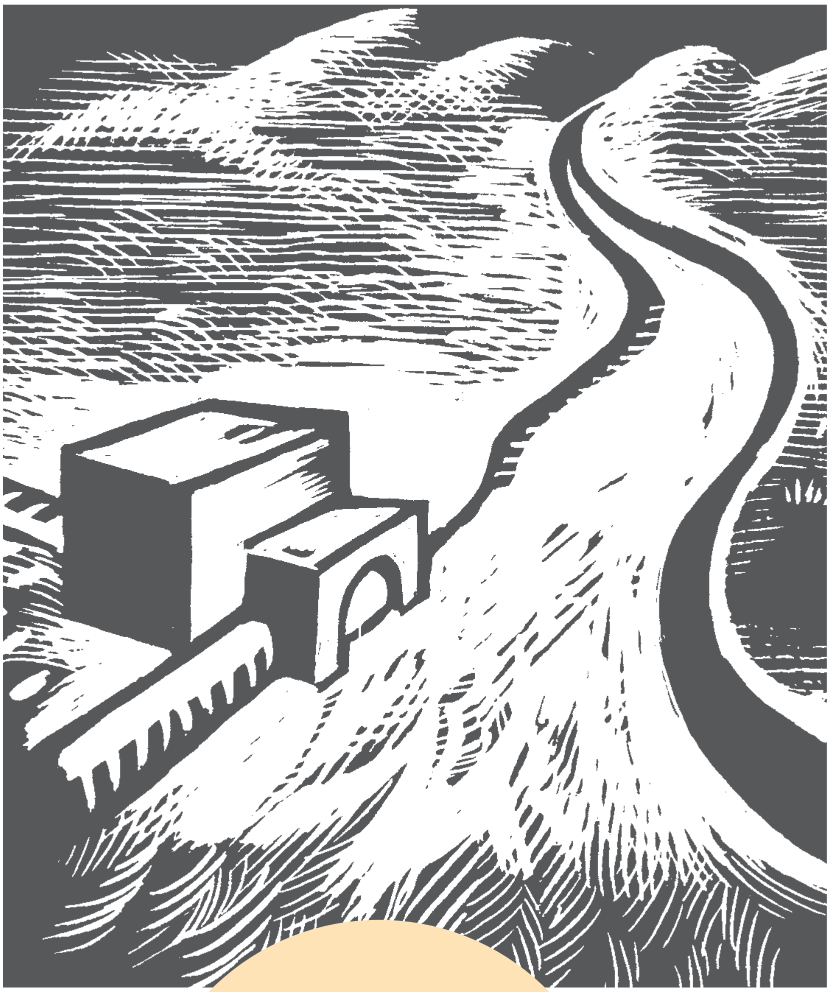
Small hydro power generation



Falling water contains stored energy which can be used to turn a turbine and generate electricity.

The concept

Nearly a quarter of the energy from the sun that reaches the Earth's surface causes water from the seas, lakes and ponds to evaporate. Some of this energy is used to make the water vapour rise (against the gravitational pull of the Earth) into the atmosphere, where it eventually condenses to form rain or snow. When it rains in the hills or snows in the mountains, a small proportion of the solar energy input remains stored. Therefore water at any height above sea level represents stored "gravitational" energy.

This energy is naturally dissipated by eddies and currents as the water runs downhill in "babbling brooks", streams and rivers until it reaches the sea. The greater the volume of water stored and the higher up it is, then the more available energy it contains. For example, water stored behind a dam in a reservoir contains considerable "potential" energy since, given the chance, if the dam burst the large volume of water would rapidly run downhill. This would cause devastation in its wake as a result of the sudden release of a large amount of energy.

To capture this energy in a controlled form, some or all of the water in a natural waterway can be diverted into a pipe. It can then be directed as a stream of water under pressure onto a water wheel or turbine wheel so that the water striking the blades causes the wheel to turn and create mechanical energy.

In water mills, large wooden water wheels rotate slowly to turn the mill stones to grind the grain. Similar principles have been used to pump water, saw wood and drive simple machinery in factories. Today a modern turbine is connected to a generator to produce electricity, which is then transmitted to the place where the energy is required. The principle is the same, whether it be the Clyde Dam on the Clutha River in Otago generating 430 MW of power from its four turbines, or a 1 kW privately owned system installed in a small stream running through the hills west of Auckland.

The issues

Hydro power is more reliable than wind or solar power generation as the water runs constantly and can often be stored. So why are small hydro generating schemes not common when there are so many streams and rivers?

A waterway is suitable for small hydro power generation only if it does not flood severely and if it has an adequate drop in height over a short distance.

Stand-alone systems are not always as reliable or cheap as mains electricity. There can be a large capital cost. The distance of the turbine from the point of use also needs to be considered as transmission cables can further increase the cost.

Maintenance of the mechanical and hydraulic equipment is required (although this may only take a few hours per month).

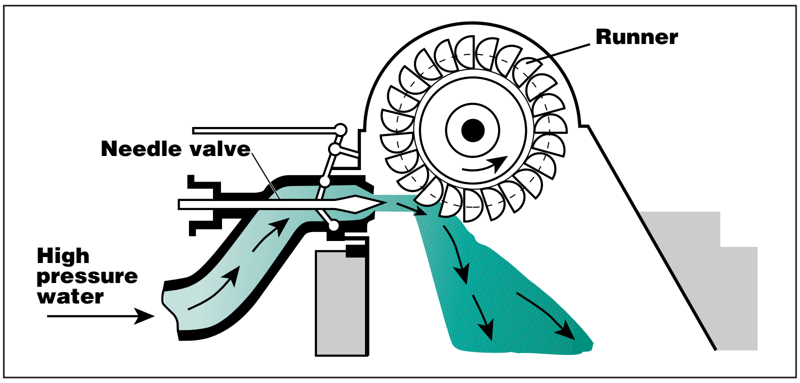
Therefore small hydro schemes are usually installed where mains electricity is not available or the mains installation costs are very high.

The technology

All that is needed for a hydro-power scheme to operate is a source of running water, a difference in water level, and a pipe supplying water to a turbine generator. The generating capacity of a hydro system depends on:

- the seasonal variations in rainfall and river flows;
- the water storage volume that can be achieved (is the stream bed suitable for damming and is it non-porous?);
- the head (or height of the water intake above the turbine outlet).

The theoretical amount of power that can be produced at a particular site depends on the rate of flow of the water and the head of fall it traverses.



A Pelton Wheel is often used when the waterway has a low flow and a high head

Theoretical power available (kW) = *Stream flow (litres/second) x Head (metres)/100*

In practice, not all the available energy can be harnessed, because of pipe friction and the inherent inefficiency of the turbine and generator used. It is also good ecological practice to divert only a proportion of the flow of the stream.

Actual power available (kW) = *Flow to the turbine (litre/sec) x (Static Head - frictional losses) (metres)/100 x Mechanical efficiency (%)/100 x generator efficiency (%)/100.*

The system efficiency depends on the type of turbine selected and the generator used. A Pelton Wheel is often used when the waterway has a low flow and a high head (say 5 l/s and 40 m) and has an efficiency of 75-85%. A crossflow (or Michell) turbine is preferable for a stream with a higher flow and lower head (say 100 l/s and 2 m) and has an efficiency of 60-70%.

Both of these examples would generate just over 1 kW of mechanical power.

This can be seen by substituting the figures into the power equation above and using the appropriate efficiency figure. To obtain the overall turbine generator efficiency one must multiply the turbine efficiency by the generator efficiency. Turbine generator efficiencies for small systems giving about 1kW output are usually around 50%.

To give optimum flexibility and to enable the use of standard electric appliances, the aim should be to provide a 230 Volt, 50 cycle, AC power supply as is received from the mains. Therefore the type of alternator and the optimum alternator rotation speed need to be carefully selected.

Several manufacturers now provide several sizes of turbine/generator sets with built-in controls which generate AC power with the desired characteristics. These simple systems do not use a water flow control, so maximum power is continually being generated. Generator speed and therefore frequency is achieved by running the alternator fully loaded. This is done by using a regulator to feed the unused energy into an energy store such as a hot water tank.

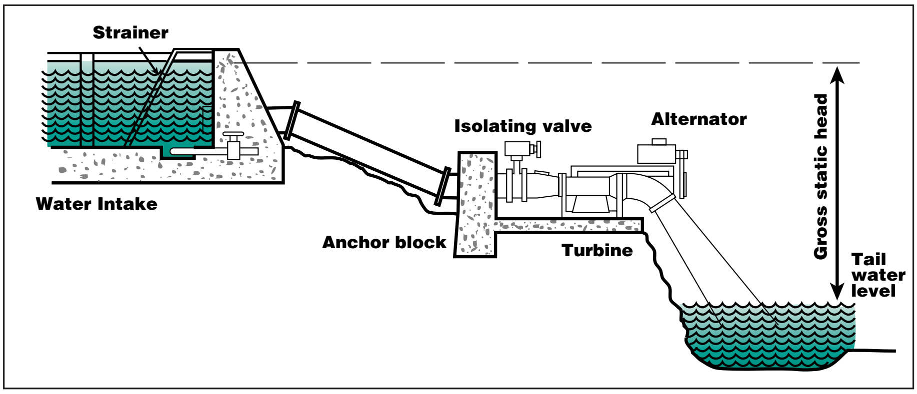


Diagram of a typical layout of an axial flow turbine.

DC systems are also available which store the power generated in batteries for either direct use or for supply through an inverter to provide an AC current. While a small hydro system is capable of supplying enough energy for the average household, the difficulty is in meeting peak demands such as for cooking. The advantage of battery storage is that it can be used to meet short-term power peaks that exceed the power output of the generator. However, batteries are expensive and so battery systems are more expensive than AC systems for the same load.

The distance of the turbine/alternator from the point of use must be considered. 1 to 2kW can be transmitted at 230 volts up to about 500 metres. The cable must be large enough to avoid excessive voltage drop. For larger distances or higher power transmission, higher voltages will be necessary. This can be achieved by using a 400V three-phase system or by using step-up/step-down transformers at each end of the line.

It may be possible to negotiate the sale of excess power generated to a power company. However this would require strict safety controls so may not be economically feasible for small schemes.

Turbine installation costs should not be under-estimated. The turbine site must be protected from flood damage.The type of parent rock material for the foundations, the accessibility of the site for installation and maintenance, and the portion of the water to be diverted to the turbine will influence the final structure design. Screens and possibly sedimentation tanks will be necessary at the intake to minimise damage or blockage of the turbine by grit and foreign objects.

The taking of any water for generating power requires granting of a resource consent or "water right" by the local regional council. Full planning details are outlined in the EECA publication *Guidelines for Renewable Energy Developments - Small Hydro*. All electrical installations must comply with the Electrical Wiring Regulations 1993.

Measuring flow and head

The first thing to do on considering the installation of a hydro scheme is to evaluate the site to determine if it is suitable to provide the power supply required.

Flow can be measured by:

- diverting the stream flow into a container (such as a bucket or drum) of known volume and timing how long it takes to fill;
- measuring the cross-sectional area (width x depth) of a uniform length of stream (say 5 m), then timing how long it takes for a partly submerged pine cone or stick to travel the distance. Flow is then calculated by:

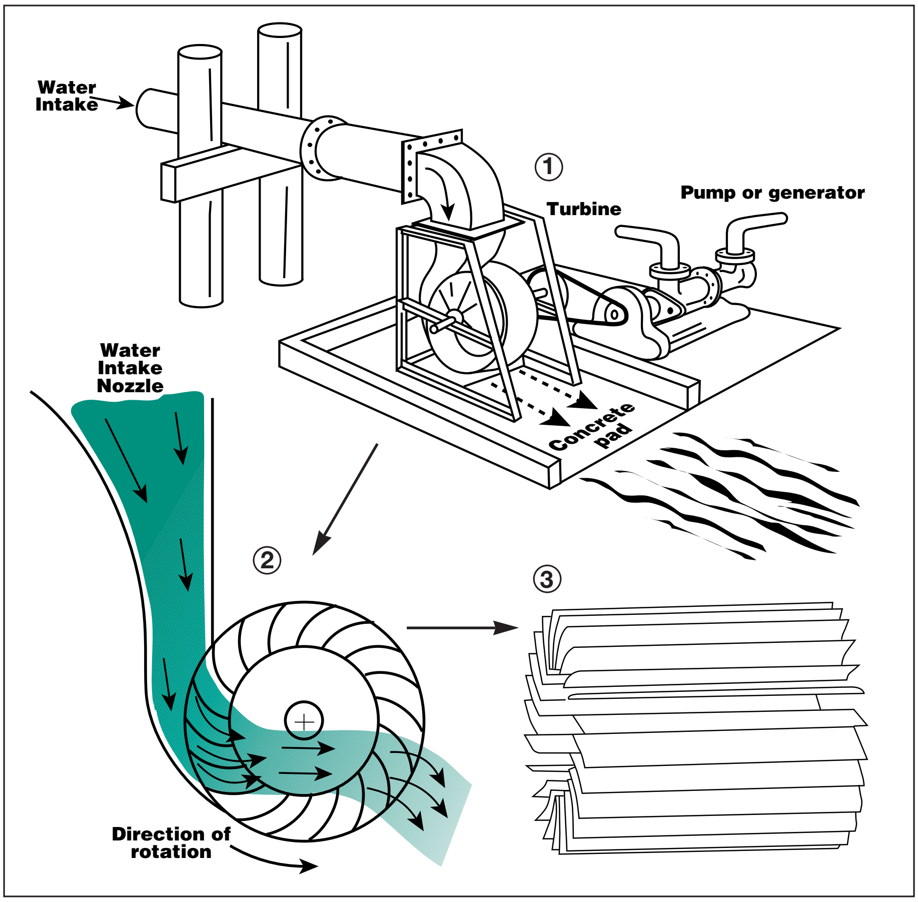
Flow (l/s) = 1000 x width (m) x depth (m) x length (m) / time (s);

- inserting a V-notch weir into the stream and damming it so all the water passes through the V-notch. The height of the water flowing through the V determines the flow rate. This is the most accurate method, but tables are required to assess the flow.

Remember that for any water course, there will be a difference of flow between winter and summer which will affect the power output produced.

The head or vertical drop from the water inlet site to the turbine outlet can be measured sufficiently accurately by three different methods.

1. Use an altimeter to measure the altitude difference between the point where the turbine is to be located and the point where the water inlet is to be located. Most low-cost altimeters available measure height to only within plus or minus 5 metres, and so should be used only on sites that have relatively high heads, in order to minimise the effect of this error. Changes in weather patterns also alter altitude readings,



1. The crossflow (Michell) turbine, suitable for a high-flow, low-head stream.
2. Cross-section through the turbine.
3. Arrangement of crossflow turbine blades.

so care should be taken to measure both the turbine and inlet altitudes on the same site visit.

2. If the turbine is to be situated at the base of a hill and a sufficient flat area exists away from the base, walk in a horizontal direction away from the hill. Pace out the distance to a point where on raising your line of vision upwards to approximately 45 degrees, you are looking at the site of the proposed water inlet. The distance away from the foot of the hill will equal the head of water.

3. Measure a 100 m length of hose pipe. Then, starting at the proposed generator site, walk with one end 100 m upstream. Place the hose end in the stream to allow it to fill; return to the downstream end; bend the pipe end to stop the flow of water and attach a pressure gauge to measure the static pressure head. A pressure of 1 bar (100 kPa or 14.3 psi) = 10 m head approximately. Repeat every 100 m till the inlet site is reached and then add up the static heads to give the total head.

These approximate figures for the head and flow can be used in the power equation to assess the approximate power output potential of the proposed site. If it looks promising, then it is advisable to seek expert advice.

Cost

The water is free but the cost of modifying stream flows, installing the turbine, purchasing the equipment and maintaining the system could be high in relation to the annual power bill, if mains power is available as an alternative. Since each installation differs, it is difficult to provide accurate cost estimates, but an AC system should be able to generate power for 10-20c/kWh depending on how much “free” labour you supply. This compares favourably with using a diesel generator or a wind/solar system and may also be a viable alternative to mains power if lines are more than two or three kilometres away. If batteries are required costs will be higher.

Case study

A Waikato kiwifruit grower had a stream running through his property with a 3m waterfall at one point. He measured the flow to be 25 l/s so selected a crossflow turbine design as the most appropriate for this high flow, low head site. He constructed a 300 mm diameter turbine from plate steel and cut sections along a 4 mm thick, 90 mm diameter steel pipe to provide the curved blades. The rectangular nozzle was designed to provide a jet of water impacting at an angle of 16 degrees to the blades across the full width of the turbine. This gave a system of 65% efficiency.

The generator installed was estimated to be 80% efficient. The generator produced 0.39 kW output or 9.4 kWh/day. This was used to charge batteries that ran the household appliances through a 230V inverter. Excess power was used to heat water.

The capital cost for installing the system, excluding labour, was approximately $5730. This included obtaining a resource consent and employing an electrician to check the wiring. This gave a simple payback period of approximately 10 years when compared with buying 3500 kWh of electricity each year. If no mains power had been available the hydro system could have been a far cheaper option than putting in new power lines.

For further information

- *New and Emerging Renewable Energy Opportunities in New Zealand*, published by the Centre for Advanced Engineering, University of Canterbury and EECA, 1996.
- *Guidelines for Renewable Energy Developments - Small Hydro*, EECA, 1996.
- *Sustainable Energy - Options for New Zealand*, DJ Redshaw and KR Dawber, University of Otago Press, Dunedin, 1996.
- *Sustainable Energy Systems study guide*, Extramural Paper 38.251, Massey University, Palmerston North.
- *Hydro Electric Turbine Systems - site analysis guide*, Powerflow Ltd, PO Box 10732, Wellington.
- *Remote area power supply: micro hydro/diesel hybrid*, (battery system), Demonstration project profile 22, EECA, 1994.
- *Remote area power system: micro hydro*, (an AC system), Project Summary Report 2, EECA, 1991.

EECA
Energy Efficiency and Conservation Authority

energy-wise Renewables - 4
© **EECA** • October 1997

The Energy Efficiency and Conservation Authority (**EECA**) is an independent government agency charged with determining and implementing practical measures for achieving greater energy efficiency in New Zealand.

For further information about Energy-Wise Renewables, and other publications in this series, please contact EECA at

Auckland: 1st Floor, 177 Parnell Road, PO Box 37-444, Parnell, Auckland
Telephone 0-9-377 5328 • Facsimile 0-9-366 0531

Wellington: 33 Bowen Street, PO Box 388, Wellington
Telephone 0-4-470 2200 • Facsimile 0-4-499 5330

Christchurch: Unit B, 52 Mandeville St, PO Box 8562, Riccarton, Christchurch
Telephone 0-3-341 1126 • Facsimile 0-3-343 1219

View EECA's home page on the Worldwide Web:
http://www.energywise.co.nz