Energy
FACTSHEET

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ON-FARM HYDROELECTRIC GENERATION

This Factsheet is an introduction to small hydroelectric power generation (under 50 kW), covering site potential (head, flow, generation estimating, water and power lines), energy needs estimating, system components, licensing and costs. Interconnection and electrical sale to a power utility is outlined.

Introduction

An on-farm hydroelectric generation system may be installed to reduce utility bills, to reduce diesel generator fuel bills, or as power sales to an electrical utility. Whatever the reasons, the feasibility of a project may include decisions on equipment, project economics, licensing requirements, utility interconnection conditions, etc. In this Factsheet, s*mall hydro* refers to hydroelectric generation systems with capacities of 2 - 50 kilowatts (kW). *Micro hydro* generally refers to systems less than 2kW.

In any installation, the main components are the water supply (reservoir or diverted flow), pipeline, powerhouse (turbine, generator, control system) and the electrical lines to deliver the power (Figure 1, next page). Before any equipment decisions are made, the site assessment is the first and most important step. The following is general information; all installations must be considered with site specific conditions.

Step 1: Site Potential

Head. Head (H) is the elevation difference (a fixed value) between the water elevation at the inlet pipe and the elevation at the turbine nozzle or exhaust.

Flow. If possible the site hydrology should be known as water flow (Q) is usually a seasonally changing value (unless a storage dam is used) and will have yearly fluctuations. The mean annual flow is sometimes used in power calculation.

Power Generation Potential. The amount of energy that can be generated in a power plant is calculated by the Flow times the Head with a conversion of units:

Theoretical (Hydraulic):

$$\textit{Power in Kilowatts (kW)} = \frac{Q\ (\text{USgpm}) \times H\ (\text{feet})}{5303}$$

System losses (due to pipe friction, turbine or water wheel, generator and connecting drive system) reduce the output. System efficiency ("water-to-wire") is typically between 70% for high head, high speed impulse turbines to under 50% for water wheels. If 53% system efficiency is assumed, power potential is:

Overall Efficiency @ 53%:

$$\textit{Power in Kilowatts} = \frac{Q\ (\text{USgpm}) \times H\ (\text{feet})}{10{,}000}$$

Or, Small Systems @ 53%:

$$\textit{Power in Watts} = \frac{Q\ (\text{USgpm}) \times H\ (\text{feet})}{10}$$

Battery Systems, Overall Efficiency @ 37%:

$$\textit{Power in Watts} = \frac{Q\ (\text{USgpm}) \times H\ (\text{feet})}{15}$$

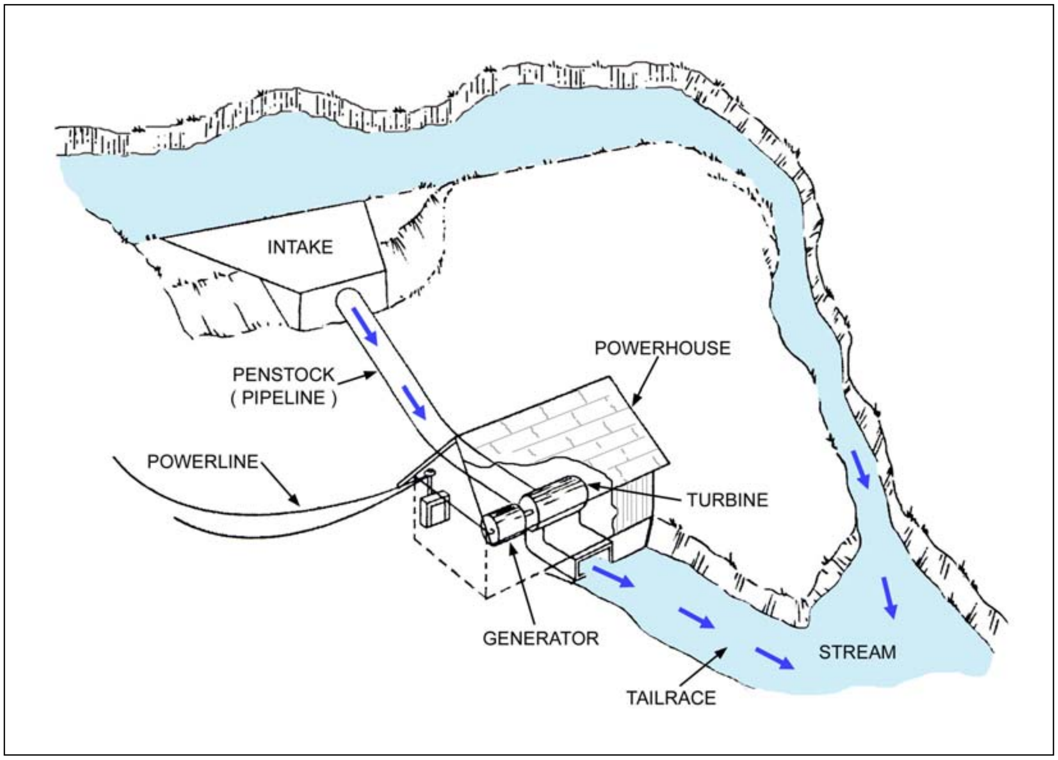
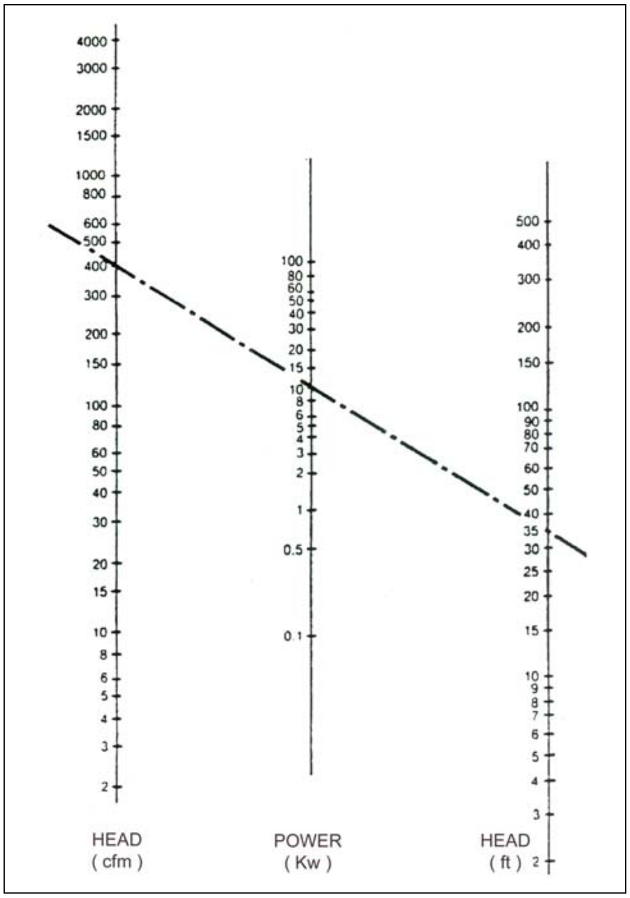


Figure 1 Components of a Typical Hydroelectric Generation Site



Source : MicroHydro Power, Ontario Ministry of Energy, 1982

Figure 2 Power Output Nomograph
(50% system efficiency)

Alternately, use the Figure 2 Nomograph, left, with a straight edge to estimate the power output. It assumes a total system efficiency of 50%. In the example shown, a flow of 400 cubic feet per minute (cfm) and a head of 35 feet would produce an estimated 10 kW of power. The same power could be generated from an 80 cfm flow over 200 feet (note: 1 cfm = 7.48 USgpm).

It is possible to provide a given amount of power with high head and low flow, low head and high flow, or any combination in between (less than 10 ft head not economical). As low heads require a large water volume and thus physically large equipment, the cost of power will likely be higher than for high head sites of similar potential. Note that turbines are usually designed for specific conditions and nothing will be gained by installing a unit that is larger than a sites capacity.

Water Line. Another site issue is the location of, and water delivery to, the powerhouse (Figure 1, above). One of the system losses is friction in the water delivery pipeline to the turbine - increased pipe length adds cost and friction loss. Heads up to about 125 feet can usually use low-friction-loss polyethylene or PVC pipe (with burial) – higher heads have pressures that are usually best suited to steel pipe (may not need burial). Pipe friction loss tables are available from References, page 8.

Power Line. One last site issue is the power line cost. It is a factor of the distance between the powerhouse and the electrical use locations, as well as the amount and the voltage of electrical energy being transmitted (higher voltages reduce line losses).

Step 2: Your Energy Requirements

On-Farm Power Use. If the power generated is to be used on-farm, the next step is to establish the minimum power requirement and match that with the site potential. As in any hydroelectric system, serving peak power load is less efficient and more costly than serving average power load. A residence can have a peak load twice or more the average load. Reducing the peak load by adjusting demand will reduce the generation size and therefore system cost. Such things as not using high energy loads at the same time, using energy efficient appliances, etc., will all reduce system size.

Table 1, below, has typical appliance loads to use in determining household power requirements. Additional farm or seasonal loads such as irrigation pumping would need to be calculated for individual situations. Note that household consumption will usually vary throughout the year, so it would be wise to study at least one complete year’s electrical bills. A generation system may be installed to meet only part of the load, such as a special pumping or heating requirement. It may also be possible to tailor water flow variations to a seasonal power demand.

Off-Farm Power Use. If the power generated is to be sold to a utility such as BC Hydro, the energy to be produced is not a “needs” decision but an economic decision. Refer to Step 5, page 7 and to Off-Farm Power Sales, page 8.

Table 1 Typical Monthly Electrical Consumption of Household Appliances

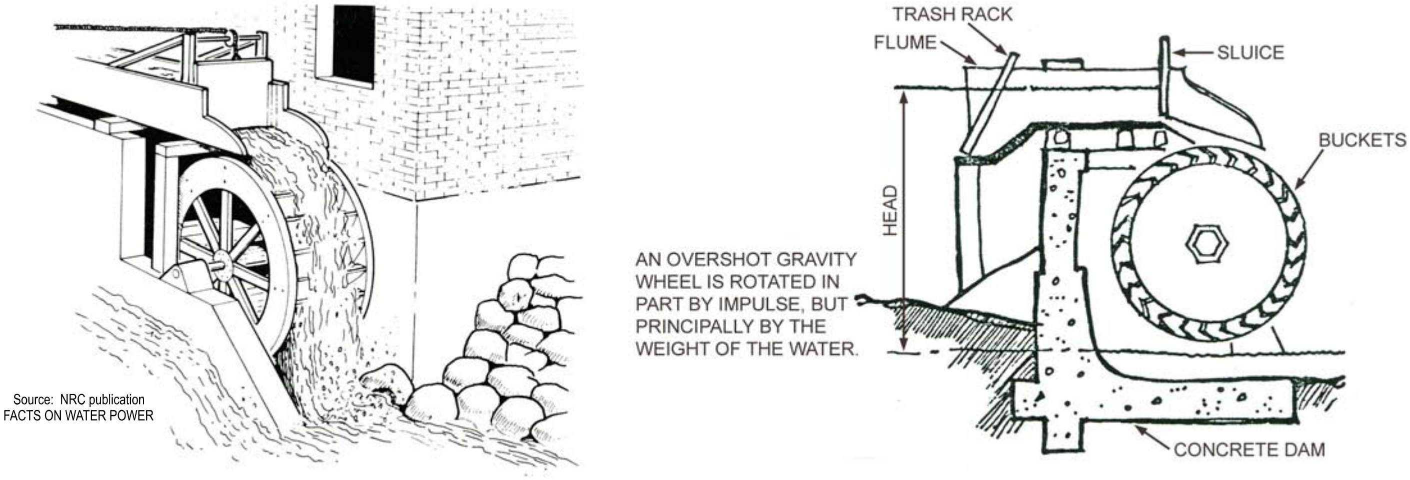
Appliance	Power Rating (watts)	Monthly Use (average hours)	Monthly Energy Use (kWh)*	Monthly Energy Cost @7¢ kWh
Range & Oven	7,200	10	60	$4.20
Electric Heating	6,000	250	1,500	$105.00
Clothes Dryer	4,600	19	87	$6.09
Water Heater (40 gal)	3,000	89	267	$18.69
Toaster	1,150	4	5	$0.35
Iron	1,100	12	13	$0.91
Vacuum Cleaner	750	10	8	$0.56
Wash Machine 15 loads/mon	700	12	8	$0.56
Water Pump (1/2 hp)	460	44	20	$1.40
Chest Freezer (15 ft)	350	240	84	$5.88
Tools - ¼” Drill (1/16 hp)	250	4	1	$0.07
- Skill Saw (1 hp)	1,000	6	6	$0.42
Refrigerator -standard 14’3	300	200	60	$4.20
-frost free 14’3	360	360	130	$9.10
TV	150	125	19	$1.33
Lights - each 60 watt	60	120	7	$0.49
- each 100 watt	100	90	9	$0.63
- each 4’ fluorescence	50	240	12	$0.84
Radio	50	120	6	$0.42
Stereo	30	120	4	$0.28

* kWh is one kilowatt (kW) used for 1 hour or 1,000 watts for 1 hour
This is the energy quantity utilities bill customers – for instance at 7¢ kWh, 1,000 watts used for 1 hour costs 7¢

Step 3: Equipment Selection

Waterwheels and Turbines. The heart of a hydroelectric system is the mechanism for converting the water source energy to mechanical energy to drive the generator. Waterwheels and most commonly used turbines are outlined below.

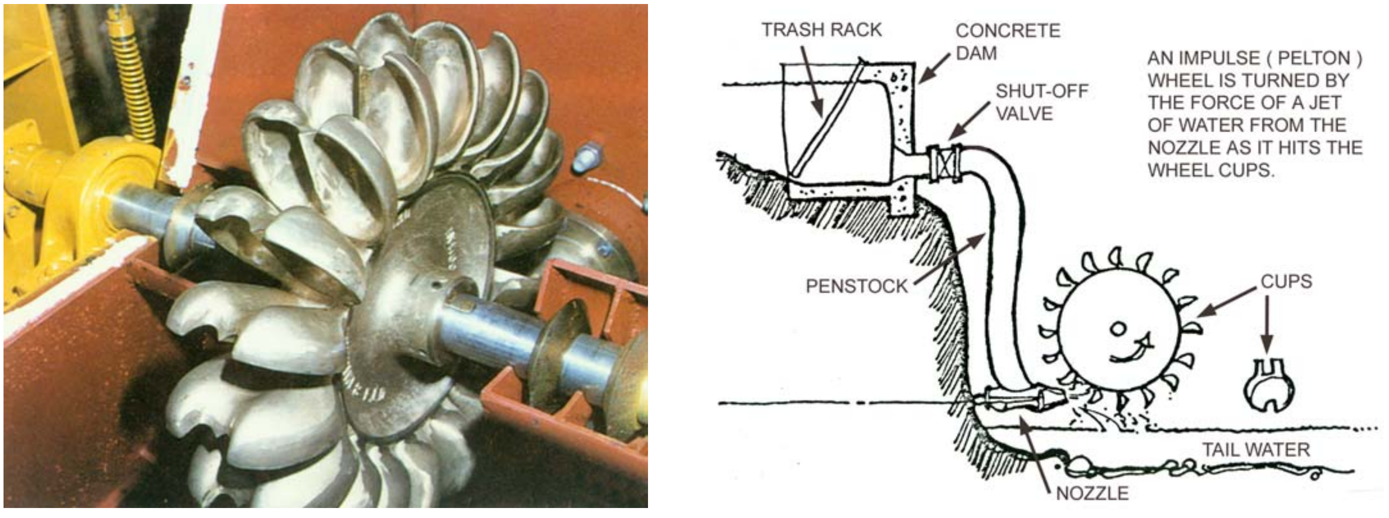
Waterwheel. Water wheels were the traditional means of obtaining useful energy from falling water (Figure 3, below) but are outdated by turbines. An overshot water wheel is rotated mainly by the weight of the water (gravity) in the buckets. They are relatively simple and can handle wide variations in flow, as well as debris in the water, but they have low efficiency and have winter icing problems. They were typically used for mechanical operations, such as grinding. Their very slow speed requires complicated, inefficient gearing-up to run at electrical generator speeds.



Source: NRC publication
FACTS ON WATER POWER

Figure 3 Typical Overshot Waterwheel Installation

Impulse Turbines. Impulse turbines use the velocity of the water from a nozzle striking individual blades or cups to rotate a wheel. They generally discharge to atmospheric pressure with no suction on the outlet side of the turbine (as with Reaction Turbines, Figure 5, next page). Impulse units are generally the simplest of all common turbines; generally used for high heads, offer high reliability, low maintenance, with efficiencies to 90%. They are widely used in small hydro systems and include the Pelton (Figure 4, below), Turgo, and Crossflow turbines.



Source :
Dependable Turbines Ltd.

Figure 4 Typical Pelton Impulse Turbine Installation

Reaction Turbines. Reaction turbines are placed directly in the water piping system and use the pressure of water flowing over the blades. They tend to be very efficient for specific head and flow combinations but efficiency falls sharply with any variation. More sophisticated adjustable units can maintain efficiency with varying flow but are more expensive. This design has a gradually enlarging discharge tube to the tailwater, to take advantage of the total head available, enhancing the value of reaction turbines in low head installations where it may be critical to use the total head. Reaction units are usually associated with very large installations and include Francis (Figure 5, below), Kaplan and Propeller turbines.

Standard industrial centrifugal pumps can be used in reverse as reaction turbines, but the correct selection of a pump for a given head and flow combination is absolutely critical and professional advice should be sought. Refer to References, page 8.

RUNNER OF REACTION TURBINE

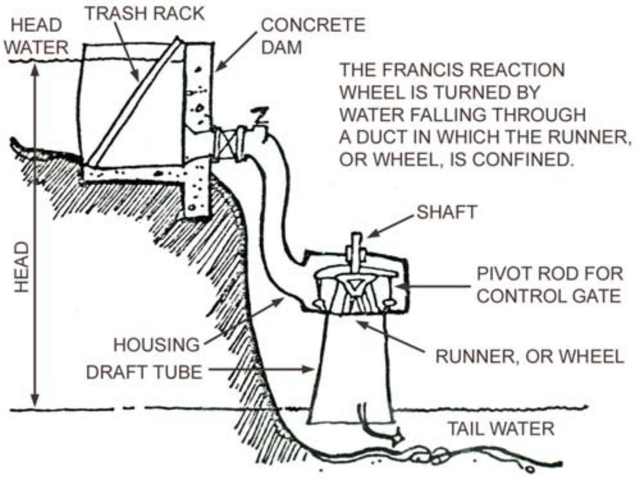


Figure 5 Typical Francis Reaction Turbine Installation

Power Generation and Control. The type of electricity and controls used.

AC or DC ? Electrical power can be generated in either alternating current (AC) or direct current (DC). DC current can be used in two ways: either directly as DC or converted to AC through the use of an inverter. The main advantage of DC is the ease of battery storage, thus extending the systems capacity. As DC generators are not speed sensitive, a governor is not required. Because the hydro generator is always charging the batteries, a deep discharge condition (a common cause of battery failure) is rare. Batteries become unwieldy and expensive in systems over 2 kW.

AC current has the advantage of allowing the use of common household appliances and tools, but must be generated with a synchronous generator and speed governor to ensure a steady frequency of 60 cycles per second. AC power cannot be stored. AC generation will be the choice if power is to be sold to a utility such as BC Hydro. Refer to Off Farm Power Sale, page 8.

Because of the prominence of AC power and availability of mass produced inexpensive AC tools and appliances, usage of DC is usually only considered for very limited electrical lifestyles such as cabins or cottages. However, with the recent development of the solid-state, user-friendly inverter, DC electricity stored in low voltage batteries can be converted to 120 volt AC in large quantities with good efficiency. A battery bank/inverter combination will be able to supply 2 to 5 kW peak loads in a residence where the average power generated may be only 200 to 800 watts, allowing the use of streams which have been overlooked in the past.

The design choice of battery storage or a direct AC system should be based on the streams' potential, closely considering the seasonal flow variations. A system less than 1 kW will have battery storage and over 2 kW systems can be direct AC, with in-between systems depending on the nature of the electrical loads.

Generator Control. Speed governing of an AC generator is required to:

- maintain the 60 cycle per second generator frequency
- prevent generator over-speeding from light or no loads
- prevent generator under-speeding from too great a load

Governing can be accomplished either by mechanically controlling the water flow to the turbine, or by electronically maintaining an electrical load on the generator. This action matches the load to the turbines' output ensuring proper system speed.

Mechanical water control governing, limiting the water flow to match the electrical load, is generally too expensive for hydro systems of less than 100 kW. In addition, while mechanical control uses reservoir-stored water most efficiency, such reservoir systems are usually too expensive for small on-farm hydroelectric generation.

An electronic load control governor is likely used on small AC hydro systems. They maintain full load on the system, dumping "surplus" power not needed by primary loads to secondary uses. As a load is turned off it is replaced by the controller, at the same time, with one of the same size. These secondary uses must be resistive in nature, such as lights, space heating or water heating and be available at all times. This control system allows the design loads to be turned or off as desired as the governor adjusts the secondary loads to maintain the power balance. The generator output must supply whatever loads are turned on, requiring ability to meet peak loads or else have the user be "peak-load-aware" and manually practice load management.

Electronic Load Management. More sophisticated systems have electronic load management to get the most useful electrical energy out of the water flow, minimizing peak loads and power dumping. An electronic controller energizes primary loads by priority, such as temporary disconnecting a freezer or heater when a stove is turned on. Temporarily turning off such loads frees-up power for user-controlled immediately-needed primary loads, avoiding a peak load that could otherwise overload the system. As power becomes available when priority primary loads are turned off, the controller re-connects lower priority primary loads, eventually reconnecting to secondary loads, always acting as a generator controller.

In this manner, a flexible load management system is set up that can be changed to suit changes in seasons, demands, etc. Connecting loads by priority, instead of at once, it can control loads that total 4 to 5 times the actual output of the power plant.

Step 4: Licensing and Permits

A water licence must be obtained from the Water Stewardship Division of the Ministry of Environment for any use of water, even non-consumptive uses as in a hydroelectric generation. If a stream is fully recorded for consumptive uses, such as irrigation or domestic systems, it does not necessarily prevent the use of that water for power generation as long as existing licence holders are accommodated. The environmental impart of a hydroelectric project must be considered, such as effect on fish by the water diversion, protection at intake works, maintenance of adequate stream flows, etc., are just some of the concerns that must be addressed.

Permits will be required from the BC Safety Authority for all electrical installations and they must comply with the Canadian Electrical Code as amended for use in BC. All equipment must be CSA approved, unless special allowance is obtained.

Step 5: Costs and Economics

Installation Cost Estimates. Small hydro installations are very site specific and costs can vary from $1500 to over $4000 per kilowatt depending on factors as:

- head (high head sites usually cheaper than low head sites of equal output)
- generation size (cost per kilowatt usually decreases as output increases)
- generation site location in relation to the power demand (powerline costs)
- amount of site work required, ease of site access, etc
- availability of used equipment
- ability of the owner/operators to perform some of the labour

Like many such developments, hydroelectric generation is less costly per kW with increased system size. For instance estimates of "micro" systems of 1kW range from $3500 to $4000 per kW while 10kW systems range from $1500 to $2500 per kW (Compass Resource Management Ltd report to BC Hydro, 2003). Therefore while a 1kW system may cost $3500 - 4000, a 10kW system may cost $15000 - 25000 but produce ten times the energy output for about 4 - 6 times the cost.

Operational Cost Estimates. Plan for annual costs such as:

- maintenance of up to 5% of installation cost
- Crown water rental of $0.003 per 1,000 cubic metres (going to $0.10 by 2009)
- Crown land rental for reservoir, pipe or power lines sites (if applicable)
- property tax assessment (where applicable)
- other site specific operational costs

Economics. Similar to cost estimates, the economics of a hydro installation are site specific. The project costs should be considered as offsetting either the acquisition and annual cost of utility hydro power or, in remote areas, the cost of diesel generation. Small hydro systems, like many renewable energy resources, may have high "front-end costs", but except for small maintenance costs, the only other major costs should be equipment overhaul every 20 to 25 years.

In the 2003 report to BC Hydro (noted above), the generation costs for small hydro systems ranged from 11 to 27 ¢/kWh (1kW system) to 5 to 16 ¢/kWh (10kW system). With the current residential rate from BC Hydro of just over 6 ¢/kWh, **a premium over the utility rate is likely to be paid for self generation with small hydro systems**. Such systems are usually considered when the utility supply is not an option or is costly to have the grid system extended to the farm property or the required site.

Use Table 2, next page, to make some basic economic decisions. First of all decide the annual power consumption in kWh and the cost or value per kWh being paid or willing to pay for electricity. Using these two values, Table 2 gives the loan that could be taken out today (at 8% over 20 years) for the cost of a hydroelectric project.

For example, if the power consumption is 12,000 kWh annually and the rate or value is 7¢/kWh, that would be equal to financing a 20-year term, 8% bank loan of $7950 to install a small hydro project (including allowance for 5% annual maintenance costs). In this case, $840 annually would have been otherwise spent for electricity (12,000 kWh @ 7¢). With 5% held back for annual maintenance (5% of $840 = $42), this leaves $798 for an annual loan payment that will pay off a 8% loan of $7950 in 20 years. Refer to this web site for calculation of other loan amounts and rates: http://www.mortgage-lenders-plus.com/calculators_loan_amortization.asp

This is a simplistic look at the economics of a long-term project. The individual costs have to be considered of all options available and a net present value of each established. Only then could you accurately determine the value of a hydro project.

An important consideration in the economics of such developments is the other uses that can be made of the water resource or the use that can be made of existing infrastructure. Fire suppression, domestic water supply and irrigation might be considered jointly with the hydroelectric project. Alternatively, an existing irrigation water diversion system may have power generation possibilities.

Table 2 FINANCING A SMALL HYDROELECTRIC PROJECT *

		Power Cost or Value (¢ per kWh)						
		6¢	**7¢**	**8¢**	**9¢**	**10¢**	**11¢**	**12¢**
Annual Electrical Consumption (1,000's kWh)	**8**	4550	5580	6060	6815	7570	8330	9085
	10	5680	6625	7570	8520	9465	10410	11360
	12	6815	7950	9085	10220	11360	12490	13630
	14	7950	9275	10600	11925	13250	14575	15900
	16	9085	10600	12115	13630	15145	16655	18170

* The table numbers are the loan amounts (at 8% over 20 years) that can be repaid from the given cost/value of electricity at the annual use levels (allowing for 5% of annual payment to go towards annual maintenance)
Calculate other loans / rates / terms at http://www.mortgage-lenders-plus.com/calculators_loan_amoritization.asp

Off-Farm Power Sale

Some farm sites may have the potential to generate energy in access of their needs and be interested in sale of power to a utility such as BC Hydro. If such power sales are considered, discuss all issues with the utility before any detailed site work or equipment purchases. Such systems will likely have one or more of the following features:

- a generation capacity that has low per kW production cost
  - these are often high head sites (likely minimum 150 feet)
- a location near the utility grid for low connection line cost
- good hydrology of the water source for continuous generation, including
  - limited seasonal changes in stream flow
  - limited year-to-year changes in stream flow
- a storage reservoir may reduce the above hydrology concerns but adds cost
- the on-farm labour and equipment ability to reduce installation costs

Net Metering. When the utility delivers electricity to a customer it is metered through a kilowatt-hour totalizing meter and billed by the consumption amount registered on the meter.

If a farm hydroelectric system was selling power to the utility, the generated power could be sent through this same meter, but with the electricity going in the opposite direction (*to* the utility rather than *from*), the meter will run backwards. This will reduce the meters total, reducing the monthly utility bill. Should power be sent to the utility in excess of what the farm used, income would be owed to the farm from the utility. This is called Net Metering as customers are only billed for their positive “net consumption” (consumption minus generation). Refer to References, next page

Currently BC Hydro has a Net Metering Rate Schedule of 5.4 ¢ per kilowatt-hour. If sales to the utility are to generate income this rate becomes a design-consideration rate. The current BC Hydro residential rate charge is just over 6 ¢/kWh so this would be the “earned-income” rate (offset cost) for the farm-generated/farm-used electricity (note irrigation rate is presently about ½ the residential cost at 3.27 ¢ per kilowatt-hour so this use would provide the farm with a lower offset cost).

Interconnection Issues. Where the electricity generated is to be sold to a power utility such as BC Hydro, the interconnection concerns and equipment must be chosen to match the utilities needs and conditions. The details of these issues are beyond the scope of this Factsheet. Discuss with the utility prior to making any equipment decisions. Refer to References, below.

Conclusion

Hydroelectric generation may offer an opportunity for farms off the utility power grid to supply their own electrical energy at a lower cost than running an engine/generator or than extending the grid to their property. **However systems may only be feasible when it is appropriate to pay a premium over utility electrical rates** as electrical cost per kWh (especially for small systems) may be greater than the utility rate.

Small hydroelectric systems are a long-term investment, they may be expensive to install, are not flexible once installed, and cannot be transferred if the farm is sold. They should be considered as other structural farm improvements having many years of operating life. A major overhaul can be expected in 20 to 25 years.

If the generation size and location offer an economic return with interconnection to a utility, such hydroelectric installations may offer some farm income diversity.

Acknowledgement

The author would like to acknowledge the expert comments of Robert Mathews, small hydro consultant, in the preparation of this Factsheet.

References and Other Information

1. ***BC Hydro*** web site for:
   - illustration of basic terms (choose "Interactive Model"):
   http://www.bchydro.com/education/4-7/4-7_2469.html
   - interconnection issues, net metering, etc are covered at:
   http://www.bchydro.com/info/ipp/ipp8842.html

2. ***BC Ministry of Agriculture & Lands Publications:***

552.000-1	BC Sprinkler Irrigation Manual (for piping; pipe friction loss tables)
501.400-1	Measuring Water Flow
510.100-1	Farm Water Storage
810.210-12	Changes In and About a Stream

3. ***BC Ministry of Environment*** web site re power generation water licensing
   http://lwbc.bc.ca/02land/tenuring/waterpower/index.html

4. ***Canadian Small Hydropower Handbook: BC Region***, Energy, Mines and Resources Canada, 1989, Tony Tung

5. ***Micro-Hydro Power***, Ontario Ministry of Energy, 1982, Publications Services Section, 5th Floor, 880 Bay Street, Toronto, Ontario, M7A 1N8

6. ***Small Hydroelectric Design Manual***, 1990 and ***Supplement***, 1991, C. Peter Koch, New Westminster, BC, 1990 (note that the *Supplement* has a section on centrifugal pumps used as turbines)

RESOURCE MANAGEMENT BRANCH
Ministry of Agriculture and Lands
1767 Angus Campbell Road
Abbotsford, BC V3G 2M3 Phone: (604) 556-3100

WRITTEN BY
Lance Brown
Engineering Technologist
Kamloops Office