator.
- IEEE 142, which specifies system grounding rules.
- ANSI C37, which defines standards for protection relays.
- National Electrical Codes

However, individual utilities may impose additional requirements.

As discussed in the *Interim Report*, two primary technical approaches exist for connecting small, distributed generation to the grid – power electronics systems, such as inverters or regenerative, variable-frequency drives, or directly coupled induction or synchronous generators.

POWER-ELECTRONICS

Many smaller, distributed generators utilize power electronics – typically an inverter or variable-frequency drive – to interconnect with the electrical power system. An example drive train is shown in Figure 6. The inverter/drive provides synchronization with the utility, power conversion and controls for power production. A system controller computes the correct loading on the turbine-generator to maximize power production. While shown as a single-phase connection, power electronics systems readily connect to three-phase circuits and are routinely utilized for systems of several hundred kilowatts.

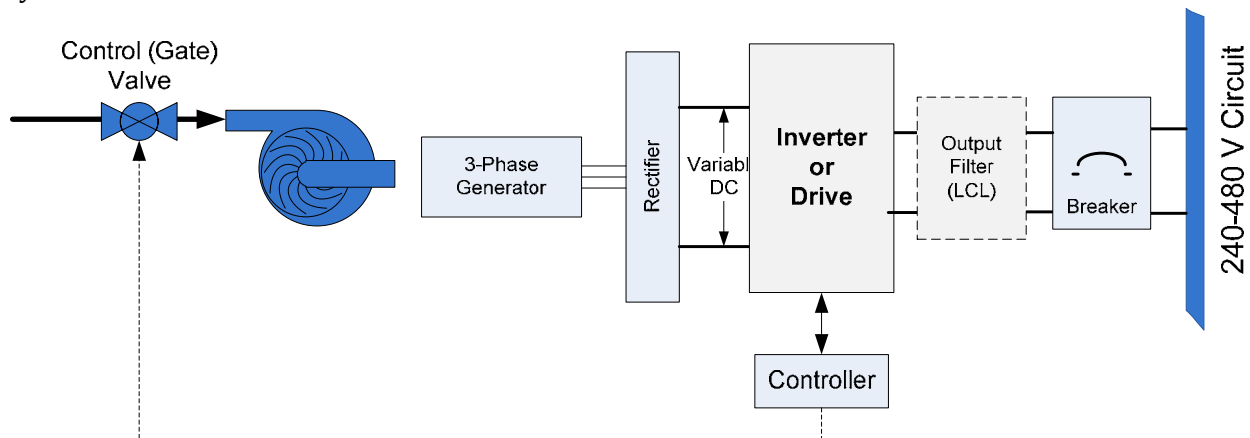


Figure 6: Typical Interconnect for Small Turbines

Most power-electronic-based systems can operate the turbine at variable speeds, which can improve efficiency at variable flow rates. Since turbine speed has some impact on water flow through the turbine, some designs can eliminate a variable-flow control device (typically a gate valve), while other designs utilize a traditional gate control.

Well-designed power-electronic systems have low fault currents, can synchronize without significant transients, and require no starting circuit. Although advanced systems have the reactive power control capability, these generators typically operate at unity power factor. Due to the high speed switching utilized in the power electronics, inverter/drives are typically coupled to an output filter which eliminates high-frequency harmonics. The filter may be included in the drive system, or may be a site-specific component.

Power electronics introduce an additional conversion step into the power system. While modern electronics are efficient, some losses are incurred. Typically, losses are 10-15% at design capacity, but efficiency typically decreases when operating above or below the design point.

DIRECT GENERATOR CONNECTION

Larger generators 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 7 (Utility transformer not shown). Direct connection benefits from higher efficiency than the inverter system, but suffers from fewer control options. Since the generator speed is effectively locked to a fixed grid frequency, the turbine typically rotates at a constant speed. Since speed is fixed, flow control must be provided externally in most cases, either through automatic or manual adjustment of intake gates. Flow control is necessary for both synchronization and load control.

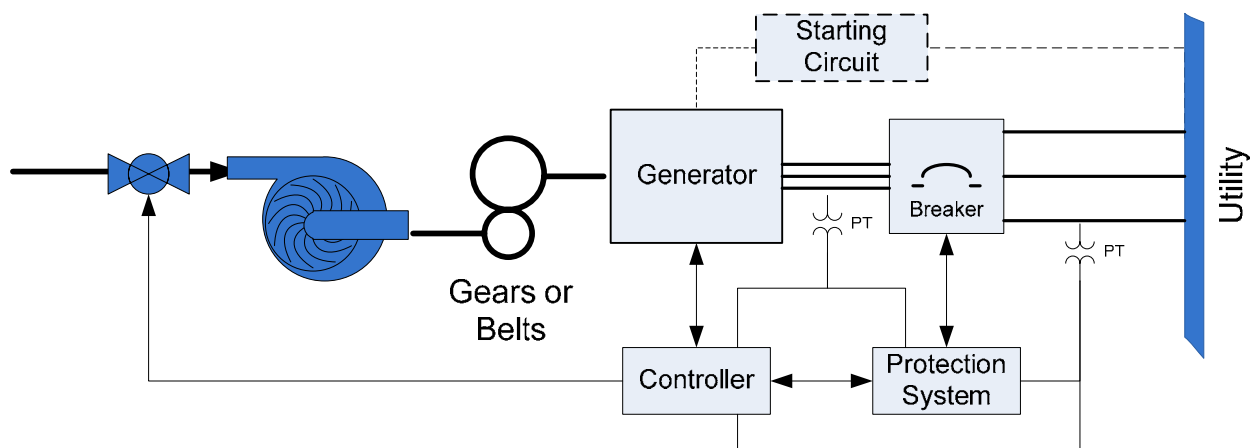


Figure 7: Typical Interconnect For Larger Turbines

Two types of generators are utilized in directly coupled systems, and each type is started and managed differently:

- Synchronous generators are started by imitating flow through the turbine to start the system spinning. Water flow is then regulated to match the generator speed to the grid frequency. When a match has been achieved, the breaker closes, connecting the generator to the grid. Water flow may then be increased to generate power. The starting operation is both complex and sensitive, and generally handled by the unit's control system.

It is important to note that a synchronous machine typically requires a method to actively control water flow to regulate the turbine speed during synchronization.

- Induction generators are similar to three-phase induction motors utilized for industrial loads. Induction machines can be started utilizing a motor starter to start the motor and turbine spinning. The motor starter limits the in-rush current to the motor, and may be required by the utility to reduce local voltage fluctuations ("flicker"). Once spinning, water flow is applied to the turbine to generate power. Alternatively, induction machines can be started similarly to synchronous machines, although this obviates the most significant advantage of induction machines over synchronous machines.

Synchronous machines are somewhat more efficient than the equivalent induction machine, operating at similar conditions. However, since industrial induction motors can be utilized as induction generators with proper design consideration, induction generators are often less expensive based upon the high-volume of induction motors.

In either case, the generators are directly coupled to a high-inertia device – the turbine – which is controlled by a slow governor – the flow-control gate. As a result, fault currents are typically high. Utilities typically require a delta-wye (Δ -Y) transformer connection, with the generator neutral tied to ground on the secondary side of the transformer. Electrical equipment must be sized to handle the fault current and slow control response, increasing the interrupt rating of the breaker. Finally, precautions must be taken to prevent turbine and generator overspeed if the breaker trips at full-power.

UTILITY AND EQUIPMENT-PROVIDER VIEW OF INTERCONNECTION

As a general rule, small hydropower equipment providers appear to favor directly coupled generation systems – most frequently synchronous machines, with a smaller number of induction machines. This result is unsurprising, given that equipment providers are most frequently selected (graded) on total efficiency and capital cost. However, purchasers should exercise caution. While directly-coupled machines have higher efficiency at rated capacity, efficiency may drop off significantly at reduced flows, due primarily to the efficiency curve roll-off of the turbine. System performance should be analyzed using *time-weighted actual flows*, not rated capacity.

In addition, installation of a direct-connect generator is likely to incur additional installation costs, which may not be quoted in the turbine package. These costs include:

- Protection relays⁵ required by the utility.
- Higher interrupt current ratings for breakers.
- Utilities typically required an engineering study for directly coupled generators (e.g. a fault study and protection coordination study) which may add significant cost.
- Controllable flow gate

The design of protection and synchronization equipment is not standardized. Significant variation exists in the implementation of these systems. A particular concern is the required “anti-islanding” function of the protection equipment, which prevents a synchronous generator⁶ or inverter from powering the local utility circuits when they are “black” – i.e. disconnected from the grid. Perhaps unsurprisingly, utilities are therefore nervous about system behavior, and generally require an in-person “witness test” of the system prior to providing interconnect permission.

Some equipment providers have implemented power-electronic solutions, typically variable-speed solutions based upon regenerative, variable-speed drive technology. These solutions appear to be driven more by the behavior of the turbine than by an effort to reduce interconnect costs, although cost reduction may be achieved as a side effect. Inverters/drives typically implement all synchronization and protection functions directly in the inverter. Quality drive units are factory certified to appropriate standards, particularly UL 1741 and IEEE 1547.x. Many utilities accept these certifications as a complete solution to synchronization and protection requirements. In addition, the output stages of an inverter/drive, including the LCL filter, typically have much lower fault currents than an equivalent sized rotating machine.

In contrast with the equipment providers, discussions with Colorado electric utilities⁷ indicate a distinct preference for power-electronics, due to the two factors listed above – lower fault currents and standardized interconnect and protection behavior.

⁵ A protection relay is a electronic control device which monitors the generation connection for issues such as ground fault, phase imbalance, or overcurrent, and disconnects the generator by opening the breaker.

⁶ By their nature, induction generators cannot operate without a grid frequency, except in rare conditions.

⁷ Conversations were conducted with XcelEnergy, Grand Valley Power regarding hydropower interconnection, and additional discussions were held with Poudre Valley REA regarding distributed generation interconnect in general.

For any generator, the utility will require an externally-accessible, lockable, disconnect between the utility and generator for the protection of line crews. Some utilities may also required a data feed from the generator to the utility's control (SCADA) system, which may require a 900 or 1800 MHz radio connection, land line or 3G cell phone connection. On occasion, utilities may also require a remote control or remote lock-out capability. Given the remote location of irrigation-based hydropower, these communication capabilities may add significant installation and operation costs.

INTERCONNECTION TECHNOLOGY SUMMARY

The table below summarizes the technology trade-offs of the two types of power systems:

Attribute	Power Electronics	Direct Connection
Interconnect protection equip.	<ul style="list-style-type: none"> Protection generally included in inverter/drive system Turbine speed control not required for grid synchronization 	<ul style="list-style-type: none"> Requires auxiliary protection equipment Grid synchronization requires speed control turbine speed control
Fault Current	<ul style="list-style-type: none"> Low Delta typically, but Wye connect OK Nominal interrupt rating on breakers. 	<ul style="list-style-type: none"> High Typically requires delta-wye connection with grounded neutral. High interrupt rating on breakers
Efficiency @ Rated	<ul style="list-style-type: none"> 85-90% typical 	<ul style="list-style-type: none"> >95% typical
Efficiency for flows above/below design capacity	<ul style="list-style-type: none"> Variable speed improves turbine efficiency for some turbine types, but power electronic losses may increase operating away from rated capacity 	<ul style="list-style-type: none"> Turbine efficiency may drop off at flows above/below design flows.
Harmonics	<ul style="list-style-type: none"> Filter required. May or may not be bundled into the drive system. 	<ul style="list-style-type: none"> Minimal filtering required. May require a resistor on neutral connection.
Protection Systems	<ul style="list-style-type: none"> Included in inverter/drive 	<ul style="list-style-type: none"> Separate, utility-approved, control relay required.
Utility Preference	<ul style="list-style-type: none"> Preferred for small systems 	<ul style="list-style-type: none"> Preferred for large systems

INTERCONNECTION AND POWER SALES

Before interconnecting and selling power to the local utility, a power provider must acquire an "interconnect agreement" with the local utility and a "power purchase agreement" with a utility which will purchase the power. While these two agreements may be with the same entity on occasion, in general they are executed with two different utilities. This section discusses the interconnection agreement first, followed by a discussion of utility structures common in Colorado, and finally power purchase types and agreements.

INTERCONNECTION

An interconnection agreement is, in most respects, similar to the service agreement executed by most customers when signing up for electrical service with their local utility. However, since far fewer generators are connected to the utility than loads, there is more variation in interconnect agreement content, topic, applications and costs. An interconnection agreement allows a customer

to generate power *in parallel with* the grid. The power may be utilized internally by the customer or may be exported to the grid.

Interconnect may occur using a single-phase or three-phase connection, determined primarily by the size of the generator. A typical maximum size for a single-phase connection is 50 kVA,⁸ although some locations can support single phase connections as high as 100 kVA. Above these limits, a three-phase connection is required. All of the generators considered in this report operate at *low voltage* – i.e. below 600 V – and would be coupled to the grid through a transformer that connects into the local medium-voltage distribution system, typically operating at 10-25 KV.

Interconnect agreements specify required equipment provided by the customer, terms of service, certification requirements and billing procedures. Most utilities charge a service fee to process the application and set up the customer's account, and a monthly "distribution charge" to cover the cost of maintaining the connection to the customer's location. The agreement will also clearly define the demarcation between the customer's and utility's responsibility for service and repair, typically defined as the secondary connection on the utility transformer.

UTILITY STRUCTURE

A few utilities in Colorado, including Public Service of Colorado (Xcel Energy), are vertically integrated utilities, operating end-to-end utilities, from generation to customer connection. More typically, the local distribution utility (e.g. Poudre Valley REA) operates the distribution system and customer connection, while a separate entity provides transmission and generation (T&G) services (TriState T&G for Poudre Valley). In most cases, the distribution utility has a "sole provider" contract with the T&G provider, which limits the power a distribution utility can purchase from sources other than the T&G provider ... including locally produced hydropower. The Governor's Energy Office (GEO) annually compiles a report summarizing utilities in Colorado⁹ which is useful for understanding the operational structure of any utility operating in the state.

Utility structure and its impact on power purchase arrangements is a substantial subject, out of the scope of this report. However, to understand the following sections, a few key points must be highlighted:

- 1) Since irrigation system hydropower plants are small – *very* small by utility standards – they will be interconnected to the distribution system. The *interconnect agreement* is therefore an agreement between the distribution utility and customer.
- 2) Many distribution utilities have the contractual flexibility to purchase small amounts of power directly from their customers. Many, but not all, utilize this flexibility. Most of these programs were initiated to support residential photovoltaic systems. While the smaller hydropower plants discussed here are similarly sized, they *may or may not qualify for these*

⁸ kVA, or kilo-volt-amps, is a measure of the *apparent power* on a circuit. It is the geometric sum of *real* and *reactive* power, or $S = \sqrt{P^2 + Q^2}$, where P is the real power, Q is the reactive power, and S is the apparent power. For generators operating near unity power factor, $Q \cong 0$, and $P \cong S$. However, certain loads, such as motors, and certain generators, such as induction generators, can have nontrivial reactive power requirements, significantly decreasing the real power capacity of the circuit below the apparent power rating.

⁹ Colorado Governor's Energy Office, 2010 Colorado Utilities Report, August 2010

programs – check with your utility. Most programs apply only to systems of 10 kW or smaller.

- 3) For systems larger than those supported by (2) above, two entities must agree to the generation: The distribution utility must agree to interconnect the generator and the T&G operator must agree to purchase the power. Either entity can block implementation.
- 4) If power is purchased by the T&G operator, the distribution utility may charge a “feed in” or “wheeling” fee, based upon the amount of power produced, to cover the cost of transmitting the power into the T&G operator’s system. These fees can be substantial – \$0.01 - \$0.02 / kWh is not uncommon – and justification for them seldom available, making it difficult to negotiate reductions.

POWER PURCHASE AGREEMENTS

The price paid for power is a complex convolution of Federal Energy Regulatory Commission (FERC) rules, state law, PUC rulings, and the negotiating leverage of the customer, T&G operator and distribution utilities.

While there are no hard-and-fast rules, it is useful to divide power purchase into three categories:

- 1) Large generators. For large systems – multiple megawatts – all generation is purchased using negotiated contracts, and state-mandated bidding rules may also apply. Few irrigation hydropower systems fall into this category.
- 2) Net-metering. Small systems – typically less than 10 kW – can be connected in a *net metering* arrangement, where produced power is combined with local loads, and the difference (i.e. *net amount*) is settled (billed) by the utility. As noted above, most net metering programs were set up of residential photovoltaic systems, and may or may not be available for hydropower.

Since net-metering provides power “behind the meter,” produced power offsets the retail price of electricity, rather than the wholesale price seen by units in (1) or (3). It is often the most financially advantageous means of using distributed generation. However, this benefit fades if the produced power exceeds local loads. It is not unusual for “net power” to provide customer benefit of more than \$0.06/kWh, while the utility credits only \$0.02-\$0.04/kWh for “excess” power sold back to the utility.

Finally, the definition of net metering varies between utilities. Some utilities allow multiple meters, at different interconnection points, to be “netted” on one bill. Others insist that net metering is exactly that – net power behind one meter.

- 3) Other. Most of the systems considered in this report lie in the no-man’s land between net-metering and large operations. Few hard-and-fast rules exist in this space. Interconnect agreements may be non-standard and problematic. The vast majority of systems in this category operate as *wholesale power producers*, under bilateral contracts with the appropriate T&G operator.

We now consider the application of (2) and (3) to the hydropower systems considered in this report.

Net metering:

For any given irrigation site, two entities may be interested in net-metered electricity production.

- 1) **Irrigation Company:** If the irrigation company has significant loads near the structure, there may be an opportunity to net meter those loads with power production. While a statistically-significant survey has not yet been conducted, *no sites* were found in our limited survey where this would be possible. However, if the local distribution utility permits net-metering across several interconnection points, it may be possible to net power production at one or more hydropower plants with pumping loads elsewhere. In this case, load and generation should be temporally well-aligned – the best case for net-metering.
- 2) **Nearby Load:** Another party near the structure could potentially develop the site and net-meter power produced with local loads. This may be practical for some smaller sites in built-up areas. Development requires a three-way agreement between the irrigation company, the local power user, and the utility.

Without a complete survey of irrigation-related sites, it is difficult to project the quantity and quality of net-metering opportunities. However, it is the opinion of this research team that few such sites exist *unless distribution utilities support net metering aggregating multiple meters*.

Wholesale power sales:

Above the net-metering size, few hard-and-fast rules exist. However, one useful classification is to consider the presence or absence of applicable renewable portfolio standards (RPS). When the resource counts against RPS, the power purchase price is significantly higher, and purchase rules are governed differently, than when RPS does not apply.

Currently, different RPS targets are specified for utilities regulated by the Colorado PUC (Xcel Energy and Black Hills Power) and unregulated entities. For this report, all sites studied in detail were in Xcel's service area, and this report will focus on the Xcel case. At the time of this report, Xcel had met all of its Colorado RPS standards, and was not in need of any additional purchases of renewable power. Therefore, no RPS-based prices were applicable to the sites studied here.

FERC mandates that all renewable power purchases be made at or below "lowest avoided cost" (LAC) unless a particular renewable source is subject to a state (or future federal) RPS that specifies another treatment. Considering Xcel Energy, current LAC is based upon Comanche III, a coal-fired thermal power plant utilized for base load. Currently published LAC is \$18.68/MWh with a capacity payment¹⁰ of \$7.63/KW-month. LAC minus Xcel's profit would therefore be the "floor" price for any power purchase agreement.

¹⁰ Capacity is the largest demand serviced by a generator during a billing, or settlement, period.

However, Xcel personnel indicated that Xcel preferred to move away from a capacity payment for renewable resources. The “capacity” of renewable resources is generally uncontrolled, and therefore does not reflect Xcel’s operating procedures. Xcel now typically offers an energy-only contract computed by inserting the proposed generation into Xcel’s existing dispatch model and running a multi-year dispatch simulation. This method tends to reward units which produce power during the summer peak months – such a irrigation hydropower – as the “displaced units” in the model are the most expensive in Xcel’s portfolio.

It is important to note that the current dispatch model typically does not react (i.e. dispatch the new unit) unless the unit is larger than 10 MW. This represents an additional challenge for small hydropower.

No firm prices are available, but off-the-record discussions indicate that recent energy-only offering prices have been in the range of 35-40 \$/MWh.

COST OF INTERCONNECTION

Interconnection costs for small hydropower plants were investigated by looking in more detail at the Grand Valley Irrigation Company sites studied for this report. Eight sites were identified, and are described in detail in the appendices. Seven sites were located in Xcel Energy’s service territory, and Xcel estimated interconnection costs. The *13 Loma Road* site was located in Grand Valley Power’s service area, and was not evaluated. Finally, one site in Xcel’s territory – *Headgate* – was not evaluated because the applicable turbine type, and thus power production, was too uncertain. Fortunately, the six remaining sites represent a representative selection of conditions.

Figure 8 summarizes the electrical service costs for all six sites, with two entries for *The Dividers*, which could be connected at single- or three-phase.

Site	Nominal Capacity		Electrical Service Constraints		Service Installation Costs		
	Site Capacity (kW)	Est Annual Production (MWh/year)	Service Capacity (kW)	Est Annual Production Constrained by Service (MWh/year)	Estimated Cost (K\$)	Cost / Capacity (\$/W)	Cost / Production over 20 years (\$/MWh)
Oldhams	4	20	4	20	5	\$ 1.25	\$ 12.50
Gates Check	7.5	38	7.5	38	5	\$ 0.67	\$ 6.58
The Falls	125	650	100	520	10	\$ 0.10	\$ 0.96
The Dividers -- 100 kW 1-phase	185	960	100	519	10	\$ 0.10	\$ 0.96
The Dividers - 150 kW 3-phase	185	960	150	778	15	\$ 0.10	\$ 0.96
First Street Drop	450	2300	500	2300	25	\$ 0.05	\$ 0.54
18.5 Rd Drop	25	130	25	130	20	\$ 0.80	\$ 7.69

FIGURE 8: SUMMARY OF INTERCONNECT COSTS

Explanation of the table:

- **Nominal Capacity:** The capacity of the site calculated from hydraulic considerations and turbine type.

- **Electrical Service Constraints:** For *The Falls* and *The Dividers*, available electrical service is less than the nominal capacity. These columns adjust the capacity and energy production appropriately.
- **Service Installation Costs:** Xcel engineers estimated service installation costs, which do not include protection relays, filters and other equipment, as noted above. To allow meaningful comparison, these costs are scaled by the service-constrained capacity and the service-constrained total power production over a 20 year period.

Figure 9 illustrates the cost of service as a function of the unit capacity. As expected, there is strong relationship between the unit size and cost, with larger sizes costing proportionally more. The exception to this rule is the *18.5 Road Drop*, which is significantly more expensive for its size than other sites. This reflects the rural location, requiring installation of overhead lines (4 spans were estimated).

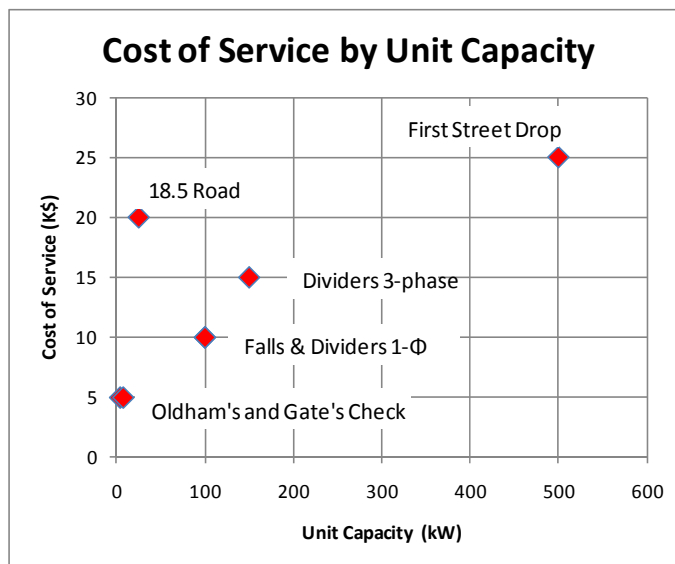
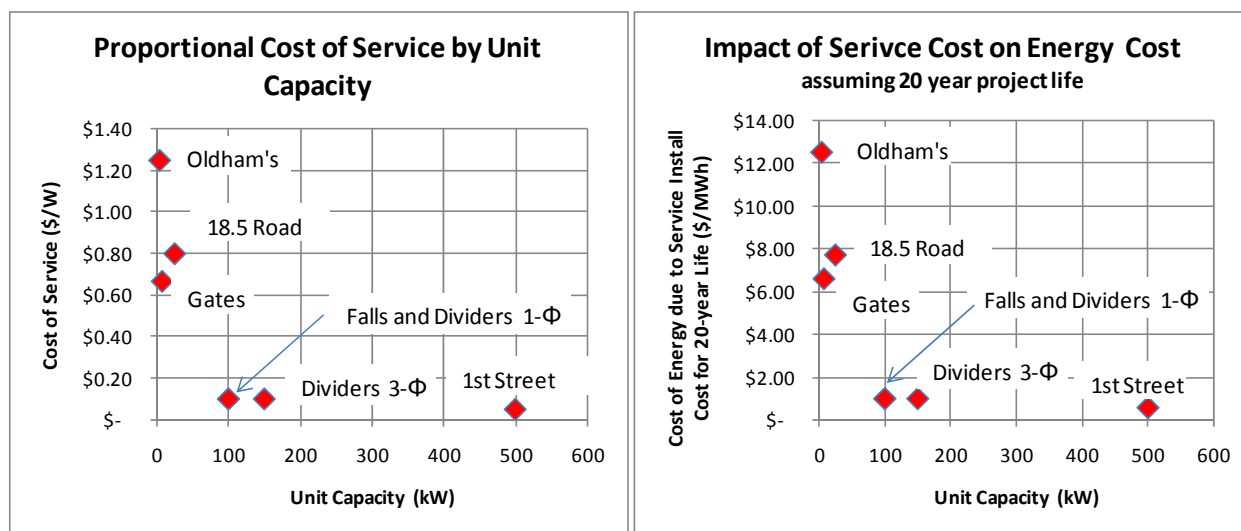


FIGURE 9: COST OF ELECTRICAL SERVICE UNIT CAPACITY

Also notable is the “Y intercept” of the cost. Regardless of size, the electrical service cost for his sample bottoms out at approximately \$5,000. A similar cost floor is seen for most small distributed generation, which is why net-metering, which shares an electrical service, is attractive for small systems.



(A) SERVICE COST / UNIT CAPACITY

(B) SERVICE COST / 20-YEAR ENERGY PRODUCTION

FIGURE 10: SERVICE COST RATIOS BASED UPON UNIT CAPACITY

Figure 10 displays the same data, scaled by the unit capacity (A) or power produced during twenty years of operation (B). Here the penalties for rural (*18.5 Road*) or small (*Gates* and *Oldham's*) sites

are clearly manifest. The rural site is probably unworkable at current power price. The sites below 10 kW could be cost-effective if net metering is an option and the power output could be tied into an existing service at low voltage. If a new service and meter are required, however, these sites are probably not viable, since the electrical service alone would cost 10-25% of the likely revenue from power purchase over twenty years.

For the larger sites, electrical services costs drop from \$0.96/MWh for the 100-200 kW sites to \$0.54/MWh for the larger *First Street* site. While these costs are only a portion of total development costs, they do appear to eliminate development potential at these sites.

ELECTRICAL INTERCONNECT CONCLUSIONS

The optimum choice of a power conversion and interconnect system for small hydropower is currently unclear. While directly coupled machines may benefit from simplicity and higher efficiency at rated load, power electronics solution may cost less to interconnect and produce higher efficiencies below rated loads. Ongoing work at CSU will study typical sites for potential system configurations and costs.

Considering revenue, irrigation-related hydropower faces severe challenges. Small sites are unlikely to be profitable without net metering, and net metering is an unlikely option unless more local distribution utilities support “netting” power production across multiple, dispersed meters. This is currently uncommon.

Larger sites are similarly challenged by

- Complex of interconnect and power purchase agreements
- Lack of standardized solutions
- Low wholesale power purchase revenue.

TASK 4: COMPARE TECHNOLOGIES TO STRUCTURES

TYPICAL STRUCTURES

Typical irrigation structures were identified throughout the course of this project. Information was collected from the returned surveys as well as the project canal investigations. Six types of structures are commonly seen on irrigation canals and ditches across the state; diversion structures, concrete lined chutes, vertical drops, checks, pipelines, and reservoir outlets. The potential exists at all of these structures to produce low head hydropower. This section will review the typical structures, and make recommendations on the types of turbines that should be considered with factors that may affect their feasibility at a particular site.

DIVERSION STRUCTURES

Almost all canals utilize a direct diversion off of a river in Colorado, unless the canal is fed by a reservoir. In order to divert directly from the river into a canal headgate at the point of diversion, a diversion structure of some sort is constructed. Diversion structures can range in size and intricacy depending on the size of both the river and the headgate. The simplest diversion structures are made by placing large boulders in the river to raise the water surface slightly and direct water into the headgate. More complex diversion structures consist of a concrete diversion dam across the river like the one pictured below. This diversion structure has an Ogee weir across the river with two sand gates that allow flushing of the sediment that builds up behind the dam. A trashrack prevents debris from entering the headgate, and gates are used to control the flow into the canal.



FIGURE 11: CONCRETE DIVERSION STRUCTURE

There are several reasons why a diversion dam like the one pictured above makes a good structure to implement low head hydropower. First, the dam extends across the flow of the river, allowing the hydropower plant to utilize the full flow of the river. Second, the existing infrastructure can be used to lower the installation cost of the unit. Installing hydropower on a rock diversion dam will be more challenging. If the organization is considering upgrading a rock diversion dam to a concrete diversion dam it would be beneficial to investigate incorporating low head hydro into the new structure early in the process.

There are several turbines that may be used at a diversion dam depending on the size, head and expected flow rate; the VLH Turbine, an Archimedean Hydro Screw, the Natel Hydroengine or a traditional Kaplan. The first three turbines are relatively new to the marketplace and are designed

to make use of existing infrastructure. Considering the geometry of the structure may dictate which turbine would be most appropriate. The VLH is produced in 5 standard sizes, and considerable cost could be saved if the turbine could “slip” into an opening. The Archimedean Hydro Screw would be best installed in an inclined opening, like a spillway type opening. Installing either a Natel Hydroengine or a traditional Kaplan will require building a wall inside one of the gates with an opening near the bottom to hook up the turbine. These turbines also require submergence of the draft tube downstream of the turbine. This may require building a stilling pool on the downstream side of the dam.

At the time this report was written there was a large difference between the price of the VLH and Archimedean Hydro Screw as compared to the Natel Hydroengine. The VLH and Archimedean Hydro Screw could be as much as 2 to 3 times more expensive than the Natel. This is for the cost of the turbine itself, not the civil infrastructure required for installation. This cost difference may decrease in the near future, all three turbines are relatively new, and more are being installed each year. The VLH and the Archimedean Hydro Screws are currently manufactured in Europe.

CONCRETE LINED CHUTES



FIGURE 12: CONCRETE LINED CHUTE

Concrete lined chutes are commonly used to transport water down a gradual hill while preventing erosion of the native ground. There are two basic methods to utilize these drops for hydropower, one would be to make use of the existing concrete chute with an Archimedean Hydro Screw, and the other would be to pipe the drop adjacent to the existing chute and use a more traditional turbine.

The length, angle and width of the chute will determine if an Archimedean Hydro Screw could be installed with minimal modification to the existing structure. The chute pictured here is too long and narrow for a Hydro Screw to “slip” into the existing infrastructure. If the infrastructure does not need significant modifications, this may be a cost effective turbine at a concrete lined chute.

The civil infrastructure required to install a traditional turbine at this site may be as costly as the turbine itself.

A pipeline will have to be run alongside the chute and a power house constructed at the bottom. The chute would then be used as a bypass if the turbine was shut down for any reason. This is important for irrigation canals with users that depend on water downstream of the turbine.

VERTICAL DROPS

When the topography of the land is more abrupt the canal may fall vertically at a drop. The infrastructure available at a vertical drop is much different than at a gradually sloping chute. In some cases the concrete infrastructure that exists to create the vertical drop may be used to house a



FIGURE 13: VERTICAL DROP

turbine. The turbine can easily be added to the existing infrastructure without costly modifications. This picture shows a typical vertical drop that might be seen in a canal system. Water cascades over the concrete structure, and could be harnessed to produce power. These drops are typically less than 15-20 feet high.

The turbines that would be appropriate at a vertical drop are the same as those appropriate at a diversion dam, where the vertical drop also occurs over a short distance. The Mavel Microturbines, and the Natel Hydroengine would likely require the least amount of modification to infrastructure. A Kaplan turbine or other inline type turbine could be installed but would require a penstock. An Archimedean Hydro-Screw or Ossberger Moveable power plant could be used with more intensive modifications to the structure.

PIPELINES

Most canal systems have some length of piped sections. Piped sections may be used to cross heavily populated areas, roads, or areas of highly permeable soils for example. Some canal systems are converting large reaches of canals with pipe as a water conservation measure. Others choose to pressurize the canal system to take advantage of the gravity head available and provide pressure to on farm irrigation practices such as sprinklers. There are numerous possible scenarios regarding pipelines and hydropower.

If the head generated in the pipeline is supplied to a downstream sprinkler system, and all of the head is required, hydropower cannot be added to the system without impacting the sprinklers. The hydropower would “burn” the head that is needed to properly operate the sprinklers. If there is excess head available, a pressure reducing valve (PRV) is typically used to lower the pressure in the pipeline to an acceptable level. Replacing the PRV with a turbine may be an opportunity to add hydropower to the system without impacting current operations. Generally an inline turbine would be added in parallel with the PRV. The PRV acts as a bypass and will allow the system to function properly if the turbine needs to be taken out of service. Other pipelines dissipate the accumulated pressure in an energy dissipation structure at the outlet of the pipeline. In this case, a bifurcation could be placed at the outlet of the pipeline to provide a leg for the turbine and a leg for a bypass.



FIGURE 14: PIPELINE WITH PRV VAULT

There are a number of inline turbines available that can be used in conjunction with an existing pipeline. The choice of turbine will depend on the flow rate and the head available. Examples of such turbines include most of the propeller type turbines, such as the Voith, Canyon Hydro, and Gilkes Kaplan, the Toshiba e-KIDS, and the Turbinator.

One additional note regarding hydropower in existing pipelines, it is possible to design some turbines and valves to maintain a downstream pressure. Although this is not the norm, occasionally, some downstream pressure is required. A hydropower facility could be located at the elevation required to accumulate the required head downstream of the unit, or the facility can be designed to “leave” some head in the pipeline immediately downstream of the turbine. If an irrigation company is considering piping sections of the system, consider hydropower during the design process to see if modification to the design could allow for the addition of hydropower in the future.

CHECKS

Check structures are used to raise the water surface in the canal, generally to supply water to an upstream headgate. These structures often result in water surface elevation drops of 5 feet or less. Checks take on various forms, but generally the concept is to raise the bottom of the canal, and



FIGURE 15: CHECK STRUCTURE

possibly constrict the sides. This will tend to increase the velocity of the water over the structure, and may provide an opportunity for a hydrokinetic turbine.

Hydrokinetic turbines produce power based on velocity instead of pressure and flow. The general equation to determine the power available at a hydrokinetic site, is as follows;

$$P = \frac{A * V^3}{3}$$

Where P= Power (Watts), A = area of the turbine in flow (ft²), V = Velocity (ft/s). Both velocity and

the depth of water at the check must be considered to determine the feasibility of using a hydrokinetic turbine. They are generally effective in the velocity range between 5 and 10 ft/sec, with at least 2 feet of depth. Each manufacturer has specific requirements for each model of turbine available.

RESERVOIR OUTLETS

There are a few additional considerations that must be made when adding a turbine to a reservoir outlet. In Colorado many small reservoirs are emptied or lowered on an annual basis to meet late season irrigation demands. The duration of flow may have a significant affect on a project's viability. Also, the variability of the head in the reservoir may influence the turbine selection and the project's viability. Most low head turbines can operate within 50-125% of the design head. Fully adjustable Kaplan turbines can extend that range to 45-150%¹¹. The power will change

¹¹ Gulliver, J and Arndt, R (1991) Hydropower Engineering Handbook, McGraw-Hill, p 4.50

proportionate to the change in head, and efficiencies will vary over the range, but the turbine will still be able to effectively operate.



FIGURE 16: RESERVOIR OUTLET

Another consideration when adding a turbine to an existing outlet is the condition and capacity of the outlet pipe. If the dam is considered jurisdictional in Colorado, the Colorado Dam Safety Branch will be involved in any modification to the dam structure, including the addition of a turbine. The FERC will also be involved in the design process and will ultimately take over jurisdiction of the dam's safety from the State.

When considering the feasibility of a reservoir site, one must understand if the outlet was designed to operate under pressure. Most dams have a valve on the upstream side of the outlet pipe, therefore the actual outlet does not run under pressure. If a turbine were added to the downstream side of the outlet pipe, it would cause the entire pipe to be pressurized. Some dams have oversized non-pressurized tunnels that lead to the outlet valve. In this case it may be possible to add a pressurized penstock and possibly the turbine inside of the tunnel, as space allows.

Typically, custom built, traditional turbines are appropriate for reservoir outlets, and the type would depend on the head available. Some of the newer low head technologies may be applicable depending on the conditions. Generally, a custom built turbine would be more efficient and suited for the exact site conditions, but potentially more expensive than a standardized model.

TASK 5: ESTIMATE A STATEWIDE POTENTIAL

We intended to use the information collected from both the surveys and the project canals to make an estimation of the statewide potential to produce low head hydropower. The intent was to obtain a statistically significant sampling of canal systems to extrapolate a statewide potential. We were unable to collect enough information to extrapolate quantitatively with confidence. Although from the data that we did collect, we can make qualitative inferences. Throughout this report we have shown that there are numerous existing structures within canal systems that can be utilized in the implementation of low head hydropower. Innovative, emerging technologies are currently entering the marketplace. These technologies have the potential of reducing the civil costs associated with installation, by utilizing these existing structures. When replacing aging infrastructure, canal companies may consider altering the design of the infrastructure slightly to accommodate these turbines.

APPENDIX A: LOW HEAD TURBINES

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 variety of configurations including one or two cells, and horizontal 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.

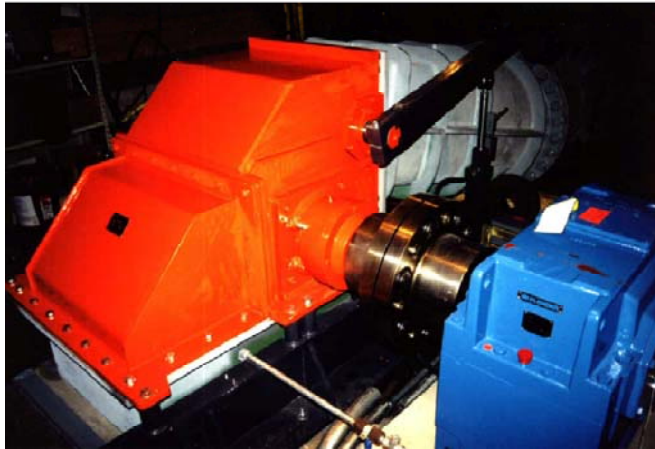


FIGURE 17: OSSBERGER CROSS FLOW TURBINE AT THE MAROON CREEK POWER PLANT, CITY OF ASPEN

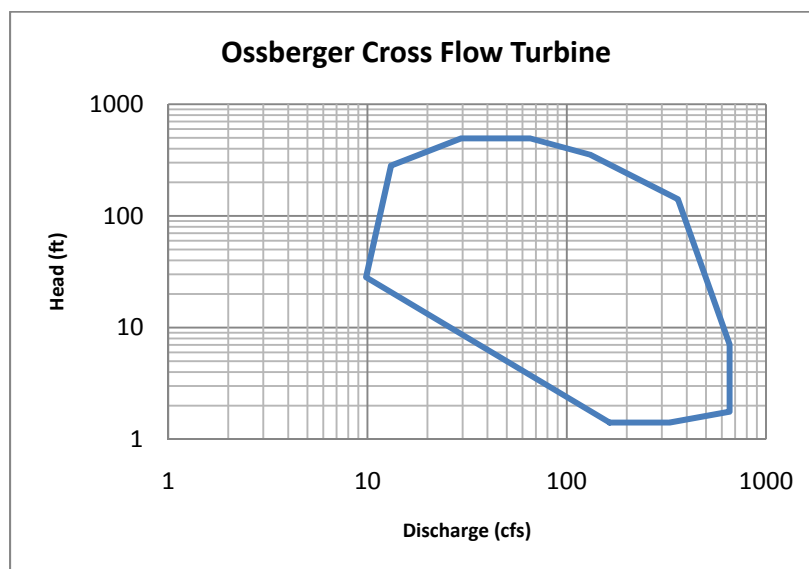


FIGURE 18: RANGE OF SITE CONDITIONS

REACTION 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 magnet 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.

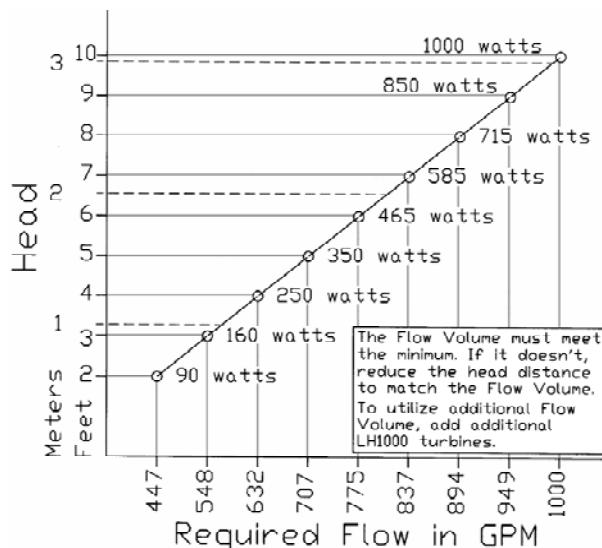


FIGURE 20: RANGE OF OPERATION
(WWW.ABSAK.COM)



FIGURE 19: TWO LH1000 TURBINES INSTALLED
IN A VAULT (ES&D, 2010)

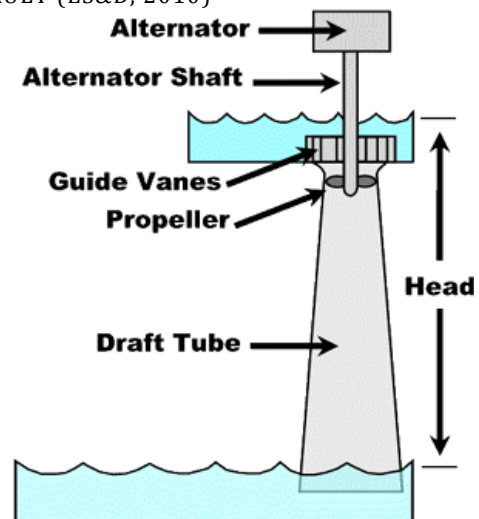


FIGURE 21: BASIC COMPONENTS
(WWW.ABSAK.COM)

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 turbine 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 22: POWER PAL

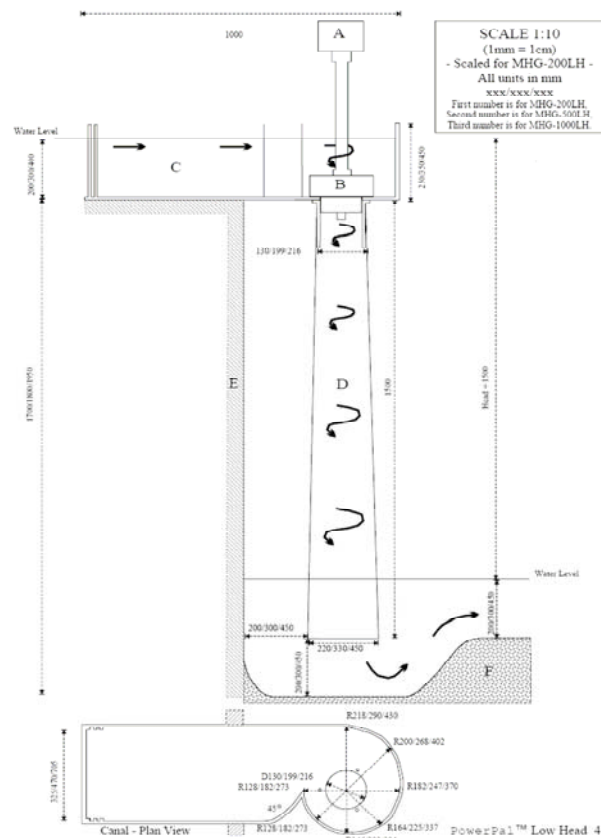


FIGURE 23: POWER PAL SCHEMATIC

REACTION 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 24: 300 KW KAPLAN TURBINE
INSTALLED IN LOGAN, UTAH



FIGURE 25: 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

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 accommodate a range of head and flow conditions.

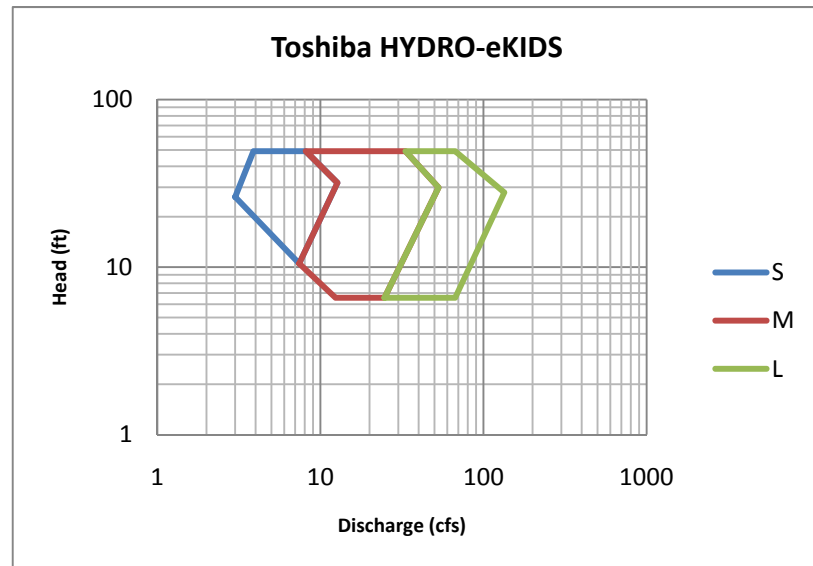


FIGURE 26: RANGE OF SITE CONDITIONS

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 disturb the existing dam.



FIGURE 27: EXAMPLE INSTALLATION WITH SIPHON INTAKE

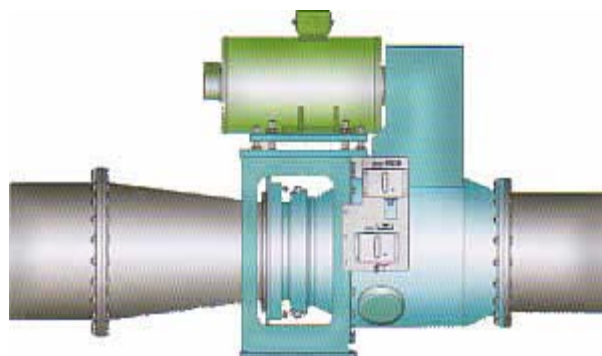


FIGURE 28: TYPE M (WWW.TIC.TOSHIBA.COM.AU)

OSSBERGER CANADA – MOVABLE POWER HOUSE

4839 Brébeuf,

Montreal,Qc, Canada, H2J 3L4

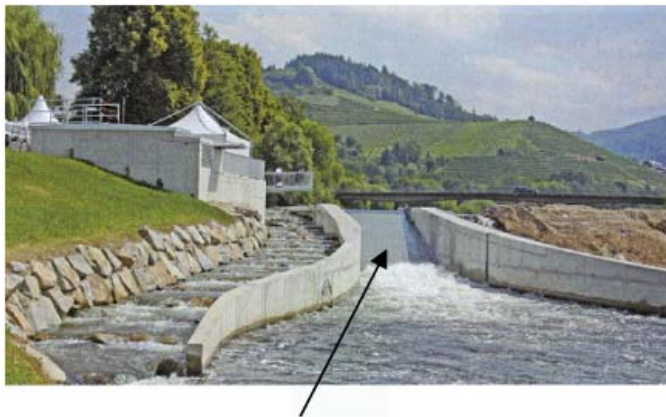
514-525-8430

<http://www.hsi-hydro.com/cd/>

In addition to the Cross Flow turbine, Ossberger has recently developed a Kaplan turbine / generator package for specific low head applications called the “Movable Power House”. This hydropower station is a completely submersible package developed to reduce overall costs of low head projects. Typical project installations would be within a weir or hydraulic control structure. There are currently five (5) power stations in production in Europe. The generator is a permanent magnet, direct connect type.

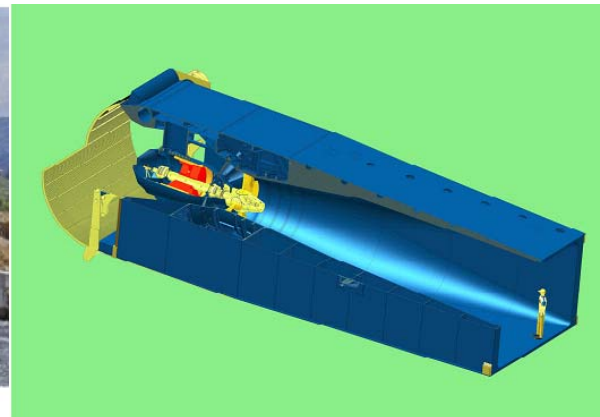
Working Range					
Head (ft)		Flow (cfs)		Power KW	
3.3	26.2	35.3	882.2	350.0	900.0

Dimensions			
Length (ft)	Width (ft)	Height (ft)	Weight (tons)
62.3	17.4	14.1	143.0



MOVABLE POWER STATION

FIGURE 29: MOVABLE POWER HOUSE INSTALATION



KAPLAN-TURBINE TYPE BBL

FIGURE 30:MOVABLE POWER HOUSE

MAVEL - MICROTURBINES
 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 existing structure that needs to be bridged. Installing the siphon outlet may decrease installation costs if modifying the existing structure is not feasible.



FIGURE 31: TM10 INSTALLATION
 (WWW.MAVEL.CZ)

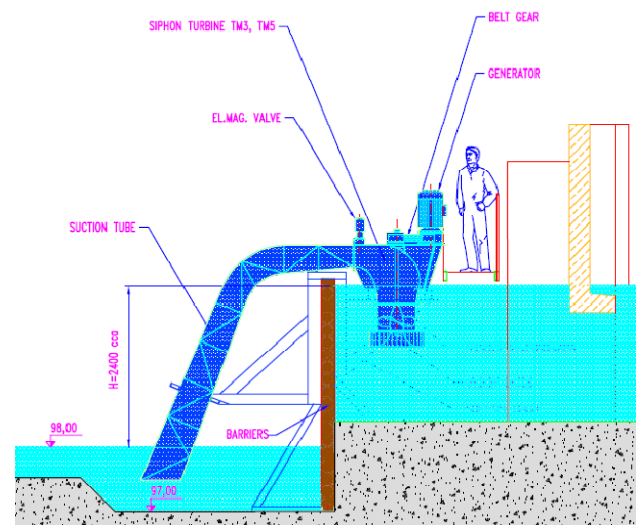


FIGURE 32: EXAMPLE INSTALLATION

VOITH HYDRO – MINIHYDRO

Jeremy A. Smith

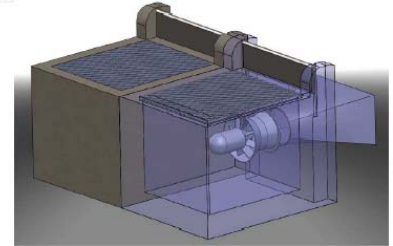
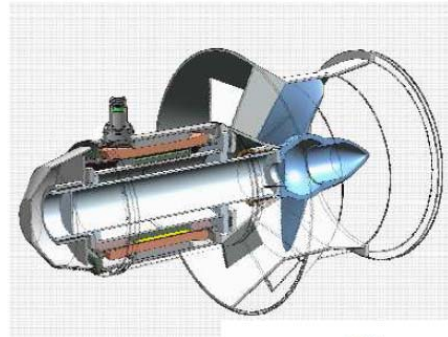
Manager, Small Hydro

Tel. 717-792-7868

Jeremy.smith@voith.com

Voiths MiniHydro concept is currently under development. The turbine will be appropriate for low head, low power applications where existing civil infrastructure may exist to reduce overall project costs. The in-line unit configuration is best suited for integration into existing channels, canals, locks, irrigation ditches, etc.

More details on this turbine will be available as the development progresses. Contact the manufacturer for more information.



Expected Operating Range		
Head (ft)	6.5	33
Flow (cfs)	35	500

REACTION 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 manufacture 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 33: ECOFLOW TURBINE (WWW.KOESSLER.COM)

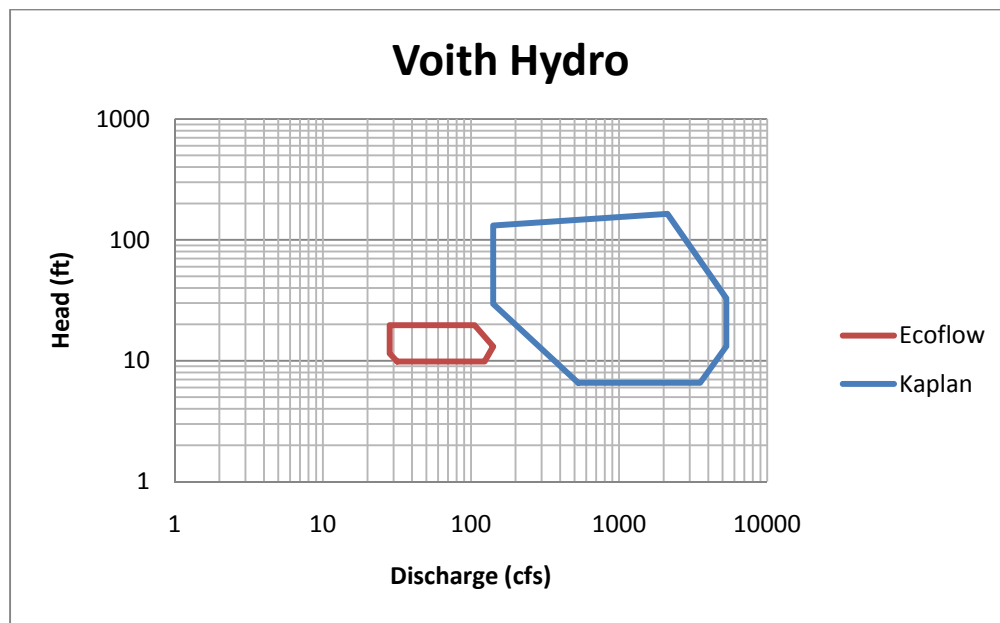


FIGURE 34: RANGE OF SITE CONDITIONS

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.

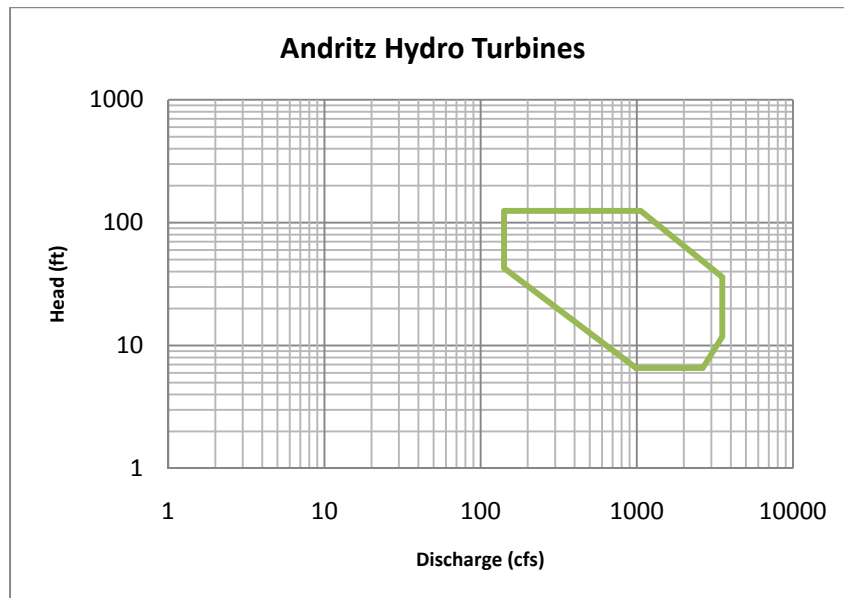


FIGURE 35: RANGE OF SITE CONDITIONS

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

GILKES – FRANCIS TURBINE

2103 – 4464 Markham Street

Victoria, BC V8Z 7X8

250-483-3883

a.robinson@gilkes.com

www.gilkes.com

Gilkes is a British company with a distributor in Canada. They manufacture both high and low head turbines, for small and large hydro applications. The company has been in existence since 1856. Gilkes designs and manufactures a Francis turbine in a range of sizes. All of the models range from low head to high head, between 10 and 700 feet.

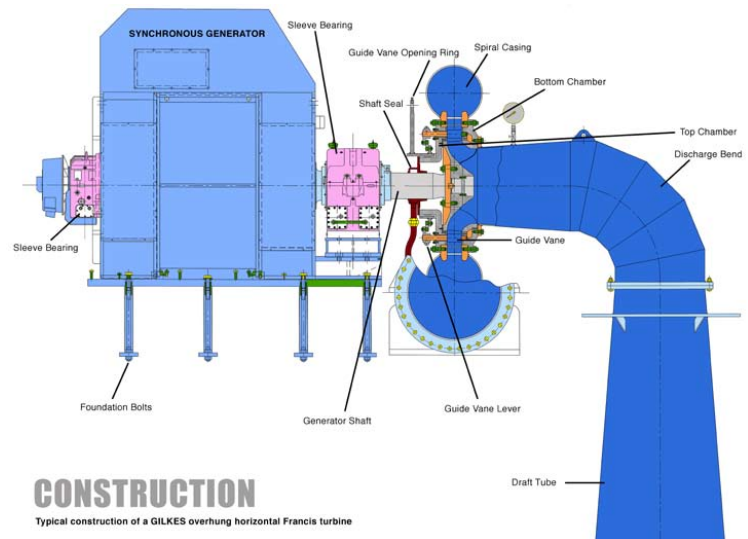


FIGURE 36: SCHEMATIC OF FRANCIS TURBINE

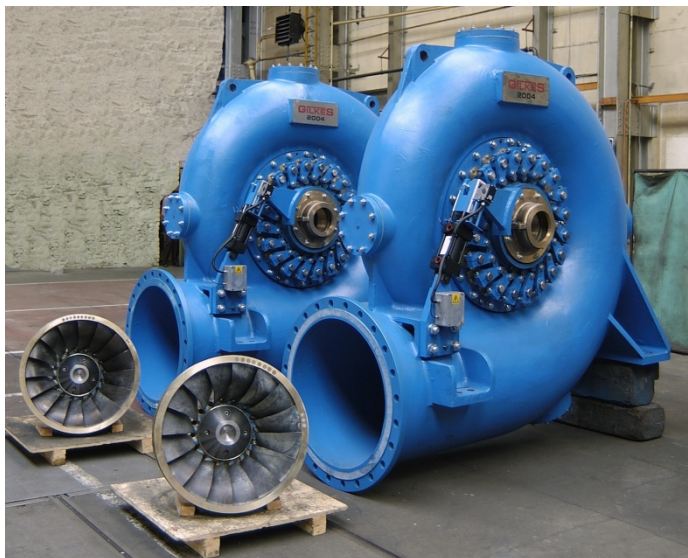


FIGURE 37: FRANCIS TURBINES

EMERGING TECHNOLOGIES

CLEAN POWER AS - TURBINATOR

Dalegata 137

N-6518 Kristiansund N

Norway

+47 71 56 66 00

<http://www.cleanpower.no/Home.aspx>

The Clean Power AS Turbinator is a relatively new technology (first installation in 2010). The Turbinator is a turbine/generator combination machine designed to be used with low to medium head ranges. To minimize total hydroplant costs, attention has been emphasized on the turbine/generator construction to reduce civil works cost to a minimum by providing a robust, simple design. The machine is designed to be exposed to the elements and requires minimal operation facility infrastructure. The generator is a permanent magnet, direct connect type.

Working Range					
Head (ft)		Flow (ft ³ /s)		Power (KW)	
32.8	196.8	17.6	176.4	100	2000



FIGURE 38: TURBINATOR



FIGURE 39: HEGSET DAM MINI HYDROPOWER PLANT

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 business into the United States. The turbine will be offered in five sizes to accommodate 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.

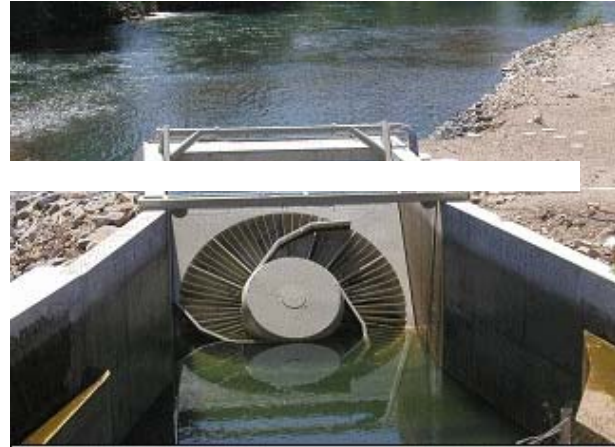


FIGURE 40: VLH TURBINE INSTALLATION
(WWW.VLH-TURBINE.COM)

Maximum discharge through the turbine at the specified head						
Runner Diameter (feet)						
Net Head (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)						
Runner Diameter (feet)						
Net Head (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			

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



FIGURE 42: PILOT INSTALLATION IN BUCKEYE, AZ
 (WWW.NATELENERGY.COM)

SCREW TYPE TURBINES

HYDROCOIL POWER

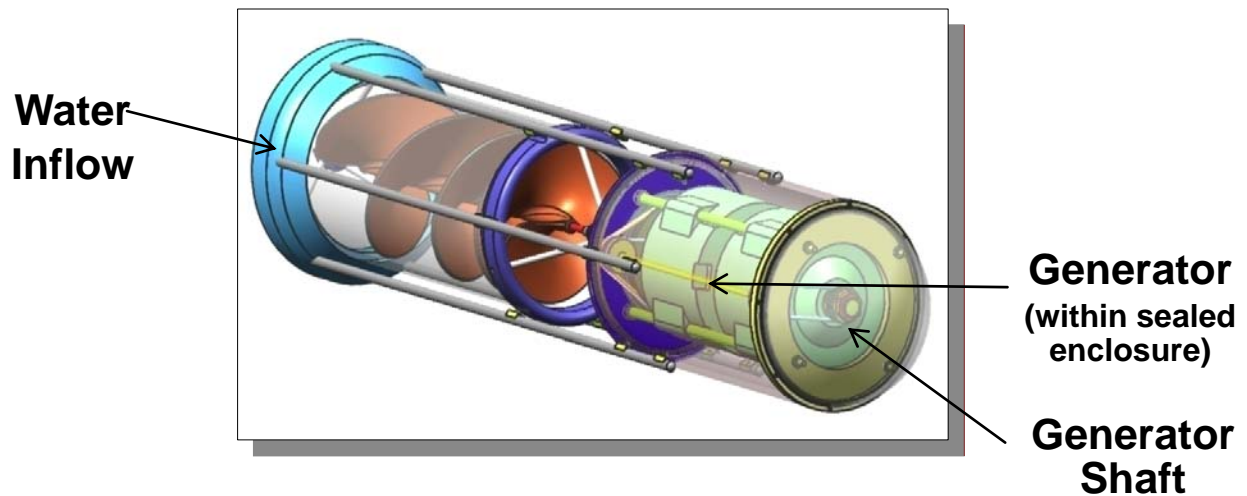
1359 Arbordale Road, 3rd floor

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 43: 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 distributors and installation in the United Kingdom. It appears that some of these distributors 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 44: HYDRODYNAMIC SCREW (WWW.RITZ-ATRO.DE)

3 HELIX POWER – ARCHIMEDES SCREW

Gregory Nau

(703) 447-2401

<http://www.3helixpower.com/>

The Archimedes Screw is a turbine/generator package. The configurations come in two assembly types: open and closed configurations. Open configurations are used for larger flow capacity screws where closed configurations are used for lower flow systems. Available packages can obtain power output from 5 KW to 500 KW.

The generator is a power systems type.



FIGURE 45: ARCHIMEDES SCREW

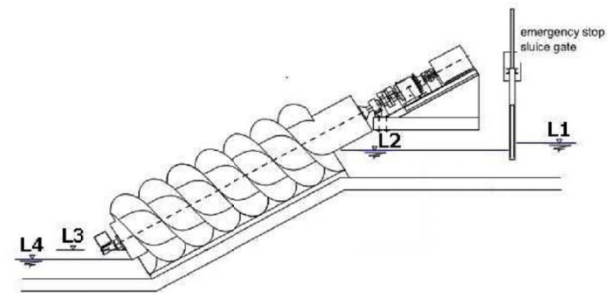


FIGURE 46: ARCHIMEDES SCREW

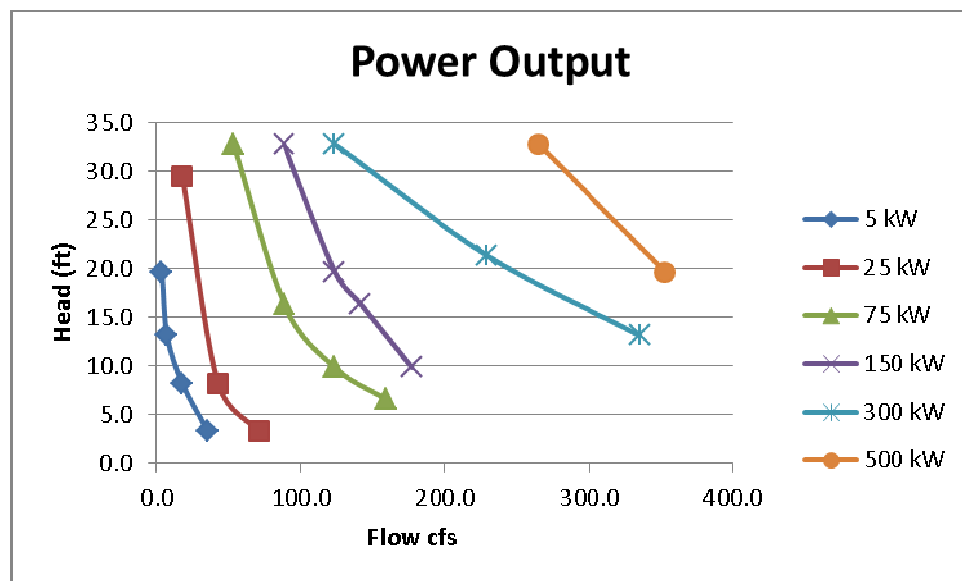


FIGURE 47: APPROXIMATE POWER OUTPUT

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 48: BREASTSHOT WATERWHEEL
(WWW.HYDROWATT.DE)



FIGURE 49: 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

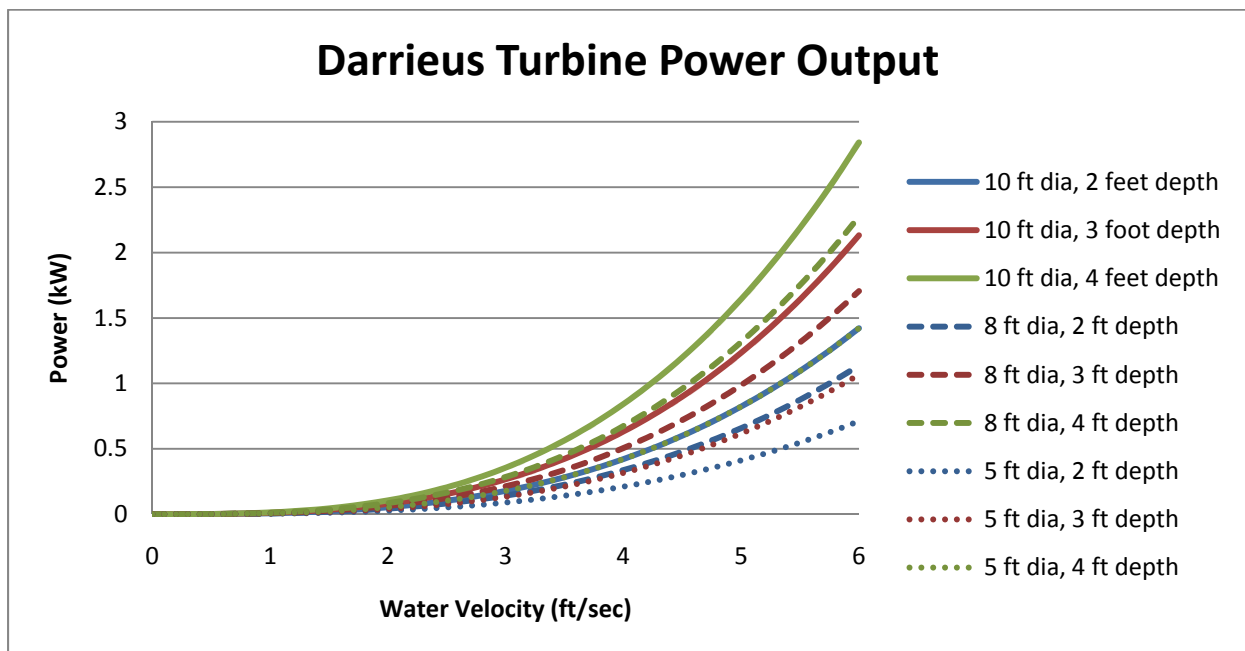


FIGURE 50: DARRIUS WATER TURBINE

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.



NEW ENERGY CORPORATION – EN CURRENT POWER GENERATION SYSTEM
Suite 473, 3553 - 31 Street NW
Calgary, Alberta, Canada, T2L 2K7
(403) 260-5240
<http://newenergycorp.ca>

New Energy Corporation's En Current Power Generation System is a hydrokinetic turbine / generator package with a number of installations in Canada and one in the United States. The system comes in 5KW, 10KW, and 25KW packages with low velocity and high velocity models for each power category. Research is currently being conducted on 125 KW and 250 KW packages. The system is designed to be placed downstream of existing hydro dams, in irrigation canals, or in the banks of large rivers. System farms can be implemented to achieve power outputs of up to 500 KW by placing multiple systems in parallel or in series within a waterway. The system is employed by either mounting to an engineered foundation or mounting to a floating platform. The generator is a permanent magnet power systems type.

Max Power Output	5 KW	5KW	10 KW	10KW	25 KW	25 KW	25 KW
Number of Blades	4	5	4	5	4	5	4
Water Velocity at Max Power (ft/s)	9.8	9.8	9.8	9.8	9.8	9.8	7.9
Total Height (ft)	7.4	7.4	10.3	10.3	13.9	13.9	17.7

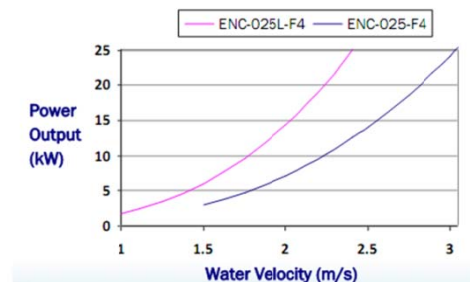


FIGURE 51: 25 KW SYSTEM

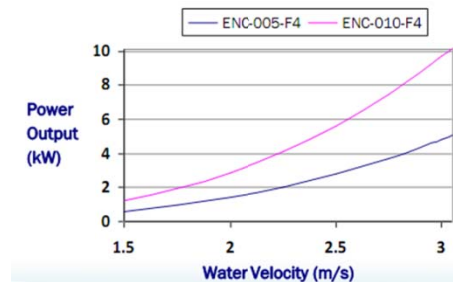


FIGURE 52: 5 KW AND 10 KW SYSTEM



FIGURE 53: EN CURRENT POWER GENERATION SYSTEM



FIGURE 54: FLOATING PLATFORM

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.

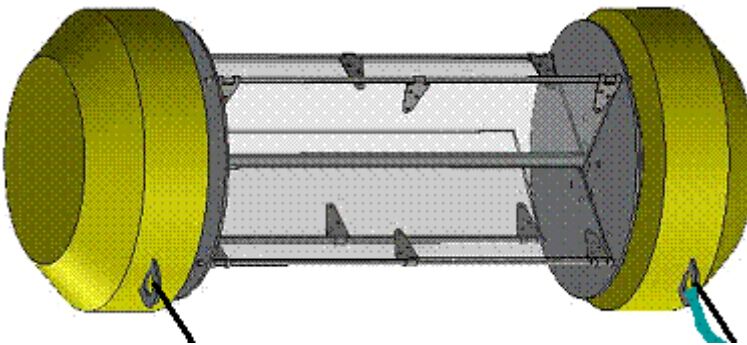


FIGURE 55: SCHEMATIC OF HYDROVOLTS TURBINE
(WWW.HYDROVOLTS.COM)

DO-IT-YOURSELF TURBINES

ELEPHANT BUTTE IRRIGATION DISTRICT

Las Cruces, 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.

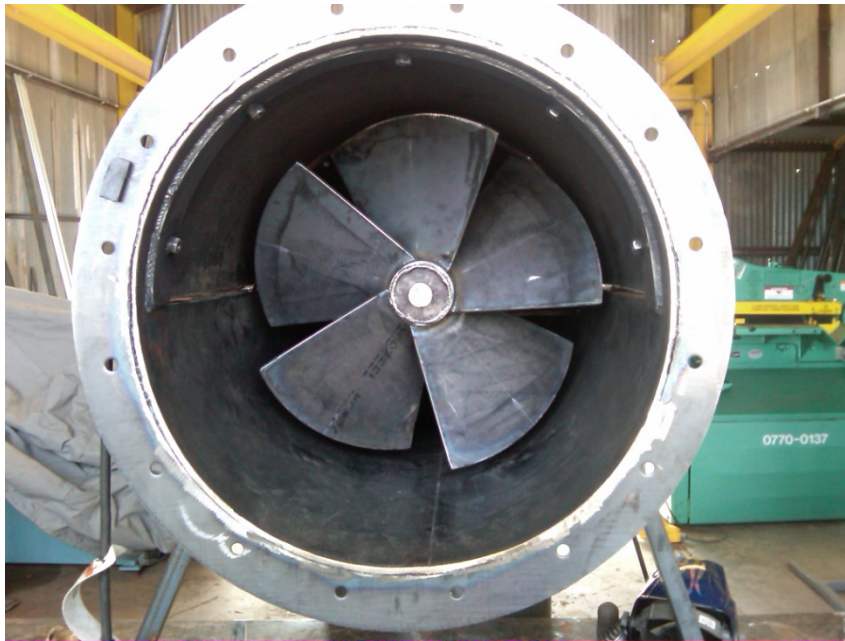


FIGURE 56: EBID KAPLAN STYLE TURBINE

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 57: INSTALLATION IN SWITZERLAND (WWW.ZOTLOETERER.COM)

APPENDIX B: PROJECT CANAL –

GRAND VALLEY IRRIGATION CANAL

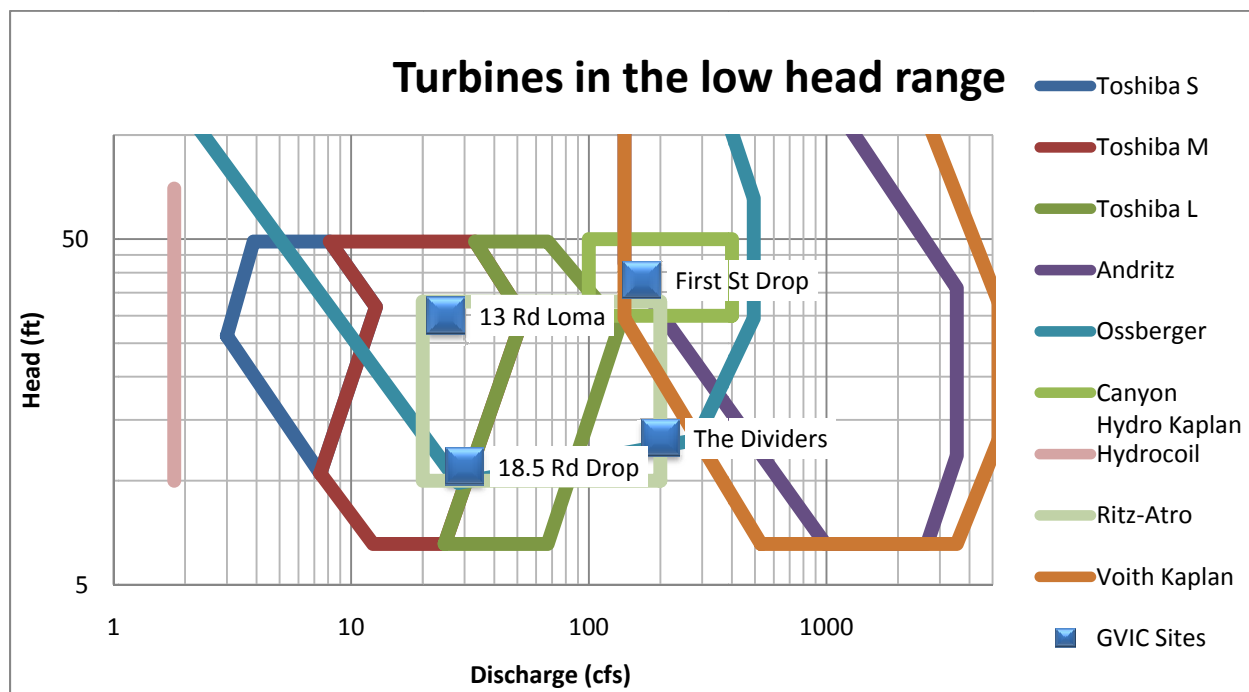
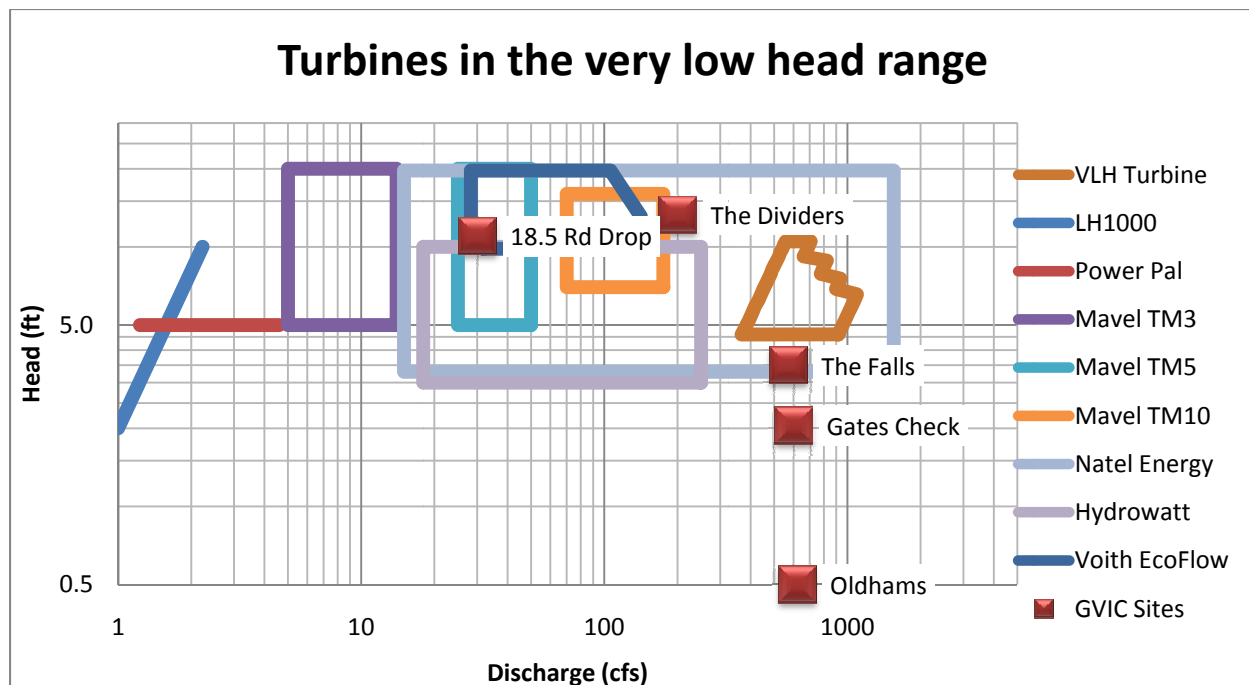
SURVEY METHODOLOGY

A detailed electrical design of each surveyed site could not be completed within the scope of this project. It was possible, however, to do a “sanity check” on electrical interconnect for each site. By coincidence, most of the sites reviewed for this report were located in the service area of Public Service of Colorado (Xcel).

For the Grand Valley Irrigation Company sites, map coordinates were communicated to Xcel, where engineers identified the sites and the appropriate interconnection point, given the size of the anticipated generation and accessibility of local electrical service. These results are summarized, below. In many cases, the electrical service observable from the site was not the interconnect point recommended by Xcel, typically due to the power requirements of the proposed turbine. For the three New Cache la Poudre sites, Xcel was not contacted. However observations could be made on site regarding the nearest possible service.

DESCRIPTION

The Grand Valley Irrigation Canal is located the Grand Valley on the Western Slope. The headgate diverts from the Colorado River in Clifton and the canal extends westward approximately 30 miles to Loma and consists of almost 100 miles of canals. The canal is owned and operated by the Grand Valley Irrigation Company and irrigates approximately 40,000 acres, with 50% of the shareholders involved in agriculture. The canal is decreed for 640 cfs and annually diverts over 250,000 ac-ft. The canal is generally in operation 216 days of the year. Eight sites have been identified in this system that may hold the potential to produce low head hydropower. Each site is shown on the following turbine selection charts. The turbines have been separated into two charts to make them more readable.



These charts show that multiple turbines are possible at many of the sites, according to the head and flow available. In the detailed discussion below each turbine will be evaluated based on the conditions and infrastructure available. The following table shows the types of turbines that are possible at each site.

Site	Mavel	Natel	Hydrowatt	Voith Kaplan	Toshiba	Andritz	Ossberger	Canyon Hydro	Hydro-Screw	Voith Ecoflo
Headgate										
Oldhams										
Gates										
Falls		X								
Dividers	X	X	X				X		X	
First St				X		X		X		
18.5 Rd	X	X	X		X		X		X	X
13 Rd					X		X		X	

HEADGATE



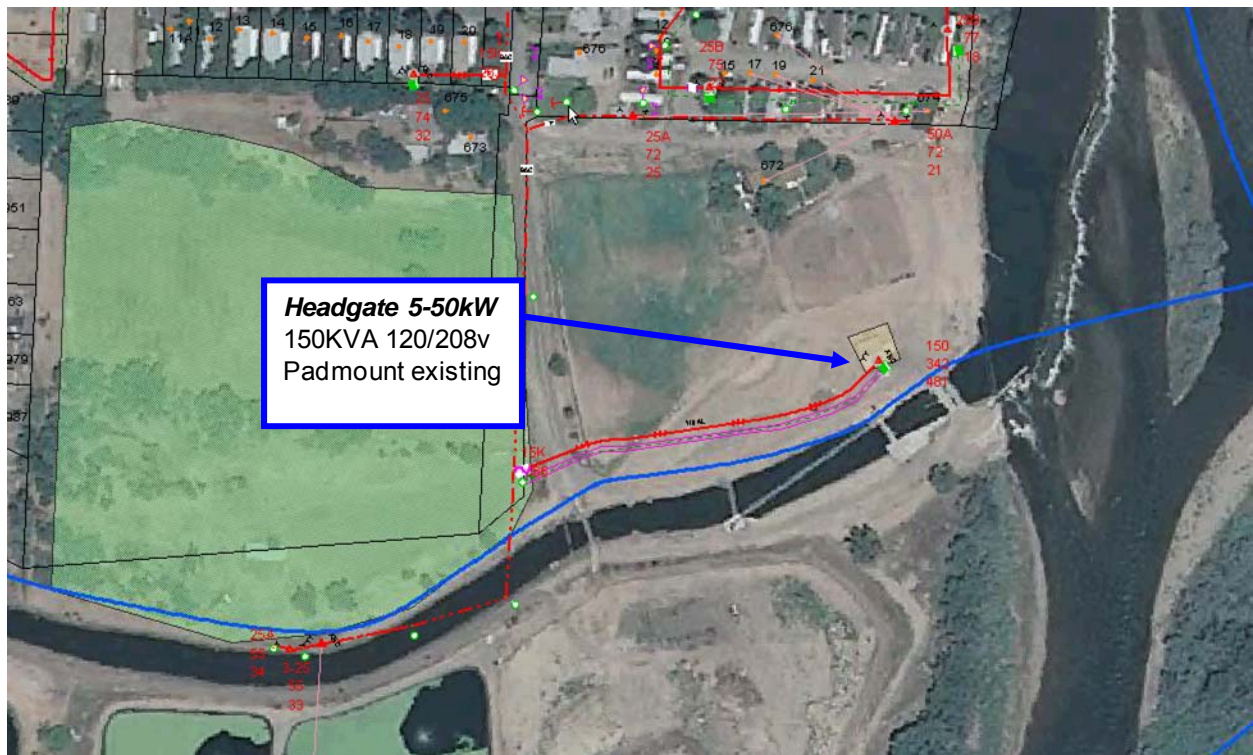
FIGURE 58- PHOTOGRAPH OF HEADGATE

The Headgate for the Grand Valley Irrigation Canal is located on the Colorado River in Palisade, Colorado. Water is diverted through a side channel from the river, during high flow this side channel does overtop and join the mainsteam of the river. To help control the amount of diversions, this structure allows the control of return flows. This structure has four bays, three with radial gates. The gates can be closed to force more water into the canal. The amount of water that passes through these gates is highly variable throughout the year. The amount of head also varies as the flows in the river change. No records exist measuring the flow through this

structure, but it does appear to hold potential to produce hydropower. Water does pass through this structure all year, increasing the amount of power that could be produced.



Due to electrical requiements at the site, interconnect for hydropower at the headgate is nearby. No costs were estimated for this site, due to uncertainty on the size and type of generator.



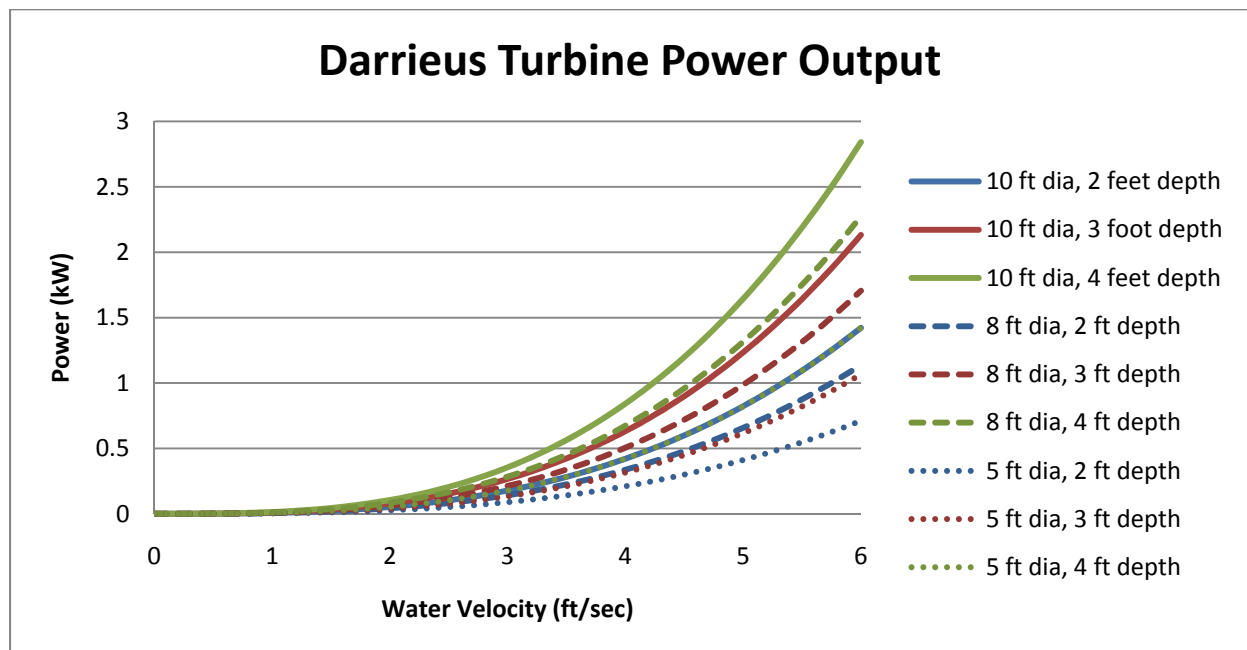
OLDHAM'S CHECK



The Oldham's check consists of a concrete lined trapezoidal section that raises the water surface approximately six inches. The average width of this section is 30 feet and the depth of water through the section is approximately 3.5 feet. The three phase power line is located just adjacent to this check. The amount of head available at this site is not sufficient to use a low head turbine, and therefore does not fall into any of the turbines listed in the table above. Most of the turbines on the market require at least five feet of head differential between the upstream and the downstream

water surface.

The concrete lined section does constrict the flow through the canal at this point, and increases the velocity of the water. We estimate that the velocity through this section is approximately 5.9 ft/sec which may make this site appropriate for a hydrokinetic turbine. If sufficient velocity is available, the feasibility of a hydrokinetic turbine is dependent on the geometry of the section. At this site it would be possible to install multiple vertical axis turbines, like the Darrieus Water Turbine. Two 10 foot diameter turbines or three 8 foot diameter turbines with a depth of three feet could be accommodated at this site. According to the power output chart supplied by Alternative Hydro Solutions below, this site could produce between 4 and 6 kW of electricity. This would result in approximately 20,000 kWhrs annually.

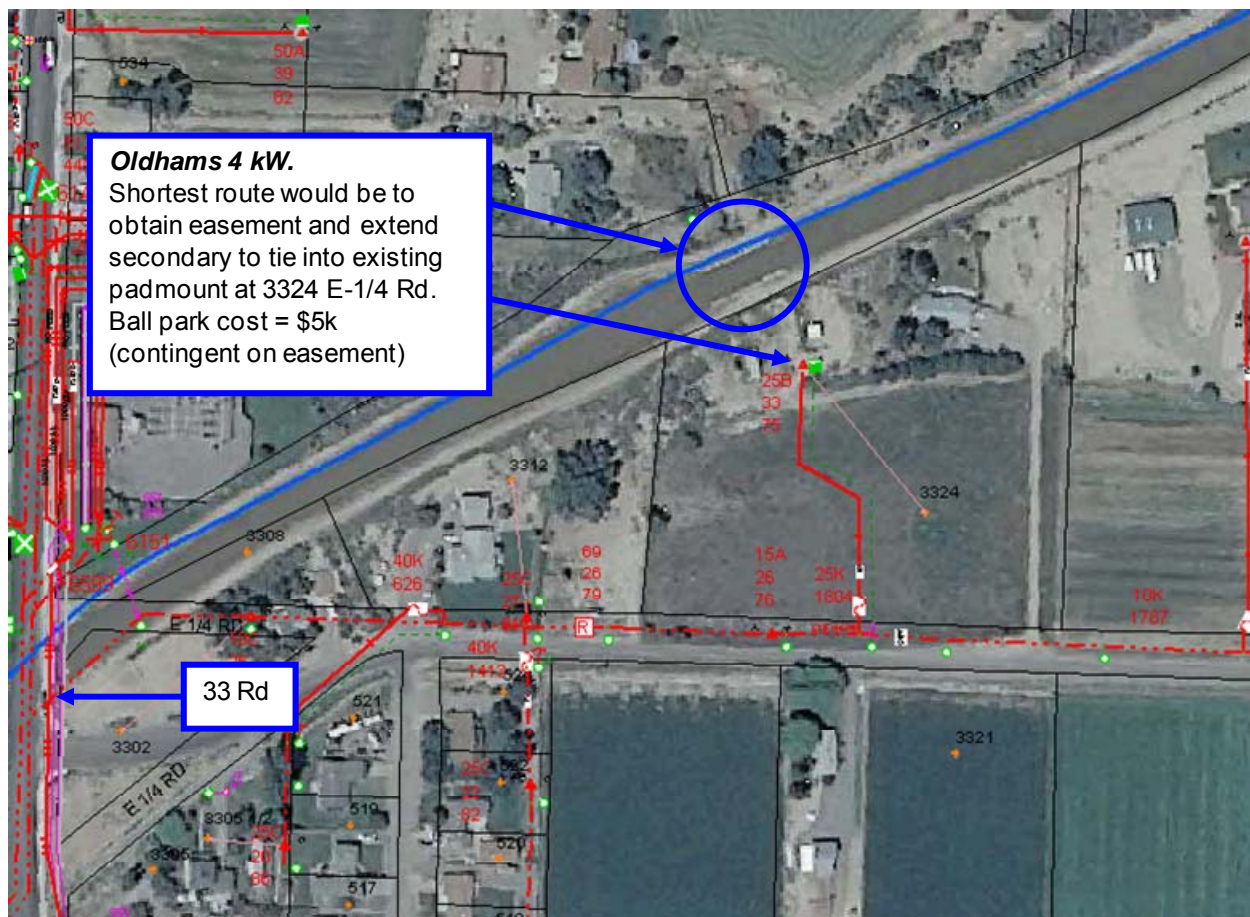


These turbines would be suspended from a bridge spanning the canal. The generator would be located on the vertical axis, above the water. This will create a possible location for floating debris to collect. Deflectors could be installed, and regular cleaning would need to be performed when floating debris is excessive.



A second type of hydrokinetic turbine that may be appropriate at this site is the Hydrovolts turbine. This turbine is not in the commercial stage yet, but the company would be willing to talk about producing a custom turbine for this site.

Electrical service for this site is nearby, with an existing transformer of sufficient capacity. Net metering could be a possibility if interest existed with neighboring land owner. For a site of this size, local involvement would also help with maintenance and operation, reducing the load on the irrigation company personnel.



GATES CHECK



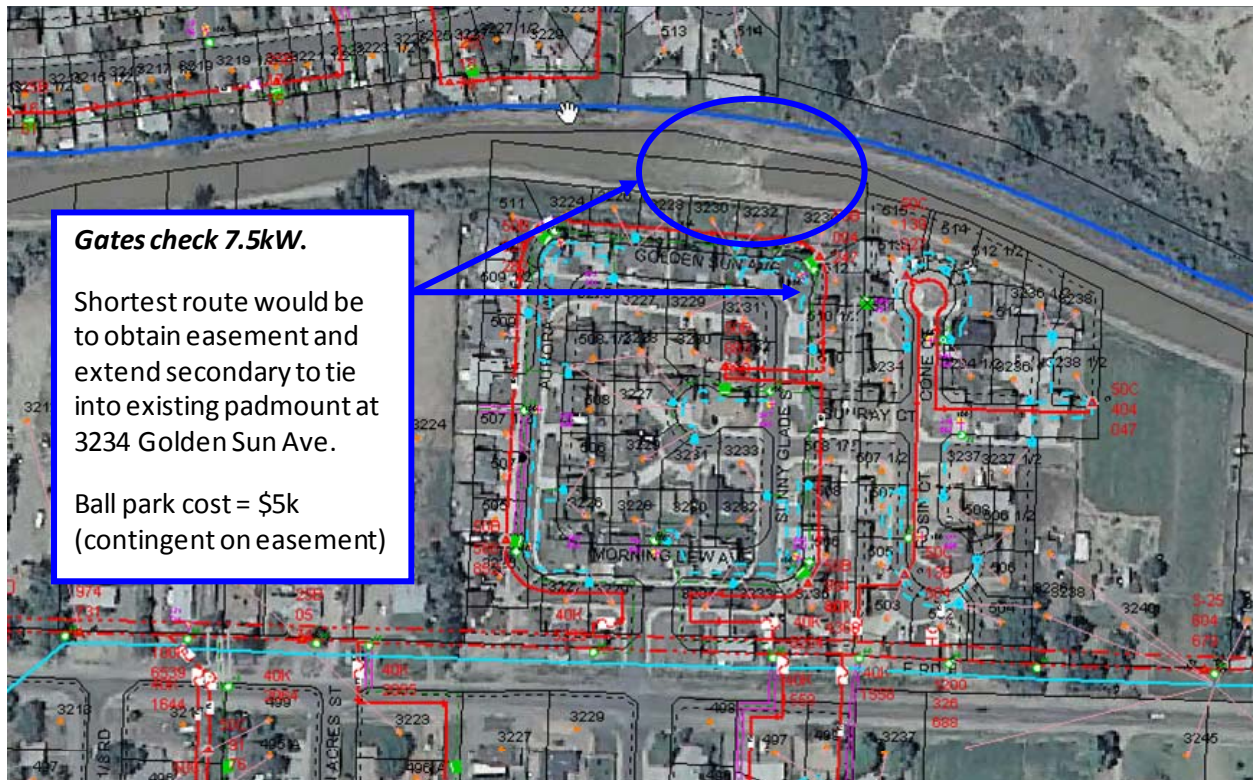
The Gates check consists of a concrete structure that spans the width of the canal, with a raised concrete floor. A pedestrian bridge is supported by two concrete piers located in the channel. The structure is 29.5 feet wide at the narrowest location. Water passes over the structure at a depth of approximately 2.5 feet. There is about 2 feet of fall between either side of the structure. The velocity of the water passing over the structure is estimated to be 8.1 ft/sec.

This site also has too little head to make it feasible for a low head turbine. Again, vertical

axis hydrokinetic turbines could be appropriate for this site. One advantage to this site is the structure above the canal that could be used to mount the turbine. If this pedestrian bridge is used for public traffic, measures would have to be taken to secure the turbine from vandalism or damage. If a turbine is installed in each bay of the structure, trash accumulation may be a problem. It could be possible to leave one bay empty and deflect floating debris away from the turbines and into the empty bay. These turbines can also be easily removed, if floating debris is present for only a short time of the year.

It would be possible to install three 8 foot diameter, 2 foot deep turbines in this structure with very little infrastructure modification. Each turbine could produce about 2.5 kW, or 38,000 kWhrs of electricity annually. The velocity of this site makes it more economical to install the hydrokinetic turbines. The same turbines can produce almost twice as much electricity at this site compared to the Oldham's check.

Electrical interconnect could be made to an existing, padmount transformer in the adjacent residential neighborhood. As with Oldham's, a possibility exists for net metering with a local homeowner or the local homeowner's association. Interest by local residents was not checked.



THE FALLS



The Falls is a concrete lined section of canal that drops about 3.5 feet. The lining is irregular, but generally trapezoidal. The section is approximately 19 feet wide, and the water travels through the section 1.75 feet deep. This results in a very high velocity of 17 ft/sec. The head and flow of this site falls within the range of the Natel Energy Hydroengine, specifically the SLH-500. This is the largest standard model that Natel offers, and is required at this site because of the relatively high flow. This turbine would produce about 125 kW, or 650,000 kWhrs of electricity annually. However, electrical

constraints, described below, limit power production to 100 kW.

The Natel turbine is best installed at a site where the entire drop occurs over a very short distance. In this case the drop occurs over about 275 feet. To install this type of turbine, the drop would need to be consolidated at the upper end of the existing drop. A structure could be installed across the canal, and the remaining slope excavated to a lower elevation with a slight slope. This type of modification to the existing infrastructure would only be economical if this part of the canal was being reconstructed for other reasons. The concrete in this drop appears to be in good condition and is not in need of replacement in the near future.

A hydrokinetic turbine is not considered at this site because of the shallow depth of water through the structure.

This site is located near a relatively new residential development equipped with underground feeders and padmount transformers. The best estimate for peak power production at this site is 125 kW. Xcel engineers indicate that the maximum allowable single-phase interconnect at this location would be 100 kW. This is a fairly high capacity rating for single phase, which should not be construed as indicative for other locations. At this size, the single-phase feed must be sourced through a dedicated transformer, and cannot be connected to another load.

The ideal interconnect would be 3-phase, and would require an additional transformer tied to a medium voltage feed approximately ½ mile from the structure. A detailed cost estimate was not performed but a rough estimate by Xcel engineers is that the cost could top \$100K. Therefore, a 100 kVA, single-phase connection would likely be used for this site.

An easement would likely be required, and net metering is not a practical option at this power level.



THE DIVIDERS



The Dividers is a rectangular concrete lined chute that discharges into a shotcrete lined stilling basin. There is approximately 13.3 feet of head and 200 cfs available. The chute is about 125 feet long and flow is controlled with two gates on the upstream end. This structure is located at a split in the canal, as shown in the photograph below. The slice gate and radial gate control the flow into the concrete chute, with the remaining water flowing down the main canal. The turbine selection chart shows that this site is suitable for five different types of low head turbines.

The Mavel, Natel and Ossberger turbines require similar infrastructure to operate. Each turbine could be located on the upstream end of the chute with the head obtained with a draft tube extending to the bottom of the chute. Alternatively the turbine could be located at the lower end of the chute with the head delivered through a pressurized pipe upstream of the turbine. Also, the turbine could be installed at the upstream end of the chute and the

remaining portion of the chute excavated to a lower grade, like suggested at the Falls site. In this case, the excavation would be very deep and result in steep side slopes, if the channel was left open. It would be possible to pipe the section from the outlet of the turbine back into the channel. Any configuration would require significant alteration to the existing infrastructure.

The SLH-100 model offered by Natel Energy would be appropriate for this site, and produce about 185 kW or 960,000 kWhrs annually. Mavels TM10 is designed to operate at a maximum of 175 cfs, and would produce between 150 and 170 kW or 830,000 kWhrs. In this case the Natel model can produce more power with these site conditions. The choice of turbine would be based on comparing the installed cost and related infrastructure improvements required.



This site was historically the site of a waterwheel that was used to lift water. The passing water would power the water wheel and carry a small portion up to the top of the bank. The photograph shows a water wheel in the Grand Valley that was used for the same purpose. This wheel has a diameter of over 35 feet and the water is lifted to the top and discharges through the suspended pipe to the top of the bank.

This site does fall within the range of conditions required for a modern water wheel. Most likely an overshot water wheel would be appropriate because of the relatively high head available. Water would enter the wheel at the top and fall around the wheel. This would require the wheel to be entirely below the elevation of the incoming water. At this site the wheel would essentially need to be below the ground surface. The extensive alterations to the existing infrastructure would likely not be balanced by the relatively low efficiency water wheel. Although this site did historically support a water wheel, it may not be appropriate at this time.

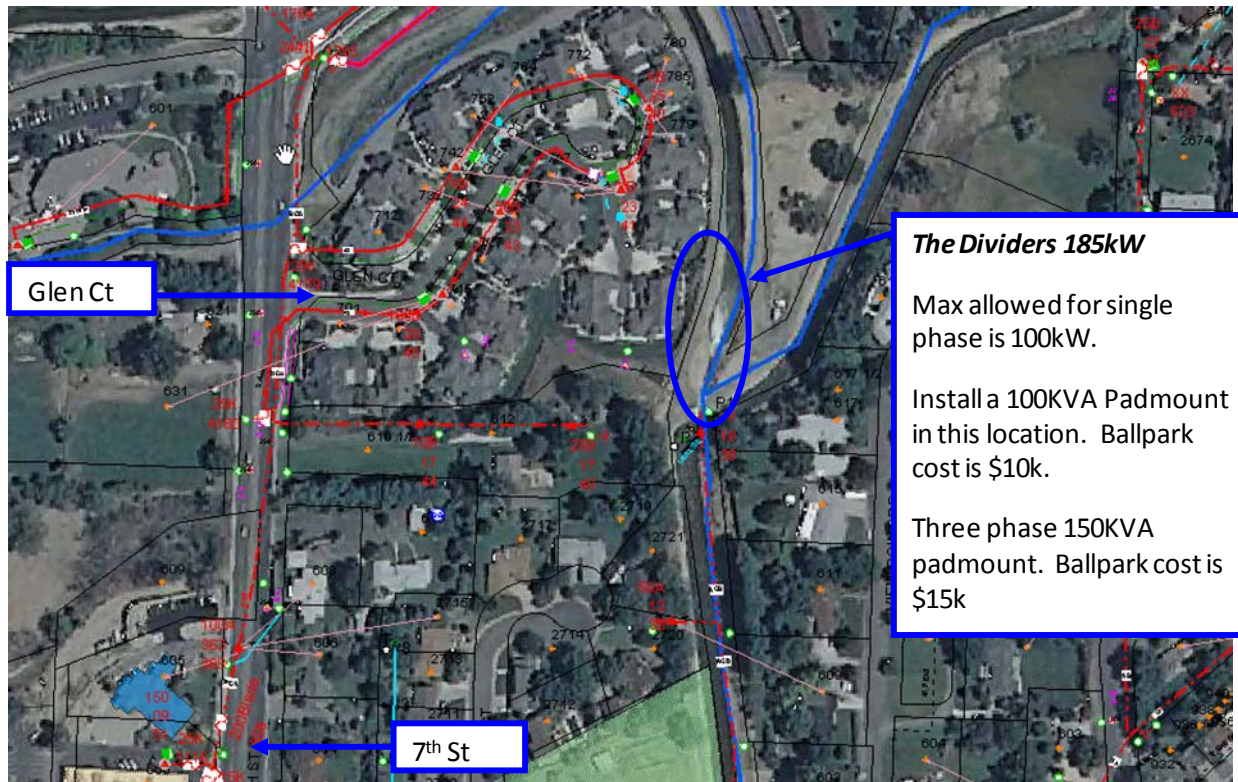


Finally, this site is a candidate for a hydrodynamic screw, based on the head and flow available. Also the existing infrastructure suggests that it may be a good site for this type of turbine. A hydrodynamic screw is placed inside of a sloped concrete chute with the turbine located at the upstream end, as shown in the photograph below. These turbines are placed on a slope between 22



and 40 degrees. This site has a slope of only 5.4 degrees. Therefore the chute would have to be modified to increase the angle, similar to the photograph. Also, the screw would have a diameter of approximately 11.3 feet, and the existing width of the chute is only 6 feet. If this chute was wider and steeper, this turbine would be a better fit for this site. This site could support a 170 kW hydrodynamic screw, with significant modification to the existing infrastructure.

Similarly to The Falls, The Dividers is located near a residential where single-phase interconnection is available to 100 kW, but 3-phase connection is more difficult to procure. As illustrated on the figure, the single-phase interconnect would occur on Glen Court, but be limited to 100 kW. A three-phase connection would be possible on 7th street, and costs were estimated for a 150 kW service, somewhat below the maximum output estimated for the site. For this site, the \$5,000 incremental cost for the larger service is exactly in line with the increased production potential. Therefore the final choice would be a matter of system optimization of all other capital costs and power purchase economics.



FIRST STREET CHUTE



The First Street Chute has similar infrastructure as the Dividers. This is a concrete lined, rectangular chute, with 38.1 feet of head and 167 cfs available. The drop occurs over about 200 feet. According to GVIC, this site was originally intended for hydroelectric development. This is the most fall seen at one structure over the entire Grand Valley Irrigation Canal. The relatively high amount of head available makes several more traditional turbines appropriate at this site. The turbine selection chart indicates that a Kaplan turbine would be appropriate at this site.

A Kaplan turbine would be installed at or near the end of this chute, with the entire length of the chute put into a pressurized pipe. The flow available at this site (167 cfs) is at the low end of the range for the larger turbines, the Andritz and Voith Kaplans. This generally means that the turbine that will fit these conditions, could also handle a lot more flow, and

therefore may be “oversized” for the site. The Canyon Hydro Kaplan may be more suited for this site, as the head and flow available is near the center of the range. This site is very similar to a recent installation by Canyon Hydro near Logan, Utah. That site had 30 feet of net head and 143 cfs available. The Canyon Hydro turbine could produce approximately 450 kW, or 2,300,000 kWhrs annually.



Electrically, the First Street Chute is an example where local observations can be misleading. Referring to the photo, power service is clearly visible near the top of the chute, as indicated by the enlarged picture. This power service, however, is unsuitable for the ~450 kW production estimated for this site. The nearest 3-phase interconnect location, shown in the plan view below, is along 26 Road. For a secondary service of 480V/600A, this interconnection would likely require an underground medium voltage branch service extension and pad-mount transformer on the site. Estimated cost is \$25K.



18.5 ROAD CHUTE



This site has a 100 foot long concrete lined chute that carries 30 cfs and falls about 11 feet. The turbine selection chart shows that four turbines could be appropriate for this site, the Mavel, Voith Ecoflow, Natel's hydroengine, or a Hydrowatt waterwheel. This site is similar to the other chutes shown in this report, and the 100 feet of length would need to be piped to install the Mavel, Ecoflow or hydroengine. The waterwheel would require significant modification to this site, and may not be

appropriate for the site conditions. There is a three phase powerline that follows the road and is adjacent to the turbine location.

Any of these three turbines would produce about 25 kW or 130,000 kWhrs annually. This site could easily and inexpensively be developed if the chute was enclosed in a pressurized pipe. If this chute was slated for replacement, that would be a good time to consider adding hydropower.

Unlike the other GVIC locations, this site is a rural location served by overhead electrical lines. Although the power production is on the low end of the studied sites, the cost of the service upgrade is high: \$20K for a 25 kW extension. This reflects the cost of extending service – estimated at 4 spans, and setting an appropriate pole-mount transformer.



13 ROAD DROP - LOMA



This drop occurs at the very western edge of the GVIC system. At this point in the canal there is only 25 cfs left flowing. This site is a 360 foot long concrete lined drop, that falls about 30 feet. This site is located in a rural area of Loma, near the interstate. There is a single phase power line near the turbine location to serve the lighting at the exit.

The conditions at this site fall within the range of three turbines, the Toshiba eKids series, the Ossberger cross flow and the Ritz-Atro hydrodynamic screw turbine. The site conditions are not conducive to the

hydrodynamic screw option, because of the long, low angled slope, so it will not be considered further. The Toshiba eKids and the Ossberger cross flow turbine would both require that the entire length of the drop be piped and the turbine located at the base of the drop. The Toshiba e-Kids turbine or the Ossberger turbine could produce about 50 kW, or 260,000 kWhrs annually. A comparison of turbine cost and related infrastructure would determine which turbine is more economical for this site.

This site is located with the Grand Valley Power service area. No electrical service location or costs were investigated.

SUMMARY

Site	Turbine Capacity	Estimated Annual Production (kWh)	Infrastructure Required	Electrical Service		Approximate Interconnect Install Cost ¹² (\$)
				Type ¹³	Service ¹⁴	
Headgate	5-50kW	25,000-260,000		N/A	3-φ	<i>Not provided</i> Existing transformer
Oldhams	4 kW	20,000	Bridge over canal	OH	1-φ	5 K\$ + easement
Gates Check	7.5 kW	38,000	None	UG	1-φ	5 K\$ + easement, use existing transformer
The Falls	125 kW	650,000	275' pipe, powerhouse	UG	3-φ desired, 1-φ possible to 100 kW	10 K\$ for 1-φ New transformer
The Dividers	185 kW	960,000	125' pipe, powerhouse	UG	3-φ desired, 1-φ possible to 100 kW	10 K\$ for 1-φ 15 K\$ for 3-φ New transformer
First Street Drop	450 kW	2,300,000	200' pipe, powerhouse	UG	3-φ	25 K\$ New transformer
18.5 Rd Drop	25 kW	130,000	100' pipe, powerhouse	PH	1-φ	20 K\$ New transformer
13 Road Loma	50 kW	260,000	360' pipe, powerhouse	unknown		unknown

¹² Install cost of the electrical services without considering protection equipment, controls and engineering.

¹³ Line type: UG = underground, OH = overhead

¹⁴ Service type: 3-φ = three-phase, 1-φ = single phase. All units are interconnected at low voltage.

APPENDIX C: PUBLICATIONS AND PRESENTATIONS

WORKSHOPS

Colorado Small Hydro Working Group “Colorado’s Low Head Hydro Potential” July 27, 2010, Glenwood Springs, CO

Rio Grande Roundtable “Colorado’s Low Head Hydro Potential” August 12, 2010, Alamosa, CO

South Metro Denver Chamber Renewable Energy Taskforce Monthly Meeting – Water, December 17, 2010, Denver, CO

Low Head Hydroelectric Opportunities – DARCA pre convention workshop, February 16, 2011, Berthoud, CO

Irrigation Water Users Session 2: Micro Hydro, “Low Head Hydropower for Ditch and Reservoir Companies” March 17, 2011, Hotchkiss, CO

iCAST Workshop: Economic Development through Hydro Power Generation, “Micro Hydro Technologies” April 20, 2011, Glenwood Springs, CO

San Luis Valley Hydropower Workshop – San Luis Valley CSU Extension, “Technical, legal and financial considerations for a microhydro project in the San Luis Valley” June 7, 2011, Alamosa, CO

CONFERENCE PRESENTATIONS /PAPERS

Colorado Renewable Energy Conference 2010 “Low Head Hydro Potential in Colorado”, Montrose, CO

United States Committee on Irrigation and Drainage, Emerging Challenges and Opportunities for Irrigation Managers, “Low Head Hydro Potential in Colorado”, April 26-29, 2011 Albuquerque, NM

Colorado Small Hydro Workshop, “Low-Head Hydro Technologies”, June 15-16, 2011, Denver, CO.

INVITED ARTICLES

Colorado Water, April/May 2011, 28(2), “Exploring Hydropower in Colorado’s Irrigation Canals”

International Water Power and Dam Construction, May 2011, “Colorado Low Head Hydropower”

NEWS ARTICLES

International Water Power and Dam Construction “Study to look at hydro potential in irrigation canals” March 4, 2011

<http://www.waterpowermagazine.com/story.asp?sectioncode=130&storyCode=2059034>

Government Technology “Colorado Examines Hydropower in Irrigation Ditches”, March 1, 2011
<http://www.govtech.com/technology/Colorado-Hydropower-Irrigation-Ditches-030111.html>

Fort Collins Coloradoan, “Colorado State University, Applegate Group Collaborate on State Grant to Investigate Hydropower in Irrigation Canals”, December 20, 2010

BrighterEnergy.org, “Researchers probe hydropower potential in Colorado Irrigation” December 22, 2010 <http://www.brighterenergy.org/21203/news/marine-hydro/researchers-probe-hydropower-potential-in-colorado-irrigation/>

Renewable Energy World, “Hydropower Study Targets Irrigation Canals”, January 6, 2011
<http://www.renewableenergyworld.com/rea/blog/post/2011/01/hydropower-study-targets-irrigation-canals>

WaterWorld “Colorado State University, Applegate Group Collaborate on State Grant to Investigate Hydropower in Irrigation Canals”, December 15, 2010
http://www.waterworld.com/index/display/news_display/1325091300.html

Colorado State University, “Colorado State University, Applegate Group Collaborate on State Grant to Investigate Hydropower in Irrigation Canals, December 15, 2010.
<http://www.news.colostate.edu/Release/Print/5529>

Today @ Colorado State Newsletter “Evaluating hydropower in Colorado’s Irrigation Ditches” December 16, 2010.

Northern Colorado Business Report “CSU, Applegate to collaborate on hydropower study” December 16, 2010, <http://www.ncbr.com/article.asp?id=55125>

HydroWorld.com “Hydropower Study Targets Irrigation Canals” January 2011,
<http://www.hydroworld.com/index/blogs/hydro-scope-blog/archives/201101/blogs/hydro-blogs/hydro-scope.html>

Valley Courier, Alamosa, CO “Water may ‘outshine’ solar in the Valley” August 13, 2010.
http://www.alamosanews.com/V2_news_articles.php?heading=0&page=72&story_id=17663

Family Farm Alliance- Water Review “Colorado Firm Takes the High Road and Pursues Low-Head Hydro Opportunities” October 2010
http://www.alamosanews.com/V2_news_articles.php?heading=0&page=72&story_id=17663

Colorado Country Life “Grants fund research on the potential for renewable hydroelectric power in Colorado irrigation ditches” February 2011