# Lesotho

## Recommended activities in small hydropower development

NRECA Small Decentralized Hydropower (SDH) Program

# LESOTHO: Recommended activities in small hydropower development

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Small Decentralized Hydropower (SDH) Program
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## Contents

## Summary and conclusions

A two-person team spent three weeks in Lesotho under the sponsorship of USAID-ST/EY to recommend hydropower activities appropriate for the country. The team found that Lesotho has the physical features appropriate for large hydropower, but that wide-scale implementation of mini- and micro-hydropower installations would be difficult. The extreme variations in seasonal flows and the low specific discharges make seasonal storage a requirement for significant amounts of dependable power.

All of Lesotho probably has 20 to 40 potentially developable micro-hydro sites in the 5 to 100 kW range. The comparatively high cost of US$ 3,000 to $6,000 per kW installed are due to the higher cost of low-head equipment and the need for long, lined headraces. Since installations will be shut down 20 to 30% of the year due to lack of river flow, locations with existing diesel units for back up are preferred.

Principal construction problems are site access, stream sediment load and deposition, and active stream bank and hill slope erosion. Soil erosion accelerated by overgrazing and poor agricultural practices is a major problem in Lesotho.

Institutional matters are of primary importance at this time and should be addressed by the Renewable Energy Technologies (RET) Project with the goal of developing institutional systems for implementation of hydro projects. For installations of less than 100 kW, the lead agency should be the Ministry of Rural Development (MORD). Cooperative agreements between MORD and technical departments of the Ministry of Water, Energy, and Mining should be executed.

Pricing structures must be economically feasible for both the purchaser and seller. End-uses must be carefully throught through and long-term operations and maintenance procedures must be established.

Potential economic benefits from decentralized hydropower are significant, but how much the consumers actually will pay for electricity and how they will use it is mostly conjecture. Site-specific data is needed to address these questions.

## Introduction

The AID Office of Energy, Science and Technology through its Cooperative Agreement with the National Rural Electric Cooperative Association (NRECA), sent a two-person team to Lesotho for a three-week period to assess the possible development of small hydropower. The team worked with the Rural Energy Technologies (RET) project which is funded by AID/Maseru and the Government of Lesotho's (GOL) Ministry of Rural Development. * RET was established to disseminate pilot renewable energy technologies in the rural areas and build the institutional bases for systems found to be technically, economically, and socially feasible. One of the project's tasks is to introduce a micro hydropower system in a rural setting to displace the use of diesel fuels.

The Kingdom of Lesotho covers an area of over 30,000 $km^2$ and is completely surrounded by the Republic of South Africa. The mountainous country has a population of over 1.2 million people, 94% of which live in the rural areas. Approximately two-thirds of the population lives in the lowlands, and the other third lives in the vast highlands area. In 1977, the average rural income was estimated to be US$ 140 per capita.[2]

### Energy supplies

Lesotho has negligible fossil energy reserves and wood resources. Hence, most of its energy supplies are imported petrol (gasoline), paraffin (kerosene), diesel, and electricity. These imports drain a significant amount of the country's hard currency; yet, Lesotho has a tremendous amount of hydropower potential which remains untapped.

The rural areas of Lesotho, with a few exceptions, do not enjoy the benefits of electric power service. There are numerous small diesel installations that power local mills and provide lighting a few hours per day for religious missions. Significant amounts of paraffin supply rural lighting, refrigeration, and some heating needs.

The Lesotho Electricity Corporation (LEC) is responsible for the transmission, distribution, and development of electric power generation in Lesotho. Presently, LEC purchases all its requirements from South Africa's Electricity Supply Commission at 2.5 cents per kWh and sells at a retail residential rate of 5.0 cents[4] A price increase of approximately 20% is expected soon. The system experienced a winter peak of 31 MW in 1981-82 and consumed over 110 million kWh during the year.[4] Fig. 1 shows the existing transmission/distribution system. LEC has no significant, financed expansion plans.

### Problem

The GOL desires to establish a measure of electric generation self-sufficiency to improve its balance-of-payments and reduce its dependence upon energy imports. It also wants to assist development by promoting feasible renewable energy technologies. The obvious choice is to develop Lesotho's hydropower potential. Several studies proposing schemes[3, 5, 6] have been completed and others are under preparation. The World Bank

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* Associates in Rural Development (ARD) of Burlington Vermont is the AID-technical assistance contractor and provides technical, management, and administrative support to the RET project.

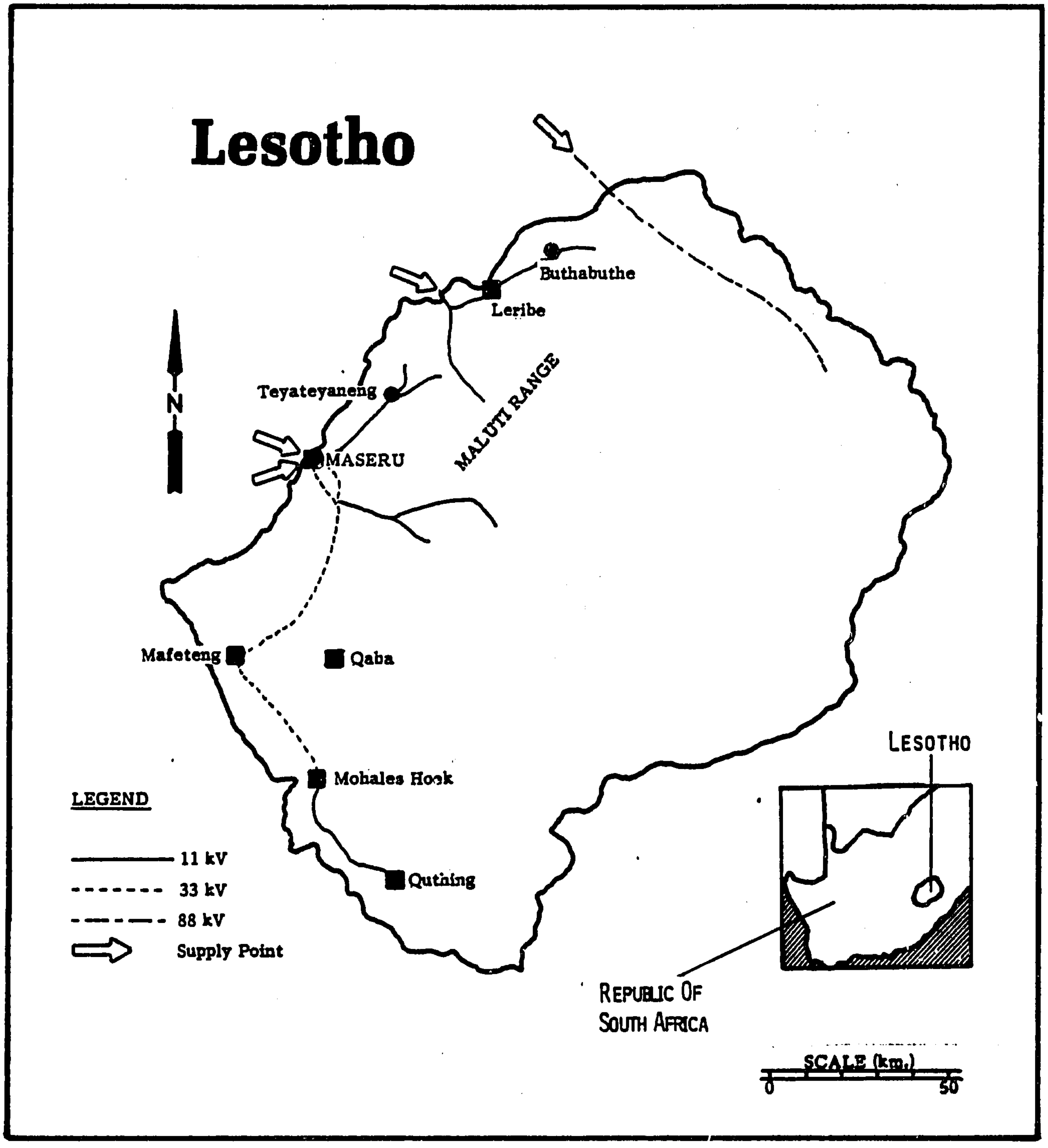


Figure 1. Existing electric transmission system.

and the European Economic Community have discussed possible financing for large hydropower schemes, and France, Norway, and the Republic of China (Taiwan) are looking at small hydro. All this hydropower activity raises certain questions.

- What is an appropriate hydropower development program for Lesotho?
- What role should the RET Project play in this program?
- How should RET implement these activities?

The country-wide precipitation pattern is very obviously and strongly influenced by the topography. Mountain areas receive an annual precipitation sometimes in excess of 1000 mm. Lowland areas and the internal valleys receive 500 to 800 mm annually. The area of highest precipitation that is closest to dense populations is in the Maluti Mountain Range.

Lesotho receives approximately 85% of its annual precipitation in the period from October to April. Up to 15% of the annual precipitation may fall in a 24-hour period as high-intensity thunderstorm rainfall.

The mean specific discharge exhibits the same pattern as mean annual precipitation. The excellent discussion and analyses by De Baulny[1] should be examined for further details.

**Assumptions**

For the purpose of the team's reconnaissance of potential micro-hydro sites, several useful hydrologic assumptions and approximate relationships were used.

Assumption No. 1

The team assumed that the mean specific discharge as given in Fig. 2, taken from the publication by De Baulny[1] was approximate for all sizes of drainage areas. Since this is not exact, smaller areas may exhibit a greater departure from the mean than larger areas.

Specific discharge is the mean annual runoff that can be expected from an area in a year's time and is given in units of depth. A specific discharge of 100 mm, for example, means that in a 12-month period a drainage area with such a discharge will yield a volume of water equal to the specific discharge multiplied by the drainage area. The average rate of this discharge for the 12-month period is the mean annual flow; the volume of water discharged divided by time. For a 37.5 $km^2$ drainage area with a specific discharge of 100 mm, the yearly volume of runoff is:

$$0.1 \times 1000 \times 1000 \times 37.5 = 3{,}750{,}000 \text{ m}^3.$$

Mean annual flow is:

$$\frac{3{,}750{,}000 \text{ m}^3}{31{,}536{,}000 \text{ sec}} = 0.119 \text{ m}^3/\text{sec}.$$

In writing this report Fig. 2 was used as a rapid means of estimating mean annual flow from ungaged drainage areas. The method consisted of calculating a coefficient equal to the mean annual flow from a drainage area of 1 $km^2$ with a mean specific discharge of 100 mm. This coefficient is:

$$\frac{0.100 \times 1000 \times 1000 \text{ m}^3}{365 \times 24 \times 60 \times 60 \text{ sec.}} = .00317 \text{ mm}$$

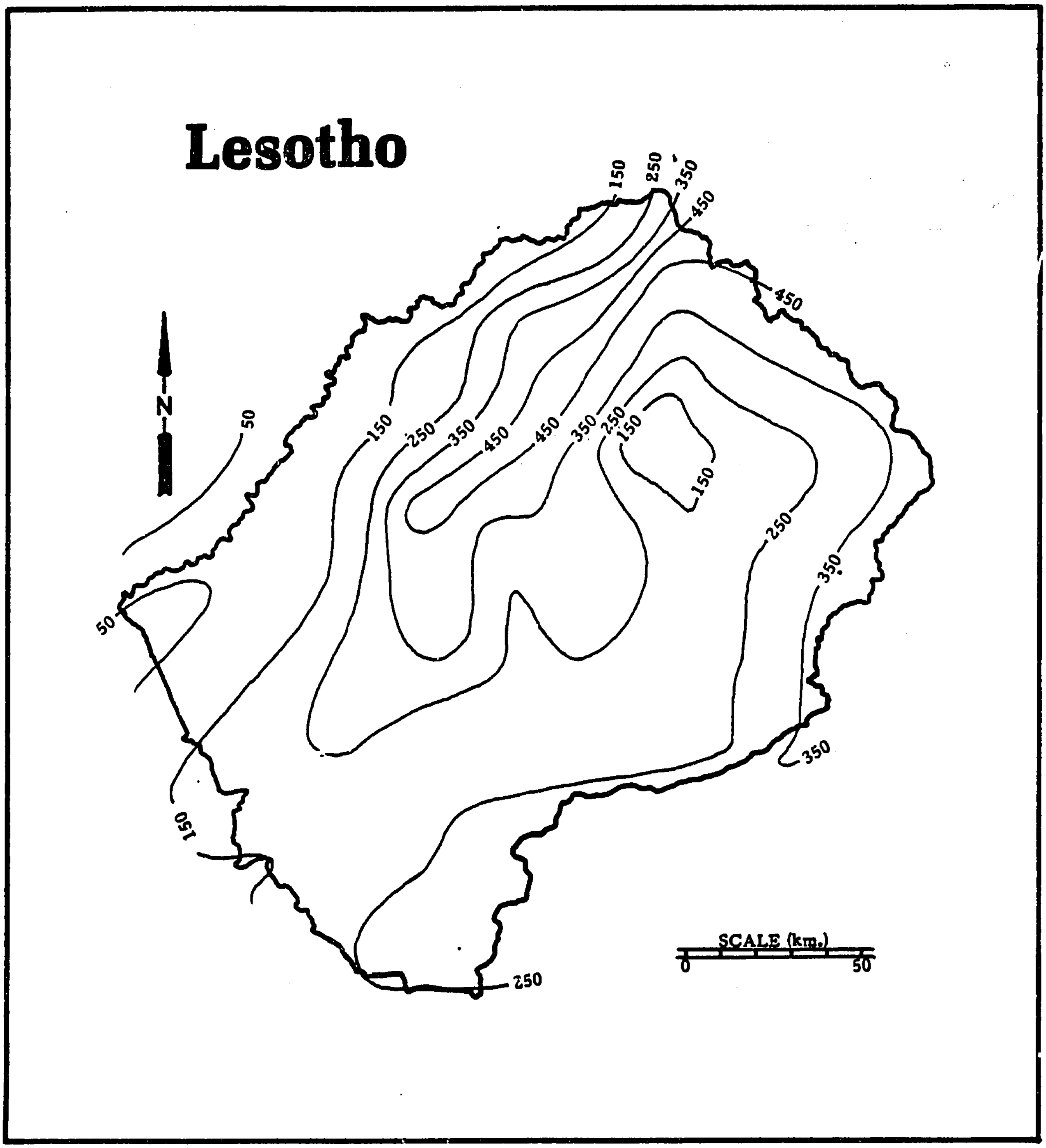


Figure 2. Mean specific discharge (mm).

Multiplying this coefficient by drainage area size in square kilometers and mean specific discharge in hundreds of millimeters produces an approximate mean annual flow.

Assumption No. 2

Another useful device was the synthesis of a dimensionless flow-duration curve from flow durations prepared for specific sites by the Sogreah Consulting Engineers[4].

This dimensionless curve is shown in Fig. 3. To use the curve, the mean annual flow for the drainage area of interest is first determined. It was assumed that the exceedence of any flow may then be determined from the graph. For example, a flow equal to 0.15 times the mean annual flow is equalled or exceeded 71% of the time.

Assumption No. 3

A third assumption used throughout this report involved turbine selection. The cross-flow turbine exhibits the best efficiency over the widest range of flows for low-head, run-of-river hydroelectric sites, and its use was assumed at all sites analyzed. Installed capacity calculations are based on mean annual flow. The minimum operating flow for a cross-flow turbine was assumed to be 15% of design, or of the mean annual, flow. The dimensionless flow duration curve indicates that, for an installation sized such that design flow equals the mean annual flow, water will be "spilling," that is, in excess of turbine capacity, about 31% of the time. Because the turbine will not operate when river flow recedes to 15% of the design turbine capacity, the turbine will run 71% of the time and be shut-down the remaining 29% of the time.

If the turbine is sized for a design flow of less than the mean annual flow, it can operate for a greater percentage of the time, as shown in the following tabulation:

| Design flow as fraction of mean annual flow | Shut-down flow (0.15 x column 1) | Percent of time turbine can run |
|---|---|---|
| 0.75 | 0.112 | 75 |
| 0.50 | 0.075 | 81 |
| 0.25 | 0.038 | 91 |

A turbine selected to operate a high percentage of the time will deliver less capacity. The solution to this problem is to install water storage capability, which involves sedimentation problems and high cost, or to install an additional turbine. Neither solution is cost effective, generally, for small installations.

**Accuracy**

A brief discussion of the magnitude of probable errors in the hydrologic calculations may be useful. Hydrometric data is difficult to gather and is subject to a great many possible errors. In the team's judgment, the Lesotho data collection network is well designed and maintained and, thus, the basic specific discharge data is estimated to be accurate to 5%.

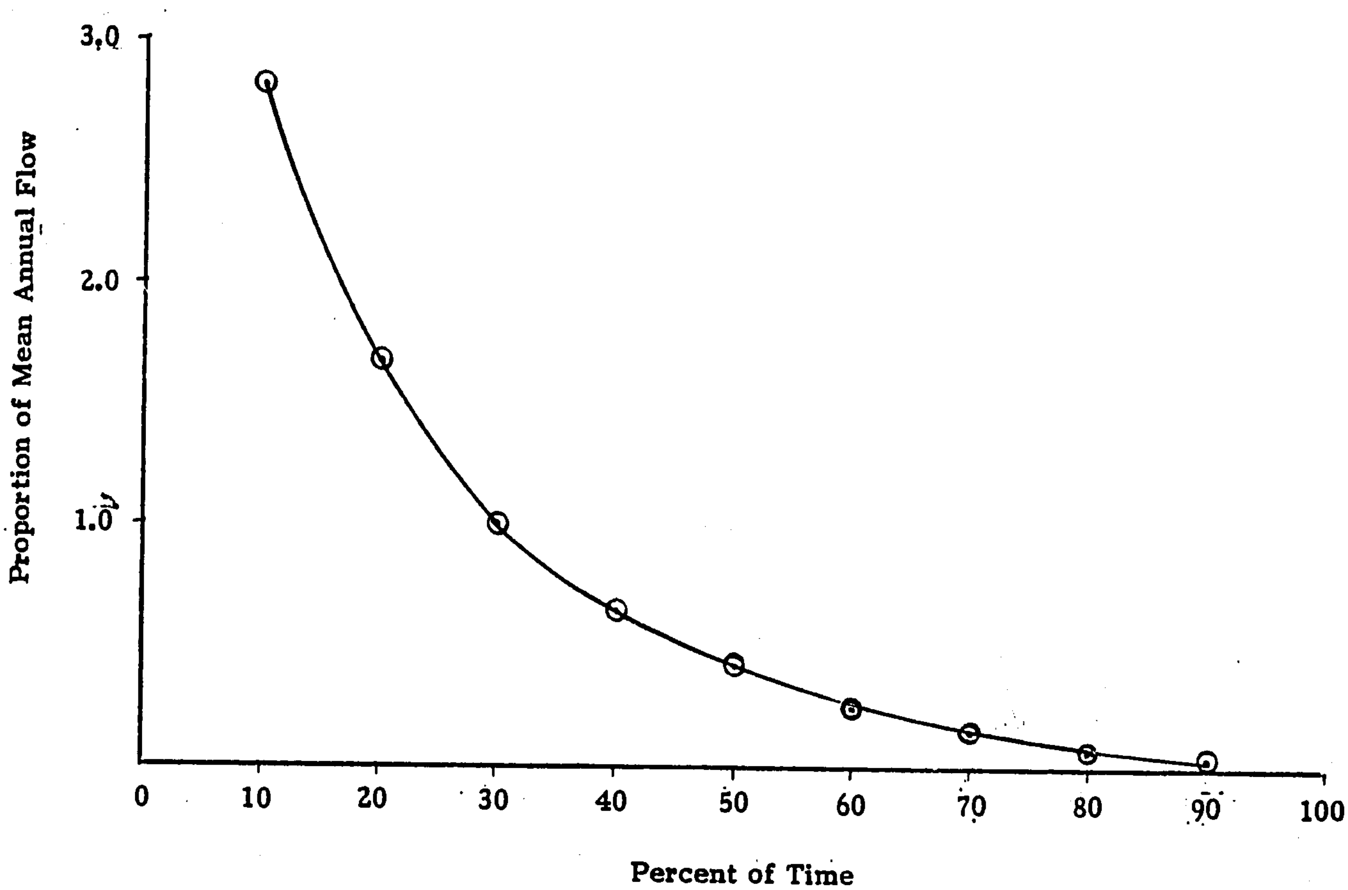


Fig. 3. Dimensionless flow duration curve based upon the report by Sogreah[4].

Small watersheds produce a higher yield than large watersheds during normal and wet years, and lower yields during droughts. For Lesotho, this report assumes discharge from a small mountain catchment may be plus or minus 10% of the mean as was estimated by De Baulny. Drainage areas referred to in this report were delineated on 1:50,000 maps and measured approximately. Errors could be within plus or minus 10%.

If these errors should all accumulate, the team's estimates of mean annual flow could be in error by about 25%. This is possible but not probable. A more reasonable standard error to apply to mean annual flow figures is probably 20%. When applied to the three Sogreah sites[6] the method used in this report produces the results shown in the following tabulations:

| Site | TLOKOENG | MOTETE | QACHA'S NEK |
|---|---|---|---|
| Drainage Area, $km^2$ | 852 | 261 | 750 |
| Specific discharge; mm from De Baulny[1] | 200 | 400 | 200 |
| Mean annual flow, $m^3/s$ by Sogreah[6] | 5.06 | 2.648 | 4.52 |
| Mean annual flow $m^3/s$ by this report | 5.40 | 3.31 | 4.76 |
| Error in percent | +6.7 | +25.0 | +5.3 |

## Scale of development

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Lesotho has several options for developing hydropower potential. The choice for the scale of development can generally be divided into large hydro (greater than 10,000 kW), mini-hydro (100 kW to 1,000 kW), and micro-hydro (less than 100 kW). The energy needs can be divided into supplying: the national grid; local, decentralized grids; and isolated religious missions, cottage industries, and villages in the rural areas. Each scale of development is appropriate for particular needs, and each has its own characteristics and recommended implementation procedures.

### Large-scale hydropower

Large-scale development projects are usually characterized by a dam with reservoir for seasonal storage, large turbo-generating units, an extra-high-tension substation, and a transmission line serving urban/industrial load centers. The typical physical features are large drainage basins, significant rainfall, and narrow gorges for a dam site, all located within a reasonable distance from large load centers. Large hydropower facilities generally provide economy-of-scale benefits such as lower per kW busbar cost, centralized management, detailed engineering studies and design, and multi-purpose water resource benefits such as flood control, fisheries, and recreation. They can attract financing from international financial institutions. Disadvantages of large-scale development are that it requires large amounts of capital and long lead times, can have significant environmental impacts, and can drain the technical and managerial resources of a small country.

Lesotho has the features necessary for large-scale development. The proposed Highlands Water Project is expected to supply the country's electricity needs when completed. This massive US$ 1,250 million project is now entering the detailed feasibility study stage with construction scheduled to begin in 1985. The proposed scheme would develop 190 MW of capacity and at the same time, supply the Republic of South Africa with 35 $m^3$ of water per second. The European Economic Community has provided a grant to assist the GOL with the detailed feasibility study.

The Highlands Water Project appears to offer tremendous benefits to both Lesotho and the Republic of South Africa. Since it will supply most of Lesotho's future electric grid demand, other large-scale hydropower schemes should not be pursued at this time. However, should the project prove infeasible, the GOL would be wise to have alternative large hydropower schemes inventoried for feasibility studies.

Although Lesotho has the natural features for large hydropower projects, projects constructed at today's prices will probably be more expensive than the short-term alternative of purchasing power from the Republic of South Africa.

### Mini-hydropower development

The characteristics of mini-hydropower schemes are usually a small dam or diversion weir and a steel penstock leading to a powerhouse containing the turbine, generator, and control equipment. Power is distributed over high-tension lines supplying a national grid or a small, local electric grid. The streams flow year-round, and the systems are generally large enough to support professional powerplant managers and operators.

Mini-hydropower plants in Lesotho would be appropriate for serving a limited number of district centers not served by the national grid. The French engineering firm, Sogreah, has studied nine such sites, and completed feasibility level studies on the three preferred sites[6]. The remaining sites have marginal feasibility. Because the number of mini-hydropower schemes is quite limited and the French have studied and discussed financing the best of these, the team recommends no activities for isolated units in the 100 kW to 1,000 kW range.

**Micro-hydropower development**

The characteristics of micro-hydropower schemes include diversion weirs for year-round streams, a power canal (or headrace), forebay, steel or PVC penstock, and powerhouse. The power can be used at the powerhouse in the form of mechanical shaft power or converted to electric power and distributed to nearby electric loads. Micro-hydropower is appropriate for serving small dispersed loads not served by the national electric grid. They are too small, generally, to be effectively managed through a national institution and, therefore, must depend upon a local institution for proper management and operation. Small grinding mills and religious missions have proved to be effective institutions for ensuring good management of micro-hydropower systems.

Lesotho has numerous, small energy loads dispersed in the rural areas, including a few that could be served by micro-hydro systems. Most of these installations would be low-head, and, hence, potential sites are difficult to locate on existing contour maps. From the limited field work done by the team, it is estimated that there are approximately 20 to 40 feasible sites in Lesotho, with an average capacity of 25 kW. The general features of these sites are sketched in Fig. 4 and discussed later in the site selection section.

Another form of micro-hydropower that appears feasible for Lesotho is the use of hydraulic rams for pumping water for household uses. They could also be used for irrigation if implemented along with soil conservation practices.

MICRO HYDROPOWER SCHEME

TYPICAL LOW-HEAD INSTALLATION

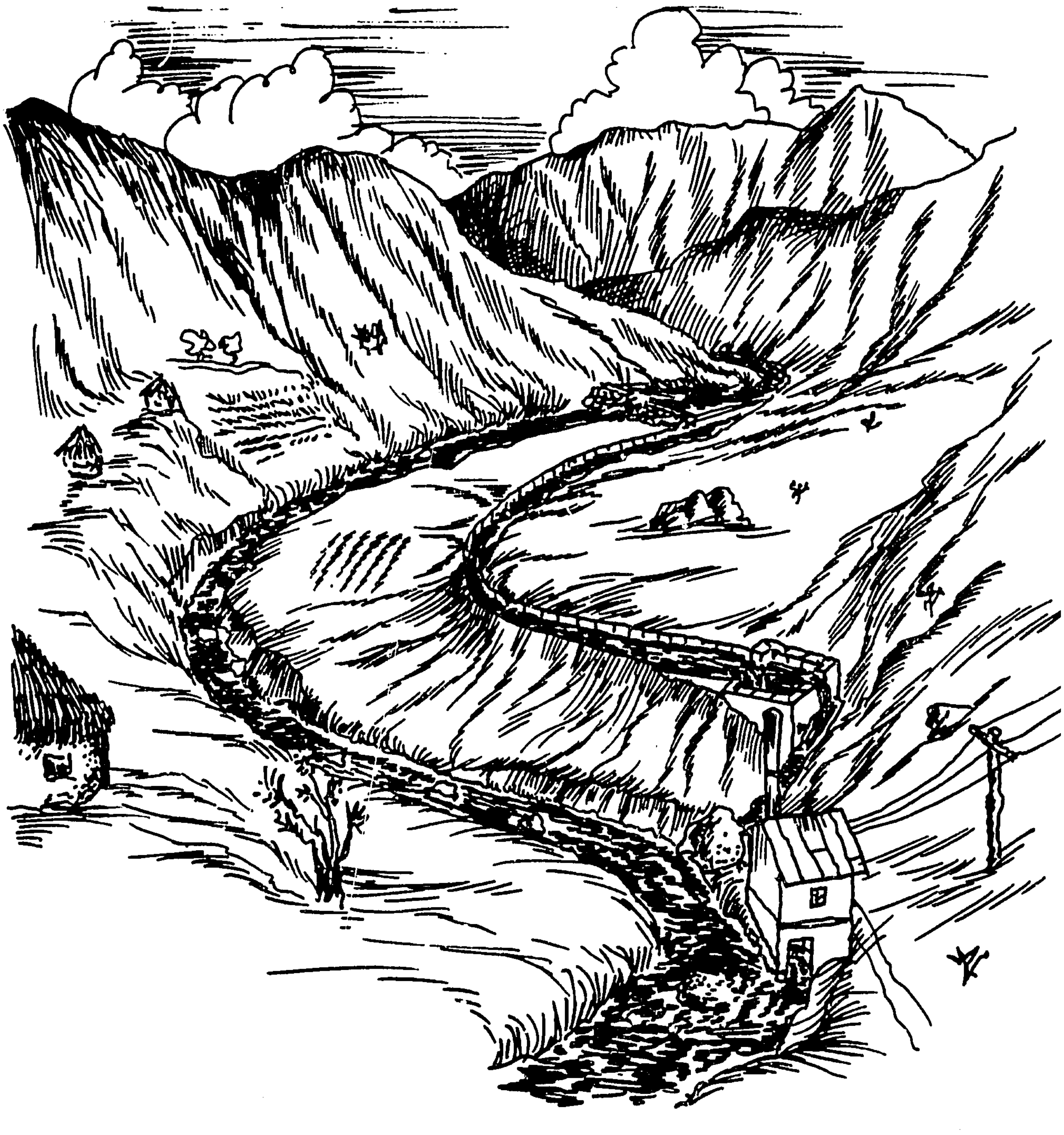

**Figure 4. Micro hydropower scheme: a typical low-head installation.**

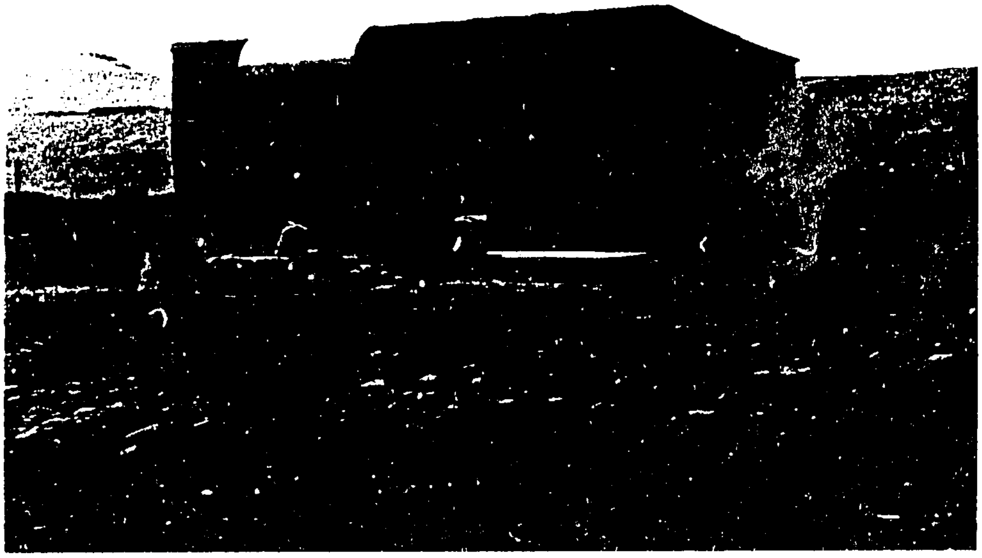

**Fig. 5** Typical rural flour mill

**Fig. 6** Typical small waterfall with micro-hydro potential.

## Evaluation of potential sites

The hydro team visited 14 potential sites during the course of its assignment. This section of the report describes the criteria used to select areas for field reconnaisance and briefly summarizes the field observations.

### Selection criteria

An adequate flow of water is an obvious and important criteria for successful hydropower installation. The team, therefore, selected sites for field reconnaisance from the area of Lesotho that has a mean annual specific discharge of at least 300 mm. (A site should also preferably have perennial flow.) This criterion correlates well with the front range of the Maluti Mountains. The team made an exception to this criterion to include a lowland drainage area on the Thupa-Kubu river since it is so close to Maseru.

A potential site should have a minimum head of 5 m. At least 3 m should result from a natural falls, and less than 2 m from a weir. With less than 5 m of head, the turbomachinery cost becomes prohibitive.

Another criterion considered was size of drainage area because area determines, to an acceptable level of accuracy for reconnaissance, the magnitude of the mean annual flow that can be expected at the site selected for study. From analysis of data and interrogation of local people, the team determined that a drainage area of at least 30 $km^2$ is required for a perennial flow of sufficient quantity to make a low-head microhydropower installation feasible.

The fourth criterion was proximity to load or potential load. This was estimated from maps and from knowledge of the area.

Distance from the existing LEC distribution lines was also considered, and sites generally that were at least 10 km from the existing grid were selected. Some exceptions were made when, in the judgment of the hydro team, it was unlikely that an extension of distribution lines into the area would occur in the foreseeable future.

Finally, vehicular access to the site was considered. Reasonably good access also reduces construction costs and enhances the economic feasibility of the installation. In addition a site developed for demonstration purposes should have reasonably good access by persons interested in adapting hydropower technology to their own specific energy needs. With these criteria as guides, 14 sites were selected for field visits. The location of these sites is shown in Fig. 7.

### Site descriptions

The first two sites are near Ha Khanyetsi on the Makhaleng River, located at 29°34' S, 27° 52' E. The drainage area is about 338 $km^2$, and mean annual flow is approximately 3.2 $m^3/s$. Site 1 is the upstream waterfall 300 m south of the St. Benedict's Clinic (Fig. 8); Site 2 is the downstream waterfall 750 m southeast of the clinic. Both sites are at about elevation 1750 m, situated in a narrow valley 100 m lower in elevation than the clinic.

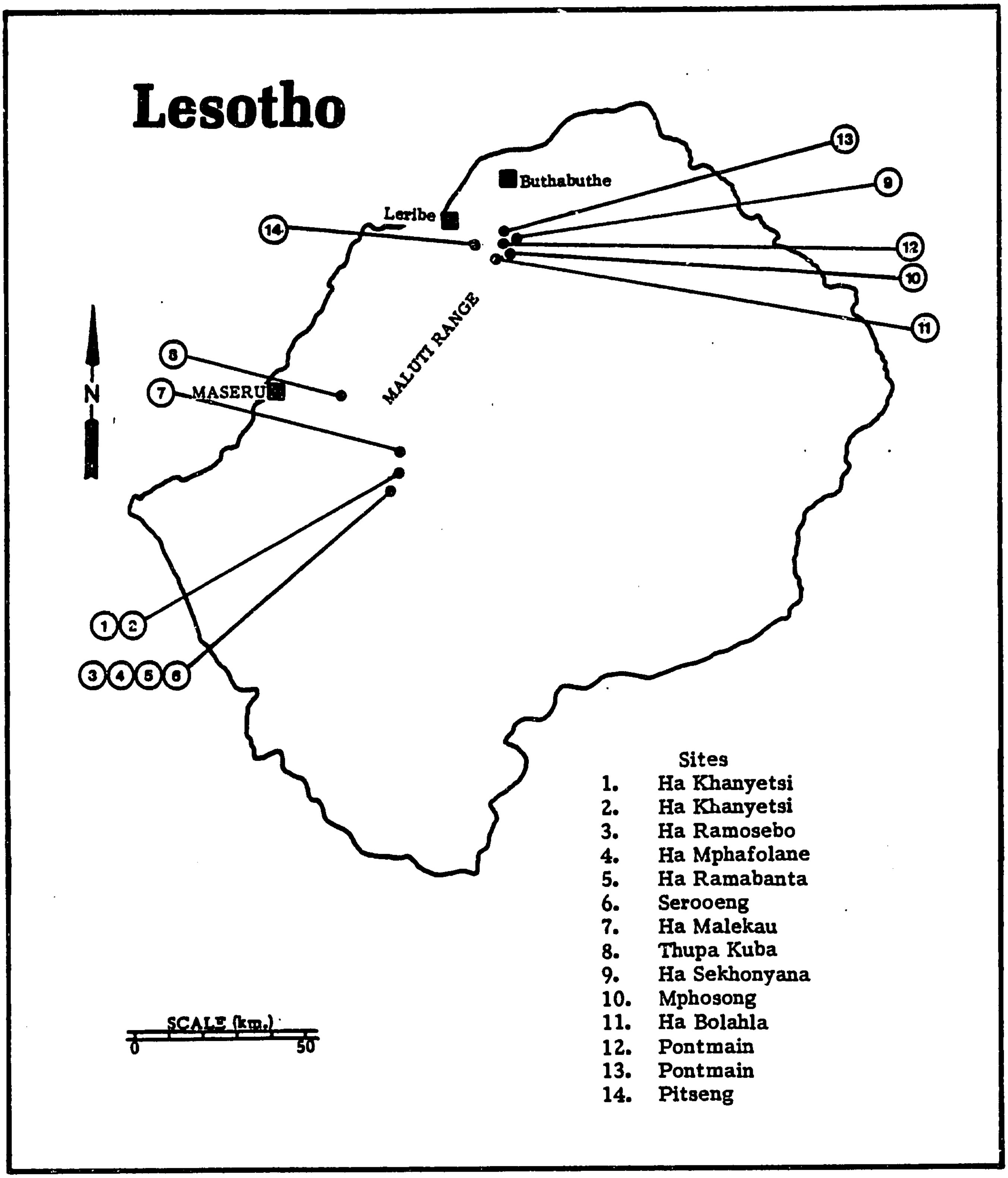


Figure 7. Site locations.

Site 1, the upstream site has a developable head of 4.5 m. A proposed development scheme consists of a low rock barrier across the river to divert flow to an intake, a concrete lined canal, 160 m in length leading to a concrete headworks, a penstock 7 m in length running from the headworks down to the powerhouse and back to the river (see Fig. 4).

Although time did not permit the hydro team to conduct a thorough analysis of the existing and projected load for the area, it is reasonable to estimate a development of 30 to 40 kW for the clinic, school, store, church, homes, and mohair spinning facility. Development of 35 kW would require diversion of 1.24 $m^3/s$, a flow that is available about 53% of the time. A crossflow turbine could operate down to a flow of about 0.19 $m^3/s$, a flow that is available about 84% of the average year. The facility would be shut down about two months a year, probably in June and July, for lack of flow. Cost of development is estimated as follows:

Site 1, Upper Falls - Ha Khanyetsi - Diversion & canal scheme

| | |
|---|---|
| Hand-placed rock diversion, 20 man-days @ M5.00* | M100.00 |
| Intake structure including trash racks and stop logs, lump sum | M5,000.00 |
| Canal, 160 m long x 1.2 m wide x 1.05 m deep rock excavation @ M50.00/$m^3$ | M12,900.00 |
| Concrete lining including wire-mesh reinforcement @ M325/$m^3$ | M29,000.00 |
| Headworks including sluiceway, waste gate, penstock transition, concrete, etc. (lump sum) | M10,000.00 |
| Penstock; 7 m x 0.5 m diameter installed @ M240/m | M1,700.00 |
| Powerhouse, 3m x 4m = 12$m^2$ @ M1,000/$m^2$ | M12,000.00 |
| Electro-mechanical equipment 35 kW @ M1500/kW | M52,500.00 |
| Access road 1 km @ M12,000/km | M12,000.00 |
| Contractor mobilization (lump sum) | M5,000.00 |
| Subtotal | M140,200.00 |

* US $1=M1.1 (Maloti).

| | |
|---|---|
| Indirect costs @ 20% of subtotal | M28,400.00 |
| Contingency @ 15% subtotal | M21,000.00 |
| Total project cost | M189,600.00 |
| Cost per installed kW | M 5,400.00 |

This estimate is for "busbar" cost and does not include transmission, wiring of buildings, or maintenance. Unit cost figures were derived from references 3, 5 and 6, interviews with LEC officials, discussions with the RET staff, and equipment manufacturer's cost data.

From an engineering point of view, this is a developable site. There are no serious construction problems or limitations. The riverbanks and channel are stable. No prime agricultural land will be disturbed. All limitations to development are institutional, such as construction management, power-purchase agreements, and operation and maintenance. These matters are discussed further in the institutional aspects section of this report.

Site 2, the downstream site, has a developable head of 7 m. The proposed development scheme is identical with that of the upstream site except that the canal is 100 m in length and the penstock is 30 m. Because available head is greater than the upstream site, only 0.76 $m^3$/s needs to be diverted. A crossflow turbine could operate down to a flow of 0.11 $m^3$/s, a flow available 91% of the time. The facility would be shut down about a month per year on the average. The cost of developing a 35 kW installed capacity is as follows:

Site 2: Lower Falls - Ha Khanyetsi

| | |
|---|---|
| Hand-placed rock diversion, 20 man-days @ M5.00/man-day | M100.00 |
| Intake structure including trashracks and stop logs | M5,000.00 |
| Canal, 100 m x 1.2 m x 0.6 m deep, rock excavation = 116 $m^3$ @ M50 /$m^3$ | M5,800.00 |
| Concrete lining including wire-mesh reinforcement, 42 $m^3$ @ M325/$m^3$ | M3,650.00 |
| Headworks including sluice way, waste gate, penstock transition, rock excavation, concrete, etc. | M10,000.00 |
| Penstock; 30 m x 0.5 diameter installed @ M240/m | M7,200.00 |
| Powerhouse, 3 m x 4 m 12 $m^2$ @ M1,000/$m^2$ | M12,000.00 |

| | |
|---|---|
| Electro-mechanical equipment<br>35 kW @ M15,000/kW | M52,500.00 |
| Access road<br>1.5 km @ M12,00/km | M18,000.00 |
| Contractor mobilization | M5,000.00 |
| Subtotal | M129,250.00 |
| Indirect costs @ 20% of subtotal | M25,850.00 |
| Contingencies @ 15% of subtotal | M19,400.00 |
| Total project cost | M174,500.00 |
| Cost per installed kW | M5,000.00 |

Costs of transmission and wiring of buildings are not included. This site presents no difficult engineering problems. The riverbanks and channel are stable. An excellent site for an intake is available at a naturally-scoured bedrock riverbend upstream of the falls.

A different development scheme can be applied to waterfall sites such as the two described above. This scheme would include a concrete sill extending across the river and dowled to bedrock. The sill would be fitted with hinged flash boards with pins holding the flash board sections in place. The pins would be of a designed strength and diameter that would cause them to bend or break during deep flood flows, allowing the flash board sections to hinge down to a horizontal position. This would permit the flood flow, which carries most of the sediment load, to pass through the installation without impedance and deposition of sediment. High flows would also flush out any accumulation of sediment that may have built up in the impoundment area during flows when the flash boards were up.

A wing wall would extend from the flash boards to an impervious stratum in the riverbank. An intake located in one of the wing walls would divert flow to a penstock which conveys water to the powerhouse.

Advantages of this development scheme include: more available head, no canal, short penstock if the powerhouse and dam can be co-located, and sediment control. Disadvantages are higher operation and maintenance costs.

As an example and for comparison, this scheme has been applied to the upper falls (Site 1) at Ha Khanyetsi in the cost estimates:

Site 1: Upper Falls - Ha Khanyetsi - Sill & Flashboard scheme.

| | |
|---|---|
| Concrete sill and wing walls (60 cm thick, 17 m sill, 45 cm high; 33 m wings 2 m high) 44 $m^3$ @ M325/$m^3$ | M4,300.00 |
| Flash boards 25.5 $m^2$ @ M21.50/$m^2$ | M500.00 |
| Hinges and Pins, x 17 sections @ M40/section | M700.00 |
| Intake, (trash racks, stop logs, transition) | M5,000.00 |
| Penstock, 50 m long, 0.5 m diameter installed @M 240/m | M12,000.00 |
| Powerhouse, 3 m x 4 m @ m 1000/$m^2$ | M12,000.00 |
| Electro-mechanical equipment 35kW @ M1500/kW | M52,500.00 |
| Access Road 1 km @ 12,000/km | M12,000.00 |
| Contractor mobilization | M5,000.00 |
| Subtotal | M114,050.00 |
| Indirect costs @ 20% of subtotal | M22,800.00 |
| Contingency @ 15% of subtotal | M17,100.00 |
| Total project cost | M153,950.00 |
| Cost per installed kW | M4,400.00 |

Map readings indicated several possible sites in the area of Makhaleng; Ha Ramabanta which were then examined in the field.

Site 3 is located on the Likolobeng River between Ha Ramosebo and Ha Marai at latitude 29° 40' S, longitude 27° 50' E. The team found no feasible sites.

Site 4 is located on an unnamed tributary of the Makhaleng River to the northeast of Ha Mphafolane at latitude 29° 41' S, longitude 27° 48' E. No feasible sites were found in this reach of the river.

Site 5 is located on the Mahaleng River directly east of Ha Ramabanta at latitude 29° 40' S, longitude 29° 48' E. No feasible sites were found in this reach of the river.

Site 6 is located on the Makhaleng River to the southwest of Serooeng at latitude 29° 37' S, longitude 27°46' E. No feasible sites were found in this reach of the river.

Site 7 is located on the Phororong River just downstream of the confluence with the Furumela, north-northeast of Ha Malekau, at latitude 29° 29' S, longitude 27° 52' E. It is marginally feasible. The drainage area is about 45 $km^2$ and the mean annual flow is approximately 0.50 $m^3/s$. A head of 5 m could be developed by directing the river into a canal at a bend and carrying the canal downstream for 330 m to a headworks/penstock/powerhouse. The penstock would convey water from the headworks on the north bank to the powerhouse on the south bank. The canal would be lined with plasticized nylon along the earth-cut section to minimize seepage and concrete along the rock-cut sections. The canal would be trapezoidal with 1 1/2 to 1 side slopes, 1 m wide at the invert, 0.36 m deep, and would have a slope of 0.001. The penstock would be 16 m long. This site could be developed for an installed capacity of 15 kW for a cost of approximately M5,000 per kW. The installation would be shut down 30% of the time due to low flow.

Actively eroding stream banks and mass movement of the hillside above the canal make this a marginally feasible site. Potential loads are a store and mill approximately 720 m from the powerhouse and a Roman Catholic outpost 560 m away. The clinic has been destroyed by a wind storm and the school is to be moved out of the potential service area.

Site 8 is on the Thupa-Kupu River 2.3 km above the confluence with the Phuthiatsana River at latitude 29° 19' S, longitude 27° 41' E. The drainage area is about 90 $km^2$ and mean annual flow is approximately 0.42 $m^3/s$. This site has a waterfall and a developable head of 10.5 m (Fig. 9).

The proposed development scheme consists of a diversion structure consisting of 17 m of flash boards on a concrete sill, an intake canal of 61 m, a headworks, a penstock of 37 m, a small powerhouse, and tailrace.

The site could be developed for an installed capacity of 30 kW. The installation would be shut down about 30% of the time due to low flow. If the site were developed for one-half the mean annual flow it would have a capacity of 15 kW and be shut down about 20% of the time. The section on hydrology provides an explanation of these relationships.

There are no engineering constraints to development. Riverbanks are constrained by bedrock. The powerhouse can be adequately protected from floods by locating it behind an outcrop on the east bank and by rip-rap.

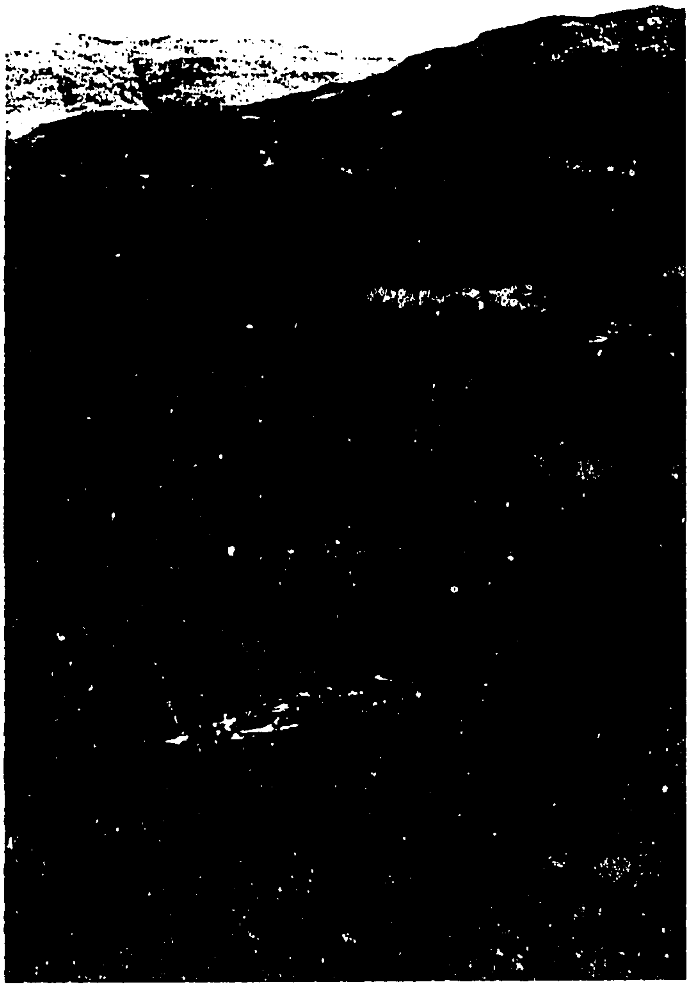

Fig. 8. Site 1: Khanyetsi; upper falls. Picture taken from plateau next to the Mission.

Fig. 9. Site 8: Thupa Kuba. The 6 m falls is located next to the pine trees. Picture taken from plateau next to the closest village.

The nearest existing load is the Thaba-Bosiu complex 3.6 km from the powerhouse. Line construction would be expensive from the powerhouse downstream for the first 2 km. The distance is too great and construction too difficult to justify suppling Thaba-Bosiu. However, a mill or some other agricultural load might be established at the site, which is adjacent to extensive, prime agricultural lands.

Site 9 is located on the Morotoaneg River near Ha Sekhonyana at latitude 28° 58' S, longitude 28° 18' E. An examination of several kilometers of the river failed to turn up any developable sites.

Site 10 is located on the Mphosong River near Mphosong at latitude 29° 01' S, longitude 28° 17' E. A search of several kilometers of the river produced one site that could be developed. This would require the construction of a dam on bed rock at the entrance to a gorge approximately 0.9 km north-northwest of the Road Works Department station at Ha Nkoana. This would require a concrete dam about 8 m in height and 15 m across as measured along the dam crest.

Mean annual flow is 0.83 $m^3/s$. The drainage area is about 58 $km^2$. A capacity of approximately 45 kW could be developed here. Due to the need for a dam it would be an expensive site to construct and very little load now exists within the service area. The Road Works' station appeared to be a storage depot with little energy requirement.

Site 11 is located on the Bolahla River near Ha Bolahla at latitude 29 011' S, longitude 28 15' E. No feasible sites were found in this area.

Site 12 is located along the Mphosong River east of the Pontmain Roman Catholic Mission, at latitude 28° 58' S, longitude 28° 14' E. A search of 2 to 4 km of river above the confluence with the Morotong failed to turn up any feasible sites.

Site 13 is a dam site on the Morotong River approximately 1.5 km downstream from the confluence with the Mphosong and 3 km north of the Pontmain Roman Catholic Mission at latitude 28° 57' S, longitude 28° 13' E. The drainage area is approximately 285 $km^2$ and the mean annual runoff is about 3.6 $m^3/s$. A dam approximately 30 m high would have an installed capacity of about 750 kW at an approximate cost of M 2,700,000 which is equivalent to M3,600 per installed kW. Such an installation, when properly analyzed, may prove to be a feasible source of electrical energy for the national distribution system of the LEC. The team did not have enough time on-site to investigate the possibilities further.

Site 14 is a dam site located on the Tsunyane River at the National Hydrometric Station numbered G-34 and at latitude 28° 57' S, longitude 28° 08' E. This site has been studied by engineers from the Republic of China and an excellent report has been submitted to the GOL.

This site, which will be referred to as the Pitseng site, was selected by the Taiwanese engineers for development. The team concurs with their choice of this site.

The team suggests that a less expensive alternative development scheme be considered. This would include the dam as proposed, a 210 m canal, a short penstock, and a powerhouse all on the south bank instead of the north bank of the river. This configuration would develop more head and may prove economical in the long-term. Our estimates indicated a gross head of about 11.4 m between the tailwater of our suggested configuration and the crest of the overflow section of the existing weir.

The members of the hydro team have rated those sites that have some potential for development. Each site was judged in each category and rated from one to ten (ten being the best). The results are given in Table 1.

TABLE 1 Summary of sites

| Site name | Khanyetsi | Khanyetsi | Ha Malekau | Thupa-Kubu | Mphosong | Pontmain | Pitseng |
|---|---|---|---|---|---|---|---|
| Site number | 1 | 2 | 7 | 8 | 10 | 13 | 14 |
| Size, $km^2$ | 338 | 338 | 45 | 90 | 58 | 285 | 135 |
| Mean Annual flow, $m^3/s$ | 3.2 | 3.2 | 0.5 | 0.42 | 0.83 | 3.6 | 1.3 |
| Distance to Load, km | 0.30 | 0.75 | 0.72 | 3.6 | 0.9 | 3.0 | 3.0 |
| Access (poor, fair, good) | P | P | F | F | P | G | G |
| Installed capacity, kW | 35 | 35 | 15 | 30 | 45 | 750 | 70 |
| Cost per installed kW, M | 5,400 | 5,000 | 5,000 | - | - | 3,600 | 5,100 |
| Construction problems (none, moderate, or severe) | M | M | S | M | M | M | M |
| Rating | 6 | 7 | 3 | 6 | 3 | 7 | 10 |

The power available from an isolated micro-hydro installation in Lesotho will vary dramatically between the wet and dry seasons. Hence, not all the standard electrical devices are appropriately served by them. In some cases, the community may be willing to change its use patterns to fit the power supply. Determining the potential uses for micro-hydro in rural communities will require knowledge of the Basotho people and careful analysis of their needs. This is not a task consulting engineers can address adequately.

**Micro-hydro**

The team recommends that the RET Project begin its work in micro-hydropower on a joint basis with another institution. RET should focus its effort toward the skills it presently has in-house; collecting base socio-economic data; introducing productive uses of electricity to the community; and evaluating the technical, economic and social feasibility of micro-hydro. A cooperating institution should be sought to provide the financing, design, construction, and project management. After RET has helped implement a project and evaluated the feasibility of a typical installation, it can consider developing its in-house technical capabilities. During the hydro team's stay in Lesotho, we learned of two possible projects that RET might work with: (1) the micro-hydro installation at Thaba Tseka, and (2) the proposed installation at Pitseng.

The team did not visit Thaba Tseka site but, from discussions, learned that the project has been constructed but is experiencing some technical problems. First, the electronic load controller is not functioning properly and has been by-passed. Second, the unit is not reaching rated output, probably due to installing a Pelton unit at a site with insufficient head. These problems can be corrected and the site can be used to conduct the socio-economic studies desired by the RET Project.

A better site is the proposed 70 kW installation at Pitseng. It appears likely that the Republic of China will finance, design, and construct this site. However, its studies did not address the uses of the power, the implementation process, and the institutional arrangements for operating and maintaining the system. Hence, the hydro team believes this is an excellent opportunity to combine the technical skills of the Taiwanese with the RET community skills. A detailed description of the proposed site is given in the reconnaissance report, Lian, et al [3]. The site was visited by the team and found to meet all the selection criteria. A proposed institutional arrangement is described in the Institutional Aspects section.

**End-use planning**

Due to the wide variations in seasonal stream flows in Lesotho, the amount of available power from a micro-hydro installation will vary seasonally. In areas with similar hydrologic conditions, diesel generators commonly supplement hydro units during the dry seasons. Where back up power supplies are not installed, the energy end-uses for the system must be planned carefully.

End-use planning should begin by looking at which potential loads require a year-round reliable source of electricity. Rural medical clinics are good examples. Restaurants usually require year-round service before owners will invest in cold storage facilities. Hotel owners generally want similar service. The total of these loads should be less than the minimum power output of the system. For the crossflow turbine, the minimum output is approximately 15% of the rated output. This minimum output will also correspond with the stream minimum-flow conditions during the dry season.

After the year-round loads have been determined, the remaining power available can be used to serve seasonal and interruptable loads.

Continued work with end-use planning is needed to determine the patterns of electrical usage and how it can be fitted to available hydropower capacity. RET has the capability to perform this important role.

The question often is asked, is micro-hydropower an energy project or a rural development project? Since the use of micro-hydro energy in Lesotho will have negligible impact on the country's overall energy imports, generally requires subsidies, and provides benefits primarily to rural communities, it should be considered a rural development project. Hence, the lead agency for micro-hydropower development should be the Ministry of Rural Development (MORD). However, the expertise required to implement hydropower projects exists in the Ministry of Water, Energy, and Mining (MOWEM) and in LEC. Hence, institutional arrangements should be established to allow MORD to tap the existing expertise in the GOL on a limited basis. Additional arrangements must be secured between the lead agency and the community receiving electric power.

## Government

It is recommended that MORD be the lead agency for hydropower projects of under 100 kW capacity and not interconnected to an electrical grid. A memorandum of understanding between MORD and MOWEM should allow for MOWEM to provide a limited number of man-hours per year for technical assistance concerned with:

- Hydrology of potential sites,
- Review and comment on final design and machinery specifications
- Training of operators
- Construction management
- Special maintenance.

## Community

It is easy to conceptualize possible uses of electricity for a target community, but the financial feasibility of the project depends upon the income generated from the sale of electricity to potential loads that may take several years to develop. Those implementating projects are often asked to convince people to invest in electrical devices, change their daily habits, and to sometimes upset their existing social structures. This process can be especially slow in communities that have not formally requested electric power service but, rather, happen to be located close to a hydropower site that the Government wants to develop.

To minimize the risk of the projected load developing too slowly, the team recommends that MORD secure from consumers in the target community signed agreements for the purchase of at least half of the plant capacity before a project advances to construction. The purchase agreements must be based upon realistic cost estimates and the consumers must understand exactly what the project will provide and what they must fund. For example, will the project provide an electrician to wire a water pump?

**Pitseng**

Special arrangements should be agreed upon for the proposed Pitseng site to involve the staff of the RET Project. Such agreements will, of course, have to be negotiated, but the recommended arrangements follow. It is assumed that the Republic of China will:

- finance the civil works, powerhouse, turbo generating unit, switchgear, and high-tension distribution
- prepare final designs
- provide a technical mission to implement and manage equipment and construction contracts.

MORD should be the owner and will assume the responsibilities of lead agency to include providing work space, clerical support, and general logistical support for the technical mission. MORD will act as project coordinator, requisition the land, facilitate importing materials and equipment, and assume responsibility for the day-to-day operation of the plant.

RET will be responsible for identifying potential uses for the power, securing purchase agreements, collecting base socio-economic data, financing low-tension and household wiring, assisting with the financing of electrical devices, demonstrating the uses of electrical power, and evaluating the project after a set number of years.

LEC will be responsible for providing electrical equipment specifications, establishing operating procedures, and training operators. LEC should assist with special maintenance and future line extensions.

It is recommended that one person be hired on a full-time basis to operate the plant, perform routine maintenance of the power plant and electrical distribution system, and collect revenues. The operator should be an employee of MORD, trained by LEC, and provided with the necessary tools for technical support and procedures to manage the small power system.

Rates should be established to pay for the operator, establish a sinking fund for maintenance, repairs, replacements, and pay debt service.

An alternate institutional arrangement is for MORD to lease the power plant to a local institution such as the church and require it to run the system on a business-like basis. Agreements would have to be drawn up concerning such matters as the electric service provided to the community and maximum rates.

1. De Baulny, H.L., "Regional Assessment of Surface Water Resources," Department of Water Resources, Ministry of Water, Energy, and Mining, Lesotho, May 1980.

2. Jacobi, Suen, "Sediment Load Estimates of Rivers in Lesotho," Ministry of Works, Department of Hydrological and Meteorological Services, June 1977.

3. Lian, Tohy T.L., Hsu, K., Chang, H.C., "Reconnaisance Report on the Mini-Hydroelectric Project in the Lowlands of the Kingdom of Lesotho," Taiwan Power Company, October 1981.

4. Sebatane, E.M., "Electricity." Lesotho Electricity Corporation, 1982.

5. Sogreah Consulting Engineers, "Development of Small-Scale Hydroelectric Power Plants in Lesotho Highlands, Interim Report," May 1981.

6. Sogreah Consulting Engineers, "Development of Small Scale Hydroelectric Power Plants in Lesotho Highlands, Preliminary Designs for Priority Sites; Tlokoeng, Motete, Qacha's Nek," September 1982.

7. "Lesotho, Renewable Energy Technology (632-0206)," AID Project Paper, August, 1979.

The following is the scope-of-work for the mini-hydro assessment team taken from cable "STATE 070108".

1. Team consisting of hydrologist, Martin Johnson and an NRECA engineer Bard Jackson, or Allen Inversin will be available for the proposed effort after May 16 for four weeks.

2. The revised terms of reference and scopes for mission review are as follows:

**Purpose :**

The purpose of this assignment is to support the mission in examining the potential for small hydropower in Lesotho.

**Terms of reference :**

A two-man team will assess the potential for small hydropower in Lesotho. Their activities will include:

A. Review existing hydrologic and potential hydroelectric data in Lesotho; examine electrical energy policy and plans and determine what size sites are the best; identify other donors' plans re: hydropower,

B. Identify and visit potential sites to confirm basic data, observe near-by activities to identify potential loads and distance to power grid,

C. Recommend appropriate scale of development, grid supply, local distribution system, or small captured load.

D. Assist in obtaining cost data for construction materials, distribution lines, and mechanical equipment. Provide the mission with list of equipment manufacturers and instructions for preparing specifications.

E. Prepare written report for AID/Maseru and give oral presentation before leaving Lesotho. Draft report to be prepared before departure, and final report delivered to mission within six weeks of teams departure.

In performing the above task, the team will work with Dr. Judy Gay, Social Scientist, and Basotho counterparts to be identified by AID/Maseru.

The two-man team to consist of a small hydro engineer and a civil engineer.

**Scope of work - Small hydro engineer**

The small hydro engineer will be responsible for the electrical - mechanical aspects of the assignment and serve as team leader with overall responsibility for conducting the assessment and preparing the report. Specific tasks are:

- review of electric energy policy and plans to determine the appropriate size,
- visit potential sites to propose a system layout and identify constraints, observe local activities,
- provide mission with list of manufacturers and instructions for preparing machinery specifications,
- develop electrical and mechanical cost estimates based upon the observed features in Lesotho,
- prepare that portion of the draft report covering the above topics,
- give oral presentations to mission of the team's major findings and recommendations.

**Scope of work - Civil engineer:**

The civil engineer will be responsible of the civil aspects including the hydrologic, hydraulic, soil, structural, and environmental issues. His duties will include:

- locating and reviewing hydrologic and topographic data to locate potential sites;
- visit potential sites and propose locations for all the civil structures depending upon soil conditions, environmental impacts, cost, etc.,
- develop labor and materials (concrete, penstocks, etc.) cost estimates,
- prepare that portion of the draft report covering his assigned duties,
- other duties as assigned by the team leader.