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SMALL DECENTRALIZED HYDROPOWER IN RWANDA

NRECA Small Decentralized Hydropower (SDH) Program

PN AAP519

SMALL DECENTRALIZED HYDROPOWER IN RWANDA

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Small Decentralized Hydropower Program
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SMALL DECENTRALIZED HYDROPOWER IN RWANDA

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1. SUMMARY

A two-man team from the National Rural Electric Cooperative Association (NRECA) spent three weeks in Rwanda under the Sponsorship of USAID, ST/EY to assist the Energy Research Center (CEAER) of the National University in the development of a small hydroelectric program.

Specific tasks included an analysis, preliminary design, cost estimates and equipment specifications for the Kaviri site which the Research Center wanted to develop as a pilot project. In addition, a reconnaissance level assessment of three other sites was to be made.

The team found that Rwanda has exceptional potential for small scale hydroelectric generation and rural electrification. Many waterfalls on small streams offer possibilities for medium-and high-head powerplants with capacities of 10 kW to 250 kW. Very preliminary cost estimates for the sites visited range from US$1000 to $6000 per kilowatt. In addition, there exist abandoned small powerplants that can be restored with a low investment, providing at the same time good experience in the design, construction and operation of small installations. Depending on the condition of the abandoned plants, the estimated cost of restoration is US$200 per kilowatt.

Development of the Kaviri site as a first demonstration project is not recommended because of high cost, difficult construction and uncertain energy use. It is believed that this project as a first undertaking could actually set back the development of small hydropower in Rwanda.

It is recommended that CEAER begin its program by reactivating the abandoned small power plant near Ruhengeri.

At the same time, it is recommended that CEAER prepare an inventory and assessment of potential new small hydropower sites. The evaluation should cover flow and power data, local needs, construction problems, and a comparison of benefits versus costs. The Swiss inventory of small hydro sites in Rwanda should be obtained. From this reconnaissance evaluation, the most favorable sites should be selected for a full feasibility investigation (including geological data) and eventual construction.

The above recommendations would ensure CEAER a more practical and successful role in the development of small hydropower than construction of a difficult and arbitrarily-selected project.

II. CONCLUSIONS AND RECOMMENDATIONS

1. A large number of waterfalls and rapids on small streams represent good opportunities for small-scale power generation in Rwanda. Available head ranges from 5 to more than 200 meters which is suitable for low cost cross-flow and impulse turbines in the 10-250 kW range.

2. Civil construction costs for a dam, headrace, and intake structure are generally low since a small diversion weir can be used in most cases. The cost of a penstock can be exorbitant where it has to be made of steel and built with heavy concrete anchors on bare rock. Penstocks should be buried using PVC wherever conditions permit.

3. Most small powerplants would be run-of-the-river installations - possibly with a daily storage - since opportunities for reservoirs are scarce in the steep terrain. Where level wide areas suitable for storage reservoirs exists, such land is usually valuable agricultural land.

4. Small hydro plants must be reasonably close to demand centers, i.e., dispensaries, schools, missions, workshops and commune (county) centers because power distribution costs are high and the small amount of power can be transmitted only over limited distances. The cost of overhead distribution is on the order of US$25,000 per kilometer.

5. Power supply to individual houses appears expensive because they are scattered all over the mountainous area. The subsistence farmers are probably unable to pay fully for services until the economic benefits of electrification are realized.

6. For the sites that were visited, the estimated project cost ranges from $1000/kW to $6000/kW. Judging by small hydro

installations that were recently completed at two religious missions, it takes about three years until a new plant can go on line. Delivery time for equipment causes major delays.

7 The Kaviri site should not be developed as a demonstration project because of its high cost, technical difficulties, and unidentified market. Failure of the pilot project would probably be a major setback in the CEAER small hydro program.

8. For new construction, the Kigembe site is more suitable because the construction is simple and low-cost. Also, a near-by market for the power appears assured. Similar reasons favor development of the upper falls on the Nyamutera River in the Ruhengeri area. However, this site is now somewhat remote.

9. An excellent opportunity for a learning experience and for generating power at low cost, appears to be at the abandoned flour mill powerplant close to Ruhengeri. The site is unique for CEAER purposes since it has both a small hydroelectric plant and a locally fabricated water wheel for mechanical power. Both plants could be reactivated at low cost and in a relatively short time. This would provide experience in higher technology and simpler home-built technology that could be applied all over the country. Purchase or lease of the site would have to be negotiated after the ownership has been determined. This project is recommended as the first step in CEAER's small hydro program.

10. It is recommended that restoration of a similar abandoned small powerplant at Nkora near Gisenyi also be considered as a high priority.

11. The consultants have not seen all the undeveloped sites, and probably not all the abandoned existing small hydro

plants in the brief time available. It is recommended that a more complete inventory be made before deciding on the construction of a pilot project. Technical data should be collected, construction difficulties determined, costs estimated, and energy uses evaluated. Comparing these factors should lead to the selection of the first project and the rating of other potential sites.

12. It is recommended that CEAER pursue a national role in satisfying Rwanda's needs for small-scale hydroelectric power, rather than building a university research project and observing its impact on the rural population.

III. OBJECTIVES OF ASSIGNMENT

A. Terms of Reference

The purpose of the assignment was to assist the Rwanda Energy Research Center in the development of a small hydro program. The proposed Kaviri Falls site was to be analyzed in detail and three additional sites were to be evaluated on a reconnaissance level. For the Kaviri Falls site, the potential head was to be determined, flow data were to be estimated on the basis of available hydrological information, a preliminary design was to be prepared, and the mechanical-electrical equipment was to be specified.

The AID ST/EY Office, through their cooperative agreement with the National Rural Electric Cooperative Association (NRECA), sent a two-man team for three weeks to Rwanda to assist in the development of the proposed small hydro program. The team accomplished the detailed analysis of the Kaviri site, assessed the technical, economic, and environmental aspects of the Kaviri and several other sites, investigated some important small hydro possibilities at existing but abandoned hydroelectric developments, and recommended step-by-step procedures for carrying out the small hydro program.

B. Review of Activities

The NRECA team arrived in Rwanda the night of November 26, 1981 and spent the following day in Kigali. The head of the AID Mission, Gene Chiararoli, gave a preliminary briefing. Maps were obtained from the Rwanda Cartographic Center and information on the energy situation was gathered in meetings with M. Alyhonse Nkubana of the Rwanda Water and Energy Department, Ministry of National Resources, and engineers of the European Economic Community (FED).

The team proceeded to Butare, home of the Rwanda National University and the Rwanda Research Center (CEAER). Preliminary discussions were held with M. Prosper, Director of CEAER, and Lane Branson, Project Advisor for the AID Renewable and Improved Traditional Energy Project. On Sunday, November 29, the first trip to the Kaviri Falls site was made. The following day the Runyombi small hydro project was visited to acquaint the CEAER personnel with the physical features of a small hydro installation.

On December 1 a field trip to Gihimbi Falls near the Rukando commune was undertaken. The Burgomastre of the local commune had requested a small hydro plant on one of two waterfalls in the vicinity. Flow and head measurements were taken at one site, but lack of time prevented an inspection of the alternative site.

The Kigambi site on the Migina River was visited on December 2. This is the site of a large fishery project which has about 10 hectares of fingerling rearing ponds. On the same day a possible site on the Mirayi River south east of Ndora was inspected and measurements taken.

On December 3 the Kaviri site was revisited. Detailed instrument data were obtained of the available head, the location and size of the dam, and the penstock alignment. Details for the intake structure, power plant, and tailrace were also determined to permit a preliminary design and cost estimate of a possible project. This preliminary design, cost estimate and project evaluation was accomplished in the following three days.

On Monday, December 6 the team went to Kibuye on Lake Kivu as the first leg of a five-day field trip. The Ndaba Falls site, with a head of about 300 m, was inspected and flow measurements obtained. The following day the team proceeded to Gisenyi. On the way a recently completed 100 kW hydro installation at the Murumba Catholic mission was visited. The same day, a complete but abandoned 150 kW installation at the Nkora River in the Gisenyi prefecture was inspected. Technical and cost data on this and all other sites mentioned in this Review of Activities will be found in following chapters.

The team continued on December 9 to Ruhengeri where a survey and conceptual layout of the Mukinga site adjacent to the Ruhengeri-Kigali road were made. This was followed by an all-day field trip up the Nyamutrera River accompanied by the local Burgomastre and a number of porters to carry the survey equipment. Measurements were obtained for a possible plant at the upper falls above the schoolhouse where a dispensary will be built and for a plant at the lowest falls closer to the present commune center.

The team returned to Kigali on December 11. On the way the team found another abandoned small hydro installation of a former grain and coffee mill close to Ruhengeri. This contained a well maintained hydroelectric plant of apparently 50 to 75 kW capacity with a cross-flow turbine which lacked the generator. In addition, there was a second installation of a locally-built waterwheel which provided mechanical power for agricultural processing machines (huskers, grinders). The machinery also appeared to be in good condition. The place attracted the team's special attention because it appeared that the installations could be reactivated at low cost and would provide an excellent opportunity to practice both high-and low-homebuilt technology.

The almost completed 13,800 kW Mukungha hydroelectric plant was also visited to show the CEAFR members of the team the sophisticated controls and instrumentation of a larger powerplant. The French technicians who are installing and testing the equipment provided valuable information.

On December 12 the team returned to Butare and spent the remaining days preparing this report. Before departure, a presentation of the team's conclusions and recommendations was made for the Director of CEAER and the head of the US AID mission. The team returned to the USA on December 20, 1981.

IV. FEATURES OF RWANDA RELATIVE TO SMALL DECENTRALIZED HYDRO

A. Topography

Rwanda is a mountainous country in Central Africa, covering about 10,000 square miles and extending from about 1° to 2 1/2° latitude south of the equator. With the exception of the most eastern portion along the Tanzania border, which consists of savanna, swamps, and lakes, the country presents a picture of innumerable steep hills and low mountains which decrease in height towards the south east. The valleys are intensively cultivated and fields of sorghum, corn, beans, bananas, tea, and coffee stretch even on the steepest slopes to the top of the low mountains to elevations of about 7,000 feet. In the northwest, a chain of volcanoes along the Zaire border ranges to heights of more than 14,000 feet. A major divide traverses the country from north to south; west of the divide the streams drain toward Lake Tanganyika and the Congo basin while the eastern rivers drain towards Lake Victoria and the Nile.

A large number of small streams cascade from the steep low mountains to the valley floors and present opportunities for medium-to high-head small hydroelectric developments. Many waterfalls are an outstanding feature of the Rwanda landscape. Even a casual observer notices the exceptional number of physical possibilities for power generation.

B. Hydrology

Rwanda has two rainy seasons: from February through May and from November to December. Average annual precipitation ranges from about one meter at lower elevations to more than two meters in the mountains. Figure IV-2 shows the monthly rainfall distribution over a 30-year period at the Kigali meteorological station. Average monthly rainfall is 82 mm (984 mm per year) with a maximum of 170 mm in April and a minimum of 8 mm in July.

Rwanda

SDH SITES VISITED

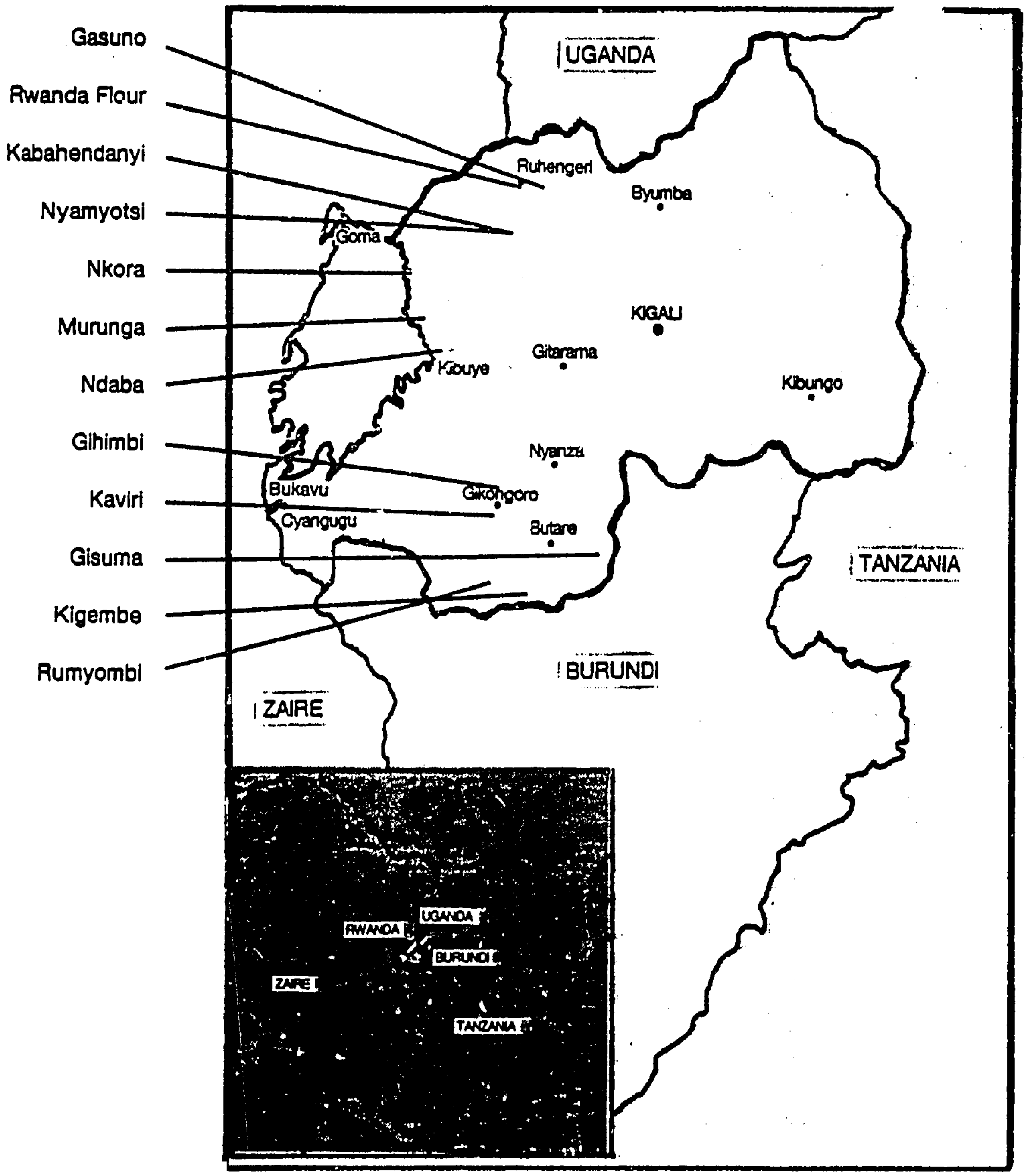


Figure IV-1

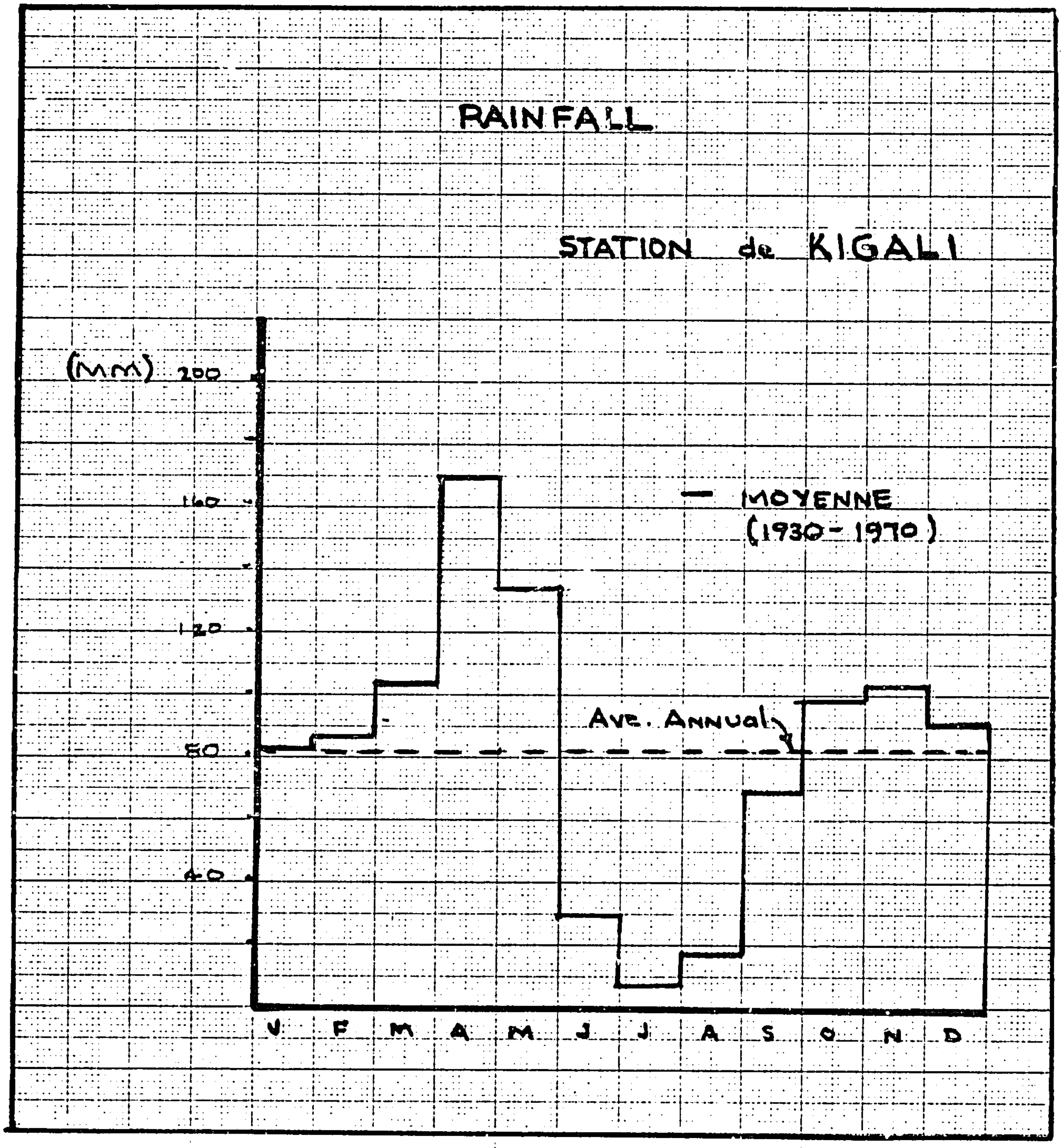

RAINFALL
STATION de KIGALI
(MM) 200
160
120
80
40
— MOYENNE
(1930 - 1970)
Ave. Annual
J F M A M J J A S O N D

Figure IV-2

Stream gauging data in Rwanda is very scarce, and for small streams nonexistent. Stream-flow records exist for two large rivers: the Akanyaru River south and east of Butare and the Nyaborongo River near Kigali. Flow correlation between these rivers and the small rivers with mini-hydro prospects is not dependable because the much smaller drainage basins cause far greater flow variations. Annual runoff volumes may be comparable on the basis of drainage areas, but these volumes are not important for small hydro plants which are generally run-of-the-river installations without storage reservoirs to even out seasonal or daily high and low flows.

Maximum, minimum, and average stream flows can be calculated on the basis of rainfall, drainage area, and runoff coefficients. Earlier hydrological studies for Rwanda determined a high correlation between these factors. High runoff coefficients were also noted for the upland areas, which is only to be expected in view of the steep slopes which are frequently bare rock. Calculation of stream flows on this basis is difficult for small drainage basins in Rwanda because of the inaccuracy and scale of available contour maps. A flow calculation for the Kaviri River, for instance, resulted in a huge discrepancy with the observed river flow, probably because the calculation was based on an inaccurate drainage area.

For the small streams of mini-hydro plants a measuring weir should be installed and regular observations made for a period of at least one year because the turbine specifications call for reasonably accurate flow information. Alternatively, the instantaneous flow can be measured by determining average cross-sectional flow area and flow velocity, making allowances for reduced velocity along the stream perimeter. Considerable judgement is required to relate the instantaneous flow to the average annual flow on which the turbine specification is based. Selecting a turbine which operates with reasonable efficiency over a wide range of flows would be appropriate.

Figure V-2 shows a flow duration curve with maximum, average, and minimum flow for a large river in Rwanda. As stated earlier, this gives only a general picture for flow conditions of small rivers.

C. Socio-Economic Features

Social and economic conditions in Rwanda have some unique features in respect to small hydro plants and electric power in general. In spite of a total population of about 4.8 million, a population density of over 180 per square kilometer, and an annual population growth rate of almost four percent, there are few population centers that could be readily served by electric power. The vast majority of people live on small subsistence farms that are scattered all over the mountainous terrain. The economy is almost entirely rural with a small demand for electrical energy. Concentrated markets for power are scarce.

Rural electrification by means of supplying power to the scattered, individual farm houses would be expensive and the ability of the subsistence farmers to pay for such service is doubtful. Since the power from small hydro plants can be transmitted only for limited distances, these plants would have to be reasonably close to the administrative and commercial centers of the communes (counties), to schools, dispensaries and work shops located frequently at existing religious missions. Fortunately, the abundance of small hydro sites makes this possible. The availability of electric energy would probably create its own market in the form of small industries such as agricultural processing plants, sawmills, and cold storage plants. Jobs and cash income would be created which is a most important factor in the existing subsistence economy.

Water power from small streams could also be used directly, without electric generators, to provide mechanical power through waterwheels which would drive mills and machinery. Such waterwheels can be fabricated locally as was done at the abandoned Ruhengeri site. The mechanical power would, of course, have to be used directly at the stream site.

D. Existing Electric Power Situation

The use of electric power is very limited in Rwanda. In 1980 about 61 gigawatt hours (61 million kilowatt hours) were consumed in the entire country, with the capital city, Kigali, representing about 44 gigawatt hours of this energy demand. The evident reason is the minimal industrial base of the economy which consists almost entirely of small-scale subsistence agriculture with low energy requirements. The limited industrial - commercial energy demand comes from mines, tea-drying plants, some light manufacturing plants, a brewery, and a radio station.

The bulk of the power production comes from medium sized hydroelectric plants. The largest plant is Mururu on the Ruzisi River with an installed capacity of 28,200 kW which is jointly owned by Zaire, Rwanda and Burundi. The Ntaruka plant near Ruhengeri is located between two lakes and has three turbine-generators with a total of 11,250 kW. At the out flow of the lower of these two lakes, a newly constructed plant (Mukungha) with two 6900 kW units will go on line early in 1982. A smaller plant at Gisenyi has 1800 kW installed. In addition, there are several mini-hydro plants with capacities up to about 150 kW which serve primarily religious missions with their shops, hospitals, and schools, and diverse local demand.

A second large plant on the Ruzisi River is under construction which is a joint Zaire - Rwanda - Burundi undertaking similar to the existing Mururu-Ruzisi plant.

A large hydroelectric potential exists at the Rusumo Falls of the Akagera River on the border of Rwanda, Tanzania, and Burundi. Various schemes to exploit this power jointly for three countries are under study.

Thermal power supplies between five and six percent of Rwanda's energy requirements. This power comes from several plants in the 40 to 400 kW range and the Kigali 2000 kW thermal station. Several religious missions have very small diesel-electric plants.

Transmission voltages are 110 kV and 70 kV for the longer lines and 30 kV for shorter, 15 kV and 6.6 kV for distribution, and secondary voltage is 220/380 V.

Projections of future electric power demand are highly speculative because of the uncertainty of industrial growth. There is little coordinated planning, and forecasting of energy growth requirements range from 6% to 17% per year, depending on the assumptions and expectations of the forecaster. There are possibilities for a cement plant, a gas liquification plant (methane deposits in Lake Kivu), fertilizer plants, new enterprises, and various manufacturing industries. In view of the limited existing power market, any one of these possibilities would entail a large percentage jump in energy requirements.

The small hydroelectric plants that this report is concerned with, would have little impact on the national energy supply. But creating small hydroelectric energy sources in isolated areas and advancing rural electrification through a productive use program could certainly change the quality of life in this rural society.

V. THE KAVIRI SITE AS A PILOT PROJECT

A. Site Description

The Kaviri site lies in the southeast portion of Rwanda, north of Butare. The Kaviri river flows to the east through the 34 km^2 catchment basin. The basin is populated by subsistance farmers whose major crops are beans, potatoes, bananas, and some coffee grown for a cash crop. Mountainous peaks which surround the basin rise to over 1900 meters from the valley floor of approximately 1600 meters.

No electrical distribution services were observed within a 10 km radius. The site is about .5 km from a small two-room school, 1.5 km from a small commercial center, and about 4.5 km from a commune. The site consists of the Kaviri River running through flat valley, dropping 20 meters through a series of small falls, and continuing to the north east.

The site has been under consideration for micro-hydro development for several years and a weir was installed to conduct flow measurements. The river has since worked its way around the weir rendering it useless for flow measurements.

B. Hydrology

The average annual rainfall in the Kaviri area is 1000 mm with an annual distribution as described in Chapter IV. Two methods were used to judge the stream flows at the site: (1) site measurements and (2) runoff coefficients with rainfall data.

Flow measurements were conducted on two separate occasions. The first is summarized in a preliminary study by CEAER which

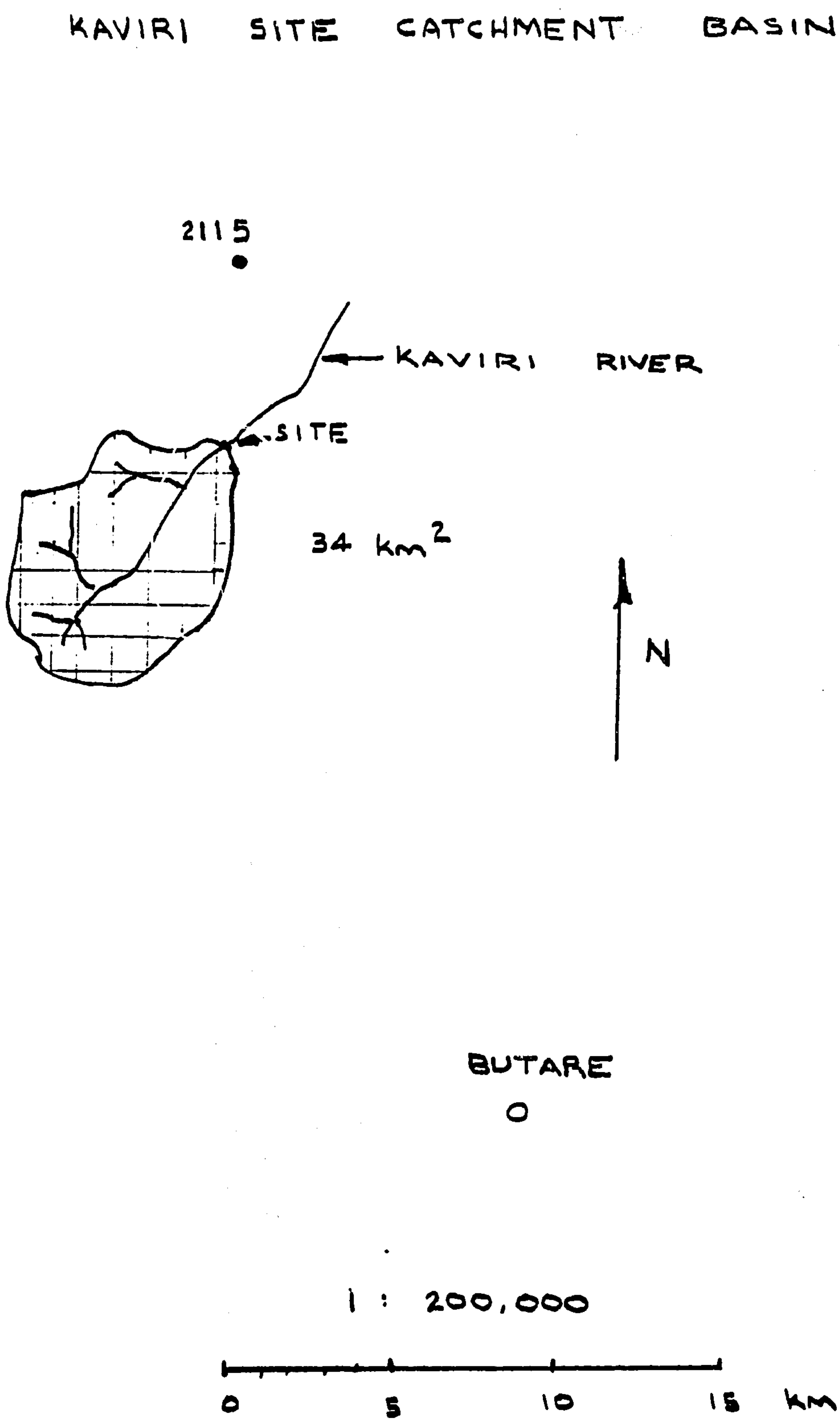

KAVIRI SITE CATCHMENT BASIN
2115
KAVIRI RIVER
SITE
34 km²
N
BUTARE
1 : 200,000
0 5 10 15 km

Figure V-1

calculated the flow to be .054 m^3/sec. The second observation was conducted by the field team which found a flow of .06 m^3/sec. It is felt that both of these observations were made during periods of minimum flow.

The second method for estimating the flow was to determine the catchment basin area (34 km^2), assume a conservative runoff coefficient (0.4) and compare this basin against flow duration curves from larger basins (Figure V-2). Such flow duration curves indicate that the ratio of average flow to minimum flow is 1.7. Then:

$$\text{Runoff} = (K)\ (1000\ mm) = .4m$$

$$\text{Volume} = (H).(A) = .4m\ (34 \times 10^6 m^2) = 13.6 \times 10^6 m^3$$

$$Q_{ave.} = \frac{13.6 \times 10^6}{31.5 \times 10^6\ sec} = .437\ m^3/sec$$

$$Q_{min} = \frac{Q_{ave.}}{1.7} = .257\ m^3/sec$$

This value is much higher than the observed value for the minimum flow. Since the observed flow is a more reliable method for flow determination, a minimum flow value of .054 m^3/sec. will be used. A suitable value for the design flow is then .054 x 1.7 = .09 m^3/sec. This is considered to be conservative, but will be used due to the lack of better flow data. However, it is very possible that additional flow is available, and that daily storage could be incorporated in the development scheme. For these two reasons, it is appropriate to design the penstock diameter to carry the flow for a second identical unit if and when the need for additional power develops, and it is determined that additional flow is actually available.

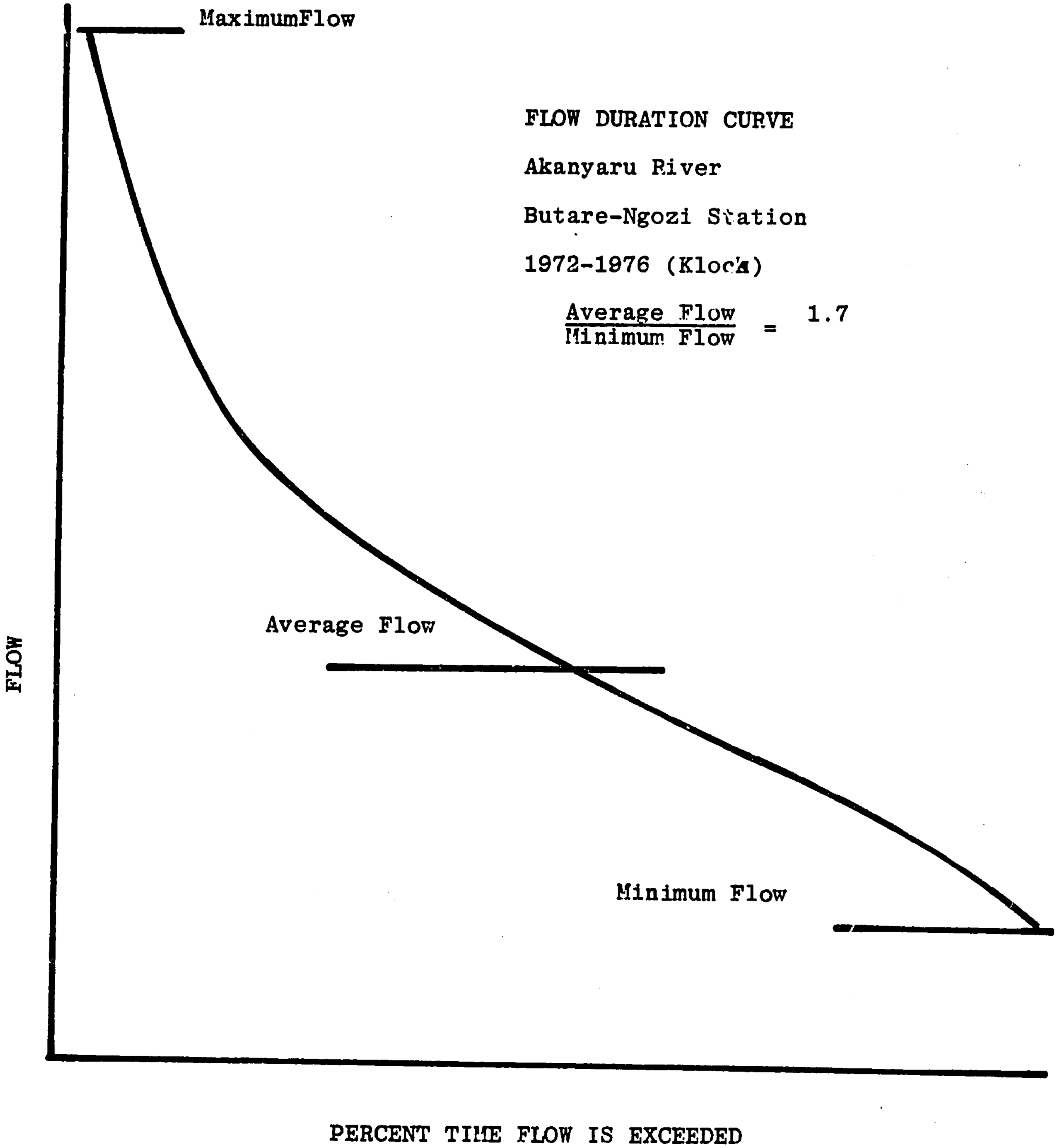

MaximumFlow
FLOW DURATION CURVE
Akanyaru River
Butare-Ngozi Station
1972-1976 (Klock)
Average Flow / Minimum Flow = 1.7
Average Flow
Minimum Flow
FLOW
PERCENT TIME FLOW IS EXCEEDED

Figure V-2

C. Project Layout

The general layout of the Kaviri site is sketched in Figure V-3. The primary features of the scheme are the weir, the intake structure, penstock, powerplant, and the distribution facilities.

Weir

The weir is an overflow concrete type with a desilting gate. See Figures V-4 and V-5. The weir must be keyed into the bedrock and a watertight bond formed between the bedrock and the weir mortar. The weir will require approximately 5m^3 of concrete/masonry construction.

Intake

The intake structure should include the forebay, trashrack, and stoplog as shown in Figure V-4 (See reference 1, page 56, reference 2 pages 159-161, and reference 7 page 15 for guidelines in designing these features). A sluice gate should be included for desilting the forebay.

Penstock

In this case steel penstock is preferred over cheaper PVC pipe due to the ability of steel to withstand physical abuse, ultravoilet light, and bending moments (beam strength). Since the surface along the penstock route is granite, the penstock cannot be buried and must be suspended between anchors and thrust blocks. The penstock route as shown in Figure V-3 would be modified during the final layout to minimize bends.

As the ratio of penstock length (104 meters) to head (19 meters) is greater than 3, surge protection must be incorporated. This could most easily be done by installing a rupture plate on a tee near the powerhouse. CEAER would have to consult with the turbine manufacturer about the best solution.

KAVIRI SITE SKETCH

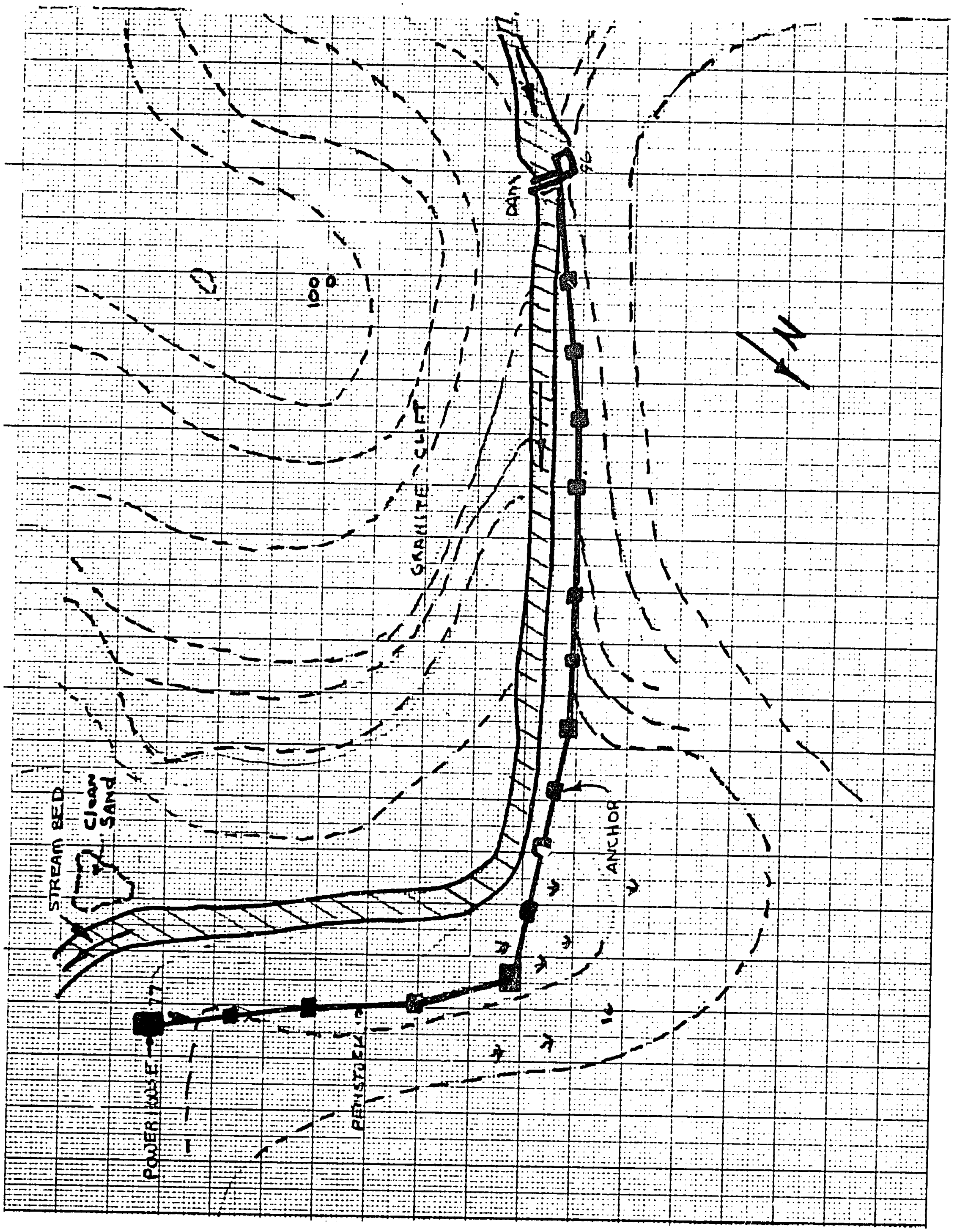


Figure V-3

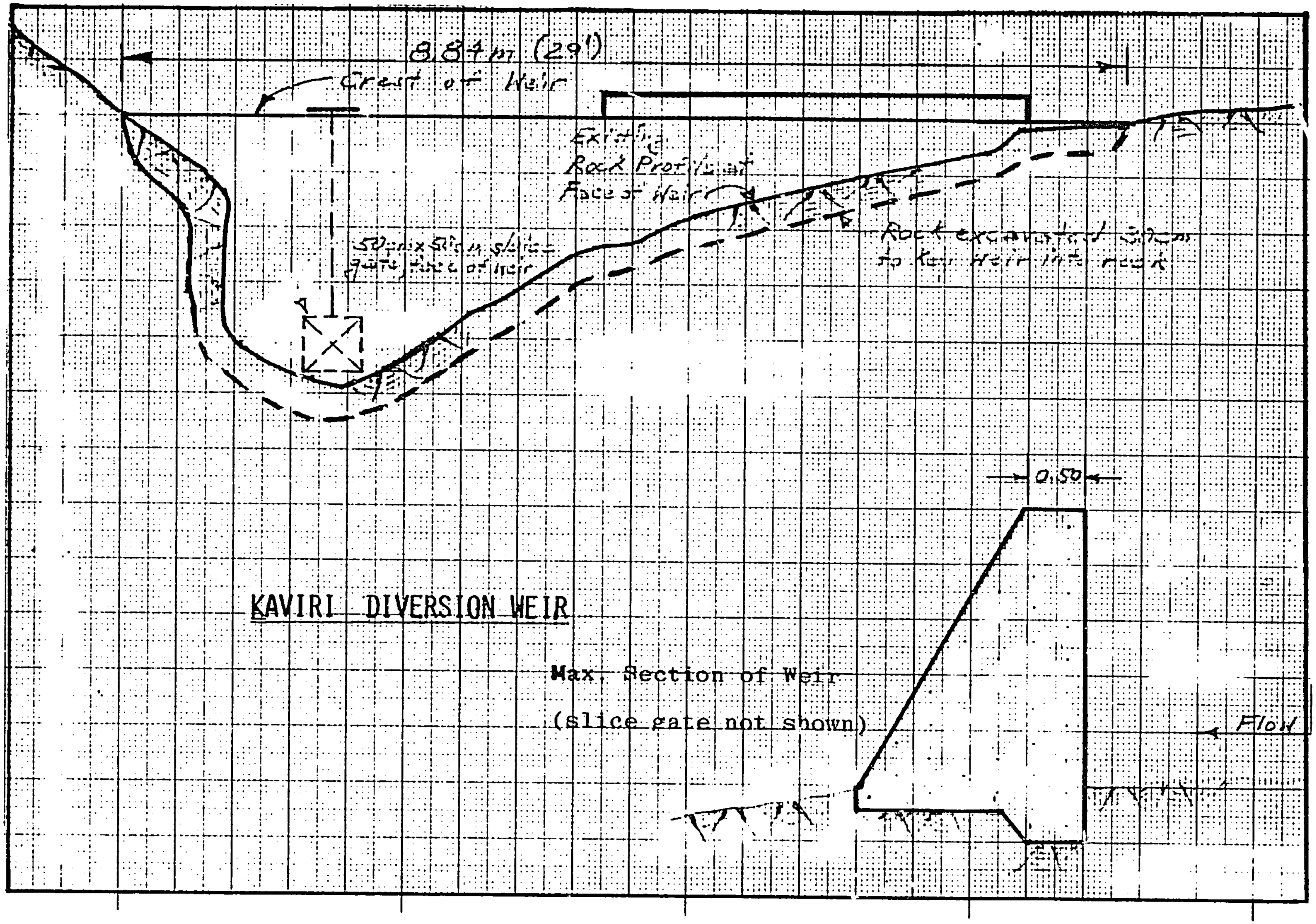
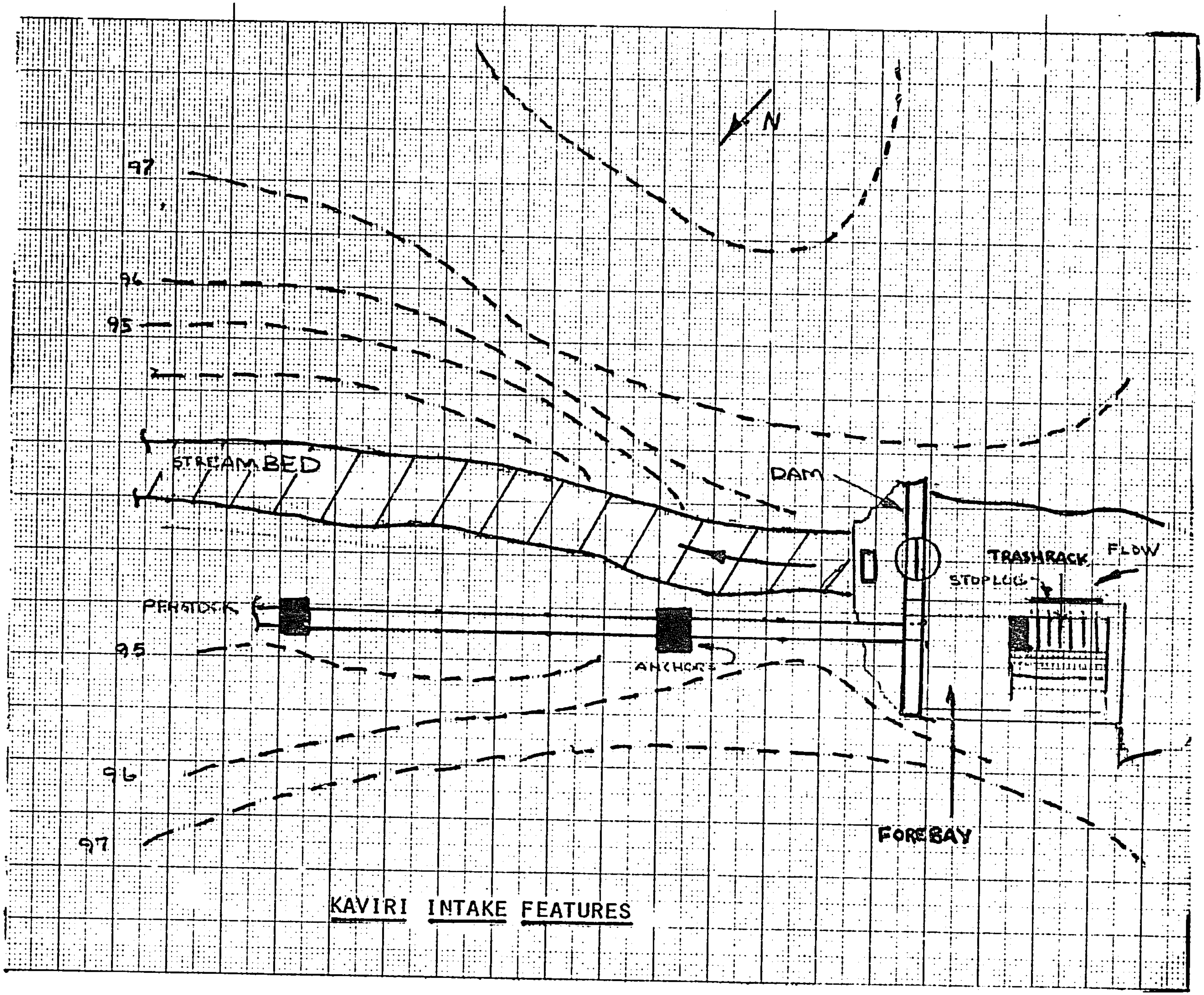

8.84m (29')
Crest of Weir
Existing Rock Profile at Face of Weir
Rock excavated
KAVIRI DIVERSION WEIR
0.50
Max. Section of Weir
(slice gate not shown)
Flow

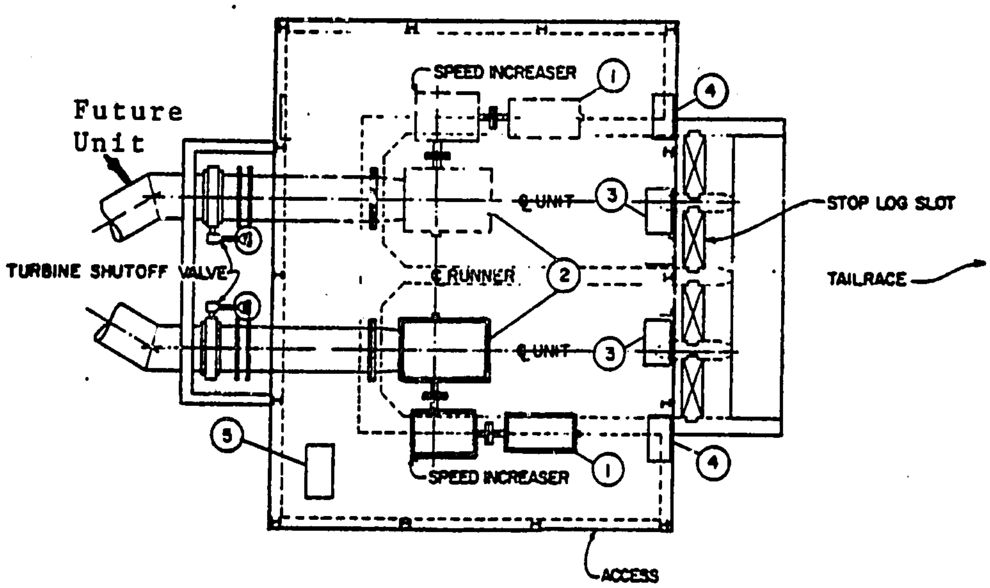
FIGURE V-4



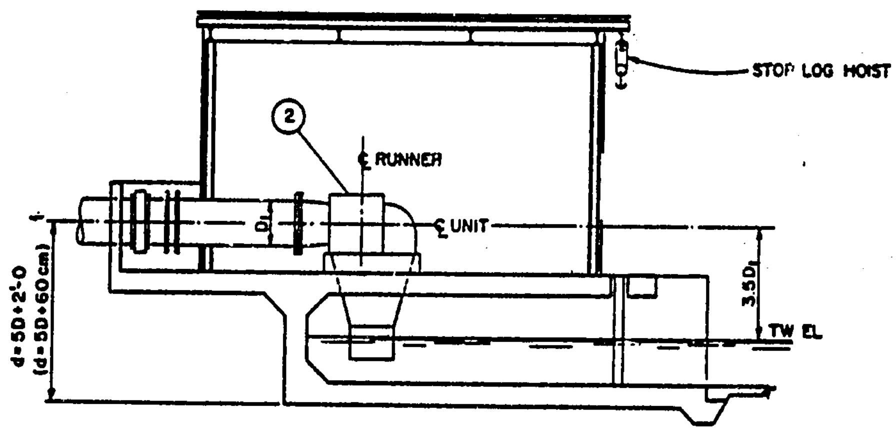
KAVIRI INTAKE FEATURES

Figure V-5

Powerhouse Layout — Crossflow Turbine, Multiple Units



PLAN



SECTION A

Equipment

1. Generator
2. Turbine
3. Governor
4. Generator Breaker
5. Control Panel

Figure V-6

Thrust blocks and anchor forces should be designed as described in reference 1, page 75-83. Metal supports may be cheaper than concrete structures. Expansion joints will be necessary and the penstock manufacturer should be consulted for the exact requirements.

At the powerhouse a "Y" should be installed for the second turbine and a pressure gauge installed before the cutoff valve. From Table 17-1, reference 1, page 58, a 0.4m (16 inch) diameter penstock is appropriate for this installation.

Powerhouse

The details of the powerhouse design are normally delayed until the turbine-generator has been selected. After the turbine type has been selected, the powerhouse layout can be estimated from reference 7. If a crossflow turbine is selected, the appropriate layout is shown in Figure V-6. The location for the powerhouse is on exposed granite rock about one meter above the tailwater level. The foundation should be keyed into the rock and able to absorb the thrust of the full penstock. (See references 1 and 2 for details).

The superstructure should include a door that securely locks, and which is large enough for the turbine-generator equipment. Access around the entire turbine, generator, windows, lights, and utility receptacles should be provided.

Powerplant

The powerplant consists of the turbine, generator, and governor. The gross head between the overflow weir and the powerhouse location is 19 meters. The losses in a 0.4 m diameter penstock, 104 meter long is (from reference 1, page 58):

$$hp = \frac{\text{losses}}{100 \text{ meters}} \times \text{penstock length}$$

$$hp = \frac{.9 \text{ m}}{100 \text{ m}} \times 104\text{m} = 1\text{m}$$

At the bend in the penstock, the flow changes approximately 60 degrees in direction. The associated head loss, from reference 1, page 58, is:

$$h_o = \frac{a\ v^2}{2\ g} = .04 \times .12 = .005 \quad \text{(negligible)}$$

The design capacity is: kW = hQ (9.8)e. As the penstock losses have been accounted for, assume e = .75. Then kW = (19- 1) (.09) (9.8).75 or 11.9 kW. Assuming a normal electric load power factor of .8, the system should be designed for a 15 kVA generator, with features for a second future unit to provide total of 30 kVA.

Turbine Generator Specifications

Specifications for the turbine and generator are:

Turbine-generator package unit designed and constructed to operate under the following conditions:
Net head: 19 to 18 meters
Flow: 0.05 m^3/sec to 0.10 m^3/sec
Turbine setting: 1 meter above tailrace
Flow regulating governor
Penstock: .4 m diameter, 104 m long, steel.
Elevation: 1600 meters
Water quality: Poor (fine silt)
Quotes to include price for complete package, F.O.B., shipment port, shipping weight and volume of the package.

Turbine

The manufacturer should specify the turbine type, configuration, speed, coupling to generator and flywheel, efficiency, runner or pitch diameter, nozzle size, and (if appropriate) number of buckets, runner or bucket material (e.g. type of steel), mounting to frame, governor type and operating speed.

Generator

Type: Synchronous A.C., self excited, internal voltage regulation
Frequency control: ± 2 hertz (isolated operation)
Voltage: 440/220 V three conductor
Phase: single
Size: 15 kVA with normal p.f. = .85
Insulation: treatment for tropical climate
Protection: overspeed, overcurrent
Control panel: voltage meter, frequency meter, current meter, watthour meter
Manufacturer to specify generator make, speed, and overspeed capabilities

Package to include cutoff valve with flange for .4 m steel penstock.

The turbine-generator equipment specification should be submitted to the following manufacturers to satisfy USAID source requirements:

Small Hydroelectric Systems and Equipment
Ossberger/Stapenhorst
Balaju Yantra Shala
C.V. Sukaradja

Addresses are found in the NRECA "Directory of Sources of Small Hydroelectric Turbines and Packages" and Figure V-7.

Distribution

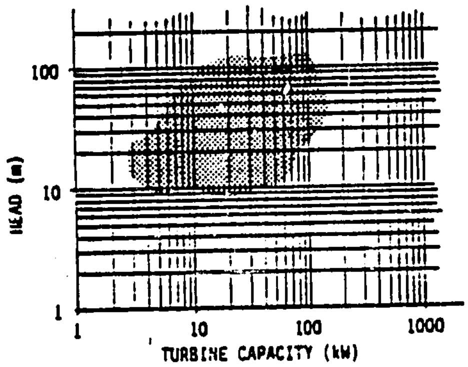
The uses for the power at Kaviri have not yet been identified. Therefore, the team had to assume possible uses of the power and specify the distribution scheme based on those assumptions. Electric power will be distributed at generator voltage to avoid the cost of transformers and haigh voltage construction. The power for the control board will be delivered to a distribution panel with six feeders. Feeders will supply station service, the commercial center (1.5 km), the nearby school (.5 km) and three spares for future loads.

Summary of Application Charts

SMALL HYDROELECTRIC SYSTEMS AND EQUIPMENT

5141 Wickersham Street
Acme, Washington 98220

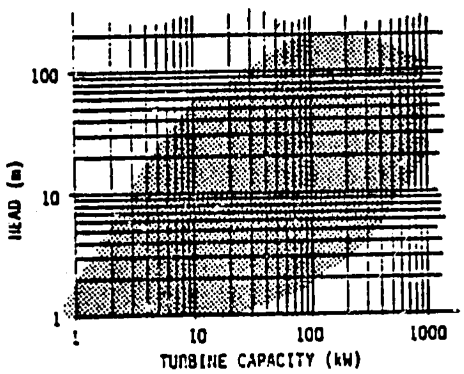
Tel: (206) 595-2312



OSSBERGER/F.W.E. STAPENHORST, INC.

F.W.E. Stapenhorst, Inc.
285 Labrosse Avenue
Pointe Claire, Quebec H9R 1A3

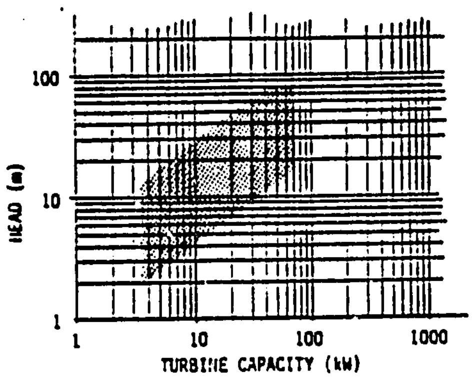
Tel: (514) 695-2044



BALAJU YANTRA SHALA (PVT.) LTD.

Post Box 209
Kathmandu, Nepal

Tel: 14809, 13379, 13296
Cable: BYS



The communal center is estimated to be 4.5 km form the site and is not economically feasible to service. Underground cable is appropriate at this voltage and is estimated to cost approximately $5,000 per km. Splices should be made by qualified electricians only.

Station service should provide lighting in the powerhouse, at the powerhouse entrance, and at the intake structure.

C. Cost

Estimates of the cost to construct the Kaviri site are, assuming the land is provided free:

	(US$)	
Intake		
Concrete $2m^3$ x $200/$m^3$	400	
Trash rack	200	
Stop log gate	80	
Drainage gate valve	40	
Construction	1000	
		1,720
Dam		
Concrete $5m^3$ x 200	1000	
Desilting gate	400	
Construction	1500	
		2,900
Penstock		
0.4 meter diameter		
$200/m x 105 m	2400	
Installation, anchors	1400	
		38,000
Powerhouse		
40 m^2 x $250/$m^2$		1,000
Turbine		
13 kW x $500/kW		6,500
Generator		
15 kVA x $85/kVA		1,275
Governor		8,000
Distribution		11,000
Sub-total		79,395
Contingencies		7,939
Total		87,334

Costs for engineering and construction management are not included because CEAER would probably perform most of these functions.

The cost of the penstock is almost one-half the total system. Most of this cost is related to the high price of imported steel and the extensive anchors required for supporting such a long penstock in granite.

E. Conclusions

The NRECA team concludes that the Kaviri project is very costly, the benefits are unknown, and the construction procedures stretch the capabilities of the local labor force. Therefore, the project should not be undertaken at this time.

The team fears that, if built, this project could become a glowing example of how costly micro-hydropower can be, and hence, not appropriate for Rwanda. It is believed that just the opposite is true; that micro-hydropower does have a place in Rwanda's future energy profile. Therefore, a more favorable site should be developed as the pilot project.

VII. OTHER UNDEVELOPED SDH SITES

The field team visited eight undeveloped sites in western Rwanda. At each site a layout was proposed, head measured, flow estimated and a very preliminary cost estimate made. At all the sites, no power use surveys were conducted because of the lack of time. The cost estimates were developed to help direct CEAER to a preferred site, and are not accurate enough for prefeasibility studies. A summary of the site data gathered is presented in Table VI-I.

Kigembe

The Kigembe site is located approximately 15 km south of Butare on the Migina River (See Figure VI-I). The site sits in a wide valley that has been developed for a ten hectare fishery. USAID is funding a project to reactivate the facilities. No electric service is presently available.

The site is located near a bridge that crosses the Migina River just downstream of the confluence with the Kagera River. After the bridge, the river runs over a small fall of about three meters. Approximately .3 km downstream from the bridge are several fish ponds fed by a canal that draws water from the Migina River about .5 km upstream of the site.

The field team considered three possible schemes for developing this site: (1) a weir installed ten meters upstream of the bridge, a headrace tunnelled through the road, and a penstock leading to a powerhouse located approximately 30 meters downstream of the falls; (2) a small weir located upstream of the bridge, a headrace that utilizes the existing side tunnel in the bridge, and a powerhouse located directly below the falls. This scheme could incorporate a "low technology" overshot waterwheel for power production; (3) the third scheme would use the existing

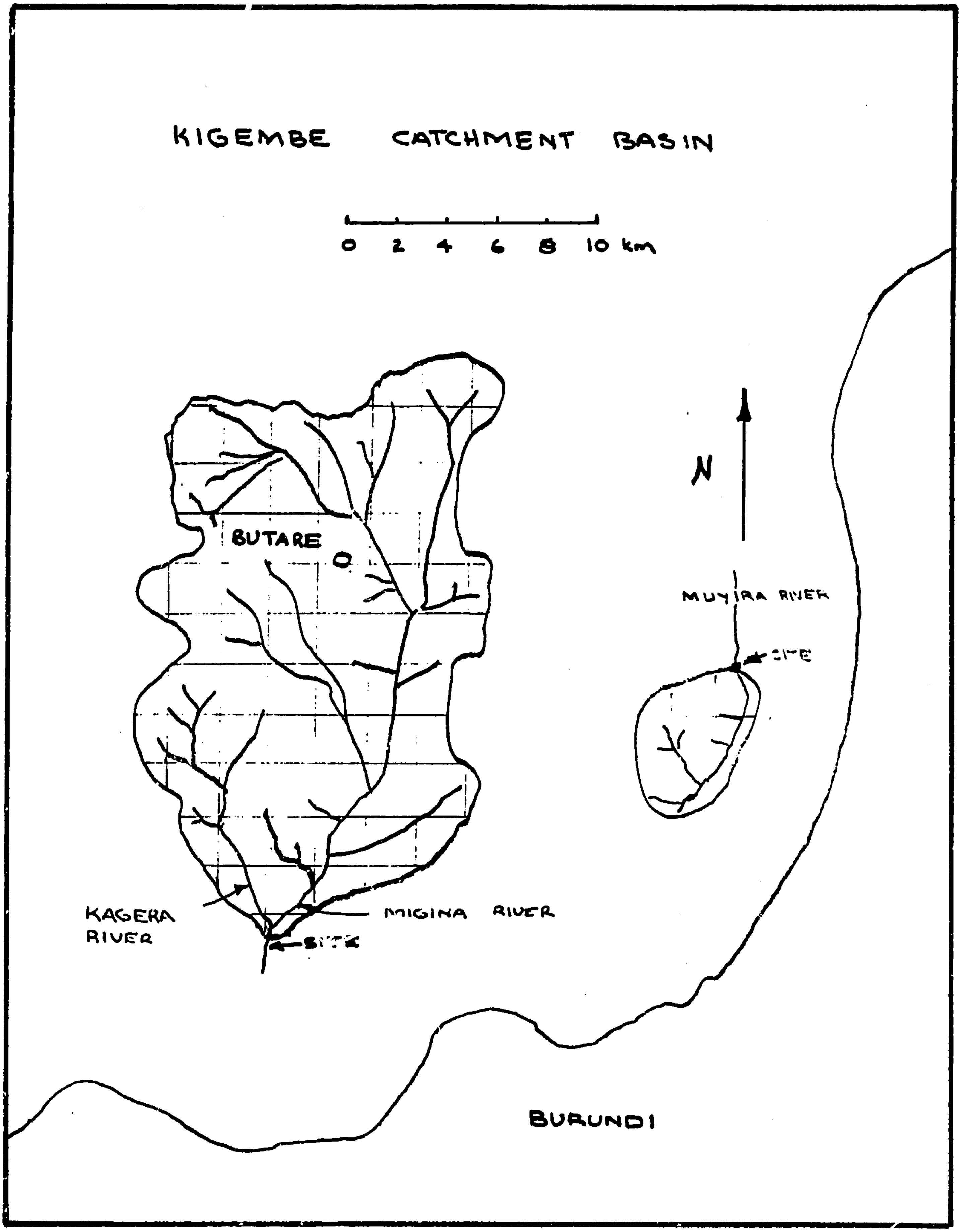

KIGEMBE CATCHMENT BASIN
0 2 4 6 8 10 km
N
BUTARE
MUYIRA RIVER
KAGERA RIVER
MIGINA RIVER
BURUNDI

Figure VI-1

canal for the fishery project as a headrace, a penstock from the canal to a powerhouse located about 30 meters downstream of the bridge. This option would provide about 5.0 meters of head and power potential of about 17 kW.

A preliminary cost estimate favored the third option. This scheme could use a low pressure penstock and a cross-flow turbine driving a small AC generator with an electronic load-controller. Using these low-cost features the scheme could provide approximately 17 kW for about $18,000. The NRECA team recommends that CEAER evaluate the impact of this use of the existing canal on the fishery project before pursuing this site further.

<u>Gisuma</u>

The Gisuma chute is located on the Muyira River (also known as the Mirayi River) southeast of Ndora. The small catchment basin of about 15 km^2 produced only about $.07 m^3/sec$ of flow on the day of the team's visit. The site sits in a wide gorge that is used primarily for cattle and goat grazing. A few huts lie within a kilometer of the site, but the nearest commercial center is over 5 km away.

The chute consists of a series of small falls, some on the order of 5 meters. The streambed has a general grade of about 30-40%. The proposed scheme would incorporate a six meter long rock pile weir; .5 meters high, a 100-meter headrace on the eastern bank of the stream, a PVC penstock, and a powerhouse located to provide approximately 30 meters of head. About 15 kW of power could be produced for about $25,000, excluding the distribution. It is not feasible to send 15 kW 5 km, so until a local use is found for the power, the site is not recommended. A 5 km underground distribution cable would cost approximately another $25,000.

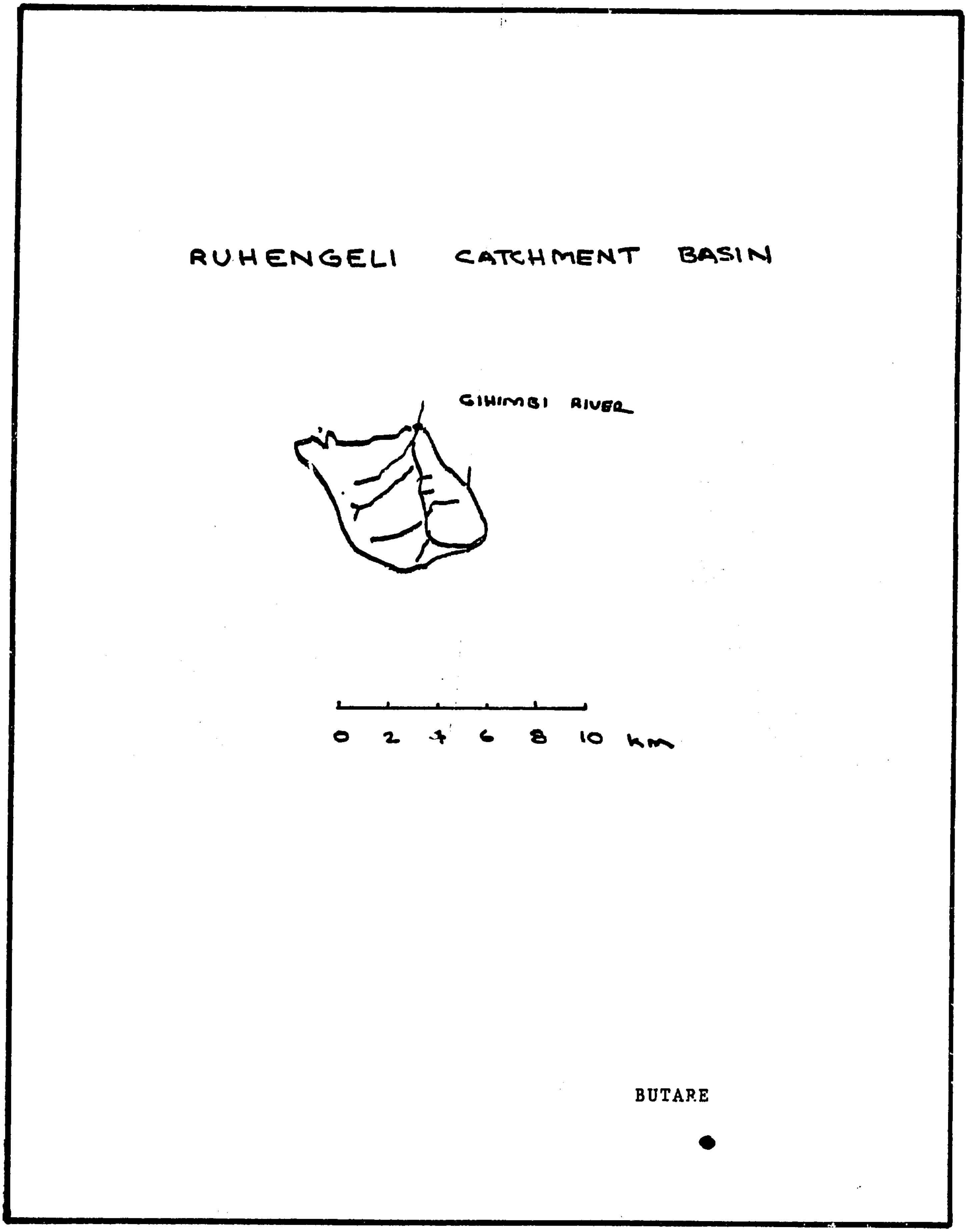

RUHENGELI CATCHMENT BASIN
GIHIMBI RIVER
0 2 4 6 8 10 km
BUTARE

Figure VI-2

Gihimbi (Ruhengeli)

The local Burgomestre (mayor) requested that CEAER investigate a small falls on the Gihimbi River near the Ruhondo commune in the Gikongora prefecture. The site consists of a chute (falls) of about 5 meters in a narrow gorge and then a general stream bed grade of about 4-6 percent. The local commune is about 1.5 km from the site (See Figure VI-2).

On the day of the visit, the field team measured a flow of about .1 m^3/sec. The proposed scheme consist of a rock pile weir 7 meters long; .5 meter high, a 20-meter headrace on the east bank of the stream, a PVC penstock, and a powerhouse located to provide approximately 7 meters of head. The approximate power potential is 5 kW and the estimated cost to develop and distribute this power to the commune is over $30,000. Obviously it is not feasible to distribute 5 kW a distance of 1.5 km, but this site should be remembered for possible waterwheel installation.

Ndaba

The team visited the falls on the Ndaba River as described in the UNDP report (Reference 3, page 2-63). The team concurs with the conclusions reached in that report (e.g. the site is too far from potential loads to be feasible.)

At the request of the local Burgomestre, the field team investigated three sites on the Nyamutera River in the Ruhengeri prefecture. (See Figure VI-3). The Burgomestre is interested in providing electric power to a local school, a new dispensary, and a new communal center to be located approximately 4.5 km upstream of where the river crosses the existing road to Ruhengeri. The three sites are: Kabehendanyi, about five km from the road; Nyamyutsi, about 3.5 km from the road; and, for lack of a better name, the Main Chute which sits approximately one km off the road.

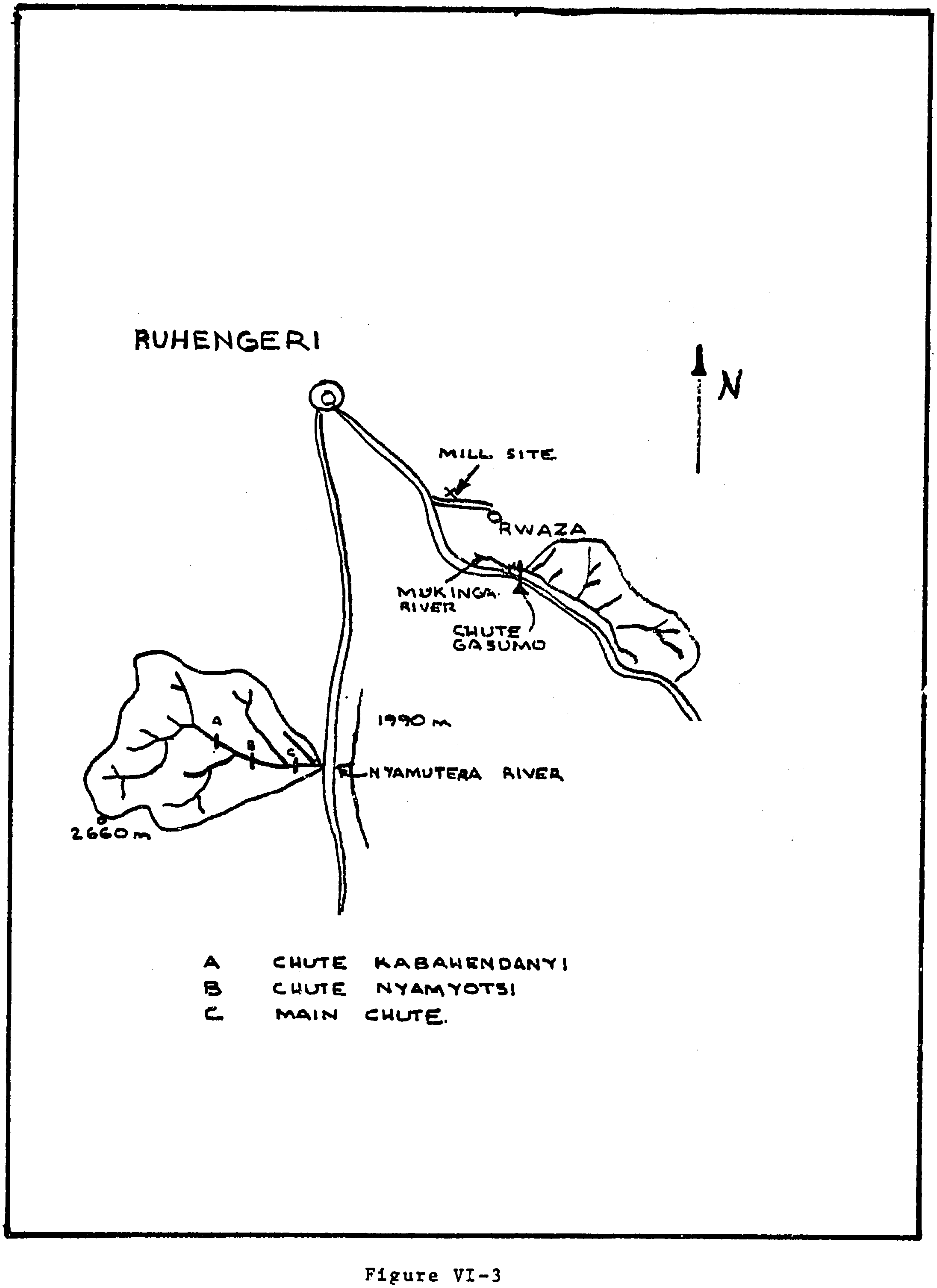
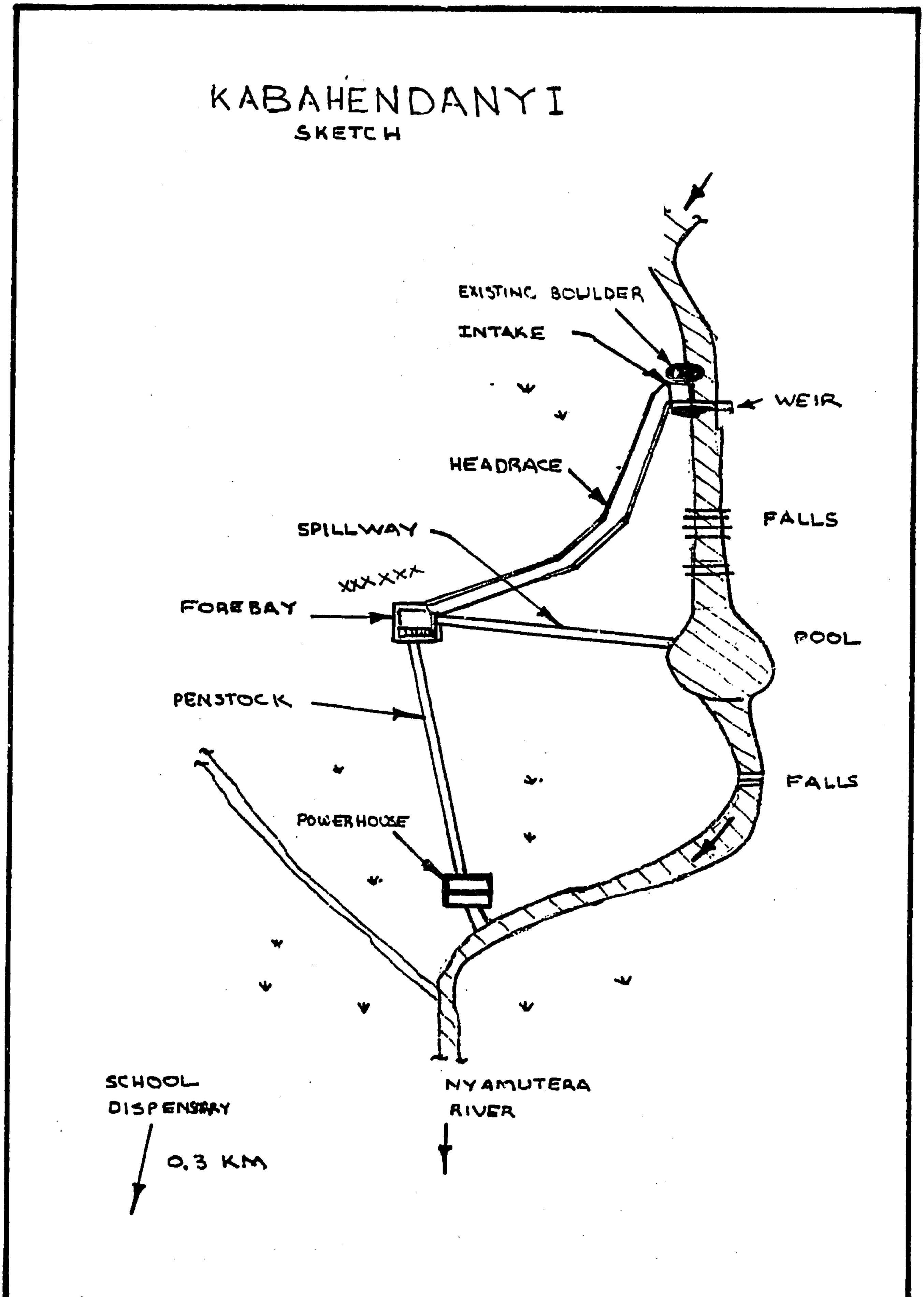

RUHENGERI
N
MILL SITE
RWAZA
MUKINGA RIVER
CHUTE GASUMO
1990 m
A
B
C
NYAMUTERA RIVER
2660 m
A CHUTE KABAHENDANYI
B CHUTE NYAMYOTSI
C MAIN CHUTE.

Figure VI-3


KABAHENDANYI
SKETCH
EXISTING BOULDER
INTAKE
WEIR
HEADRACE
FALLS
SPILLWAY
XXXXXX
FOREBAY
POOL
PENSTOCK
FALLS
POWERHOUSE
SCHOOL
DISPENSARY
0.3 KM
NYAMUTERA
RIVER

FigureVI-4

Kabahendanyi

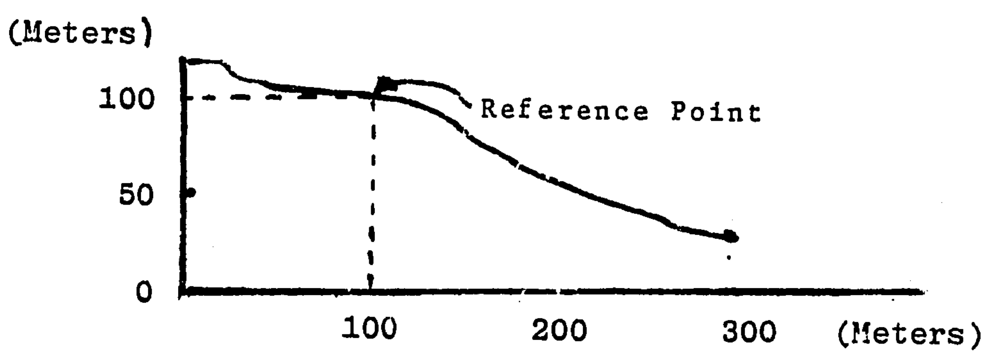
The Kabahendanyi site consists of two main falls with a head potential of about 20 meters. The team estimated the flow to be about 0.8m^3/sec. A sketch of the proposed layout is shown in Figure VI-4. It consist of a weir 7 meters long, 1.5 meters high, a 50-meter headrace, a 30-meter penstock, powerplant, and overhead distribution to the future location of the communal center approximately .4 km away. The total power potential is about 110 kW and would cost approximately $176,000 to develop. The team feels that this site is worthy of further investigation.

Nyamyotsi

The Nyamyotsi site is downstream of the Kabahendanyi site, has a little more flow, approximately 37 meters of head, and power potential for about 250 kW. The general layout is similar to the Kabahendanyi site and the estimated cost per kW is about the same. Since the Kabahendanyi site requires less investment, is closer to the load, and more closely matches the expected load in the area, it is preferred over the Nyamyotsi site. (See Annex 2).

Main Chute

The Main Chute is visible from the road and lies just downstream of the confluence with a major tributary to the Nyamutera River. The flow was estimated to be 1.2 m^3/sec. The profile of the streambed is:



The river continues to fall at a rapid rate below the section surveyed. In the portion studied, the power potential exceeds 850 kW. As this site is situated even farther away from the load center, and since it has much more potential than needed by the local population at this time, it should be left for future development and possible intertie to the national grid.

Gasumo

The Gasumo site is on the Mukinga River in the Cyabingo commune about eight km from Ruhengeri. (See Figure VI-3 and VI-5). The site is located near the road from which one can see the 25-meter waterfalls.

The field team considered two options for developing this site: (1) a 46-meter long weir, 1.5 meters high, a penstock 100 meters long, and powerhouse located to provide a full 26 meters of head. The second option is to use a small existing pool carved into the rock as the forebay, construct a seven meter long weir with a 80-meter penstock to provide 20.5 meters of head. A preliminary cost analysis favored the first option primarily because of the additional power provided by the difference in heads. The first scheme could produce approximately 42 kW of power for an investment of about $154,000. Development of this site has many of the same problems found at the Kaviri site (e.g. need for steel penstock, and no known use for the power in the immediate area). The NRECA team recommends that this site not be developed at this time.

GASUMO SITE SKETCH

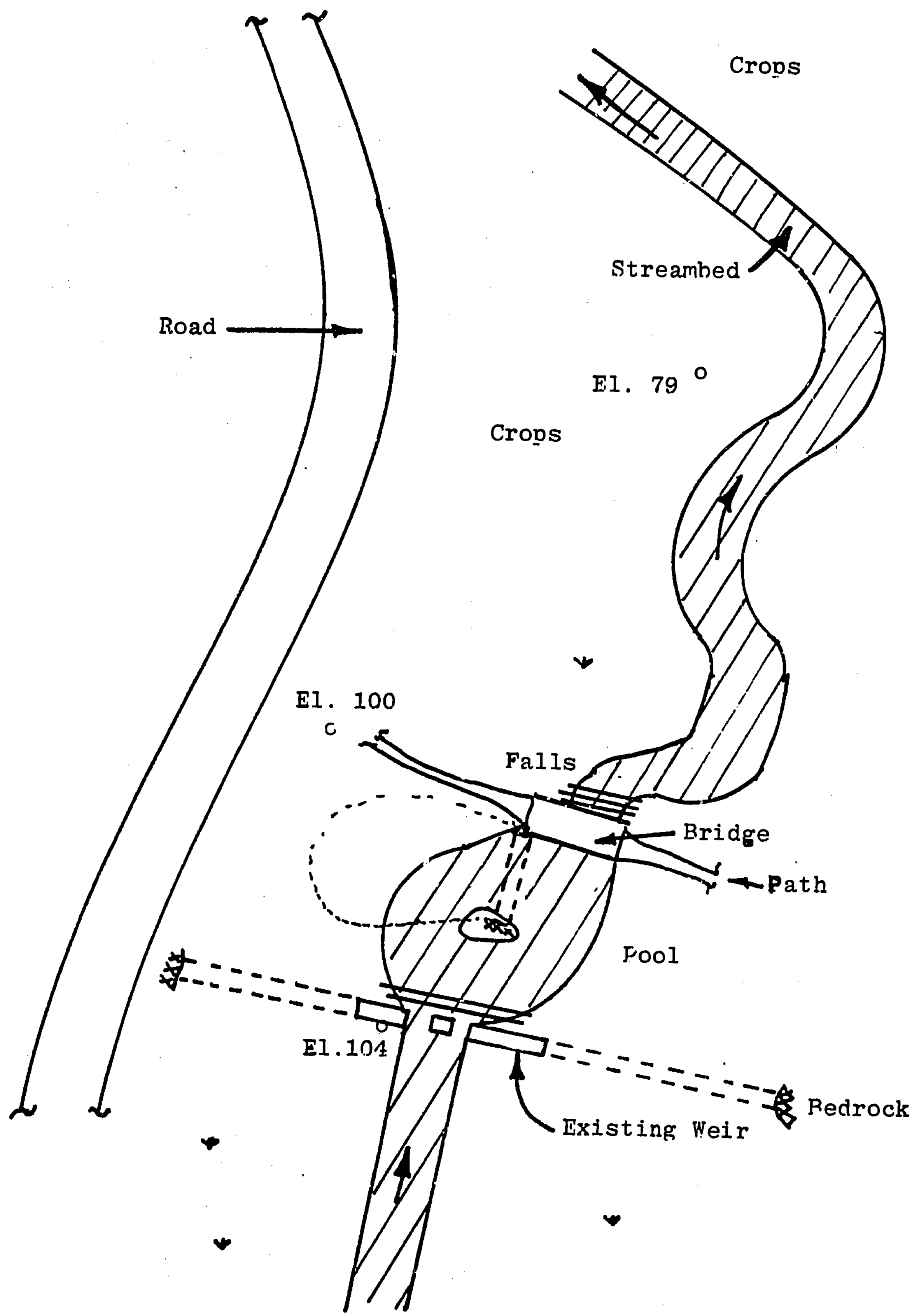


FIGURE VI-5

SUMMARY OF UNDEVELOPED POTENTIAL SMALL HYDRO SITES

	Chute Name	River	Head (m)	Assumed Flow m^3/sec.	Power kw	Approx. Cost US$	Approx. $/kW	Comment
1.	Kigembe	Migina	5.0	.5	17	18,000	1000	very good
2.	Gisuma	Mirayi (Muyira)	30	.07	15	50,000	3,330	poor
3.	---	Sihimbi	7	.1	5	30,000	6,000	very poor
4.	Ndaba	Ndaba	300	.1	240	810,000	3,500	poor
5.	Gasvmo	Mukinga	26	.23	42	154,000	3,660	poor - could improve if nearby load found
6.	Kaba-hendanyi	Nyamutera	20	.8	100	160,000	1,600	good
7.	Nyamyotsi	"	37	1.0	250	417,000	1,600	fair
8.	Main	"	88	1.2	850	1,500,000	1,800	too large for CEAER Program

TABLE VI-1

VII. DEVELOPED SDH PROJECTS

The field team visited four developed small hydroelectric sites in Rwanda. The first site, Rumyombi, was under construction and very close to operation. The second site at Murunga was operating during our visit. The last two developed sites were abandoned power plants and the most interesting of the sites visited.

Rumyombi

Rumyombi is the site of a joint church Mission/government-sponsored school near the Burundi border in southwest Rwanda. The church Mission is constructing a 125 kW hydroelectric installation to replace a diesel generator. The project has the following features:

Head:	29 meters
Design flow:	0.55 m^3/sec
Turbine:	180 hp Ossberger cross-flow
Generator:	125 kW, 3Ø
Weir:	Reinforced concrete, 3 meters high, anchored to bedrock with steel bars. Two sluice gates for flushing sediment
Headrace:	Rectangular shape sediment basin with sluice gate
Forebay:	Submerged trashrack to allow floating debris to pass over and into spillway
Spillway:	Angled back along side of headrace to collect overflow, sluice flow, and ground runoff
Penstock:	Steel; buried
Distribution:	3 km of 10 kV overhead line

The project is very close to completion. All the civil works are complete, the distribution lines installed, and they are in the process of connecting the transformer and electrical controls. The project required over three years to construct and employed up to 300 local laborers. It was designed to be labor intensive with items such as wooden planks and form supports being hand cut from logs.

The site is managed by the Union of Baptist Church of Rwanda. The church financed half the project, and the Government of Rwanda the other half.

Murunga

Murunga is located approximately halfway between Kibuye and Gisenyi. The Catholic Mission there has designed, constructed, and is now operating a 100 kW hydroelectric plant. The power is used for a sorghum mill, dispensary, parish lighting, oil press, carpenter shop, and welding shop. The installation has the following features:

Head:	75 meters
Flow:	.20 m^3/sec
Penstock:	Steel; buried; 140 meters long; 0.4 m diameter; 5mm thick
Turbine:	Ossberger cross-flow; 100 kW; 857 rpm
Generator:	400 v; 125 kVA; 50 hz; 1500 rpm 3Ø
Distribution:	400/6600 step-up transformer, 1 km of overhead line, step down transformer
Headrace:	Lined canal (brick with mortar surface); 340 meters long
Weir:	Masonry with mortar surface
Cost: (US$)	Concrete - $200/m^3$ Headrace - $15,000 Turbine-generator-penstock and transformer - $170,000 (seems low) Total cost - $450,000

The installation took three years to plan, design and construct. It has been successfully operating for two years. The following minor problems have developed there are worth noting:

- cracks are forming in the headrace canal as no expansion joints were used;
- dirt from the banks above the canal erodes into the canal since no culvert was installed and attempts to start grass on the bank have failed;
- water velocities in the spillway are great enough to cause erosion of the mortar surface;
- the two inch-diameter sluice valve is too small for cleaning the sediment basin; it now requires up to four hours to clean the basin

The above information was obtained from Jon Peters, Plant Designer and Mission Technical Officer. Mr. Peters also assisted in the Rumyombi site design.

<u>Nkora</u>

Nkora is located on Lake Kivu, approximately 20 km south of Gisenyi. A 125 kVA hydroelectric plant was constructed here to power a coffee cooperative. After a number of management problems, the plant operations stopped and the site was abandoned in 1974. Although the field team was unable to enter the powerhouse, the following information was obtained from local sources:

Head:	30.5 meters
Flow:	.4 - .6m^3/sec
Turbine:	Ossberger cross-flow 400 rpm good condition
Speed increaser:	400/1500 rpm flat belt pulley; needs new belt
Generator:	3 phase, 380 v, 125 kVA, 50 hz 1500 rpm; manufactured by APG, one pole is burnt, hence, a new generator is required
Controls:	Condition unknown
Distribution:	Underground feeder to machinery room in good condition
Intake, forebay:	Good condition but needs cleaning
Penstock:	Steel; .6m diameter

It is estimated that the powerplant could be rehabilitated for about $25,000. A World Bank study estimated a cost of $100,000 to put the entire coffee processing operation back into production. (See Annex 2).

The above information was obtained during a conversation with Verjus Hadelin who worked at the Nkora site from 1970 to 1974.

Rehabilation of the Nkora powerplant offers the best returns (cost/kW output) of all the sites the field team visited. A portion of the power output could easily be delivered to a small commune .5 km away on the Lake Kivu shore. Additional capacity would be available for production uses such as: coffee milling, a fishing center, or even a resort hotel. The NRECA team recommends this site for future development.

<u>Rwanda Flour and Coffee Mill</u>. The most interesting site visited by the field team was an abandoned flour and coffee mill located off the road south of Ruhengeri (See Figure 8-3). The mill is on the Nyamutukura River near the Kigombe commune. A layout of the site is sketched in Figure VII-1. The site consists of two separate power plants: a hydroelectric installation and a waterwheel which drives a mechanical shaft for the mill.

The layout of the electric plant is sketched in Figure VII-2. The head at the plant is from eight to ten meters and the penstock is about .6 meters in diameter. Assuming a design velocity in the penstock of about three m/sec, the installation could provide from 50 to 75 kW. The penstock, cutoff valve, turbine, speed increaser, and flywheel all appeared to be in good condition. The governor (DUMONT) is questionable and the generator and control equipment are missing. The cost to restore this installation is estimated to be between $10,000 to $20,000 depending upon the actual condition of the equipment.

The layout of the mill is sketched in Figure VII-3. The waterwheel that was used here is sitting on the grass between the mill and electric power plant. The waterwheel, shaft, bearings, and drive pulley would all have to be replaced. The jackshaft, huller, and grinder all appear to be in operable condition. Cost to restore this installation is estimated to be between $5,000 and $10,000.

The NRECA team recommends that restoration of the Rwanda Flour and Coffee Mill be pursued by CEAER.

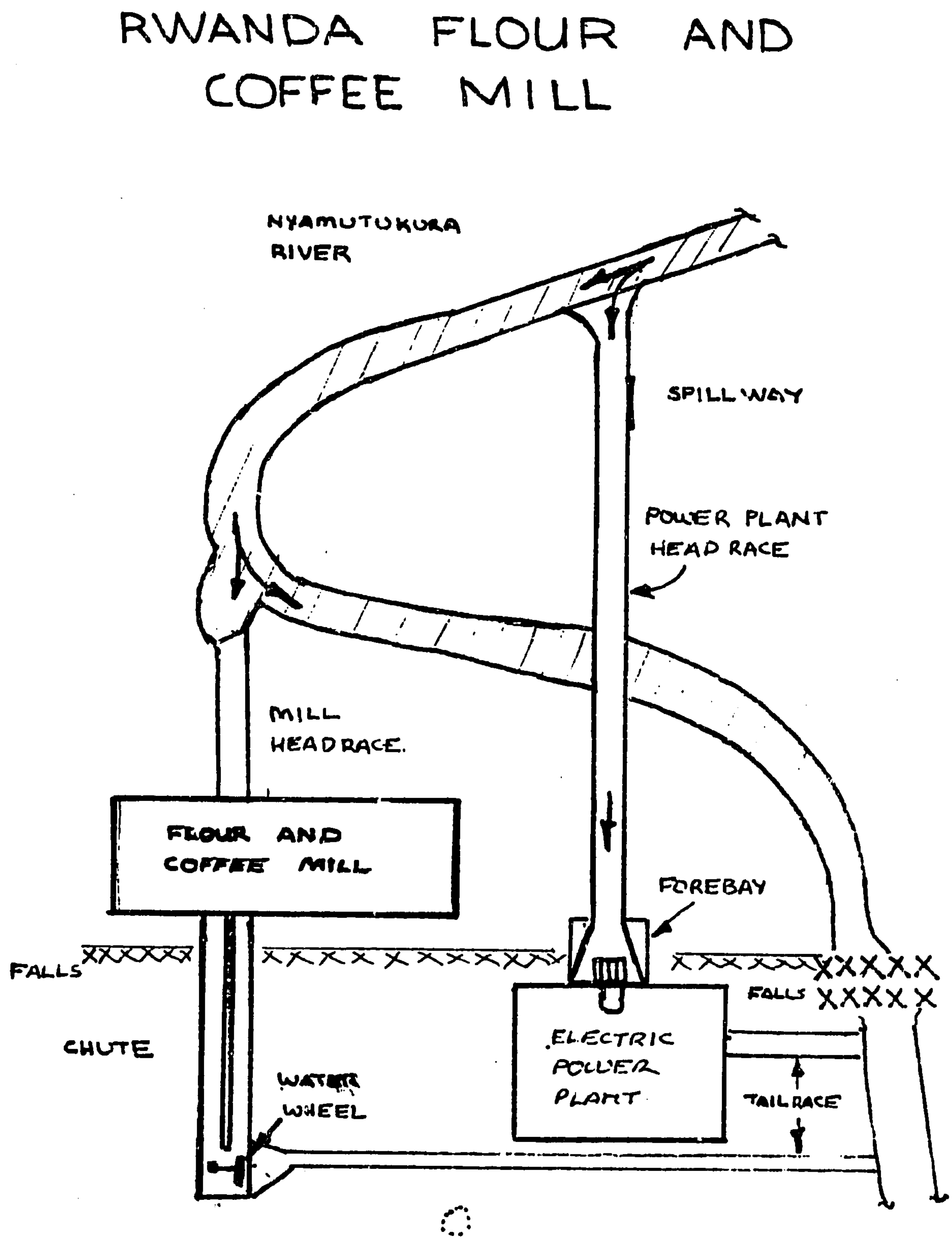

RWANDA FLOUR AND COFFEE MILL
NYAMUTUKURA RIVER
SPILLWAY
POWER PLANT HEAD RACE
MILL HEADRACE.
FLOUR AND COFFEE MILL
FOREBAY
FALLS
FALLS
CHUTE
WATER WHEEL
ELECTRIC POWER PLANT
TAIL RACE

Figure VII-1

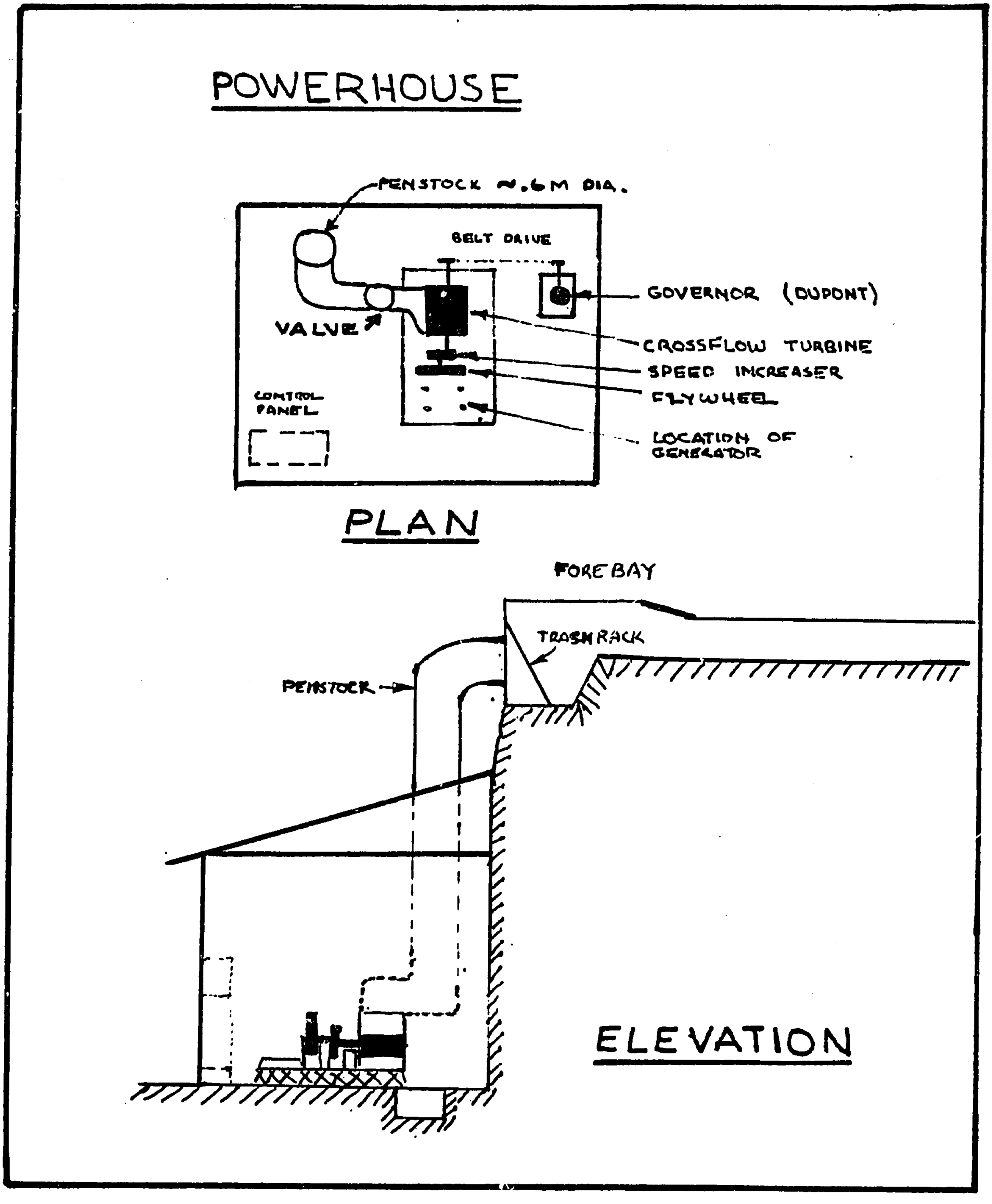

POWERHOUSE
PENSTOCK ~.6M DIA.
BELT DRIVE
GOVERNOR (DUPONT)
VALVE
CROSSFLOW TURBINE
SPEED INCREASER
FLYWHEEL
CONTROL PANEL
LOCATION OF GENERATOR
PLAN
FOREBAY
TRASH RACK
PENSTOCK
ELEVATION

Figure VII-2

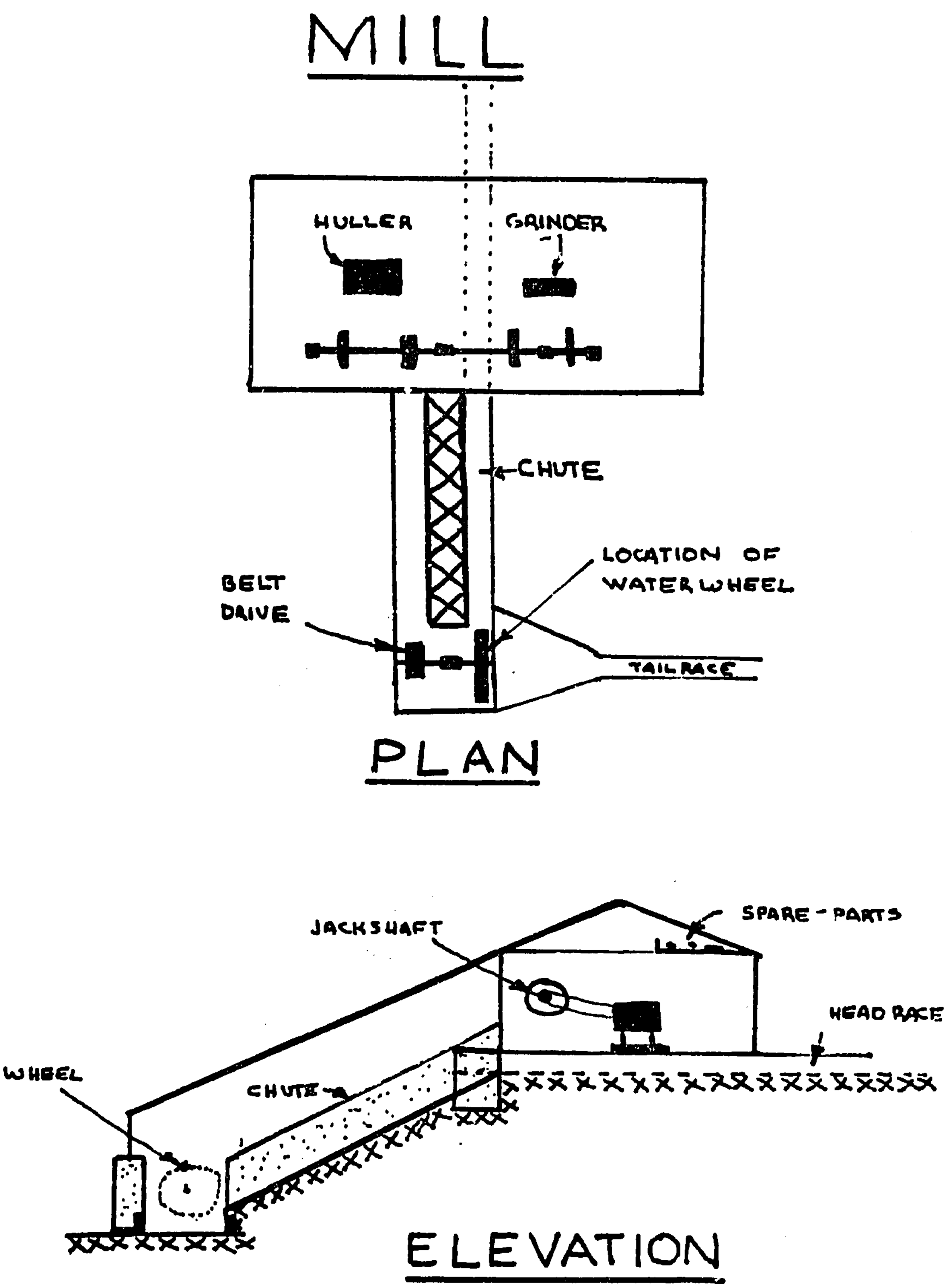

MILL
HULLER
GRINDER
CHUTE
BELT DRIVE
LOCATION OF WATER WHEEL
TAIL RACE
PLAN
JACKSHAFT
SPARE-PARTS
HEAD RACE
WHEEL
CHUTE
ELEVATION

Figure VII-3

VIII. RECOMMENDED SDH PROGRAM FOR CEAER

The NRECA team recognizes the large potential for small decentralized hydropower in Rwanda. The recommendations offered in this chapter are aimed at the objective that CEAER play a practical role in the development of small decentralized hydropower in Rwanda. This objective differs in some aspects from the objectives of the Renewable Energy Project: to install a micro-hydro power unit and observe its impact on the rural population. With this difference in objectives recognized by all parties, the NRECA recommends that CEAER pursue small hydro development along two courses of action: (A) restoration of abandoned sites, (B) development of new sites.

A. Restoration of Abandoned Sites

A.1. Restore the Rwanda Flour and Coffee Mill site. Restoration of this site would give the Center valuable experience in the design, construction, and operation of a small hydropower installation at a low cost. Power from the electric powerplant could be distributed to the local commune and the impact of electrification observed. Development of the waterwheel, designed and constructed by CEAER, would give Rwanda a locally manufactured turbine that could find applications at numerous low-head sites throughout the country. This installation would provide CEAER the perfect opportunity to experiment with various mechanical uses of hydropower which would be of great interest and value to Central Africa. The site could develop into a Small Hydro Research Center for all of Africa.

A.2 Restore the abandoned site at Nkora after the uses and operation of the mill installation have been observed.

B. Development of New Sites

B.1. It is recommended that CEAER conduct a survey of potential hydropower sites throughout Rwanda and build an inventory of such sites. CEAER should obtain and use the Swiss inventory of micro-hydro sites in Rwanda.

B.2 CEAER should conduct a reconnaissance survey and analysis of potential sites and then evaluate sites on a prefeasibility level to include an assessment of local needs, construction problems, and a comparison of site benefits against estimated project cost. This prefeasibility evaluation would lead to selection of the most favorable sites and eventually to construction of the best sites (most likely not Kaviri).

B.3. The Center should begin collecting flow data at sites which appear most favorable.

B.4. After the Center has gained the experience from restoring the mill site, it should undertake the construction of a new site.

Further guidance in developing a national program for small hydropower is contained in the NRECA papers, "A Methodology for Countrywide Assessments of Small Hydropower Potential" and "A Methodology for Prefeasibility Studies of Candidate Mini-Hydro Sites."

IX. REFERENCES

(1) Nozaki, Tsuguo, "Guía Para la Elaboración de Pequeñas Centrales Hidroeléctricas Destinadas a la Electrificación Rural del Perú", June 1980.

(2) NRECA, "Small Hydroelectric Powerplants", 1981.

(3) UNDP, "Development of the Kagera River Basin", Draft Mission Report, 1980.

(4) NRECA, "Directory of Sources of Small Hydroelectric Turbines and Packages", 1981.

(5) CEAER, "Etude Preliminaire de la Possibilité d'Exploitation de la Chute Masumo Située Entre les Communes Kinyamakara et Karama sur le Ruisseau Kauiri en Prefecture de Gikongoro", 1980.

(6) Nkubana Alphonse "Développement De La Production Et De La Consommation D'Energie Hydroélectrique Au Rwanda", See Perspectives D'Avenir, 8/12/1979.

(7) Hamm, Hans, "Low Cost Development of Small Water Power Sites", VITA, 1977.

(8) USDI, "Reconnaissance Evaluation of Small, Low-Head Hydroelectric Installations", 1980.

ANNEX 1

COST FIGURES

The cost figures used by the NRECA team were derived from several sources which agreed on some items and differed on others. The following gives the cost figures used, the sources of information, and recommendations for refining the cost estimates used.

Concrete The figure of $200 per cubic meter for concrete in place was used by the team. This figure agrees with Klock[3] and was confirmed in a conversation with Jon Peters. The concrete in western Rwanda is imported from Zaire and expensive. This cost figure includes the labor cost in preparing and constructing the structures. Reinforced concrete would cost about twice this amount.

Penstock Klock[3] uses a figure of $660 per meter for a 50 cm (20") steel penstock. This size is larger than generally used for mini-hydro installation and this figure is much higher than cost curves used for mini-hydro schemes. Therefore, the team reduced this cost to under $400 per meter. Over one-half of this amount is for the material and the remainder for the installation (anchor, etc,). When possible, PVC pipe should be used and the penstock cost can be cut in half. At low-head installations concrete penstocks are possible.

Headrace The team used $50 per meter for a lined canal in soft soil which was confirmed in conversations with Jon Peters. The reason for this low cost is the low wages ($1/day) given laborers.

Distribution Klock[3] uses a figure of $25,000 per km for 15 kV distribution line which was confirmed in conversation with Nkubana Alphonse[6]. Hence, the NRECA team also used this figure. For low voltage applications where underground cable can be utilized, a figure of $5,000/km was used.

Powerhouse The powerhouse cost figures include the foundation, tailrace, and the superstructure. The team used a figure of $\$250/m^2$ which came from the cost of the Rumyombi and Murunga powerhouses. The foundation requirements represent the major portion of this cost and remaining superstructure cost would utilize local construction materials.

Powerplant The powerplant cost figure includes the turbine, generator, governor, electrical controls, speed increaser and flywheel if appropriate. The cost figures used varied from $500/kW for a waterwheel to $1500/kW for large, lower head crossflow turbines with hydraulic governors. Factors to consider when selecting an appropriate cost figure are:

- o Can the installation use an electric load controller?
- o What type of turbine is required - a relatively low cost high head, or a more expensive low-head reaction turbine?
- o Will the installation ever be synchronized with other units? If so, then the control devices will be more costly.
- o Can the installation generate DC power? These installations (usually under 10 kW) will not require an expensive governor.

The NRECA team recommends that CEAER view the cost figures used in this report as a start from which to refine and improve as more country-specific data is collected in the course of their Small Hydro Program.

NKORA

125 kW

Hydroelectric Plant

NYAMYOTSI

Site on the Nyamutera River

ANNEX - 2