PICO HYDRO FOR VILLAGE POWER

A Practical Manual for Schemes up to 5 kW in Hilly Areas

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Disclaimer

The authors accept no responsibility for injury or death resulting from incorrect manufacturing, installation or operation of equipment described in this manual. All electrical and mechanical installation and repair work should always be supervised and checked by a qualified and experienced technician or engineer.

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1 INTRODUCTION

What is Pico Hydro?

Pico hydro is hydro power with a maximum electrical output of five kilowatts. Hydro power systems of this size benefit in terms of cost and simplicity from different approaches in the design, planning and installation than those which are applied to larger hydro power. Recent innovations in pico hydro technology have made it an economic source of power even in some of the worlds poorest and most inaccessible places. It is also a versatile power source. AC electricity can be produced enabling standard electrical appliances to be used and the electricity can be distributed to a whole village. Common examples of devices which can be powered by pico hydro are light bulbs, radio's, televisions, refrigerators and food processors. Mechanical power can be utilised with some designs. This is useful for direct drive of machinery such as workshop tools, grain mills and other agro-processing equipment. This manual explains how to select and install pico hydro systems for hilly and mountainous locations.

The Market

On a global scale, a very substantial market exists in developing countries for pico hydro systems (up to 5 kW). There are several reasons for the existence of this market.

- Often, small communities are without electricity even in countries with extensive grid electrification. Despite the high demand for electrification, grid connection of small communities remains unattractive to utilities due to the relatively low power consumption.
- Only small water flows are required for pico hydro so there are numerous suitable sites. A small stream or spring often provides enough water.
- Pico hydro equipment is small and compact. The component parts can be easily transported into remote and inaccessible regions.
- Local manufacture is possible. The design principles and fabrication processes can be easily learned. This keeps some equipment costs in proportion with local wages.
- The number of houses connected to each scheme is small, typically under 100 households. It is therefore easier to raise the required capital and to manage maintenance and revenue collection.
- Carefully designed pico hydro schemes have a lower cost per kilowatt than solar or wind power. Diesel generator systems, although initially cheaper, have a higher cost per kilowatt over their lifetime because of the associated fuel costs.

Hindrances to Market Development

The principle reasons why the market for pico hydro remains untapped are that pico turbine-generator units are not available in many countries. Where they are available, few people know how to design and install complete schemes.

Aims

This manual aims to help overcome these problems by providing clear instructions for design and installation of schemes on a local level. Designs are recommended which emphasise simplicity, low maintenance and long life expectancy. The induction generator is one example of technology which is becoming increasingly incorporated into low cost / high reliability schemes of this size. It is especially suitable for direct-drive with small Pelton turbine runners which can rotate at the required speed. The operation of induction motors as generators is described and full instructions are given for the electrical connections.

The penstock pipe and distribution cable are often the most expensive components in pico hydro electrification projects. Cost saving approaches to the civil works and distribution systems play an important part in successful implementation and these are also described.

Scope

The focus of this manual is the implementation of hydro technology for the electrification of small villages in hilly or mountainous regions. This constrains the scope of the designs to turbine and generator units which are suitable for medium to higher head sites (more than 20m metres) and AC generation as low voltage DC systems cannot easily convey electricity over more than a few metres. Many aspects of the implementation methods described however, are common also to other designs including those suited to low head sites and to those which benefit individual consumers rather than small communities.

Complementary Publications

Complementary manuals have been written to help encourage more widespread adoption of pico-hydro technology. A manual for manufacturers, "The Pico Power Pack – Fabrication and Assembly Instructions" aims to stimulate local production of recommended designs and therefore help to reduce the problems of availability which exist in many countries.

The "Starting a Business Using Water Power" guide encourages applications for income generation and community benefit using pico hydro. In particular, proven examples of successful commercial applications are described. By encouraging local entrepreneurs to use pico hydro as the source of power for a business, the technology can be more readily financed even in areas where development loans or subsidies are not available to rural people.

Readership

Finally, this manual is aimed at everyone with an interest in pico hydro or rural electrification. It is particularly intended for those who are thinking about this technology for the first time. It seeks to inspire sufficient confidence to encourage local implementation by "first-time" hydro engineers. With this in mind, criticisms from readers would be welcomed to allow the guidelines and procedures to be refined and updated in the light of further experience.

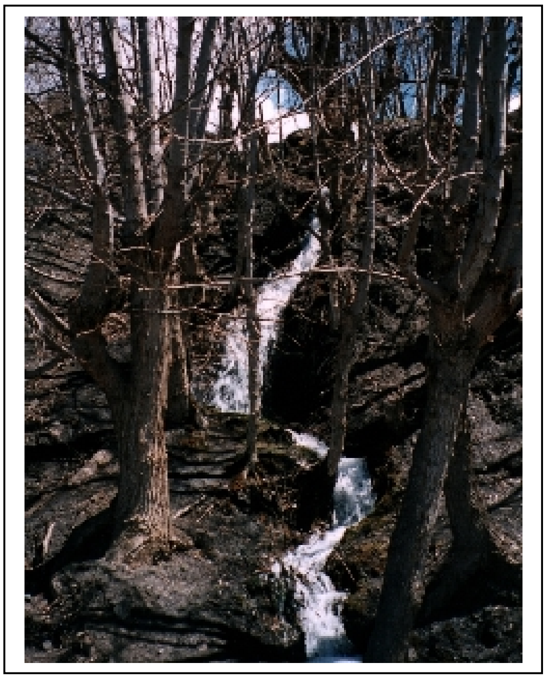


Figure 1-1 Pico hydro resources are abundant – the flow in a spring is often sufficient to generate electricity. (Jarcot, Mustang, Nepal)

2 THE BASICS OF PICO HYDRO

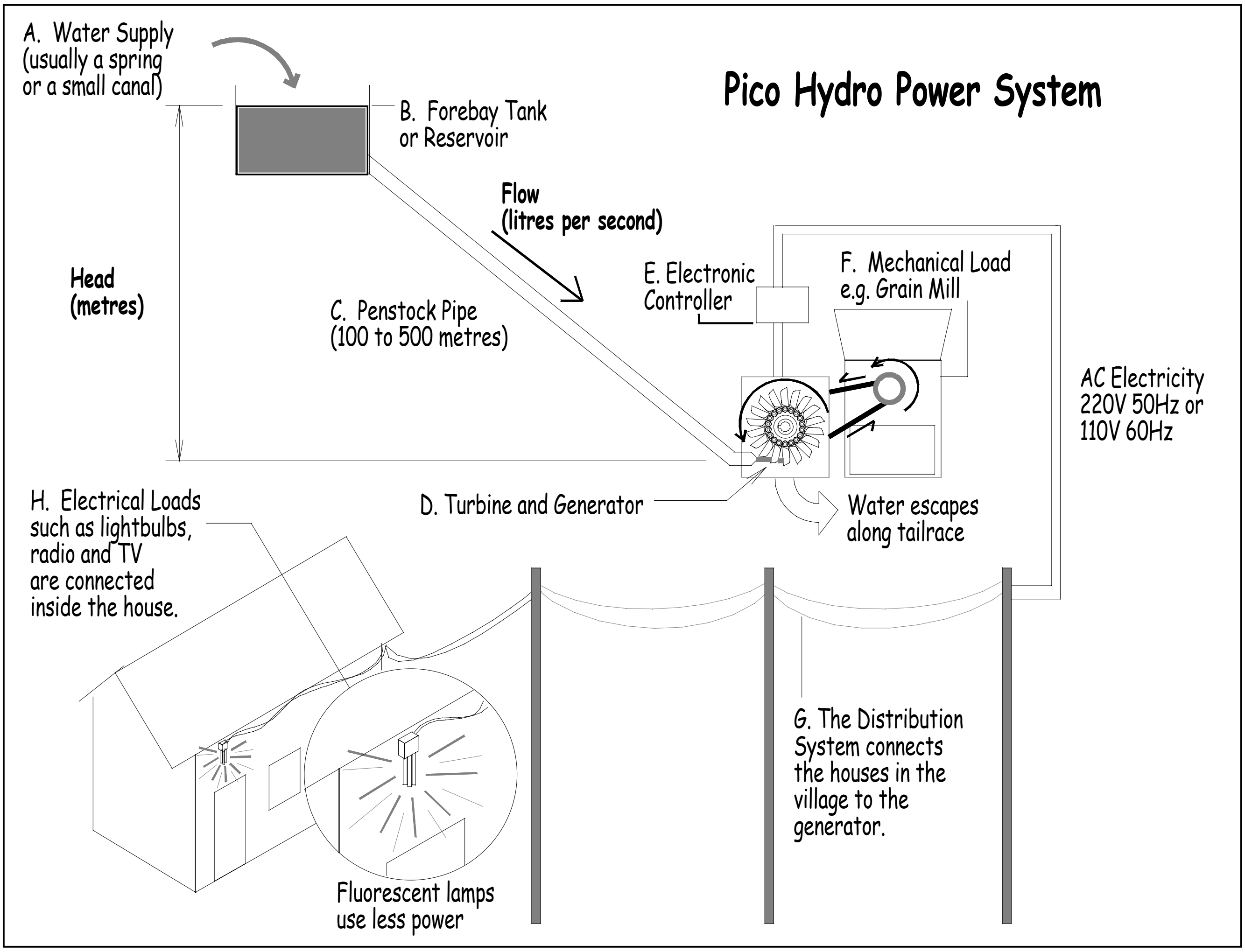


Figure 2-1 Components of a Pico Hydro System

A pico hydro system makes use of the power in falling water. Figure 2-1 shows the layout of a pico hydro system. Each of the components has been described in more detail below.

A The source of water is a stream or sometimes an irrigation canal. Small amounts of water can also be diverted from larger flows such as rivers. The most important considerations are that the source of water is reliable and not needed by someone else. Springs make excellent sources as they can often be depended on even in dry weather and are usually clean. This means that the intake is less likely to become silted up and require regular cleaning. For more information about the water source and intake, look at Section 10.1.

B The water is fed into a forebay tank. This is sometimes enlarged to form a small reservoir. A reservoir can be a useful energy store if the water available is insufficient in the dry season. For advice on design and construction of forebay tanks, read Section 10.2.

C The water flows from the forebay tank or reservoir down a long pipe called the penstock. At the end of the penstock it comes out of a nozzle as a high-pressure jet. See Section 11 for help with choosing the right penstock. The design of pico hydro system described in this manual is suitable for places where there are hills or mountains. In fact, a drop (or head) of at least 20 meters is recommended. A drop of 20 metres or more also means that the amount of water needed to produce enough power for the basic needs of a village is quite small.

D. The power in the jet, called hydraulic power or hydro power, is transmitted to a turbine runner which changes it into mechanical power. The turbine runner has blades or buckets which cause it to rotate when they are struck by water. The turbine is a general name that usually refers to the runner, the nozzle and the surrounding case. The runner typically spins 1500 times each minute. The turbine is attached to a generator. The purpose of the generator is to convert rotating power into electrical power. This is how the water flowing in a small stream can become electricity.

E. An electronic controller is connected to the generator. This matches the electrical power that is produced, to the electrical loads that are connected. This is necessary to stop the voltage from going up and down. Without a load controller, the voltage changes as lights and other devices are switched on and off.

POWER

Power is measured in **Watts (W)** or **kilowatts (kW).** There are 1000 W in 1 kW. Pico Hydro Power has a maximum electrical power output of 5 kW. It is important to say which type of power you are referring to when discussing a hydro power project as there are three types and they will all have a different value. The water power (or *hydraulic power*) will always be more than the mechanical and electrical power. This is because, as the power is converted from one form to another, some is lost at each stage as illustrated in Figure 2-2

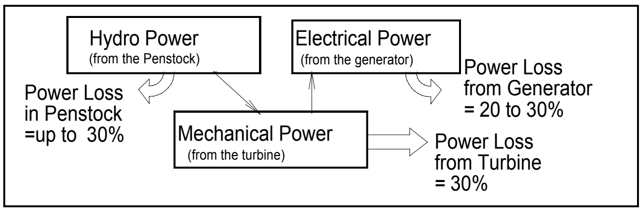


Figure 2-2 Some power is lost at each stage during the conversion from a water jet to electricity

The biggest loss usually occurs when the power in the jet of water is converted into rotating, mechanical power by hitting the turbine runner. On a well-designed and constructed scheme approximately one third (30%) of the power of the jet will be lost here. The losses can be much higher on poorer quality schemes. A further 20% to 30% will be lost in the generator when the mechanical power is converted to electricity. Some power is also lost in the penstock. Water in contact with the walls of the pipe is slowed down by friction. This power loss is expressed in metres of head loss. Its value is typically up to 20%-30% of the total head. Before the losses in the pipe are taken into account, the drop is referred to as the gross head and after losses have been subtracted it is called the net head.

EFFICIENCY

Efficiency is the word used to describe how well the power is converted from one form to another. A turbine that has an efficiency of 70% will convert 70% of the hydraulic power into mechanical power (30% being lost). The system efficiency is the combined efficiency of all the processes together. **The system efficiency for electricity generation using pico hydro is typically between 40% and 50%.**

i.e. as a rough estimate, if there is found to be 2.8 kW of hydraulic power in a small stream, the electricity which could reasonably be expected is:

2.8 x 45% = 2.8 x 0.45 = 1.26 kW

Example 1 Calculate the hydraulic power in a small stream

The **Hydraulic Power** in a stream can be calculated when the **Head** and the **Flow** have been measured. The formula to calculate Hydraulic Power is as follows:

Power = **Head** (metres) **x Flow** (litres/sec) **x9.81**

What is the Power in a stream if the head is 60 m and the flow is 10 l/s?

Power = 60 x 10 x 9.81
= **5886** watts (**W**) or **5.9** kilowatts (**kW**)

F. The Mechanical Load is a machine which is connected to the turbine shaft often using a pulley system so that power can be drawn from the turbine. The rotating force of the turbine runner can be used to directly turn equipment such as grain mills, or woodwork machinery. Although approximately 10% of the mechanical power is lost in the pulley system, this is still a very efficient way of using the power. More power is available because none is lost in the generator or in an electric motor. For advice on mechanical loads look at Section 13.4.

G. The Distribution System connects the electricity supply from the generator to the houses. This is often one of the most expensive parts of the system. Section 14 gives detailed information on how to design the distribution system and choose the correct size of cable.

H. The Consumer Loads are usually connected inside houses. Electrical load is a general name which refers to any device which uses the electricity generated. The type of electrical loads that are connected on a pico hydro scheme will partly depend on the amount of power that is generated. Fluorescent lights are preferred because they use much less power for an equivalent amount of light as filament light bulbs do. This means that more lights can be connected to the same generator. More information on choosing light bulbs and other electrical loads is given in Section 13.1.

Example 2 Calculate (i) the net head, (ii) the useful mechanical power and (iii) the electrical power which could be generated from the stream described in Example 1

Use the following assumptions: 25% of the head is lost as friction in the penstock, the turbine is 65% efficient and the generator is 80% efficient?

(i) Calculate the net head

If 25% of the head is lost as friction in the pipe the head loss is 0.25 x 60 = 15m. If 15m are lost then the useful head (or **net** head) is

= 60 - 15 = **45 m**

The net hydraulic power available at the turbine is now less than the hydraulic power using the total (gross) head:

Power = Net Head x Flow x 9.81

= 45 x 10 x 9.81

= **4414 W**

(ii) Calculate the mechanical power

If the turbine is 65% efficient the mechanical power produced will be:

Power (Mechanical)

=net hydraulic power x turbine efficiency

= 4414 x 0.65

= **2870 W**

(ii) Calculate the useful electrical power

If the generator is 80% efficient, then the electrical power available for lighting and other purposes is:

Power (Electrical)

=mechanical power xgenerator efficiency

= 2870 x 0.8

= **2295 W** or **2.3 kW**

3 IDENTIFYING YOUR FIRST SCHEME

If you are starting up in the pico hydro business or starting a programme of community pico hydros it is important to carefully select the first scheme as this will act as a focus for future interest. When identifying the site for your first scheme it is important to maximise the gain and minimise the pain! The following hints and tips will help.

3.1 General Location

1. **Accessible to you:**

Look for sites in districts that that you can get to easily so that your travel costs are minimised and you can visit easily if problems occur.

2. **Accessible to customers/funders:**

Select districts that are near to where many of your future customers are based and close to project funders to make it easy for the people that are key to your future business to visit you.

3.2 Specific Location

1. **No major technical challenges:**

Identify a site that is not too challenging technically, i.e. no complicated civil works required to transport water, ample flow, and a head that is well suited to available, well proven turbine technology.

2. **Close proximity to consumers:**

Short distribution lines keep costs low, are easier to construct and maintain.

3. **Small number of consumers:**

Select a site where the number of customers will be small, as the power capacity can then be small, reducing risk. Also the smaller the number of consumers the easier it is to organise and manage the project.

4. **Well organised and motivated community:**

It is very important that the recipients of the power are a harmonious community, with no major divisions, highly motivated towards having a pico hydro and prepared to contribute labour and money to the project. If there are skilled people within the community that can help with installation then this is a further benefit.

5. **Close to a road or other major route:**

By choosing a popular location it will be easy to encourage people to visit the project and to spread the news about your capabilities.

3.3 Achieving Maximum Publicity

- Invite an important local person to open the scheme and encourage the local press to come to the opening by producing a carefully written press release (it is worth spending a few dollars getting a marketing expert to help with this).
- Produce an eye-catching leaflet or flyer to give to people and to encourage them to use you to install a scheme for them.
- Put up some nice signs to direct people to the scheme.
- Encourage the owners of the scheme to start small enterprises using the pico hydro power. A highly illustrated, easy to read booklet on 'Water Power for a Village Business' is available from the same source as this manual.

4 PLANNING A PICO HYDRO SCHEME

This section gives an overview of what is required to implement a pico hydro project for village electrification. This allows the developer to fully understand what is involved beforehand. The order of the steps is important to ensure that the implementation is well organised.

STEP 1 COST AND AVAILABILITY

Establish the source of key components particularly the turbine-generator and controller Determine the range of head / flow / power outputs of available equipment. Obtain approximate cost of total scheme from turbine-generator supplier and / or other schemes. Otherwise assume a cost of $3,000/kW.

> Visit other schemes and suppliers of turbines-generator equipment, pipe, and cable. These will be the most expensive components.

STEP 2 INITIAL OVERVIEW

Determine whether there is:
a) local desire for electricity or mechanical power, b) willingness to pay,
c) local ability to manage a scheme,
d) grid electricity available or planned

STEP 3 POWER ESTIMATE

Make a preliminary estimate of the heads and flows in the area to determine whether there is likely to be sufficient power for a pico hydro.

STEP 4 DEMAND SURVEY A

Estimate the number of houses within a radius of 1km from the water supply and, of those, which are willing to pay for an electricity supply.

> 1km radius is the distance over which the electricity can most easily and economically be transmitted. Make assumptions about the capital, maintenance and operating costs and use these to decide on a suitable tariff and connection cost (see Section 5.3)

STEP 5 DEMAND SURVEY B

Examine what existing activities that require expenditure on energy or which take large amounts of time to carry out would benefit from hydro power?

STEP 6 SIZING AND COSTING

Estimate the size of generator required to meet the energy demand. Estimate the cost based on information collected at STEP 1.

STEP 7 VIABILITY CHECK

Choose the most favourable size of scheme using the demand survey and power estimate. Then compare the likely annual income with the capital cost. A rough guide to financial viability is:

- if the annual income <10% of the capital cost then the scheme is not viable.
- if the income is 10-25% of the capital then the scheme could be possible .
- if the annual income is more than 25% of the capital cost then the scheme is viable.

STEP 8 HEAD & FLOW

Decide on a suitable combination or combinations of head and flow to produced required power from available turbine-generator. Assumptions about the system efficiency should also be made. If in doubt assume an overall efficiency (water power to electrical power) of 45%.

STEP 9 VILLAGE MEETING

Present the findings of the survey to the community at an open meeting to which local government staff and local development organisations should also be encouraged to attend.

> Present all information as estimates. Overestimate the costs and underestimate the power available. Suggest options for ownership (individual, group, community) and explain the responsibilities and funding possibilities. Only proceed to the detailed survey when there is local agreement on ownership and funding. Consider requirement for payment for survey.

STEP 10 DETAILED SURVEY

Conduct a detailed site survey.

Is the available net head sufficient to meet requirements? Will the penstock be excessively long? Can it be shortened by the use of a channel? Can the flow be relied on throughout the whole year or is storage required? Use local knowledge. If in doubt, wait until the end of the dry season and check flows.

STEP 11 FINALISE POWER OUTPUT

Modify the original estimate of generator size based on accurate assessment of site hydraulic potential (available power in the stream).

It may seem tempting to implement a larger scheme than has initially been planned if the site characteristics allow. There are a number of reasons why it is preferable to keep the size of the scheme small, even if the site has potential for a larger turbine/ generator combination:

- Small schemes cost less and easier to implement
- If mistakes are made with the installation of a small scheme, then they are cheaper to correct
- Maintenance and repair costs will be lower

STEP 12 SCALE MAP

Draw a scale map of the site

STEP 13 SCHEME LAYOUT

Sketch scheme layout, using the site plan map as the basis. Write on lengths of penstock, any canals and each different section of the distribution system if one is required. Draw to scale.

STEP 14 REVISE LAYOUT

Look for alternative layouts that could allow the length of the penstock or the distribution system to be reduced so that costs can be cut. This may involve repositioning the powerhouse or the use of canals.

STEP 15 DETAILED COSTING

Make a realistic cost assessment of the major scheme components and obtain written quotations.

Scheme components: penstock, turbine and generator unit, distribution system, civil works and additional items. Add at least 5% for contingencies (unforeseen additional costs) Constantly be on the look-out for cheaper suppliers but do not cut corners which will reduce the quality of the scheme. Negotiate discounts based on the quantity of materials which will be required.

STEP 16 FINANCIAL VIABILITY

Use cost assessment to check if the scheme is still financially viable. Compare forecast income from electricity tariff with loan repayment costs.

If not, look where the major costs are occurring and see if they can be reduced. Seek cheaper estimates for cable, water pipe. Consider a different size of scheme or connecting more consumers and use energy efficient lamps so revenue/repayment levels are increased.

STEP 17 CONSUMER CONTRACTS

Agree consumer contracts for electricity supply which include the amount of monthly tariff and the number of light-packages provided in each house.

STEP 18 ORGANISE FINANCE

Arrange finance based on supply contracts.

STEP 19 ORDER MATERIALS

Order materials and equipment and deliver to site

STEP 20 INSTALLATION

Install scheme

STEP 21 OPERATOR TRAINING

Train local operator in operation and maintenance and safety of the system and the owners in management of the scheme.

> Management training should cover collection of repayment or tariff and repayment of credit. Also the operation of a maintenance fund to ensure that scheme continues to operate.

STEP 22 CONSUMER TRAINING

Provide information and training to consumers about safety and usage of electricity.

STEP 23 COMMISSION SCHEME

5 OWNERSHIP AND VIABILITY

5.1 Ownership Options

There are two main ownership options for pico hydro schemes:

Community Ownership- consumers of the power pay for the scheme and any net income goes back to the community

Entrepreneur Ownership- one or more entrepreneurs pay for the scheme and receive the profit from sales of power.

Other models such as Government Ownership are less common for pico hydro schemes. The requirements for viability vary depending on the ownership model. In the case of Community Ownership, viability is assessed in terms of whether the quality of life improvements and financial savings over other energy sources are greater than the cost of the scheme. In the case of Entrepreneur Ownership, viability is measured mainly by the return on investment for the entrepreneur. Each ownership model has advantages and disadvantages.

	Pro's and Con's
C.O.	Usually the benefits are more evenly distributed with a higher proportion of households receiving a connection.
E. O.	Profit motive usually ensures that maintenance and repair is given more attention, income-generating end-uses for the power are a priority, management by an individual rather than a committee is more straight-forward. However, poorest community members may be excluded because of higher tariff's.

Table 5-1 Comparison of Community Ownership (C.O.) with Entrepreneur Ownership (E.O.) of pico hydro schemes.

A demand survey and financial viability calculations are very important to establish whether or not a pico hydro scheme is viable and to determine the most appropriate scheme size.

5.2 Cost Breakdown

Scheme costs can be divided into capital costs and running costs:

Capital Costs – The capital cost is the total cost of purchasing and installing all of the scheme components. The capital cost is raised through a combination of one or more of the following: private funds, bank loans, government subsidy and charitable donations. If no other data is available, $3000/kW can be used as a conservative figure for the total capital cost of a pico hydro scheme, excluding house wiring, building work and distribution poles.

Running Costs - In order to collect the tariff and repay the loans it is essential that the scheme remains operational once installed. The running costs are those costs associated with the operation and maintenance. The wages of the scheme operator vary from country to country although US$ 30 to US$ 50 per month is typical, as the job is normally considered to be part-time and this salary can be supplemented with other income. The salary will also depend on the number of individual consumers as a distribution system for a scheme with many houses connected will require more maintenance than one with fewer houses. On very small schemes, the operator may have a free lamp instead of receiving wages.

Maintenance costs arise because of the need to repair or replace damaged and worn components in order to keep the scheme operating reliably. These can be assumed to be a fixed proportion of the total capital cost (e.g. 4-6% per year). The exact figure depends upon equipment and installation quality and attention given to maintenance. If in doubt, assume 6%.

5.3 Tariff Setting

The tariff is the amount that consumers are charged for their electricity service. For pico hydro schemes the tariff is usually a fixed amount which is charged each month. This is made possible by the use of load limiters instead of electricity meters as these prevent the consumer from drawing more current than they have subscribed to, as explained in Section 15.3. How the tariff level is set depends on the type of scheme ownership and how the scheme is financed. Provision must be made to increase the tariff to compensate for price increases (inflation). Linking the rise in tariff to other price rises, such as national electricity tariffs, may make this process easier. The use of 'light packages' enables the consumer to see a directly link between the level of service which they receive for the tariff which is paid.

Light Packages
A light package is an electricity supply that is sufficient for one lamp and possibly a radio. The advantage of this system is that the cost of the service can be easily compared to the benefit obtained. If tube lighting is used, a single light package may typically provide 15W. Load limiters are fitted which limit the power supplied to that required for the number of light packages chosen. The consumer pays a fixed monthly fee per light package.

Community-owned scheme with no bank loan

In this case the consumers pay a one-off fee which pays for the capital cost of the scheme and a small monthly tariff which covers operation and maintenance.

The costs to the consumers can be estimated as follows:

1. The connection cost per light package is calculated using data from other pico hydro schemes or by assuming $3000/kW excluding house wiring. For example, if the scheme cost is $3000/kW and each light package is 15W then the capital cost of one light package will be $45. This must be paid up-front to allow the scheme components to be purchased. House wiring must also be paid for.
2. Estimate the maintenance costs of the scheme. This will be $0.23 per package per month if the maintenance fund is 6% of the capital cost ($3000/kW) as recommended above.
3. Estimate the monthly cost of operator wages and divide by the approximate total number of light packages to find the operation cost per light package. For example if approximately 100 light packages are expected to be subscribed to and the wages will be $30 per month, the operator cost per package will be 30/100 = $0.3
4. Add the operator costs to the maintenance cost to obtain the running cost per light package which will be payable by the consumers each month.

Community scheme with no capital available

Often rural households lack sufficient disposable funds to pay for pico hydro and under these circumstances a loan, usually from a bank, should be considered. A realistic payback period for the loan should be determined. This is usually between 3 and 15 years. Having determined a suitable payback period, banks and other credit sources should be approached to establish the repayments required per $1000 borrowed and the terms of the loan especially regarding collateral.

Having found the best credit deal, the steps to determine the tariff in this case are as follows:

1. Determine the capital cost per light package as before. (e.g. $45)
2. Calculate the monthly loan repayments for each $1000 borrowed and from this work out the repayment for $1. (e.g. if $30 per month for $1000 borrowed then 30/1000= $0.03 per $1 borrowed.)
3. Calculate the monthly repayment per light package by multiplying the capital cost per light package by the monthly repayment for $1. (e.g. 0.03x45 = $1.35 per light per month).
4. Add maintenance costs, calculated as before and an allowance for the operator wages to obtain the total monthly tariff per light package.

Entrepreneur-owned scheme

The entrepreneur needs to determine the return on investment that they require for a pico hydro scheme to be sufficiently profitable and a worthwhile investment. For example, this may be 10% above the cost of a bank loan. This can be used to calculate the monthly cost per light package in a similar way to that described above. The survey will then determine whether there are sufficient households willing to purchase the light packages at this rate.

5.4 Consumer Agreement

Before the demand survey is conducted the terms of the consumer agreement should be clearly established. This will help to clarify exactly what benefit the consumers will receive and at what cost and level of labour contribution. Key points to explain are as follows:

- What a light package is and the implications of a limited electricity supply (e.g. what appliances can and cannot be connected if a socket for an electric plug is provided)
- The costs per light package (Connection charge, cost of house wiring, monthly tariff) and how the monthly tariff will change with time.
- If the electricity will be provided between particular times of the day (e.g. 4pm to 11pm) then this should be stated.
- During the dry season the times may vary due to reduced availability of water.
- The labour contribution required to construct the powerhouse, penstock, intake and distribution poles.

EXPLAIN THE ADVANTAGES and DISADVANTAGES

When finding out who is interested in receiving an electricity connection, it is important to explain the advantages. The main advantages of electricity for most people in rural communities are:

- improved lighting for cooking and study
- better air quality because no kerosene lamps
- less money spent on batteries or kerosene
- less risk of fire

The ability to demonstrate electric tube light in local houses is very advantageous. One method of doing this is by using a pre-charged “emergency light” (see Section 13.1)

A disadvantage of the pico hydro scheme for lighting and other small loads is that the consumers must make a commitment to pay the tariff every month. This differs from other energy types such as kerosene and small batteries which are bought whenever funds are available.

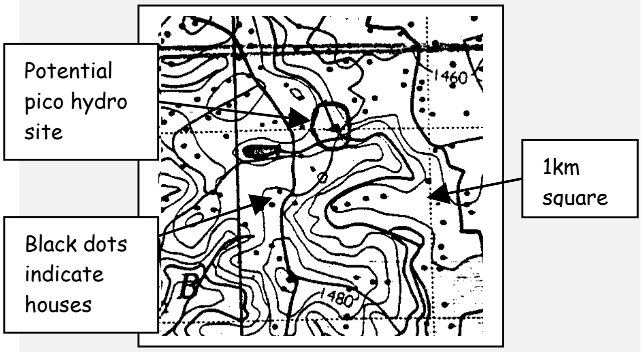
5.5 Demand Survey

The demand survey is a very important step for most schemes. It enables the developer to find out how many light packages are required at the tariff and connection fee which have been calculated and hence the correct size of scheme to be installed. The following questions will need to be answered in order to proceed with the scheme design:

1. How many houses are there within a 1km radius of the source of water / proposed generator site?
2. Within this area, how many people are prepared to pay for electricity and how much?
3. What activities currently occurring would benefit from pico hydro power?

How many houses are there?

The number of houses within a 1km radius will probably be known by local people and can be checked by walking around the area. 1km is usually the economical distance over which electricity from a pico hydro unit can be transmitted. For some countries recent Ordnance Survey maps are available. Map scales of 1:50,000 may have individual houses marked. If a map can be expanded on a photocopier, this makes it easier to identify features in a particular area and to mark on additional houses that are not shown. A map of a rural community living near to a small hydro resource in Kenya is shown below.



It is sometimes possible to supply power to houses that are further away by using a transformer although this adds cost and complexity. Battery charging for people more than 1 km from the generator is an additional possibility (see Section 13.1). The best place for the generator is usually as near to the centre of the village as possible. The position of the generator also depends on the water source. For more advice on selecting the best site and the scheme layout, read Section 6.

How many people will pay for electricity?

1. Conduct a survey of households within a 1km radius of the best generator location. Obtain name, address and the number of light packages that would be purchased using the tariff level

and one-off fee / house wiring cost which have been calculated. This can be done through community meetings or visiting the houses individually. The consumers must make a firm commitment to the supply agreement and sign for the number of packages which they will subscribe to.
2. Use the results of the survey to decide on the power required to supply the total number of light packages and size the scheme.

What other activities could benefit?

Other activities, normally done by hand or using diesel engines can use pico hydro-power instead. Planning uses for the hydro system during the day, when energy is not needed for lights, is called increasing the load factor. Improving the amount of time that the hydro system is 'busy' can help to lower the cost per light package. However, the extra income should only be included in the calculations if these businesses will be established from the beginning of the project. Popular uses for pico hydro-power in addition to lighting include:

- agro-processing including threshing and milling
- battery charging
- ice-making and refrigeration
- power for tools in a workshop.

Use Section 13 to find out how other activities could be powered by pico hydro. The complimentary publication **"Starting a Business Using Water Power"** gives more income-generating ideas.

Example of Viability Calculations:

At a village in Ethiopia, Africa, there is interest in developing power from an irrigation canal. There is up to 4.5 kW electrical power available all year round at this site. The community leaders want to know how much it will cost to install the scheme and connect to 60 houses.

There are two possibilities:

1. **the community funds all the costs themselves**

2. **the community borrow the capital costs from a bank and just fund the house-wiring themselves**

Calculate a tariff for a 15W light package for each financing option and decide which is the most viable.

1. No bank loan

Assuming the capital cost of the installed system is $3000/kW, the capital cost per 15W light package is 15/1000 x 3000 = $45.

The costs for the house wiring of a light package of this size have been investigated in Addis Ababa. Component details and costs for the house wiring and load limiter are as follows:

Item	**Specification**	Cost $
Bulb + holder	9W CFL	8.22
Switch	In line	0.60
Socket	Wall Mounted	0.72
Cable	$0.75mm^2$ x 5m	0.60
Fuse + Holder	3A / 220V	0.60
Load limiter	PTC Thermistor	0.97
Switch	220V Isolation	0.97
Plastic Box	75 x 50 x 25mm	1.20
Seal for box	Printed Label	0.12
	Total	**$14.00**

The annual maintenance costs will be calculated as 6% of the capital costs. Per Light package this is
45 x 0.06 /12 = $0.23 per month.

The operator is expected to be paid $30 per month. It is expected that each of the 60 houses will take an average of two light packages each. That gives an operator cost per light package of 30/120 = $0.25

So for this option the consumer will need to pay the following <u>per light package</u>:

One-off fee	$45.00
House wiring	$14.00
Monthly maintenance	$0.23
Monthly operator cost	$0.25

For example, a consumer subscribing to 2 packages would have to pay 2x[$45 + $14] = $118 initially and a monthly tariff of approximately 2x[$0.23 + $0.25] = $0.96.

2. Scheme financed through bank credit.

The interest rates at local banks have been investigated. One bank is prepared to lend the capital required at an annual interest rate of 25%. This is the best deal. They require the land registration papers of community members as collateral.
The annual repayments (R) for each $1000 borrowed can be calculated using the following formula:

$$R = L \times \frac{i(1+i)^n}{(1+i)^n - 1}$$

L = loan amount (e.g. $1000)
i = interest rate (e.g. 25%)
n = number of years of repayment

The repayments have been calculated for loans taken over 5, 10 and 15 years.
For 5 years the annual repayment is :

$$R = 1000 \times \frac{0.25(1+0.25)^5}{(1+0.25)^5 - 1} = \$372$$

Over 5 years this is a total repayment of $1860

Similarly,
for a 10 year term
the annual repayments are $280
(total repayment = $2,800)

for a 15 year term
the annual repayments are $259
(total repayment = $3,887)

Based on the annual repayments it is now possible to calculate the monthly tariff per light package:

The capital cost for one light package is $45 and the house wiring cost is $14. Assuming that bank credit is used to pay for 100% of the scheme costs including house wiring (but excluding poles and building works) then the monthly tariff is calculated as follows:

For a five year loan repayment
Monthly repayment costs per $1000 borrowed
= 372 / 12 = $31

Per light package +house wiring this is a monthly repayment of $59 x 31/1000 = $1.83

Similar repayments can be calculated for repayment terms of 10 years and 15 years

Summary of tariff costs for one lamp package:

Loan repayment period	5 years	10 years	15 years
Repayments for scheme and house wiring	$1.83	$1.38	$1.27
Maintenance (6%)	$0.23	$0.23	$0.23
Operator cost	$0.25	$0.25	$0.25
Total monthly tariff	**$2.31**	**$1.86**	**$1.75**

Comments
Operator and maintenance costs are calculated as before. The interested is assumed to be calculated annually and unchanging for different repayment periods. In reality the interest rates are usually lower for longer repayment periods and for larger sums.

6 SCHEME LAYOUTS

6.1 What factors decide the layout?

Since decisions regarding the scheme layout will affect the power output, reliability, cost and convenience of the service, it is worth considering several options to make sure that the best layout is chosen.

The factors requiring consideration when selecting the best layout are as follows:

- **Location of the houses in relation to the water**
  If the houses are a long way from the turbine, the scheme is likely to be expensive. Reduce this cost by careful planning.

- **Power requirement**
  The power generated depends on how much water is taken (flow rate) and the number of metres which it falls (head). These are both affected by the layout.

- **Water rights**
  Checking water rights and negotiating water usage with everyone affected is an important part of the planning process. Questions such as the following should be asked:
  Whose land will be used for the scheme?
  Who else uses the water and for what purpose?
  Clear agreements should be reached before any installation work begins. This will avoid disputes that could affect the operation of the scheme after commissioning.

- ***Cost and availability of different components***
  The layout affects the cost and the power output. The major challenge of the layout designer, is to keep the penstock and the distribution system as short as possible. Both the cost and power losses increase as they get longer. Remote areas will have more limited access for transportation of building materials. This may affect the design of civil works such as intakes, canals and reservoirs.

- **Water supply and irrigation projects**
  In some cases it is possible to combine a pico hydro scheme with other local initiatives such as the development of domestic water supply or new irrigation systems. This may affect decisions regarding the layout.

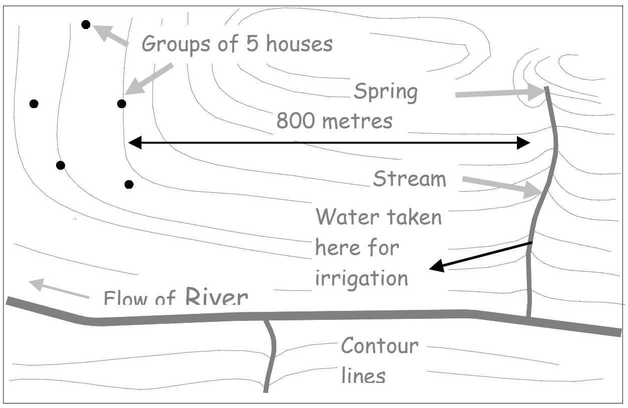
The task facing the layout designer usually involves several compromises. The most obvious layout for a particular site may not be the best and other options should be considered.

The length of the penstock pipe and the length of the distribution cable, in particular, must be carefully judged. It will be helpful, when considering different layouts, if the local cost for different sizes and types of plastic pipe and cables are available. This will allow rough estimates to be made for quick comparison.

Detailed designs are not required at this stage, but it will be helpful if the designer has read and understood Sections 10, 11 and 14 before making final layout decisions.

6.2 Examples of Scheme Layout

Figure 6-1 A map of the site is essential when planning the layout. On this map, points of the same height have been joined with contour lines.



Four different scheme layouts are considered in the following example of a typical hillside electrification project.

At this site, there is sufficient water in the stream all year round to supply approximately 100W of electricity to each of 25 houses. However, there is a considerable distance between the water source and the nearest houses in the village (approximately 800m) and during the dry season, some water is taken from lower down the stream and used to irrigate farm land. A map of the site has been drawn and is shown in Figure 6-1

Contour lines have been added which join together places of the same height. There is 10m difference in height between each of the contour lines increasing away from the river which flows through a valley.

Note: In figures, each dot represents 5 houses.

As the stream is some distance from the village there are a number of possible layouts to consider. The main points of each layout have been summarised to allow a quick comparison to be made.

6.3 Layout 1: Long Penstock, Short Cable

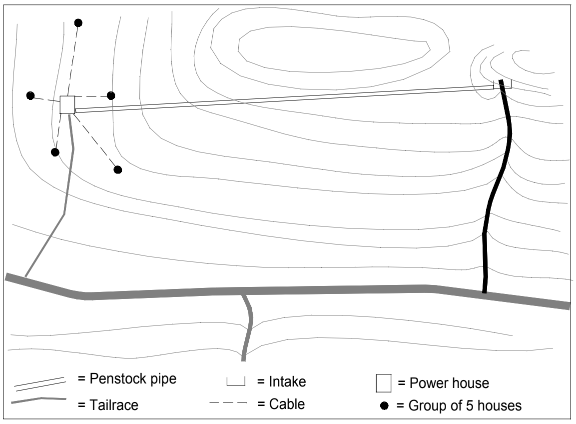


Figure 6-2 Layout 1 has a short distribution system saving on cable cost. However, a longer penstock will be more expensive.

In Layout 1, a long penstock brings water to a convenient powerhouse in the village keeping the distribution system short. The civil works are kept to a minimum, because the intake is also the forebay tank.

- Water in the tailrace is not returned to the original stream and therefore irrigation is affected. Water rights will be an important issue with every layout except with Layout 2.
- Much of the head will be lost unless a penstock of large diameter is used.
- The cost of this pipe is likely to be the most significant scheme cost with this layout. See Section 11 for advice on choosing a penstock.

6.4 Layout 2: Short Penstock, Long Cable

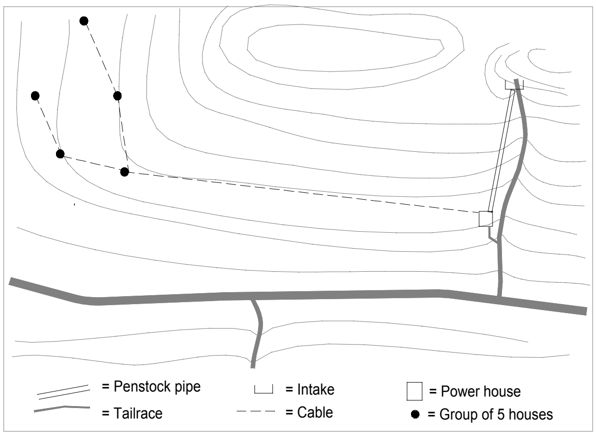


Figure 6-3 Layout 2 Short penstock and long distribution system. Water rights are not affected.

In this design, the cost and the head losses will both be reduced because the penstock is shorter. The water in the tailrace rejoins the original stream so irrigation is not disrupted

- Distribution cable will be expensive and needs careful selection to minimise the cost and avoid a large volt drop.
- The powerhouse is a long way from the village which may be very inconvenient.

For advice on designing and costing the distribution system, consult Section 14.

6.5 Layout 3: Using a Canal

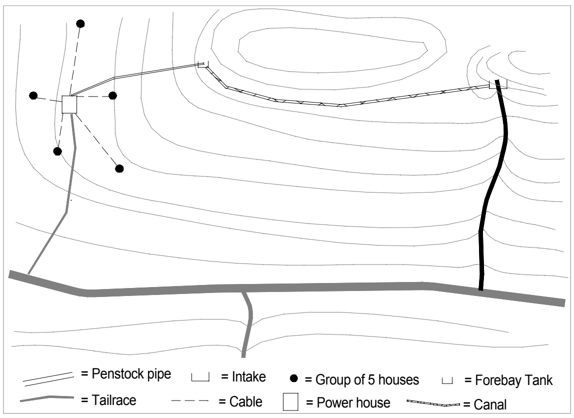


Figure 6-4 Layout 3 Use of a canal replaces the need for a long distribution system or penstock.

In this layout, the water is brought nearer to the village using a canal. A lot of manual work is required to dig a long canal like this but the penstock and distribution cables can both be short and will therefore cost less.

- An earth lined canal will require regular maintenance
- A concrete lined canal will be more reliable but expensive particularly at remote sites
- Canals should be avoided in areas which have landslides

Section 10.2 gives information about designing a small canal.

6.6 Layout 4: Low Pressure Pipe and Storage

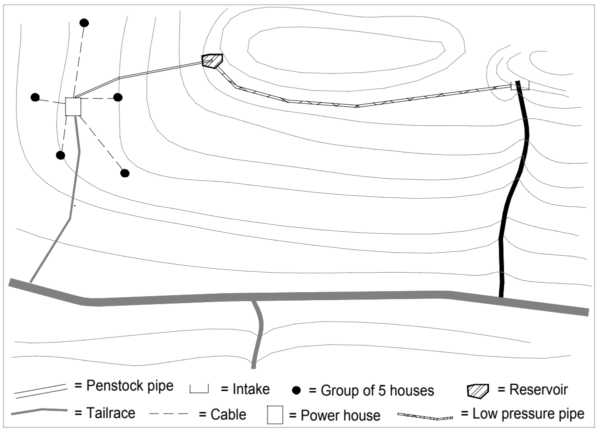


Figure 6-5 Layout 4. A modified version of the last layout The canal is replaced with a low-pressure pipe. The forebay has been enlarged to add a means of energy storage.

Layout 4 is almost the same as 3 but the canal is replaced by a piece of low-pressure pipe and the forebay is enlarged to form a small reservoir. A suitable low-pressure pipe is often sold as drainage pipe. This type of pipe is considerably cheaper per meter than penstock pipe.

- Maintenance is reduced as there is no canal
- A pipe is easier to install than a canal.
- More building materials, labour and maintenance are required for the reservoir and extra pipe must be purchased.
- A reservoir allows easier management of water resources during the dry season and smaller pipe to be used to bring the water from the stream.

Section 10.3 explains how to design a small reservoir.