Micro Hydro Power

Resource Assessment Handbook

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By

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Chapter 1 INTRODUCTION

1.1.History of Small Hydro Power technology

Hydropower is a renewable, non-polluting and environmentally benign source of energy. Hydropower is based on simple concepts. Moving water turns a turbine, the turbine spins a generator, and electricity is produced. Many other components may be in a system, but it all begins with the energy in the moving water. The use of water falling through a height has been utilized as a source of energy since a long time. It is perhaps the oldest renewable energy technique known to the mankind for mechanical energy conversion as well as electricity generation. In the ancient times waterwheels were used extensively, but it was only at the beginning of the 19th Century with the invention of the hydro turbines that the use of hydropower got popularized.

Small-scale hydropower was the most common way of electricity generating in the early 20th century. The first commercial use of hydroelectric power to produce electricity was a waterwheel on the Fox River in Wisconsin in 1882 that supplied power for lighting to two paper mills and a house. Within a matter of weeks of this installation, a power plant was also put into commercial service at Minneapolis[1]. India has a century old history of hydropower and the beginning was from small hydro. The first hydro power plant was of 130 kW set up in Darjeeling during 1897, marked the development of hydropower in the country. Similarly, by 1924 Switzerland had nearly 7000 small scale hydropower stations in use. Even today, Small hydro is the largest contributor of electricity from renewable energy sources, both at European and world level. With the advancement of technology, and increasing requirement of electricity, the thrust of electricity generation was shifted to large size hydro and thermal power stations.

However, it is only during the last two decades that there is a renewed interest in the development of small hydro power (SHP) projects mainly due to its benefits particularly concerning environment and ability to produce power in remote areas. Small hydro projects are economically viable and have relatively short gestation period. The major constraints associated with large hydro projects are usually not encountered in small hydro projects. Renewed interest in the technology of small scale hydropower actually started in China which has more than 85,000 small-scale, electricity producing, hydropower plants[2].

Hydropower will continue to play important role throughout the 21st Century, in world electricity supply. Hydropower development does have some challenges besides the technical, economic and

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[1] http://en.wikipedia.org/wiki/Hydroelectricity

[2] http://practicalaction.org/practicalanswers/product_info.php?products_id=41

environmental advantages it shares above other power generation (fossil fuel based) technologies. At the beginning of the new Millennium hydropower provided almost 20% (2600 TWh/year) of the electricity world consumption (12900 TWh/year). It plays a major role in several countries. According to a study of hydropower resources in 175 countries, more than 150 have hydropower resources. For 65 of them, hydro produces more than 50% of electricity; for 24, more than 90% and 10 countries have almost all their electricity requirements met through hydropower[3].

1.2.Small Hydro Power Project Classification

Hydro power projects are generally categorized in two segments i.e. small and large hydro. Different countries are following different norms keeping the upper limit of small hydro ranging from 5 to 50 MW. The world over, however, there is no consensus on the definition of small hydropower. Some countries like Portugal, Spain, Ireland, Greece and Belgium, accept 10 MW as the upper limit for installed capacity. In Italy the limit is fixed at 3 MW (plants with larger installed power should sell their electricity at lower prices) and in Sweden 1.5 MW. In France the limit has been recently established at 12 MW, not as an explicit limit of MHP, but as the maximum value of installed power for which the grid has the obligation to buy electricity from renewable energy sources. In the UK 20MW is generally accepted as the threshold for small hydro. Though different countries have different criteria to classify hydro power plants, a general classification of hydro power plants is as follows:

Type	Capacity
Large- hydro	More than 100 MW and usually feeding into a large electricity grid
Medium-hydro	15 – 100 MW - usually feeding a grid
Small-hydro	1 - 15 MW - usually feeding into a grid
Mini-hydro	Above 100 kW, but below 1 MW; either stand alone schemes or more often feeding into the grid
Micro-hydro	From 5kW up to 100 kW; usually provided power for a small community or rural industry in remote areas away from the grid
Pico-hydro	From a few hundred watts up to 5kW

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[3] http://www.uniseo.org/hydropower.html

In India though, hydro projects up to 25 MW station capacities have been categorized as Small Hydro Power (SHP) projects. The Ministry of New and Renewable Energy, Government of India is the agency responsible for planning, financing and installation of SHP up to 25 MW capacities. Further classification for small hydro power in India is as under:

Type	Capacity in kW
Micro Hydro	Up to 100
Mini Hydro	101 to 2000
Small Hydro	2001 to 25000
Large hydro	> 25000

Apart from the above classification, some of the other terms in vogue nowadays when describing very small hydro power plants are ‘Pico Hydro’ (less than 5 kW) and ‘Tiny Hydro’ (less than 1 kW).

Small hydro plants are also classified according to the “Head” or the vertical distance through which the water is made to impact the turbines. The usual classifications are given below:

Type	Head range
High head	100-m and above
Medium head	30 - 100 m
Low head	2 - 30 m

These ranges are not rigid but are merely means of categorizing sites.

Schemes can also be defined as:-

- Run-of-river schemes
- Schemes with the powerhouse located at the base of a dam
- Schemes integrated on a canal or in a water supply pipe

Most of the small hydro power plants are “run-of-river” schemes, implying that they do not have any water storage capability. The power is generated only when enough water is available from the river/stream. When the stream/river flow reduces below the design flow value, the generation ceases as the water does not flow through the intake structure into the turbines. Small hydro plants may be stand alone systems in isolated areas/sites, but could also be grid connected (either local grids or regional/national grids). The connection to the grid has the advantage of easier control of the electrical system frequency of the electricity, but has the disadvantage of being tripped off the system due to problems outside of the plant operator’s control.

For the purpose of this training manual, we will restrict our discussions and design principles to mini and micro hydro power plants only, i.e. up to about 5 MW capacity, though, most of the design principles would also apply to other small hydro power systems. **The term Micro Hydro Power (henceforth used as MHP) will be used extensively in this manual and it will imply a plant size of 100 kW to 5 MW**.

1.3. General principles of MHP

Power generation from water depends upon a combination of head and flow. Both must be available to produce electricity. Water is diverted from a stream into a pipeline, where it is directed downhill and through the turbine (flow). The vertical drop (head) creates pressure at the bottom end of the pipeline. The pressurized water emerging from the end of the pipe creates the force that drives the turbine. The turbine in turn drives the generator where electrical power is produced. More flow or more head produces more electricity. Electrical power output will always be slightly less than water power input due to turbine and system inefficiencies.

Water pressure or Head is created by the difference in elevation between the water intake and the turbine. Head can be expressed as vertical distance (feet or meters), or as pressure, such as pounds per square inch (psi). Net head is the pressure available at the turbine when water is flowing, which will always be less than the pressure when the water flow is turned off (static head), due to the friction between the water and the pipe. Pipeline diameter also has an effect on net head.

Flow is quantity of water available, and is expressed as ‘volume per unit of time’, such as gallons per minute (gpm), cubic metres per second (m^3/s), or liters per minute (lpm). Design flow is the maximum flow for which the hydro system is designed. It will likely be less than the maximum flow of the stream (especially during the rainy season), more than the minimum flow, and a compromise between potential electrical output and system cost.

1.4. Power from a MHP

To know the power potential of water in a stream it is necessary to know the flow quantity of water available from the stream (for power generation) and the available head.

The quantity of water available for power generation is the amount of water (in m^3 or litres) which can be diverted through an intake into the pipeline (penstock) in a certain amount of time. This is normally expressed in cubic meters per second (m^3/s) or in litres per second (l/s).

Head is the vertical difference in level (in meters) through which the water falls down.

The theoretical power (P) available from a given head of water is in exact proportion to the head and the quantity of water available.

$$P = Q \times H \times e \times 9.81 \text{ Kilowatts (kW)}$$

Where,
P = Power at the generator terminal, in kilowatts (kW)
H = The gross head from the pipeline intake to the tailwater in metres (m)
Q = Flow in pipeline, in cubic metres per second (m^3/s)
e = The efficiency of the plant, considering head loss in the pipeline and the efficiency of the turbine and generator, expressed by a decimal (e.g. 85% efficiency= 0.85)
9.81 is a constant and is the product of the density of water and the acceleration due to gravity (g)

This available power will be converted by the hydro turbine in mechanical power.

The losses in a hydro plant are:
(a) losses in energy caused by flow disturbances at the intake to the pipeline, friction in the pipeline, and further flow disturbances at valves and bends; and
(b) loss of power caused by friction and design inefficiencies in the turbine and generator.

The energy losses in the pipeline and at valves and bends are called head losses: they represent the difference between the gross head and the net head that is available at the turbine. The head losses in the pipeline could range from 2 percent to 10 percent of the gross head, depending on the length of the pipeline and the velocity of the flow. The maximum turbine efficiency could range from 80 percent to 95 percent depending on the type of turbine, and the generator efficiency will be about 90 percent.

Usually for design purposes, the head losses can be combined with the losses in the turbine and generator, and an overall plant efficiency of 85 percent (or e = 0.85) can be used.

1.5.Advantages and Disadvantages of MHP plants

1.5.1. Pros (Advantages) of Micro Hydro

Clean energy source: Hydropower does not produce greenhouse gas emissions, which are the major cause of the international concerns about environmental problems: Hydroelectricity does not involve a process of combustion, therefore it avoids polluting emissions like carbon dioxide (responsible for global warming) that otherwise would be produced by conventional energy when burning fossil fuels. MHP is a clean energy source (it does not produce waste in the rivers, or air pollution) and renewable (the fuel for hydropower is water, which is not consumed in the electricity generation process)

Efficient energy source: It only takes a small amount of flow (as little as two gallons per minute) or a drop as low as two feet to generate electricity with micro hydro. Since MHP is a decentralised energy source located close to the consumers, transmission losses can be reduced. Although electricity can be delivered as far as a mile away to the location where it is being used.

Reliable electricity source: Hydro produces a continuous supply of electrical energy in comparison to other small-scale renewable technologies. The peak energy season is during the winter months when large quantities of electricity are required. Power is usually continuously available on demand and the energy available is predictable.

No reservoir required: Microhydro is considered to function as a 'run-of-river' system, meaning that the water passing through the generator is directed back into the stream with relatively minimal or no impact on the surrounding ecology.

Cost effective energy solution: Building a small-scale hydro-power system can cost from $1,000 - $20,000 USD/kW, depending on site characteristics, power plant size and location. Maintenance costs are relatively small in comparison to other technologies. Given a reasonable head, it is a concentrated energy source. It is a long-lasting and robust technology – the life of systems can be as long as 50 years or more without major new investments (the average life considered for investment purposes however is about 30 years).

Power for developing countries: Because of the low-cost versatility and longevity of micro hydro, developing countries can manufacture and implement the technology to help supply much needed electricity to small communities and remote villages. No fuel and limited maintenance are required, so running costs are low (compared with diesel power). Localized power can be utuilized for the benefit of the local economy.

1.5.2. Cons (Disadvantages) of Micro Hydro

Site specific technology: In order to take full advantage of the electrical potential of small streams, a suitable site is needed. Factors to consider are: distance from the power source to the location where energy is required (this is not very common to find), stream size (including flow rate, output and drop), and a balance of system components — inverter, batteries, controller, transmission line and pipelines.

Energy expansion not possible: There is always a maximum useful power output (size and flow from small streams for example) available from a given hydropower site, which limits the increase in power generation and the level of expansion of activities which can make use of the power.

Seasonal variations: In many locations the flow in a stream fluctuates seasonally and this can limit the firm power output to quite a small fraction of the possible peak output. During summer months there is likely to be less flow and therefore less power output. Advanced planning and investigations are needed to ensure adequate energy generation and power demands are met.

Environmental and ecological concerns: MHP, like any energy-production activity, has impacts on the local ecosystem (on the quality of river and river ecosystems, noise, landscape). However, new legislative frameworks, innovative technology, improved methods of operating MHP and above all the willingness of all actors to integrate environmental concerns are steadily reducing these local environmental impacts. MHP plants, if well equipped, with fish ladders and environmentally friendly runner blades, are not an obstacle even for fish migration.

1.6.Typical uses

The use of power generated from any source can be categorized as productive use or consumptive use. Besides consumptive and productive use a distinction can be made between the use of power in a mechanical way or in the form of electricity.

A productive use is an activity performed in which money (or something equivalent) is exchanged for a service. It can also be defined as an activity which produces (products) that can fetch money or something equivalent. Most of those activities take place in small businesses. Eg. Saw mills, carpentry shop, lathe machines, grain grinding, etc. that use power from MHP plants. Using the energy generated with a hydro scheme in a mechanical way has some advantages over the use of electricity as intermediary.

All other uses of power are called consumptive. These include uses of energy to upgrade standards of living. Consumptive use will therefore take place in or near the house.

The typical uses are given in a tabular format below:

	Electrical end-uses	Mechanical end-uses
Productive end-use	Generally mechanical uses with electricity as intermediate step: Heating, Lighting, irrigation pumpsets, rural industries/ business, battery charging, etc.	Agro-processing, textiles fabrication, ice cream production, cooling, drying

Consumptive end-use	domestic lighting, cooking, domestic cooling/heating, radio and television, Battery charging, etc.	

1.7.Components of a MHP scheme

Figure 1 below shows the major components of a typical micro hydropower scheme.

The water in the river is diverted by the weir through an opening in the river side (the 'intake') into a channel (this could be open or buried depending upon the site conditions). A settling basin is built in to the channel to remove sand and silt from the water. The channel follows the contour of the area so as to preserve the elevation of the diverted water. The channel directs the water into a small reservoir/tank known as the 'forebay' from where it is directed on to the turbines through a closed pipe known as the 'penstock'. The penstock essentially directs the water in a uniform stream on to the turbine at a lower level. The turning shaft of the turbine can be used to rotate a mechanical device (such as a grinding mill, oil expeller, wood lathe, etc.) directly, or to operate an electricity generator. The machinery or appliances which are energised by the turbine (or MHP) are called the 'load'. When electricity is generated, the 'power house' where the generator is located transfers the electricity to a step-up 'transformer' which is then transmitted to the grid sub-station or to the village/area where this electricity is to be used.

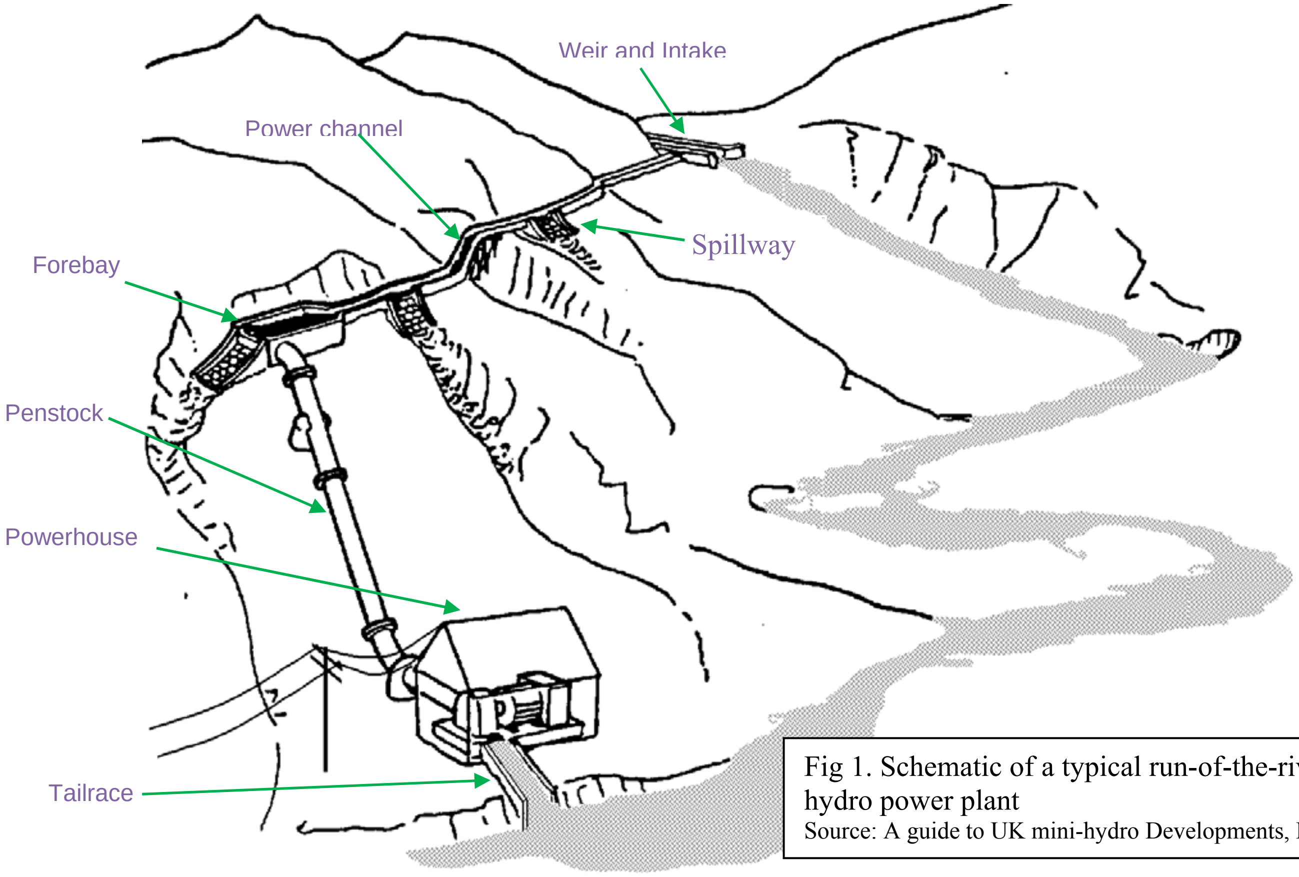


Fig 1. Schematic of a typical run-of-the-river small hydro power plant
Source: A guide to UK mini-hydro Developments, BHA 2005

1.7.1. Civil works

A micro hydropower station essentially needs water to be diverted from the stream and brought to the turbines without losing the elevation/head. Given below are some of the important factors that must be kept in mind while designing a micro hydropower system:

Available head: The design of the system has effects on the net head delivered to the turbine. Components such as the channel and penstock cannot be perfectly efficient. Inefficiencies appear as losses of useful head of pressure.

Flow variations: The river flow varies during the year but the hydro installation is designed for almost a constant flow. If the channel overflows there will be serious damage to the surroundings. The weir and intake must therefore be designed for such eventualities and divert only the required amount of flow irrespective of whether the river is in low or in high flow. The main function of the weir is to ensure that a constant flow in the channel is maintained when there is less flow in the river. The intake structure is designed to regulate the flow to within reasonable limits when the river is in high flow. Further regulation of the channel flow is provided by the spillways.

Sediment: Flowing water in the river sometimes carry small particles of hard abrasive matter (sediment) which can cause wear to the turbine if they are not removed before the water enters the penstock. Sediment may also block the intake or cause the channel to clog up if adequate precautions are not taken.

Floods: Flood water will carry larger suspended particles and will even cause large stones to roll along the stream bed. Unless careful design principles are applied, the diversion weir, the intake structure and the embankment walls of the river may be damaged.

Turbulence: In all parts of the water supply line, including the weir, the intake and the channel, sudden alterations to the flow direction will create turbulence which erodes structures and causes energy losses.

Most common civil structures used in a MHP scheme are:

1.7.1.1. Weir and intake

A micro hydro power system necessitates that water from the river to be diverted and extracted in a reliable and controllable manner. The water flowing in the channel must be regulated during high river flow and low flow conditions. A weir can be used to raise the water level and ensure a constant supply to the intake. Sometimes it is possible to avoid building a weir by using natural features of the river. A permanent pool in river could also act as a weir.

Another condition in site selection of the weir is to protect it from damage. Sometimes, in remote hilly regions, where annual flooding is common it may be prudent to build temporary weir using local resources and manpower. The temporary weir is a simple structure at low cost using local labour, skills and materials. It is expected to be destroyed by annual or bi-annual flooding. However, advanced planning has to be done for rebuilding of the weir.

The intake of a MHP is designed to divert only a portion of the stream flow or the complete flow – depending upon the flow conditions and the requirement.

MHP schemes use different types of intakes distinguished by the method used to divert the water into the intake. For MHP schemes, intake systems are smaller and simpler. The following three types of intakes have been described here: side intake with and without a weir and the bottom intake. The advantages and disadvantages associated with each of these are given in the table below:

Attributes	**Side intake without weir**	**Side intake with weir**	**Bottom intake**
Advantages	1. Relatively cheap 2. No complex machinery required for construction	1. Control over water level 2. Little maintenance necessary (if well designed)	1. Very useful at fluctuating flows. Even the lowest flow can be diverted 2. No maintenance required (if well designed)
Disadvantages	1. Regular maintenance and repairs required 2. At low flows very little water will be diverted and therefore this type of intake is not suitable for rivers with great fluctuations in flow.	1. Low flow can not be diverted properly 2. Modern materials like concrete necessary	1. Expensive 2. Local materials not useable 3. Good design required to prevent blockage by sediment

Note:

Side intake with weir: The weir used in this arrangement can be partly or completely submerged into the water.

Bottom intake: At a bottom intake the whole weir is submerged into the water. Excess water will pass the intake by flowing over the weir.

A steel or wooden bar (‘skimmer’) can be positioned on the water surface at an angle to the flow, if floating debris is a problem, so as to stop the debris and protect the intake.

1.7.1.2. Power Channels

The power channel or simply a channel conducts the water from the intake to the forebay tank. The length of a channel depends upon the topography of the region and the distance of powerhouse from the intake. Also the designing of the MHP systems states the length of the channel – sometimes a long channel combined with a short penstock can be cheaper or required, while in other cases a combination of short channel with long penstock would be more suitable. In the Himalayan region, the MHP channels are sometimes as long as a few kilometres to create a head of 10 to 60 metres or more.

Generally power channels are excavated and to reduce friction and prevent leakages these are often lined with cement, clay or polythene sheet. Size and shape of a channel and material used for lining are often a dictated by cost and head considerations. During the process of flowing past the walls and bed material, the water loses energy. The rougher the material, the greater the friction loss and higher is the elevation difference needed between channel entry and exit.

In hilly regions it is common that the power channel would have to cross small streams. In such situations it is often prudent to build a complete crossing over the channel, as during rainy season, flash floods and/or rocks/mud may block the channel or worse still, wash away sections of the channel. Sometimes just the provision of a drain running under the channel (in case of very small streams along stable slopes) is usually adequate.

The power channel has some important parts which are described in the sub-sections below:

1.7.1.3. Settling basin

The water diverted from the stream and carried by the channel usually carries a suspension of small particles such as sand that are hard and abrasive and can cause expensive damage and rapid wear to turbine runners. To get rid of such particles and sediments, the water flow is allowed to slow down in ‘settling basins’ so that the sand and silt particles settle on the basin floor. The deposits are then periodically flushed.

The design of settling basin depends upon the flow quantity, speed of flow and the tolerance level of the turbine (smallest particle that can be allowed). The maximum speed of the water in the settling basin can thus be calculated as slower the flow, lower is the carrying capacity of the water. The flow speed in the settling basin can be lowered by increasing the cross section area.

1.7.1.4. Spillways

Spillways along the power channel are designed to permit overflow at certain points along the channel. The spillway acts as a flow regulator for the channel. During floods the water flow through the intake can be twice the normal channel flow, so the spillway must be large enough to divert this excess flow. The spillway can also be designed with control gates to empty the channel. The spillway should be designed in such a manner that the excess flow is fed back to the without damaging the foundations of the channel.

1.7.1.5. Forebay tank

The forebay tank serves the purpose of providing steady and continuous flow into the turbine through the penstocks. Forebay also acts as the last settling basin and allows the last particles to settle down before the water enters the penstock. Forebay can also be a reservoir to store water – depending on its size (large dams or reservoirs in large hydropower schemes are technically forebay).

A sluice will make it possible to close the entrance to the penstock. In front of the penstock a trashrack need to be installed to prevent large particles to enter the penstock.
A spillway completes the forebay tank.

1.7.2. Penstock

The penstock is the pipe which conveys water under pressure from the forebay tank to the turbine. Penstock is a significant component of the MHP scheme and needs to be designed and selected carefully as it represents a major expense in the total budget (for some high head installations this alone could cost as much as 30% of the total costs). Here the main aspects to consider are head loss and capital cost. Head loss due to friction in the pipe decreases dramatically with increasing pipe diameter. Conversely, pipe costs increase steeply with diameter. Therefore a compromise between cost and performance is considered for design and selection of pipe diameter and material.

While designing penstocks, the first principle is to identify available pipe options and then to decided upon acceptable head loss (5% of the gross head is generally considered). The details of the pipes of various materials and diameters with losses close to this target are then tabulated and compared for cost effectiveness. A smaller penstock may be lighter on pocket, but the extra head loss may account for lost revenue from generated electricity each year.

1.7.2.1. Materials

The factors to be considered while deciding upon the material to be used for a particular penstock are:

- terrain,
- soil type
- weather conditions
- weight and ease of installation,
- accessibility of the site
- likelihood of structural damage

- availability
- surface roughness,
- design life and maintenance
- method of jointing
- design pressure,
- relative cost.

The following materials can be considered for use as penstock pipes in micro hydro schemes:

- wooden planks or tree bark (for very small installations)
- spun ductile iron
- GI Pipes
- mild steel,
- unplastified polyvinyl chloride (uPVC),
- high density polyethylene (HDPE),
- asbestos cement,
- prestressed concrete,
- glass reinforced plastic (GRP).

Mild steel, uPVC and HDPE are the most common used materials.

1.7.2.2. Penstock joining

Pipes are generally available in standard lengths (it is easier for transportation also) and have to be joined together on site. There are several methods of joining penstock pipes and the factors to be considered when choosing the best joint system for a particular scheme are:

- pipe material,
- whether any degree of joint flexibility is required,
- ease of installation
- skill level of personnel,
- costs.

Generally, the pipes are joined by one of the following four methods:

- flanged,
- spigot and socket,
- mechanical,
- welded.

1.7.2.3. Burying or supporting the penstock

Penstock pipelines can either be laid upon the surface or buried underground. This generally depends upon the material of the pipe, the nature of the terrain and environmental and cost considerations.

While burying a penstock, it is very important to ensure proper installation because any subsequent problems such as leaks are much harder to detect and resolve. In case vehicles are likely to cross over the buried pipelines, they must be buried at least 750 -1000 mm below ground level. Burying the pipeline carefully and correctly enhances the life of the MHP scheme and greatly reduces the chances of disruption in power generation especially in hilly terrain with heavy landslides.

If the natural terrain does not permit burying the penstock then the penstock is run overground. In such conditions piers, anchors and thrust blocks are needed to stabilize the pipeline (especially if these happen to be very long) to withstand the weight of the pipes plus water and expansion and contraction of the pipe (due to changing temperature).

Support piers are used basically to bear the weight of the pipes plus water being carried. Anchors are large structures fixed along the length of a penstock, restraining all movements (horizontal or vertical) by anchoring the penstock to the ground. For a bend or contraction in the pipeline, a thrust block is used to oppose the specific force generated by the bend or contraction. All of these structures are usually built of rubble masonry or cement concrete. Sometimes, the anchor blocks may need steel reinforcement (for long pipelines).

1.7.3. Turbines

Turbine is the main piece of equipment in the MHP scheme that converts energy of the falling water into the rotating shaft power. The selection of the most suitable turbine for any particular hydro site depends mainly on two of the site characteristics – head and flow available. All turbines have a power-speed characteristic. This means they will operate most efficiently at a particular speed, head and flow combination. Thus the desired running speed of the generator or the devices being connected/ loading on to the turbine also influence selection. Other important consideration is whether the turbine is expected to generate power at part-flow conditions.

The design speed of a turbine is largely determined by the head under which it operates. Turbines can be classified as high head, medium head or low head machines. They are also typified by the operating principle and can be either impulse or reaction turbines. The basic turbine classification is given in the table below:

	High Head	Medium Head	Low Head
Impulse turbines	Pelton Turgo	Cross-flow Multi-jet Pelton Turgo	Cross-flow
Reaction turbines		Francis	Propeller Kaplan

Difference between impulse and reaction turbines

The rotating part (called ‘runner’) of a reaction turbine is completely submerged in water and is enclosed in a pressure casing. The runner blades are designed in a manner such that the pressure difference across their surface imposes lift forces (similar to the principle used for airplane wings) which cause the runner to turn/rotate.

The impulse turbine (as the name suggests) on the other hand is never immersed in water but operates in air, driven by a jet (or jets) of water striking its blades. The nozzle of the penstock converts the head of the water (from forebay tank) into a high speed jet that hits the turbine runner blades that deflect the jet so as to utilize the change of momentum of the water and converting this as the force on the blades – enabling it to rotate.

Impulse turbines are usually cheaper then reaction turbines because there is no need for a pressure casing nor for carefully engineered clearances, but they are also only suitable for relatively higher heads.

1.7.3.1. Impulse turbines

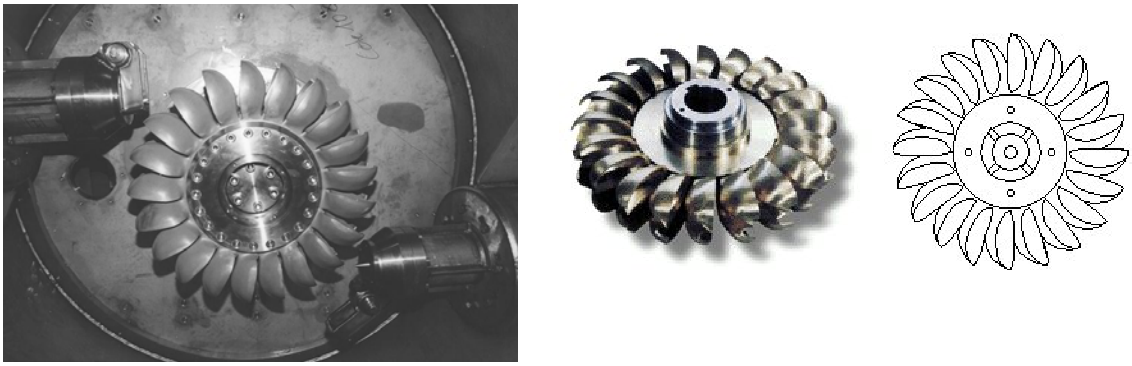
Impulse turbines are more widely used for micro-hydro applications as compared to reaction turbines because they have several advantages such as simple design (no pressure seals around the shaft and better access to working parts - easier to fabricate and maintain), greater tolerance towards sand and other particles in the water, and better part-flow efficiencies.

The impulse turbines are not suitable for low head sites as they have lower specific speeds and to couple it to a standard alternator, the speed would have to be increases to a great extent. The multi-jet Pelton, crossflow and Turgo turbines are suitable for medium heads.

Pelton turbine

A Pelton turbine consists of a set of specially shaped buckets mounted on a periphery of a circular disc. It is turned by forced jets of water which are discharged from one or more nozzles and impinge on the buckets. The resulting impulse spins the turbine runner, imparting energy to the turbine shaft. The buckets are split into two halves so that the central area does not act as a dead spot incapable of deflecting water away from the oncoming jet.

Pelton Runner (Source: Guide on How to Develop a Small Hydropower Plant ESHA 2004)



The cutaway on the lower lip allows the following bucket to move further before cutting off the jet propelling the bucket ahead of it and also permits a smoother entrance of the bucket into the jet. The Pelton bucket is designed to deflect the jet through 165 degrees which is the maximum angle possible without the return jet interfering with the following bucket for the oncoming jet. They are used only for sites with high heads ranging from 60 m to more than 1000 m.

The *Ghatta* and the Multi-Purpose Power Unit

The *Ghatta* is a traditional waterwheel with a vertical axis used extensively in the Himalayan region. The water generally hits the waterwheel from above while the axis of the waterwheel is vertical. The turbine (waterwheel) is made out of wood to enable simple building and repair techniques to be used. As a consequence of this design the traditional waterwheel have very low efficiency and power output (maximum 12 kW).

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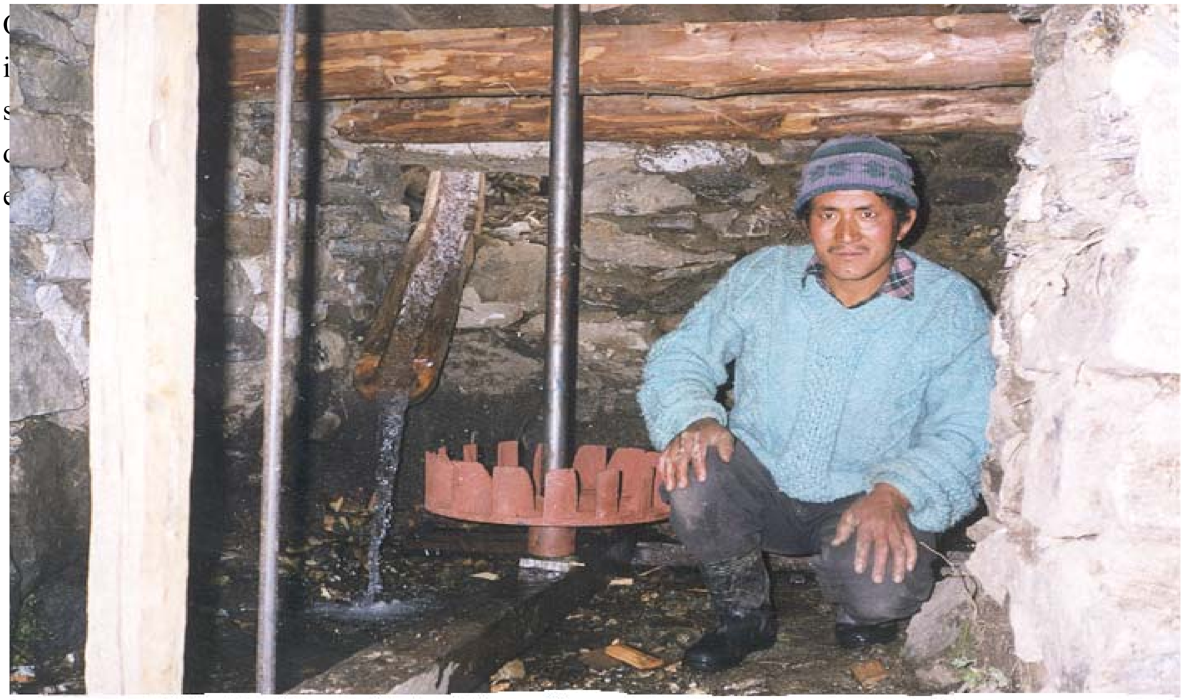
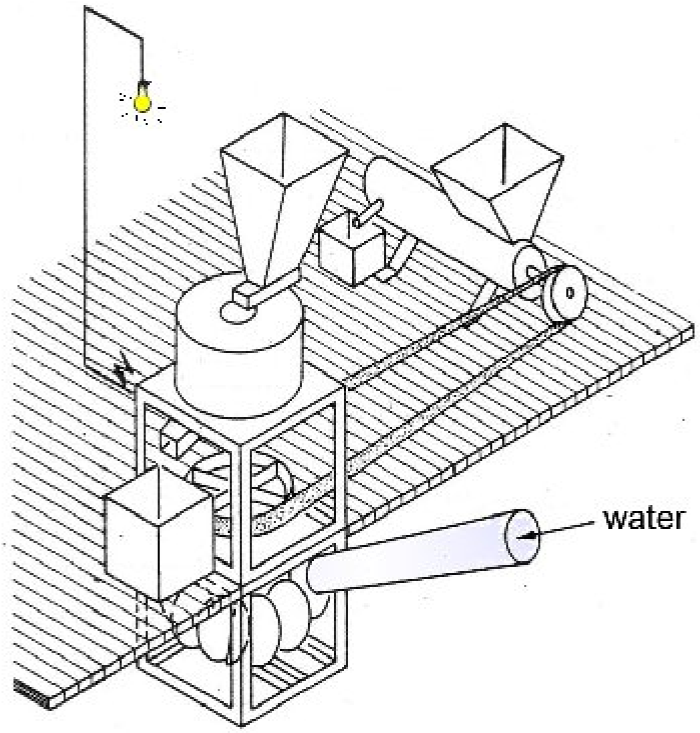


Improved watermill runner being installed in a village in India

The Multi-Purpose Power Unit (MPPU) as the name suggests is a micro-hydro scheme with several types of machinery connected to it. The MPPU was developed in Nepal. The concept of the MPPU is basically the same as that of the improved *Ghatta* – a vertical axis runner with a fixed and a rotating grinding stone (for grinding operations), and having belt and pulley arrangements to deliver power to other applications.



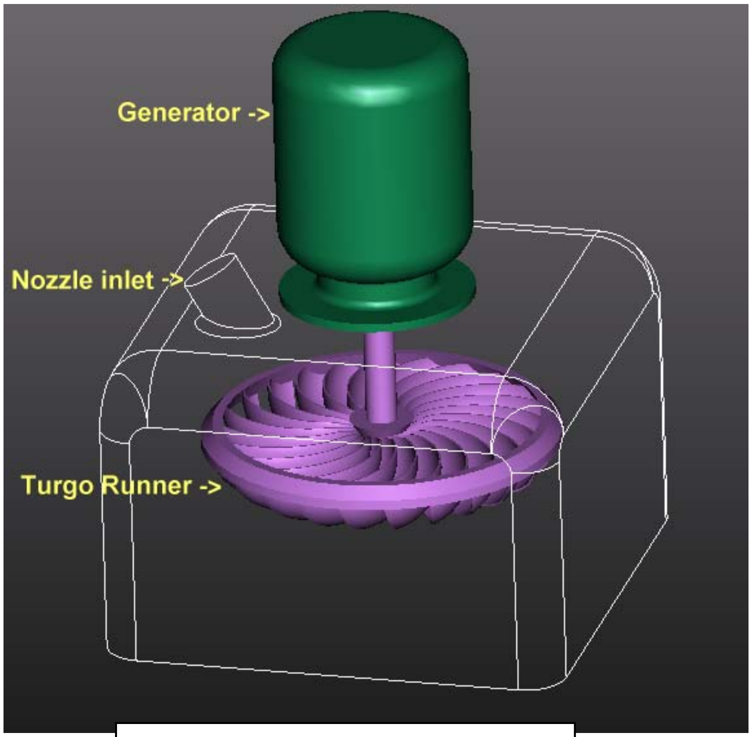
Multi-purpose power unit (Source: http://www.microhydropower.net/basics/turbines.php)

All components are made out of steel or cast iron instead of wood, water delivery system is improved (with pipes as penstock and simple nozzles) and friction losses are reduced compared to the improved *Ghatta*. Design philosophy was to produce a device as cheap and simple as possible. Special attention was given to transportability. Technical complexity, power output and prices of MPPU are generally in between those of the improved *Ghatta* and crossflow turbines.

Turgo impulse turbines

The Turgo turbine is an impulse turbine designed for medium head applications. These turbines achieve operational efficiencies of up to 87%. Developed in 1919 by Gilkes as a modification of the Pelton wheel, the Turgo has certain advantages over Francis and Pelton designs for some applications. Firstly, the runner is less expensive to make than a Pelton wheel while it does not need an airtight housing like the Francis turbines. Finally the Turgo has higher specific speeds and at the same time can handle greater quantum of flows than a Pelton wheel of the similar diameter, leading to reduced generator and installation cost. Turgo turbines operate in a head range where the Francis and Pelton overlap. Turgo installations are usually preferred for small hydro schemes where low cost is very important.

Turgo turbine is an impulse turbine where water does not change pressure but changes direction as it moves through the turbine blades. The water's potential energy is converted to kinetic energy with a penstock and nozzle. The high speed water jet is then directed on the turbine blades which deflect and reverse the flow and the water exits with very little energy. Like all turbines with nozzles, blockage by debris must be prevented for effective operation. A Turgo runner looks like a Pelton runner split in half. For the same power, the Turgo runner is one half the diameter of the Pelton runner, and so twice the specific speed. The Turgo can handle a greater water flow than the Pelton because exiting water doesn't interfere with adjacent buckets.



Turgo impulse turbine

The specific speed of Turgo runners is between the Francis and Pelton. Single or multiple nozzles can be used. Increasing the number of jets increases the specific speed of the runner by the square root of the number of jets i.e., four jets yield twice the specific speed of one jet on the same turbine.

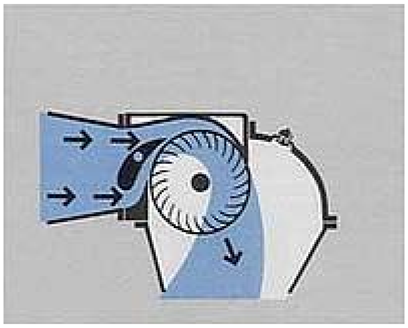
Crossflow turbine

Also called a Michell-Banki turbine a crossflow turbine has a drum-shaped runner consisting of two parallel discs connected together near their rims by a series of curved blades. A crossflow turbine always has its runner shaft horizontal (unlike Pelton and Turgo turbines which can have either horizontal or vertical shaft orientation).

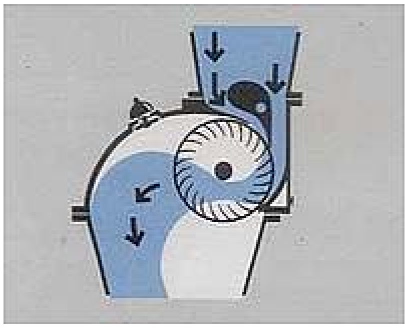
Unlike most water turbines, which have axial or radial flows, in a crossflow turbine the water passes through the turbine transversely, or across the turbine blades. As with a waterwheel, water enters at the turbine's edge. After passing the runner, it leaves on the opposite side. Going through the runner twice provides additional efficiency. When the water leaves the runner, it also helps clean the runner of small debris and pollution. The cross-flow turbines generally operate at low-speeds.

Crossflow turbines are also often constructed as two turbines of different capacity that share the same shaft. The turbine wheels are the same diameter, but different lengths to handle different volumes at the same pressure. The subdivided wheels are usually built with volumes in ratios of 1:2. The subdivided regulating unit (the guide vane system in the turbine's upstream section) provides flexible operation, with ⅓, ⅔ or 100% output, depending on the flow. Low operating costs are obtained with the turbine's relatively simple construction. The water flows through the blade channels in two directions: outside to inside, and inside to outside. Most turbines are run with two jets, arranged so that the two water jets in the runner will not affect each other. It is, however, essential that the turbine, head and turbine speed are harmonised.

The turbine consists of a cylindrical water wheel or runner with a horizontal shaft, composed of numerous blades (up to 37), arranged radially and tangentially. The edge of the blades are sharpened to reduce resistance to the flow of water. A blade is made in a part-circular cross-section (pipe cut over its whole length). The ends of the blades are welded to disks to form a cage like a hamster cage and are sometimes called "squirrel cage turbines"; instead of the bars, the turbine has trough-shaped steel blades.



Picture 1: Inflow horizontal



Picture 2: Inflow vertical

http://www.ossberger.de/cms/en/hydro/the-ossberger-turbine/

The water flows first from the outside of the turbine to its inside. The regulating unit, shaped like a vane or tongue, varies the cross-section of the flow. These divide and direct the flow so that the water enters the runner smoothly for any width of opening. The guide vanes should seal to the edges of the turbine casing so that when the water is low, they can shut off the water supply. The guide vanes therefore act as the valves between the penstock and turbine. The water jet is directed towards the cylindrical runner by a fixed nozzle. The water enters the runner at an angle of about 45 degrees, transmitting some of the water's kinetic energy to the active cylindrical blades. The turbine geometry (nozzle-runner-shaft) assures that the water jet is effective. The water acts on the runner twice, but most of the power is transferred on the first pass, when the water enters the runner. Only ⅓ of the power is transferred to the runner when the water is leaving the turbine.

The cross-flow turbine is of the impulse type, so the pressure remains constant at the runner. The peak efficiency of a crossflow turbine is somewhat less than a Kaplan, Francis or Pelton turbine. However, the crossflow turbine has a flat efficiency curve under varying load. With a split runner and turbine chamber, the turbine maintains its efficiency while the flow and load vary from 1/6th to the maximum.

The crossflow turbines are mostly used in mini and micro hydropower units less than 2 MW and with heads less than 200 m, since it has a low price and good regulation. Particularly with small run-of-the-river schemes, the flat efficiency curve yields better performance than other turbine systems, as flow in small streams varies seasonally. The efficiency of a turbine is determined whether electricity is produced during the periods when rivers have low heads. Due to its better performance even at partial loads, the crossflow turbine is well-suited to stand-alone electricity generation. It is simple in construction and that makes it easier to repair and maintain than other turbine types.

Another advantage is that the crossflow turbines gets cleaned as the water leaves the runner (small sand particles, grass, leaves, etc. get washed away), preventing losses. So although the turbine's efficiency is somewhat lower, it is more reliable than other types. Other turbine types get clogged easily, and consequently face power losses despite higher nominal efficiencies.

1.7.3.2. Reaction turbines

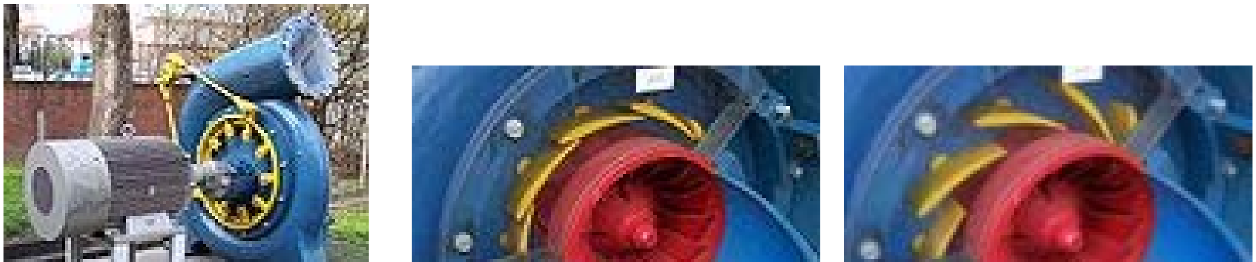
The more popular reaction turbines are the Francis turbine and the propeller turbine. Kaplan turbine is a unique design of the propeller turbine. Given the same head and flow conditions, reaction turbines rotate faster than impulse turbines. This high specific speed makes it possible for a reaction turbine to be coupled directly to an alternator without requiring a speed-increasing drive system. This specific feature enables simplicity (less maintenance) and cost savings in the hydro scheme. The Francis turbine is suitable for medium heads, while the propeller is more suitable for low heads.

The reaction turbines require more sophisticated fabrication than impulse turbines because they involve the use of larger and more intricately profiled blades together with carefully profiled casings. The higher costs are often offset by high efficiency and the advantages of high running speeds at low heads from relatively compact machines. Expertise and precision required during fabrication make these turbines less attractive for use in micro-hydro in developing countries. Most reaction turbines tend to have poor part-flow efficiency characteristics

Francis turbine

The Francis turbine is a reaction turbine where water changes pressure as it moves through the turbine, transferring its energy. A watertight casement is needed to contain the water flow. Generally such turbines are suitable for sites such as dams where they are located between the high pressure water source and the low pressure water exit.

The inlet of a Francis turbine is spiral shaped. Guide vanes direct the water tangentially to the turbine runner. This radial flow acts on the runner's vanes, causing the runner to spin. The guide vanes (or wicket gate) are adjustable to allow efficient turbine operation for a wide range of flow conditions. As the water moves through the runner, it’s spinning radius decreases, further delivering pressure acting on the runner. This, in addition to the pressure within the water, is the basic principle on which the Francis turbine operates. While exiting the turbine, water acts on cup shaped runner buckets leaving without any turbulence or swirl and hence almost all of the kinetic or potential energy is transferred. The turbine's exit tube is shaped to help decelerate the water flow and recover the pressure.



Francis Turbine and generator

Guide vanes at minimum flow setting (cut-away view)

Guide vanes at full flow setting (cut-away view)

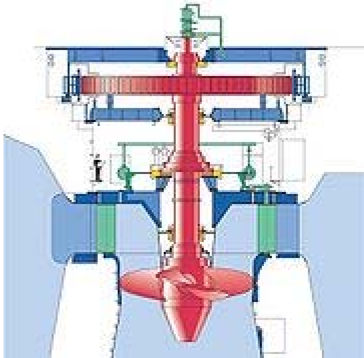
Francis turbines can be designed for a wide range of heads and flows and along with their high efficiency makes them one of the most widely used turbines in the world. Large Francis turbines are usually designed specifically for each site so as to gain highest levels of efficiencies (these are typically in the range of over 90%). Francis turbines cover a wide range of head – from 20 meters to 700 meters, and can be designed for outputs power ranging from just a few kilowatts to one Gigawatt.

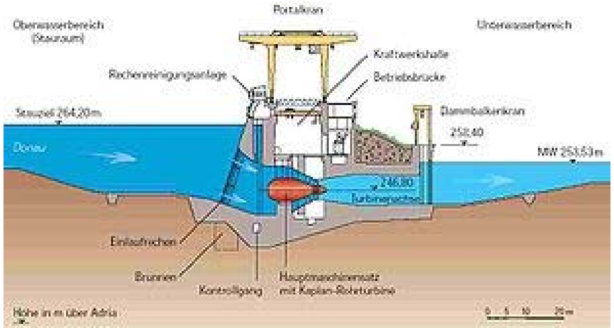
Kaplan turbine

The Kaplan turbine has adjustable blades and was developed on the basic platform (design principles) of the Francis turbine by the Viktor Kaplan in 1913. The main advantage of Kaplan turbines is its ability to work in low head sites which was not possible with Francis turbines. Kaplan turbines are widely used in high-flow, low-head power production.

The Kaplan turbine is an inward flow reaction turbine, which means that the working fluid changes pressure as it moves through the turbine and gives up its energy. The design combines radial and axial features. The inlet is a scroll-shaped tube that wraps around the turbine's wicket gate. Water is directed tangentially through the wicket gate and spirals on to a propeller shaped runner, causing it to spin. The outlet is a specially shaped draft tube that helps decelerate the water and recover kinetic energy.

The turbine does not need to be at the lowest point of water flow, as long as the draft tube remains full of water. A higher turbine location, however, increases the suction that is imparted on the turbine blades by the draft tube that may lead to cavitations due to the pressure drop. Typically the efficiencies achieved for Kaplan turbine are over 90%, mainly due to the variable geometry of wicket gate and turbine blades. This efficiency however may be lower for very low head applications. Since the propeller blades are rotated by high-pressure hydraulic oil, a critical design





element of Kaplan turbine is to maintain a positive seal to prevent leakage of oil into the waterway.

Kaplan turbines are widely used throughout the world for electrical power production. They are especially suited for the low head hydro and high flow conditions – mostly in canal based MHP sites. Inexpensive micro turbines can be manufactured for specific site conditions (e.g. for head as low one metre). Large Kaplan turbines are individually designed for each site to operate at the highest possible efficiency, typically over 90%. They are very expensive to design, manufacture and install, but operate for decades.

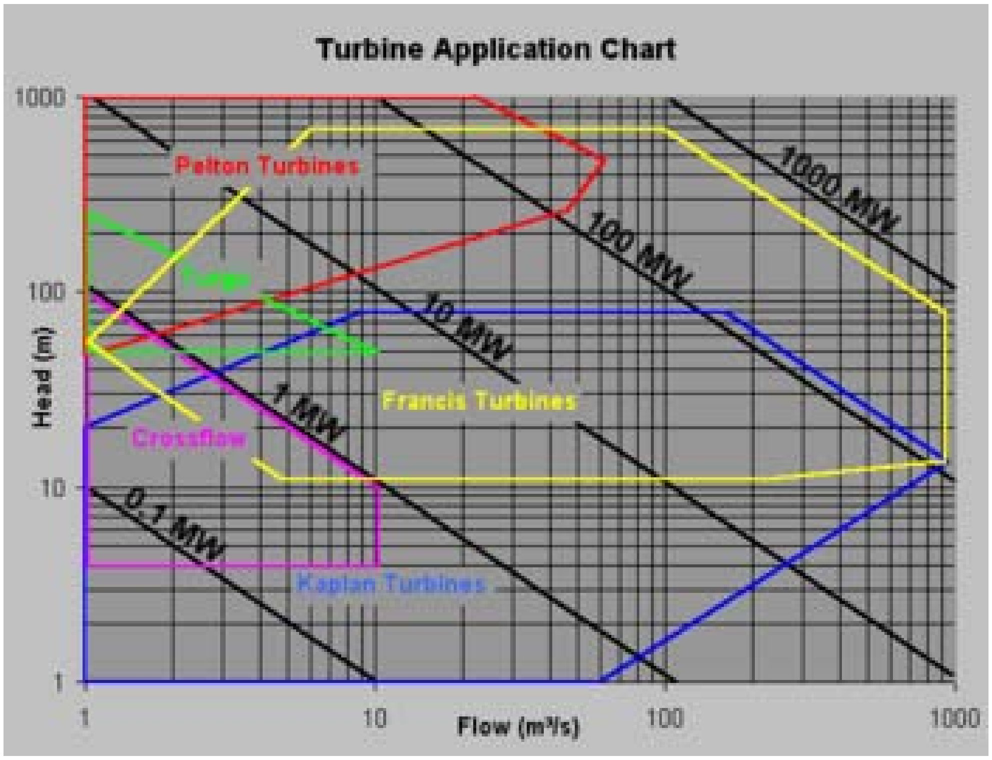
Reverse pump turbines

Centrifugal pumps can be used as turbines by passing water through them in reverse. The potential advantages are the lower costs due to mass production (also local production), the availability of spare parts and the wider dealer/support networks. The disadvantages are that their performance characteristics have not been studied extensively and these poor part-flow efficiencies. Pumps as turbines have been used at several locations but the technology still remains unproven.

1.7.4. Turbine selection

Selection of an appropriate turbine to a large extent is dependent upon the available water head and to a lesser extent on the available flow rate. In general, impulse turbines are used for high head sites, and reaction turbines are used for low head sites. Kaplan turbines with adjustable blade pitch are suitable for wide ranges of flow or head conditions, since their peak efficiency can be achieved over a wide range of flow conditions.

Small turbines (less than 10 MW) may have horizontal shafts, and even fairly large bulb-type turbines up to 100 MW or so may be horizontal. Very large Francis and Kaplan machines usually have vertical shafts because this makes best use of the available head, and makes installation of a generator more economical. Pelton turbines may be installed either vertically or horizontally. Some impulse turbines use multiple water jets per runner to increase specific speed and balance shaft thrust.



Turbine type, dimensions and design are basically governed by the following criteria:

- Net head
- Variation of flow discharge through the turbine
- Rotational speed
- Cavitation problems (quality of water available from penstock)
- Cost

The main criterion considered in turbine selection is the net head. The figure given above (Turbine Application Chart) specifies the range of operating heads for each turbine type. The figure above and the table below show some overlapping, so that for a given head several types of turbines can be used.

Turbine Type	Typical range of heads (H = head in m)
Hydraulic wheel turbine	$0.2 < H < 4$
Archimedes' screw turbine	$1 < H < 10$
Kaplan & Propeller	$2 < H < 40$
Francis	$10 < H < 350$
Pelton	$50 < H < 1300$
Michell-Banki	$3 < H < 250$
Turgo	$50 < H < 250$

The selection is particularly critical in low-head schemes, where large discharges need to be handled to be economically viable.

1.7.5. Drive systems

The drive system transmits power from the turbine shaft to the generator shaft or the shaft powering another device through a coupling device. It also serves the function of changing the rotational speed from the one shaft to the other when the turbine speed is different to the required speed of the alternator or device.

The following options are mostly used for micro hydropower schemes:

1. Direct drive,
2. Flat belt and pulleys,
3. V or wedge belt and pulleys,
4. Chain and sprocket, and
5. Gearbox.

1.7.5.1. Direct drive

Direct drive, as the name suggests is used only in case the shaft speeds of the turbine and the alternator or device are identical because it uses a flexible coupling to join the two shafts together directly. The advantages are low maintenance, high efficiency (>98%) and low cost. The only drawback of having direct drive arrangement is that the alignment of the two shafts becomes extremely critical unlike that in an indirect drive system.

1.7.5.2. Flat belt and pulleys

Modern flat belts run at high tension and are made of a strong inner band coated with a high friction material such as rubber. They have higher efficiencies than V-belts drives and run cleaner (i.e. with less rubber dust). One pulley must have a slightly convex profile (crowned) which together with good alignment, keeps the belt in position while in either vertical or horizontal use.

The main disadvantage of this arrangement is that higher tension is needed than with other drives which translate into higher loads for bearings, sometimes requiring additional heavier duty bearings to be used with standard alternators. Also they may not be as easily available in some areas as compared to V-belt drive systems. Flat belts generally require narrower pulleys for an equivalent multi V-belt with advantages in cost and reduced overhang.

1.7.5.3. "V" or wedge belts and pulleys

This is the most commonly used mechanism for micro hydropower schemes of up to 100 kW. A major advantage is that these belts are very well known and widely available because of their extensive use in all kinds of small industrial machinery.

V-belts are different from flat belts as the frictional grip on the pulley is caused by wedging action of the side walls of the belt within the pulley grooves. Hence less tension is required to maintain the grip and less radial load is imposed on the shaft and bearings.

Usually a number of V-belts are run side by side in multiple-governed pulleys. Matching sets of belts are required for tension to be evenly distributed and these sets can be difficult to obtain in some countries. At higher powers and torques multiple V-belt installations can become cumbersome with eight or more large belts and very wide pulleys.

1.7.5.4. Timing belt and sprocket pulley

Most common applications of these drives are on vehicle camshaft drives and involve toothed belts and pulleys. These are highly efficient (about 98%) and clean running. The belt tension is lower than in any other belt drive, giving reduced bearing loads but at the same time the belts do not slip on overload and this can sometimes damage the shafts and bearings. The major drawbacks are the cost of belts and pulleys and are not available everywhere. They are especially worth considering for smaller drives (less than 3 kW) where efficiency is a major consideration for viability. Speed ratios can be up to 10:1.

1.7.5.5. Chain and sprocket

Chains and sprocket arrangement can achieve high efficiencies but its lifetime is compromised at such high efficiencies. For chain and sprocket system to have long life, its efficiency reduces and is similar to that of belt drives. The main disadvantage of such drive systems is their high cost, poor availability, higher maintenance costs (the sprocket wheels need to be replaced periodically and needs high & frequent requirements). However, very high speed ratios of greater than 20:1 can be achieved.

1.7.5.6. Gearbox

Gearboxes are used with larger machines when belt drives become too cumbersome and inefficient. Problems of specification alignment, maintenance and costs rule them out except in cases where they are specified as part of a turbine-generator set.

1.7.6. Electrical power

Machinery can be driven directly by a turbine as in traditional grain mills and many modern timber sawing mills, but converting the power into electricity has several additional advantages. For instance, it enables the use of all types of electrical appliances from lighting to electric motors and also the flexibility of having the appliances at any point either near or far from the turbine. The device which converts mechanical energy into electrical energy is called a generator. The most common type of generator produces alternative current and is known as an alternator.

1.7.6.1. AC and DC

Two types of current are produced by electrical generators, either alternating current (AC) or direct current (DC). In the case of AC the voltage cycles sinusoidally with time, from positive peak value to negative. Because the voltage changes its sign the resulting current also continually reverses direction in a cyclic pattern. DC current flows in a single direction as the result of a steady voltage. DC is not usually used in modern power installations except for very low-powered systems of a few hundred watts or less.

Alternating voltage can be produced in a stationery coil or armature by a rotating magnetic field, but more usually a coil is rotated in a stationary magnetic field. The magnetic field can be produced either by a permanent magnet or by another coil (i.e., an electro-magnet) know as a field coil which is fed by direct current known as the excitation current. A generator supplying alternative current is described as an alternator to distinguish it from a machine designed to supply DC current which is known as a DC generator or dynamo. Current flows when a voltage difference is place across a conducting body. In AC circuits the magnitude and timing of the current cycle relative to the voltage cycle will depend on whether the conductivity body is resistance, inductive, capacitive or some combination of these elements.

1.7.7. Governors (Turbine controls)

Turbines are designed for a specific net head and discharge. Any variation in these two factors must be compensated for to achieve efficient and trouble free operation. This is usually accomplished by opening or closing the control devices, such as the wicket-gates, vanes, spear nozzles or valves, to keep either the outlet power, the level of the water surface in the intake, or the turbine discharge constant.

A governor is a combination of devices and mechanisms, which detect speed deviation and convert it into a change in servomotor position. Several types of governors are available varying from old fashioned purely mechanical to mechanical-hydraulic to electrical-hydraulic and mechanical-electrical. The purely mechanical governor is used with smaller turbines, because its control valve is easy to operate and does not require a big effort. These governors use a flyball mass mechanism driven by the turbine shaft.

For MHP schemes at remote locations (not connected to the grid), the parameter that needs to be controlled is the turbine speed, which controls the frequency. In an off grid system, if the generator becomes overloaded the turbine slows down. Therefore an increase in the flow of water is needed to ensure that the turbine does not stall. If there is not enough water to do this then either some of the load must be removed or the turbine will have to be shut down. On the other hand if the load decreases then the flow to the turbine is decreased or it can be kept constant and the extra energy can be diverted into a ballast (dummy) load connected to the generator terminals.

In the first approach, speed (frequency) regulation is accomplished with devices called speed governors. The speed governors normally control the flow – once a gate opening is calculated, the actuator gives the necessary instruction to the servomotor, which results in an extension or retraction of the servo’s rod. To ensure that the rod actually reaches the calculated position, feedback is provided to the electronic actuator.

The other inexpensive method is the use of electronic load governor. In this case, it is assumed that at full load, constant head and flow, the turbine will operate at design speed. Hence maintaining full load from the generator the turbine will always run at a constant speed. As we know that if the load decreases the turbine will tend to increase its speed. In a modern electrical-hydraulic governor a sensor located on the generator shaft continuously senses the turbine speed. The input is fed into a summing junction, where it is compared to a speed reference. If the speed sensor signal differs from the reference signal, it emits an error signal (positive or negative) that, once amplified, is sent to the servomotor so this can act in the required sense.

The controllers that follow the first approach do not have any power limit. The Electronic Load Governors however, are not used where MHP exceeds 100 kW capacities.

1.7.8. Switchgear equipment

The term switchgear, used in association with the electric power system, or grid, refers to the combination of electrical disconnects, fuses and/or circuit breakers used to isolate electrical equipment. Switchgear is used both to de-energize equipment to allow work to be done and to clear faults downstream. One of the basic functions of switchgear is protection, which is interruption of short-circuit and overload fault currents while maintaining service to unaffected circuits. Switchgear also provides isolation of circuits from power supplies. Switchgear also is used to enhance system availability by allowing more than one source to feed a load. Switchgear must be installed to control the generators and to interface them with the grid or with an isolated load. It must provide protection for the generators, main transformer and station service transformer.

In several countries the electricity supply regulations place a statutory obligation on the electric utilities to maintain the safety and quality of electricity supply within defined limits. The independent power producers must operate their plants in such a way that the utility is able to fulfill its obligations. Therefore various associated electrical devices are required inside the powerhouse for the safety and protection of the equipment. The generator breaker, either air, magnetic or vacuum operated, is used to connect or disconnect the generator from the power grid. Instrument transformers, both power transformers (PTs) and current transformers (CTs) are used to transform high voltages and currents down to more manageable levels for metering. The generator control equipment is used to control the generator voltage, power factor and circuit breakers.

1.7.9. Automatic control

Small hydro schemes are normally unattended and operated through an automatic control system. Since all MHP schemes are unique, it is impossible to determine and standardize the extent of automation that should be included in a given system. However, some requirements of general automation application are:

- The system must include the necessary relays and devices to detect malfunctioning of a serious nature and then act to bring the unit or the entire plant to a safe condition.
- Relevant operational data of the plant should be collected and made readily available for making operational decisions, and stored in a database for later evaluation of plant performance.
- An intelligent control system should be included to allow for full plant operation in an unattended environment.
- It must be possible to access the control system from a remote location and override any automatic decisions.

- The system should be able to communicate with similar units, up and downstream, for the purpose of optimizing operating procedures.
- Fault anticipation constitutes an enhancement to the control system. Using an expert system, fed with baseline operational data, it is possible to anticipate faults before they occur and take corrective action so that the fault does not occur.

Automatic control systems can significantly reduce the cost of energy production by reducing maintenance and increasing reliability, while running the turbines more efficiently and producing more energy from the available water.

Chapter 2 Resource Assessment

2.1.National and Regional levels

For national and regional resource assessment, the satellite images are used to develop GIS database for identification of source, selection of site, environmental planning, digital terrain model data (DTM), and transmission line network and ranking of the sites. Generally such exercises for large scale resource assessments are carried out by a team comprising GIS, hydrology, hydropower experts, etc.

Geographic Information System (GIS) is a computer based information system used to digitally represent and analyze the geographic features present on the earth's surface. The methodology for assessing the Hydro Power potential for a region can be done using the following methods.

2.1.1. Regional flow Duration Models

Flow duration curve is a simple graphical depiction of variability of water flow at a location without any reference to the sequence in which this flow would be available. Flow duration curve for the prospective sites for which adequate flow data is available can be directly developed. Flow for various levels of dependability for gauged site may be estimated from this curve. However, in real life situations, most of the prospective sites for hyrdo-power projects are likely to be ungauged where the sites either have insignificant data or no flow data available for such analyses.

To derive a flow duration curve for a location on a stream for which adequate flow data are not available, Regional flow duration curve may be used. Regional flow models are developed on the basis of data available for a few other gauged catchments in the same region or transposed from similar nearby region. Such models are employed to compute flow duration curves for ungauged catchments in that region. Availability of such regional flow duration models is of paramount significance (for example in estimating the potential of hyrdo-power in remote hilly regions of the country).

The yearly flow duration model provides the pattern of flow at an ungauged catchment. For the development of flow duration model, the physiographic characteristics of catchment like area, perimeter, length of main channel, elevation of highest and lowest points, geology of area, hydro-geology of area, land use pattern, climate and other parameters should be taken into account. Depending upon the data availability, the flow duration obtained from above regional flow models may be used only for pre-feasibility studies. This can be followed up with a detailed site feasibility study (for potential sites) based on the actual measurement of the discharge from the river/stream.

2.1.2. Remote Sensing Data for Catchment Analysis

The remote sensing technology is an effective tool for the identification of suitable sites for locating new hydropower projects especially in the inaccessible areas like Himalayas where the water recourse potential is high. Remote Sensing data available in the near infrared region (0.8 um - 1.1 um) provides clearly the contrast between land and water features and therefore is best suited for mapping perennial streams. IRS-LISS III-Geocoded False Colour Composites (FCCs) data may be used for identification of catchment boundary, drainage network; perennial streams, land-use and vegetation cover for such assessments. The elevation contours and spot heights from topographic maps can used to generate Digital Elevation model (DEM) of these catchments using any of the several GIS software packages available – Manifold, ARC-INFO, MapInfo, etc. For further analysis, the catchment boundary, drainage network and location of major habitation can be overlaid on these DEMs.

2.1.3. Digital Terrain Models (DTMs)

Digital Terrain Models can be used for computation of slope, channel length, area of catchment, head available for power generation and location of suitable sites for civil structures of small hydro power projects such as Diversion Weir, Feeder and Head Race Channel, Desilting Tank, Forebay Tank, Power House Building etc. The satellite imagery and GIS can further be used to plan the suitable (optimum) pathways, profile analysis, the engineering design of towers and wires and the cost estimation of transmission line network or feeder line to the nearest substation.

2.2. Resource estimation at local levels (site specific)

The only resource needed for a small/micro hydro power plant is flowing water available at a gradient. Planning for any small hydro plant begins with the (near to) accurate estimation of head and flow available at the proposed site. In the following subsections various methods for measuring the head and discharge available have been described in detail.

2.2.1. Measurement of head

Several methods exist for measurement of the available head. Some methods are more suitable on low-head sites, but are too tedious and inaccurate on high-heads. It is always advisable to take several separate measurements of the head at each site.

A further very important factor is that the gross head does not remain constant but varies with the river flow. As the flow in the river increases, the tail-water level often rises faster than the headwater level, thus reducing the total head available. Although this head variation is much less than the variation in flow, it can significantly affect the power available, especially in low-head schemes where even 0.5 metre is critical. To assess the available gross head accurately, head water and tail-water levels need to be measured for the full range of river flows. Some of the more common methods/techniques used for measurement of head are:

2.2.1.1. Dumpy levels and theodolite

The use of a dumpy level (or builder's level) is the conventional method for measuring head and should be used wherever time and funds allow. These devices need precise calibrations and should be used by experienced operators. Dumpy levels are used with staffs to measure head in a series of stages. A dumpy level is a device which allows the operator to take sight on a staff held by a colleague, knowing that the line of sight is exactly horizontal. Stages are usually limited by the length of the staff to a height change (usually of no more than 3 m). A clear unobstructed view is needed, so sites with lots of vegetation are generally difficult to assess with this method.

Dumpy levels only allow a horizontal sight but theodolite can also measure vertical and horizontal angles, giving greater versatility and allowing faster work.

2.2.1.2. Sighting meters

Hand-held sighting meters measures angle of inclination of a slope (these are also called Inclinometers or Abney levels). They are small and compact, and sometimes include a range finder which eliminates the problem of measuring linear distance. The error in estimation is typically between 2 and 10 % depending upon the skill of the user.

2.2.1.3. Water-filled tube and pressure gauge

This is probably one of the simplest methods for measuring the available head, but it does have certain shortcomings. The two main sources of errors which must (and can) be avoided are ‘out of calibration’ gauges and air bubbles in the hose. To avoid the first error, the gauge should be recalibrated both before and after each major site survey. To avoid the second, a clear plastic tube should be used so that the bubbles can be seen.

This method can be used on high-heads as well as low ones, but the choice of pressure gauge depends on the head to be measured.

2.2.1.4. Water filled tube and rod

This method is well suited for low-head sites. It is cheap, reasonably accurate and does not report many errors. Two or three separate attempts should be made to ensure that the final results are consistent and reliable. In addition the results can also be cross-checked with measurements made by another method, for instance by water filled hose and pressure gauge.

2.2.1.5. Spirit level and plank

This method is similar in principle to the water filled tube and rod method. In this method, a carpenter's spirit level placed on a reliably straight plank of wood and the horizontal sighting is established. On gentle slopes this method tends to be very slow, but on steep slopes it is useful. Taking two readings at each step (by marking on end of the plank and turning it around) cancels the errors. The error is generally around 2%.

2.2.1.6. Maps

As discussed in the earlier section on Regional assessments, large-scale maps are useful for approximate head values, but are not always available or totally reliable. For high-head sites (>100 m) 1:50,000 maps are useful for prefeasibility studies and are generally available.

2.2.1.7. Altimeters

Altimeters are quite useful for high-head pre-feasibility studies. Surveying altimeters generally give errors in the range of as less as 3% in 100 m. Atmospheric pressure variations need to be allowed for, however, and this method cannot be generally recommended except for approximate readings (pre-feasibility studies).

2.2.2. Measurement of flow

The purpose of a hydrology study is to predict the variation in the flow during the year. Since the flow varies from day to day, a one-off measurement is of limited use. In absence of any hydrological analysis, a long-term measuring system may be set up. Such a system is often used to reinforce the hydrological approach and is also the most reliable way of determining actual flow at a site. One-off measurements are useful to give a spot check on hydrological predictions.

The flow measuring techniques discussed here are:

- the weir method
- stage control method
- the salt gulp method
- the bucket method
- the float method
- current meters

2.2.2.1. Measuring weirs

A flow measurement weir is a weir with a notch in it through which all the water in the stream is made to flow/pass. The flow rate can be determined from the difference in height between the upstream water level and the bottom of the notch. For reliable results, the crest of the weir must be sharp and sediment must be prevented from accumulating behind the weir.

Weirs can be made of concrete, metal or even timber and must always be oriented at right angles to the stream flow. Location of the weir should be at a point where the stream is straight and free from eddies. Upstream, the distance between the point of measurement and the crest of the weir should be at least twice the maximum head to be measured. There should be no obstructions to flow near the notch and the weir must be perfectly sealed against leakage.

2.2.2.2. Rectangular notch measuring weir

For short-term or dry-season measurements, temporary measuring weirs (generally made of wood) are used and are staked into the bank and stream bed. It is necessary to estimate the range of flows to be measured before the weir, to ensure appropriate sizing of the weir notch. The use of permanent weirs may be a useful approach for small streams, but for larger streams staging of weirs would be a better alternative.

2.2.2.3. 'Salt gulp' method

The 'salt gulp' method of flow measurement is adapted from dilution gauging methods with radioactive tracers used for rivers. It is somewhat easy to carry out, reasonably accurate (error probability is less than 7%), and reliable for a wide range of stream types. It gives better results the more turbulent the stream. Using this approach, a spot check of stream flow can be taken in less than 10 minutes with very little equipment.

A bucket of heavily salted water is poured into the stream. The cloud of salty water in the stream starts to spread out while travelling downstream. After some distance downstream it will have filled the width of the stream. The cloud will have a leading part which is weak in salt, a middle part which is strong in salt and a lagging part which is weak again. The saltiness (salinity) of the water can be measured with an electrical conductivity meter. If the stream is small, it will not dilute the salt very much, so the electrical conductivity of the cloud (which is greater the saltier the water) will be high. Therefore low flows are indicated by high conductivity and vice versa. The flow rate is therefore inversely proportional to the degree of conductivity of the cloud.

The above phenomenon assumes that the cloud passes the probe in the same time in each case. But the slower the flow, the longer the cloud takes to pass the probe. Thus flow is also inversely proportional to the cloud-passing time. The equipments needed for ‘salt gulp’ flow measurement are a bucket, table salt, a thermometer and a conductivity meter (range 0-1000 mS).

2.2.2.4. Bucket method

The bucket method is the simplest and fastest way of measuring flow in very small streams. The entire flow is diverted into a bucket or barrel and the time for the container to be filled is recorded. The flow rate is obtained simply by dividing the volume of the container by the filling time. Flows of up to 20 l/s can be measured using a 200-litre oil barrel. Equipment needed are a bucket/barrel and a stopwatch.

2.2.2.5. Float method

The principle of all velocity-area methods is that flow (Q) is equal to the average velocity (V) over a uniform cross-sectional area (A). Mathematically it can be represented as:

$$\mathbf{Q = V \times A}$$

The cross-sectional profile of a stream bed is selected in such a way that it does not alter too much over a certain distance/length of the stream (one can also take an average cross-section for a known length of stream – provided the stream bed is not altering too much). A series of floats, mostly pieces of wood, are then timed over a measured length of stream. A flow velocity is obtained by averaging the results over a large number of trails. This velocity must then be reduced by a correction factor which estimates the mean velocity as opposed to the surface velocity. By multiplying averaged and corrected flow velocity, the volume flow rate can be estimated.

2.2.2.6. Current meters

This is more accurate than the float method. A current meter consists of a shaft with a propeller or revolving cups connected to the end. The propeller is free to rotate and the speed of rotation is related to the stream velocity. A simple mechanical counter records the number of revolutions of a propeller placed at a desired depth. By averaging readings taken evenly throughout the cross section, an average speed of the stream can be obtained.

Chapter 3 System sizing

Once the resource assessment for micro hydro is done and the technical feasibility of a micro hydro power plant is established, it is essential to match this up with the economic feasibility also. Economic feasibility means that there is sufficient demand for the power generated by the MHP and that the revenue for at least meeting the operation and maintenance expenses would be generation by the operations. The first step towards establishing economic feasibility is assessing the demand.

3.1.Demand assessment

Community interaction is the best and most accurate method to estimate the demand from any particular community. Participatory Rural Appraisal (PRA) techniques can be utilized to gain quick understanding of the usage pattern and future growth of the energy demand at pre-feasibility stages – to evaluate the economics of the MHP scheme. However, it is strongly recommended that once the economic viability is established, continuous interaction with community is essential from the very beginning (and at each stage of planning, execution, setting up institutional mechanisms) for implementation of a MHP scheme.

The steps to be followed for electricity demand assessment of any village/ area is given below:

3.1.1. Step 1: Need-wise Estimation of Energy Demand

The total energy demand for various end-uses such as cooking, lighting, etc. is estimated using pre-designed analysis formats as explained below. Energy demand is essentially the total energy presently being consumed for different end-uses. The calculated demand is expressed in standard units of electricity – kilowatt-hour (kWh) and is used for arriving at the size of the MHP system that would cater to this demand.

a. Household Needs

Demand can be calculated using the simple table below using a calculator or computer (MS Excel). One of the better ways is to make this table in MS Excel on a computer and fill in the formulas. Thus when a field investigator puts in the raw data, the Spreadsheet calculates the Connected Load[4] in kW and Demand[5] in kWh/Year for each connected device and end-use. A sample calculation has been shown below. For example, the lighting demand of fluorescent lamps for a village (of 50 households) could be calculated as shown in the following table. The manual

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[4] The sum of the capacities or ratings of the electric power consuming devices.

[5] Total energy consumed in a year

calculation method is shown in the “Connected Load”, “Operation hours per year”, and “Demand kWh/year” cells.

Format 1. Calculation of lighting demand

S. No.	Device	No. of households having device	Points per household	Device rating W	Connected load (W)	Operation hours per day	Operation days per year	Operation hours per year	Demand kWh/year
1	Fluorescent bulb	50	2	40	50×2×40 =4000	6	300	6× 300 = 1800	4000×1800 = 7200 kWh
2									

Similarly, the power required for fans, etc. used in a house can also be calculated in the above table.

b. Irrigation Needs

Demand for irrigation can be estimated on the basis of existing energy consumption and/or future planning (e.g. estimation of the number of farmers that would install irrigation pump-sets once dedicated power is available). This would need sufficient amount of interaction with the community. The total energy demand for irrigation is calculated on the basis of the existing number of each type of pump, their average rating, average hours of operation per day (in different seasons) and average days of operation in a year.

Format 2: Calculation of electricity demand for irrigation

Sl. No	Type	No. of pumps	Device rating hP	Device rating KW (1hP=0.745 kW)	Connected load kW	Operation hours per day	Operation days per year	Operation hours per year	Demand kWh/yr
1									
2									

An energy intervention in irrigation is based on the premise that there is adequate and assured water availability. However, while energy for irrigation is a serious problem in most rural areas, a more basic issue is that of availability of water itself. Thus, before planning an intervention in this area, there is a need to ascertain whether there is reliable water availability or not. The investigator would need to address the question of what is the greater constraint; Availability of Water or Availability of Energy for Irrigation. If the problem is water, then this need for irrigation cannot be met with providing electricity alone and hence this need would not be considered. If, however, the problem is that of energy, then the investigator would need to find out current sources of energy. The user will then look at the energy required to pump the water and the renewable resources available.

c. Small Industries Needs

This information has to be collected for every industry in the village/target area. Typical industries in a village include flour mills, rice mills, oil mills, weaving, etc. Most of these are operational only for a few hours during the day. The energy load from Small Industries is treated as an additional load – to be catered to only in combination with other loads such as lighting or irrigation. Hence, it is assumed that the small industries will be operated during those hours of the day when the load from other devices is either low or is nil. This is important for ensuring a good Plant Load Factor[6]. If this coordination of loads is not possible, then it is likely that the cost of the necessary higher capacity system may not be economically viable. Hence, the household and business loads should be planned and considered separately.

Format 3: Electricity demand for small industries

Sl. No.	Device	No. of devices	Device rating kW	Connected load kW	Operation hours per day	Operation days per year	Operation hours per year	Demand kWh/yr
1								
2								

3.1.2. Step 2: MHP System Sizing

This step is undertaken to determine the system size for technologies that would supply electricity through a local grid.

3.1.2.1. Factors in System Sizing

a. **Timing Flexibility:** Period of use in a day and flexibility in timing (i.e., can the load be catered to in the evening hours instead of morning. An example of a flexible timing load is a domestic flour mill which can be run practically anytime during the day)

b. **Connected load** and whether all of it is operated simultaneously (are all the fans likely to be operated all at once or only 50%)

c. **Load Splitting** : Possibility of splitting load (can half the irrigation pumpsets be run in the day and the rest in the evening)

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[6] The ratio of the average power load of an electric power plant to its rated capacity

d. **Number of days of operation in a year**

e. **Number of hours of operation per day**

f. **Criticality of the application** to the user community (in an agricultural community irrigation would be critical, as would be lighting in a community of artisans)

3.1.3. Step 3. The Load Scheduling Chart

A load scheduling chart is a 24 hour cyclic depiction of device/appliance usage considering that all of them are being used within the 24 hour period. Typically for rural areas, only one load scheduling chart is enough for planning/ system sizing. However in some cases, different scheduling charts may be needed for different season depending upon the usage of appliances. For example, during summers the fans or air conditioners may be used but not the room heaters/blowers – and all of these have different usage pattern and seasonality.

a. Pick all loads that are not negotiable and slot them against the Time of use. For example the lighting load of bulbs should be slotted only against the time slots between 1800 hrs till 0500hrs. However, the general usage in rural areas (where the MHP are installed/used) is between 1800 till 2200 hrs and then again between 0400-0500 hrs in the morning. Similarly plot each of the non-negotiable load (like fans, TV, etc.)
b. These are added up in a separate column at the end
c. In the remaining loads, look for **timing flexibility**. If this is flexible, then these can be slotted any time during the day when there is less or no load (example irrigation pumpsets or flour mills). If the timings for these loads are not flexible, and then they fall into the first category of loads and have to be considered.
d. In case of large loads like irrigation pumpsets which are flexible, we can also think of splitting them in batches so as to have an better load/demand distribution across 24 hour cycle.
e. Finally look for no-load windows[7]. These times are opportunities for additional load to be added, or load to be shifted into these times.

Please see the example given below for better understanding

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[7] No load windows are those timings of the day (or night) when there is no load or the total load is less than the maximum load at any other time of the day.

3.1.4. Example from a typical village in India

In a typical village of about 200 households in North India, the following loads and consumption patter is expected/assumed.

Lighting load:
48 kW for 365 days @ 6 hours per day (assumption: 4 light points of 60 W each per household)
Timing flexibility – none (i.e. all lights are needed at the same time in the evening)
Splitting load – none (all households will need the light at the same time)
Hence connected load 48 kW
Load to be considered for system sizing 48 kW

Fan load
90 kW for 120 days @3 hours per day
Not to be considered for system sizing in first cut

TV load
37.5 kW for 365 days @ 3 hours per day
Timing flexibility – none (i.e. televisions will be on at specific time each day)
Splitting load – none (i.e. everyone wants them on at the same time)
Hence connected load 37.5 kW
Load to be considered for system sizing 37.5 kW

Domestic flour mill load
12 kW for 365 days @ 1 hour per day
Timing flexibility – yes (i.e. load can be on at selected time during day)
Splitting load – none (i.e. load cannot be broken into smaller loads at different times)
Not to be considered for system sizing in first cut

Irrigation pump-sets

Electrical

84 kW for 150 days @ 6 hours/day
Timing flexibility - none (i.e. load must be on at certain times each day)
Splitting load – yes (i.e. since each pump has to run for only 6 hours, the pumps can be run in maximum four batches, thus reducing the connected load)

Currently diesel, but will shift to electric once available

164 kW for 150 days @ 6 hours/day
Timing flexibility – yes (i.e. pumps can be run at different time of day)
Splitting load – yes (i.e. since each pump has to run for only 6 hours, the pumps may be run in four batches, thus reducing the connected load)

Hence the total irrigation load is **164 + 84 = 260 kW**

Since this can be split in four batches, Load to be considered for system sizing 260/4 =65 kW

Therefore total load to be considered

Lighting	48 kW
TV	37 kW
Irrigation pump-sets	65 kW

LOAD SCHEDULING CHART

Sl. No	Time	Lighting	TV	Irrigation Batch 1	Irrigation Batch 2	Irrigation Batch 3	Irrigation Batch 4	Fan load in summer	Total Load	Add 15%
1	00:00			65				45	110	126.50
2	01:00			65				45	110	126.50
3	02:00			65				45	110	126.50
4	03:00			65				45	110	126.50
5	04:00	48		65					113	129.95
6	05:00	48		65					113	129.95
7	06:00				65				65	74.75
8	07:00				65				65	74.75
9	08:00				65				65	74.75
10	09:00				65				65	74.75
11	10:00				65				65	74.75
12	11:00				65				65	74.75
13	12:00					65		45	110	126.50
14	13:00					65		45	110	126.50
15	14:00					65		45	110	126.50
16	15:00					65		45	65	126.50
17	16:00					65			65	74.75
18	17:00					65			65	74.75
19	18:00	48	37				65		150	172.50
20	19:00	48	37				65		150	172.50
21	20:00	48	37				65		150	172.50

22	21:00	48					65		113	129.95
23	22:00						65	45	110	126.50
24	23:00						65	45	110	126.50

Thus the System Size for this village for lighting and irrigation load would be **172.50 kW** – the maximum load in a 24 hour cycle (or approx 175 kW). It may be noted that the Domestic Flour mill load (12 kW) which was not considered in first round can now be slotted in any one hour during the hours except evening 6.00 pm till 9.00 pm. Similarly, some other industries can be developed and provided with power during the morning and afternoon times when the load is only from that of pump-sets.

3.2.MHP ECONOMICS AND COSTS

Hydroelectric plants generally are quite competitive and economical when compared to the conventional fossil fuel based power plants. However, the small hydro, especially the mini and micro hydro, installed in remote hilly regions are somewhat costlier and are competitive to conventional power only when allowances for external costs associated with fossil fuels and nuclear power etc are considered.

The geographical and geological features along with the effective head, available flow, equipment (turbines, generators etc.) and civil engineering works determine the capital required for any small hydro power project. If the project can make use of the existing weirs, dams, storage reservoirs (ponds), etc. these can significantly reduce both environmental impact and costs. MHP sites with low heads and high flows require greater inputs of capital as larger civil engineering works and turbine machinery is required to handle the large volume of water. If, however, the MHP power plant can serve a dual purpose - power generation as well as flood control or power generation and irrigation or power generation and drinking water purposes, then the payback period significantly reduces. However, while deciding to invest in a MHP plant, it is also necessary to keep in mind the cost of using water (water charges and/or concession fees) and the administrative procedure to obtain the clearances/ licenses. Operation and maintenance (O&M) costs, including repairs and insurance form another set of recurring expenses for MHP. For MHP plants this can be in the range of 1.5-5% of total capital costs.

For estimating whether a particular MHP scheme is financially feasible, several financial tools and techniques can be used. The simple payback period method is the easiest to calculate though a more rigorous test for financial viability is to check the net present value (NPV) and the internal rate of return (IRR). NPV and IRR take into consideration the several factors and are designed to incorporate the time value of money.

The ratio of the total investment to the power installed or the ratio of the total investment to the annual energy produced for a project is also useful while considering investment decisions between a number of projects. This is a sort of an initial assessment decision and does not take into account the profitability of a given scheme.

3.2.1. Simple Payback method

The payback method determines the number of years required for the invested capital to be offset by resulting benefits. The number of years required for the investment to be recovered is called as payback period. The calculation is as follows:

$$Payback\ Period = \frac{Investment\ Cost}{Net\ Annual\ \mathrm{Re}venue}$$

The method usually does not capture the opportunity cost of capital. The opportunity cost of capital is the return from the same capital from an alternative investment activity the MHP. Investment costs are usually defined as initial costs (civil works, electrical and hydro mechanical equipment) and benefits are the resulting net yearly revenues expected from selling the electricity produced, after deducting the operation and maintenance costs, at constant value money. Usually, if the payback period exceeds 7 years then the small hydro project is to be considered to be not profitable.

However, the payback method does not compare the selection from different technical solutions for the same installation, or choosing among several projects. In fact it does not consider cash flows beyond the payback period and thus does not measure the efficacy of the investment over its entire life. Under the payback method of analysis, projects with shorter payback periods rank higher than those with longer paybacks.

For the investor, when using this method it is advisable to accept projects that recover the investment and if there is a choice, select the project, which pays back earliest. This method is simple to use but it is attractive if liquidity is an issue but does not explicitly allow for the “time value of money” for investors.

3.2.2. Return on Investment method

The return on investment (ROI) calculates average annual benefits, net of yearly costs, such as depreciation, as a percentage of the original book value of the investment. The calculation is as follows:-

$$\text{Return on Investment} = \frac{\text{Net Annual Revenue} - \text{Depreciation}}{\text{Investment Cost}} \times 100$$

Using ROI can provide a quick estimate of the project's net profits, and can provide a basis for comparing several different projects. Under this method of analysis, returns for the project's entire useful life are considered (unlike the payback period method, which considers only the period that it takes to recover the original investment). However, the ROI method uses income data rather than cash flow and it completely ignores the time value of money. To resolve this problem, the net present value of the project, as well as its internal rate of return should be considered.

3.3.Management of MHP plants (Institutional Mechanisms)

Community participation is now widely accepted as a pre-requisite to ensuring equity and sustainability of local infrastructure investments, such as water supply or rural electrification. However, it is not simple to practice this completely. Experience with rural electrification co-operatives for example, is varied and depends on the local culture and the extent to which all members of a community have been involved in decision making processes (e.g. women's groups, farmers clubs, chamber of commerce, etc). Success has been more forthcoming where intermediary organizations have helped the local planning process. A variety of ownership and management options may be considered depending on the context.

Electrical supply systems should ideally be owned by those with the most important stake in their success. For instance public or national utility ownership of decentralized electrification schemes may make sense for larger towns or district administrative headquarters. Such schemes may also be suitable for private development and operation particularly where there is potential for integration with the grid. Private ownership may be appropriate where there is a major industrial load that provides the major energy demand for the plant - examples include grain mills, textile mills, etc., where excess power can be sold to the neighboring community. Ownership may also be franchised by the utility or the State to a commercial operator as in Mexico, but to continue to be ultimately owned by the State.

At the local level where village and district rural energy supplies are implemented, suitable owners may be community based organizations, electrification co-operatives supported by local NGOs, or branches of national NGOs. Community ownership may be most appropriate in the majority of villages and small towns which are beyond the reach of the main grid and where the loads are poorly developed. In Peru the micro hydro schemes are owned by the community but operation and maintenance is contracted to a private service company. In Sri Lanka the Electricity Consumers Society own, operate and manage. All sectors of the population need to be involved in planning from the outset if the community is to own or manage the scheme. As electricity is new to such communities, an intermediary can provide useful help in planning. Guidelines for developing a range of options and arriving at a consensus on the scope of electrification and on tariffs have been developed and used successfully in Sri Lanka, Nepal, Zimbabwe, and Mexico.

Chapter 4 CONCLUSION

4.1. *Summary*

Hydropower is a clean source of energy. It does not consume but only uses the water, and after use the water is available for other purposes (although on a lower horizontal level). The conversion of the potential energy of water into mechanical energy is a technology with a high efficiency (in most cases double that of conventional thermal power stations). The use of hydropower can make a contribution to savings on exhaustible energy sources (fossil fuels). MHP contributes to sustainable development by being economically feasible, respecting the environment (avoiding greenhouse gas emissions) and allowing decentralized production for the development of dispersed populations. MHP plants create local jobs for the monitoring of the operation of the plant.

Small-scale micro hydro power is both an efficient and reliable form of energy, most of the time. However, there are certain disadvantages that should be considered before constructing a small hydro power system. It is crucial to have a grasp of the potential energy benefits as well as the limitations of hydro technology. There are some common misconceptions about micro-hydro power that need to be addressed. With the right research and skills, micro hydro can be an excellent method of harnessing renewable energy from small streams.

Various approaches have been used to diffuse micro hydro the world over that varies according to local circumstances. Generally, the approach or strategy utilized for diffusion of MHP involved a combination of the following five aspects:

Project Promoters	Government owned utilities Non-Governmental Organizations Equipment manufacturers Individual entrepreneurs Multilateral or bilateral aid agencies
Financing Mechanisms	Formal development bank loans and grants Grants from charities Equity from private (local) savings and contributions in kind
Plant Owners/ Managers	Utilities Municipal authorities Existing formal businesses such as Tea Estates Individual (village based) entrepreneurs Village or community groups
Technical Support	Change agents (Village Catalysts, barefoot engineers)

Mechanisms	Engineering workshops Existing consulting engineers NGO
Main End-uses	Domestic lighting/ radios/ television Social services (to schools, health centres, street lights) Productive end-uses, usually using motive power

Source: Best Practices for Sustainable Development of Micro Hydro Power in Developing Countries. Smail Khennas and Andrew Barnett, in association with London Economics & deLucia Associates, Cambridge Massachusetts, USA for The Department for International Development, UK and The World Bank. March 2000

4.2.Environmental impact

The ecological impact of small-scale hydro is minimal; however the low-level environmental effects must be taken into consideration before construction begins. Stream water will be diverted away from a portion of the stream, and proper caution must be exercised to ensure there will be no damaging impact on the local ecology or civil infrastructure.

4.3.Misconceptions about hydro power

<u>Small streams do not provide enough force to generate power</u>: Energy output is dependent on two major factors: the stream flow (how much water runs through the system) and drop (or head), which is the vertical distance the water will fall through the water turbine.

<u>A large water reservoir is required</u>: Most small-scale hydro systems require very little or no reservoir in order to power the turbines. These systems are commonly known as ‘run-of-river’, meaning the water will run straight through the generator and back into the stream. This has a minimal environmental impact on the local ecosystem.

<u>Hydro generators will damage the local ecosystem</u>: Careful design is required to ensure the system has a minimal impact on the local ecology. A small amount of energy compromise may result, but this will ensure that the project does not have an effect on local fish stocks. The Environment Agency requires that stream levels must be maintained at a certain level in order to sustain the life within. Since there is no loss of water in the generation process, these requirements can easily be met.

<u>Micro hydro electricity is unreliable</u>: Technology advances (such as maintenance-free water intake equipment and solid-state electrical equipment) ensure that these systems are often more reliable in remote areas. Often these systems are more dependable than the local power main.

The electricity generated is low quality: If the latest electronic control equipment, inverters and alternators are used, the resultant power supply has the potential to be of higher quality the main electrical power grid.

Hydro power is free: Micro power development can be cost-intensive to build and maintain. There are some fixed maintenance costs. These costs vary according to site location and material requirements.

Annex 1

Tools for Site assessment, Feasibility, and planning for Micro hydro Power

1. SIMAHPP®is Windows based software used to simulate and assess the feasibility of hydropower projects, particularly for small-scale hydro projects with a capacity of up to 10 MW. It is a multi-site, multi-option simulator intended to solve a wide range of problems such as determining design flow to chose appropriate hydro turbine, optimized time of operation in a year so as to maximize the hydropower and thus increasing the annual energy production, determine the energy revenue, estimate investment as well as O&M costs, determine amortization rates, net annual incomes, payback periods, and indicates the quantity of carbon emission reduction potential if the planned hydropower project is to be operational. It also suggests appropriate turbine types. For advanced capabilities, see also SIMAHPP Pro (http://www.hydroxpert.com/?p=112)

2. The RETScreen Software Hydro Power Model can be used worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for central-grid, isolated-grid and off-grid hydro power (hydroelectric) projects, ranging in size from large dams with multi-turbines to small and mini hydro installations using weirs to small scale single-turbine micro hydro systems. The model addresses both run-of-river and water storage (reservoir) developments, and it incorporates sophisticated formulae for calculating efficiencies of a wide variety of hydro turbines, such as Kaplan, Francis, Propeller, Pelton, Turgo and Cross-flow models. In RETScreen, hydrological data are specified as a flow-duration curve, and costs can be estimated using an advanced formula costing method tool. The software (available in multiple languages) also includes product, project, hydrology and climate databases, and a detailed user manual.
http://www.retscreen.net/ang/g_small.php

3. Regional Flow Estimation Model (IIT Roorkee)
Small hydropower projects are normally run-of-the-river schemes with no storage of water. For a project to be economically viable it is essential to know whether there will be sufficient discharge available or not. As a normal practice flow duration curves are used to determine the dependable flows. However, at many potential sites the discharge data of stream is not available and also the representative discharge of streams in the close vicinity with more or less similar topographical and physiographical conditions is not available upon which a reliable estimate could be made.

To determine the flow duration curve at such ungauged site, Hydra-HP software has been developed. Hydra-HP, a new and innovated PC based software package that provides a rapid means of estimating small hydropower potential at any location in Himachal Pradesh. The software incorporates a regional flow estimation model derived from extensive statistical analysis of state wide river flow data and catchment information. The minimum PC configuration required to run Hydra-HP software is; any IBM compatible PC with 386 processor, 2 MB RAM, 3.5" DD and Windows 3.1 or above.
http://www.gisdevelopment.net/application/utility/power/utilityp0009.htm

4. HydrA is a PC based software package for rapidly estimating hydropower potential at any location in the UK or Spain. (1) Catchment Characteristics module; (2) Flow regime estimation module; (3) Turbine selection module; (4) Power potential module
http://www.nerc-wallingford.ac.uk/ih/www/products/pdf/hydra.pdf

Annex 2

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Use of GIS for Micro Hydro Power

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Annex 3. Select Case Studies of successful MHP installations

Microhydro in Kenya

Source: http://practicalaction.org/?id=micro_hydro

Tungu-Kabri project, Mbuiru
The Tungu-Kabri micro-hydro power project in Kenya is a cheap, sustainable and small-scale technology that harnesses the energy of falling water to make electricity.

The Tungu-Kabri Micro-hydro Power Project is the first of its kind in Kenya. Funded by the United Nations Development Programme and developed by Practical Action East Africa and the Kenyan Ministry of Energy, the project benefits 200 households (around 1,000 people) in the Mbuiru village river community. The project is a cheap, sustainable and small-scale technology that harnesses the energy of falling water to make electricity. It also alleviates the environmental problems associated with using wood and dung for cooking, diesel for milling and kerosene for lighting - and keeps on working, even in the face of drought.

The problem
Life is hard for the women and men in rural Kenya and the need for access to modern, 'clean' energy is acute. 96 per cent off Kenyans live without access to grid electricity. In rural homes, families spend at least a third of their income on kerosene for lighting and diesel for the milling of grain. Kenyan women also devote a huge amount of time collecting, processing and using wood and dung for cooking - time which could be spent on child care, education or income generation.

And according to the UN, in a country where nearly 80 percent of the population rely on farming for a living, poor farmers face declining yields and incomes in the traditional coffee and tea growing areas which pushes them into even more biting poverty. Just to survive, they will be forced to clear forests in higher, cooler, areas. This can only add to environmental damage, which in turn can lead to increased poverty, hunger and ill health.
Putting the power in people's hands

Mbuiru village - 200 kilometres north of Nairobi - is a typical rural village in Kenya. It is very poor, with few opportunities for change. However, villagers in Mbuiru had the will to help themselves to generate the power to beat drought and poverty.

Step 1 The project site is assessed. Many rivers do keep flowing, however bad the drought. Practical Action looked at flow records going back 40 years, to ensure the water power project will work. The River Tubgu, near Mbuiru is perfect.

Step 2 Practical Action explains its intentions at a village meeting. The villagers have many questions - the only hydro-power people know about means big dams. Practical Action explains how a small scheme could help them, how it works and how it would belong to all the villagers. Everyone is eager.

Step 3 Villagers hold back the river and start to build an intake weir and canal, giving up every Thursday to labour for months. Families work together, digging, shifting stones and laying concrete. The canal alone takes many weeks to build.

Step 4 Groups of villagers toil to make bays to clean dirt out of the water, and build a tank to hold the water before it goes through ‘penstock’ pipes into a turbine. People learn to mend as they build, so they can do repairs themselves.

Step 5 Two years later, power! The powerhouse goes up, in goes the machinery. Now the river can be released. The villagers hold their breath. It works and all that effort seems worthwhile.

Impact on the future

"This power is wonderful’, says villager Mrs Kaburu. ‘All of us will feel the benefit for many years to come’. The project generates an estimated 18 kilowatts of electrical energy. This amount can light 90 homes and Practical Action estimates that the power the system generates will benefit about 200 households. In the months ahead, the villagers will be able to light their homes, save time and run small enterprises with this power. This will bring them a little vital money, to help buy clothes, food, and even schooling for their children. Also, water power also means less wood is used - so the environment benefits.

Microhydro in Nepal

Ghandruk Micro-Hydro Electrification Plant

Background

Ghandruk Micro- Hydro electrification Plant is located at Ghandruk Village in the northwest of Western Development Region. It takes about two days walk on the tourist trail from Pokhara to reach the Village. Situated at an altitude of 2300 m on the mountain top facing north towards the Machhapuchhre Peak of Annapurna Range, it is a home of about 277 subsistence farmer families. Many of the families have at least one who have been in British or Indian army. The Ghandruk village is also a regional headquater for "Annapurna Conservation Area Project (ACAP)" a project of the King Mahendra Trust for Nature Conservation (KMTNC), a leading nonprofit making environmental organization in Nepal with aims to protect the fragile environment of the Annapurna region.

Description of The Micro Hydro Project

The project was conceived in 1988 with the aims: (a) to provide electricity as an infrastructure for the development of tourism and (b) to substitute the fuelwood consumption for cooking and thus protect the environmental degradation in ACAP project area by reducing the use of fuelwood.

With ACAP's initiation a user's committee of 13 persons under the then Pradhan Pancha Mr. Min Bahadur Gurung was formed to take necessary actions to install the microhydro in 1988. Development & Consulting Service (DCS), Butwal was entrusted for the job of site selection design and cost estimate in August 1989. The estimated cost of the project came to be 2.2 million rupees, which was increased to 3.6 million. The financing and expenditure details are given in Table MH 1.1.

The construction and installation of the plant was carried by DCS with technical support from Intermediate Technology Group (ITDG) from November 1990 and completed in May 1992.

Problems encountered during the construction of the project are; i) explosion of the penstock pipe at bad welded joints during test run period. Although the supplier agreed to replace without cost to the project it delayed the project; ii) water rights problem was raised by residents of ward no. 2, who were not beneficiaries of the project. They were deprived of water from Chane Khola due to its diversion. ACAP assisted by agreeing to provide a diesel mill to the residents of Chane.

Management and Organisation

The plant is owned and managed by a community governed by a constitution ratified by the meeting of the representatives of the member households and the representatives of ACAP. The organization, composition and duties of various committees are given below.

Table MH 1.1: Financing and Expenditure of the Project

Sources of Finance	**Planned**	**Actual**	
Grants			Grant/Tot. Cost
Canadian Co-operation Office	900000	900,000	= 69.9%

ACAP (with WWF-US and KMT-US)	316500	1166076	
HMG/N subsidy through ADB/N	450000	450000	
Loan			Loant/Tot. Cost
ADB/N Loan	450000	450000	=12.5%
Equity			Equity/Tot. Cost
Equity of local people - cash	83500	428318	=17.5%
Equity of local people - labour		200000	
Total	**2200000**		
Expenditure			
Design, Installation and Materials (DCS)		1511073	
Equipment purchased by ACAP		1111355	
Labour cost		659257	
Local labour		200000	
Other Expenses		112709	
Total			

Source: Ghandruk Micro-Hydro Power Project Office and ACAP Office, Ghandruk.

General Body Meetings	Composition	Functions
At least once a year before the firs week of 10th Nepali month (Falgun) Quorum requirement 51 %	a) Person from each household contributing forced labour b) 5 persons who have pledged their assets for loan c) A chairman is selected daily to conduct the meeting d) ACAP chief of Ghandruk member secretary e) At present there are 18 members in the General Body	a) Formation of Village Electri-fication Committee b) Fixation of tariff rates c) Ratification of annual budget d) Creation of Posts e) Works which can not be performed by the group

Special Power of the ACAP Chief Ghandruk

Decision made either by the Village Electrification Committee or by the General Body with less than 283 of members, if found against the interest of the power project, the ACAP chief, of Ghandruk can dismiss or direct to change the decision. However, the General Body Special Meeting with 2/3 members presence can reject such directives.

The community based management has demonstrated following benefits:

a) Involvement of beneficiaries at all stage has developed a sense of belonging to the project.

b) Local resources mobilized.

c) Transparency in the project activities such as proper book keeping which is made public regularly, mandatory transaction through bank account, audit of account and opportunity to raise voice in the meeting of the General Body for dissatisfaction has helped the project to be more institutionalized and vigilant.

d) The requirement of annual budget approval by General Body Meeting has made the VEC responsible for plan of the action for the subsequent year based on the experience of the current year.

e) Rules and regulations pertaining to the distribution and use of electricity are well set. The General Body decides tariff rates. This has made easier to realize the tariff.

f) There is a strong support and control of ACAP. It has provided strong back stopping for financing and technical affairs. Furthermore, the presence of experienced Alternative Energy Officer in ACAP has contributed substantially to solve technical, managerial and socio-economic problems promptly. He is also instrumental to provide on job training to the operators of the plant.

Despite having several benefits from the community managed system, the following demerits were also seen:

a) The community is heavily dependent on ACAP in technical and financial matter. Dependency syndrome is predominating; it is thwarting the community initiative

b) A clear-cut demarcation on the functions to be performed by the committee and ACAP is not so far set. Generally the committee is carrying out the direction given by ACAP official.

c) In case ACAP withdraws its association, the community may have difficulties in getting technical support. For this purpose it will be difficult to mobilize the committee. Unless an arrangement is made withdrawal of ACAP will be fatal to the project.

d) ACAP plays a dominating role because it has special right to nullify the decision of the General Body with less than 2/3 majority. This has also discouraged the participation of beneficiaries. This claim in the constitution is kept probably to check or streamline the decision of General Body.

Major Technical Features

Measured minimum flow : 23 lps (observed after commissioning)
Design Discharge : 35 lps
Penstock length : 540 m
Penstock diameter : 150 mm / 175 mm

Head : 200 m
Turbine Type : Pelton Single Jet
Turbine RPM : 1500
Generator Capacity : 85 KVA, p.f.= -0.8, 3 phase
Type : Synchronous
Control : Electronic Load Control with water and air cooled ballast
Generator Voltage : 380/415 Volts
Distribution Voltage : 220/380 Volts

Impact From the Project

There was a negative impact from the project when the pipe burst at the time of test run. Dissatisfaction had grown up among the villagers. The owner of the diesel mill, which was installed about 15 years ago, had sold the diesel engine, even before the electricity was available. The villagers felt hardship without the mill for some period de to delay in electricity supply.

Improved hygiene and health condition. One of the resident Mrs. Bhagawati Pandey states that her kitchen used to be smoky and she often had headaches and chest problems. Now she feels that her health is much improved.

The project has provided comfort to the residents as well as tourists. The villagers have realized its usefulness and heading towards the forest conservation through the use of low wattage cooker. One resident of that people from nearby villages are saying that Ghandruk has become gay and lively because of the arrival of electricity.

Problems and Constraints

One of the major problem of the plant is its under utilization during the day time. The villagers are still not aware of the multiple uses of electricity. They do not know exactly what types of machines or equipments could be operated from the electricity. They still think electricity could be used only for lighting. An awareness and motivation in this regard is highly needed. A study indicates that about 80% energy is spent on boiling water alone in the village. If the electrical energy available during the daytime is utilized to heat water, plant load factor would significantly increase and burden on forest resources could be lessened.

Conclusion

The ACAP was instrumental in the implementation of this project. The micro-hydropower plant could provide economic prosperity for the villagers, if unutilised power could be used for productive end uses like power loom, bakery, saw mill etc. The wastage of hot water from the controlling device could be used for hot shower to the tourists and would bring additional income. This project could serve as a good model for other community owned and managed micro hydro installations.

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