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.