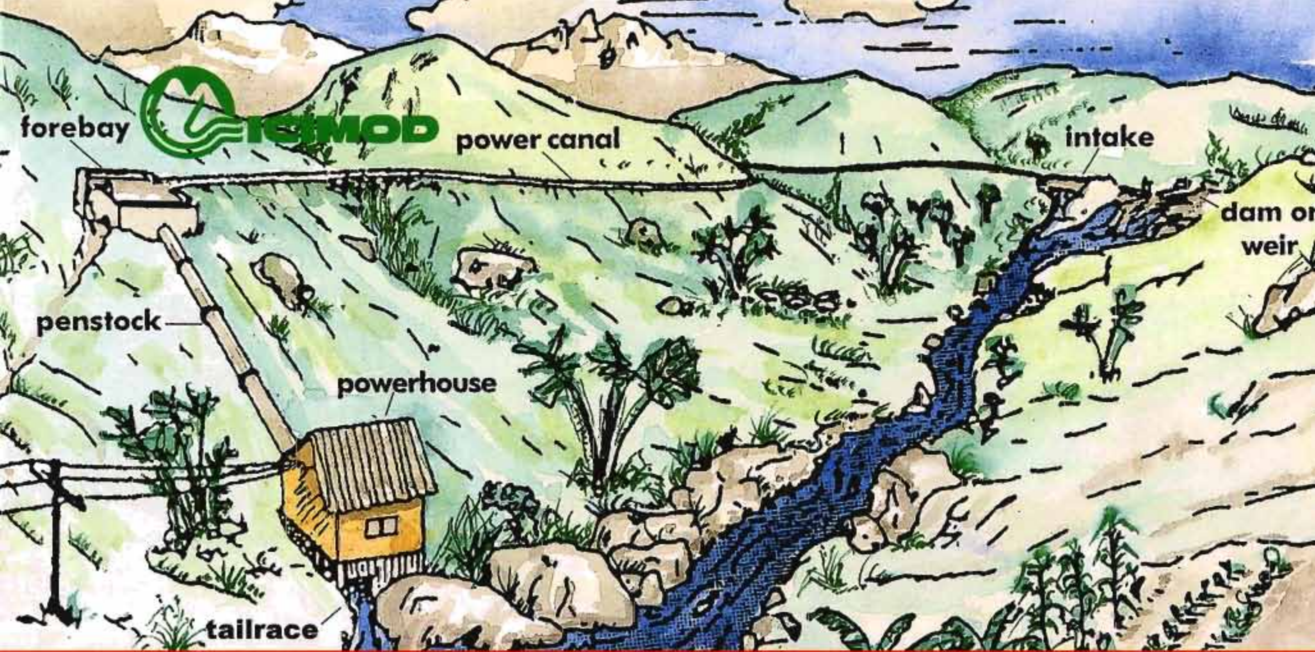
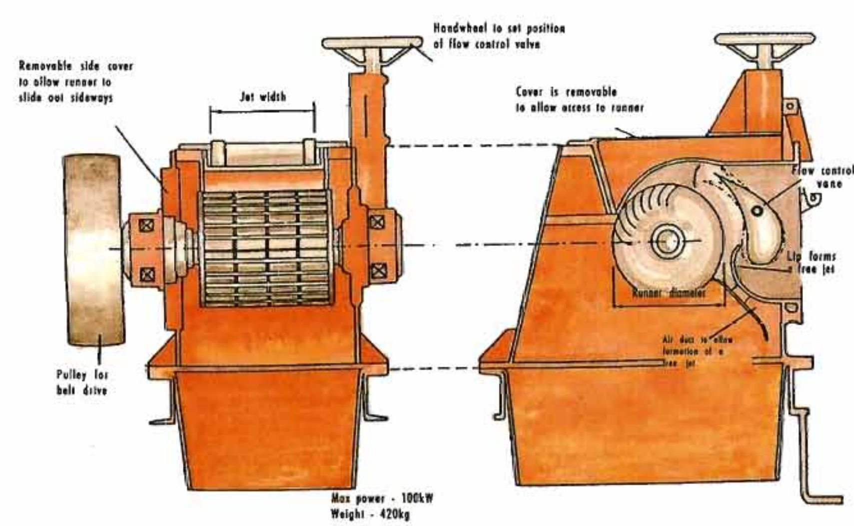


Manual for Survey and Layout Design of Private Micro-hydropower Plants



International Centre for Integrated Mountain Development
Kathmandu, Nepal
1999

Manual for Survey and Layout Design of Private Micro-hydropower Plants

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Kathmandu, Nepal
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Preface

This manual has been prepared as one of a series of four manuals for the various groups of technicians and professionals engaged in design, survey, feasibility studies, manufacture, installation, management, operation, and maintenance and repair of private micro-hydropower (MHP) installations in the Hindu Kush-Himalayan region. The main reason for preparing the manuals was the felt and stated need of such groups for whom there are few opportunities for adequate training and no appropriate supporting manuals available. The lack of such opportunities and support is now recognised to be one of the main reasons why such schemes are less successful than hoped. They are being designed, installed, and operated by people who have not had sufficient opportunity to acquire the necessary skills.

The current manual is aimed at site surveyors, layout designers, and consultants who carry out surveys and prepare feasibility studies for private MHP plants for communities or entrepreneurs in remote and underdeveloped mountain areas. It is intended to provide some assistance to such professionals both as a training aid and as a reference document. As the intended readers of the manual may have had a somewhat limited formal education, an attempt has been made to keep the contents simple. However, there is always a problem of balance between simplifying so far that the information is no longer useful and the information being so complicated that those who need it are unable to use it. An attempt has been made to achieve the optimum balance.

All the manuals, including this one, have been prepared as a component of the project 'Capacity Building for Mini- and Micro-Hydropower Development in Selected Countries of the Hindu Kush-Himalayan Region - Phase II'. The project was generously funded by *NORAD* and implemented by ICIMOD. The first draft of this manual was prepared by DCS -Technology Development, Butwal, Nepal, and was revised by Dr. A. A. Junejo, the Project Coordinator of the MMHP project, and two consultants, Mr. Ajoy Karki and Mr. Ram Kumar Lal Karna. DCS-Technology Development performed an admirable job in providing all the necessary information in one document. ICIMOD is very grateful to DCS - Technology Development and other contributors for their inputs and hard work.

This is a first attempt to produce and publish manuals such as these for the user groups mentioned above; and it is quite possible that some important aspects have been overlooked, or some information not provided in the most effective way. We would very much welcome receiving any comments and suggestions for improvements or additions for subsequent editions from users of the manual, experts, and institutions concerned with MMHP. After any necessary modification these manuals will be translated, published, and distributed in India, Nepal, and Pakistan to the prospective users and beneficiaries and relevant institutions. It is also hoped that some training agencies will find them to be useful supporting material for their training programmes.

Anwar A. Junejo
Coordinator, MMHP Project
ICIMOD

Abbreviations and Acronyms

HKH : Hindu Kush-Himalayas

MMHP : mini- and micro-hydropower

MHP : micro-hydropower

NGO : non-government organization

kW : kilowatt

POI : profit on investment

PVC : polyvinyl chloride

ELC : electronic load controller

Rs : Rupees (Nepali)

HDPE : high density polyethylene

CGI : corrugated galvanised iron

rpm : revolutions per minute

ACSR : aluminium conductor steel reinforced (cables)

N.B. The source of definations 'Gross head' and 'Net head' is Crawford, N.H., Small hydropower: Hydrological Methodology without 'Stream Flow Data'. In Small Hydropwer for Asian Rural Development. Elliot, C.R. (ed), pp80-148. Thailand: Asian Institute of Technology.

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CHAPTER 1
Introduction

The pattern of development in the Hindu Kush-Himalayan (HKH) region varies considerably from country to country and area to area. However, the overall picture in this formidable mountain range is rather bleak with only very few exceptions. Usually, underdevelopment, poverty, inaccessibility, and lack of physical infrastructure are prevalent. Energy, a key ingredient for improving living conditions and fuelling the development process, is generally in short supply, and the inhabitants have to rely on local natural resources of fuelwood and other biomass to meet their daily needs. In many mountain areas, there are few areas in which trees can grow, or the existing forest has been depleted to an unsustainable level, resulting in soil erosion and other severe environmental problems.

More recently, electricity, especially for lighting, has come to be regarded as a necessity rather than a luxury, and people living in remote areas are demanding access to electric power. Similarly, mechanical power is needed for normal tasks such as milling and oil expelling, to reduce the drudgery of daily chores, and to improve productivity. Consequently, more appropriate and modern energy generation systems are needed to meet the increasing demand in remote and underdeveloped mountain areas.

Mini- and micro-hydropower (MMHP) appears to be an appropriate resource for meeting the energy needs of people in the HKH region. Potential energy resources from hydropower are far greater than present or projected demand. By using small power plants established to fulfill the demands of individual communities, it is possible to avoid the problems and costs associated with transmission and transport of energy to remote, inaccessible areas with small populations. Private Installations set up on the initiative of beneficiary communities or local entrepreneurs in a decentralised manner are particularly effective, and the equipment is also indigenous and low-cost. Experience in Nepal and elsewhere has clearly demonstrated that such plants, especially in the micro range (up to 100kW), can be economically viable if certain support is provided and the entrepreneur(s)/owner(s) are able to manage, operate, and maintain the plants properly. The four manuals for micro-hydropower (MHP) plants prepared for ICIMOD, of which this is one, are intended to provide some of the necessary support and information to enable such plants to be properly selected, sited, designed, installed, managed, operated, maintained, and repaired. They address much of the need for information identified through various studies and consultations.

1.1 Applicability of MHP

There are many areas in the HKH region that are inaccessible and underdeveloped, and where the population is scattered, poor, and mostly unaware of technological progress/benefits. Isolated micro-hydropower (MHP) plants are usually the least-cost option for providing energy in such areas. This is mainly because other options for the supply of energy, such as grid extension and diesel power, are more expensive and difficult to install or operate. Since small water streams are usually available in most of the HKH region, it is quite easy to construct MHP plants to meet the energy needs of a small village or cluster of settlements. These needs may be for electricity, mainly for lighting during the evenings, or for motive power to be used for agro-processing, wood working, and/or other small-scale industries. The size of plant needed for these applications may range from 200W to about 200kW. In the lowest range, up to five kW, the end-use would only be electricity for lighting, since running processing equipment at such a low power would be difficult. In the medium range (5–50kW), the plant may provide energy for agro-processing or industry only, electricity only, or a combination of both; while larger-sized plants (40–200kW) usually only generate electricity, which may be used for lighting and other domestic uses and/or for industrial applications. Thus the type of technology, level of sophistication of the equipment, and system of management and operation are rather different for power plants in the different ranges.

In the case of larger-sized plants, attempts have also been made to use electricity for cooking and heating (including water heating) especially to use the power available during off-peak hours. The use of electricity for heating (particularly cooking) can contribute significantly towards reducing the burning of wood and other biomass; and thus countering the negative impacts on environment and health from burning biomass. In addition to meeting the needs of an area, a properly designed, installed, and managed MHP plant can also contribute significantly towards employment/income generation, improved living conditions, and improved educational facilities.

1.2 About this Manual

This manual is one of a series of four, initiated and sponsored by ICIMOD, aimed at different MHP practitioners including surveyors, designers of schemes, manufacturers, installers, managers, operators, and repairers. The current volume has been prepared mainly as a source of information and support for those technicians and professionals who:

- undertake surveys of sites proposed for run-of-the-river type MHP installations;
- prepare feasibility reports covering:
    - physical feasibility, does the physical situation on site allow requisite power to be generated?

- technical feasibility, is the site suitable for accommodating the various civil engineering structures required for an MHP scheme?
- sociological feasibility, is the local community willing and able to take on the commitments of an MHP scheme?
- economic feasibility; can the MHP scheme generate enough income?

• and who design the layout of a scheme.

In writing the manual, it has been assumed that the target group is reasonably literate and has had some exposure to micro-hydro technology. The manual's users may not be qualified engineers, but they should have some basic engineering qualification (diploma/ certificate level) and, more important, relevant experience.

The design of an MHP scheme is a complicated procedure, as all sites are different with different problems and needs. It is impossible to cover all the aspects of feasibility for all ranges of MMHP within a single manual. The information given in this manual is intended to be used for straightforward designs of MHP schemes in the range of up to 50kW at sites meeting the criteria laid down in the chapters. For more complicated and larger schemes, say above 50kW, a qualified engineer will have to make the design using more detailed manuals and books and site data.

As the title suggests, this manual only deals with the situation on site, especially the layout; i.e., the location and route of civil engineering structures such as the dam/diversion weir, intake, power canal (sometimes called headrace), forebay, penstock, powerhouse, and tailrace. The design and/or selection of the actual electro-mechanical equipment is beyond the scope of this manual; except that the type and size of the turbine may have to be decided upon at this stage. It is hoped that the information provided in this manual will enable professionals to survey the site, measure/estimate various parameters, decide whether the scheme is viable, and design the layout/location of the civil engineering structures. It is expected that a person having some survey qualifications and experience would not actually need additional training to enable him* to carry out the above tasks using this manual. Nevertheless, it would no doubt be more effective and beneficial if such a person were able to attend a training programme based on the manual before starting work.

* Note: Throughout this manual the masculine term is used to refer to persons whether male or female

CHAPTER 2
Basic Details of an MHP Scheme

In this chapter, we try to describe the main features of an MHP scheme and their functions, together with considerations and procedures for the site survey and design of the layout. Figure 2.1 shows the main features or components of an MHP scheme. These include a river, from which part of the flow is to be diverted for power generation, a small weir, intake, power canal (headrace), forebay, penstock pipe, powerhouse, and tailrace. Depending upon such factors as the size of the plant and length of the canal, many other components such as a sluice gate, cross-irons, trash racks, and valves may also be provided at various locations.

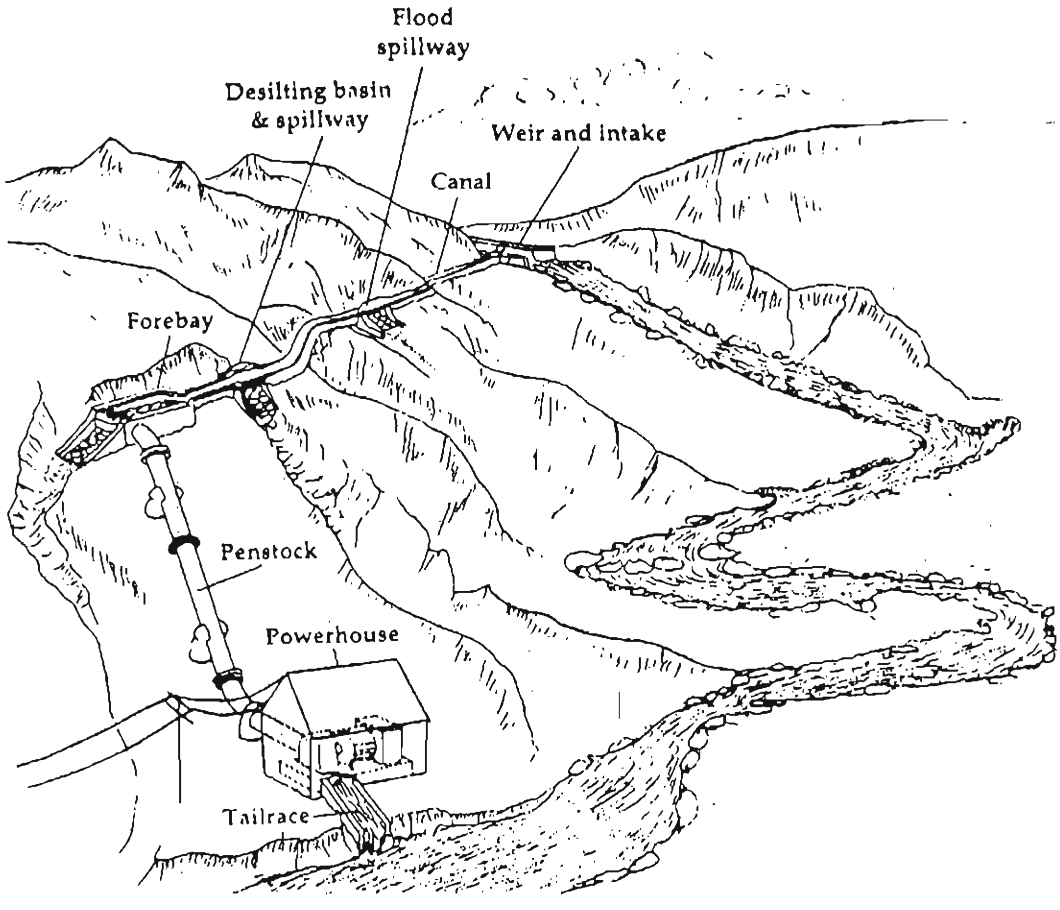

Figure 2.1: The Main Components of a Micro-Hydro Scheme

2.1 Main Components and Structures

The first man-made component in a run-of-the-river type MHP plant is a weir or dam built across the stream to raise the level of the water so that some of it can be diverted to enter the power canal through the intake mouth (Figure 2.2). The weir does not stop the flow in the stream completely; it only raises the water level to a predetermined position above which the stream flows over the weir. During the high-flow season, a weir is usually unnecessary or even undesirable. Therefore, in many smaller installations, temporary weirs are built from boulders and stones that are washed away during the high flow period and rebuilt during the dry season. In other cases, the weirs may be permanent structures, sometimes having wooden gates to maintain the desired water level.

As shown in Figure 2.2, the intake is simply a window (sometimes called an intake mouth) in a well-constructed retaining wall that allows a controlled flow into the canal. The window may have some vertical bars or even a crude trash rack to prevent the entry of stones or other such material. The intake can also be a very simple structure made of mud and stones without any bars or regulating system; depending upon the size, sophistication, and cost of the plant. It is usually desirable, however, to incorporate some components in the intake to control the flow of water and debris into the power canal.

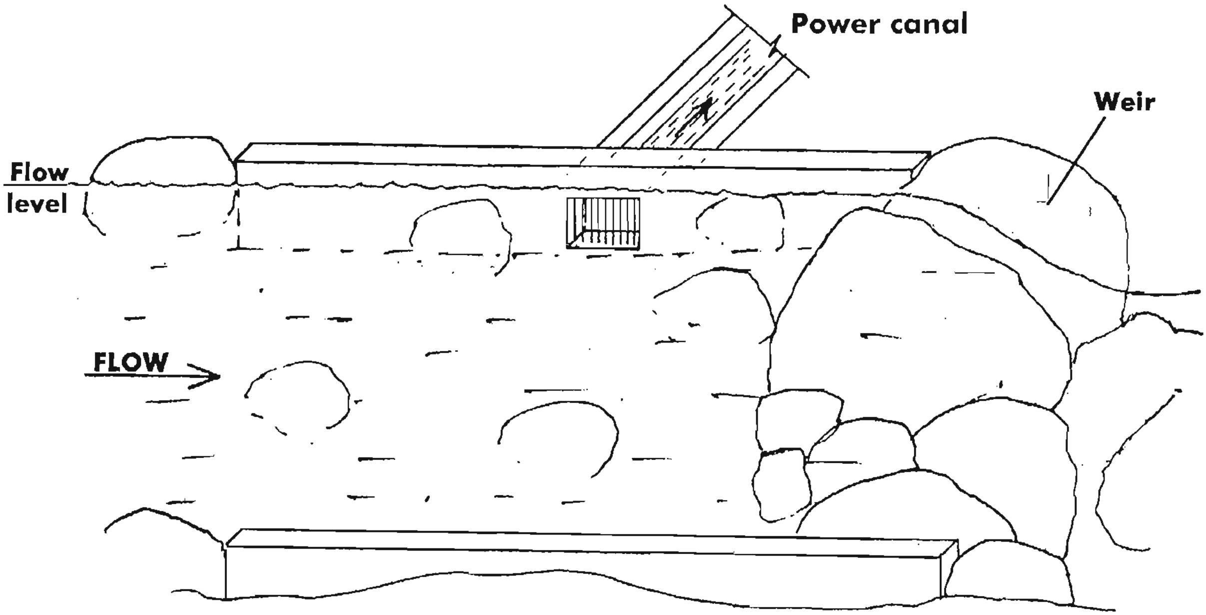

Figure 2.2: The Water Intake and a Temporary or Natural Weir

As shown in Figure 2.1, the power canal or headrace carries the required flow from the intake to the forebay safely. Its width, slope, and cross-section should be designed for optimum performance. The headrace can be constructed from a pipe over a part or the whole of the length. If it is an open channel, it can be constructed from loam, stones, and mortar and may sometimes be lined with a suitable sealant. In order to ensure that excessive flow does not enter and get transported to the forebay, spillways and sometimes gate(s) are also provided in the canal, preferably nearer the intake. Similarly, gravel and silt is 'settled' from flowing water in one or more desilting basins in which the flow is slowed by increasing the cross-sectional area, particularly the width, allowing the particles to settle. Structures are also constructed to 'flush' out the accumulated silt at appropriate intervals.

The destination of water flowing in the canal is the forebay, where water enters the penstock pipe. The forebay is usually a small rectangular tank in which the mouth of the penstock is located. The mouth is covered with a trash rack to prevent entry of solid materials, especially suspended materials such as leaves and branches. The forebay usually contains a spillway, desilting chamber, and flushing gate as well.

The penstock is a robust pipe which transports water from the forebay to the nozzles in the turbine. Here, the potential energy of the water is converted into kinetic energy which in turn rotates the turbine. The penstock is usually the most expensive component in the water transporting system and is made from mild steel or high density polyethylene (HDPE). Usually, a valve is provided in the penstock near the lower exit to stop or control the flow. Sometimes a valve or a stopper is also provided at its mouth in the forebay. The penstock has to be properly supported and anchored since the flowing (or stopped) water can cause forces and vibrations of significant magnitude.

The main job of the surveyors, and particularly the designers, of the layout is to site (identify the locations of) the weir and intake, the power canal, the forebay, the penstock, the powerhouse, and the tailrace. The locations of the three main components, the intake, the forebay, and the powerhouse, are the most crucial and depend upon the minimum acceptable power that needs to be generated.

2.2 Parameters for Layout Design

Power generated is calculated using the following equation:

$$\text{Power (kW)} = 9.81 \times \text{efficiency of system} \times \text{flow } (m^3/s) \times \text{head (m)}$$

The conversion efficiency varies with the type of turbine and flow conditions; but, in the preliminary stage of calculations, it is assumed to be between 0.5 and 0.6. Thus the net head* (the vertical height of water from the level in the forebay to the level of the exit nozzles in the powerhouse, where it emits and hits the turbine blades) and the flow are the main parameters. The maximum amount of flow that can be diverted from the river for power generation, and which is available without problem all year round, is referred to as the design flow or rated flow. It is usually less than the minimum flow available in the river/stream during the dry season. This is mainly because some water may have to be left flowing in the original stream for other purposes such as drinking and washing, support of riverine life, or irrigation. Thus, it is necessary to estimate or measure flow during the dry season. Depending upon the needs, the amount of flow to be left in the stream is determined and deducted from the total flow to arrive at the design flow. The value of the design flow is used in the design of various structures and components including the turbines.

For example; if the measured flow in a stream is 150 l/s during the month of March (considered to be the driest month and thus minimum flow), and about 30 l/s needs to be retained in the stream, then the design flow available for the MHP installation would be 120 l/s. Some other factors also need to be taken into account. The minimum flow may vary during the dry seasons of different years; therefore, the choice of design flow should be made carefully. It is usually preferable to measure flows more than once during the dry season to get more reliable values, or even during the dry seasons of two or more consecutive years. However, this may not be a serious problem in many situations where only a small portion of the minimum available flow is to be diverted for the MHP scheme.

It should be realised that the actual flow determined after the installation is complete may be higher or lower than the flow calculated on the basis of the information available at the time of the site survey. The owner-manager may even be able to increase the flow deliberately after the completion of the plant with a little additional expenditure by, for example, raising the weir. In any case, the initial estimates are often not very accurate even when they are based on actual measurements.

The gross head** is chosen so that the maximum power can be produced within the possibilities presented by the site. The layout, that is the exact and relative positions of the individual components, is then designed accordingly. The correct choice of gross head is very important, since it can be difficult and expensive to change the layout, and thus the gross head, after construction is complete. The optimum sites for the three components, powerhouse, forebay, and intake, are selected by an iterative process. Usually, the

* Net head is defined as the difference between total head at the entrance to the turbine proper (entrance to the spiral casing and the total head at the tailrace).

** Gross head is defined as the difference between head water and tail water elevations.

first step is to identify a suitable location for the powerhouse, then to choose a position for the forebay giving the requisite gross head, and then to survey the path of the proposed headrace to reach the intake. If no suitable position can be found for the forebay or intake, then a new site must be selected for the powerhouse (and/or forebay) and the process repeated. The interconnecting components, the penstock and the canal, must also be located on stable ground. If the proposed path of the canal or penstock is found to be unstable, or to make construction difficult as a result of problems, e.g., too steep a slope, obstructing rock, or easily eroded soil, then again another suitable location must be found for the powerhouse, forebay, canal, and intake, and the whole process repeated. The proposed locations may be changed many times before the optimum layout is achieved. A whole range of geological aspects will affect the final selection of the layout.

Once the basic layout has been determined, the route of the small channel (tailrace) that transports the water exiting from the turbine back to the river also needs to be finalised. This is not usually difficult. In a few cases, it may be possible to use this exit water for irrigation of the surrounding land.

After finalising the location of the components of the MHP scheme, maps or sketches are prepared showing distances, heights, angles, bends, and other necessary information. The locations are also demarcated on the ground.

After the completion of the preliminary survey and layout, it is usually necessary to carry out a more detailed survey and investigation to measure the distances, heights, angles, and so on more accurately and to determine the exact dimensions and sizes of the intake, canal, forebay, penstock (especially the penstock), and powerhouse. The flow may also be measured more accurately, if possible during the dry season. The forebay, powerhouse, and tailrace may also be designed and sketches prepared. Other investigations would include geological and soil conditions, landslide and flooding possibilities, and environmental considerations.

It is sometimes possible to complete all the surveys, measurements, and design work within one site visit, especially for a smaller plant, say less then 20kW. However, it is advisable to conduct the second detailed survey one to three months after the preliminary survey and to observe any changes in such things as the terrain, the stream, and forest cover. These aspects are discussed in more detail in the following chapters.

CHAPTER 3
Data Collection and the Design Process

As discussed in Chapter 2, in order to design an MHP plant properly, it is necessary first to collect information and data about such things as the power required, the capabilities and keenness of the recipient communities/entrepreneurs, and the potential of the site. This data and information are collected from sources that include the promoters or owners of the plant, other persons or individuals who are or have been working in the area, and, most importantly; through site visits, discussions, meetings, and surveys. In the following sections the main topics for which information and data need to be collected and analysed are discussed, together with the methodology and sources that can be used.

3.1 Information Collection before the Site Visit

Considerable information should be collected before first travelling to the site. This information should also be useful for making travel and accommodation arrangements. If possible, information should be obtained about the site, the local community, the economy, the water source (or sources), the weather, and the social conditions. The main source of information would normally be the entrepreneur or representatives of the community pursuing installation of the plant; i.e., the people who have approached the organization to conduct the survey. Other possible sources are personnel from non-government organizations (NGOs) working in the area, or employees of banks, schools, or other offices working and living in the area. Although it might be quite difficult to find such a person (or people), an effort should made because information from them is likely to be less biased. Although further visits to the site and proper surveys will be necessary, this pre-visit information can facilitate many aspects of the visit and may even decrease the length of time needed at the site. The contact people may also be helpful in making arrangements for the trip and stay.

A form similar to that shown in Annex I may be used for collecting information. This form includes sections on location of the site; travel route, mode, and distance; contact persons in the area; accommodation arrangements; some ideas about the number and type of consumers; the social and economic situation; and, of course, some description of the water source, terrain, and climate. While collecting such information, it should be kept in mind that the person being interviewed may have little knowledge of technical subjects and questions should be phrased simply so they can be easily understood and should be repeated if necessary. Even so, the information obtained may not be totally accurate.

3.2 Preparations for the Site Visit

During the visit, a number of surveys and other tasks will have to be performed. Preparations need to be made for these, and equipment and other items acquired and carried to the site. The tasks to be prepared include the following.

- Arrival and stay in the Project area
- Meetings with community members/leaders/representatives, entrepreneurs
- Reconnaissance survey
- Survey of demand
- Preliminary site survey
- Preparation of sketches/maps
- Photography at the site

The first matter to be determined is the timing of the visit, which should be convenient from the point of view of travel, stay, and working at the site. It should be during a dry period (not too much rain) and not too hot or too cold. Otherwise, work at the site may be difficult. In Nepal the convenient period for surveys (including measuring minimum flow) is between February and May. The optimum period may be different in other countries and/or sub-regions of the HKH area. Appropriate information needs to be obtained from the people of the area, the Meteorology Department of the country, and other sources.

Usually two persons should travel to the site, especially during the first visit: a qualified and experienced surveyor and an assistant. They should be able to get along with each other and work well together. Later, however, it should be possible to locate and engage one or more local persons to assist in the survey work and other tasks such as organizing meetings.

It is not easy to estimate the time needed for completing all the surveys, meetings, and layout design. For an experienced surveyor, the minimum time needed would be three days, excluding travel time, if the site is easy, the community helpful, and adequate information has been collected before the visit. In general, however, at least five to seven days should be allowed for the first visit and preliminary survey.

3.2.1 Survey and Other Related Equipment

It would be very useful to acquire maps for the project area with topographical contours on a scale of 1:50,000 or better. Such maps are not easily available for some countries of the Himalayan region, but they are generally available for Nepal.

The choice of survey material to be carried to the site depends partly on the decision made on the methodology to be used for flow measurement (see section 3.8). It is both expensive and embarrassing to have to return to the office to collect necessary equipment, thus a check list should be prepared beforehand showing the equipment needed. A typical check list is shown in Annex 2. Most of the equipment, especially the delicate optical equipment, needs to be packed properly for transportation to the site.

Proper clothing is also important: shoes, caps, glasses, and gloves are needed. Warm clothes and a sleeping bag are also essential. Thus attention should be paid to packing the appropriate personal belongings for the trip; taking into account the weight limitation, since in general all luggage has to be carried by somebody.

3.3 Arrival at the Site

After arriving and settling down at the site or village, where the team is to stay, safely and with all equipment intact, the first thing to be done is to contact the people who are to look after the team and make arrangements for their stay, meetings, and survey. The actual work can only start when the team has established these contacts, is comfortably settled into lodgings, and arrangements have been made for further travel to the villages of beneficiaries and the site.

The second important task is to try to contact those directly concerned and discuss with them the work plan for the next few days. These initial meetings should also be helpful in assessing how keen the community or the entrepreneur and his partners/supporters are about the installation, and how much help/assistance they are prepared to offer to the team. The message should always be that this is their project and the team has come to assist.

For a community owned and/or managed plant, the third task is to organize a meeting of representatives of different ethnic/caste/religious/and economic groups and anyone else who would like to attend. The main objective of this first meeting is to meet the potential beneficiaries and assess their keenness, capability, and willingness to assist and work for the installation. Overall, the following aspects should be covered.

- Know and meet the various groups and build rapport and trust.
- Explain why the team has come.
- Provide as much information as possible about the proposed MHP plant and explain the need for the local community to be involved in such things as decision-making, surveys, installation, management, operation, and repairs, as well as any other contributions.
- Collect additional information about such things as the site, stream, consumers, previous surveys.

- Assess the keenness and capacity of the potential beneficiaries through their responses to what they are being told (avoid asking direct questions).
- Sense any inter-community conflicts: social, economic, related to land/water, etc.
- Ask how beneficial the group thinks the MHP would be for the community and what they themselves would be able to do.
- Ask if they have any fears or misgivings about potential negative effects of the MHP plant: land use, diversion of water, effect on their *ghatta*(s).
- Ask if potential beneficiaries really want an MHP for electricity and if they are willing to contribute in cash and kind to have it installed.
- Ask how much power they think is needed.
- Ask who would be the manager of the plant, whether the participants would trust such a person, and whether they think he is competent and experienced enough to do the job.
- Ask if the potential beneficiaries think it would be appropriate to form a committee to look after both the installation and operation of the plant; and if so who would be the proper people to work as members of the committee. (The actual committee may be formed later after more thorough consultations and assessment of the leading people.)
- Ask the participants to identify four to five suitably qualified people to assist in the survey work. Such persons should be interviewed later and, if found suitable and willing to assist, should be assigned some tasks.

This meeting should be treated as a preliminary meeting and most of the discussion should be informal. The community leaders should not be given the impression that the team is following some pre-planned course. At the same time, some notes may be taken of facts related to the assessment.

It would be useful to hold a similar type of meeting for an entrepreneur-owned plant. The main objective in this case would be to judge the reaction of the people towards the plant, and whether the owner was capable of dealing with the issues and concerns raised by the community members. The entrepreneur might be asked to organize such a meeting himself.

3.4 Reconnaissance Survey

This survey involves visual inspection of the site for a few hours to become familiar with the prevailing conditions and gain some idea about such things as the flow, elevation (whether the slope is gentle or steep and allows more or less head), terrain, vegetation, land uses, and water uses. Photographs of the site, stream, terrain, and likely location of the civil structures may also be taken. Some community representatives and helpers should accompany the survey team to discuss the following.

- Whether any previous survey had been conducted; and, if yes, what were the results? Did any one have records? Even if proper records of a previous survey are available and thought reliable, it is still necessary to perform a survey, but it might be possible to shorten some aspects of the survey and layout design.
- Had any sites already been considered or identified for, say, the powerhouse/mill, forebay, power canal, and intake?
- General items such as who owned the land where the powerhouse was proposed, would the intake be suitable, and was there a proper location for digging/constructing a canal?

Some very rough estimates of flow may be made using the float method, for example. The terrain should be inspected for possible siting of the powerhouse, forebay, canal, and intake. Some idea about the availability of head can also be obtained, using, for example, an altimeter, thus enabling a very rough calculation of the power potential of the site.

The main objective of the reconnaissance survey is to become familiar with the site, consider or evaluate locations for the main components, and make a very rough estimate of the potential of the site.

3.5 Comprehensive Meeting with the Beneficiary Groups

At this stage, the survey team should have a very rough idea of the demand for power (through discussions before the site visit and during the preliminary meeting) and the power potential (from a previous or reconnaissance survey). Looking at the site, very rough estimates of costs can also be made. With these figures in mind , this is the time to hold a more comprehensive and decisive meeting with community members, leaders, and representatives of different ethnic/economic groups. Women representatives should be included if at all possible. The main objective of the meeting is to discuss and clarify all major background aspects, such as demand, power, costs, funding, contributions and other support, some technical details, other end uses, management, tariffs, incomes, repair and maintenance, and back-stopping. The team members should facilitate the discussions rather than lead them, and make the community feel that they are talking about their own plant/property, its benefits, and the necessary effort and responsibilities.

All known information should be presented at the meeting and discussion encouraged. The team members should observe and assess the possibility of cooperation and working together between the different ethnic and other groups; try to identify any real conflicts within the groups; and assess the keenness and ability of potential beneficiaries to participate in and contribute to the installation and later manage and operate the plant successfully.

Assessment should also be made of whether most of the consumers are willing or able to pay for the electricity. The technical and managerial capabilities of the community nominees may also be assessed. Conflicts or different views relating to the land on which the plant and its components are to be situated must also be discussed and assessed. The required level of income and tariffs and the types of tariff (fixed, metered, other) and their implications should also be discussed and conclusions drawn if possible. The advantages of having a significant net positive income that can be used to improve the plant and its services in the long run should also be explained. If appropriate, formation of a Users' Committee to look after the arrangements should be facilitated at this stage. Some suggestions or ideas from the villagers about industrial applications may also be discussed, evaluated, and finalised if possible.

It may be necessary to interrupt the survey or even recommend abandoning the installation plans if it becomes clear during the meeting that the capabilities or interest of the community are limited or serious conflicts exist about, say, water or land use. The meeting, for example, may become unruly or even break up.

3.6 Demand Survey

This survey is mainly concerned with the counting of households and other potential consumers (shops, lodges, offices, temples, schools, industry), who are ready to commit themselves to receive power and pay for it, and with calculating the total demand for power. The survey can be conducted before the comprehensive meeting or even before the reconnaissance survey, but it is better to take up this detailed work after the first decision to go ahead has been made.

The usual form of tariff for low-cost plants is a fixed rate based on power to be used or connected, with current limiting devices to ensure that the power used is kept within the limits. The power needs of each consumer are calculated in terms of the number of light bulbs or tube lights, radios, TVs , fans, and other pieces of equipment to be connected and their wattage rating. The forms shown in Annexes 3 to 7 can be used to record the power needs of customers (rounded up to the next highest 50 or 100 watts). Industrial uses discussed and agreed upon by the community may also be added. The figures are added together to give a final figure for the present total power needed, allowing for power losses in the transmission and distribution lines. This final figure is the minimum present power demand and, if the power potential of the site is significantly less than this value then the installation process would have to be abandoned.

If the plant under consideration is entrepreneur owned; then the power needs for electricity and/or agro-processing may be estimated in a similar way and the minimum power demand computed.

Usually, after discussions with the community, the figure for the power demand will be increased in order to cater to the needs for the immediate future (next 1-2 years) when other residents in the area ask for connections. An assessment of such future demand should be made and added to the minimum power demand to give the desirable power capacity of the plant. The additional future demand is usually between 10 and 50 per cent of the current minimum demand. The desirable power capacity should be taken as the rated power of the MHP plant to be designed and installed.

The survey of demand should be accurate and thorough, as it is not usually repeated at the time of the detailed site survey. If considered necessary, however, some reliable community members may be requested to carry out a more thorough survey later.

3.7 Preliminary Site Survey

The survey includes flow measurement when the flow is at a minimum (in the dry season); determination or selection of the head needed to generate the required rated power; flow measurement, land survey, and measurement of heights (heads),* slopes, and distances to locate the powerhouse, forebay, power canal, and intake so that the rated power can be generated. These surveys and measurements are described below.

3.8 Flow Measurement

The method of flow measurement to be used for a particular stream depends mainly on the volume of flow and whether it is turbulent or calm. Very few natural streams are non-turbulent, especially in mountainous terrain, except for smaller sections. The following methods are usually appropriate in the developing countries for measurement of flow of mountain streams.

1) The bucket method:	for flows up to 20 l/s.
2) The velocity-area method using a) a flow meter	for larger streams (flow> 20 l/s) with a depth of at least 10 cm at the deepest point
b) a float	for any volume of flow in a calmer (less turbulent) stream
3) The weir method:	for larger streams (flow> 50 l/s), a rectangular or triangular weir can be used.
4) The salt dilution method:	for all streams with smaller flows

* It is important to ensure that all height measurements are made using a completely vertical measuring rod or tape. A simple plumb line (a small heavy weight hung on one end of a string) can be used to check that the measuring line is vertical.

The following general rules should be followed.

- The location for the flow measurement should be chosen carefully so that the depth of the stream is adequate, measurements can be made easily, and flow is not diverted by being broken up into sections or seeping underground to rejoin the main flow somewhere downstream.
- The timing of the measurement should also be such that the flow is steady (not changing significantly) during the period in which measurements are made.
- It is useful to measure the flow by at least two different methods so that the results are more reliable. If the difference in the values obtained by two different methods is more than 20 per cent, something may be wrong. Either the flow is changing, or at least one of the measuring methods has not been performed properly.
- Flow measurement using a float is not very accurate and its use should be confined to the initial rough measurements.

The different methods of flow measurement are described briefly below. These descriptions should be adequate for surveyors who are already familiar with the concept of flow and its measurement. However, those who are totally new to the subject might find it difficult to make accurate measurements using the brief descriptions. Novices are advised to learn the methods from other experienced persons or, if this is not possible, to read more detailed textbooks on the subject.

3.8.1 The Bucket Method

This is a very simple and accurate method if the flow is relatively small (say <20 l/s). A bucket or other container of known size is used as a measure (Figure 3.1). All the water in the stream is diverted into the container through a pipe or a trough and the time taken to fill the container is measured. The flow, Q, is given by:

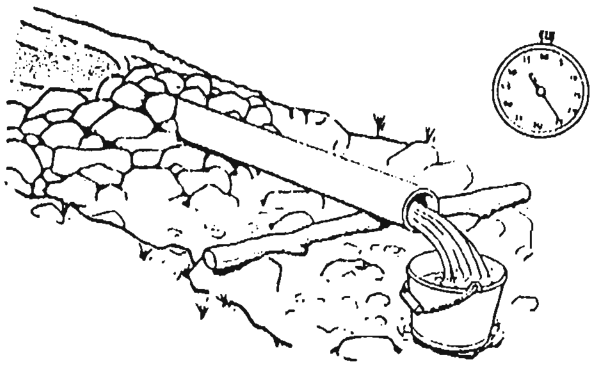

Figure 3.1: The Bucket Method

$$Q\,(l/s) = \frac{\text{volume of container in litres}}{\text{no. of seconds to fill it}}$$

Care must be taken to channel all the flow into the container. Usually, a dam is built around the pipe and the area is temporarily sealed with earth, plastic/rubber sheets, stones, or similar, to prevent leakage. If possible, in order to obtain reasonable accuracy, the capacity of the container should be such that it takes more than five seconds to fill.

3.8.2 The Velocity-Area Method

a. Using a Flow meter

This method is quite useful and reasonably accurate if a proper flow measuring instrument is available. The basic technique is illustrated in Figure 3.2. A suitable point is selected carefully along the stream; the cross-sectional area at this point is divided into different sections; the width, depth, and profile are used to calculate the area of each section; and the average velocity of each section is measured by a current meter (flow meter) held at its centre. The average flow is calculated using the general formula for flow, Q:

$$Q = \sum a_i \times v_i = a_1 \times v_1 + a_2 \times v_2 + a_3 \times v_3 + \ldots\ldots$$

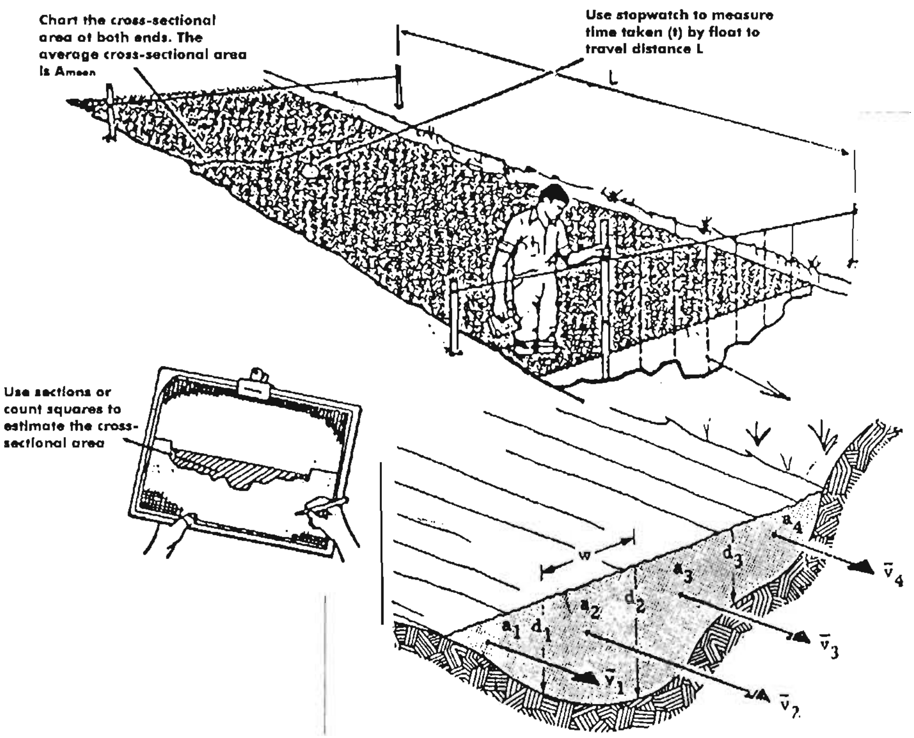

Figure 3.2: Velocity–Area Method Using a Flow Meter

The sub areas can be calculated as if the sections were trapezoid using

$$A = average\ depth\ (d)\ x\ width\ (w) = \frac{d_1 + d_2}{2}\ x\ w$$

or by counting squares on squared paper using an outline of the cross-section profile.

There are many types of flow/current meter available that are light and quite easy to carry (see for example Figure 3.3), although they are somewhat expensive.

An appropriate location must be selected, preferably along a straight and non-turbulent length of the stream. Both the stream bed and the width should be reasonably uniform and not covered with protruding materials such as rocks. The water should be adequate for most of the cross-section; and the mean depth should be at least 100mm, preferably more.

Elaborate instructions and tables are provided with the current meters to enable proper and accurate calculation of the velocity. The depth at which the rotor must be located is also specified. The preferred depth for many types of meters is 0.6 of the total depth of water at that point. Many meters are mounted on measuring rods so that the depth can be measured at the same time as the flow, and the rotor can be located easily at the requisite depth.

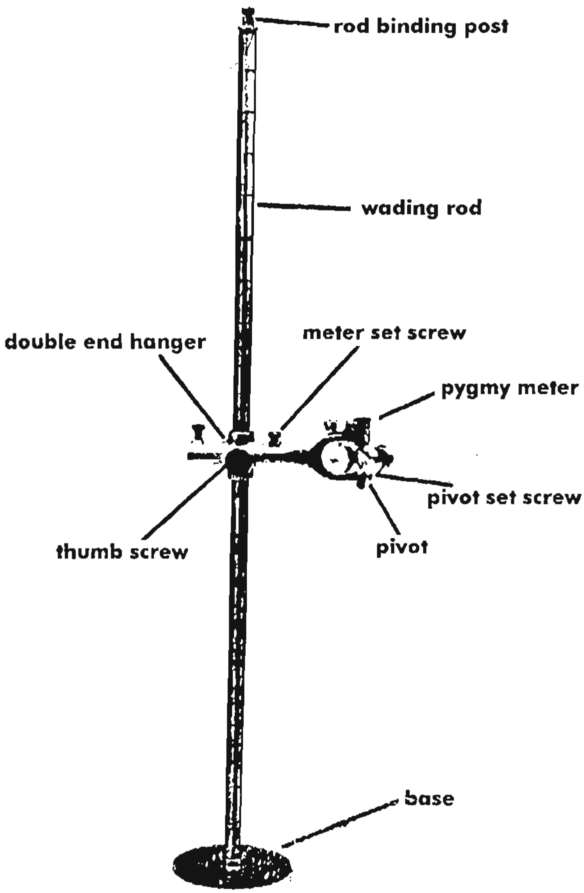

Figure 3.3: A Typical Current/Flow Meter

b. Using a Float

This method is similar to the above, but the flow is measured using a small floating object rather than a flow meter. The object chosen should float partially submerged in the water and can be a piece of light wood or a more elaborate, specially constructed float like those shown in Figure 3.4. The float is placed at the centre of the stream and the time taken for it to travel a certain distance (or the distance covered in a certain time) is measured. The surface velocity (V_s) of the water at the centre of the stream is given by:

$$V_s \text{ m/s} = \text{Distance travelled by float (m)/Time taken(s)}$$

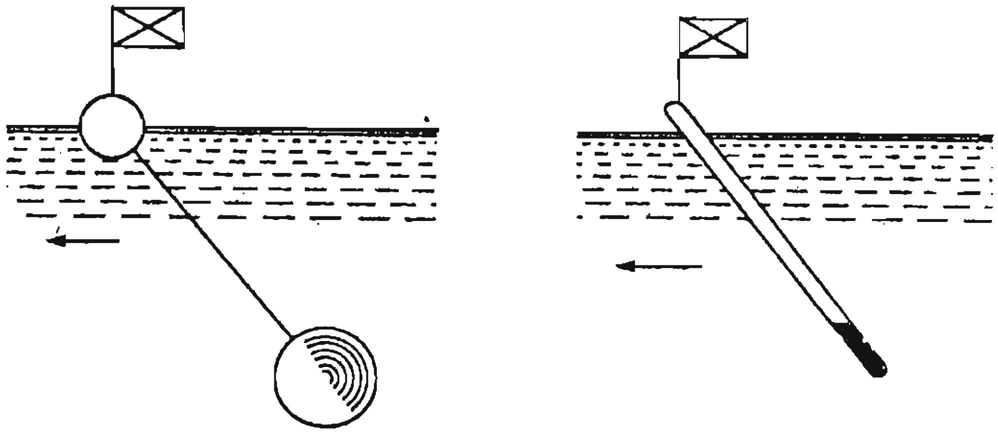

Figure 3.4: Some Proper Floats

V_s is not the average velocity of the stream since the water moves at a slower speed near the banks and the bottom of the stream. A correction factor 'C' needs to be introduced to determine the average velocity, $\overline{V}$, of the stream.

$$i.e., \overline{V} = C \times V_s$$

C varies between 0.4 and 0.95 depending on the conditions.

For example;	for shallow turbulent streams	C = 0.45
	for small regular streams with a smooth bed	C = 0.65
	for large, slow, clear streams	C = 0.75
	for large, deep streams with a smooth bed	C = 0.85

The cross-sectional area of the stream (A) is calculated by measuring the depth at different points along the chosen cross-section as explained in the previous section and Figure 3.2. The flow, Q, is then calculated as follows.

$$Q = \bar{V} \times A = C \times V_s \times A$$

The accuracy of measurements by this method may be quite low with a possible error of ±50 per cent, or even higher, and other methods of measurement should be used as far as possible. The accuracy can be improved through experience by comparing the flow measurements obtained using different methods and thus learning to choose the correct value for the correcting factor C.

3.8.3 The Weir Method

Many types of weir can be used to measure the flow in streams. The method of measuring, two different types of weir, and the equations used to calculate the flow Q, are shown in Figure 3.5. The most convenient weir is the rectangular type, mainly because it can be constructed from wood on site if an amateur carpenter is available. If the weir has been made properly, the flow measurement can be accurate within ±5 per cent. However, it is unlikely that this level of accuracy will be achieved in most practical situations.

This weir can measure flows of between 10 and 400 l/s. The length, L, of the weir should be at least three times the height of the flow h (see Figure 3.5). Furthermore, h should be large enough to be measured accurately (about 50mm or more) but not more than 0.5m. The following precautions need to be taken when measuring the flow.

- The crest of the weir should have a reasonably sharp edge
- The water flow over the weir should fall; i.e., the water level in the downstream channel should be considerably lower than the crest
- The crest of the weir should be at least 2h higher than the upstream bed.
- The crest should be as horizontal as possible so that the head, h, is constant along the length of the crest.
- The area surrounding the weir should be well sealed so that all flow passes over the crest.
- The head, h, should be measured as accurately as possible and the measuring rod should be installed at a distance of about 4h upstream from the crest (Figure 3.5)

Another useful weir is the 90° triangular notch (commonly called a V-notch, Figure 3.5). This is a more convenient measuring weir than the rectangular weir having just one dimension (90° angle). It needs to be produced accurately in a workshop, but it is more suitable for measuring small flows, and a small version can easily be carried to the site and fixed to wooden planks *in situ* for measurements of flows of between three and 300l/s.

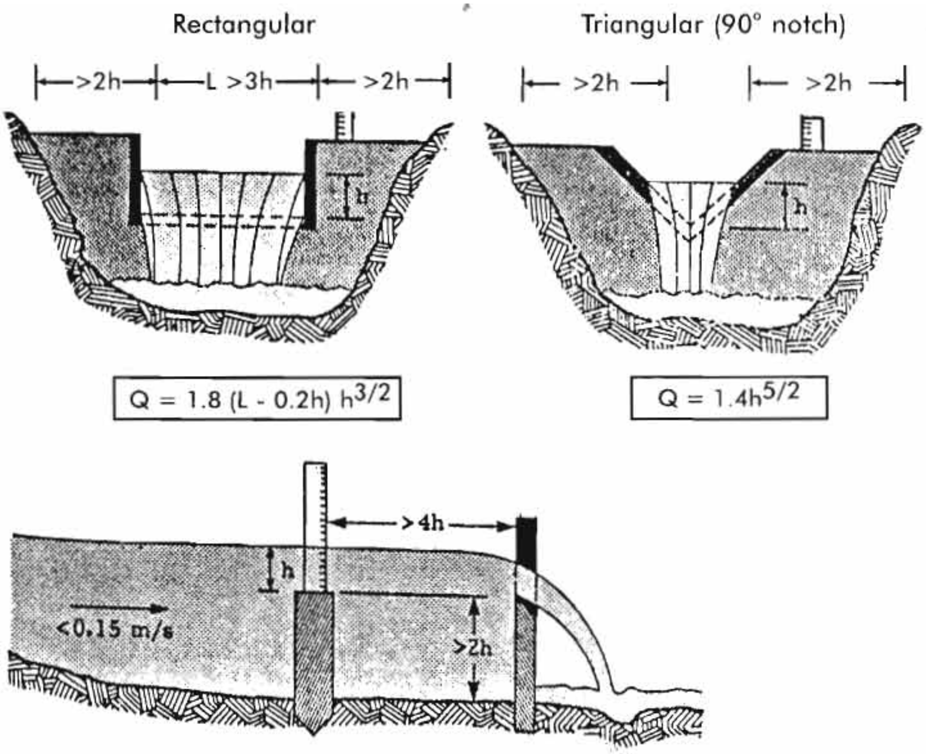

Figure 3.5: Flow Measurement Using a Weir

3.8.4 The Salt-Dilution Method

This method of flow measurement is proving to be quite convenient, accurate, and quick for small, shallow, and turbulent mountain streams. The way in which the measurement is made is illustrated in Figure 3.6. If the conductivity meter is well calibrated and the measurement is carried out properly, the accuracy should be better than ± 7 per cent; which is quite acceptable for MHP schemes. The meter used to measure the conductivity of the water is a small device that can be carried around quite easily. Such meters cost between 50 and 400 US$.

The method is as follows. A known weight of pure dry salt is completely dissolved in a bucket full of water. The water is mixed with the stream water as quickly as possible, but without muddying the water severely, at a pre-selected location. The probe of the conductivity meter is immersed about 30 - 50m downstream near to the bed and centre of the stream and conductivity readings are taken every five or 10 seconds. The readings will rise, reach a peak, and fall back to the base level, over a period of time. Usually two people are needed to take and record the readings.

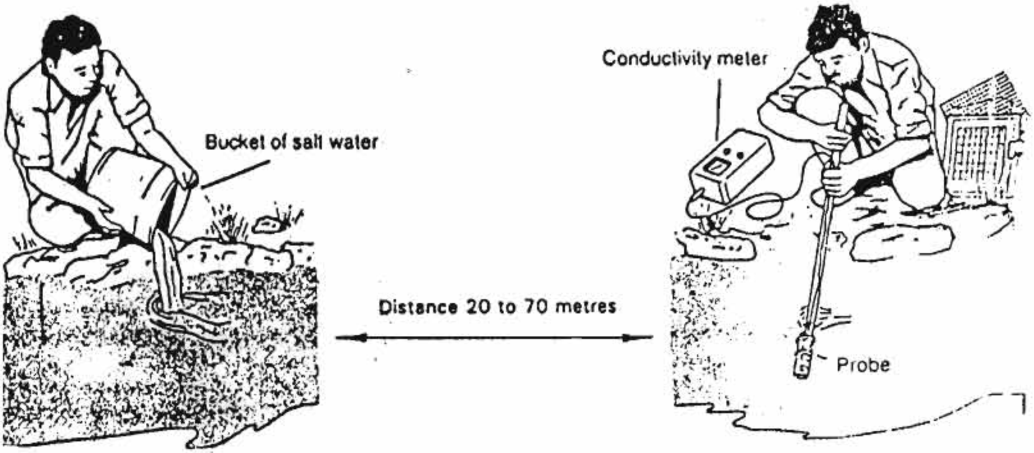

Figure 3.6: Flow Measurement Using the Salt Dilution Method

The readings are taken continuously until the conductivity values have returned to normal (which means that all the salt water has passed the probe). A graph of change in conductivity with time is plotted, and the area under the curves calculated (Figure 3.7). If graph paper is used, the area can be calculated easily by counting the squares. The temperature of the stream should also be measured. The flow, Q, is then calculated using the following equation.

$$Q\,(m^3/s) = \frac{Mass\ of\ salt\ (kg)}{Conversion\ factor\ k\ (kg/m3/ohm-1)\ x\ area\ under\ the\ curve\ (ohm^{-1}s)}$$

The conversion factor, k, depends on the temperature, and its value is given in the manual for the conductivity meter. More detailed instructions for flow measurement are also provided in the manuals.

The following points should be kept in mind when using the salt-dilution method and the conductivity meter.

- The curve should be smooth and have an adequate peak. It should not be distorted. If it is distorted in the way shown in the examples in Figure3.7, follow the instructions given to achieve a good curve.
- The measurement process should be repeated two or three times to achieve reliable results (if the results do not match, recalibrate the instrument or contact the supplier).
- An electronic integrator is also available which can calculate the area automatically when the readings are fed into it. However, this may be an unnecessary additional

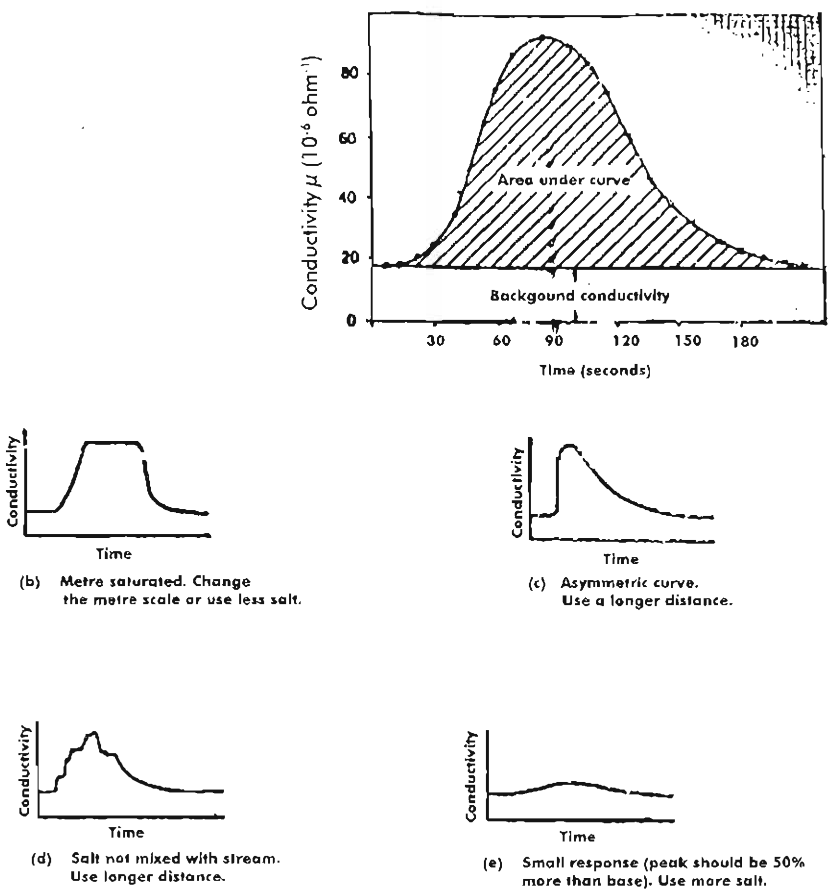

Figure 3.7: Typical Curves Showing the Change in Conductivity Over Time (The Ideal Curve is Shown, Together with Typical Distorted Curves and Recommendations for Corrective Measures)

expenditure if the measurements are not taken frequently. In any case the curve should still be plotted so that its shape can be checked.

- The method is suitable for small flows and fast streams. If the stream is too shallow or very fast then the results may be misleading. Therefore, a relatively calm section of the stream should be selected for measurements.
- Use about 100g of salt for every 0.1 m^3/s of flow.
- The distance between the place where the salt is added and the place where the probe is inserted should be between 30 and 50 metres.
- Sometimes a coefficient is written on the probe which must be applied to the equation to get the correct value of flow.

3.9 Determining the Head

As explained earlier, the final head is determined by the location of the powerhouse and the forebay, which also determine the route of the canal and intake. The surveyor should first calculate the value of gross head required from the simplified power equation; i.e., $h_g = P/5Q$ where P is the total power required, that is the minimum present power demand plus losses, and Q is the flow. The surveyor then starts by tentatively selecting a suitable site for the powerhouse and the forebay and measuring the height and distance between the two. If the height of the forebay above the base (floor) of the powerhouse is adequate, the ground is stable, and the route for the penstock is relatively short, he may then proceed to find a suitable route for the power canal and the site for the intake. If any of these conditions are not fulfilled, then he must look for a new site for the component in question and repeat the process for all the other components. He may have to accept a smaller or larger head than originally desired as a result of limitations on siting possibilities for the major components. Thus the process of 'determining the head' involves a lot of surveying including measurement of distances (both horizontal and along a slope), heights, and angles and bends. At the same time, the geological and other conditions of the selected locations must also be examined and evaluated to ensure that they are fit for constructing such structures and that no natural or human/animal damage will result.

Some experts suggest performing the process in reverse; that is selecting a suitable site for the intake first, then siting the canal, forebay, penstock, and powerhouse in that order. For this it is necessary to first have some idea of the area where the MHP plant and its components are to be located. This method may be more appropriate if the value of the head is not so critical. Whichever method is followed, it is certain that the survey and selection process will have to be repeated many times, selecting the location of one component, siting the others, encountering problems, starting with another location, and so on.

The necessary and desirable characteristics for the locations of each of the civil structures are described in the following sections.

Powerhouse and Forebay

- The powerhouse must be easily accessible and near to the consumption centres.
- An adequate area must be available for all the facilities and mechanical units proposed.
- The location must be firm and not threatened by landslides, falling stones, floods, or similar.
- The location must lie above the 50-year flood level of the stream.
- It must be possible to construct a tailrace easily to carry the water leaving the turbine to the stream.

- The requisite land for the powerhouse, penstock, and forebay must be available or easily acquired.
- (If cost is a crucial factor or only a small area is available, then for small plants for an electricity scheme the possibility may also be explored of constructing a robust portable structure to cover just the turbine and generator.)
- The location of the powerhouse and the forebay should provide the desirable head.
- As the penstock is an expensive component it should be as short as possible and its path should be straight and without serious obstructions (protrusions and depressions). Thus the slope needs to be fairly steep.
- The path of the penstock should also be on firm ground and not liable to slip as a result of heavy rains, landslides, or similar.

If both the available flow and the available head are more than necessary; then it would be advisable to increase the head and minimise the design flow. This approach reduces the cost of mechanical equipment and transportation. However, by increasing the gross head, the length of the canal will increase which makes it more vulnerable to damage, the length of penstock would also increase but the diameter will decrease.

Power Canal

The third site to select and survey is the path of the power canal from the proposed forebay to the intake. The considerations include the following.

- The path should be stable and not threatened by storm gulleys, landslides, falling rocks, or similar.
- The construction of the canal must be feasible and not too expensive.
- The path should not contain obstructions that would hinder construction, make construction expensive, or shorten the life of the canal (avoid, for example, a vertical or near vertical cliff, a large storm gully, or terrain susceptible to erosion or landslides). If such a situation exists, then the construction of the canal is seen as the most serious problem; and the best approach would be to select a suitable route for the canal first on any side of the stream and then select the sites for the intake, forebay, and powerhouse.
- Sometimes an aquaduct (covered if necessary to prevent damage from falling stones) or a pipe may be used for part of the route of the canal to cross a gulley or a depression (Figure 3.8). Similarly, the possibility may also be explored of building a canal or installing a pipe around a large rock or other obstruction (on the hillside), if the rock is in the way of the normal path of the canal. This approach would be advisable since in many situations it may not be possible to locate a terrain without any obstructions or other problems.

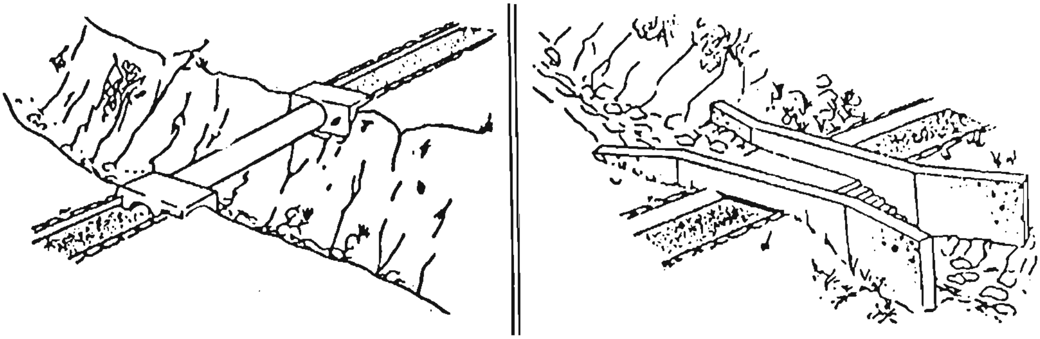

Figure 3.8: Different Choices for Parts of a Canal and Crossing

- Different types of construction for different sections of the canal may also be tentatively decided at this stage depending upon the geological conditions (extent of erosion, greenery, obstructions, and similar).
- Usually, the power canal should be constructed in such a way that only a minimum amount of rainwater enters it. To achieve this, a drainage channel should be provided wherever necessary and possible. In addition, more spillways may be provided at appropriate locations to prevent damage to the canal and forebay as a result of additional flow caused by rainwater.
- The canal path should have a small gradient. A gradient of two to four metres per km (1:125 to 1:250) is considered adequate for earthen channels. If the number of bends is large, or the cross-section is non-uniform over the whole length, then the gradient may be increased slightly to compensate for the losses and to ensure that the velocities in the canal are within the permissible range, as shown below for different soil types.

Type of Soil	Velocity Range
Sand	0.3 - 0.4 m/s
Sandy loam	0.4 - 0.6 m/s
Clayey loam	0.6 - 0.8 m/s
Clay	0.8 - 2.0 m/s

Intake

Some suitable and unsuitable locations for an intake are illustrated in Figure 3.9.

- Usually the site of the intake should be suitable to accommodate the construction of a weir downstream of the intake mouth.
- The intake should be sited at a place where the stream is relatively permanent; for example, flowing over bedrock and not prone to accumulation of silt.

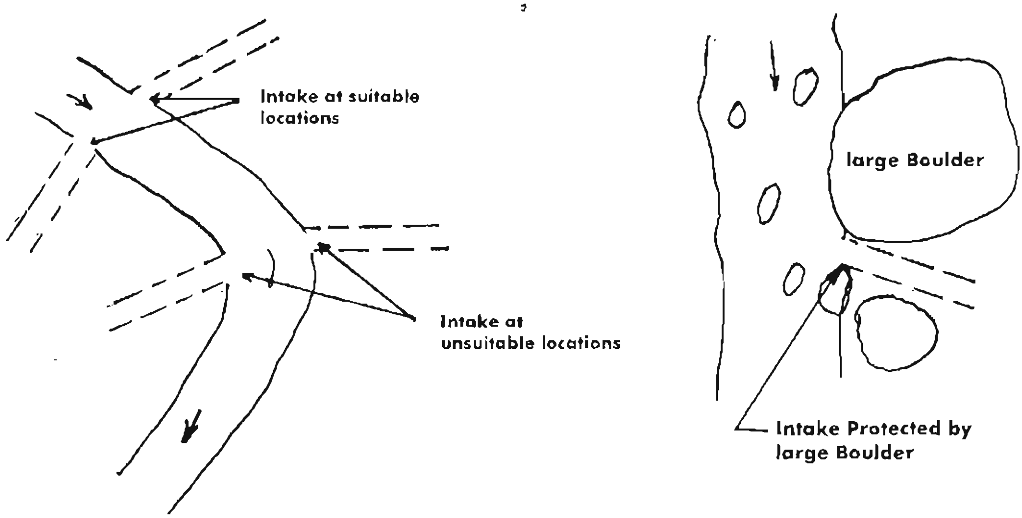

Figure 3.9: Suitable and Unsuitable Locations for an Intake

- The stream should not have a large gradient upstream of the intake.
- The stream should be relatively straight both upstream and downstream of the intake to avoid damage from sharply turning flood waters. If really necessary, the intake may be placed on the outside of a bend; but not on the inside. However, if the silt load in the stream is high, this may also be a problem.
- Sometimes the intake can be protected by locating it under or downstream of a large boulder.

Weir

Two types of natural and temporary weir are illustrated in Figure 3.10.

- A weir may not be needed if the inherent features of the stream automatically divert adequate water to the intake during the dry season (a natural weir).
- Sometimes, a temporary weir or partial diversion dam can be built for smaller schemes which is washed away during the high floods and rebuilt easily during the low-flow period when it is really needed (Figure 3.10b).
- Since considerable silt or gravel is likely to accumulate at the foot of the weir, it should be constructed about 50 metres or so downstream of the intake.
- A permanent weir can also be build from gabions, stone masonry, or concrete, depending upon the level of high flows and the amount of debris carried during such periods.

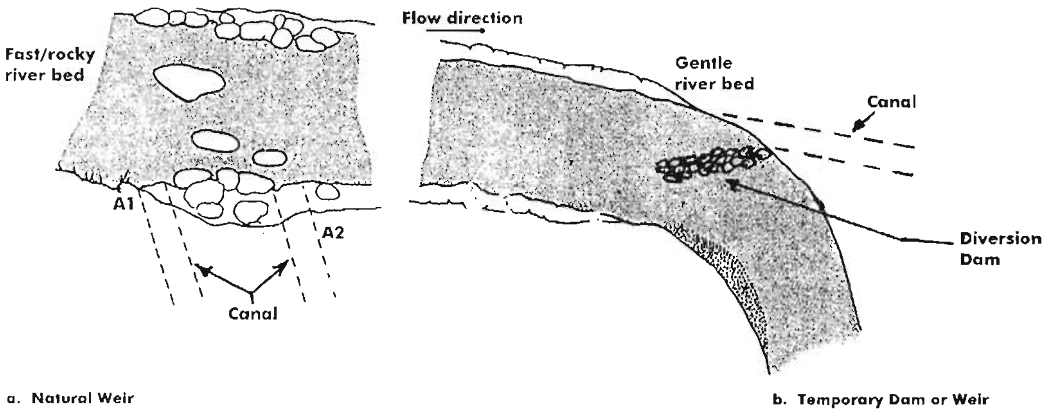

Figure 3.10: A Natural Weir and a Temporary Diversion Dam

3.10 Measuring the Head

Once suitable locations have been selected for all the civil structures, the available head and the distances between these structures should be measured. The head can be measured using one or two of the following methods.

3.10.1 Using a Clinometer (Abney Level)

The clinometer (also called an Abney level) is a smaller version of a line level and is used to measure vertical angles. If possible it should incorporate a range finder. It is used to measure the angle of the slope and this is used to calculate the gross head. The method is illustrated in Figure 3.11. The accuracy available from this rather small and cheap instrument is better than ± 5 per cent for measuring the head. The other equipment needed is a measuring tape (30m), two strong sticks of equal length (~1.5m long) and marking pins or pegs.

Procedure

1. Place one stick/ranging rod at the starting point of the survey, for example, the location of the turbine base in the powerhouse, and the second stick at the first intermediate point, less than 30 metres away.
2. Measure the straight sloping distance, L_1, between the tops of the sticks and record.
3. Place the Abney level on top of the first stick and sight the top of the second; turn the spirit level until the bubble is at the centre of the split eyepiece and record the measured angle a_1.
4. Move the first stick to the next location along the route of the penstock, preferably less than 30m away.

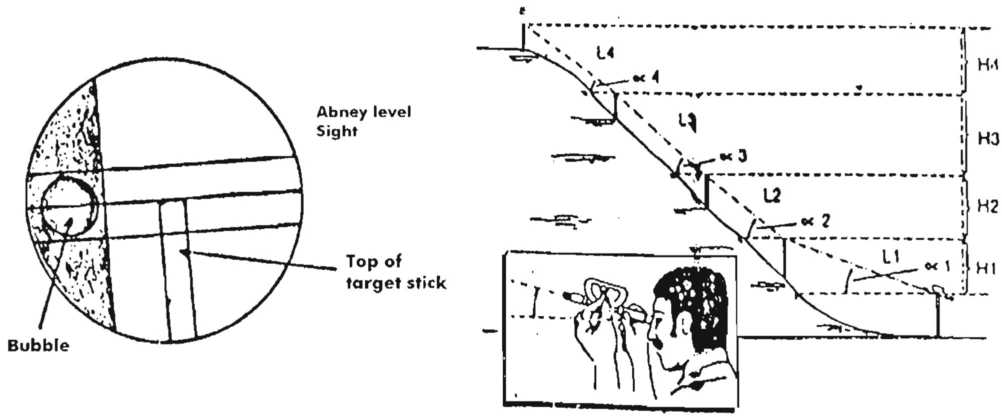

Figure 3.11: Measuring the Head with an Abney Level

5. Repeat operations 2 and 3 from the second stick aiming at the new position of the first stick; record the slope distance L_2 and angle a_2.
6. Move the second stick to the next position along the penstock and repeat operations 2-5, until the base of the forebay is reached.

Table 3: Sample Record Sheet for Abney Level Measurement

Positions	Distance between Positions (m)	Angle α between positions	$H = L \times \sin\alpha$	Remarks
1 & 2	$L_1 =$	$\alpha_1 =$	$h_1 =$	
2 & 3	$L_2 =$	$\alpha_2 =$	$h_2 =$	
3 & 4	$L_3 =$	$\alpha_3 =$	$h_3 =$	
Total head (m) $= h_1 + h_2 + h_3 + \ldots\ldots$				

3.10.2 *Using a Water-Filled Tube*

This is one of the simplest and cheapest methods for measuring small heads. The method is illustrated in Figure 3.12. The equipment needed is a 20m long, transparent plastic tube with a diameter of about 10-12mm, two graded rods, a measuring tape, and some marking pins/pegs. Usually, two people are needed to take the measurements. This method can be quite accurate if the surveyors are experienced. However, it should be repeated three or more times to ensure that no mistakes have been made.

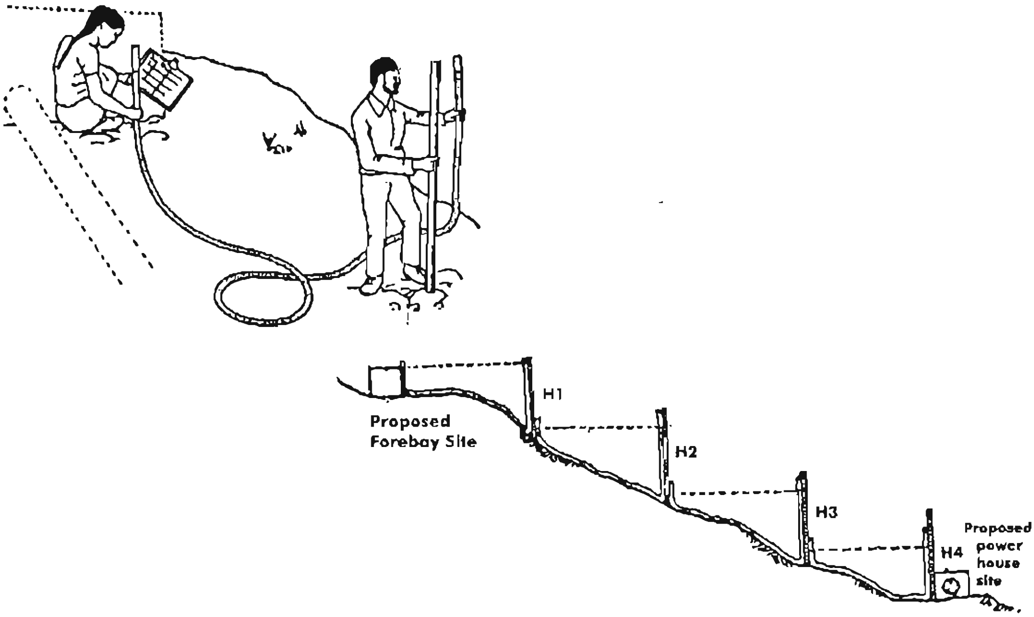

Figure 3.12: Measuring the Head Using a Water-Filled Tube

Procedure

1. Starting from the site of the forebay, fill the plastic tube with sediment free water. You should hold one end of the pipe while your assistant holds the other end, both about shoulder high. Remove all bubbles by stroking various parts of the uncoiled tube.
2. Ask your assistant to walk slowly down the hill along the path of the proposed route of the penstock; he should keep raising his end of the pipe while you slowly lower yours to ensure that water does not spill from either end of the pipe. The assistant should stop when your end of the pipe nearly reaches the ground.
3. Measure the heights of water in the pipe above ground level using the graded rods (h_1 and h_2) and the horizontal distance L_1. Mark both positions (1 and 2) with pegs and record all the readings on the record sheet.
4. Direct your assistant to stay in the same position and lower his end of the pipe while you move to a new position below him (position 3) along the penstock route, raising your end of the pipe until the water level reaches about head high at your end and nearly touches the ground at your assistant's end.
5. Read and record the new readings at positions 2 and 3, and measure the distance between the points along the slope. Record the readings.
6. Repeat the process until one of you reaches the base mark for the turbine.

Record Sheet for Water Tube Measurements					
Positions	1st height above ground	2nd height above ground	Difference h (m)	distance L (m)	Remarks
1 - 2 2 - 3 3 - 4					
Total			Head =	Distance =	

3.10.3 Using a Water-Filled Tube with a Pressure Gauge

This method is similar to the one described above but can be simpler, since an aneroid pressure gauge is used to measure the pressure and thus the head.

The procedure for the measurements is also similar, but the water height above the ground is only measured at the higher position, and a pressure reading is taken at the lower position. The record sheet is similar to that shown above except that the second entry for the height is replaced by a pressure reading, which is later converted into a height reading.

Some important points should be noted.

1. The pressure gauge should be frequently and properly calibrated in the office or *in situ*.
2. Air bubbles must be completely removed from the tube.
3. The measurements should be repeated two or three times.

If the surveyor can perform the water-filled tube method properly there is no need to use the pressure gauge method, which incorporates an additional instrument and which may be inaccurate.

3.10.4 Using an Altimeter

Conventional aneroid type barometers or altimeters are usually difficult to use and can be quite inaccurate. The new digital altimeters are easy to use and cheaper (~200-500 US$) and can be used for initial and rough measurements, especially for large heads (<100m). The method of measurement with an altimeter simply involves taking the readings wherever needed, say at the site of the turbine, the forebay, and the intake, and using the differences in readings to calculate the head, gradient, and other desired quantities. It must be remembered that the accuracy of readings is affected by changes in altitude atmospheric pressure, and temperature. Therefore, another more accurate method would have to be used to measure the height later. For this reason, altimeters are not very popular.

3.10.5 Other Methods

There are many other methods that can be used to measure the head and professional surveyors would have no problem using them. For example, a simple plank to which a spirit level has been attached can be used together with two graded rods to measure height differences between two positions. This equipment is heavy and cumbersome to use, however. Similarly, more accurate and expensive levels and theodolites can be used, but these require considerable practice and skill to master. Consequently, the Abney level and water-filled tube methods, which are fairly accurate, cheap, and easy to use, are probably the best methods for MHP schemes with heads of less than 100m.

3.11 Methods Used for Other Surveys

The other surveys to be carried out while visiting a prospective MHP site are distance measurements, both horizontal and along slopes, and land/area surveys that can be used to prepare or update sketches or maps for future use. The two dimensional (area) surveys also include measurements of distances, slopes, and angles; which have to be integrated to prepare two- or even three-dimensional maps and to calculate the lengths of such things as canals and transmission lines.

Distances are usually measured using tapes or 'chains'. The latter are sturdier than tapes in rough field conditions. Bends or turns can be measured on the ground or by using an optical instrument such as an Abney level. Some pegs or pins are also needed that can be driven into the ground to mark the various points (starting points, end points, intermediate points) from which distances have been measured and readings taken. The readings and markings are recorded in measurement books and reproduced on drawing sheets to prepare maps of the area. The maps may also include elevation readings such as topographic maps.

It is not possible to describe all the techniques for performing these surveys in a manual of this size. However, reasonable common sense and some prior familiarity with the equipment and methods should be sufficient to enable surveyors to take the measurements. For example, any one surveying should know how to measure a straight distance between two points, or to measure an angle between two straight lines using methods of geometry.

3.12 Examples

The following section provides examples of the way in which surveys are conducted, the design flow chosen, and the head determined in a hypothetical MHP project.

Example 3.1

A survey conducted to assess the demand concluded that at least 26kW power was required at present to meet the existing demands of about 200 interested consumers. However, there were about 75 additional prospective consumers who, if eventually connected, would need additional peak power of 8kW. The flow measurement indicated that 180 l/s water was available during the dry season; it was learned that the flow can fall below this value in some dry seasons. Discussions with the community members indicated that a minimum of 30 l/s must be allowed to flow in the stream at all times and not be diverted for the MHP plant.

The following decisions need to be taken at this stage.

What should the design flow be; and what is the minimum and desirable head?

Decision Methodology

Design Flow. The measured flow is 180 l/s from which 30 l/s need to be deducted. Thus the design flow (Q_d) should be 150 l/s, or lower as the flow may decrease even further during some dry seasons. Some of the options available are as follow.

a) Use the available figure of 150 l/s and be prepared to accept lower power for one or two months in some dry seasons in future.

b) Wait for further surveys to see if a higher but viable gross head (h_g) is available so that the flow can be reduced easily while still achieving the power required from the higher head.

c) If the survey of demand and discussions with the community indicate that it would not be a serious problem to accept less peak power (less than the required value but equivalent to or higher than the minimum value) during the three to four months of the dry season, an even higher value of flow, say 180 l/s, could be selected for Q_d (but it would not be advisable to go higher than this value).

The Minimum and Desirable Head

The minimum (acceptable) power, P; is 26kW, and the design flow, Q, is taken as 150 l/s, i.e., 0.15 m³/s. The minimum desirable gross head h_g is given by:

$$h_g = P/5Q = 26/5 \times 0.150 = 34.7 \text{ or } 35 \text{ metres}$$

This simple equation should incorporate all the losses (including the head loss).
If a lower flow value, for example 120 l/s, is used then

$$h_g = 26/5 \times 0.12 = 43 \text{ metres}$$

If the desirable value of power is used then

$$h_g = (26+8)/5 \times 0.12 = 57 \text{ metres}$$

Therefore, the maximum head that would be needed is 57 metres, and the minimum acceptable head would be 35 metres.

Although some idea about the available head might have been gained during the reconnaissance survey, a good decision would be to complete the preliminary survey to determine the head range that is easily available without having to extend the canal too far.

Example 3.2

The preliminary survey of the site has revealed that, with the given location of the powerhouse, there are two possible locations for the forebay and other allied upstream structures, including the canal and the intake. The two possibilities give:

i) h_g = 32m, the length of the penstock is 48 metres and the length of the canal is about 650 metres; and
ii) h_g = 48m, the length of the penstock is 73 metres and the length of the canal is 1,100 metres.

How do we go about deciding the design flow and design gross head?

Decision Methodology

It appears to be inadvisable to shift the location of the powerhouse because the land is easily available and accessible. The location is also suitable for extending the transmission lines and disturbance to the surrounding lands is minimal. Thus the main decisions that need to be taken are the values to use for the head and flow.

For most practical purposes it is useful to have a high head and low flow. This would suggest choosing the second possibility with a head of 48m. But the canal for this option is too long. Using a design flow of 120 l/s (the most suitable value), the power from the second option would be:

$$P = 5Q\,h_g = 5 \times 0.12 \times 48 = 28.8kW$$

It might be advisable to re-survey the route of the canal to judge whether such a long canal would actually be sufficiently stable in the long run. The geological conditions might also be investigated to ascertain whether there could be any possibility of slip, excessive run-off (rainwater flow) from the top, or other such problems. If the canal route is fairly safe and if any minor vulnerable sections can be stabilised using concrete or good retaining walls, then this choice might be made.

If the canal site appears vulnerable, then the first option should be examined. The desirable flow value of 120 l/s would not give the required power with this smaller head. The power ,P, with a flow of 150 l/s would be

$$P = 5 \times 0.15 \times 32 = 24kW$$

Thus the available power is still not adequate and we would have to consider whether to accept this value for the power that is not much lower than the minimum needed (26kW). The plant can still be designed for a higher output, say 30kW; which it would be able to generate for six to eight months of the year; but the consumers would have to accept having less power for the remaining period. It is clear, however, that the chances of increasing the power supply in the future are slim. One suggestion would be to have a meeting with the communities/recipients and discuss both options; particularly the last, and arrive at a consensus through discussions. It might even be necessary to have two meetings, one at a later date. The aspects to be determined should be considered in the following order.

1. Pursue the first option of using $h_g = 48m$ and investigate the canal more thoroughly to assess its suitability. If the site is not judged to be suitable, then
2. the option of generating 24kW should be examined in more detail and discussions held with the communities to discover whether they would be happy in the long run with this low value of power. If this was not possible; then
3. consider the third option of installing a larger (~30kW) plant and accepting less power for a few months. Again the community should be encouraged to decide after identifying the possibilities and discussing the implications.
4. If this last option is not acceptable to the community; then the recommendation from the surveyors should be not to go ahead with the installation.

Note. This example was deliberately presented in this way to illustrate that such surveys and the ensuing decisions are almost never straightforward or just a problem of simple mathematical calculations.

3.13 Survey for the Transmission Lines

After the location of the powerhouse has been fixed (and is not likely to be changed), a survey should be carried out to fix the route of the transmission lines and measure their lengths. This survey mostly involves measurement of distances and sometimes heights if hills are to be crossed. The main figures to be calculated are the lengths of the wires to be installed and the numbers of other allied equipment such as poles, insulators, and lightning arresters.

The figures for the lengths will also be used when calculating the costs.

The following points should be kept in mind when designing the layout for the transmission lines.

1. Ideally, the transmission lines should travel along straight lines to minimise costs and avoid lateral loads on the poles. This is rarely possible, however, especially as it may be necessary to avoid such things as patches of cultivated land, a group of trees, or houses. Still, the basic principle should be to avoid bends and diversions as far as possible.
2. If the lines are to pass through areas of cultivated land, the poles must be located on the banks between two pieces of land so that they are relatively safe and farmers' lands are not affected.
3. Crossing of the transmission lines through thick forest should be avoided, if really necessary then the path of the lines should be cleared of trees.

3.14 Preparation of Sketches

During and after completing the survey, it is necessary to prepare sketches of the area for reference as well as for the future work of survey and installation. It is also advisable to mark the locations of the sites on the ground with pegs or other such materials. The sketches will have to be improved later and proper drawings prepared. It is desirable to prepare the following sketches.

1. An overall sketch of the area (say on a scale of 1:10,000) showing the relevant portion of the stream and the nearby beneficiary settlements. The distances between the main features should also be included. Some heights may be mentioned, but detailed contours are not needed. An example is shown in Figure 3.13.
2. A more detailed sketch of the MHP location which includes the powerhouse, penstock, forebay, power canal, intake, and relevant portion of the river. The scale should be around 1:1,000. The contour lines traversing the main components should be shown together with the altitude values if possible. Otherwise, only the altitude values (absolute or relative) may be shown for the main locations and important sub-locations.

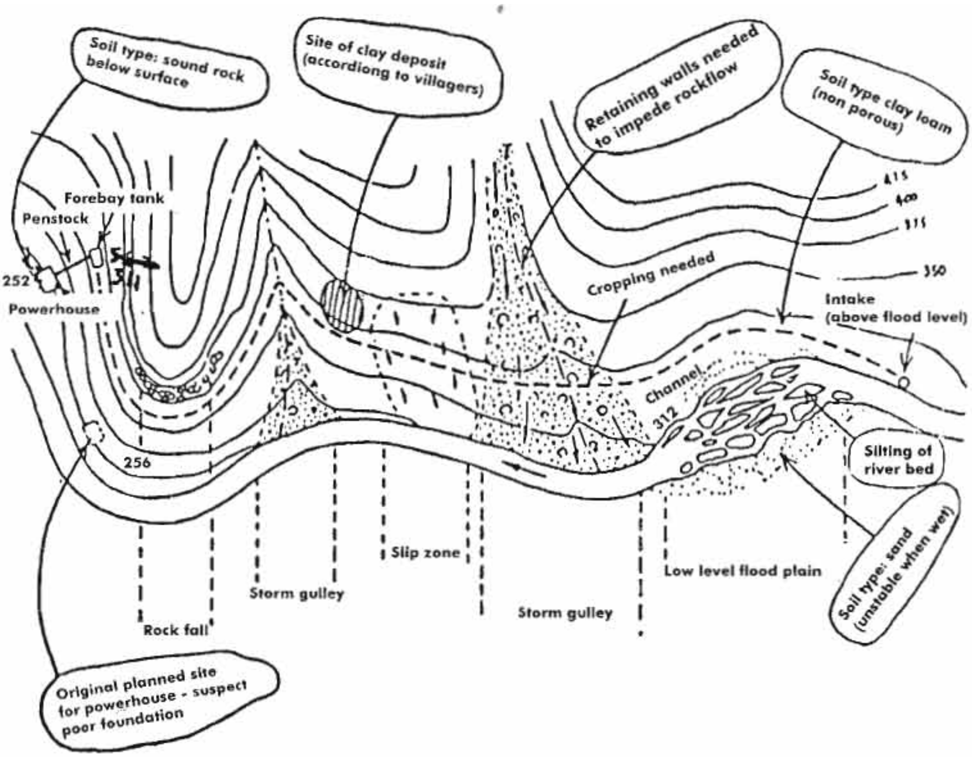

Figure 3.13: A Typical Sketch of the MHP Site and Settlements

3. The results of the survey for the transmission lines should also be shown, either separately or superimposed on the first sketch. It is desirable to have a separate sketch since the transmission lines are affected by land and topographical features such as cultivated land and the boundaries between fields, forest, and high intervening hills. The lengths of the transmission lines can be written next to the relevant lines.

   If possible, these sketches should be redrawn to give drawings of reasonable quality so that they can be used later for detailed survey and installation.

3.15 Organizing a Second Meeting

After most of the survey has been completed, and some rough calculations of the power potential and rough estimates of the costs made, it would be useful for community-owned projects to have another meeting with most of the members of the community. Participation in the meeting should be as full and have a wide a range as possible. Participants should be informed about the costs, possible problems or shortcomings, and possible end uses. It would be useful to facilitate the formation of a Users' Committee at this time. The points to be covered include the following.

- Describe again the work involved and the responsibilities, duties, and possible problems to be faced by the communities in the management of the plant.
- Prepare and agree upon a draft of an agreement between the community and the sponsor(s).
- Discuss the possibility of other end uses, including agro-processing, saw mill, and workshops, with the aim of using power during the daytime off-peak period. Adequate information should be provided on the costs, power needs, and methods of operation and maintenance for, and possible incomes from, such machinery. If electricity is to be the main output of the plant, it may be more beneficial and even cost-effective to use electrical motors situated at convenient locations to drive the industrial units.
- Identify key persons/leaders of different communities/groups for further consultation in future.
- Discuss further the other uses of the water (present as well as future ones) and assess any signs of conflict or differences of opinion. Try to assist in resolving such differences.
- Discuss tariffs for domestic, commercial, and industrial uses and put forward suggestions.
- Work out some initial figures for incomes, expenditure, and net incomes for the benefit of the users/owners.
- Inform the users how such incomes could be used in the best interests of the plant, its services, and its benefits to the community.
- Facilitate the formation of a User or Management Committee with a few members (about five); comprising those who are most interested in and informed about the installation and operation.

The main objective of the meeting is to motivate the community and make them aware of the benefits of the MHP plant, as well as the effort, organization, and hard work that will be needed to make it a success.

3.16 Other Aspects to be Covered During the Preliminary Survey

A number of other aspects should be considered, surveyed, assessed and/or analysed so that conclusions can be drawn or opinions formed about the probability of success of the plant (in terms of such factors as income, service, and long-term performance). These aspects include the following. They mainly apply to community owned or managed plants, but some aspects are also relevant to entrepreneur owned plants.

Assessment of the Community

The community needs to be assessed with regard to the following.

- How keen most of the community members are for the MHP and electricity; and their willingness to actively support and work for the survey, installation, etc of the plant. As discussed earlier, ideally the community members or leaders should themselves initiate any efforts to install a plant in their area. Sometimes, however, the promoting agencies may also initiate activities leading to a possible installation. In both cases, but more so in the second case, the communities and their leaders have to be motivated to provide assistance and contribution right from the beginning. The interest of the communities and their leaders in supporting and contributing to the installation is an indicator for the likely level of success of the plant after it comes into operation. This assessment should be made more or less informally through dialogue, discussions, and meetings. The level of support and assistance provided during the survey is another indicator of the general level of enthusiasm for the plant.
- Conflicts within the communities and/or between different communities; and whether the different groups would be able to collaborate with each other. Other uses of water such as for irrigation, washing, and drinking, should also be examined and opinions formed. Similarly, there may be differences of opinion regarding the use of the land for the powerhouse, channels, and other components. The main concern is whether one or more communities would be able to work together to make both the installation and the operation of the plant a success.
- Potential within the community (or of certain members who need to be identified) for business sense, management, and technical operations. Questions should be asked about business experience (keeping shops/lodges, buying/selling agricultural commodities) and about technical experience related to water mills (*ghatta*(s)), diesel mills, transport, or other machinery. These investigations should be helpful for identifying prospective operators or even managers. The assessment should also be undertaken, mainly through discussions with shop owners, traders, and community leaders.
- The various discussions may also be formal, but more authentic information can usually be gathered through informal discussions in tea shops or other social places with different people.
- Finally the capability of the households to pay the initial installation charges, including the wiring from the pole to the bulbs within the houses, should be assessed. These charges may be as much as a few thousand rupees. Clearly, there will be many families who would find it difficult to pay for the connection immediately. However, the main point to discover is whether a large proportion of the potential customers (say 70 per cent or more) falls into this category, since this would indicate a serious problem. During the survey of the households, some idea should be obtained about total incomes (particularly cash incomes) and a figure arrived at as to how many customers

would ask for connections immediately after the powerhouse begins to supply electricity.

3.17 Environmental Aspects of an MHP

A small-scale run-of-the-river type MHP plant installed in a remote area is probably the least harmful option environmentally for providing power to a community. This includes construction, operation, and the materials used for construction. Nevertheless, some negative environmental impact is possible; especially if the plant is not properly designed or installed. Most potential problems relate to flow of water from the stream to the forebay through the canal, or to the powerhouse through the penstock. The following possibilities should be investigated and precautionary measures taken.

- Seepage of water from the canal, forebay, or penstock can cause damage to downstream lands or houses, or lead to erosion and/or landslides. Such seepage should be minimised and a drainage system provided wherever possible.
- Breaching of the canal could cause more serious damage in a short time to land or crops. Proper design and construction of the canal is again the answer.
- Since the flow in such channels is usually quite low, the damage is almost never excessive. Equally, the villagers/communities are capable of repairing any damage quite quickly. Nevertheless, it would not be good if a canal were to break down frequently. Thus the design, construction, and maintenance should be adequate.
- It may be necessary to cut some trees or bushes to construct the powerhouse, the civil structures, and the transmission lines. Although this damage is never extensive or even significant, care should be exercised to fell the minimum number of trees or bushes; and to choose the route for the canal and transmission lines accordingly.
- Some minor environmental problems may be encountered if the flow in the original stream becomes very low or it dries up completely. Although the dried up portion of the stream may be of a very short length, usually less than one km, it may be inconvenient for people who use it for drinking and washing. The riverine life may also be adversely affected. The following precautionary measures are advisable.

    - A minimum prescribed flow should be left in the stream even if this means reducing the power output.
    - If it is necessary to divert most of the water for power generation, a study should be made of whether the effect on fish or other important riverine life would be severe.
    - Find out how many people/families take water from the dried up portion of the stream for their normal daily needs; and whether they would face difficulties.

3.18 Financial Analysis and Viability

When the preliminary surveys are complete and the layout has been finalised, the costs, both capital and running costs, should be calculated[1].

All costs must be included: the electro-mechanical equipment; civil works, construction materials, labour, transportation, tools, spares, and so on. The expenditures for which cash payment must be made should be listed separately from contributions or acquisitions in kind such as free labour, free construction materials, free land, and so on.

The running costs should mainly include the salaries of the manager and operators, consumables and spares (grease, brushes for generator, bearing set), and cleaning and maintenance of the canal and civil works.

An attempt should then be made to estimate the income from the sale of electricity to various consumers (domestic, commercial, social/services, industrial). The net income can then be calculated. The minimum acceptable net income for entrepreneur owned plants should be 20 per cent of the capital investment (simple payback period 5 years or less)[2]

Such high incomes are usually not possible for community-owned and managed plants which are mainly intended to generate electricity for lighting and other domestic uses (such as radio and TV). A net income of about five per cent of the capital would usually be considered satisfactory and viable for such plants, and the income would mainly be used for major repairs and replacement of parts. However, if a loan is to be repaid, then the yearly installment should also be included in the running expenses and the tariffs must be fixed so that the cash income is sufficient for the loan repayment and to provide a net income.

It should be made clear to everyone concerned that the figures are only estimates; and the actual expenditure and income may differ considerably from these. The more experienced and qualified the surveyors and estimators are, the more accurate the estimates will be.

1 It is not necessary or even convenient to make all these calculations on the site. This can be done in the office. However, it is necessary to pass on these figures to the community or entrepreneur as soon as possible to assist them in making decisions and arranging the required funds.

2 Some experts have suggested fairly complex mathematical methods for financial analysis. While these methods may be necessary or useful for large investors/plants, they are usually beyond the capacities of ordinary local entrepreneurs and are of little use to them.

It should be emphasised again, that an effort should be made to use the maximum amount of energy available from the plant to give an increased income without any additional investment. Possible end uses and industries should be discussed with the entrepreneurs or community leaders. An extra effort will be needed to collect and provide information about such things as equipment, costs, operational techniques, training available, and income estimates. Prospective entrepreneurs may also need information about possible sources of funding and procedures for getting loans. All these additional but necessary efforts are worthwhile for the promoters since they can lead to increased financial viability of the plants and a good name for this environmentally friendly energy source for inaccessible and underdeveloped mountain areas.

3.19 Survey or Feasibility Report

The final outcome of the site visit, surveys, and assessments is a feasibility or survey report which includes the data, sketches/drawings, results, estimates, and conclusions. This report may be prepared at the site or in the office after returning from the site, and the final findings and conclusions should be about whether the plant is viable technically, financially and/or in terms of service. Almost all the information and data that have been collected should be included in the report.

A typical report would include the following.

- Location and description of the project area
- Economic situation and social conditions
- Description of site including settlements, population, households, and shops (include sketch/map)
- Main communities and lead persons
- Survey of demand: data-analysis, estimate of power demand (minimum and desirable values) including possible and committed industrial end uses
- Reconnaissance survey and results (include sketch/map)
- Results of meetings and discussions with entrepreneurs and community members/ leaders. Results of assessment (keenness, capabilities, cooperation, conflicts, economic and technical abilities)
- Preliminary survey and results of
    - flow measurement
    - geological aspects/problems
    - layout survey and head measurements
    - location of civil structures and sizes (head, penstock length, forebay size, canal length, intake size and type/structural details, weir type and size), include sketches/ drawings

- Specific features or problems of the site/layout
- Is desirable or minimum power available? comments and recommendations on whether to go ahead
- Other important aspects, for example water uses, environmental aspects, and social conditions and suggestions (for example funding to provide cheaper connections to poorer families)
- Survey for transmission lines, distances, sizes, losses
- Costs, incomes, and financial analysis
- Conclusions and specific suggestions

Although there are many topics to be covered, it is advisable to make the main report short (less than 20 pages). Some forms completed during the survey and other papers can be included as annexes. The data in the Initial Inquiry Form can be corrected and provided in some way and other sketches and tables and such like also included if necessary.

If the constraints on size permit, a few photographs of the site, especially those identifying locations of civil structures, should also be included in the report.

CHAPTER 4
Detailed Site Survey

4.1 Justification and Objectives

The preliminary survey discussed in Chapter 3 should indicate whether an MHP scheme is technically and financially viable. The main purpose of the preliminary survey is to determine the power available from the proposed scheme (i.e., the head and flow available), fix the locations of the major structures, and estimate the project costs. For MHP schemes in the lower range (installed capacity less than 20kW), this preliminary survey, which might have been prepared in more detail, is usually adequate for the design phase. For schemes with an installed capacity exceeding 20kW, however, a second more detailed survey is essential since more and more precise data are required. This second survey is the detailed site survey. The reasons why an additional detailed survey is needed for larger MHP schemes are as follow.

- A large investment is involved; therefore more accurate survey data should be collected to authenticate previous results.
- Components such as lengths and bends for mild steel penstock are pre-fabricated at a workshop. If the survey work is not accurate enough they will not fit the site leading to increased expense and delays.
- If the ground slopes and other technical parameters are not measured with sufficient accuracy, the construction of the civil structures may be problematic.
- Inaccurate estimates of the flow and head may result in under or oversizing the plant.

It is very important to involve the entrepreneur or the community members/ leaders/ beneficiaries in the planning process for their plants. It is the entrepreneurs or the community members who will operate and manage the schemes, thus they need to be involved in the decision-making process from the beginning. Furthermore, disputes about such things as a headrace route traversing a farmer's field are more likely to be resolved amicably if all people have been involved in the planning process.

There should be a gap of about two to three months between the preliminary and detailed surveys; such that the detailed survey can still be undertaken during the dry season. If possible, the gap should be about a year to include one monsoon season so that any changes at the site such as signs of slope instability and flood levels can be observed.

The detailed site survey of an MHP scheme includes the topics described in the following sections.

4.2 Flow Measurement

In Nepal, the minimum discharge usually occurs during mid-winter (early February) in streams that have a significant flow from snow melt, and just prior to the pre-monsoon rains (April-May) in streams that originate from spring sources (in other HKH areas the time of minimum discharge may be different.) If the site visit for the detailed survey is made during the low flow period, then the minimum discharge available for the proposed MHP scheme can be determined without further hydrological analysis.

During the site visit, the flow should be measured by at least two different methods, either those described in Chapter 3 or more accurate methods if possible. If visual inspection of the flow indicates that it is less than 20 l/s, then the bucket method would be accurate and reliable. For flows above 20 l/s, one of the two methods used should, if possible, be the salt dilution method with a conductivity meter. If the conductivity meter is in good condition and properly calibrated it can measure flows very accurately. The flow measurements obtained using a conductivity meter should be checked independently using another method such as the weir method or a current meter. This is because it is easy to make mistakes with the conductivity meter and the equipment can also malfunction at the site. For example, improper calibration or salt that has impurities can produce different flow results. Similarly, if the voltage of the batteries drops, the measurement will be grossly inaccurate.

It may be possible to use the weir method during the detailed site survey if a suitable location has been identified during the initial survey and the surveyor has measured the width of the river at the measurement site.

It is recommended that the surveyor undertakes flow measurements at least twice each time and on two different days. If all measurements are consistent, then the average figure should be used. If one set of measurements is significantly different then the reason for this should be sought, for example heavy rainfall during the previous night or low voltage of the conductivity meter. If a reasonable explanation cannot be found, then further measurements should be undertaken until the results become consistent. Consistent results on two consecutive days using two different methods is the best indication of accurate and reliable flow measurement. The float method is not recommended for detailed flow measurements.

The flow measurement results can also be verified subjectively at the site through discussions with the local community members. They are familiar with the flow conditions of the river. The following questions can be used as guidelines while discussing low flow conditions with local community members.

Low flow questions

- Is this the least flow (water level) or does it decrease further? If so by how much? One-third of the present level? Half the present level?
- Has this been a normal year or an exceptionally wet or dry year?
- What is the lowest water level that you have observed at the proposed intake area and how many years ago was that?

Although, it is not generally necessary to determine the flood flows of the source stream, the flood levels are important, especially at the intake and the powerhouse sites. Structures (such as the orifice and trashrack) that are below the flood level can be damaged or washed away during the annual flood. If the flood level is known, then permanent structures can be located safely above this level.

The annual floods deposit sand/silt particles on the river banks and wash away the vegetation. Observing the level of such deposits and such changes will indicate the annual flood levels. If there is exposed bedrock along the river banks, then the colour above and below the flood level on such rock is different. It is usually darker below the annual flood level.

Local community members are usually familiar with flood conditions and therefore the site observations can be verified by discussions with them. The following questions can be used as guidelines when discussing flood conditions with local community members.

Flood flow questions

- How high was the flood level at the proposed intake site during the last monsoon?
- What is the highest flood level you have observed at this site in the last 20 years?
- What is the highest flood level that you have observed in the last 20 years at the proposed powerhouse site?
- Does the river carry large boulders during the annual floods? What is the largest size of boulder that the river can move during the annual floods?

4.3 Optimising the Location of Civil Structures

Before undertaking the site measurements, the surveyor should inspect the proposed locations and routes a few times and verify that the layout selected during the preliminary survey is indeed optimal. Changes such as relocation of structures should only be made if they are found to be necessary in the light of new observations. For example, if the headrace canal or penstock routes appear to be unstable or have been swept away by landslides, then they will have to be relocated. Similarly, the recent monsoon flood levels may indicate relocating the intake and the powerhouse structures. Flood issues have been covered in the previous section.

4.3.1 Site Stability

It is essential to have some understanding of slope stability to identify possible problem areas so that the proposed scheme can be safely located. If a geological map of the project area is available, the surveyor should take it to the site. Usually the scale of such geological maps is too small to cover the details required for the MHP project, but they can provide a general understanding of the area.

Locating all MHP structures on stable ground will keep the design simple, lower construction costs, and minimise future risks from landslides or other instability problems.

The presence of any of the following features may indicate unstable slopes.

- Widening of landslip zones that may affect civil structures
- Widening or deepening of storm gullies along the route of the canal and penstock
- Cracks along the ground slope (also known as tension cracks); the ground downhill of the crack line is liable to slide
- Trees leaning downslope or bending upwards from the base — This indicates that the hillside is moving
- Water springs or seepage at the base of a slope — These can cause slides on the slopes above if the drainage path is blocked
- Fresh rock faces exposed on a cliff — These indicate falling rocks that can damage the headrace or penstock routes below
- The presence of soft, weatherable rock — This can easily erode during the rains.
- Open joints or cracks in rock
- Overhangs and loose rock
- Fresh debris and stone deposits at the base of a slope
- Exposed tree roots indicating surface soil erosion
- Steeper profile at the base of a slope
- Dead or overturned woody plants and grass clumps

The following features along a hillside or rock face indicate a stable slope.

- Presence of complete vegetation cover
- A straight and even slope profile down the hillside
- Rock surfaces covered with moss or lichen, or having a weathered skin

- Hard, impermeable rock with few joints or cracks
- Well-packed debris, especially with fine material packed into voids between coarse material
- Well-established trees and shrubs standing vertically
- Stable storm gullies

Slope instability is often triggered by surface or groundwater flow. Surface water and springs can be diverted from the civil structures by constructing catch drains along the canal and penstock routes. Landslides are less likely to occur on a dry slope than on a saturated one. Therefore, if instability problems are expected as a result of surface or groundwater, the locations and proposed alignment of the catch drains should be noted while at the site. Catch drains are small canals that divert surface water (resulting from rain, for example) away from the structures and keep the slopes relatively dry.

During the detailed site survey, signs of slope stability (or otherwise) should be investigated in the following key areas.

- Above, and below the proposed headrace and penstock routes
- Below the proposed location of a settling basin or a forebay tank
- Above and below the proposed location of the powerhouse

Instability in these areas can weaken the support around the foundations through land slipping away or collapsing, or result in damage to structures from falling debris.

If changes need to be made; or if relocation of other structures is considered necessary as a result of changes at the site, such changes should be made before undertaking site measurements.

The following aspects should also be considered in order to optimise the location of structures.

The Weir and Intake

The proposed intake location should be such that it is possible to divert the flow from the river towards the headrace either naturally or by constructing a simple low weir. The stream should be straight both upstream and downstream of the intake, as discussed in Chapter 3. The riverbed should be permanent at the intake site so that it does not meander or change its course leaving the intake dry.

If it becomes necessary to locate an intake at a river bend, then it should be located on the outside of the bend but not exactly on the bend (Figure 3.9). The sediment load is higher on the inside of the bend, and as the flow recedes in the river the water course moves away from this location. Locating an intake right on the outside of a bend makes it vulnerable to flood damage. Thus the ideal intake location is along a straight stretch of the stream, and if that is not possible on the outside of a bend but upstream from it. This ensures there will be flow available during the dry season and minimises problems related to sediment load.

The Headrace Canal

The canal should be diverted away from the river course as early as possible to minimise possible damage from high floods. If signs of instability, such as landslip, tension cracks, or falling rocks, are observed, the headrace alignment should be changed to avoid these areas. HDPE pipe may be a viable option for steep sections of the route.

Settling Basins

Generally, the first settling basin should be located as close to the intake as possible so that any sediments are removed early and the maintenance of the canal is minimised. The proposed location should be such that it is possible to flush the sediments without causing soil erosion or damage to other structures. If the stream is not far away, the sediments can be discharged back into it. If possible, the second structure should be combined with the forebay to minimise cost, especially when the length of the canal is short. If the canal is very short, one basin may be sufficient.

Forebay

As with the settling basin, the location of the forebay should be such that it is possible to safely discharge the entire flow if the valve in the powerhouse has to be closed suddenly (as a result of system malfunction). If this structure cannot be combined with the settling basin, then another structure should be provided to settle the sediments.

Penstock Route

The penstock route should start where the ground profile gets steeper and should be kept as straight as possible, since bends require anchor blocks and involve additional expense. The flatter the ground slope, the longer the penstock. Ideally, a ground slope of around 45° (1:1 vertical:horizontal) is optimal. If the ground slope is steeper than this, it will be difficult to lay the penstock manually and to construct support piers and anchor blocks. If signs of instability, such as landslip, tension cracks, or falling rocks, are observed, the penstock location should be changed to avoid these areas.

Anchor Blocks

Anchor blocks should be located at any bends in the penstock and near the powerhouse on firm and stable ground. One anchor block should also be provided on a straight penstock if its length exceeds 50m.

Support Piers

These piers support the weight of the penstock pipe and water between the anchor blocks wherever it is laid above ground. It is usually cheaper to construct more support piers than to increase the thickness of the pipe to avoid sagging.

The Powerhouse

There should be adequate space for a powerhouse with the required dimensions to fit the electro-mechanical equipment at the chosen location. Apart from being on stable ground, the proposed location should also be safe from floods. Finally, it should also be possible to discharge the tail water safely back into the river.

4.4 Head Measurement

As discussed in Chapter 3, the measurement of the head involves determining the vertical height from the forebay to the powerhouse floor (turbine centreline). If the penstock route is straight and short (say less than 20m) and an Abney level is not available, the head can be determined using the tube method. If the route has vertical bends, then the tube method should not be used since such bends cannot be measured this way.

For MHP schemes that have only a few vertical bends and a penstock length limited to about 50m, the Abney level is generally the most appropriate equipment for measuring the head. It is relatively inexpensive (around US$ 200) and weighs less than one kg. As discussed in Chapter 3, a record sheet should be prepared and all bend angles should be recorded accurately. Measurements should always be taken at intermediate points where there are changes in the ground profile. It is important to mark the measurement points on the ground by sinking wooden pegs or stones (or painting) so that installation is done accurately.

Most MHP schemes do not have horizontal bends, i.e., the penstock alignment is straight on plan even if it has a few vertical bends. For schemes where horizontal bends cannot be avoided, a theodolite or a similar measuring instrument becomes necessary. This is because it is not possible to measure horizontal angles with an Abney level. Similarly, if the penstock length is long (>50m), or the MHP scheme is more than 50kW, a theodolite should be used to achieve the accuracy needed. The use of such equipment may require an experienced surveyor and additional cost. However, the cost of such a professional survey is almost always justified compared to the added expenses that might result from inaccurate survey work. Optimal design of a scheme can reduce the project cost by 20 per cent or even more, and an accurate survey is the key for optimising the design.

4.5 Measuring and Demarcating Other Locations

The detailed site survey should also include measuring and demarcating the locations of all structures. Unless a theodolite is used to measure the head (in which case the same equipment can be used to measure other locations), an Abney level and a 30m tape is generally suitable for this purpose. The measurement should be carried out from the intake to the powerhouse and tailrace, following the route identified and finalised during the preliminary and detailed surveys.

The detailed survey should include measuring the width and water depth at the proposed intake location. The river gradient upstream and downstream of the intake should be measured with the Abney level. Then the ground slope and length along the headrace canal route should be measured. Intermediate points where there are changes in the ground slope should be measured in the same way as described for the head measurements. This will be useful for determining the canal bed slope during the design phase. The locations and levels (with respect to the intake or the powerhouse) of all major structures, such as the settling basin, forebay, anchor blocks, support piers, and powerhouse, should be measured and recorded during the detailed survey. The locations and lengths of the settling basin flushing system and spillways should also be measured at this stage. Similarly, all the important features noticed during the site visit, such as the locations of cliffs, landslide-prone areas, and gullies, should be recorded. Finally, the locations and routes of all structures should be marked on site (by sinking wooden pegs or painting rocks) so that they can be located without any difficulty during the construction phase.

It is advisable to finalise all survey calculations at the site even if it takes a day or two longer. If errors are found in the survey data, or if some additional information is required, it will be easier to rectify this at the site. It will be significantly more expensive if such errors are found at a later stage in the design office and a subsequent site survey is required.

It is also recommended that the surveyor take a series of photographs that can be combined to show the general layout from the intake to the powerhouse as well as the locations of all major structures. These photographs will be useful to recall the features of the scheme in the design office later, or for further discussions such as when expert advice is sought. Finally, the surveyor should also prepare at least a general plan of the scheme and the adjoining area using an appropriate scale as discussed in Chapter 3.

4.6 Final Decision

Based on the site observations and survey work, a final decision should be made about whether to proceed with the construction work for schemes of less than 20kW of installed capacity, or to the detailed design phase for larger schemes. If major technical difficulties have been found during the site visit such as a long and difficult headrace crossing or landslide areas requiring significant retaining structures, the decision might be made not to proceed further. The surveyor or the designer should bear in mind that not all sites are feasible and a decision not to proceed further with unfeasible schemes saves unnecessary expenditure.

If the scheme is technically feasible (for example, the headrace and penstock routes are along stable ground), then a decision should be made to proceed further.

4.7 Survey Report

After completion of the survey work, a report should be prepared describing all the aspects of the scheme. This report is usually prepared in the office after the team returns from the field and in consultation with other senior staff. The report should cover the following.

- The results of flow measurements, review of sites, other survey changes in the layout if any and the reason for them; results of meetings; and the final decision, all in reasonable detail
- In addition, the following maps/sketches/drawings should be included as annexes together with all forms, record sheets, and similar, filled out during the detailed survey.
    - General plan of the project area, including the location of the scheme and the community that it serves
    - General plan of the MHP scheme showing the locations of all civil structures
    - A plan and cross-sections for the sites of the above structures
- Availability and cost of construction materials including cement
- Site photographs with clear labels indicating the locations of the major structures
- The available power may also be calculated using a more accurate power equation than that given in Chapter 3: $P = 9.81 \times h \times Q \times h_{net}$. This equation includes a factor 'h' for the efficiency and allows for losses in the head. The efficiency depends upon the type and quality of the turbine, and h_{net} can be calculated from the measured head (h_g) after determining and deducting the friction losses in the penstock.

CHAPTER 5
Design of the Scheme

The design of an MHP scheme involves specifying the locations, sizes, materials, and other parameters of all components that are to be constructed or installed at the site. An ideal design should be such that based on it an experienced installer should be able to construct the scheme independently of, or with only nominal assistance from, the designer.

The design of the scheme is based primarily on the information obtained during the various surveys. Therefore, it can only be as good as the results of these surveys. The design process is iterative since the dimensions and other parameters of the MHP components are interdependent.

5.1 Diversion Weir

A weir should be constructed to raise the water level in the river upstream if the river flow cannot be diverted naturally into the intake during the low flow period. In rare cases, it may be possible to locate a suitable natural weir of large boulders which requires only minimum additional construction work such as placing more boulders or gabions. However, the type of weir most commonly suitable for MHP plants is a temporary weir constructed or repaired every year after the annual floods. For schemes located in remote areas, this option is appropriate and economical since such a weir does not require cement or skilled labourers. There are two common types of temporary weir.

- A weir across the whole width of the stream, the main design parameter being the height (Figure 5.1).
- A diversion dam that extends along the length of the stream but gradually moves towards the centre to divert more water (Figure 3.10.b). This type of dam is suitable for low flows and for continuous demand at a particular time. It can be further extended if more river flow needs to be diverted.

More permanent weirs constructed from gabions, masonry, or concrete should only be considered if the river does not move boulders during the floods, the site is less than a day's walk from the roadhead, and there is a scarcity of water during the dry season. Permanent weirs can be constructed of plum concrete (1:3:6 with 40% plum), or stone masonry in 1:4 cement mortar. Gabion weirs are semi-permanent structures that usually require some annual maintenance.

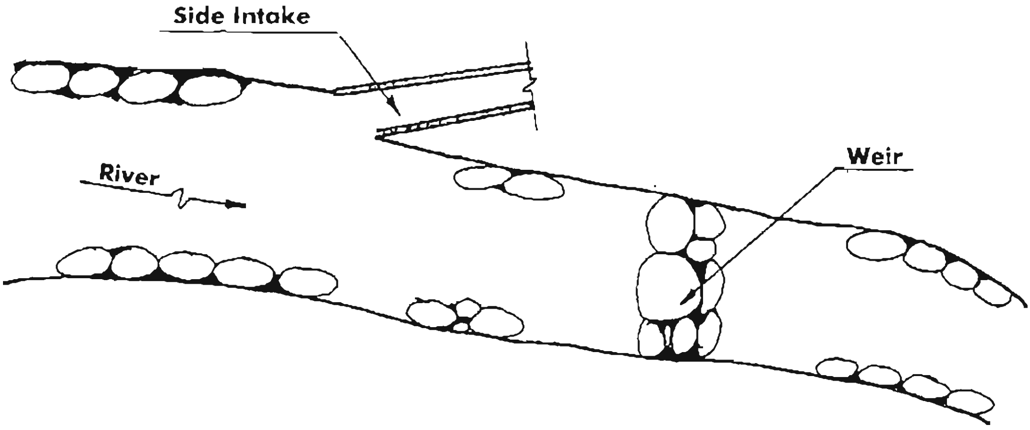

Figure 5.1: Side Intake with Temporary Diversion Weir

For both permanent and temporary weirs, the height should be kept as low as possible but enough to divert the required flow, and the slopes should be gradual so that boulders can roll over the weir. In order to determine the height of a temporary or permanent weir, the river depth/level during the dry season must be known together with the upper height of the orifice (the intake mouth, discussed in section 5.2). The intake height should be such that the water level rises above the upper edge of the orifice. The height of temporary weirs may have to be increased or decreased during the operation of the plant.

5.2 Intake

The intake should be so designed that the head loss is minimal and the entry of excessive flow (during floods) as well as bed load and other floating debris is minimised. Side intakes are most commonly used in MHP schemes since they are simple and less expensive than other types and most suitable for run-of-the-river type plants.

5.2.1 Design of Side Intake

A side intake can be designed either as an extension of the headrace canal (without any proper orifice) as shown in Figure 5.1, or as a rectangular orifice (Figure 3.9). If designed as an extension of the headrace canal, the procedure is to design a canal (discussed in section 5.3) capable of conveying the design flow and extend it to the side intake at the river bank. The initial length of the headrace that is in the flood zone of the stream is sometimes made wider to allow for seepage, especially if this section is temporary. A disadvantage of this type of intake is that it is not possible to automatically limit excess flows from entering the headrace during floods.

A rectangular orifice is a specially constructed opening in the side wall along the river bank, as shown in Figure 5.2, which allows the design flow to enter into the headrace but limits excess flows during floods. It should be sized such that it is submerged at the time of design flow during the low flow season, since this will limit excess flows during floods. An alternative to an orifice is to install a gate immediately downstream of the intake. This allows more control of the flow through varying the opening of the gate. However, such gates require more maintenance work and are also more vulnerable to flood damage.

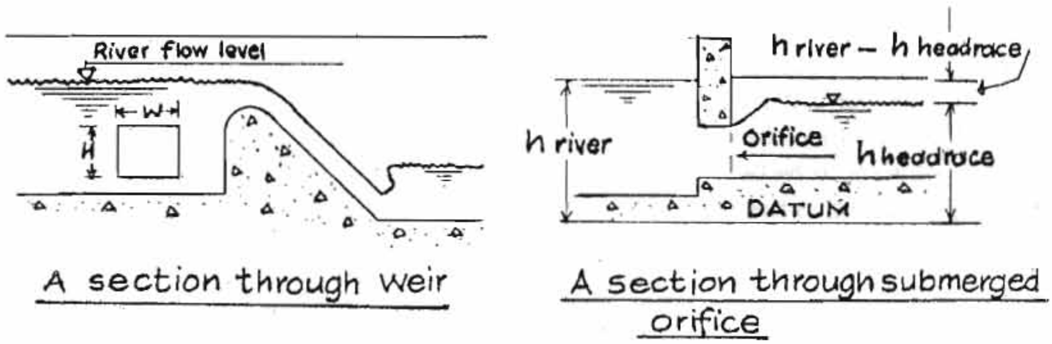

Figure 5.2: Sections through a Weir and a Submerged Orifice

The discharge through an orifice when submerged is given by:

$$Q = A \times V = AC\sqrt{2g\left(h_{river} - h_{headrace}\right)} \qquad (1)$$

where

Q is the discharge through the orifice in m^3/s

V is the velocity through the orifice in m/s

A is the area of orifice in m^2

$h_{river} - h_{headrace}$ is the difference between the river and the headrace canal water levels (Figure 5.2).

C is the coefficient of discharge of the orifice. For a sharp edged and roughly finished, fully submerged concrete or masonry orifice structure this value can be as low as 0.6 and for a carefully finished and smooth opening it can be up to 0.8.

If it is economically feasible to construct such an orifice, then the excess flow can be minimised during the monsoons.

The size of the orifice is calculated as follows.

- Assume an initial velocity through the orifice of less than 3 m/s. Then calculate the required area of the orifice opening using Q = V x A.
- For a rectangular opening, A = W x H where W is the width and H is the height of the orifice. Set H such that the water surface level at the headrace canal immediately downstream of it is slightly higher than the upper edge of the orifice. This ensures that the orifice is submerged. Calculations for the water level in the headrace are discussed in section 5.3.
- Now calculate h_{river} for the design flow conditions. This can be done by either rearranging the orifice equation (since all other parameters are known) or by trial and error. The h_{river} is the water depth that needs to be maintained in the river during normal conditions. If the actual level in the river is less during low flow, then the weir crest level will have to be taken to be equal to h_{river} (Figure 5.2).
- If the flood level in the river is known, the flow through the orifice for such conditions should be calculated using h_{river} = flood level (which can be determined by noting flood marks or information from the local community). The water level in the canal with a known flood flow in the headrace can be calculated as discussed in section 5.2. The excess flow will have to be spilled back into the river or nearby gullies. Note that if a weir is placed across the river, the flood level may be somewhat higher than before since the weir raises the water level. For temporary weirs this is not a problem since they normally get washed away. If a permanent weir is used, allowances should be made for this when calculating h_{river} (such as by adding the weir height above the measured flood level).

5.2.2 Trashracks for Side Intakes

A coarse trashrack should be placed at the intake mouth to prevent floating logs, cobbles, and boulders from entering the headrace canal and causing damage. Such a trashrack is fabricated using flat steel plates, angles, or bars (square or circular, about 25mm in diameter) that are welded together at fixed intervals. Since the coarse trashrack can get continuously impounded by cobblestones and other large particles, it needs to be strong. A bar spacing of between 50 and 200mm is generally adequate depending on the size of stones that the river carries during floods.

5.3 Headrace Canal

Many types of headrace canal made of different materials and using different methods of construction are used in MHP schemes. The types of canal and methods of designing the various components are described in the following sections.

5.3.1 Types of Canal

- Simple earthen or unlined canals

  These are constructed by simply excavating the ground to the required canal shape and are the cheapest type. Such canals can be used on stable ground where seepage (which usually exists) is not likely to cause instability problems such as landslides. Compaction of the earth and planting vegetation on the canal banks will increase stability and reduce seepage.

- Canals lined with stone masonry with mud mortar

  The second stronger option is to line the canal with stone masonry using mud mortar. There will be less seepage from this type of canal than from an earthen canal, but the construction will require more labour, materials, and funds. These canals should be used where a small amount of seepage will not cause slope instability, or where flow is limited, that is there is no extra flow that can be diverted into the canal to compensate for seepage.

- Canals lined with stone masonry with cement mortar

  The advantage of this type of canal is that seepage is minimal in comparison with earthen or stone-mud canals. However, this type of canal is significantly more expensive than the previous two types as a result of the cost of cement. A stone masonry in cement mortar canal is only needed along stretches where the soil is porous (causing high seepage losses) or where seepage is likely to trigger landslides.

- Canals lined with concrete

  Concrete canals are rarely used in MHP schemes except for short lengths at difficult locations, since they are more expensive than stone masonry with cement mortar canals. There is virtually no seepage from concrete canals. However, if the area is not stable then the whole structure can slide unless properly restrained or supported.

- Covered canals and pipes

  Where stones and other debris are likely to fall from above the headrace route, the canal can either be covered or pipes may be used. Flat stones are an economical way of covering canals; an expensive alternative is to use reinforced concrete slabs. Buried pipes made, for example, from HDPE also offer protection from falling debris. Another advantage of HDPE pipes is that they are flexible and can adjust to a certain amount of ground movement.

5.3.2 Design of the Headrace Canal

The canal dimensions and cross-section are governed by the following criteria.

- Flow and velocity

  The cross-sectional area should be such that the velocity is within the limits for the design flow (Table 5.1). Freeboard should also be allowed for excessive flow.

Table 5.1: Recommended side slopes and maximum velocities for headrace canals

Canal material	Side Slope (N = h/v)	Maximum recommended velocity for canals	
		less than 0.3m depth	less than 1m depth
Sandy loam	1.5 to 2.0	0.4	0.7
Loam	1.0 to 1.5	0.5	0.8
Clay loam	1.25	0.6	0.9
Clay	1.0	0.8	1.0
Stone masonry with mud mortar	0.5 to 1.0	1.0	1.0
Stone masonry with cement mortar	0 (i.e., vertical) to 1.5	1.5	1.5
Concrete	0 to 1.5	2.0	3.0

- Slope of the side

  The stability of the side walls of the canal depends on their slope. The effect of slope is different for the different types of material used in wall construction. For example, a vertical side wall will not be stable over a long period in a simple earthen canal, but will be stable if the walls are made of stone masonry in cement mortar or of concrete. In the following we define the slope of the side, N, as the ratio of the horizontal breadth, h, divided by the vertical height, v, of the canal wall, as shown in Figure 5.3. The recommended side slope for different types of canal is given in Table 5.1.

- Headloss and seepage

  Headloss can be minimised by routing the canal along even to gently sloping ground. Headloss is governed by the type of canal as well as the number and magnitude of bends. There are less frictional and head losses when the water flows over a smooth surface like that of cement plaster. The frictional losses are indicated by the roughness coefficient 'n', The values of n for different types of canal are given in Table 5.2.

- The Design Procedure for Canals

  1. Decide on the canal type according to the site conditions and taking into account stability and seepage (see above).

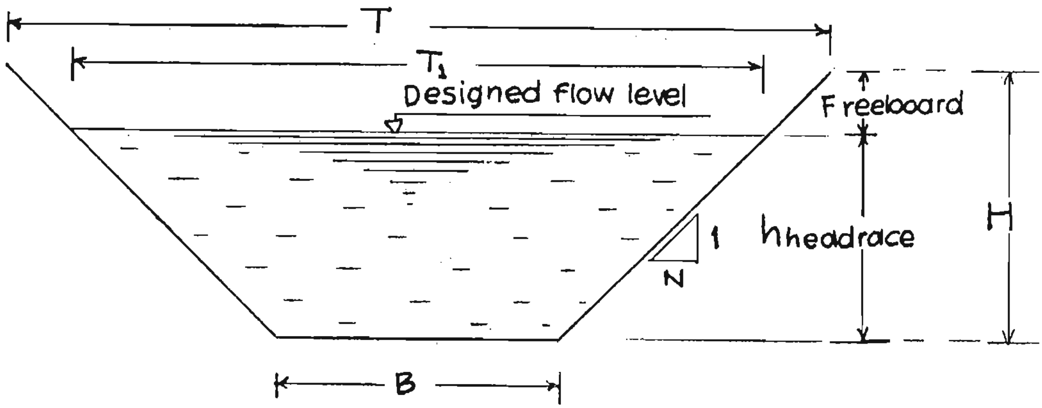

Figure 5.3: Headrace Canal with Trapezoidal Cross-Section

Table 5.2: Roughness Coefficients for Different Canals

Canal type	Description	Roughness coefficient 'n'
Earthen canals	Clay, with stones and sand, after ageing	0.020
	Gravelly or sandy loam, maintained with minimum vegetation	0.030
	Lined with coarse stones, maintained with minimum vegetation	0.040
Rock canals	Medium coarse rock muck	0.037
	Rock muck from careful blasting	0.045
	Very coarse rock muck, large irregularities	0.059
	Rubble masonry with mud mortar	0.025
Masonry canals	Brickwork, bricks, and/or clinker with well-pointed cement mortar	0.015
	Normal masonry with cement mortar	0.017
	Coarse rubble masonry and coarsely hewn stones with cement mortar	0.020
Concrete canals	Smooth cement finish	0.010
	Concrete for which wood formwork was used, unplastered	0.015
	Tamped concrete with smooth surface	0.016
	Coarse concrete lining	0.018
	Irregular concrete surface	0.020

2. Choose a suitable velocity (V) for the type of canal selected by referring to Table 5.1; and find the roughness coefficient (n) from Table 5.2

3. Calculate the cross-sectional area (A) from the equation $A = \frac{Q}{V}$

Where Q is the design flow

4. Using Table 5.1 decide on the side slope (N)

5. Calculate the required dimensions using the following equations

$$X = 2 \times \sqrt{(1+N^2)} - 2 \times N \qquad (2)$$

X is the factor used to optimise the canal shape. For a rectangular canal, N = 0 and X = 2.

6. The desirable depth of water in the canal, $h_{headrace}$ (see Figure 5.3), is calculated using X.

$$h_{headrace} = \sqrt{\frac{A}{X+N}} \qquad (3)$$

The width of the bed B (see Figure 5.3) is given by
Finally the width of the top T (see Figure 5.3) is given by

$$B = X \times h_{headrace} \qquad (4)$$

$$= B + (2 \times h_{headrace} \times N) \qquad (5)$$

If because of conditions at the site it is not possible to construct the optimum shape (for example, the width available is too narrow), then either the width or the height should be selected to suit the site conditions.

7. The velocity must be less than 90 per cent of the 'critical velocity limit' to ensure uniform flow in the canal. The critical velocity limit, V_c, is given by

$$_c = \sqrt{\frac{A \times 9.81}{T}} \qquad (6)$$

If the canal velocity is greater than $0.9V_c$ then repeat the calculations using a lower velocity (i.e., start again from step 2).

8. Calculate the wetted perimeter, P, using

$$P = B + 2 \times h_{headrace} \times \sqrt{(1 + N^2)} \qquad (7)$$

9. Calculate the hydraulic radius, R, using

$$R = A/P \qquad (8)$$

10. The slope (S) can now be found from Manning's equation

$$S = \left[\frac{n\,V}{R^{0.667}}\right]^2 \qquad (9)$$

11. Now calculate the head loss in the canal from

$$Head\ loss = L \times S \qquad (10)$$

where L is the length of the canal section. If the slope of the canal varies along different sections, calculate the head loss for each section and add them up. If the loss is too high, or if the actual ground slope differs from the calculated canal slope, repeat the calculations using different velocities.

12. Allow a freeboard of about 300mm for flows up to 500 l/s.

5.3.3 Design of Spillways

Excess flow that enters into the intake during flood flows needs to be spilled as early as possible. This is achieved by incorporating a spillway close to the intake. If the headrace canal is long, another spillway may be required along the canal section so that the entire design flow can be diverted if the canal is blocked as a result of falling debris or landslides. Finally, a third spillway is almost always required at the forebay to spill the flow in case of sudden valve closure at the powerhouse as may occur during emergencies. The sizing of the spillway is based on the following equation.

$$L_{spillway} = \frac{Q_{flood} - Q_{design}}{1.6 \times (h_{flood} - h_{sp})^{1.5}} \qquad (11)$$

where,

Q_{flood} is the flood flow that enters the intake in m³/s
Q_{design} is the design flow in the headrace canal
h_{flood} is the height of the flood level in the canal
h_{sp} is the height of the spillway crest from the canal bed

Figure 5.4 shows a section through a spillway.

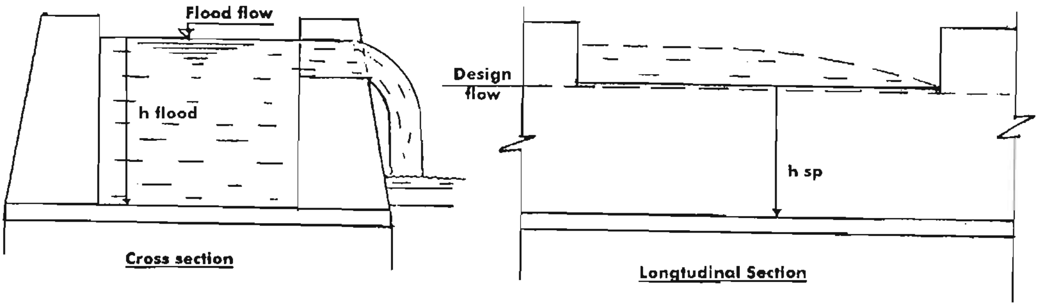

Figure 5.4: Spillway Design

The design procedure involves first calculating the maximum height of the water level in the canal during a flood (h_{flood}). Then the height of the spillway crest (h_{sp}) is set such that it is about 50mm higher than the design water level. This ensures that part of the design flow is not spilled, which would decrease the power output. '1.6' is a coefficient for a broad crested weir of a spillway with round edges which is easy to construct.

5.4 Settling Basins

Figure 5.5 shows the typical design of a settling basin. Settlling basins for an MHP scheme should have the following characteristics.

- The settling area should be large enough to reduce the velocity sufficiently to settle the sediments in the basin.
- It should be easy to flush the deposited silt.
- The basin should have a sufficient volume to store the settled particles until they are flushed.
- It should be possible to lead the discharge and sediments flushed from the basin safely into the river or a nearby gully without causing erosion or damage to other structures.
- Sharp bends should be avoided just before or within the basin since they cause turbulent flows which prevent the settling of particles.

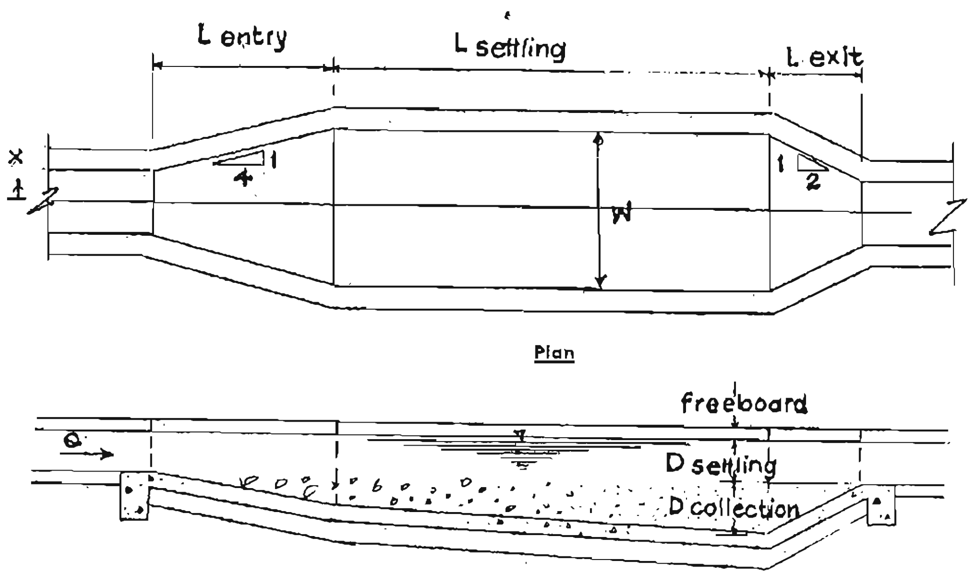

Figure 5.5: A Settling Basin

To reduce costs, one settling basin should be combined with the forebay, if possible.

5.4.1 Design of Settling Basins

The design of the settling basin is based on the following assumptions.

- Only particles with a diameter of 0.3mm or more are settled.
- A reasonable frequency for emptying the sediment from the basin during the monsoon period is twice a day (i.e., every 12 hours). It may not be convenient to empty the basin more often since this will interrupt power production. Similarly, if the flushing interval is increased a larger storage capacity will be required. Since the silt load in the river is less during the dry season, the emptying frequency could then be as low as twice a week.
- The sediments generally have a density of about 2,600kg/m^3 when dry. However, when submerged, they occupy more space and therefore the density decreases. This is measured in terms of the packing factor. The packing factor for submerged sediments is about 50 per cent, i.e., the density of sediment decreases by half when submerged.
- The concentration of suspended particles in the river flow varies seasonally and also depends on factors such as geology and vegetation cover of the catchment area. Therefore, it may be difficult to obtain data on sediment concentration. In this case, it

is reasonable to design the settling basin for 5kg/m³ of sediment concentration for monsoon flows.

The design procedure is as follows.

1. Choose a suitable basin width, W, two to five times the width of the headrace canal, depending upon the available width at the site (the larger the better).
2. Calculate the settling length ($L_{settling}$) using the following equation.

$$L_{settling} = \frac{2Q}{W \times V_{vertical}} \qquad (12)$$

where, Q is the design flow in m³/s,

$V_{vertical}$ = is the fall velocity, taken as 0.03 m/s, the value for 0.3mm particles.

Normally, the length of the settling basin should be four to 10 times the width.

3. Calculate the expected silt load, S_{load}, in the basin using the following equation.

$$S_{load} = Q \times T \times C \qquad (13)$$

where,

S_{load} = silt load in kg stored in the basin
Q = discharge in m³/s
T = silt emptying frequency in seconds. Use 12 hours = 12 x 60 x 60 = 43,200 seconds
C = silt concentration of the incoming flow in kg/m³, use 0.5kg/m³ in the absence of actual silt concentration data.

4. Now calculate the volume of the silt load using the following equation:

$$O_{silt} = \frac{S_{load}}{S_{density} \times P_{factor}} \qquad (14)$$

where,

VO_{silt} = volume of silt stored in the basin in m³.
$S_{density}$ = density of silt, use the value 2,600kg/m³ unless other reliable data are available
P_{factor} = packing factor of sediments submerged in water = 0.5 (50%).

5. The settling zone should have the capacity to store the calculated value of VO_{silt}. This storage space is achieved by increasing the depth of the basin for the area calculated earlier.

Calculate the average collection depth required, $D_{collection}$

$$D_{collection} = \frac{VO_{silt}}{L_{settling} \times W} \qquad (15)$$

A tapered entry ensures that the incoming flow is evenly distributed in the basin (Figure 5.5). The entry length should have a slope of 1:4. The exit length can be shorter, with a slope of up to 1:2. Note that no exit length is required if the settling basin is combined with the forebay.

5.5 The Forebay

Figure 5.6 shows a section through a typical forebay. The function of the forebay is to provide adequate submergence for the penstock mouth so that the transition from an open channel to pressure flow in a pipe can occur smoothly. If an earthen canal is constructed between the settling basin and the forebay, unusual high velocity in the canal (such as during the monsoon) can cause erosion and carry sediments to the forebay. In such cases the forebay should also be designed to serve as a secondary settling basin. However, if the headrace upstream of the forebay consists of HDPE pipe or a cement masonry canal, and the settling basin is functioning well, there may be no need for a second settling.

The position of the submergence head (depth of water above the crown of the penstock pipe) is shown in Figure 5.6. If the head is too small, the pipe will draw in air and the flow in the penstock will fluctuate. The minimum submergence head required for the penstock pipe can be calculated as follows.

$$h_{submergence} = \frac{1.5V^2}{2g} \qquad (16)$$

where, V is the velocity in the penstock.

The minimum size of the forebay should be such that a person can get in and be able to clean it. Even if in general no sediment load is expected in the forebay, it may nevertheless occur, e.g., when the settling basin fills up quickly during the monsoon or rainwater enters the canal. If a person can get into the forebay and clean it occasionally, at least during the annual maintenance period, this will not be a problem. This is another reason for providing a gap between the bottom of the penstock pipe and the floor of the forebay as shown in Figure 5.6.

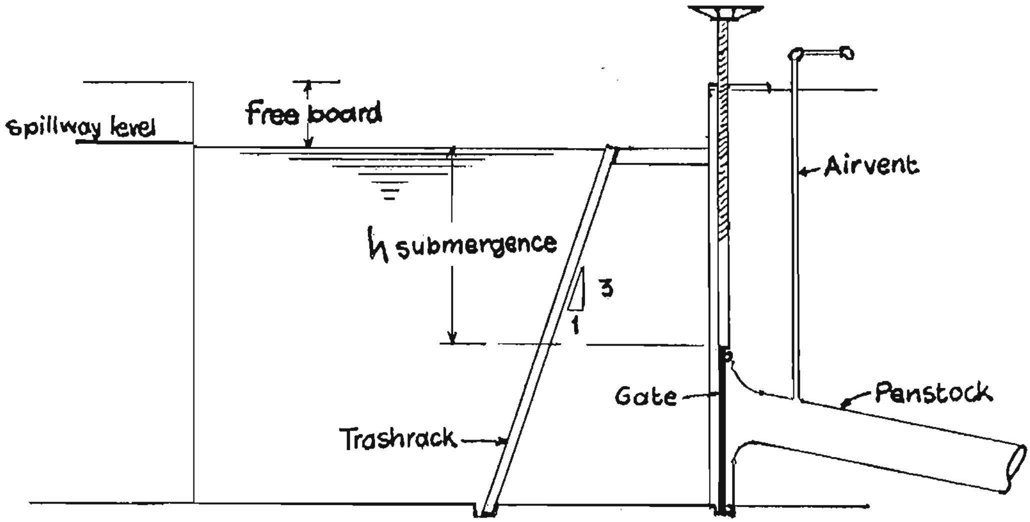

Figure 5.6: Submergence Head for Forebay

Incorporating a gate at the entrance of the penstock will make maintenance work on the turbine easier. The gate can be closed and the penstock emptied so that work can be carried out on the turbine. Rapid closure of the gate, however, could create negative pressure (i.e., a vacuum) inside the pipe and even cause it to collapse. Therefore an air vent should be placed as shown in Figure 5.6 to prevent such a situation. Air can then be drawn from the air vent pipe into the penstock.

The trashrack at the forebay should be placed at a slope of 1:3 both for efficient hydraulic performance and ease of cleaning (by raking, for example). The spacing between the trashrack bars should be about half the nozzle diameter for Pelton turbines and half the spacing between blades for crossflow turbines. This prevents the turbines from being obstructed by sediments and minimises the chances of surge.

5.6 The Penstock

Selecting the size of the penstock pipe requires selecting both the diameter and the wall thickness so that headloss is minimal and the pipe is strong enough to withstand any high pressure (surge) resulting from sudden blockage of the flow. The length of the pipe can be determined from the survey data.

Mild steel and HDPE pipes are the most common materials used for the penstock in MHP schemes. HDPE pipes are usually economical for low heads and flows and are easy to join and repair. They are also flexible enough to accommodate small angle bends or radial expansions resulting from pressure surges, and they are light. The disadvantage is that these pipes can degrade if exposed to ultra-violet rays (sunlight) and temperature variations and hence need to be buried.

5.6.1 Design of the Penstock Pipe

- The pipe diameter

  The following equation should be used to calculate the pipe diameter if the penstock length is less than 100m.

$$D = 41 \times Q^{0.38} \qquad (17)$$

where, D is the inside pipe diameter in mm and Q is the design flow in l/s.

If the penstock pipe is longer than 100m, a detailed analysis is required. Such an analysis is beyond the scope of this manual and other texts should be referred to.

- Pipe thickness

  The thickness of the pipe depends on the pipe diameter, the material, and the type of turbine selected. The surge effect is different for different types of turbine and hence the pipe thickness can differ even when the design flow, static head, and pipe materials are similar.

  The calculation of the mimimum wall thickness of the penstock for Pelton and crossflow turbines is as follows.

  Use the following method to calculate the surge head.

  1. Calculate the pressure wave velocity 'a' using

$$a = \frac{1400}{\sqrt{1 + \left(\frac{2.1 \times 10^9 \times d}{E \times t}\right)}} \qquad (18)$$

where,

the value of Young's Modulus (E) for mild steel is 210 x 10^9 N/m^2 and for HDPE is 0.2 to 0.8 x 10^9 N/m^2

d is the pipe diameter in m

t is the wall thickness in m

2. Calculate velocity v in the penstock; $V = \dfrac{4Q}{\pi d^2}$ (19)

3. Calculate the surge head (h_{surge}) from

$$h_{surge} = \frac{av}{g} \times \frac{1}{n} \qquad (20)$$

where,

n is the number of nozzles in the turbine(s)

Note that in a Pelton turbine, which may have more than one nozzle, it is highly unlikely for more than one nozzle to be blocked (by silt/stones) simultaneously. Therefore, the surge head is also divided by the number of nozzles (n). For single jet Pelton and cross flow turbines n = 1.

4. Now calculate the total head

$$h_{total} = h_{gross} + h_{surge} \qquad (21)$$

5. If the pipe is made of mild steel, it will be subject to corrosion and welding or rolling defects. Thus the effective thickness, $t_{effective}$, will be less than the original thickness, t. For mild steel, assume an initial thickness, t and calculate $t_{effective}$ using the following guidelines.

a) If the pipes are joined by welding divide the initial thickness by 1.1.
b) If the pipe is prepared by rolling flat sheets, divide the initial thickness by 1.2.
c) Since mild steel pipe is subject to corrosion, subtract one mm for every 10 years of plant life or part thereof.

For example, the effective thickness of a four mm thick flat rolled and welded mild steel pipe designed for a 10-year life is

$$t_{effective} = \frac{4}{1.1 \times 1.2} - 1 = 2.03\,mm$$

Note that this does not apply to HDPE pipes where the effective thickness is the same as the original thickness of the pipe.

6. Calculate the safety factor (SF) using the following equation.

$$SF = \frac{t_{effective} \times S}{5 \times h_{total} \times 10^3 \times d} \qquad (22)$$

where,

S is the ultimate tensile strength of the pipe material in N/m^2. For mild steel S is usually taken as 350×10^6 N/m^2. For HDPE the value is between 6 and 9×10^6 N/m^2.

d is the internal diameter of the pipe in m

7. If SF <3.5, reject this penstock option and repeat the calculation for a greater thickness.

In a crossflow turbine, instantaneous blockage of water is not possible since there is no obstruction at the end of the manifold, unless an additional valve is also provided. Therefore surge pressure can only develop if the runner valve is closed rapidly.

A simple procedure to determine the thickness of the penstock pipe for a crossflow turbine is to add 20 per cent to the gross head to allow for surge pressure, i.e., $h_{total} = 1.2 \times h_{gross}$. This results in a more conservative value for the surge head, but its contribution to the increase in the thickness will anyway be insignificant since crossflow turbines are only used for low head schemes.

Once the total head is known, the procedure is the same as for the Pelton turbines (i.e., start calculations from step 4 for the Pelton turbine).

5.7 Anchor Blocks

An anchor block is a mass of concrete fixed into the ground that holds the penstock to restrain the pipe movement in all directions. It is constructed of plum concrete which is 1:3:6 (1 part cement, 3 parts sand, 6 parts aggregate) with about 40 per cent boulders placed evenly around the block as shown in Figure 5.7. The boulders add weight to the block and therefore increase stability while reducing the volume of cement required. For MHP schemes with a gross head of less than 60m and a design flow of less than 200 l/s, The following guidelines can be used to determine the size of an anchor block.

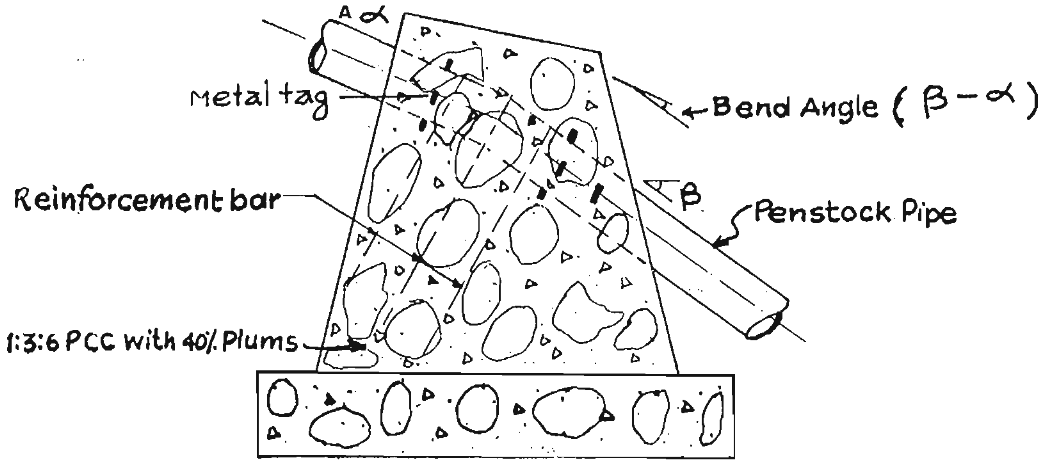

Figure 5.7 : An Anchor Block

- For straight sections, locate one anchor block every 30m along the length of the penstock. Use one m^3 of plum concrete for a pipe diameter of 300mm. If the pipe diameter is more or less, say 200mm, then adjust the amount proportionately. (200/300) x 1 m^3 = 0.67 m^3.
- Always provide an anchor block at the bends in the penstock keeping a maximum distance of 30m between two blocks. For bends less than 45°, use double the concrete volume required for a straight section. For example, if the pipe diameter is 350mm and the bend is 20°, then use (350/300) x 2 m^3 = 2.33 m^3 of concrete for the anchor block. If the bend angle is larger than 45°, then the required volume of concrete is three times that for a straight section.

For larger MHP schemes, more detailed calculations are required that are beyond the scope of this publication.

5.8 Support Piers

Support piers restrain the vertical forces of the penstock resulting from the weight of the pipe and water. However, they allow axial movement resulting from thermal expansion or contraction (Figure 5.8).

Support piers are generally constructed out of stone masonry in 1:6 cement–mortar. A metal plate should be placed on the support pier where the penstock pipe rests to minimise frictional effects and increase the useful life of the pipe. A further semi-circular strip of metal is usually laid around the penstock and bolted to the pier to provide some control over unwanted movements.

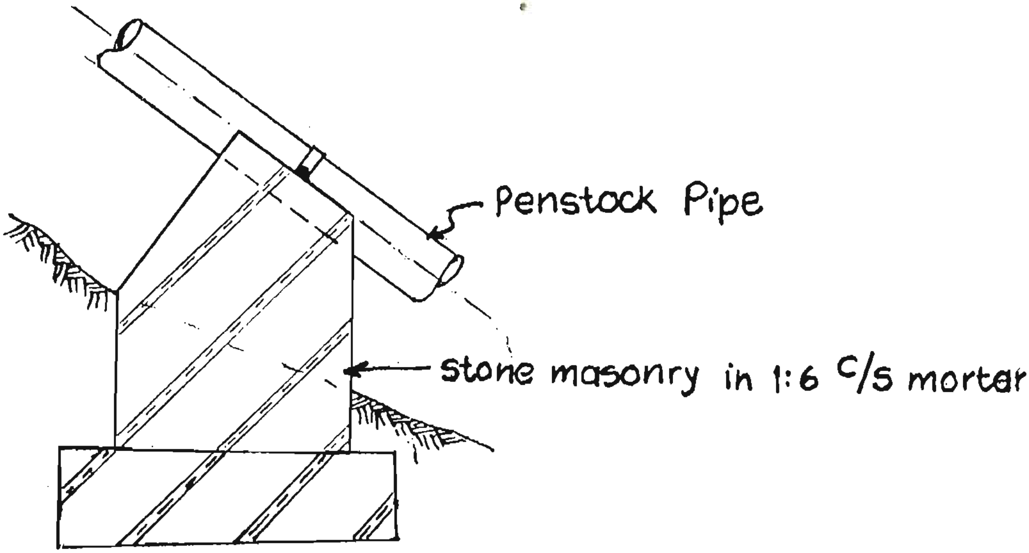

Figure 5.8: A Support Pier

Table 5.3 should be used to determine the spacing of support piers for mild steel pipes that are welded or connected by flanges according to British Standard specifications (minimum flange thickness = 16mm). (Support piers are not required for buried pipes.) Note that in Table 5.3 the support pier spacing is the horizontal (plan) length and not the sloping length of the pipe. For flanged mild steel pipes that do not meet British Standards, one support per individual pipe length should be used with the pier placed in the middle.

For small MHP schemes (h_{gross} <60m and Q <200 l/s) Figure 5.8 can be used as a guide for the shape of the support pier if the penstock pipe is less than one metre above the

Table 5.3: Spacing of support piers

Pipe diameter (mm) =>	100	200	300	400	500
Pipe thickness (mm)	Support pier spacing (horizontal), metres				
2	2	2	2.5	3	3
4	3	3	3	4	4
6	4	4.5	5	6	6

ground. The base of the pier(s) should be at least 1m x 1m. The size of the top piece on which the penstock is supported should be at least 0.5m along the direction of the penstock and about one metre width at right angles to the penstock. The uphill wall surface should be perpendicular to the penstock pipe. The required depth of foundation depends on the condition of the soil, but it should be at least 300mm.

For larger schemes, or if the penstock pipe is more than one metre above the ground, a more detailed calculation is required which is beyond the scope of this publication.

5.9 Expansion Joints

Above ground penstock pipes are subjected to expansion or contraction in length as a result of changes in the ambient temperature. The change depends on the change in temperature and the type of material used. Table 5.4 can be used to determine the changes in lengths for mild steel pipes of various lengths in different temperature ranges. The expansion lengths can be extrapolated to give intermediate values. Note that the maximum expected temperature variation should be used for the calculation (such as between when the pipe is empty during a mid-summer afternoon, and the lowest winter temperature).

Table 5.4: Thermal length change of mild steel pipe (mm)

Maximum temperature variation °C	Length between anchor blocks in m				
	10	20	30	40	50
Change in length (mm)					
25	3	6	9	12	15
35	4	8	13	17	21
45	5	11	16	22	27

A sliding type of expansion joint such as that shown in Figure 5.9 is commonly used in MHP schemes. It can be placed between two consecutive pipe lengths and can either be welded or bolted to the pipes. The stay rings are tightened to compress the packing and prevent leaking. Jute, rubber, or a similar type of fibre is used for packing. The penstock pipe expansion or contraction is accommodated by the gap in the expansion joint. Therefore, the gap in the expansion joint should be about twice the expansion length derived from Table 5.4.

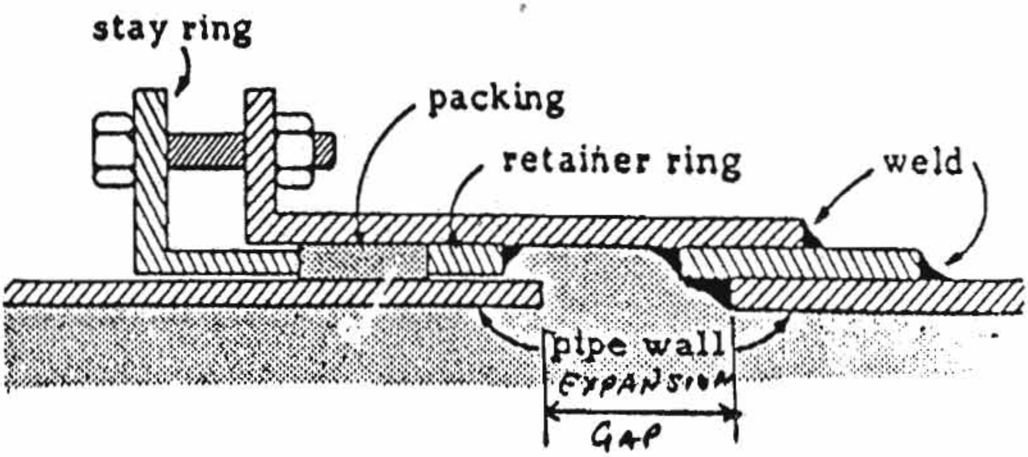

Figure 5.9: Sliding Expansion Joint

5.10 The Powerhouse

The main function of the powerhouse is to protect the electro-mechanical units from rain and other weather effects. Costs can be brought down if the construction is similar to that of other houses in the area. The powerhouse walls can be built of stone masonry in mud mortar with cement pointing on the surfaces. The roof can be covered with corrugated, galvanised iron (CGI) sheets. The powerhouse should be big enough that all the electro-mechanical equipment can fit in and be easily accessible for operation and repair work. If agro-processing units are also installed inside the powerhouse, additional space should be provided so that it is not overcrowded when people are working or delivering grain and so on. When planning the size of the powerhouse, all electro-mechanical units should be drawn to scale and laid out so that they fit in the plan area of the drawing.

The machine foundations should be constructed out of reinforced concrete so that all the loads, including the dynamic forces of the generator and the turbine, are properly supported and the alignment does not change over the years.

5.11 Turbine Type, Size and Accessories

Crossflow and Pelton turbines are the two most commonly used turbines in MHP schemes. Typical examples are illustrated in Figure 5.10. The type and size of the turbine to be selected for a particular site depends on the net head ($h_{net} = h_{gross}$ - losses) and the design flow.

Generally, crossflow turbines are used for high flow and low head schemes and are suitable for heads of less than 50m. Conversely, Pelton turbines are used for high head (50m

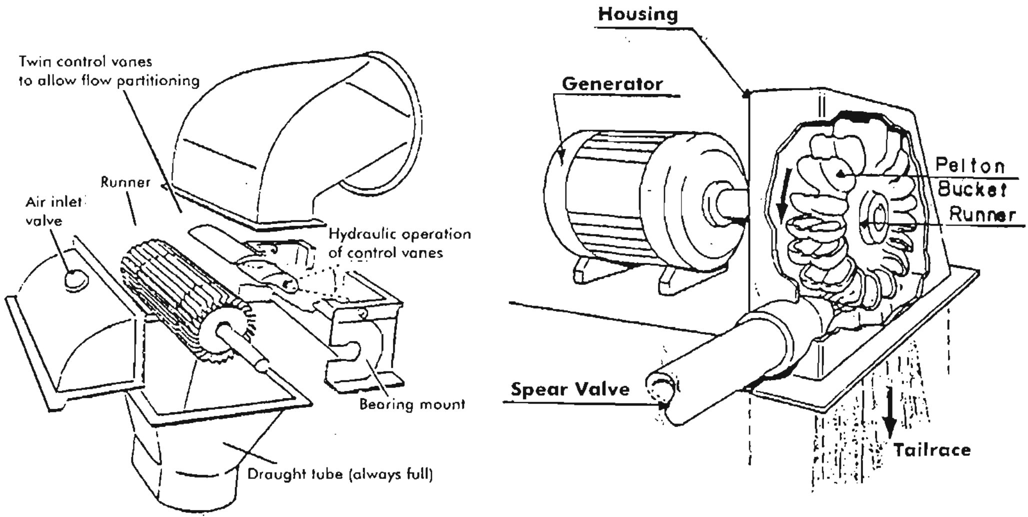

Figure 5.10: Crossflow and Pelton Turbines

and more), low flow schemes and are the only alternative if the net head exceeds 100m. A single jet Pelton turbine is usually less expensive than a multi jet one. However, a single jet may require a large runner and the penstock pipe may also have to be thicker to allow for the greater possible surge as discussed earlier. The Nomogram shown in Figure 5.11 can be used to select an appropriate turbine for the site conditions. The procedure is as follows.

- First draw a straight line connecting the turbine shaft power and the net head. Note that the turbine shaft power = 1.1 x power output. This allows for about 10 per cent loss in the generator.
- Now select a suitable turbine shaft speed (RPM) and extend a line from this point so that it is perpendicular to the previous line (turbine shaft power to head). This second line will point to either a single jet Pelton, multi-jet Pelton, or a crossflow turbine. If the line ends at the overlap region between turbine types, then both types are feasible. If the line ends beyond the crossflow range, try again with a different RPM.

Note that the suitable range of shaft speeds for a 1,500 RPM generator turbine lie between 400 RPM and 1,500 RPM. If possible for electrification schemes, the turbine shaft speed should be set at 1,500 RPM, which allows for direct coupling between the generator and the turbine since most MHP generators are designed to operate at 1,500 RPM. However, this is only possible with fast running Pelton turbines. For crossflow turbines, the usual rated speed is between 400 and 1,000 RPM. In such cases, a belt drive with the requisite speed ratio will be required. Once the turbine type and the RPM are known for a fixed head and flow, their price can be obtained from the manufacturer.

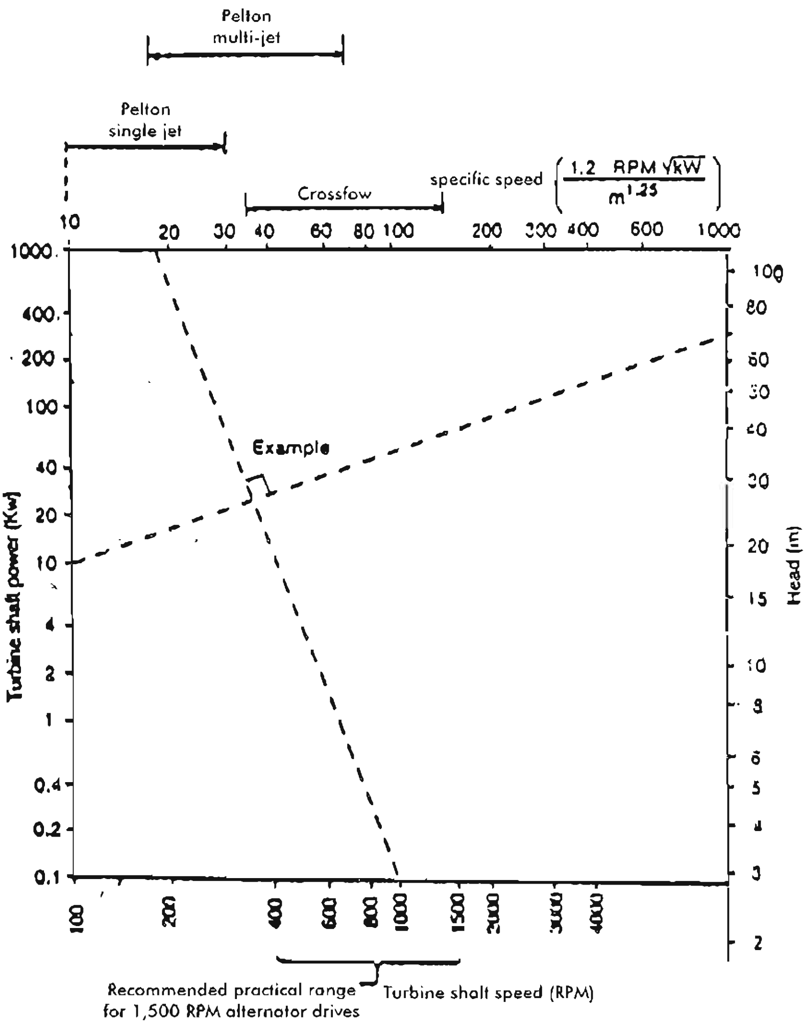

Figure 5.11: Turbine Selection Nomogram
(Source Harvey et al. 1993)

5.12 Generator Type and Size

Induction or synchronous type generators are mostly used in MHP schemes. Induction generators are inexpensive and appropriate for very small schemes of up to 10kW. For larger schemes, the induction generator load controller may not be very reliable. Table

5.5 below should be used to select the type of generator for the power output required. Once the generator type has been determined, the required nominal generator output power in kVA should be calculated using the following equation.

$$\text{Generator nominal range kVA} = \frac{\text{power output in kW}}{(A \times B \times C \times D)} \qquad (23)$$

Note that the power output is the available power in kW calculated using the power equation. The factors A, B, C, and D can be found from Table 5.6.

Table 5.5: Selection of Generator Type

Type of scheme/generator	Very small schemes up to 10kW	Small schemes, 10kW to 20kW	Medium to large schemes, over 20kW
Type of generator	Induction, single or 3 phase, 2nd choice: synchronous	Synchronous, 3 phase only 2nd choice: induction, 3 phase only	Synchronous, 3 phase only

Table 5.6: Factors Affecting Generator Rating

	Ambient temperature in °C	20	25	30	35	40	45	50	55
A	Factor	1.10	1.08	1.06	1.03	1.00	0.96	0.92	0.88
	Altitude in m	1000	1500	2000	2500	3000	3500	4000	4500
B	Factor	1.00	0.96	0.93	0.90	0.86	0.83	0.80	0.77
C	ELC correction factor	Without electronic load controller (ELC)						1.00	
		With electronic load controller						0.83	
D	Power factor	When only light bulbs are used							
		When tube lights and other appliances are used							

Example

Determine the generator rating for an MHP scheme designed for a power output of 20kW. The site is located at 1,700m above sea level and the ambient temperature inside the powerhouse during midsummer afternoons can be up to 35°C. An ELC will be used in the plant and the villagers also plan to use tube lights.

Calculation

A = 1.03 for 35°C

$$B = 0.96 - \left(\frac{0.03}{500} \times 200\right) = 0.95 \text{ for } 1{,}700\text{m altitude.}$$

C = 0.83 with ELC

D = 0.80 when tube lights are used

Required generator rating (kVA) = Power output inkW/(A x B x C x D)

= 20/(1.03 x 0.95 x 0.83 x 0.80)

= 31kVA

Note that if the calculated rating (kVA) of the generator is not available in the market, the next higher one should be selected. In the above example, a 35kVA generator may have to be purchased. However, since calculations like the above are not exact, a 30kW generator may also be considered; especially if the cost differences are significant.

5.13 Transmission Lines

The power generated in the plant needs to be distributed to the consumers via the main transmission line and secondary distribution lines.

- Selection of underground or overhead lines
  Transmission lines can either be buried (underground) or installed overhead on poles. Overhead lines are more common since they are less expensive and easier to install than underground lines. Overhead lines are also easy to repair and maintain. However, when houses are more densely located or heavy snowfall is expected during winter, underground transmission lines may be a viable alternative; if properly installed and protected, they should need very little maintenance.

- Selection of high voltage or low voltage
  If the powerhouse is far from the villages (load centres), high voltage transmission may be required together with step-up and step-down transformers to reduce line losses. However, this is an expensive option. In such a case the transmission voltage is stepped up to 11kV via the transformer at the powerhouse and stepped down to

400V at the village with another transformer. Then a low voltage (400V for three phase and 220V for single phase) distribution line is used. The general rule is to use a low voltage transmission line if the product of the power produced and the length of transmission line is less than 54kW.km (i.e., power output x transmission length < 54kW.km). If the installed capacity exceeds 10kW, a three phase transmission line should be used.

- Sizing of overhead transmission cables
  Aluminum conductor steel reinforced (ACSR) cables are generally used for overhead transmission lines in MHP schemes. These are available in various sizes and are named after certain animals (the larger the cable diameter the larger the type of animal whose name is used). The parameters required to size the commonly used ACSR cables are given below in Table 5.7.

Table 5.7: ACSR Transmission Line Parameters

Name	Equivalent aluminium area (mm^2)	Current rating in still air (amp)	Resistance (Ω/km)
Squirrel	20.7	76	1.374
Gopher	25.9	85	1.098
Weasel	31.2	95	0.9116
Rabbit	52.2	135	0.5449
Dog	103.6	205	0.2745

PVC (polyvinyl chloride) insulated armoured or unarmoured cables are used for underground transmission lines. These cables have insulated cores placed inside a PVC pipe for protection against moisture or other adverse effects when buried. The armoured PVC cables have an additional strip of steel strands inside the PVC pipe for protection against dynamic loads resulting, for example, from vehicular movement. More detailed design of underground cables is beyond the scope of this manual.

The following procedure is used to calculate the transmission line conductors for overhead lines.

- Determine the power factor (D in Table 5.6)
- Calculate the current, I, to be transmitted

Single phase; $$I = \frac{P}{V \times Power\ factor\ (D)} \qquad (24)$$

Three phase; $$I = \frac{P}{\sqrt{3} \times V \times Power\ fctor\ (D)} \qquad (25)$$

Where I = Current in amperes
P = Power in watts
V = Voltage, 220 V for single phase and 400 V for three phase

- Select a cable size from Table 5.7 so that the current rating is higher than the calculated current (I).
- Estimate the transmission line length (L) in km from the survey data.
- Determine the resistance R in W/km of the selected cable from Table 5.7 or from the manufacturer's catalogue. Note that the values may vary slightly between manufacturers.
- Calculate the voltage drop (V_{drop}) as follows.

Three phase: $$_{drop} = I \times L \times R \qquad (26)$$

Single phase: $$_{drop} = 2 \times I \times L \times R \qquad (27)$$

- If the calculated V_{drop} is higher than 13 per cent (preferably 10%) select the next higher size conductor and repeat the calculations.
- Calculate the loss of power (P_{loss}) in the transmission line as follows.

$$P_{loss} = I^2 \times L \times R \qquad (28)$$

This equation is used for determining the maximum power that can be used by the consumers (installed capacity - P_{loss}) and for which they can be billed.

Example

Determine the transmission line wire size for an MHP scheme that has an installed capacity of 20kW. The survey data show that the transmission line is 1.5 km long and the villagers may use bulbs, tube lights, and other appliances.

Calculation

Power out x transmission length = 20kW x 1.5 km = 30kW.km (< 54kW.km). Therefore, low voltage transmission is possible.

Since the installed capacity is higher than 10kW, a three-phase generation and transmission system will be required.
Power factor = 0.8

Transmitted current: $I = \frac{P}{\sqrt{3 \times V \times Power\ factor\,(D)}} = \frac{20{,}000}{\sqrt{3 \times 400 \times 0.8}}$

$= 36\ A$

For I = 36 A, choose SQUIRREL (Rated I = 76 A) which is the smallest size ACSR overhead transmission line.

From Table 5.7, R = 1.374 W /km

$V_{drop} = I \times L \times R$
$= 36 \times 1.5 \times 1.374$
$= 74\ V$

$\%\ V_{drop} = (74/400) \times 100\% = 18.5\% > 13\%$, NOT ACCEPTABLE

Try WEASEL, R = 0.9116 W/km
$V_{drop} = I \times L \times R$
$= 36 \times 1.5 \times 0.9116$
$= 49\ V$
$\%\ V_{drop} = (49/400) \times 100\% = 12.3\% < 13\%$, ACCEPTABLE

Check the power loss in the transmission line:

$P_{loss} = I^2 \times L \times R$
$= 36^2 \times 1.5 \times 0.9116$
$= 1772\ W = 1.77 kW$

Therefore only 20 - 1.77 = 18.23kW are available for the consumers from this scheme.

CHAPTER 6
Financial Analysis and Feasibility

An MHP scheme will be sustainable only if all of the following conditions are met.

- The scheme is technically feasible,
- socially acceptable, and
- financially viable.

A technically feasible MHP scheme is one in which the head, flow, and locations are such that the scheme can be physically constructed at the selected site. These have been covered in the previous chapters.

AN MHP scheme is socially acceptable and feasible if the community members are capable and prepared to manage it and willing to use and pay for the power produced. This subject has also been dealt with in Chapter 3.

The present chapter covers the third point, financial viability, and deals with all the general financial aspects of MHP schemes. The financial considerations for entrepreneur and community-owned schemes are different. A private entrepreneur-owned scheme needs to generate a return on the investment, as with any other business venture. On the other hand, community owned schemes are usually not profit driven. As long as sufficient income can be generated to meet the annual operation and maintenance expenses and to pay a portion of the community loan, they can be considered financially viable.

6.1 Detailed Cost Estimates

An accurate cost estimate for a proposed MHP scheme is a prerequisite for financial analysis. It is based on the design of the scheme as well as material, labour, and transportation costs. The detailed drawings can be used to determine the excavation quantity, masonry, and concrete work. Similarly the cost of electro-mechanical equipment, including transportation and installation charges, can be obtained from the manufacturers. In this way a detailed cost estimate can be prepared as shown in Annex 6.1.

Once the detailed cost estimate has been prepared, the costs should be tabulated under the major headings (Table 6.1). An allowance should be made for contingencies. This will allow for uncertainties in the cost estimate. If most of the figures, such as labour rates and material costs, are accurate, a contingency of 10 per cent is adequate. Note that if the scheme is to be constructed more than a year after the cost estimates were made, then the contingency should be increased accordingly to reflect the likely increase in material and labour costs.

Apart from construction costs, there may also be other costs, such as design and supervision costs (for the technicians), as well as management or supervision costs of the entrepreneur or some community member(s) responsible for the coordination of the project. If there are such expenses, they should also be included in the cost estimate.

Table 6.1: Summary of Costs

No	Description	Amount (Rs)
1	Intake	a
2	Headrace	b
3	Settling basin(s)	c
4	Forebay	d
5	Penstock	e
6	Anchor blocks	f
7	Support piers	g
8	Powerhouse and machine foundation	h
9	Electro-mechanical installation in powerhouse including transportation	i
10	Transmission line and poles	j
11	SUBTOTAL	$k = a + b + c + d + e + f + g + h + i + j$
12	10% contingency	$l = k \times 0.10$
13	TOTAL CONSTRUCTION COST	$m = k + l$
14	Design, supervision and management costs	n
15	Land costs	P
16	TOTAL PROJECT COST	$T = m + n + p$

6.2 Financial Analysis

Financial analysis of an MHP scheme can be undertaken once the total cost has been determined. Depending on the type of ownership, the simplified methods discussed below can be used to assess the financial viability of the scheme. It should be noted that the financial analysis discussed below is preliminary and should be used only as an indication of whether the scheme proposed appears to be sufficiently viable financially to start the construction. For larger plants, a more in-depth analysis may be carried out, which is beyond the scope of this publication.

An entrepreneur will probably not install an MHP scheme unless his expected annual profit is higher than the commercial bank interest rate or equal to what he can expect had he invested in another business with equal risk. Therefore, for such schemes a minimum annual profit on investment (POI) of 20 per cent should be used as the criterion for financial viability.

A community-owned scheme is not usually profit driven. Therefore, for such schemes a minimum net annual income of two per cent (preferably 5 per cent) after repayment of any loan installment should be used as the criterion for financial viability.

The minimum annual profit can also be ensured by adjusting the tariff, but note that an unaffordably high tariff rate may result in the rejection of the scheme by the consumers. The consumers will not buy the power produced (for electricity and agro-processing) if they cannot afford the tariff.

If the scheme is eligible for subsidy, this sum should be deducted from the total project cost, since the entrepreneur or community does not have to pay it back. Similarly if contributions in kind are to be made, for example donation of land, labour, or materials, the total equivalent cost of these should be deducted from the total project cost.

The following procedure should be used to determine the financial viability of an MHP scheme.

- First determine the principal sum (total investment) that the entrepreneur or community needs to invest as follows.

$$P = T - S - C$$

where
P is the principal sum
T is the total project cost and
S is the subsidy received
C is the monetary equivalent of contributions in kind

- Calculate the total annual income from the scheme. This can include income from the sales of both electricity and power for agro-processing.
- Estimate the total annual expenditure of the scheme. Depending on site specific conditions, such annual expenditure will be different for different schemes. It should include any payment made to keep the plant operating. Table 6.2 below presents an example of the annual expenditure that can be expected in an MHP scheme.

Table 6.2: Annual Expenditure		
No	**Description**	**Amount (Rs)**
1	Salaries for operators and manager	a
2	Annual scheme maintenance cost (use 2% of total project cost if no other information is available.)	b
3	Interest on loan	c
4	Other expenditure (travel, communications, etc.)	d
5	Total annual expenditure	e = a+b+c+d

It is recommended that studies of existing MHP schemes be carried out to estimate the actual percentage of the total project cost required for annual maintenance. In the absence of such data, two per cent of the total project cost is recommended to be taken for the annual maintenance cost as shown in Table 6.2.

- Even with regular maintenance, electro-mechanical units, such as the turbine and the generator, will have to be replaced completely once their useful life is over. Setting aside a certain percentage of the total project cost each year will provide sufficient funds for replacement of such equipment in the future. It is recommended that studies also be conducted on existing schemes to determine the average percentage of the project cost required for this. In the absence of such information, three per cent % of the total project cost is recommended to be set aside for replacement of such major parts.
- The annual profit can now be calculated as follows.
  - Annual profit = Annual income - Annual expenditure - Replacement fund
  - For entrepreneur schemes; if the annual profit is 20 per cent or higher of the principal, the scheme can be considered financially viable. If it is less than 20 per cent, reject the scheme.
  - For community schemes; if the annual profit is at least two per cent % of the principal, accept the scheme as financially viable. If it is less than two per cent, reject the scheme.

The example below illustrates the above methodology.

Example 6.1

An entrepreneur is considering whether he should install an MHP scheme. The installed capacity is 15kW and the total project cost is Rs 1,020,000. The expected subsidy from the government is Rs 306,000 and he plans to draw a loan of Rs 500,000 from the bank at an annual interest rate of 16 per cent.

The entrepreneur's monthly income is estimated to be as follows.

1. 60W bulbs x 100 @ Rs 75 per bulb/month
2. 40W bulbs x 150 @ Rs 50 per bulb/month
3. 25W bulbs x 120 @ Rs 35 per bulb/month
4. Income from agro-processing Rs 9,000/month (average)

The entrepreneur's monthly expenses on salaries are as follow.

1. Salary to operators: Rs 2,000/month
2. Salary to the manager: Rs 2,500/month

Determine whether the scheme is financially viable.

FINANCIAL ANALYSIS

A. Principal

Principal (P) = Total project cost - Subsidy
Or, P = Rs 1,020,000 - Rs 306,000 = Rs 714,000

B. Annual income

Sales of electricity

1. 60W bulbs:100 bulbs x Rs 75 per bulb/month x 12 months = Rs 90,000
2. 40W bulbs:150 bulbs x Rs 50 per bulb/month x 12 months = Rs 90,000
3. 25W bulbs:120 bulbs x Rs 35 per bulb/month x 12 months = Rs 50,400
4. Agro-processing: Rs 9,000/month x 12 month = Rs108,000

Total annual income = Rs 338,400.

C. Annual expenditure

Annual expenditure

No	Description	Amount (Rs)
1	Salaries for operators and manager: Rs (2,000 + 2,500)/month x 12	54,000
2	Annual scheme maintenance cost: assume 2% of total project cost Rs 0.02 x 1,020,000	20,400
3	Interest on loan: Rs 0.16 x 500,000	80,000
4	Total annual expenditure	154,400

D. Replacement fund

Set three per cent of the total project cost for replacement fund:
= 0.03 x 1,020,000
= Rs 30,600

E. Annual profit

Annual profit = Annual income - Annual expenditure - Replacement fund
= 338,400 - 154,400 - 30,600
= Rs 153,400

% Annual profit = (annual profit/principal) x 100
= (153,400/714,000) x 100
Annual profit = 21.5%

Therefore, this scheme is financially viable for the entrepreneur. Note that, as the entrepreneur pays part of the loan component annually, the profit will increase since the interest on the loan will decrease.

With the same conditions, this scheme would also be viable as a community-owned scheme since the acceptable profit margin is lower. The community may decide to lower the tariff rates so that the annual profit is about five per cent.

ANNEXES

Annex 1

MHP Initial Enquiry Form

To be filled in consultation with the entrepreneur, community facilitator(s), and/or other relevant persons.

1. Information about the Location **Date: ....,.**

Name of main customer/community leader......................... Position: ....

Address:..

Name of main village: ....District ....

VDC: ....WardNo.:.............................

Other village(s): ....Name of stream: ....

Nearest road head: .... Days' walk ....

Nearest airport ....Days' walk ....

Travel route details: ....

Has this proposal been discussed with the VDC Chairman? Yes/No

the community? Yes/No

Names of other important community leaders and persons concerned.

Name: ....Position: ....

Name: ....Position: ....

2. Information on the Power Potential

Flow estimates

Width of stream in wet season ....m
in dry season ....m

Depth of stream in wet season ....m
in dry season ....m

Has there been a survey in the past? Yes/No.

If yes, how much flow, head, power was determined?

....

....

Are there waterfalls in the stream? Yes/No

Does the stream dry up at any time of the year? Yes/No

Which is the driest month of the year? ....

How many hours/days walk to the spring of the stream? ....

Is the stream water used for any of the following?

- Irrigation Yes/No, Up/Downstream
- Drinking water Yes/No, Up/Downstream
- *Ghatta*(s) Yes/No, Up/Downstream
- MHP installations Yes/No, Up/Downstream
- Other ...., Up/Downstream
- Is there an existing channel that can be used? Yes/No

Summary

How can the flow be measured?
Weir? Yes/No
Float method? Yes/No
Velocity-area method? Yes/No
Salt gulp dilution method? Yes/No
Other ....

- How many *Ghatta*(s) can be run one after the other in the dry season? ....

Appropriate method for head measurement
....
....
....
....
....
....

3. Geological Information

Are any of the following features present along the proposed canal route. If so, approximately how much/many?

		Distance			Distance
Cultivated land	Yes/No	........m	Steep hillsides	Yes/No	.........m
Slope areas	Yes/No	........m	Cliffs	Yes/No	.........m
Gullies	Yes/No	........m	Landslides	Yes/No	........m
Flooding	Yes/No	........m			

Are there any other features affecting the stability of the proposed channel? Yes/No. If so what? ....

4. Climate and Related Information for the Project Area

Does it ever snow at the proposed MHP site? Yes/No. If yes, how long does the snow stay on the ground? ....

Annual rainfall .... Do monsoon rains come every year? ....

If yes, how long do they last?.. ....

Type of vegetation and forests? ....

What crops are grown? ....

Is there a weather station in the area? Yes/No

5. Potential End Uses of MHP

Would any of the following be useful?

Rice huller	Yes/No	Flour mill	Yes/No
Oil expeller	Yes/No	Generator	Yes/No
Sawmill	Yes/No	Paper mill	Yes/No
Workshop	Yes/No	Vegetable/fruit dryer	Yes/No

Other ....

....

6. Electricity Requirements

	No.	Estimated electricity consumption in kW	Names of villages
Households	_______	_______________	___________
Shops/cafes	_______	_______________	___________
Hotels/lodges	_______	_______________	___________
HMG and other offices	_______	_______________	___________
Industry	_______	_______________	___________
Other	_______	_______________	___________

7. Socioeconomic Information

How much can you/the community invest? Rs ....

Can you/the community get a loan? Yes/No Rs ....

Is there any other funding available to you/the community, e.g.; from government, NGOs, other donors, and if so, how much? Rs ....

Total financial capability Rs ....

Are there any conflicts between parts of the community? Yes/No

If yes, describe. ....

....

Surveyor's view of capability of the community(ies) to pay for electricity. ....

....

....

How far is the proposed MHP site from the main villages that would benefit from the plant?

The nearest village: name .... km ......min walk ......hh ......

The 2nd nearest village: name .... km ......min walk ......hh ......

The 3rd nearest village: name .... km ......min walk ......hh ......

Which of the following are locally available?

Firewood	Yes/No	If yes, cost per load ....
Kerosene	Yes/No	If yes, cost per litre ....
Diesel	Yes/No	If yes, cost per litre ....

Which of the following exist?

Ghatta(s)	Yes/No	If yes, how many?.......................... What distance? ....km .... min walk
MHP mill	Yes/No	If yes, how many? .... What distance? ....km .... min walk
Diesel mill	Yes/No	If yes, how many?.......................... What distance? ....km ....min walk
Grid line	Yes/No	If yes, what distance? ....km ....min walk

Industry (describe) ....

List local prices of building materials, wages, and transport.

		Locally available
Wood	.......................Rs /.............	Yes/No
Stone	.......................Rs /.............	Yes/No
Sand	.......................Rs /	Yes/No
Gravel	.......................Rs /	Yes/No
Semi-skilled labour	.......................Rs / day,	Yes/No
Mason	.......................Rs / day,	Yes/No
Carpenter	.......................Rs / day,	Yes/No
Technician	.......................Rs / day,	Yes/No
Transport from road head		
Standard loads	.......................Rs / 50kg load	Yes/No
	.......................Rs /kg	
Difficult loads	.......................Rs / 50kg load	Yes/No
	.......................Rs /kg	

8. Community Contribution in Kind

Would the community provide?

Land for MHP plant	Yes/No
Local wood	Yes/No
Sand/stone/gravel	Yes/No
Construction labour	Yes/No
Manual transport labour	Yes/No

Checklist for Survey and Other Equipment

Particulars	Required		Checked date	Tick when packed
	Yes	No		
Topographic maps (1:50,000 or better)				
Markers				
Survey forms				
Paper/Notebook				
Graph paper				
Clip/drawing board				
Ruler/squares				
Pens + pencils + eraser				
Plastic files				
Camera				
Tape 5m				
Tape 30m				
Compass				
Abney level				
Surveyor's level				
Measuring rods				
Theodolite				
Altitude meter				
Pedometer				
Salt 2 kg				
Conductivity meter				
Thermometer				
Bucket				
Weir (V notch)				
Polythene sheet				
Spirit level / trapping panel				
Stop watch				
Plastic pipe 20m				
String				
Chaining pins				
Pegs				
Knife / *Khukuri*				
Umbrella				
Sleeping bag				
First aid kit				
Candles/matchbox				
Torch				
Calculator				
Water bottle				
Dried food				

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Annex 3

Household Survey Data

S. No.	Name	Type of House	No. of Rooms	No. of Bulbs	Other Uses	Power Req.	Monthly Income	Remarks
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
31								
32								
33								
34								
35								
	Total Power Required							

Shop Survey Data

S. No	Name of Shop Owner	Type of Shop	No. of Rooms	No. of Bulbs	Other Uses	Power Req.	Remarks
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
Total Power Required							

Other uses include fans, radios, TV, irons, and so on.

Annex 5

Gumba/Temple/School/Office/Other

S. No.	Name	Type	No. of Rooms	No. of Bulbs	Other Uses	Power Req.	Remarks
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
Total Power Required							

Annex 6

Lodge Survey Data

S. No.	Name	Type (high/med./low)	No. of Rooms	No. of Bulbs	Other Uses	Power Req.	Remarks
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
Total Power Required							

Small-scale Industries

S. No.	Owner/Name	Type	Power Req.	Remarks
B.	Planned Small-scale/industries			

Annex 8

Detailed Cost Estimate for .... Micro-Hydro Scheme

No.	DESCRIPTION	UNIT	QTY	RATE	COST (35 kW)
1	INTAKE				
1.1	Excavation	m^3			
1.2	Removal of boulders				
1.3	Construction of temporary weirs				
1.4	Gabion work				
1.4.1	Cost of 10 SWG mesh wire	kg			
1.4.2	Transportation of mesh wire	kg			
1.4.3	Gabion box preparation	m^3			
1.4.4	Filling of stone in gabion boxes	m^3			
	SUBTOTAL 1				A
2	HEADRACE CANAL				
2.1	Excavation	m^3			
2.2	Stone masonry (1:4 c/s)	m^3			
2.3	Cement (50 kg bag)	bag			
2.4	River alignment and stabilising work				
2.5	Gravel trap and spillway				
	SUBTOTAL 2				B
3	SETTLING BASIN/FOREBAY				
3.1	Excavation	m^3			
3.2	1:4 c/s stone masonry work	m^3			
3.3	1:3:6 PCC flooring	m^3			
3.4	1:2 c/s plaster (12.5 mm thick)	m^2			
3.5	Fabrication of sediment flush pipe, gates, etc.				
3.6	Porter charge for item 2.3				
3.7	Cement (50 kg bag)	bag			
	SUBTOTAL 3				C
4	ANCHOR BLOCK				
4.1	Excavation	m^3			
4.2	1:3:6 PCC with 40% plums	m^3			
4.3	Cement (50 kg bag)	bag			
4.4	Reinforcement bars (10 mm)	kg			
	SUBTOTAL 4				D
5	SUPPORT PIERS				
5.1	Excavation	m^3			
5.2	Stone masonry in 1:6 c/m	m^3			
5.3	Cement (50 kg bag)	bag			
	SUBTOTAL 5				E

No.	DESCRIPTION	UNIT	QTY	RATE	COST (35kW)
6	PENSTOCK				
6.1	Penstock fabrication and transportation	kg			
6.2	Porter charge for item 6.1	kg			
6.3	Fabrication of expansion joints and transportation	set			
6.4	Porter charge for item 6.3	set			
6.5	Installation of penstock and expansion joints				
	SUBTOTAL 6				F
7	POWERHOUSE AND TAILRACE				
7.1	4m x 5m house (locally made)				
7.2	Machine foundation				
7.2.1	Excavation	m^3			
7.2.2	1:1.5:3 RC works	m^3			
7.2.3	Stone soiling, sand and gravel packing	m^3			
7.2.4	Cement (50 kg bag)	bag			
7.2.5	Reinforcement bars (10 mm dia)	kg			
7.3	Tailrace pipe				
7.3.1	Fabrication and transportation	kg			
7.3.2	Porter charge for item 7.3.1	kg			
7.3.3	Pipe installation	m			
	SUBTOTAL 7				G
8	ELECTRO-MECHANICAL				
8.1	kVA generator	No.			
8.2	kW ELC with ballast tank	No.			
8.3	Cross-flow turbine with adapter	No.			
8.4	Control panel & switch gear				
8.5	ACSR SQUIRREL line conductor transportation and 3 phase. total distance = km	km			
8.6	Insulators and tension cables				
8.7	Transportation of items 8.1 to 8.6	trips			
8.8	Porter charge for generator	kg			
8.9	Porter charge for ELC and ballast tank	kg			
8.10	Porter charge for turbine and adapter	kg			
8.11	Porter charge for ACSR conductor	kg			
8.12	Porter charge for insulators & tension cables				
8.13	Wooden poles (to be prepared at site)	No.			
8.14	Transmission line erection				
8.15	Electro-mechanical installation at powerhouse				
	SUBTOTAL 8				H
	TOTAL CONSTRUCTION COST				=A+B+C+D +E+F+G+H

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Bhutan	China
India	Myanmar
Nepal	Pakistan

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