PNAAS014

IAA-38544

WORKING GROUP EXERCISES

Small Hyrdopower in Africa

Introduction

The workshop participants will be asked to study two problems during the course of the week involving the design, costing, and economic analysis of small hydropower projects at an actual site in Swaziland. The purpose of these exercises will be to allow the participants an opportunity to gain practical experience in conducting preliminary feasibility assessments of small hydro projects under two entirely different sets of circumstances. In each exercise, the participants will be charged with undertaking the preliminary design of a project with the objective of providing a more cost-effective source of electrical energy than presently exists.

The first scheme, on the order of several megawatts, will be interconnected with the grid to displace thermally generated electricity. The second scheme, a micro-hydro plant, will be designed to replace an existing diesel generator set which serves the energy needs of a rural community located far from the national grid.

The basic technical characteristics of the site will be given. The responsibility of the participant will be to examine different design approaches in search of the most cost-effective means of addressing the energy needs of each case.

The participants will be assigned to one of four groups, each of which will elect a leader who may also serve as the group spokesman. Each group will be assisted by several resource people, and will be responsible for developing what is believed to be the most cost-effective design for each of the two schemes. This will be done by first developing a design at a location which looks promising, after analyzing an aerial photograph of the site with superimposed contours. After that design has been costed and a cost/kW obtained, the participants should attempt to identify those costs which could be reduced by making modifications in the design. This could involve the development of a number of different configurations. The groups are encouraged to explore as many cost-cutting possibilities in this manner as possible within the allotted time for working group discussions.

The same assumptions will be used by each group to facilitate the comparison of results. Once the design having the lowest investment cost per kW is found, economic analysis is performed to assess the cost-effectiveness of the projects in comparison to the existing thermal energy source and the net return on investment. On the last day of the workshop, each group leader will present his group's findings so that comparisons of their designs may be made and conclusions reached.

The cost figures used in these exercises do not necessarily represent costs found in Swaziland or any other specific country. In planning for, and designing, a hydropower scheme for a specific country, these cost figures would be subject to changes to reflect actual cost conditions in the country in question. Also, it should be noted that the unit costs and procedures used are in simplified form to permit this exercise to be completed within the allotted time. For example, assumptions regarding hydrology are presented in a very general and condensed manner. A more complete study would require such factors to be considered in greater detail. All figures are in U.S. dollars.

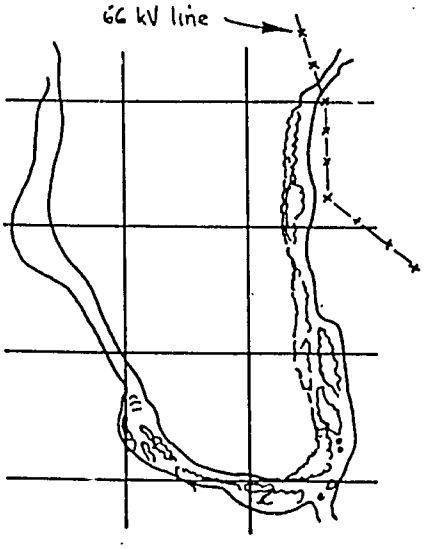
Case A. Grid-Connected Scheme

A 66 kV transmission line providing power from large power plants in the south to regions in the north, traverses the site area as shown in Map 1. The existing power system is supplied mostly by thermal stations, supplemented by hydro. The average fuel cost for the thermal-generated energy is $0.05/kWh. This cost is expected to increase in real terms by 2% a year due to the heavy reliance on imported petroleum. It would be economically desirable, therefore, to constuct a hydropower plant that could feed less costly energy into the grid.

An initial attempt to design such a scheme is presented below. In implementing this 3.7 MW plant, a capital cost of $1,500/kW would be incurred. The first exercise is to assess whether a small hydropower plant could be developed at the site to supply energy to the grid at a lower cost than this plant. The following assumptions are to be made:

- Q = average flow = 10 m^3/s
- e = total conversion efficiency = 80%
- single turbo-generating unit to be used
- f = plant factor = 90%
- useful plant life = 30 years
- construction period is 3 years
- annual O&M cost is 1.5% of capital cost
- the discount rate is 10% for purposes of economic analysis.

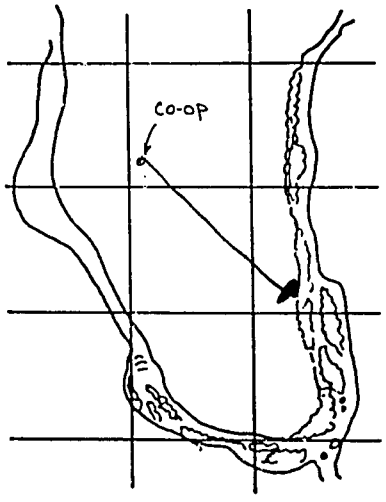
Other information to be used in completing this exercise is found in Appendix I.



Map 1

Case B. Isolated Scheme

In an area many miles from the nearest power grid, an agriculture cooperative (shown in Map 2) is presently using a 50 kW diesel generator to provide electricity for irrigation pumps, agricultural processing machines, and some nighttime lighting. Due to the high cost of fuel ($0.15/kWh), the diesel is used sparingly, usually only a few hours each day.



Map 2

The following table presents a summary of the existing energy demand.

Load	kW	kWh
1. Irrigation pumps	45	33,000
2. Processing machines	10	5,000
3. Cold storage plant	20	50,000
4. Clinic	5	10,000
5. Lighting	15	27,000
6. Cottage industries	5	5,000
Total annual energy required		130,000

The diesel engine is beginning to break down with increasing frequency and will soon need replacing. Moreover, the cooperative's electricity demand has increased. A clinic is to be established, requiring refrigeration of medicines among other electrical needs. There are plans to install a cold storage plant for preservation of fruits and other produce. Land is being cleared to allow more area to be cultivated, which will require additional electrical energy for irrigation and processing. Finally, the villagers in the area have asked for electrical service for lighting and to operate small appliances and machinery used in cottage industries.

Demand growth in future years is expected to average 3% a year, mostly in new household demand due to population growth and the addition ofnew cottage industries. This will not affect peak load, since the increased energy requirements can be accomodated during off-peak periods. The total conincident peak load would not exceed 70 kW during the life of the plant.

The task is to determine whether a 70 kW hydropower plant can be designed to harness a portion of the waterpower potential available at the site at an energy cost lower than that of a similarly sized diesel generator.

For this exercise, the following assumptions are made:

- e = total plant conversion efficiency = 60%
- useful life = 30 years
- construction could be completed in one year
- new diesel plant would have a capital cost of $700/kW installed and would need to be replaced every 10 years. Operation and maintenance costs would be 4.5% of the capital cost. Fuel cost would

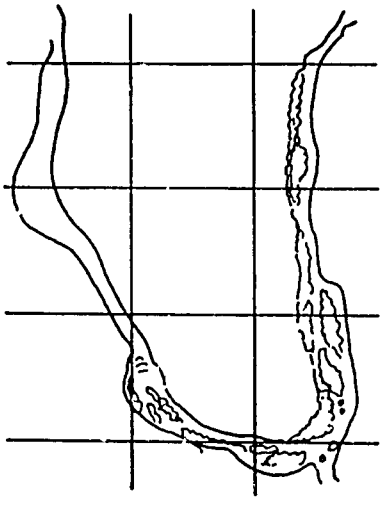
be $0.15/kWh, subject to an escalation factor of 1.02.

- annual O&M cost for the hydro plant is 2.5% of capital cost
- the discount rate is 10%.

Other information to be used in completing this exercise is found in Appendix I.

SUMMARY SHEET 1

Scheme number: ___



average power P = _____ kW

head H = _____ m

flow Q = _____ m^3/s

plant factor f = _____

annual energy E = _____ kWh

Costs (x ₦1,000)

weir	_____	engineering (5%)	_____
intake	_____	site supervision (10%)	_____
canal	_____	contingency (10%)	_____
tunnel	_____		
forebay	_____	TOTAL	_____
penstock	_____	construction period interest (15%)	_____
powerhouse	_____		
turbine	_____	TOTAL CONSTRUCTION COST	_____
generator	_____		
switchgear	_____	COST/kW = _____	
access road	_____		
distribution	_____		
transmission	_____		
substation	_____		
SUB-TOTAL	_____		

CASE A

COST-EFFECTIVENESS ANALYSIS

Discount rate: 10 %

Options: hydro vs. grid

Year	Hydro Capital	Hydro O&M	Hydro Total	Grid Total	PW Factor	Total PW Costs Hydro	Total PW Costs Grid
1					1.000		
2					.909		
3					.826		
4					.751		
5					.683		
6					.621		
7					.564		
8					.513		
9					.467		
10					.424		
11					.386		
12					.350		
13					.319		
14					.290		
15					.263		
16					.239		
17					.218		
18					.198		
19					.180		
20					.164		
21					.149		
22					.135		
23					.123		
24					.112		
25					.102		
26					.092		
27					.084		
28					.076		
29					.069		
30					.063		
31					.057		
32					.052		
33					.047		
Total							

COST-EFFECTIVENESS ANALYSIS

Discount rate: 10 %

Option: 70 kW hydro

CASE B

Year	Capital	O&M	Total	PW Factor	Total PW Costs
1				1.000	
2				.909	
3				.826	
4				.751	
5				.683	
6				.621	
7				.564	
8				.513	
9				.467	
10				.424	
11				.386	
12				.350	
13				.319	
14				.290	
15				.263	
16				.239	
17				.218	
18				.198	
19				.180	
20				.164	
21				.149	
22				.135	
23				.123	
24				.112	
25				.102	
26				.092	
27				.084	
28				.076	
29				.069	
30				.063	
31				.057	
Total					

1

COST-EFFECTIVENESS ANALYSIS

Discount rate: 10%

Option: 70 kW diesel

CASE B

Year	Capital	O&M	Energy	Total	PW Factor	Total PW Costs
1					1.000	
2					.909	
3					.826	
4					.751	
5					.683	
6					.621	
7					.564	
8					.513	
9					.467	
10					.424	
11					.386	
12					.350	
13					.319	
14					.290	
15					.263	
16					.239	
17					.218	
18					.198	
19					.180	
20					.164	
21					.149	
22					.135	
23					.123	
24					.112	
25					.102	
26					.092	
27					.084	
28					.076	
29					.069	
30					.063	
31					.057	
Total						

DIESEL ENERGY COST CALCULATION

Yr.	Demand Growth Rate	Energy Demand	Energy Cost Escalator	Unit Energy Cost	Total Energy Cost
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
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22					
23					
24					
25					
26					
27					
28					
29					
30					
31					

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ECONOMIC ANALYSIS

Discount rate: 10 %

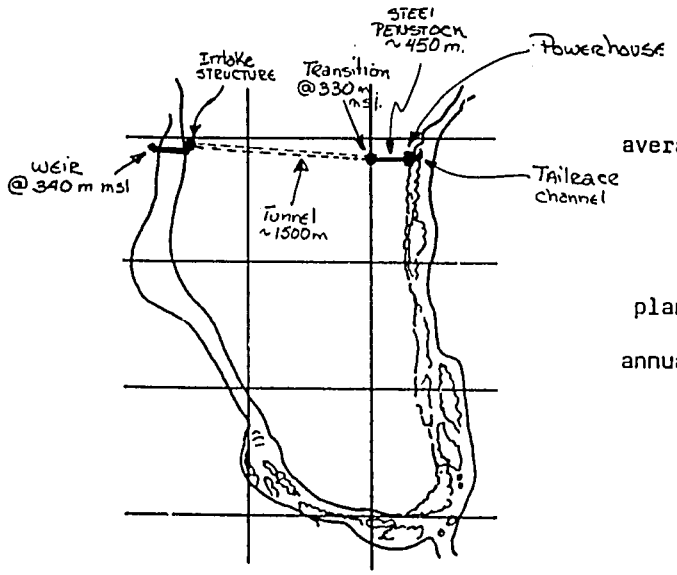
	PW Factor	Project Costs		Project Benefits		Net Cash Flow	
		Nominal	Discounted	Nominal	Discounted	Nominal	Discounted
1	1.000						
2	.909						
3	.826						
4	.751						
5	.683						
6	.621						
7	.564						
8	.513						
9	.467						
10	.424						
11	.386						
12	.350						
13	.319						
14	.290						
15	.263						
16	.239						
[illegible]	.218						
18	.198						
19	.180						
20	.164						
21	.149						
22	.135						
23	.123						
24	.112						
25	.102						
26	.092						
27	.084						
28	.076						
29	.069						
30	.063						
31	.057						
32	.052						
[illegible]	.047						
TOTALS							

Benefit/cost ratio:

Internal rate of return:

SUMMARY SHEET 1

Scheme number: SAMPLE - A1



average power P = 3700 kW

head H = 50 m gross 45m(net)

flow Q = 10 m^3/s

plant factor f = 80%

annual energy E = 26×10^6 kWh

Costs (x 1000)

weir	250
intake	50
canal	–
tunnel	750
forebay	–
penstock	540
powerhouse	150
turbine	1,300
generator	370
switchgear	240
access road	5
distribution	–
transmission	5
substation	90
SUB-TOTAL	3750

engineering (5%)	190
site supervision (10%)	380
contingency (10%)	380
TOTAL	4,700
construction period interest (15%)	700
TOTAL CONSTRUCTION COST	5400,000

COST/kW = £ 1460

Worksheet for Sample Exercise

General Concept: MAXIMIZE head and therefore power by tunnelling through entire "horseshoe" - This will be done as a "first cut" with no attempt to optimize the development

choice of tunnel route - shortest distance across horseshoe at first glance - locate weir in this general area where contours are closest together.

1. WEIR - locate at contour ± 340 and construct weir to be 4 meters high -
from curve - cost will be ~ $1000 / meter of crest length
from map - length ~ 250 m.

Cost - $250,000

2. Intake - concrete, trashrack, gate, etc.
from curve L.S. Cost - $50,000

3. Canal - none

4. Tunnel - (excavation costs)
Use a pressurized tunnel - for 10 m^3/sec flow
Assume a tunnel velocity of 3 m/sec
try tunnel diameter of ~2.5 meters
Assume ℄ tunnel @ 341 - this should give enough submergence ?! (check later)
will this cause sediment problems? - probably not as 4 m weir will act as stilling basin.
Assume tunnel exit @ contour 330 -
∴ length ~ 1500 m. @ $500/m cost - $750,000.

5. Forebay – no! – Assume pond sufficient

6. Losses – make transition from tunnel to steel penstock @ contour 330 and run directly downhill. – Assume 2 m diameter penstock for 5% loss

7. Penstock – penstock length ~ 450m from curves $1200/m cost – $540,000

8. Power Equation

Gross head – 344 – 295 m = 49m
loss @ 5% = 2.5m
46.5m.

flow – given @ 10 m³/sec.
efficiency – given @ 80%

$\therefore P = .8 \cdot 10 \cdot Q \cdot H_n$
$= .8 \cdot 10 \cdot 10 \cdot 46.5$
$= 3700$ KW

9. Powerhouse

from curve and extrapolating @ ~head of 50 m. ~ cost – $150,000

10 Turbine

from curve for > 1000 KW @ $350/KW – 3700 KW cost – $1,300,000

Generator -

from table - 3700 kW @ $100/kW COST - $370,000

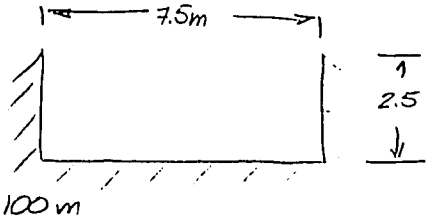
Switchgear

from table 3700 kW @ $65/kW COST $240,000

11. Tailrace

Assume channel in bedrock @ excavation cost of $15/m³

Assume :



length - 100 m

∴ 2.5 × 7.5 × 100 = 1875 m³ COST $28,000

12. Transmission

66 kV line passes within 100 m of powerhouse ∴ 1 span with connection equipment ESTIMATE COST $5,000

13. Step-up Substation

from table - EST. @ $25/kW COST $90,000

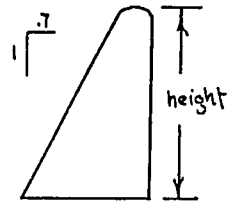
14. Access Road

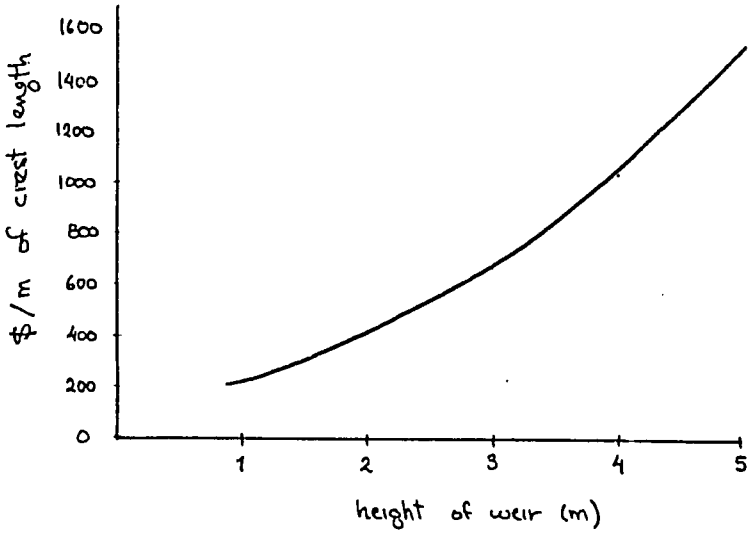
Approx. 1.5 km of road upgrade and install gravel. EST. COST $5,000

APPENDIX I: REFERENCE INFORMATION

1. Weir costs

Assumes a concrete overflow weir and a cost of installed reinforced concrete @ $150/m^3. For low weir heights, costs of excavation, rock bolting, and foundation dominate. Therefore costs level to about $200/m.





2. Intake costs

Lump sum costs include trashrack, sluice gate, settling basin, etc.

$50,000 for schemes greater than 1,000 MW

$4,000 for schemes less than 100 kW

3. Excavation costs

unclassified	$7/m^3	
surface rock	$15/m^3	
tunneling	$500/m	(for tunnels of low head schemes in the low megawatt range)

4. Canal costs

Unlined earth canals will be used and their cost is approximately that of excavation. A maximum flow velocity in the canal of 0.8 m/s is assumed and the cross-sectional area excavated equals the cross sectional area of the water in the canal.

5. Forebay costs

Costs include concrete, sluice gate, stop-logs, etc.

$25,000 for schemes greater than 1 MW

$2,000 for schemes less than 100 kW

6. Penstock losses

Losses for steel penstock are given below:

$$\frac{\Delta H}{L} = .001 \frac{V^2}{D}$$

where ΔH = frictional head loss

L = penstock length

D = penstock diameter

V = flow velocity

H = head

Q = flow

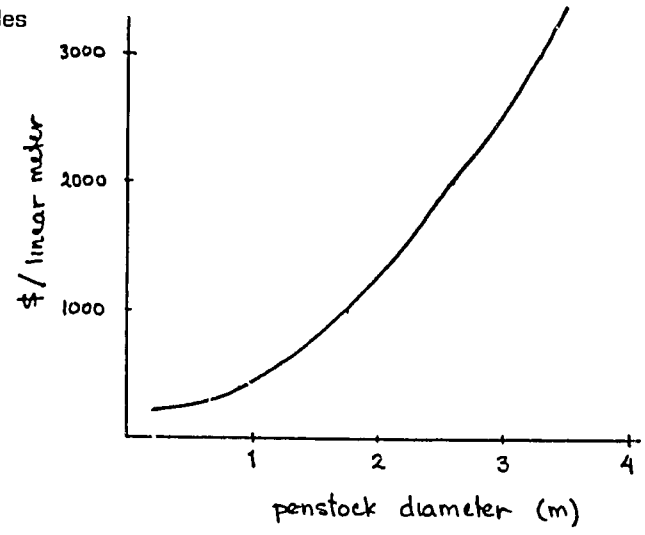
Losses should be kept to within 5%. Therefore $\frac{\Delta H}{H} \leq .05$.

Since $Q = V \cdot \frac{\pi D^2}{4}$ then the required penstock diameter for a 5% head loss can be derived. This becomes:

$$D = \sqrt[5]{\frac{Q^2}{30} \cdot \frac{L}{H}}$$

7. Penstock costs

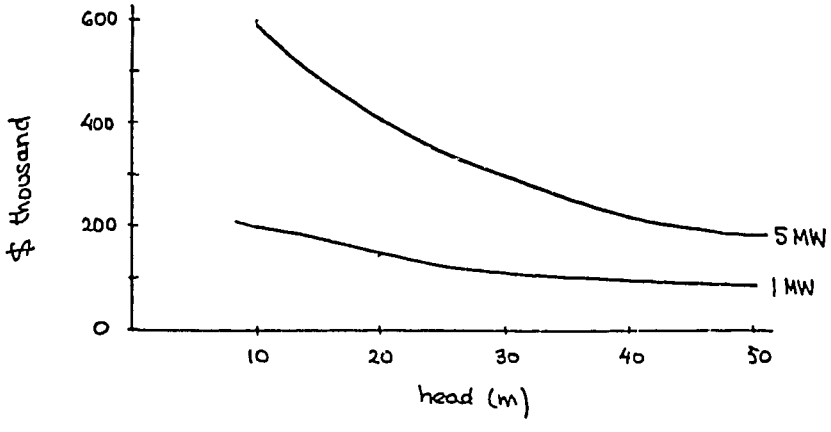
Costs are based on minimum handling thickness, includes steel penstock, supports, site clearing, and excavation.



8. Power equation

$P = 10 e Q H_n$ where e = efficiency = 60% (for P < 100 kW)
= 80% (for P > 100 kW)
Q = flow (m^3/s)
H_n = net head (m)

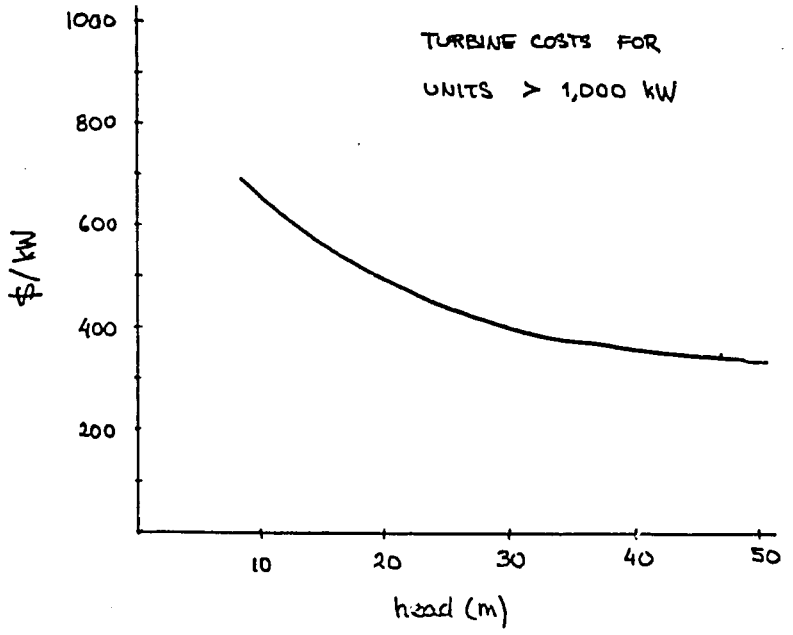
9. Powerhouse costs



For the 70 kW unit, a lump sum powerhouse cost of $7,000 is assumed.

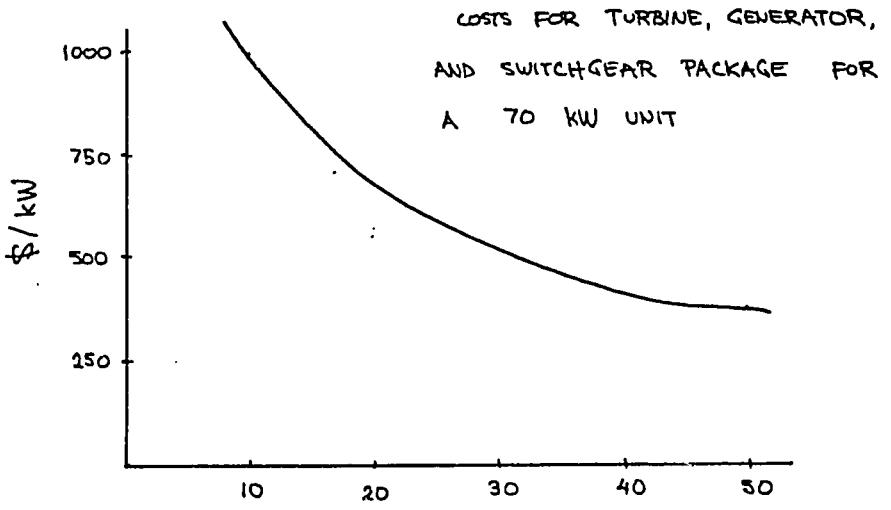
10. Turbine, generator, and switchgear costs

For turbines greater than about 1,000 kW:



Generator $100/kW
Switchgear $65/kW

For a 70 kW turbo-generating unit:



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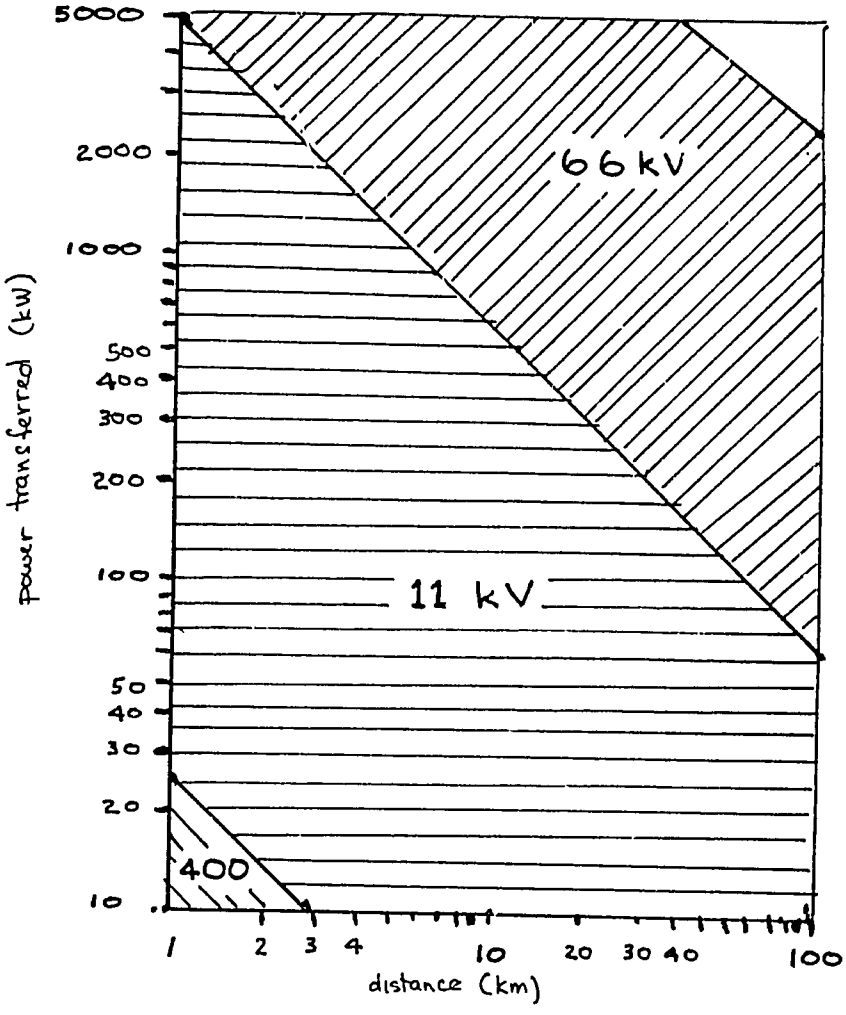
11. Distribution line voltage



12. Distribution costs

66 kV, 3 phase	$40,000/km
11 kV, 3 phase	$10,000/km
400 V, 3 phase	$2,000/km

sub-station costs

13. Sub-station costs

$25/kW

14. Access road costs

Cost is for a gravel road on gently sloping terrain.

$3,000/km

SMALL HYDROELECTRIC PROJECTS COMPLEMENT IRRIGATION AND WATER DISTRIBUTION SYSTEMS

by David C. Willer 1/

INTRODUCTION

In recent years, irrigation and municipal water systems have been extensively investigated as potential sources of low-cost electrical energy. The possibility of generating power exists at every drop in the hydraulic gradient of a water supply system; however, the capital costs associated with low-head plants are commonly very high, and some drops may not be suitable for producing power economically. This paper addresses the retrofitting of existing water supply systems to include small hydroelectric projects, the inclusion of small hydroelectric projects in new systems, and several case studies. Although this paper deals primarily with projects developed on irrigation systems, the ideas presented here are also applicable to domestic water supply and other water systems.

GENERAL

Provisions for drops in the hydraulic gradients of water supply systems are required when the terrain falls more rapidly than the hydraulic gradient of the flowing water. The change in the gradient of the terrain can occur abruptly or very gradually. If it is a gradual change on a canal, the designer normally provides a series of check structures with sudden drops. The upstream water surface elevation is maintained by a gate in the canal, and the water falls into a basin at the downstream water surface elevation. The basin may be only a pool of water controlled by a sill. This type of structure, called a drop structure, is common in irrigation systems for drops of up to about 20 feet (6 meters) of fall.

For locations where the drop exceeds 20 feet (6 meters), the flow is normally conveyed to the lower level by a chute, with an energy dissipator at the bottom of the chute. The energy dissipator reduces the high velocity

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chute flow to the low velocity canal flow. There are many examples of these structures in irrigation systems.

Other potential locations for power developments may be at the diversion dam on the river which supplies the water, at the outlet works for terminal reservoirs, at wasteways on the canal (for water wasted and not used in the system), and at the outlet works from main supply reservoirs. Each of the above named facilities, and in particular the diversion dam on the river, are prime locations for possible power generation.

TYPES OF PROJECTS

A typical project developed on an existing system will generally fall into the low-head range, that is, a drop of 60 feet (18 meters) or less, and propeller-type and crossflow turbines would be most commonly utilized, although Francis-type turbines may have some limited applications.

There are many configurations of low head turbines, and no one can be cited as typical. Figure 1 is included to illustrate several possibilities that can exist at any particular location. This Figure illustrates a number of alternative installations which were studied at a canal drop near Boise, Idaho, U.S.A. This fairly typical example illustrates that while the detailed configurations of the possible alternatives may vary considerably a number of features are common to most low-head retrofits. These common features are:

1. An intake structure or connection to an existing structure.
2. A short penstock or open channel conveyance facility.
3. A powerhouse.
4. Hydroelectric generation and control equipment in the powerhouse.
5. A by-pass facility to pass the flows around the power plant in the event of sudden power outage and when the plant is shut down for maintenance.

For the alternatives shown in Figure 1, the installed capacity of each of the plants was 1900 kW with a design flow of 700 cubic feet per second. The results of a cost comparison for the various power plant layouts and turbine configurations are shown on Table 1. The costs shown do not include costs which would be common to all alternative installations, such as transmission

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lines and indirect costs. The results of the cost comparison showed that the vertical shaft propeller with concrete penstock and scroll case had the lowest overall cost. However, the open flume vertical shaft propeller turbine and the tube turbine configuration were both very close (1.2 and 1.3 percent higher respectively).

It should be noted at this point that one unknown factor in this example is the amount of rock excavation associated with the open flume configuration. In this case, outcroppings of basalt rock exist in the general vicinity of the project, and if basalt rock is encountered during excavation, the estimated cost would be considerably increased because of the larger excavation associated with this configuration.

It was therefore judged that the vertical shaft propeller turbine and the tube turbine were effectually equal and it would not be known which configuration was actually lower in cost until actual firm bids were received.

DESIGN CONSIDERATIONS FOR PROJECTS AT EXISTING DEVELOPMENTS

Power Generation. The potential power generation for a given site is totally dependent upon the timing and magnitude of flows in the conveyance system. If the irrigation season lasts only six to eight months a year, then power can be generated only during that period of time. For this reason, plants on conveyance systems usually need to be tied into a grid system and are not suitable for isolated systems. In our studies, we have found areas where, even though the water is not needed for irrigation, there is ample supply of water in the river that could be diverted into the system, run through a power plant to generate power, and then wasted into a drainage way that eventually finds its way back to the river. Under these circumstances, power may be firm and can be used for isolated systems.

Although plants usually need to be tied into a grid system, each situation needs to be examined carefully. In an isolated system the electric loads, which might originate from irrigation pumping, may coincide with the generation of power from the irrigation project, thus making the power project feasible.

Where power is fed into a power grid, the energy has the value of the energy that it is replacing in the system. If the generation is dependable and occurs at the same time as the system peak, capacity credit can be provided in addition to an energy credit.

Bypass Flow Consideration. When the power plant is located on the conveyance system, provisions are required to bypass the flow around the power project when there is a sudden load rejection in the unit or when the unit is being repaired or maintained. These bypass facilities can take various forms, such as weirs or automatic gates that open and pass the exact amount of water previously flowing through the turbines. The system used for bypassing water needs to be reliable. For that reason, where there is sufficient room to accommodate the structure, the bypass is most commonly a weir.

If the power plant rejects the flow of water by closing the wicket gates, a water hammer condition exists that will cause surge pressures and must be considered in the design of the penstock. The faster the closure time, the greater the increase in the pressure. Additionally, the water in the canal behind the powerplant will rise, encroaching upon the freeboard of the canal. The length of the weir structure needs to be sufficiently long to minimize the increase in water surface.

Where the power is proposed to be developed at the end of an aqueduct system, the bypass system normally considered is a synchronous pressure relief valve that opens up when the turbine wicket gates close. The linkage between the valve and the turbine can be mechanical, hydraulic, or electrical, with mechanical being preferred. Other designs which have been considered include permitting the turbine to increase its speed to run away speed, and providing a turbine runner that will limit the flow of water. A bypass gate that can be opened manually when the operator can reach the plant would also be included for this type of design. Where no pressure rise can be tolerated in an aqueduct system, an impulse turbine with jet deflectors can be used.

Constructability. One of the more inportant aspects of design of power plants at existing structures is constructability. Generally, the existing demand for water must be met without fail. The only time construction can take place in the waterway area is when no water is flowing on the system. This generally requires that a construction schedule be established and rigidly adhered to. Cofferdams of earth and/or concrete may be needed to

protect the work area. The materials for the construction that would enable the construction of the facility to provide for the passing of water should be present before any work is started.

Geology and Soils Considerations. The structures involved in retrofitting existing drop structures for hydro generation facilities are larger and heavier than those used for the new sites and geologic and soil conditions are therefore of more concern. It will generally be found, however, that the unit bearing pressures are still quite low and are considerably less than for the more massive structures used for medium and large hydroelectric installations.

The existing structure being utilized for the hydroelectric installation will often be found to have equal or higher unit bearing pressures than the new installation and the site will therefore in all likelihood present no geologic problems for the new construction. In many cases it will be found that the site was originally chosen because adequate foundation conditions existed for the existing structure.

Rather than being concerned with allowable bearing pressures, a common problem encountered at low-head installations where the turbine setting is low with respect to the tailwater is the existence of net uplift pressures. In this case additional weight must often be added to the power plant in the form of thicker walls and foundations.

DESIGN CONSIDERATIONS FOR NEW DEVELOPMENTS

In planning new irrigation developments, consideration should be given to the possible inclusion of small hydroelectric power plants. It should be noted, however, that not every new development being planned can accommodate hydroelectric power. Whether power can be developed economically or not depends primarily upon the change in elevation between the proposed diversion and the elevation of the area to be served.

In the design of new systems, the most obvious location for power generation is at the storage dam for water and at the diversion dam that diverts water into the canal system. Usually the diverion dam diverts only a small portion of the water in the river, having a large flow in the river which may be used to develop power. Diversion dams are usually located as close as possible to the area to be irrigated to reduce the cost of the conveyance

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system. Where there is a potential of developing power along the canal, this criteria need not necessarily be followed. The diversion dam can be located at the most geographically suitable location.

In general, the design and layout of the conveyance system for a joint irrigation/hydroelectric development is different than an irrigation only supply system. The alignment and grade of an irrigation supply canal is normally as direct a route as possible, balancing cuts and fills, and where the terrain falls more rapidly than the hydraulic gradient of the canal, minimum depth check structures are installed to slow the flow of water. The systems are primarily layed out to minimize the check structures. For hydropower, the canal needs to be as flat a grade as possible to minimize head loss until an appropriate ground feature permits the water to fall in a penstock and maximize the fall. Figure 2 shows an example of a typical layout for an irrigation system which requires water to be carried from point A to B, and a revision of the layout to maximize the hydro power potential.

One of the first calculations that should be made in the design of such a system is to determine the minimum drop in elevation for a specific canal design flow needed to develop power economically. As an example, a chart as shown on Figure 3 could be prepared for a typical power plant layout. The chart appears in several publications. This chart is based on a penstock slope of 1 to 5 between the intake and power plant. As noted on the chart, the value of power for the area is estimated to be 65 mills per kilowatt hour. Therefore, if the design flow for power is 500 cubic feet per second, the minimum drop for economical power projects is 14 feet. For a design flow of 400 cubic feet per second, the minimum drop is 20 feet. Generally, the design flow for power in an irrigation system should be a flow which is at about the 25 percent exceedance point on a flow duration curve.

Another calculation which should be made is to determine the value of one foot of head in annual power generation. By knowing the value, then at each proposed drop, an economic study can be made to determine if the tail water can be lowered by lowering the canal invert by a like amount or head water raised by increasing the berms on each side of the canal.

Other areas which should be investigated in the early stages of project development are whether water could be diverted all year around into the system so power could be generated throughout the year. Water that is not

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needed during the off season would be wasted back into the river system. Also, if there is sufficient flow it may be possible to make the supply canal to the power plant larger and generate power in a wasteway, as it flows into the river.

CASE HISTORIES

In order to further illustrate the preceding, the following projects are presented:

I. TURLOCK IRRIGATION DISTRICT, DROP 1 AND DROP 9

Turlock Irrigation District conveys water from a diversion dam on the Tuolumne River to their district service area in a long supply canal. There are two drops on the canal, Drop 1 and Drop 9, where it was deemed feasible to install power plants. The plants were constructed and have been operating since 1980.

Significant information about these power plants is as follows:

	Drop 1 Plant	Drop 9 Plant
Peak Flow	2000 cubic feet per second	1500 cubic feet per second
Hydraulic Drop	29 feet	17 feet
Installed Capacity	3 - 1000 kW units	2 - 550 kW units
Average Annual Generation	11,200 000 kWh	4,700,000 kWh
Capital Cost	$2,400,000	$1,400,000
Estimated O.M.&A. Cost	$33,000	$19,000
Annual Cost	$208,000	$118,000
Cost per kWh (1979 cost level)	18.6 mills/kWh	25.2 mills/kWh

Many design features commonly found in larger plants are not necessary on small hydroelectric projects, which result in subsequent cost savings to the owner. On these two projects, for example:

1. No station power is provided when the transmission line is disengaged from the power plant high voltage line. Also, no braking machinery was provided on the turbine-generator for shutdown. Upon load rejection and loss of station power, a 12-volt battery connected to the governor closes the wicket gates and another 12-volt battery continues to pump and circulate bearing cooling water as long as the unit spins.
2. The generators are air-cooled. The air drawn into the power plant is filtered and vented out the top of the power plant.
3. Generator bearing cooling water is provided by a closed pipe system with a heat exchanger in the forebay which only needs to overcome friction losses in the pipe and heat exchanges. This alleviates the need for duplex strainers, sump pumps, etc.
4. Wooden (Lignum vitae) bearings cooled and lubricated by water are provided on the turbine, alleviating the need for turbine oil bearing, heat exchange, pump, strainer, etc.
5. No comfort facilities were planned for personnel because the plants are unmanned. Drinking water and toilets are brought to the plant when needed. No heating or air conditioning are provided.

In regards to the economic feasibility of this project, the Turlock Irrigation District is one of several irrigation districts in California which furnishes electrical power to the citizens within their boundaries. Their resources consist of hydroelectric generation and purchase of power from the City of San Francisco and Pacific Gas and Electric Company. The power generated is being substituted for more expensive power previously purchased.

II. THE GARLAND CANAL PROJECT

This project, which is owned by Shohone Irrigation District, Wyoming, consists of a power plant with an installed capacity of 2,000 kilowatts (kW). Flows are conveyed to the plant by a new concrete penstock located parallel to the existing Ralston Chute. Concrete pipe, manufactured at the site by the irrigation district, was used for the penstock. The existing Ralston Chute is being left in place to serve as a bypass for the penstock in case of a plant failure and to convey Garland Canal flows in excess of the plant capacity.

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The power plant is located at the downstream end of the concrete penstock. The tailrace discharges into the same stilling basin as the existing chute, approximately one hundred feet downstream of the current discharge point. Average monthly flows vary from 450 cfs to 800 cfs and the flows drop fifty feet in a distance of approximately one-half mile. Average annual generation is 10,000,000 kWh. Estimated capital cost is $3,500,000 and annual expenses are about $60,000 with energy production cost of 38 mills/kWh (1982 cost level).

In assessing the number and size of units, and the use of adjustable or fixed runners for the Garland Canal Power Project, the results indicated that the optimal installation for the site would be one tube turbine with fixed blades.

During the normal operating mode of the facilities, all Garland Canal flows, up to a maximum of 600 cfs and down to a minimum of 200 cfs, will pass through the power plant. If conditions occur, such as an extremely low water year, the plant would be shut down and the flow would be diverted through the existing Ralston Chute. Since the maximum plant capacity will be 600 cfs, all Garland Canal flows in excess of this value will pass down the existing Ralston Chute.

If an instantaneous plant outage occurred, this would be an "emergency" condition where the generator output would be rejected by the system grid and the butterfly valve located immediately upstream of the turbine would automatically close. The excess water would spill over the concrete weir and down the Ralston Chute and the flow would thus completely bypass the power plant. While this condition is possible and must therefore be anticipated, it would be of very short duration and would occur very infrequently.

In case of repairs, the plant would normally be shut down. The flow would be down the Ralston Chute and the plant would be bypassed as in the emergency condition described above. This condition also is expected to occur only very infrequently. All normal maintenance would be performed in the off-irrigation season (early November to mid-April) when all facilities are shut down. It is anticipated that preventive maintenance procedures will make unanticipated breakdowns unlikely.

This project is under construction, and is expected to generate power this summer (1983).

III. THE CENTRAL OREGON SIPHON POWER PROJECT

This project, owned by the Central Oregon Irrigation District, Oregon, uses an existing irrigation facility which includes an intake, headworks, an inverted siphon pipeline, and an unlined canal. Figure 4 shows the general arrangement of the project. From the headworks, the pipeline generally parallels the river for approximately 6000 feet to where it conveys water into an existing canal. From the existing canal, the water will be diverted into two new 84-inch penstocks to a new powerhouse located on the river approximately 150 feet lower than the headworks. Other facilities required are a new diversion weir in the river, a diversion check structure in the canal, a switchyard, and lining for approximately 1100 feet of canal between siphon discharge and penstock intake.

The flow available for power production at the Central Oregon Siphon Power Project site is the difference between the amount of flow that can be diverted through the siphon and the flow required for irrigation deliveries from the canal downstream from the proposed powerhouse site. The flow used for power production will be returned to the river immediately below the proposed power plant.

The installed capacity is 6,5000 kW consisting of two 3,250 kW horizontal shaft Francis turbine/generator units, each rated at 130 cfs. Average annual generation is estimated at 35,260,000 kWh. Estimated capital costs are $13,000,000 (1983 cost levels). Cost per kWh is 47.0 mills. Normal operation of the power plant will be completely automatic, with remote control and supervision of the turbines via telemetering. The turbines will normally be brought on-line and shut down by remote control. Any required wicket gate adjustments will normally be made automatically by the governor in response to fluctuating water surface elevations at the penstock intake. The plant will be equipped with sensing devices to automatically shut down the turbine if required due to mechanical or electrical malfunction. An operator would then be required to go to the powerhouse to investigate the malfunction and to bring the unit back on-line locally.

When the plant has to shut down quickly, water will be diverted from the runner through the Howell-Bunger bypass valve connected to the scroll case. Operation of the valve will be controlled by the hydraulic governor and will be synchronous with the operation of the wicket gates. If the cause of the shutdown is temporary, i.e., temporary loss of power grid load, the turbine will remain in a no-load, near-speed condition until load is restored and then come back on line automatically. If the cause of the shut-down is a serious malfunction of the equipment, the wicket gates will close, and flow will be bypassed entirely through the valve. At the discretion of the operating personnel, the headworks gates on the river will then be opened and the diverted flows would be restricted to those needed for irrigation purposes.

IV. THE TALAVERA RIVER IRRIGATION SYSTEM (TRIS)

This project is located in Central Luzon, Philippines. The main canal is composed of a series of drops and mildly sloping sections. The hydrosite is located on an existing 15-meter, drop-chute structure on the TRIS main canal.

As shown on Figure 5, the proposed development at the site would consist of the installation of an Allis-Chalmers standardized hydroelectric generating unit including a 1000 mm diameter standard tube turbine and an 807-kilowatt generator.

The existing drop chute at the site consists of an inlet structure, an inclined rectangular chute about 80 meters in length with a vertical drop of 15.45 meters, and a stilling basin at the base of the chute. The lower canal then proceeds downstream at almost right angles to the drop. At the beginning of the drop the upper canal is aligned in a westerly direction and the lower canal in a south easterly direction. The canal alignment thus has almost a U-shaped configuration through the drop.

The proposed development would start with an inlet structure located just above the drop inlet. A rectangular concrete perstock about 95 meters in length would then convey the flows to the powerplant which would be located on the lower canal just downstream of the existing stilling basin.

Steel gates would be added to the existing inlet structure to direct the canal flows into the penstock. The preliminary layout of the proposed facilities is shown on drawing PT1-S300.

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The installed capacity at the site would be 807 kilowatts and the net hydraulic head is 15.45 meters less hydraulic losses. The average annual energy production for TRIS No. 1 would be 4,220,000 kWh and the peak power production would be 807 kW.

The 4,220,000 kWh of annual electrical energy generation is equivalent to the energy that would be produced in a new diesel generator using about 1,100,000 liters of fuel annually. No economic data is available on the cost of power for this site.

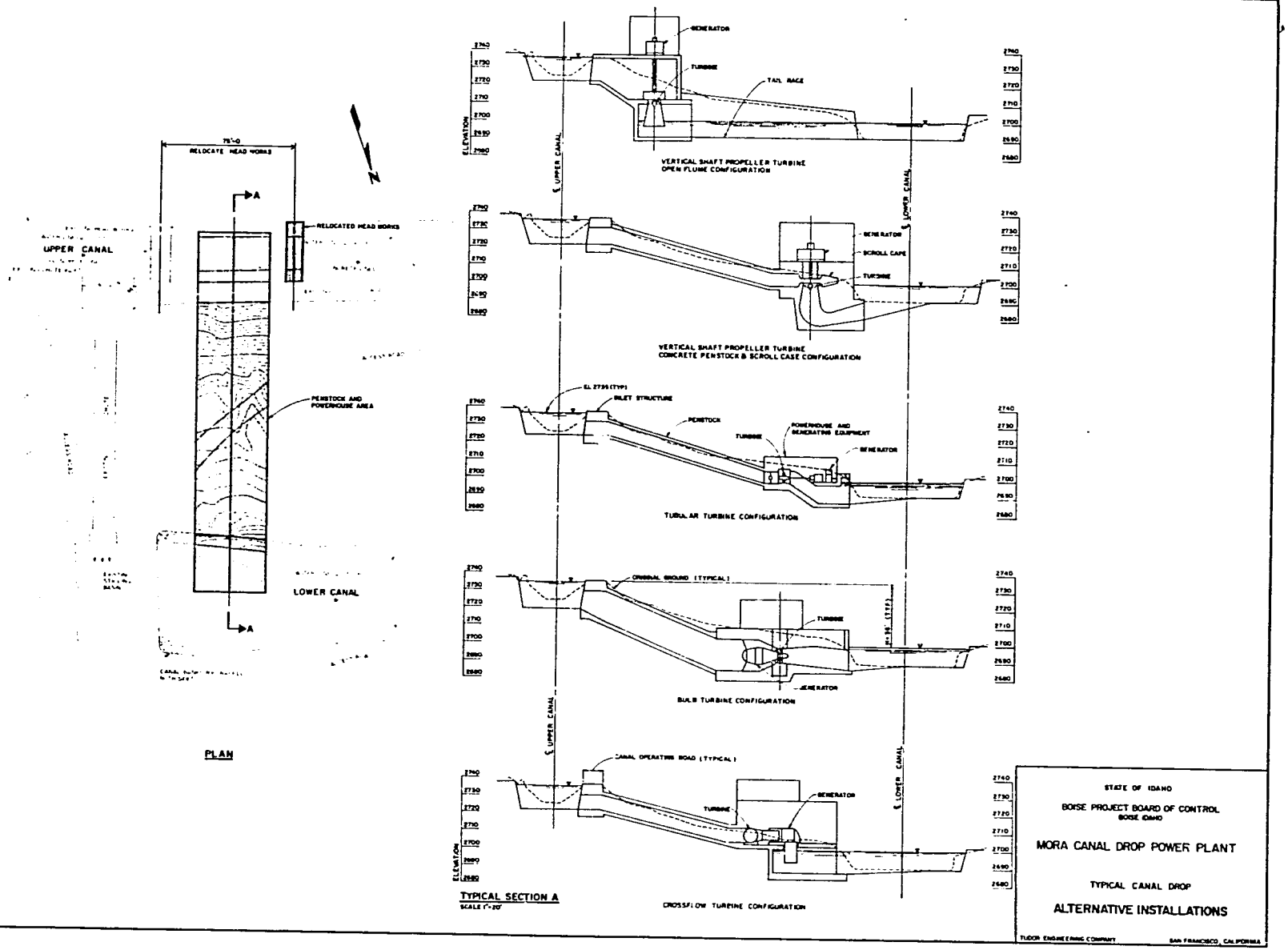
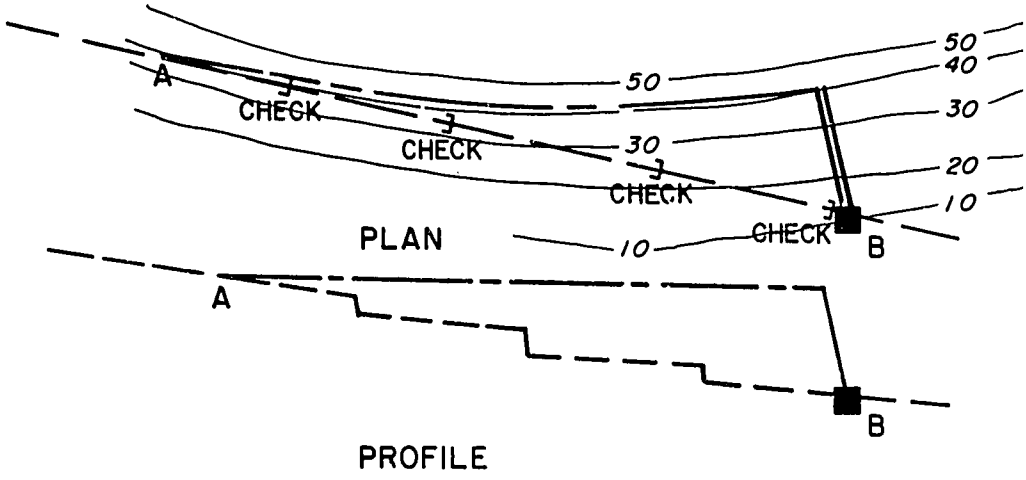
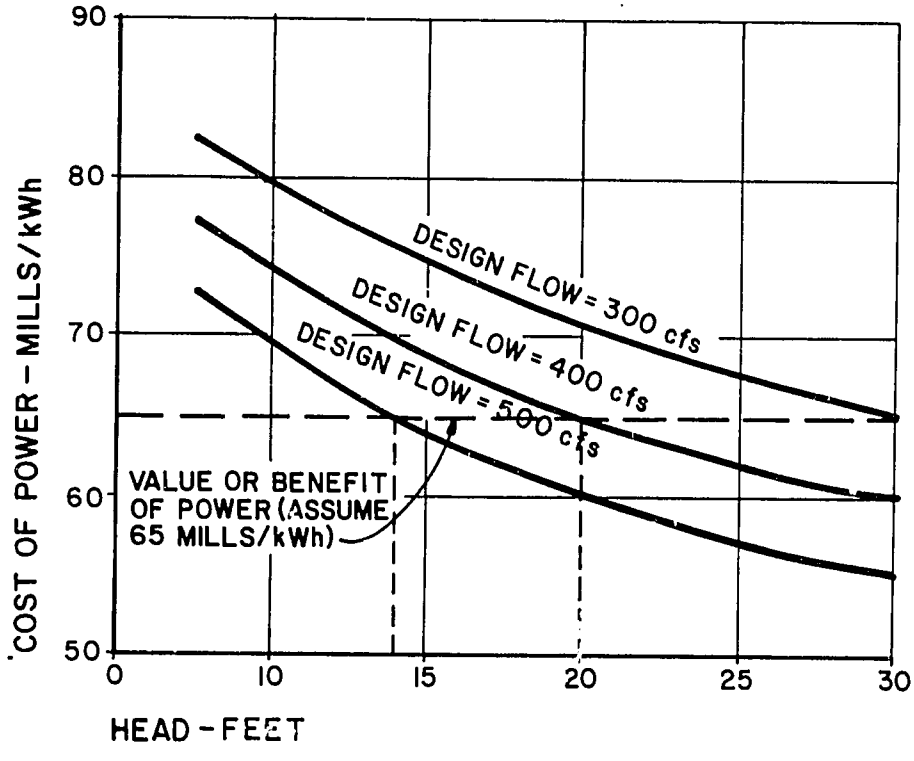

UPPER CANAL
LOWER CANAL
RELOCATED HEAD WORKS
PENSTOCK AND POWERHOUSE AREA
PLAN
TYPICAL SECTION A
ELEVATION
GENERATOR
TURBINE
TAIL RACE
VERTICAL SHAFT PROPELLER TURBINE OPEN FLUME CONFIGURATION
SCROLL CASE
VERTICAL SHAFT PROPELLER TURBINE CONCRETE PENSTOCK & SCROLL CASE CONFIGURATION
INLET STRUCTURE
PENSTOCK
POWERHOUSE AND GENERATING EQUIPMENT
TUBULAR TURBINE CONFIGURATION
ORIGINAL GROUND (TYPICAL)
BULB TURBINE CONFIGURATION
CANAL OPERATING ROAD (TYPICAL)
CROSSFLOW TURBINE CONFIGURATION
STATE OF IDAHO
BOISE PROJECT BOARD OF CONTROL
BOISE IDAHO
MORA CANAL DROP POWER PLANT
TYPICAL CANAL DROP
ALTERNATIVE INSTALLATIONS
TUDOR ENGINEERING COMPANY
SAN FRANCISCO, CALIFORNIA

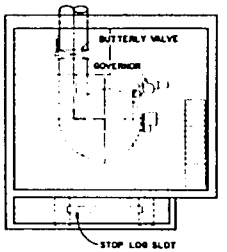
FIGURE 1



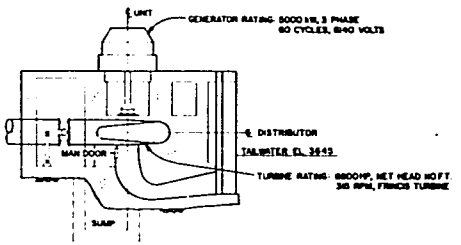
EXAMPLE SHOWING DIFFERENT LAYOUTS FOR AN IRRIGATION ONLY AND IRRIGATION/HYDROELECTRIC DEVELOPMENT. **FIGURE 2**



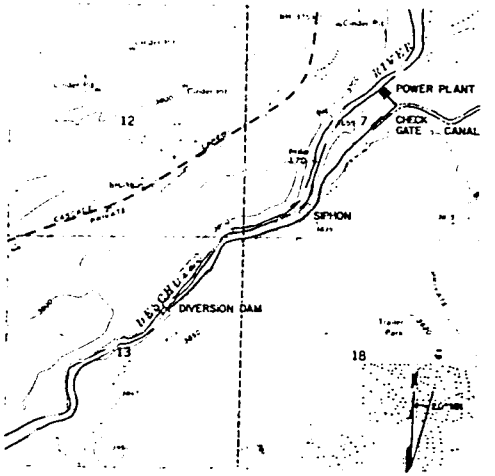
EXAMPLE OF MINIMUM ECONOMIC HEAD FOR POWER GENERATION **FIGURE 3**



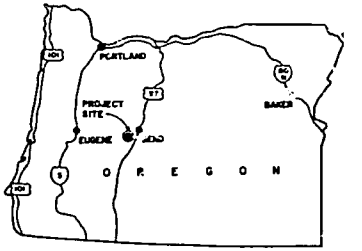
PLAN
SCALE 1/8" = 1'-0



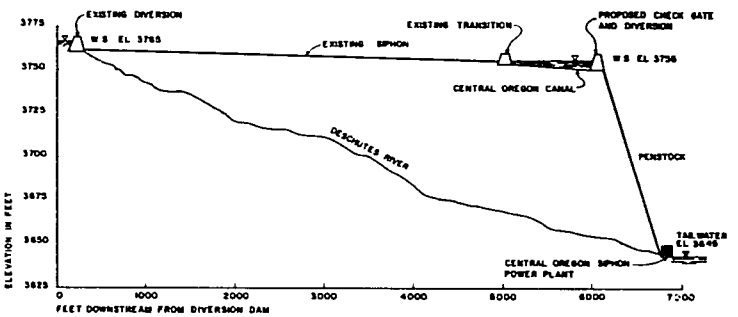
SECTION ALONG C.L. POWER PLANT
SCALE 1/8" = 1'-0



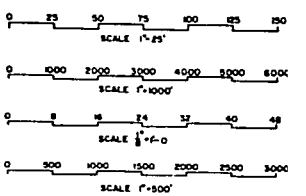
VICINITY MAP
SCALE 1" = 1000'



LOCATION MAP
NO SCALE



PROFILE
SCALE HORIZ 1" = 500'
VERT 1" = 25'



CENTRAL OREGON IRRIGATION DISTRICT
REDMOND, OREGON

CENTRAL OREGON SIPHON POWER PROJECT
BEND, OREGON
PROJECT MAP

TUDOR ENGINEERING COMPANY SAN FRANCISCO, CALIFORNIA

FIGURE 4

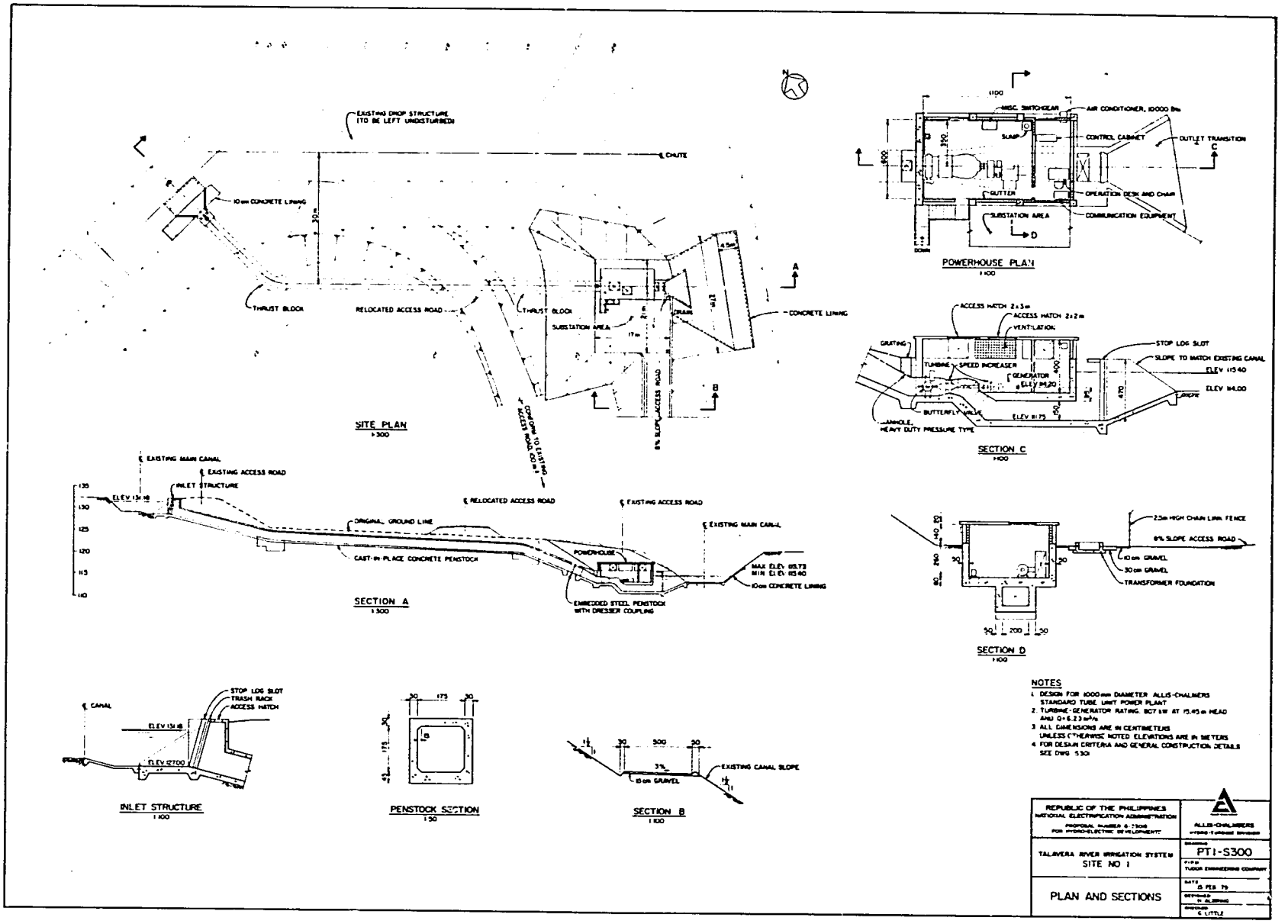

EXISTING DROP STRUCTURE (TO BE LEFT UNDISTURBED)
℄ CHUTE
10 cm CONCRETE LINING
THRUST BLOCK
RELOCATED ACCESS ROAD
THRUST BLOCK
SUBSTATION AREA
DRAIN
CONCRETE LINING
8% SLOPE ACCESS ROAD
SITE PLAN
1:300
℄ EXISTING MAIN CANAL
EXISTING ACCESS ROAD
INLET STRUCTURE
ELEV 134.18
℄ RELOCATED ACCESS ROAD
℄ EXISTING ACCESS ROAD
ORIGINAL GROUND LINE
℄ EXISTING MAIN CANAL
CAST-IN-PLACE CONCRETE PENSTOCK
POWERHOUSE
MAX ELEV 115.73
MIN ELEV 115.40
10cm CONCRETE LINING
EMBEDDED STEEL PENSTOCK WITH DRESSER COUPLING
SECTION A
1:300
MISC. SWITCHGEAR
AIR CONDITIONER, 10000 Btu
SUMP
CONTROL CABINET
OUTLET TRANSITION
GUTTER
OPERATION DESK AND CHAIR
SUBSTATION AREA
COMMUNICATION EQUIPMENT
POWERHOUSE PLAN
1:100
ACCESS HATCH 2x3m
ACCESS HATCH 2x2m
VENTILATION
GRATING
STOP LOG SLOT
SLOPE TO MATCH EXISTING CANAL
TURBINE
SPEED INCREASER
GENERATOR
ELEV 114.20
ELEV 115.40
ELEV 114.00
BUTTERFLY VALVE
ELEV 111.75
MANHOLE, HEAVY DUTY PRESSURE TYPE
SECTION C
1:100
2.5m HIGH CHAIN LINK FENCE
8% SLOPE ACCESS ROAD
10 cm GRAVEL
30 cm GRAVEL
TRANSFORMER FOUNDATION
SECTION D
1:100
℄ CANAL
STOP LOG SLOT
TRASH RACK
ACCESS HATCH
ELEV 134.18
ELEV 2700
INLET STRUCTURE
1:100
PENSTOCK SECTION
1:50
EXISTING CANAL SLOPE
15 cm GRAVEL
SECTION B
1:100
NOTES
1. DESIGN FOR 1000mm DIAMETER ALLIS-CHALMERS STANDARD TUBE UNIT POWER PLANT
2. TURBINE-GENERATOR RATING 807 kW AT 15.45 m HEAD AND Q = 6.23 m³/s
3. ALL DIMENSIONS ARE IN CENTIMETERS UNLESS OTHERWISE NOTED ELEVATIONS ARE IN METERS
4. FOR DESIGN CRITERIA AND GENERAL CONSTRUCTION DETAILS SEE DWG 5301
REPUBLIC OF THE PHILIPPINES
NATIONAL ELECTRIFICATION ADMINISTRATION
PROPOSAL NUMBER 6-7308
FOR HYDRO-ELECTRIC DEVELOPMENT
ALLIS-CHALMERS
TALAVERA RIVER IRRIGATION SYSTEM
SITE NO 1
PTI-S300
TUDOR ENGINEERING COMPANY
15 FEB 79
PLAN AND SECTIONS
C. LITTLE

FIGURE 5

BIOGRAPHICAL SKETCH

David C. Willer is a civil engineering graduate of the University of Iowa and University of Southern California and is a registered engineer in five states. He has practiced engineering related to power generation and power economics for 30 years. He has been employed by Dravo Corporation, Southern California Edison Company, Bechtel Corporation and Tudor Engineering Company. In the last 17 years at Tudor, he rose from Project Engineer to his present position, Vice President and officer in charge of hydroelectric engineering, with responsibility for Corporate Marketing and Business Development. Tudor's hydroelectric projects range in geography from Malaysia to Alaska to Northern Carolina. Their projects vary in size from as small as 300 kW in Alaska to 284,000 kW at Granite Creek Hydroelectric Project in California, which has a static head of 3,550 feet. In regard to Tudor's involvement with power generation at irrigation projects, Tudor has completed in the last eight years design on four small hydroelectric projects now in operation (totalling 26.5 MW), one plant in "start-up" mode (13 MW), four plants now under construction (totalling 16.5 MW), and four plants now out for construction bids (totalling 25 MW). At present, Tudor has three plants in final design (totalling 25 MW). In addition, Tudor is involved in the planning and licensing activity of an additional 23 hydroelectric project involving irrigation projects in the Western United States.

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ECONOMIC ISSUES IN SMALL HYDROPOWER DEVELOPMENT

by

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National Rural Electric Cooperative Association

Paper presented at the regional workshop
"Small Hydropower in Africa"

Mbabane, Swaziland
June 20-24, 1983

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Biographical sketch

Paul J. Clark, Training and Information Specialist for NRECA's Small Decentralized Hydropower (SDH) Program, is currently developing a handbook for economic analysis and planning of small hydropower projects.

Prior to joining the SDH Program staff in February 1981, Mr. Clark served on the professional staff of the U.S. Senate Budget Committee from 1977-81, where he was responsible for developing policy positions on national fiscal and monetary affairs. Mr. Clark also served for two years as legislative assistant to Senator Gary Hart (D.-Colo) for economic, energy, and tax policy issues.

Mr. Clark received his B.A. in political science from the Colorado College in 1972 and his M.A. in international studies/economic development from the American University in 1978.

ECONOMIC ISSUES IN SMALL HYDROPOWER DEVELOPMENT

I. Introduction

Economic analysis of small hydropower projects is essentially a comparative analysis of the costs of supplying energy from alternative generating sources within the context of specific site conditions. The basis for comparison depends on alternative energy supply means which are available to the energy planner. Most often the choices are large thermal or hydro-electric generating stations linked to a national or regional transmission grid, or small diesel generators in the case of isolated areas. Other energy technologies may also be considered: biogas systems, solar thermal or photovoltaic systems, geothermal energy systems, or wind energy systems. The determining factors in assessing which energy option offers the most cost-effective investment option are derived from site studies aimed at answering questions such as:

- What are the costs of extending the grid to the site?
- What is the delivered cost of diesel fuel?
- What are the unit installed costs of alternative energy generation systems, and how often must plant be replaced?
- What constraints exist on the availability of fuel, wind, water, sunlight, and biomass feedstock for energy generation at the site?

In addition to these questions are energy demand considerations which may affect the energy supply choice:

- Will energy demand be sufficient to warrant a large capital investment, such as an extension of the grid or construction of a hydropower scheme?
- Do energy demand patterns correspond with energy supply patterns, in the case of renewable energy technologies, which may offer only part-year or part-day generation?

Finally, in the case of projects which supply energy to small, isolated communities, issues relating to the ease of operation and maintenance, and the social acceptability of the energy system must be taken into account. The ultimate objective of economic analysis is to determine the net consequences of investing in small hydropower projects: do net benefits justify the investment? The first step is to establish the most cost-effective means of providing energy. The second step, if the small hydro option is competitive, is to determine the net return on investment.

II. Cost considerations

General statements on comparative costs of energy generation are not possible, since costs will depend on a wide range of conditions which may vary from case to case, both between countries and between regions within the same country.

Capital costs for alternative generating options in the developing countries as estimated by the World Bank in 1980 are shown in Table 1.

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Table 1. Comparative capital costs of different generation options in oil-importing developing countries (1)

Generator Type		Investment Cost 1980 US Dollars per kW Installed[a]
Hydropower	- Large, High Head	1100
	- Low Head, Mini-Hydro	3500
Diesel	- Large, Heavy Oil Fuel, Coastal Location	1000
	- Small, Light Oil Fuel, Inland Location	800
Steam	- Large, Gas-Fired	800
	- Large, Coal-Fired	1000
	- Large, Oil Fired (Imported)	800
	- Small, Heavy Oil-Fired, Inland Location	1400
	- Small, Wood-Fired	1500
Geothermal	- Dry Steam Field	1400
	- Wet Steam/Hot Water Field	2800
Nuclear	- Large Multiple Units	1600
	- Single Small Unit	2200
Solar Photovoltaic		20,000-30,000[b]
Wind Generator		5,000-15,000[b]

[a] Investment cost includes costs of transmission and distribution.

[b] Both solar energy and wind power are intermittent energy sources which require storage to make energy available on demand at all times. Investment costs given above are system costs with storage included.

The figure shown for low-head mini-hydropower is not unreasonable, but experience has shown that the cost/kW installed of small hydropower projects in the developing countries is widely variable, depending on factors specific to each site. Some of the principal factors which influence capital costs include:

- Head availability. Higher heads tend to reduce unit costs since energy can be generated with less water than low-head sites, meaning equipment can be smaller and generally less complex.

- Water supply. Under ideal conditions, water should be plentiful, clean, and in supply year-round. Intermittent flows, which are not uncommon on many small rivers and streams, means that impoundment dams may be needed to store water during low-flow periods, increasing civil costs. Water which carries large amounts of rock and sediment may increase maintenance and replacement costs and necessitate the addition of settlement structures to remove rocks and sediment from the water before entering the penstock.

- Access difficulty. Difficult terrain surrounding the site may require considerable expenditures for access roads.

Another factor often cited as a major determinant of unit cost is the size of the plant. There is considerable debate on this argument, which holds that unit costs increase as plant capacity declines. Some say that there are unavoidable "fixed" costs in small hydropower plants of any size, including site inspection, engineering, management, and maintenance costs. Civil structures, including dams, powerhouses, and penstocks, and the turbo-generating equipment may cost less in absolute terms for a very small plant, but these costs do not decrease proportionally with capacity. In general, it is this view that economies-of-scale tend to make smaller hydropower projects unattractive as investment options.

While the economies-of-scale argument is difficult to dispute, given the experience of hydropower development in the industrial nations, the experience to date in the developing countries suggests that economies-of-scale may operate in reverse to some degree. Table 2 gives capital cost data for eighteen small hydropower projects built in the developing countries since 1971. A quick glance at this data shows that the average unit cost installed for plants under 100 kW in this group is approximately half that of the plants above 100 kW. The explanation for this phenomenon rests in the fact that

TABLE 2. Capital Costs for Small Hydro Plants in Developing Countries (2)

Country	Capacity (kW)	Head (m)	Cost per kW[a]	Equipment as % of cost	Comments
Thailand	800	40	[illegible],850	15%	Concrete construction for civil works
Ecuador	400	40	2,200	36%	Lined canal; imported equipment
Ecuador	400	19	2,700	30%	Lined canal; direct intake; imported equipment
Nepal[b]	200	58	900	36%	Partly lined canal; loose-packed rock dam
Nepal	120	14	900	21%	Masonry-lined headrace
Indonesia	120	15	1,300	58%	No headrace; local turbine
Thailand	100	79	950	21%	Concrete construction for civil works
Philippines[b]	100	27	750	38%	Local construction materials and turbine
Indonesia	90	19	1,050	54%	Concrete-lined headrace
Nepal	80	16	1,050	23%	Local materials and turbines
Nepal	80	34	1,050	11%	Local materials and turbines
Nepal	25	22	650	28%	Existing irrigation works
Indonesia[b]	15	22	600	30%	No headrace or governor, used alternator
Thailand	15	10	2,350	41%	Earth dam and headrace
Thailand	~ 10	6	1,500	27%	Lined canal; local turbine
Pakistan[b]	10	c	270	61%	Local materials and equipment
Nepal	9.5	9	600	46%	Local materials and equipment, except penstock
Pakistan[b]	7.5	c	[illegible]	50%	Local materials and equipment

[a] Not including transmission and distribution costs.
[b] Projects implemented and managed locally.
[c] Precise heads unknown, but generally between 5-10 m.

standard, conventional approaches to the design and construction of very small plants may not be necessary. Case studies have been made of small hydropower programs in several countries where micro-hydro plants have been built on the basis of local initiative at very low cost. The major attributes of this unconventional approach are:

- the avoidance of conventional engineering concepts which require scaling down standard civil and mechanical components used on large hydropower plants to smaller sizes;
- the adoption of site study approaches based on "minimum needs" rather than maximum potential, reducing the need for exacting hydrologic data;
- the recognition of opportunities to improvise civil components, taking full advantage of locally available construction materials and labor; and
- the use of locally-fabricated turbines and accessories based on uncomplicated designs and simple construction techniques which are adequate to serve modest energy requirements.

To be sure, the economies of scale rule holds true, given the approach to development. Fig. 1 compares the capital cost curve for conventionally engineered projects with two alternative approaches to small hydropower development which have been documented in the developing countries. Each approach, represented in three

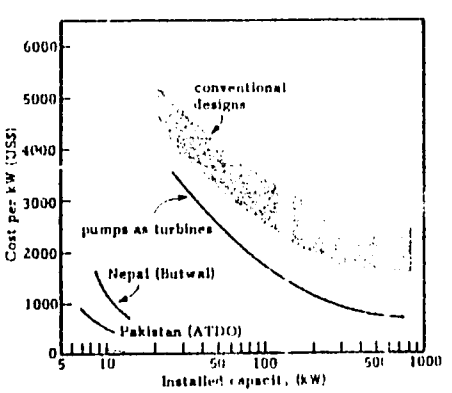

Fig. 1. Cost curves for different approaches to small hydro development.

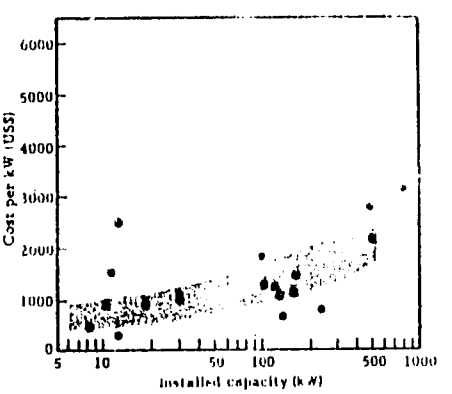

Fig. 2. Cost curve of small hydro plants listed in Table 2.

different curves ranging from the very simple (Pakistan) to the more complex (conventionally built small hydropower plants in the U.S.), has its own economies-of-scale character. But taken together, the data shows that costs tend to increase with plant size, as confirmed by Fig. 2. The underlying thesis is that with very small projects, innovations are possible that are not now possible with larger plants. An alternative approach which helps to bridge the cost gap between unconventional (smaller) and

conventional (larger) plants would be to standardize certain components using off-the-shelf designs and equipment, as reflected in the pump-turbine curve shown in Fig. 1 (3).

While the inconventional approach may result in plants that do not capture the full energy potential of sites, energy requirements--and the means to pay for energy--are likely to be modest in many remote rural communities. And although these plants may be less efficient and more prone to more frequent maintenance and earlier replacement, they are also more easily maintained and replaced then conventionally engineered plants built in such areas. Moreover, as energy requirements increase, plants built along simple lines initially may be up-graded at a later time to capture more energy potential more efficiently.

III. Use considerations

The benefits arising from small hydropower projects are derived from its uses in both quantitative and qualitative terms. Benefits are realized in different forms. Benefits from the producer's point of view may include:

- cost-savings in providing energy more cheaply than existing energy sources; and
- revenues from energy service to new loads.

Benefits from the consumer's point of view may include:

- cost-savings from reduced energy expenditures;
- additional cash income resulting from increased productivity and extended working hours;
- leisure income; and
- social benefits (comfort, convenience, security, prestige, etc.).

Benefits from the national point of view may include:

- greater reliability of energy supply;
- potentially fewer negative environmental impacts;
- potentially greater positive environmental impacts (erosion, deforestation, flood, and sedimentaion control); and
- foreign exchange savings.

Before moving to a discussion of how these benefits are considered in the economic analysis, some comments on the quantitative and qualitative nature of energy use from small hydropower plants are in order.

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Capacity utilization

Capital costs are meaningless in determining the ultimate delivered cost of energy without first taking into account the degree to which the plant is used, economically speaking. Thus, unit energy costs will depend on two factors: capital costs and capacity utilization.

Capacity utilization of small hydropower plants is affected by water supply conditions and by demand conditions. Small rivers and streams in tropical areas frequently suffer from intermittent flows, due to the concentration of annual rainfall during wet seasons. Unless excess flow during these periods can be stored behind dams, operation of the plant during dry periods may be limited.

Even during periods when the plant may operate at full capacity, utilization may be constrained by irregularities in demand for energy. Load factors, which give the ratio of peak load to average load, are indicators of the nature of demand constraints for a given plant. Low load factors indicate the plant utilization is high only for very high periods, with much lower plant utilization during the majority of the time the plant is operated. Low load factors alone can have disastrous effects on the economic viability of small hydropower stations. Table 3 gives average load factors for five 200 kW plants installed in northern India during the 1970's. Assuming capital recovery over six years, the kWh costs for each plant vary considerably, even with a relatively small difference in load factor.

Table 3. Effect of load factors on generating cost (4)

Project	Average load factors (%)	Average kWh cost (cents)
Guptkashi	23.6	7.0
Genti-Cherra	20.3	8.3
Tilwara	22.3	10.1
Koti	10.7	27.5
Deoprayag	4.1	62.5

[a] Assumes full depreciation over 6 years.

From this example it is evident that small hydropower plants may not be economical in situations where utilization rates remain low and highly variable. Other energy solutions may be sought for such cases, such as the installation of diesel-driven generators. Figure 3 illustrates the conditions under which diesel generators offer a more cost-effective energy generation means than a similarly sized small hydropower plant. Cost-effectiveness for the hydro option increases as utilization rates increase, whereas the reverse is true for the diesel option. This is due to the low operating cost of hydropower systems since no fuel cost is involved. Fuel accounts for the majority of diesel energy costs, on the other hand, meaning that the diesel option is competitive only if utilization rates are low, below 20 % in this analysis.

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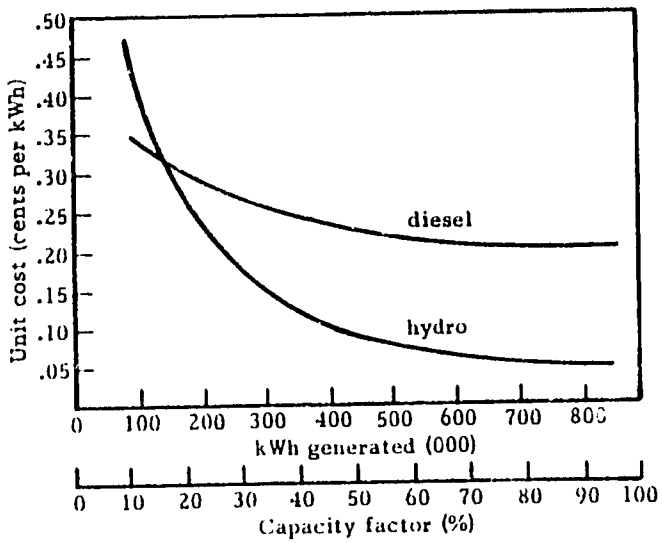

Fig. 3. Effect of capacity factor on unit cost of production (100 kW plant). Assumptions: hydro capital cost is $3,000 per kW; diesel capital cost is $450 per kW; annual O & M cost is 1.5% of capital cost for hydro, 4.5% for diesel; fuel cost for diesel is 18 cents per kWh; useful life is 30 years for hydro, 20 years for diesel; discount rate is 12%.

Supply and demand management

With all small hydropower projects, but particularly with small isolated plants, it is important to attempt to achieve a dynamic equilibrium between energy supply and the demand for energy. It has been seen how plants which are underutilized result in high energy costs. Two methods may be employed to minimize plant underutilization, one dealing with capacity (supply) planning, and one dealing with load (demand) management.

In the latter method, load leveling techniques are used to build up energy demand during off-peak periods, and reduce demand during times when energy requirements are normally high, such as evening hours and during mealtimes. Energy pricing policies may be used to penalize energy use during periods of normally high demand, and reward users of energy during times of low demand. Alternatively, more direct measures can be taken to level out loads on the plant. One measure is to develop means of storing energy during off-peak periods for use during peak times. Battery storage can be used in the case of low-level electrical applications. For uses requiring heat, such as cooking, electrical energy can be converted into heat by means of resistance coils, and then stored in an appropriate medium, such as insulated metal or stones. Another measure is to promote "productive" uses of energy during off-peak periods. Examples of productive end uses include irrigation pumps, foodstuff processing machinery, commercial appliances, and low-horsepower motors used in light rural industries. It has been NRECA's experience that promotion of productive uses such as these can have a considerable impact on the economic viability of rural electrification projects by raising energy demand and income growth in a community.

In the case of an isolated project, it is more difficult to approach a dynamic supply/demand equilibrium from a supply point of view, but not impossible. The

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objective on the supply side is to avoid investing prematurely in capacity which is not needed. In a 20-year or 30-year planning period, energy demand will most likely change dramatically over time. A community requiring 10 kW of capacity initially may need several hundred kW twenty years later. However the investment in a larger hydropower plant than is required for the first ten years or so could make the average cost of energy over the life of the project prohibitively high. One method of permitting incremental capacity growth is to build the plant in stages. For example, plants may be designed to operate with several turbines, which can be added over a period of several years. Alternatively, a very simple design can be used for the initial period which could be upgraded with more elaborate structures and equipment at a later date. Another incremental approach would involve the installation of a small diesel generator, having a much lower capital cost, to serve the community during the initial load-building years, which could then be replaced by the hydro plant when energy demand warrants the greater capital investment.

IV. Methodology for Prefeasibility Analysis

The methodology used for conducting economic prefeasibility analysis depends on the purpose of the energy project. Small hydropower projects can serve two objectives, from a supply point of view:

(1) to displace a more costly means of energy production; and
(2) to provide a new source of power.

In the first case, total project costs are compared with the cost of the alternative energy production means, where the benefits are equal to the cost-savings resulting from the provision of small hydropower to displace more costly energy. In the second case, total project costs are compared with benefits arising from the addition of new generating capacity, usually shown as revenues from the sale of energy. Projects may serve both objectives by reducing existing energy costs and providing additional capacity to serve greater energy demand.

An analysis must first be performed to assess whether the small hydropower investment offers a cost-effective means of supplying energy to serve a given amount of energy demand, stated as energy (kWh) production.

Cost-effectiveness

This level of analysis is a useful tool in screening projects as part of a regional or national survey of potential small hydropower sites. It is also an essential step in assessing the net benefits of small hydro projects whose primary purpose is to displace the higher cost of delivering energy by other, existing means. The most commonly used method to make this comparison is to find the present worth value of total life-cycle costs for each alternative. Costs, including capital costs and recurring costs, are entered in the years they occur. Total annual costs are then discounted to take into account the time-value of money.

The discounting process is needed to reflect the opportunity cost of capital, since the real value of an expenditure made in the future is less the real value of an equal expenditure made today. This is important in comparing the life-cycle costs of producing

energy from hydro and diesel plants, since the majority of costs for the hydro project are made initially, while the costs of the diesel alternative are spread more evenly throughout the life of the project.

Recurring costs include operation and maintenance (O&M) costs and energy costs (with or without a real escalation factor). Inflation and the cost of money are already reflected in the discount rate, and thus are not needed, provided the discount rate selected approximates market interest rates. Equation (1) is the basic formula used in finding the total life-cycle cost in present worth terms.

$$\text{Total Cost} = CC + \sum_{n=1}^{L} \frac{O\&M_n + (E_n \times P_n)}{(1+r)^n}$$

where:

CC = capital cost

L = life of project

$O\&M_n$ = operation and maintenance cost in year n

E_n = unit energy cost ($/kWh) in year n

P_n = kWh production in year n

r = discount rate

Equation (1). Present worth cost calculation.

Capital cost in the case of the grid extension option includes the cost of extending transmission lines to the area to be served, and necessary transformer and protection equipment. Capital costs for the diesel alternative should be the average unit installed cost of diesel generators times the number of kW which the small hydropower plant would supply. It should be noted that diesel generators have a shorter lifespan than hydropower plants. Capital replacement for the diesel should therefore be shown every 5-15 years, depending on the average useful life period of such plants in the area.

Unit energy cost in the case of a diesel plant is the cost of diesel fuel to produce one kWh of energy. In the case of a grid extension option, it is the cost of producing (or purchasing) a kWh of energy on the grid.* This cost should be the long-term marginal cost of producing an additional unit of energy. Extension of the grid does not necessarily eliminate the need to invest in additional capacity, particularly in view of future load growth. The long-term marginal cost should therefore be based on demand studies which take into account additions to capacity that will be needed to serve the additional load over the duration of the period being studied. In the small hydro case, energy cost is zero, since there is no fuel cost. Escalation factors may be applied to the energy cost of both the diesel and grid options, to reflect real cost increases for fuel. A 2% escalation

*In cases where the power is purchased from sources outside the country, this cost should be shown as the wholesale purchase price of electricity.

rate is generally used. To find the full annual energy cost for either option, the average kWh energy cost is multiplied by the annual kWh production assumed for the small hydropower plant.

O&M costs for the small hydro option are generally considered to be 1.5% of capital cost, except in the case of very small plants, where a more precise calculation should be made to reflect actual costs of an operator's salary, and minor maintenance and replacement costs.* O&M costs for the diesel option, requiring greater maintenance expenditures, is generally shown as 4.5% of capital cost. O&M cost for the grid option is zero, since these costs are already reflected in the long-term marginal cost of energy.

The study period over which total costs are calculated should be the expected useful life of the small hydro project. This period is frequently given as 30 years, although many plants operate twice as long, if properly maintained. For purposes of prefeasibility analysis, depreciation costs can be left out of the calculation.

Life-cycle costs are found by adding the total annual discounted costs for each option. The option giving the lowest total cost is the preferred investment strategy. If the small hydro option fails this preliminary test, it should be rejected. If the small hydro option offers a lower cost option than the diesel or grid options, then further analysis of the small hydro project may proceed.

Return on investment

The purpose of the cost-effectiveness analysis is to enable planners to achieve efficient resource allocation. In developing countries, political decisions are often made to provide electrical service to rural areas regardless of the net economic consequences of such a decision. The results of the cost-effectiveness analysis may therefore provide a basis for making investment decisions. This is not advisable, however, since benefit considerations have not yet been taken into account and may show that investments in alternative projects, such as transportation, would be more worthwhile. Needed, then, is a basis on which inter-sectoral resource allocation choices can be determined. Moreover, lending institutions generally require that further analysis be provided which examines the return on investment.

There are two economic indices used in determing the return on investment:

- benefit/cost ratio
- internal rate of return.

In each case, annual net cash flows are calculated by subtracting costs from benefits. Cost, benefit and net cash flows should be shown in both nominal and discounted terms for each year in the study period.

Benefit/cost ratio. This is a commonly used index to assess whether projects are economically feasible. The discounting process used in the cost-effectiveness analysis is also used here, only benefit flows are calculated as well. The comparison of total

* For a 50 kW plant costing $2,000/kW installed, for example, total capital costs would be $100,000. Annual O&M costs would likely exceed 1.5% of this cost ($1,500).

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present worth costs and benefits provides a ratio which indicates the economic attractiveness of a project. Equation (2) gives the economic formula used to derive benefit/cost ratios.

$$B/C = \frac{\sum_{n=1}^{L} \frac{B_n}{(1+r)^n}}{\sum_{n=1}^{L} \frac{C_n}{(1+r)^n}}$$

where:

B_n = Benefits in year n

C_n = Costs in year n

L = Life of project

r = discount rate

Equation (2). Benefit/cost calculation in present worth terms.

Projects with a benefit/cost ratio of less than 1 are considered unfeasible. Projects with a ratio of 1 or greater merit additional study to assess what rate of return is possible. This calculation is reviewed next.

Internal rate of return. To refine the assessment of net economic return on investment, the internal rate of return is calculated for the project. In the preceeding cashflow analysis, a discount rate is selected which represents the opportunity cost of capital. The purpose of this analysis is to find at what discount (interest) rate total costs and benefits are equal. Thus the undiscounted cashflows are used in this calculation. This interest rate, which represents the internal rate of return for the project, can be determined by trial and error in applying different discount rates to the cashflows until the correct value is found. Projects should have a internal rate of return exceeding the rate of return possible with other competing projects to be worth undertaking, strictly speaking. However if the project yields an internal rate of return approximating long-term market interest rates, the project is generally considered feasible.

It should be noted that the feasibility of projects as determined by the rate of return will depend considerably on the source of financing. Financing from private sources may require an internal rate of return of more than 20% for small hydropower projects, due to the high degree of financial risk that may be perceived with such projects. At the other extreme, where local communities may be able to raise their own resources to construct projects (possibly with government support) the rate of return may not be as important to the investment decision as non-financial considerations relating to the overall socio-economic development goals of the area. International development banks generally look for an internal rate of return of about 10%, although again, decisions to finance may also rely on how well the small hydropower, project complements other development projects and goals in the area.

Calculating project benefits

Although many direct and indirect benefits may be used to justify an investment on small hydropower, for purposes of prefeasibility analysis only benefits which can be represented in monetary terms are generally included, representing more of a financial than an economic analysis. Thus, certain long-term social and economic benefits such as education or health improvements, and the socio-political benefits resulting from the provision of electricity to new rural areas; and short-term benefits, such as increased productivity and security, are difficult to compute in monetary terms and are generally not included as specific benefits for prefeasibility analysis purposes. These benefits may be stated in qualitative terms, and could make a project with only a marginally attractive rate of return appear more worthwhile. Benefits which can be quantified more easily in monetary terms include cost-savings from the displacmenet of other energy sources and revenues from the sale of energy.

As mentioned at the beginning of this section, small hydro projects may serve the function of reducing existing energy costs or providing a source of energy to serve new and additional energy needs. A second distinction is also needed in defining the basis for calculating economic benefits, from a demand point of view; a distinction between plants which are interconnected with a transmission grid and those serving an isolated load.

With grid-connected projects, benefit calculations for purposes of prefeasibility analysis are relatively simple. Annual benefits for hydropower projects in the lower capacity range are generally equal to total cash savings from the displacement of other more expensive energy production serving the grid. For these projects, assuming the transmission network covers a sufficiently large demand area, the basis for calculating these benefits is the annual kWh production capability of the plant. More detailed analysis of daily and annual load characteristics on the grid system at the full feasibility stage may show that demand fluctuations prevent full absorption of the plant's generating capability, particularly during off-peak periods when the base load may be served by cheaper means (e.g. large hydropower).

In conducting prefeasibility analysis of isolated projects, demand analysis becomes more important. Benefits in the form of cash savings and revenues are based not on the estimated output, but on estimated demand.* Since loads are likely to be variable, and possibly quite low, assumptions for sale of power and energy displacement must be fairly carefully defined by estimating the nature of energy demand for specific categories of consumers, or specific end uses.

Small isolated projects serving new loads may also present special problems in quantifying benefits, since in some cases revenues - representing to some degree the economic value of the energy - are either not collected or are based on tariff schedules substantially below the economic value of the energy provided. To allow a more complete assessment of economic benefits, a measure of the willingness of users to pay for the energy provided may be surveyed by estimating the user's existing energy costs, the resulting increase in productivity, and the higher quality of life which is attributable to the energy (5).

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* A general review of demand analysis is provided in Jackson & Lawrence, "Electrical Distribution and End Uses for Isolated Systems."

Finally, demand for energy is likely to change over time. To account for this, one or more escalation factors may be applied to annual benefit totals to reflect demand growth. As a general rule, demand growth in newly electrified areas averages 5-10% a year, except in the early years of operation when initial consumer build-up may yield a higher growth rate. Moreover, energy production estimates should also take into account the possibility of grid interconnection during the life of the project, at which time excess energy could be fed to other demand centers. Benefit calculations for years following interconnection may therefore increase. In the same vein, annual cost calculations may be lower during the initial years of a project, if it can be built in stages to accomodate greater loads on the system, including additional loads resulting from grid interconnection.

Sensitivity analysis

Life-cycle costs, benefit/cost ratios, and internal rates of return may vary considerably when assumptions are changed. Since it is hard to predict certain conditions, such as diesel fuel costs and demand for energy, sensitivity calculations may be made to see if the net value of projects remain favorable under different conditions. Certain assumptions in the baseline calculation should be changed to reflect, for example, higher discount rates, hydro capital costs, fuel costs, and different rates of energy demand growth. The results of these calculations can help to ascertain the degree of risk involved in a project, and how durable the project's economics are under more adverse conditions.

V. Conclusion

The process of identifying economically feasible projects cannot be divorced from the larger macro-economic context in which the projects are being considered. Issues pertaining to the country's power sector program and the overall development plan of the area will have an important bearing on the desirability of specific small hydropower projects. Moreover, capital is scarce in many developing countries, particularly capital which is available in hard currencies. Small hydropower projects are relatively capital-intensive and thus should undergo rigorous examination at the full feasibility stage to ensure that the capital resources of the country are efficiently allocated. Shadow pricing of the major elements of a project should be applied to assign the real economic value, for example, of labor and foreign exchange. Similarly, the discount rate should be sufficiently high to reflect the real value of capital to the society as a whole.

In view of the scarcity of foreign capital, full advantage should be taken of opportunities to utilize locally available resources. Above all, the ultimate value of projects will depend on the uses of the energy produced. Productive uses of electrical energy yield multiplier effects to a project which are greater than those associated with uses to provide greater convenience or a more pleasant lifestyle. While these uses are certainly desirable, the rural poor may not be able to afford the luxury of energy expenditures for such ends. Productive uses, on the other hand, mean increased employment opportunities, higher output levels, and additional income to a community. Planners and administrators, therefore, should not overlook the need to incorporate productive uses in any project to provide electricity to rural areas.

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INTEGRATING RENEWABLE ENERGY WITH END USES*

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ABSTRACT

This paper is a discussion of various types of energy used by different societies, a program for balanced and comprehensive village development, various end uses for energy in a village, a radical approach to planning and design for energy resources, integration of energy sources with end uses, and specific application of these principles to micro-hydrpower.

1. PRESENT ENERGY SOURCES

At the present time there are societies and cultures in the world which illustrate the different types of energy systems utilized by people to carry out their living activities. These include the human-powered society, the animal-powered society, the imported energy society, and the society using an array of renewable energy resources.

1.1. The Human-Powered Society

Energy in rural areas of the 3rd and 4th worlds (as defined by Barbara Ward) is usually provided by people -- both men and women. An enormous amount of human energy is responsible for most of the production of the necessities of life -- including food, water, clothing and shelter. This is a cycle that is a never-ending process. It continues day after day and year after year. Added to this human energy is the burning of local organic matter (such as wood, shrubs, and cow dung) as fuel for very simple cooking and heating. This natural resource is usually being depleted at a very rapid rate.

Because there is a limit to the amount of human energy available from one person or one family, this limitation becomes a constraint on the total amount of goods and services that can be produced by human power alone. This limitation forces such a family into a bare subsistence level of living. In fact, most of the people of the world who depend upon human power alone are living much below a bare subsistence level. This is the "poorest of the poor" -- the "Fourth World" of which Barbara Ward speaks.

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*A paper presented at the Conference/Workshop on Renewable Energy Sources, Lahore, Pakistan, 18-22 March 1983.

Finally, with this type of energy system, more than 90% of the population is required simply to produce the food for the region.

1.2. The Animal-Powered Society

When animal power (such as oxen, horses, mules, donkeys, buffalos, or camels) is added to supplement human power, then the amount of production greatly increases, but the level of living seldom exceeds bare subsistence by very much. This is the situation for much of the Third World. Here the proportion of the population involved in production of food and fiber is still more than 80%.

1.3. The Imported Energy Society

This society, consisting of the more-developed nations, is mining and using the non-renewable energy resources of the entire earth. Using mechanized equipment and artificial fertilizers, this society replaces most of the human power, and all of the animal power, with machinery. Consequently, only 5% of the population is required to produce their food and fiber.

2. USING AN ARRAY OF RENEWABLE ENERGY RESOURCES

Although there are various combinations and blends of these types of societies existing today, the foregoing situation must be changed dramatically for two reasons:

1. The Imported Energy Society will soon consume nearly all of the earth's non-renewable energy resources.

2. The other societies have a right to a better life and a higher standard of living than the drudgery and deprivation which is their lot today.

It follows, then, that for a family or a community in the third and fourth worlds to rise significantly above a bare subsistence level of living, it is necessary to bring in supplemental energy beyond the human, animal, and local organic matter sources. In order to avoid moving more in the direction of the Imported Energy Society, however, this supplemental energy can be provided from one or more of the following renewable sources of energy:

1. Bio mass (e.g., biogas, producer gas, methanol, wood, and charcoal)

2. Solar energy (both thermal and photovoltaic)

3. Hydropower (both electrical and direct mechanical). Also wave power in certain limited areas.

4. Windpower (both electrical and direct mechanical)

With this type of energy system available to a family or a community, a much smaller percentage of the population is required to produce the necessary food and fiber — which frees other people for other activities which can greatly improve the standard of living for all.

3. A PROGRAM FOR BALANCED AND COMPREHENSIVE DEVELOPMENT

Having renewable energy available to a community does not guarantee that this will result in a higher standard of living, or that the people in the community will even move significantly away from the poverty, hunger, disease, illiteracy, and drudgery that now exists. To accomplish this a complete (balanced and comprehensive) program of development is required. This process of development can be described graphically by the Development Wheel, see Albertson 1972 and 1983, and Albertson & Chaudhry 1972, see Fig. 1.

The Development Wheel indicates that for development to occur it is necessary to organize and utilize all resources available in the community and outside the community. Existing indigenous manpower resources must initiate action by utilizing information resources from all available sources which will give guidance on which policies, procedures and principles and which institutional resources are needed to utilize the existing natural resources, the existing infrastructure resources, and the existing financial resources -- within the constraints of the existing socio-cultural resources -- to produce

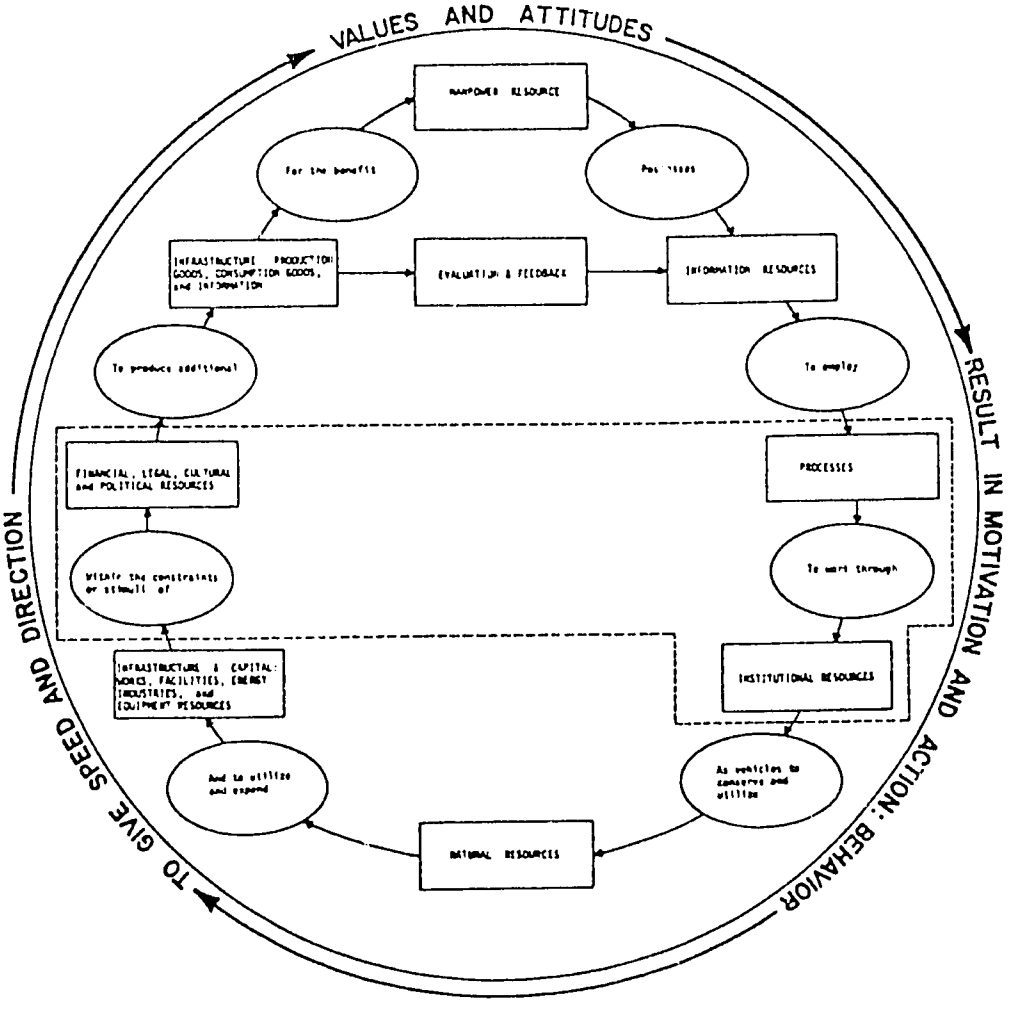

Fig. 1. The Development Wheel, Illustrating the Development Process. (Adapted from Albertson 1972.)

more goods, services and information resources for the benefit of the manpower resources. The additional information resources obtained from this process provide the basis for new and better policies, procedures and principles and improved institutional resources to better utilize the natural resources to build additional infrastructure to create still more goods, services and information for the benefit of the people. This cyclic phenomenon is the process of development, but there must be initial motivation for a community to actively and aggressively initiate and pursue these steps. It is the values and attitudes held by the people in the community that result in motivation and action to give speed and direction to the development wheel process.

For this reason, it is important to have an "entry point" into a village or community or a "rally point" which will excite and motivate the leaders and most of the people to initiate and aggressively pursue this process. Successful models existing at present indicate that either health or energy can serve as an entry or rally point, see Arole 1980 and 1982 and Abdullah 1962. Along with this entry point, however, must be a total plan for balanced and comprehensive development. The steps required for such a plan include the following:

1. The entry or rally point will stimulate and activate the leaders and people of the community (the manpower resource) to seek out the information resources required for a development program. These information resources are to be found both within the community and outside the community. Assembling and analyzing these information resources usually requires outside help from people trained to obtain information from inside and outside the village, to analyze the information, and to advise the village on the steps to be taken to activate the development process described in the development wheel.

2. On the basis of the information resources, policies, principles, and procedures must be established as fundamentals which can be used as a framework for a balanced development program. These include:

a. The principles of self-reliance and persistence.
b. The policy of recognizing the value of, and a willingness to learn from, the illiterate poor and deprived masses.
c. The basic concept that village people are intelligent and willing and able to acquire new skills to improve their own lot and that of their community.
d. The policy of maximum delegation of responsibility and commensurate authority to workers at all levels, see Arole and Arole 1982, page 13.
e. The basic concept of "Make do" with local resources (both material and human resources)
f. Decisions having an effect on the community must be made by a democratic process following discussions in which all persons affected are involved as equals and not just the village leaders discussing with technical or specialized personnel (perhaps from outside the village).
g. There must be a basic theme throughout, that everyone has a very important role to play, and that the total success of each community effort depends upon each person fulfilling his responsibilities.
h. Another basic theme is that the contribution of each person is to be of service and benefit to others as well as personal gain or benefit for himself (i.e., there must be a combination of both the service motive and the profit motive).
i. An egalitarian society must exist in which any caste system, aparthied, or elitism is eliminated.
j. The entire program must be a "grass-roots" approach, see Brown 1982.
k. Government must not interfere with these policies, principles and procedures, but must permit and encourage entirely free development by

the villagers -- and government at all levels must encourage and help the villagers with filing applications and quickly obtaining approvals on any governmental programs which will be useful to the villagers (e.g., family planning, leprosy control, bio-gas installations, improved housing, safe drinking water, see Arole and Arole 1982, p. 4).

l. The entry point should be a health program, or a combination of a health program and an energy program (in most cases), in order to give the village a topic or project around which to rally and to organize and agree to certain pre-conditions.

m. The pre-conditions should be that the entire village will agree to:
   (1) Designate a VHW (preferably a woman) who will receive regular training at a central training center.
   (2) Designate an SW (Social Worker) who will receive special training and work in his/her village.
   (3) Designate an ATW (Agricultural and Technical Worker) who will receive special training and work in his/her village.
   (4) Provide volunteers to work on special projects in their village and at the District Center and Regional Center.

n. There must be an evaluation component which will first obtain baseline data and information, data at various stages of the project, and data at the end of the project in order to assess the progress (of each part of the project) that is being made from year to year and in order to learn continuously how to improve this and other projects in other regions or countries.

3. An <u>institutional structure</u> must be established which will provide organizations that can be used as vehicles to carry out the foregoing policies, procedures, and basic principles. These institutions should include:

a. A Village Council which is truly representative of all segments of the community and is democratically selected to be used as a framework for discussions and decision-making about community-wide issues and problems (e.g., an unpolluted water supply, sanitary waste disposal, vaccination programs, a central energy system).

b. A Women's Group, see Arole and Arole 1982.

c. A Men's Group, see Arole and Arole 1982.

d. District Centers and Regional Centers need to be established to provide:
   (1) Mobile health units, clinics and hospitals for the 3-tier health program. Arole and Arole 1982, give an excellent description of the way this component should operate.
   (2) Training centers for VHW's, ATW's, volunteer workers, and others, see Arole 1982, p. 14.
   (3) Demonstrations for farming practices and techniques, energy systems, etc.
   (4) Supplies, equipment, materials, and purchasing expertise.
   (5) Business and industry advice and counsel.
   (6) Marketing help and expertise for village products.

e. The creation of <u>self-evaluation (Struggle)</u> groups for changing attitudes and prejudices, and for personal decision-making (this might be handled in the Men's & Women's Groups -- although they are primarily for community decision-making and action -- or it might be done in religious groups if they are available and interested).

f. Educational institutions and programs must be created and activated which will include both formal education (usually for the children) and non-formal education for adults and school drop-outs, see Arole and Arole 1982. The non-formal education programs must be highly practical and aimed specifically at making each person more productive.

g. Businesses and industries need to be created to utilize and conserve the natural resources available to the community and to produce products (goods) and services which can be consumed or utilized both within the community and (especially) exported to obtain employment and income for the people of the community.

4. Once the information resources and institutional resources are available for use, the community is in a position to develop, utilize and conserve the natural resources to yield products which can be consumed within the community or can be exported to outside markets to bring income into the community. The industries created (as institutions) to produce these products will provide employment for people in the community. Examples of natural resources available for development include:

a. Agricultural land
b. Water resources
c. Minerals such as a rock quarry
d. Soil for making clay products
e. Sun for heat, cooking, and electricity
f. Wind for electricity or mechanical power
g. Trees and forests
h. Air and water for nitrogen, hydrogen, and oxygen

These natural resources serve not only as raw materials to be refined but also as sources of energy for living and for industry. Careful study must be made of how to develop and integrate the energy and industry in a balanced manner, and to project a time schedule setting out all the steps to be taken and when. This usually requires expert help from outside.

5. As the natural resources are utilized more and more, products result which improve the standard of living and income is produced which can be used to improve and expand the infrastructure as well as the goods and services to benefit the people (manpower resource). It will also provide new information -- all of which forms a basis for the cycle to be repeated over and over and for village development to take place at a rapid rate.

6. This entire program and process must be accomplished within the constraints of the financial, legal, cultural, and political resources available to the community. If the policies, principles, and procedures described in 2. are established, however, these constraints will be minimal. For the most part, the financial resources required are already available in the community just waiting to be mobilized and utilized to implement a well-planned design for exploitation of the natural resources.

The foregoing development model has been derived from a combination of concepts, including the process of development (see Albertson 1972, Albertson & Chaudhry 1972). The China Model (see Albertson & Nickum 1975), the Arole Model (see Arole 1980 and 1982) and the Abdullah Model (see Abdullah 1982, and Inversin 1981 and 1982).

A very important first step toward this balanced program of development can be the introduction of an array of renewable energy resources together with the development of end uses of the energy which will help to accomplish the complete program described in the foregoing paragraphs, see Fig. 2 and Boyle 1982, and Thapar and Dubow 1982.

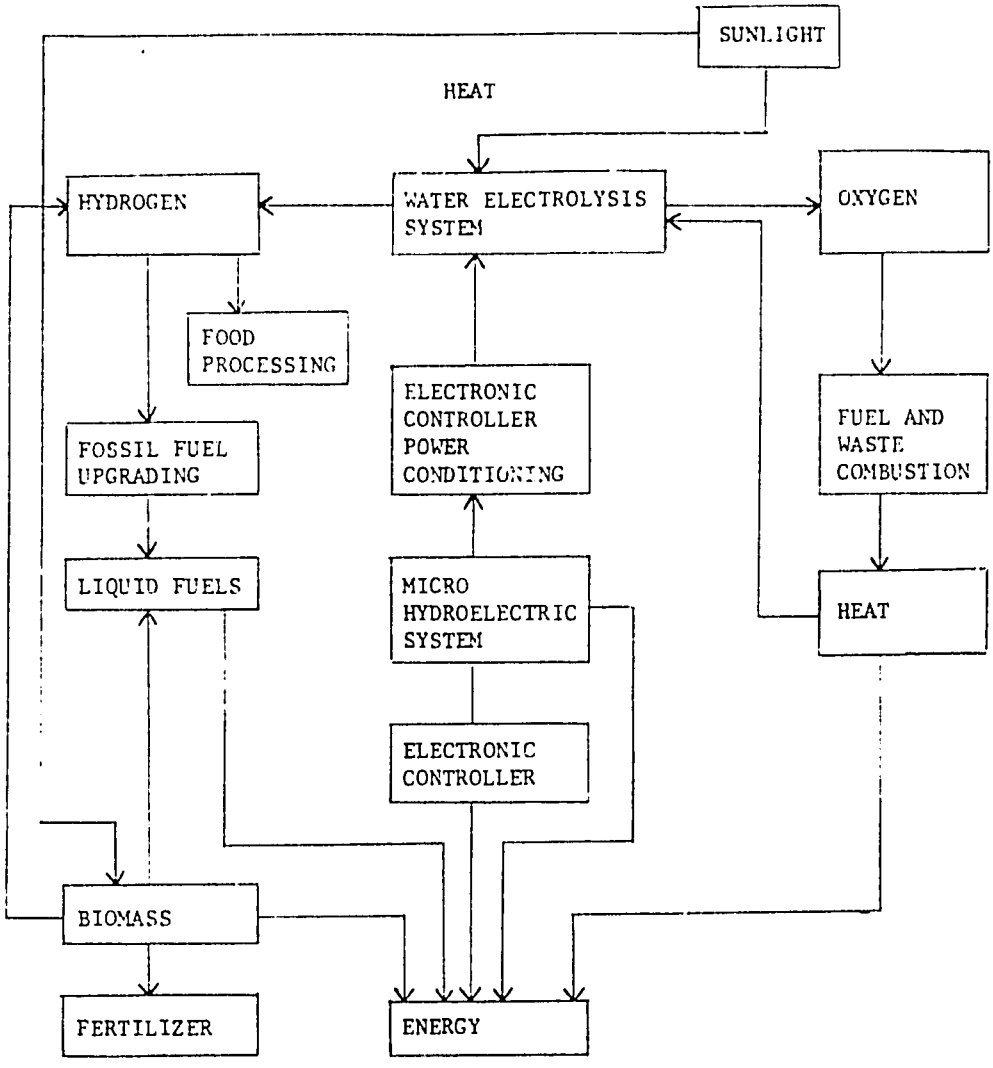

Fig. 2. Flow Chart for an Energy System Integrated with End Uses (from Thapar and Dubow, 1982).

4. END USES OF ENERGY

When considering energy developments for a community, it is necessary also to study and consider the end uses for the energy, see Thapar and Dubow 1982; and Boyle 1982. There are three main categories of end uses for the energy that is brought in to supplement energy from human, animal, or local organic matter sources. They are:

1. Conveniences for living, such as electric lights, refrigerators, electric stoves, radios and TVs, street lights and washing machines.

2. The production of raw materials, such as farm produce and natural resources like timber.

3. The refinement, processing, preserving, or storing of these (or imported) raw materials, such as the milling of flour, the drying of grain, the refrigeration or canning of fruits and vegetables, the production of clay products, or the spinning and weaving of cotton or wool cloth. This includes the creation of entirely new products such as crafts.

The utilization of the renewable energy resources for these end uses cannot be accomplished on a permanent and successful basis without the initiative and heavy involvement of the community as a whole and many of its individual members throughout the entire process. In fact, the community must take the initiative or the project is very likely not to succeed. The types of end uses which should be considered are given in Tables 1 and 2 from Boyle 1982.

5. USING A BLEND OF ENERGY RESOURCES

It is difficult for the Imported Energy Society, which is so accustomed to the exclusive use of electricity and petroleum products to meet its energy needs, to realize that the array of renewable energy resources which are available, see 2., can all be used to create a blend of energy for a community which will optimize the benefits and minimize the costs. There are many industrial processes which require heat that can be provided in part, if not entirely, by

Process or Operation	Equipment	Motor Rating (HP)	Output (Lbs/hr)	Power Consumption (kWH/100 lbs)
Oil Pressing & Extraction	Hydraulic Press			
	Large	22	1,500	1.3
	Medium	16	1,000	1.5
	Small	8	130	4.5
	Screw Expeller			
	Large	20	2,000	1.0
	Medium	15	1,000	1.5
	Small	5	100	5.0
Rice Hulling	Disc Sheller (German)	25	2,400	0.8-1.0
	Japanese Rubber Roller Sheller	3	300	2.0-2.5
Cereal Milling	Large	20	800	1.5-2.0
	Small	5	180	2.0-3.0
Cotton Ginning	Large	20		
	Small	5	78	2.75-3.2
Fodder Chopping	Rotary Cutter	2-10		.25-1.0
Sugar Cane Processing	Crusher			
	Refining Pan	3-15		.50-3.0

Table 1. Characteristics of End-Use Equipment in India as of 1963 (from Boyle 1982)

Type of Agro-Industry	Range of Power Requirements (kW)
Saw mill	30 - 60
Carpentry shop	3 - 15
Sugar mill	10 - 20
Grain mill	3 - 20
Loom	0.5 - 6
Coffee processing	5 - 30
Quarry	6 - 30
Ice factory	6 - 60
Preparation of fish	5 - 10
Cold storage plant	6 - 60
Roofing tile plant	2 - 12
Pumping station	2 - 100

Table 2. Power Requirements for Rural Industries in Colombia (from Boyle

solar thermal and/or biomass processes. Likewise, there are industries which require mechanical energy which can be provided by a direct hook-up to wind power or hydropower. Where electrical energy is necessary, this can be provided by a combination of windpower, hydropower, and solar photovoltaic. It can also be provided, or at least assisted, by thermal processes through steam generation. Examples and characteristics of these end uses are given by Thapar and Dubow 1981, and Boyle 1982, see Tables 1 and 2, and Fig. 1.

Selecting the proper blend of energy resources requires careful fitting and matching of the industries and other end uses for the energy, both for the present and for the foreseeable future. This integration process is described in the following sections.

6. A RADICAL NEW APPROACH REQUIRED

In order to accomplish the new balanced program of energy and "end use" development described in this paper, in an economically feasible manner, a radically different approach is required from traditional methods planning and design. These traditional methods usually establish an electric or gas utility for a community in a highly sophisticated manner which would be so expensive that a benefit/cost ratio greater than one would be impossible. This degree of sophistication and complexity, however, is neither possible nor desirable for nearly all of the rural areas of the third and fourth worlds.

The radically different approach proposed herein is composed of a series of components that are described in part by Nasaruddin & Alias 1981, Langhome 1977, and Inversin 1981 and 1982. These components consist of the following:

1. Encourage a modern but simplified and inexpensive design for the power generation equipment and facilities instead of the costly design that most utilities feel is necessary (which would cost $2-3000/kW of installed capacity

and would have to be built by people outside the community that is to benefit), see Abdullah 1982, and Inversin 1981 and 1982.

2. The same statement as 1. above for the power transmission and distribution system.

3. Encourage planning and loans for the small business and industry, which result from the new energy source, at a very small beginning with expansion built in as the new owners and managers gain experience and demonstrate a market for their products.

4. Help the people of the community to plan and design all aspects of the new development in such a way that they can build, operate, service and maintain all components by themselves with little or no outside help.

If this new approach is utilized, the cost of electrical power may be as low as $2-300/kW of installed capacity (10% of the traditional cost), see Abdullah 1982, and Inversin 1981 and 1982, and the benefit/cost ratio will be significantly greater than 1.0 for the entire development plan. Furthermore, there will be a solid economic and experience base to build upon for future expansion.

7. PROCEDURE AND STEPS

The process of integrating renewable energy with end uses involves a series of steps which are necessary to insure success, see Albertson 1972 and Arole 1980 and 1982. These include the following:

1. A reconnaissance survey must be conducted to determine the basic interest of the community and the general feasibility of a project.

2. The community must take the initiative to demonstrate clearly their strong interest and their willingness to put in great effort on planning, designing, building, operating, and maintaining all aspects and features of the project.

3. There must be one or more clearly identified leader(s) in the community who are willing to put in enormous amounts of time on the project, and it must be clear that other members of the community are willing and anxious to work with this leader(s).

4. The collection and analysis of data from the community and the region which will be adequate for decision-making regarding the technical, economic, and social aspects of the project, must be obtained.

5. The community must be willing to initiate and operate other components which are necessary for balanced and comprehensive development, see item 3.

6. There should be an evaluation component to the project which determines basic characteristics of the community before the project begins and at various stages of growth and development of the project as it progresses. This is essential to be able to assess accurately the true costs and benefits of the project, and to learn from the project in order to help other projects. The technique for doing this is given by AMARU IV Cooperative, 1982.

8. HYDROPOWER AS AN ENERGY SOURCE

Mini and micro hydropower is one of the best sources possible for a rural and isolated community. This assumes, of course, that both water and head are available. Much has already been written on this subject, see Albertson 1982 and Goodman 1981. Costs for hydropower, however, can vary from as low as $200 to $10,000/kW of installed capacity, and it has been found that in order to achieve economic justification the cost usually must be less than $1000/kW.

One of the most difficult problems to overcome with the generation of mini and micro hydropower has been the control of voltage and frequency. New and simple electronic devices, however, have been developed which deserve careful consideration, see Woodward and Boys 1980, Thapar and Dubow 1981 and 1982, and Langhome 1977.

Another problem has been the turbine, but the crossflow turbine has been clearly demonstrated as the most appropriate for local construction, see Abdullah 1982 and Langhome 1977. For a high head and very small discharge, a Pelton wheel has been developed and is manufactured by Armstrong-Evans of England. Because of the greatly reduced cost resulting from mass production, the use of centrifugal pumps run backward as turbines is a very attractive alternative.

The primary problems of the technology of mini and micro hydropower have now been solved. Likewise, the technical problems of other renewable energy sources are well on the way to solution. This now leaves the real challenge for the development of a community in the socio-cultural-political arena as described in sections 3. and 7. of this paper.

An example of what was accomplished in the Northwest Frontier Province of Pakistan is given in Table 3 which lists some of the end uses for several mini-hydropower stations with a range of installed capacity from 5 kW to 20 kW. Abdullah 1982 reports that these developments resulted in the following socio-cultural-economic changes in the communities served:

1. A sense of participation in development schemes
2. A sense of pride
3. Increased awareness of need for development
4. Increased hours of study and work
5. Smokeless lighting, leading to healthy environment
6. Reduction in tree cutting
7. Introduction of small-scale industrial activity
8. Employment generation and increased income.

9. OTHER ENERGY SOURCES

There are other important sources of renewable energy which have been demonstrated to be economically feasible under the right circumstances in rural (and in some cases urban) areas. These are already being used in many different locations worldwide:

1. Biogas generators using both animal and human wastes

2. Solar cookers both with and without concentration reflectors (e.g., 350 chapatis per day are being cooked at the Arole hospital on a solar cooker designed and built by P.K. Kulkarni of Pune, India)

3. Solar water pumps using photovoltaic cells

4. Solar water heaters for both personal and industrial use

5. Windmills for pumping water or milling grain by direct mechanical hook-up, or for generating electric power.

10. SUMMARY STATEMENT

The technology now exists for an impressive and very useful array of alternative renewable energy resources to help the people of the 3rd and 4th worlds to move from the human-powered and animal-powered societies into a much more desirable way of life without entering the parasitic imported energy society. The main problem today is finding ways to overcome the socio-cultural-political constraints which prevent these developments. Perhaps the program of balanced and comprehensive development described in this paper, including an integration of renewable energy resources with productive end uses, will be a step in the right direction.

Site	Location	Discharge Cusec	Head ft.	Installed Capacity, kW	Houses Electrified	Street Lights	Industrial Activity
1.	Lilloni	10	18	12	60	7	flour mill, rice huller, oil expeller, cotton gin, band saw, wood lathe, tool grinder
2.	Alpuri	15	20	12	190	31	
3.	Shang	6	40	10	44	15	flour mill, band saw, cotton gin
4.	Melvegai	3	80	10	43	20	flour mill, rice huller, cotton gin, wood lathe, tool grinder
5.	Barkalay	3	30	5	35	8	
6.	Barkana	10	20	10	40	8	cotton gin, wheat thresher
7.	Paras	8	105	20	under construction		

Table 3. Data on Mini Hydropower Plants in NWFP, Pakistan (from Abdullah 1982)

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ENERGY PLANNING:
Understanding and Dealing with Possibilities and Constraints

Several years ago I gave a talk at another USAID-sponsored conference entitled "Mission Impossible? National Energy Planning in the Developing World." At that time, I was field manager of a USAID-funded national energy policy and planning project with the Sudanese Ministry of Energy and Mines. I argued at that time that "energy planners" cannot fulfill their objectives by ignoring the political, cultural and economic realities of a society and that planners must address the concerns of the politicians, leaders and decision makers of the country s/he is working in if s/he has any hope of proposing solutions which are not only acceptable but also workable. That is to say, the people planners work for respond to real issues that they consider most pressing. These are the prime imperatives of their jobs. Simply put, the old adage that "the squeaky wheel gets the oil" is most appropriate for understanding the process of affecting change or maintaining the status quo. Any planner who loses sight of this is sure to be frustrated in his or her position. At this time I would further add that concentration on the ends(for example, projects) to the virtual exclusion of the means(that is, the development <u>process</u>) leads to failure on the part of the planner. The <u>process</u> of energy planning (within the overall context of development planning) is of paramount importance.

I would like to focus this address on some of the

"realities" of the energy planning process as I perceive it because it is both something with which I am somewhat familiar and because it is the topic I was asked to address. In the course of doing so I would like to offer some of my own views as to why planning so often seems to be an exercise in futility and mere paperwork and how I believe it can be improved.

First of all, most of us here at this conference are specialists, trained in and inclined towards fields we know best. Moreover, most of you are from Africa and your concerns are focused on African development issues, some of which are generalizable to other developing countries and some of which are particular to this continent and to your own countries. Most of the topics which will be addressed during the next week will focus on many of the issues that concern the development of small-scale hydropower. I would like to take the opportunity kindly offered me at this conference to attempt to set before you some propositions which are intended to be stimulating and provocative rather than authoritative.

One of the statements about Africa that one so often hears concerns the tremendous potential of this continent. Various statistics are cited which show how much of the the world's arable land, how much of the world's mineral resources and how much of the world's hydro-potential are found in Africa. Then, one generally hears about all of the failed projects in Africa, of all the plans discarded because things just do not seem to work out as they are supposed to. When projects fail or fail to live up to planners' and politicians' expectations, consultants and evaluators are generally brought out to determine what

went wrong. In more cases than not, the post mortem of a particular project or plan centers on fairly consistent issues: This project or that scheme just did not take into enough consideration the locale's, the country's or the region's scarce resources; or the project or plan did not fully evaluate the particular constraints that could have been and should have been forseen at the outset, or it did not place the people's or the country's priorities in proper perspective.

The irony of this all is that one always hears in speeches, such as mine, the need for integrated planning, for taking into consideration local realities, for gauging the priorities, bottlenecks and resource constraints when planning or funding a project. As a consultant to a major donor agency and one who has worked within an African ministry I can asssre you that there is no dearth of reports, pre-feasibility and feasibility studies, and the like in any government agency in most African countries. The key questions we should all ask are that with all these studies, with the supposed awareness of the constraints and realities of project implementation in the developing world(and the developed world, I might add) "What goes wrong? Why don't things work out right?"

I would argue that our emphasis on project implementation rather than the process of development planning is the primary cause for things not working out as planners and technicians would like. It is more expedient in the short run and less of a task to design a project in isolation, without considering the many issues involved in the develop-

ment process, than it is to take all the factors of development into consideration. That is, "top-down"(or "trickle down") development is easier, requires less time, and involves fewer complex and unpleasant issues for the planner to consider than trying to determine just exactly what we are trying to accomplish as energy planners and technicians.

Few of us present at this seminar need to be told of the improtance of energy in our modern world. It may be less obvious to many of us that comprehensive energy planning is a must for national, and regional development today. Most of us are concerned primarily with one particular field or interest that often seems to preclude our attending to the "big picture." And, if our own special interests do not preclude our attending to the macro-issues, then almost invariably the demands of our jobs, on our limited time and personnel resources seem to preclude such attention to the overall picture. Nonetheless, an understanding of the big or macro picture is important from many different standpoints. I believe one of the most important reasons why overall, integrated energy planning is imperative is that few countries can afford to waste scarce economic or human resources. National, regional and local energy planning is intended primarily to provide the framework for the most rational and least expensive means by which a country, region or locale can satisfy its present and future energy needs. And those needs are the needs of people, not the needs of some indefinable entity. Without the framework, the constraints and barriers to growth and development are exacerbated.

The first step in energy planning is an energy assessment. I(quite arbitrarily) divide an assessment into two components; one technical, the other essentially socio-political. The former(the technical) is considerably easier to accomplish(particularly within a short period of time) than the latter(the socio-political). However, when presented or viewed in isolation, the technical is quite misleading and ultimately, I would argue, detrimental to the development process. Nonetheless, the technical is more often than not the major focus of consultants' proposals, reports and national energy assessments. Technically-oriented assessments are assumed somehow to be "unbiased" and value-free and therefore of great use to the politician or leader for implementing recomendations or plans. This common emphasis on the technical, to the exclusion of the socio-political, leads to so much emphasis on project development and implementation. I would argue that this, in turn, leads to the failure of so many plans and projects, failure to address the very needs we as planners and technicians have set out to address.

However, I would like to discuss in some detail the technical side of an assessment for it is <u>an</u> essential(but not <u>the</u> essential) component of energy planners' ability to see the "big picture" and to recommend solutions to energy problems. The purpose of a technical assessment is to provide the planner, technician or leader with as clear a picture as possible of what are present and, if possible, past patterns of energy production, supply and utilization. An assessment is like the economist's black

box, providing inputs and outputs but opened to reveal, to the greatest extent possible, the means, the channels by which energy gets from the initial supply or production point to the point of end use. I can assure you that very few world leaders, whether in the developing world or the developed world, have a very clear idea of the process and means by which energy is produced, supplied and consumed, yet we base so much of our analysis, so many of our plans and policies on a very poor picture of this process. To cite but one example, we hear so much about the woodfuels crisis in the Third World yet in very few countries do we have a clear idea of who produces, harvests and transports woodfuels much less how much is produced, transported and consumed. Nonetheless, we see project after project proposed and implemented to improve production, to improve the efficiency of consumption and so on. I am not faulting the attempts to improve production and consumption; I am only pointing out that oftentimes we are recommending actions on the basis of very limited and imprecise information. An assessment should also be designed to provide some idea of the potential, or possible, sources of supply and utilization. Again, this should be based on as clear and precise sources of information as possible. As energy planners we break this into several components.

First, we examine the current sources of energy and their uses. We attempt, based on economic and sociological data, to project(all things being equal, that is given current and past trends) what future consumption might be. Simultaneously, we examine any surveys or studies that have been made on the country's or region's potential for de-

velopment or utilization of alternative, whether indigenous or imported, sources of energy supplies. By "alternative" I mean only other sources of energy whether they be conventional or otherwise. If no studies have been conducted on the country's or region's potential for development of other energy resources and we, as planners, see even the slightest possibility for development of such resources, we call upon specialists to examine those possibilities. The National Rural Electric Cooperatives Association(NRECA) has conducted many such studies on hydropower potential in in numerous countries. Other agencies have conducted similar studies on various renewable resources such as woodfuels, bagasse(sugar cane waste), solar energy and so on.
When we examine the potential for a particular source of energy, whether conventional or renewable, we must always attempt to view it in comparison with the potential for development and utilization of other sources of energy. Again, this comparison cannot be based solely on economic or technical criteria(although both are important) but must be placed within an overall framework of benefits and costs. One must also examine the possibilities of utilizing a potential source of energy for other uses.. For example, water resources can be used for both irrigation or hydropower and in some cases for both. However, the development priority or technical feasibility may preclude hydropower development in favor of utilization for irrigation. In addition to exploring untapped, or poorly utilized indigenous energy resources the planner should assess the potential for other "alternative" sources of energy whether from foreign suppliers(particularly if the costs of supply are less),

of upgrading or improving existing distribution networks or of improving the efficiency of current energy use.

These then are the major components of a technical energy assessment. They must, however, be placed within a framework of the country's, region's or locale's economy (as well as the international economy) and the various political and sociological factors relevant to that country, region or locale. The planner then attempts to offer a series of projections, or scenarios, by which the country's leaders can base their decisions on how to plan for the country's energy future. These scenarios are devised by varying the assumptions of our energy assessment model. For example, we may wish to learn how energy consumption might change if we vary our estimates about the economy's growth rate, or vary the prices of the country's energy supplies, or change our assumptions about the country's population growth rate. Any changes in these and many other assumptions alter the overall "macro" picture. This exercise is intended to provide the leaders, the decision makers, be they ;ministers or technicians, with as broad a view as possible for determining how they might alter the country's energy growth path.

One can easily see, then, that these essentially biased assumptions are key to the utilization of the technical assessment we have conducted. If those assumptions are not stated explicitly, the planning instrument loses its real effectiveness, its potential for providing leaders with the tools for affecting changes or offering viable solutions to problems.

What I have given up to this point sounds very theoretical; it is a kind of recipe. The theory of national or regional energy planning is relatively simple. What makes energy planning and, I would argue, <u>any</u> national or regional planning so difficult is that energy does not exist within a vacuum. The energy planner is not merely a technician trying to analyze an inert black box. Rather s/he is an individual with biases working with dozens, perhaps hundreds of other individuals with their own set of biases, assumptions and priorities. Moreover, the planner is planning or projecting the supply, production and use of energy by many, many people. And, the planner is almost always working with a <u>very</u> imperfect picture. If s/he loses sight of this, the exercise remains theoretical and academic and bears little resemblance to reality.

On the one hand, the technical data(by which I mean "facts" and figures) available to the planner are more often than not incomplete, dated or so fraught with unstated/unspecified biases that their usefulness is severely limited. On the other hand, the planner operates within an environment of constraints. That is why I call energy planning the art of understanding and dealing with both constraints and possibilities. For example, a small-scale hydropower project may be infinately feasible from an on-site technical perspective, from a sociological and from a political perspective. But, there may be no infrastructure by which to support the construction of the facility, or no foreign exchange by which to sustain purchase of spare parts, or little technical expertise or will on the part of local people to continue the operation of the facility. I overstate the obvious only

because too often we see projects that seem to make good sense when one sits in Nairobi or Washington or London, but which make virtually no sense when one sits in Kigali or Juba. And many of these projects are funded and completed and never work or cease operation once the foreign technicians depart or when the foreign exchange runs low due to a poor cotton, tea or coffee harvest. This is why I emphasize that the planner must have some feel for the local potential for a project, that s/he must have some idea of the country's, region's or locale's ability and will to implement the plan or project and to sustain it after completion before s/he attempts to sell the idea to others.

In reviewing materials for this conference I had the opportunity to study the NRECA's reports on small-scale hydropower in Pakistan and Nepal. What impressed me most was that most of the success of developing local hydropower resources centered on the involvement and participation of local people in the design and construction of those hydro-facilities. That is, planners, technicians <u>and</u> local people were involved together in the <u>process</u> of developing those hydro-resources. While it was important that locally available materials were utilized in developing those facilities, the key, in my mind, was the cooperation and involvement of local people in determining their own needs and futures. This should be most revealing to us. It demonstrates that the planner, whether at a local or national level, must first and foremost be a listener, an observor with eyes focused on and ears attentive to the needs and

desires and capabilities of the people. The planner must realize that s/he cannot dictate the best solutions but must be an arbiter, a mediator and a facilitator who has special tools to add to and assist the development process. Before we can bring those tools to bear, we must first understand the priorities and the realities of society.

I say this because I can point to many energy problems, such as deforestation, and I can show that they are very real local, regional or national problems. But, how can I hope to affect change or stop the problem if the people involved do not perceive them to be important problems? I cannot impose a solution to the problems or propose that national leaders impose solutions by, say, planting thousands of trees if local people, national or regional leaders are not aware of the problems or not involved in addressing them. The most I can do in that situation is attempt to educate people about the problems, or better yet, attempt to design means by which the problems can be dealt with among other problems of more importance to the people involved. To use the deforestation example again, perhaps deforestation is part of a greater problem of poor agricultural production, environmental degradation and so on. Then, it is incumbent upon me as a planner to put the deforestation problem within the overall context of the rural dwellers' problems as a whole. Without doing so, I cannot really hope for success.

If we look at another example, charcoal production, we can cite many reasons in Africa why production should be improved. From a technical point of view we can see that charcoal production in most African countries is terribly inefficient. In some cases charcoal production

yields less that 10% of the caloric value of the wood used for production. There is also much wastage from the point of production to the point of end use. We can also show that production efficiency can be tripled or quadrupled through construction and use of improved kilns(for example, improved earthen kilns, metal or brick kilns, and so on). But first we must determine who produces the charcoal(which we do not really know in many countries). Because improved kilns are often more expensive and capital-intensive than traditional production modes we may be displacing labor and concentrating production in the hands of relatively better off individuals(producers) if we propose improved kilns without providing means of alternative employment or financing improved production by small producers. Small producers can hardly be expected to welcome improved "development" of production if they do not benefit from it or are displaced by it. This is all to say that from a technical point of view, solutions may make a lot of sense, but from a socio-political point of view they may be extremely disruptive and produce undesired side effects. Hence, projects that do not gauge these potential effects may, and often do, fail.

In this case we need to ask whether improved efficiency of production is our or a particular society's primary objective. Or, is improved charcoal production(and better wood resource utilization) one of many objectives such as improved agricultural production, or more equitable distribution of national waalt? Can we integrate improved charcoal production(or, say, small-scale hydropower generation) with other development objectives? These are tought questions

that require considerable thought and study. But, they are the type of questions that we so often avoid because it is more expedient and requires less study to propose a particular project than it is to view a problem or issue within the context of development as a whole.

During the course of this talk I have expressed many reservations about energy and development planning. That must seem ironic coming from an "energy planner." I do not wish to leave the impression that I believe energy planning to be a futile or worthless exercise. On the contrary, I am an ardent proponent of planning. But what I wish to put across is that we must ask ourselves what we really wish to accomplish and how we define "successful" development. These are also the very questions we must ask those leaders or individuals who seek our assistance. We must define our priorities and our limitations and we must ask of others that they do the same. We must place energy development within the context of overall development and explicitly state and list the priorities we see in our work. We must view any particular type of energy source or resource, whether we are speaking of hydropower or woodfuels, as one among many other possible resources. We must realize that technical solutions work well in the laboratory or classroom but are often of little value when working with people in real life. Those people have their own priorities, needs and views of the way life ought to be. Thus, before we can speak of "local involvement" we need to understand the whole, the "big"

picture. In the end, I would argue that there are no quick and easy solutions for the mere task of defing the possibilities and constraints is a process that should take considerable time. To do justice to the process of development and achieve meaningful results there must be a strong will to expend the time and effort on the part of the donors and the recipients, the planners and the local beneficiaries. I happen to believe that meaningful change and improvement in people's lives are possible and I believe that you will hear about many such possibilities and successes over the next few days.

HYDROLOGIC INVESTIGATIONS FOR SMALL HYDROPOWER SITES

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INTRODUCTION

We are concerned with determining the feasibility of extracting energy from a river and using it to turn a shaft. This "shaft power" can be used to perform useful work such as electrical generation, the grinding of grain, and so forth. The amount of power that can be extracted is calculated from the kinetic energy of the water that flows through the turbine.

$$E = 1/2\ MV^2 \qquad (1)$$

Power is the rate of energy conversion or the number of energy units converted in unit time.

$$P = \frac{E}{t} \qquad (2)$$

where E = energy, M = mass, V = velocity, P = Power and t = time.

In waterpower engineering the mass is a function of the cubic meters of water involved and velocity is a function of net head (H_n). The relationship is commonly written as

$$kW = 9.81\ Q\ H_n\ e \qquad (3)$$

where kW = the potential installed capacity (power) in kilowatts, Q = flow through the turbine in cubic meters per second, H_n is net head in meters, and e = efficiency.

The hydrologic feasibility study of a potential hydro-electric site is primarily concerned with measuring or calculating

I) Net head available for power generation at the site;

II) Magnitude, frequency and distribution of flows available for power generation at the site; and

III) Magnitude and frequency of flood waters that must be passed through the site without damage to the installation.

This paper will deal with each of these major topics in turn.

I. NET HEAD

The first step is to determine the net head available for power generation at the site.

This requires that the gross head be measured directly at the site using one of the standard and proven differential leveling techniques. Measurements of head should be carefully performed and all calculations should be checked and verified. Use of measurements of head from miscellaneous sources or from persons unknown to the hydrologic investigator is not recommended.

Emphasis must be placed on the importance of this measurement. Because it is a relatively straightforward operation it is often left to or assigned to inexperienced people to obtain. It is strongly advised that measurement of gross head be performed under the direct supervision of the principal investigator using the best available survey techniques.

The net or usable head is the gross head reduced by the head loss due to friction and tailwater affects;

$$H_n = H_g - H_f \qquad (4)$$

where H_g = gross head, and H_f = head loss.

In most small hydro sites head loss is small but not negligible. It is calculated by well known and proven methods such as the Darcy Weisbach equation, which is

$$H_f = f \times \frac{L \times V^2}{D \quad 2g} \qquad (5)$$

In which f is a friction factor, L is a length, D is a width or diameter, V is a velocity, and g is acceleration due to gravity. In practice head loss is calculated for the entire length of the flow route through the hydroelectric station including intake, gates, penstock or canal, bifurcations, turbine, and so forth. It

is important that these calculations be done with care. A 10% error in the net head calculation can be disastrous to the economic feasibility of a site.

It is just as important to understand how changes in tailwater elevation can affect net head, and how these affects are measured. As we all know, a hydro site generally consists of a dam, penstock, powerhouse and tailrace. During high flows the water over the dam is relatively broad and shallow and the depth of water flowing over the dam increases slowly. On the other hand, the flow of the water in the undisturbed channel at the tailrace tends to be relatively narrow and deep. This means that depth increases slowly at the dam and rapidly at the tailrace during high flows. Since net head is largely dependent on the difference in elevation between water levels at the dam and at the tailrace, it is obvious that net head can be decreased significantly during high flows in the river.
This head loss due to tailwater elevation can be calculated or measured in two ways. Headwater, or depth of flow over the dam, can best be calculated using one of the weir formulas in Table 1.

The relationship between amount of flow in the river and depth of flow at the tailrace is expressed as a curve or table expressing the depth versus flow relationship. Three methods for constructing this relationship are briefly outlined here.

TYPE OF OUTLET	STAGE-DISCHARGE RELATIONSHIP*
Rectangular, sharp-crested weir without contractions	$Q = 3.33LH^{1.5}$
Rectangular, sharp-crested weir with contractions	$Q = 3.34LH^{1.47}$
Trapezoidal, sharp-crested (Cipoletti) weir with sides sloping at 4:1	$Q = 3.37LH^{1.5}$
Triangular, sharp-crested weir	
120° V-notch	$Q = 4.43H^{2.45}$
90° V-notch	$Q = 2.48H^{2.48}$
30° V-notch	$Q = 0.67H^{2.5}$
Rectangular, broad-crested weir	$Q = 2.7LH^{1.5}$, but with many variations depending upon the form of the crest
Natural stream, small channel below lake in Labrador	$Q = 14.3H^{1.34}$, but with many variations depending upon the form of the channel

*Q = outflow (cfs)
H = water elevation above bottom of outlet (ft)
L = width of rectangular outlet (ft)

TABLE 1. Stage-discharge relationships for typical reservoir outlets. From Dunne and Leopold (1).

The most accurate method is to construct the relationship by using field measurements, using current meters or some other proven method for measuring the river flow accurately, and an accurate staff gauge for measuring depth at the tailrace location. Usually four or five such measurements, if properly distributed over the range of flows expected, will suffice.

The second method is to use the slope-area method. In this method an open channel flow equation, such as the well known Mannings equation, is used. In the Mannings equation

$$V = \frac{1.49}{n} \times R^{2/3} \times S^{1/2} \qquad (6)$$

In which V = mean velocity in the downstream direction, n is a relative roughness coefficient, R = hydraulic radius = $\frac{A}{P}$,

A = cross sectional area of flow in the downstream direction, P = the wetted perimeter of this flow, and S = the hydraulic gradiant. Table 2 provides some values of n, the relatively roughness coefficient in the Manning equation.

TABLE 2 .

Values of n for the Kutter and Manning Formulas

DESCRIPTION OF CHANNEL	RANGE OF n
Glazed brick	0.011-0.015
Brick in mortar	0.012-0.017
Neat cement	0.010-0.013
Concrete pipe	0.012-0.016
Plank flumes	0.010-0.016
Concrete-lined channels	0.012-0.018
Cement rubble	0.017-0.030
Dry rubble	0.025-0.035
Dressed stonework	0.013-0.017
Smooth metal flumes	0.011-0.015
Corrugated metal flumes	0.022-0.030
Earth canal, straight and uniform	0.017-0.025
Rock canal, trimmed smooth and uniform	0.025-0.035
Rock canal, rough	0.035-0.045
Sluggish, winding channels	0.022-0.030
Canals, stony bed, weeds along bank	0.025-0.040
Earth bottom, rubble sides	0.028-0.035

NATURAL CHANNELS:

(1) Clean, straight, full stage, no pools	0.025-0.033
(2) As above with weeds and stones	0.030-0.040
(3) Winding, pools, shallows,but clean	0.033-0.045
(4) As above at low stages	0.040-0.055
(5) As (3) with weeds and stones	0.035-0.050
(6) As (4) with large stones	0.045-0.060
(7) Sluggish, weedy, or with deep pools	0.050-0.080
(8) Very weedy and sluggish	0.075-0.150

From Linsley, Kohler and Paulhus (2)

To apply this technique the investigator first plots the curves that illustrate the relationship between depth, cross sectional area and wetted perimeter at the channel cross section that controls the depth of flow at the tailrace. These measurements are taken directly in the field using standard surveying techniques. The investigator then selects roughness coefficients with the awareness that the roughness coefficient is relative and may change as depth of flow increases. The investigator then selects four or five depths that bracket the actual depth of flow to be expected, and, by substitution in the Manning equation, calculates the flow in the river that corresponds to each depth. Depth and flow are then plotted and the relationship between the two variables is obtained.

The results of a great many such measurements in natural channels show that depth increases as the 0.35 power of flow

$$D = cQ^{0.35} \tag{7}$$

in which D = mean depth of flow, c is a constant for the section and usually has a value between 0.10 and 0.25, and Q is the flow.

The third method is to use a dimensionless rating curve such as the one shown in Figure 1.

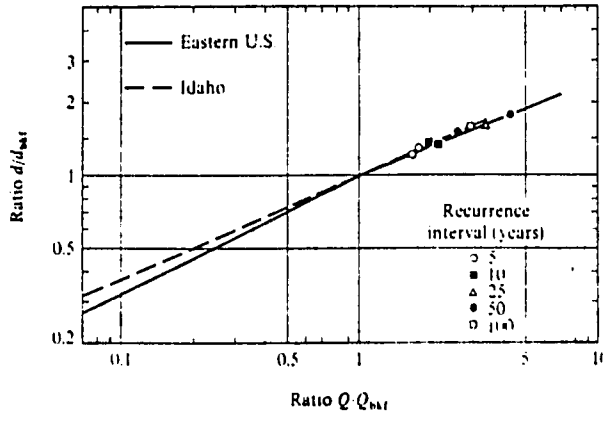


FIG 1 . Dimensionless rating curves for two different physiographic regions. From Dunne and Leopold (1)

To use the figure the investigator calculates the flow and measures the depth for the bankfull condition. Once this is done the figure can be used to quickly develop the relationship needed. Like most quick and easy solutions, it is less accurate than the others outlined here. Figures 2 and 3 illustrate the change in head as flow increases for a small hydro site in Vermont.

The spillway rating curve (Figure 2) shows how depth of flow over the dam is related to the amount of flow going down the river.

The tailwater rating curve (Figure 3) shows how depth at that point changes with flow.

To illustrate the tailwater affect assume a low flow of 500 cubic feet per second. Water surface at the spillway is 440 feet m.s.l. and water surface at the tailwater is 389.5 feet m.s.l. Gross head is the difference in elevation, 440 - 389.5 = 50.5 feet. Now assume a flow of 2000 cubic feet per second. The spillway elevation is 441.0 and the tailwater elevation is 392.0. The gross head is now 49.0 feet, a decrease of 1.5 feet from the previous situation. These curves can be combined with each other and with a flow duration curve to produce a head-duration curve.

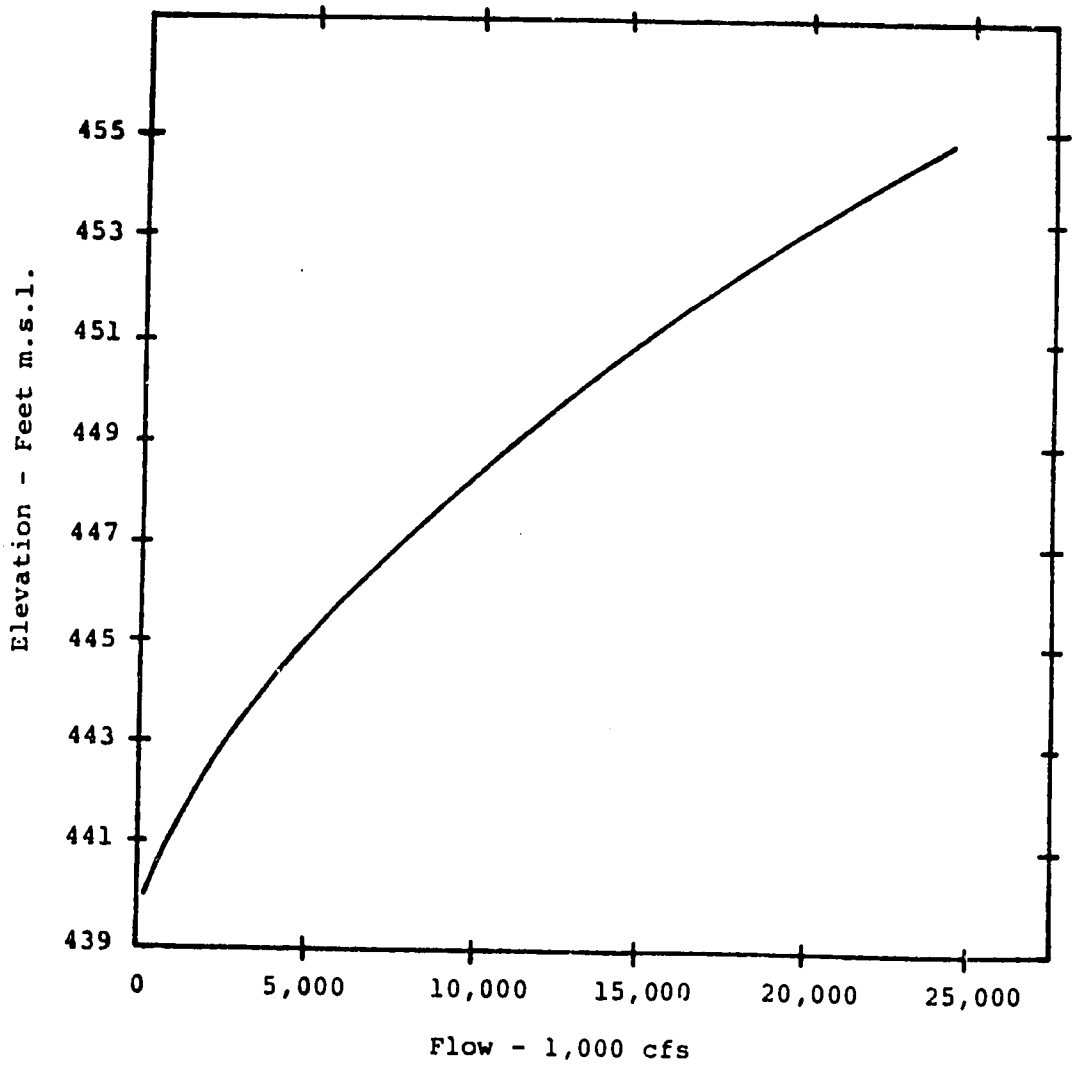


FIG 2 . Brockway Mills Spillway Rating Curve. From Hansen and Associates (3).

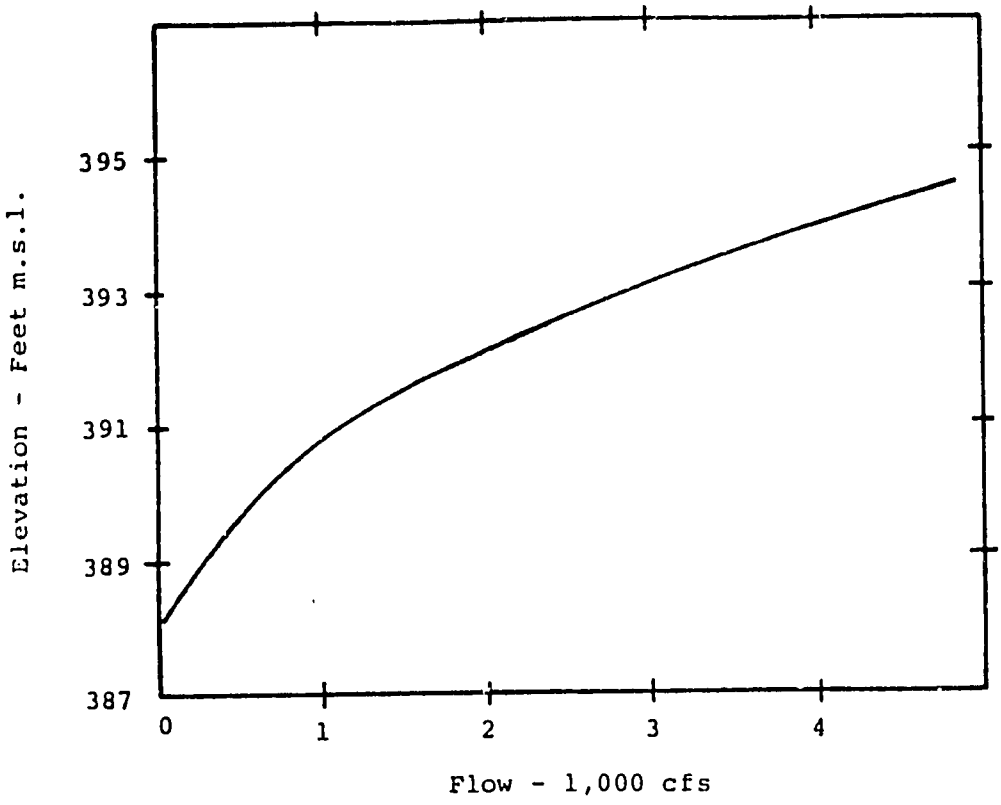


FIG 3 . Brockway Mills Tailwater Rating Curve. From Hansen and Associates (3).

We can briefly summarize the measurement of head by stating that a gross head should be carefully measured by competent and supervised people and all calculations should be carefully checked. Head loss through the hydroelectric station should be carefully calculated using standard methods. The change in tailwater elevation is very frequently the greatest source of head loss and should be measured or calculated using one of the three methods outlined.

II. FLOWS AVAILABLE FOR POWER GENERATION

Returning to Formula (3) for a moment, it is obvious that the great unknown is Q, the rate of flow that can be harnessed for hydro development. Exact and complete information on flow is obviously critical to a feasibility study. It is just as obvious that excellent long term records rarely exist for a particular site and the investigator is usually faced with using whatever data is available, if any.

For the purpose of determining how much power and energy can be feasibly extracted from the stream the investigator must produce a flow duration curve. The flow duration curve must be based upon as many years of record as is available, must be based upon daily flows if at all possible, and should indicate in some form the magnitude and frequency of wettest and driest years. Flow

duration curves for each month of the year are highly desirable but a good annual flow duration curve based upon daily flow and a long term period of record is perfectly adequate. The flow duration curve is a cummulative frequency curve that shows the percent of time during which specified flows are equalled or exceeded in a given period. Figure 4 shows the average annual flow duration curve for the Moretown #8 hydroelectric project in Vermont.

This figure is based upon 51 years of continuous daily records from a stream gaging station that is located 2.3 miles upstream from the site. The mean daily flow in the stream is 256 cubic feet per second (7.25 cubic meters per second), and the drainage area above the site is 143 square miles (370 square kilometers). This is perhaps an ideal situation but an appropriate one to use for the introduction to flow duration curves.

To construct a flow duration curve for such a situation is relatively simple but somewhat tedious. First, records are obtained from the gaging station. In this case the gaging stationed monitored a 139 square mile drainage area and the hydro station was downstream and at a point that has a 143 square mile drainage area. In this instance it was decided that all daily flows for the entire period of record could be adjusted by multiplying by the ratio of the areas (daily flow at gage x $\frac{143}{139}$) in order to obtain the mean daily flow at the hydro station. In

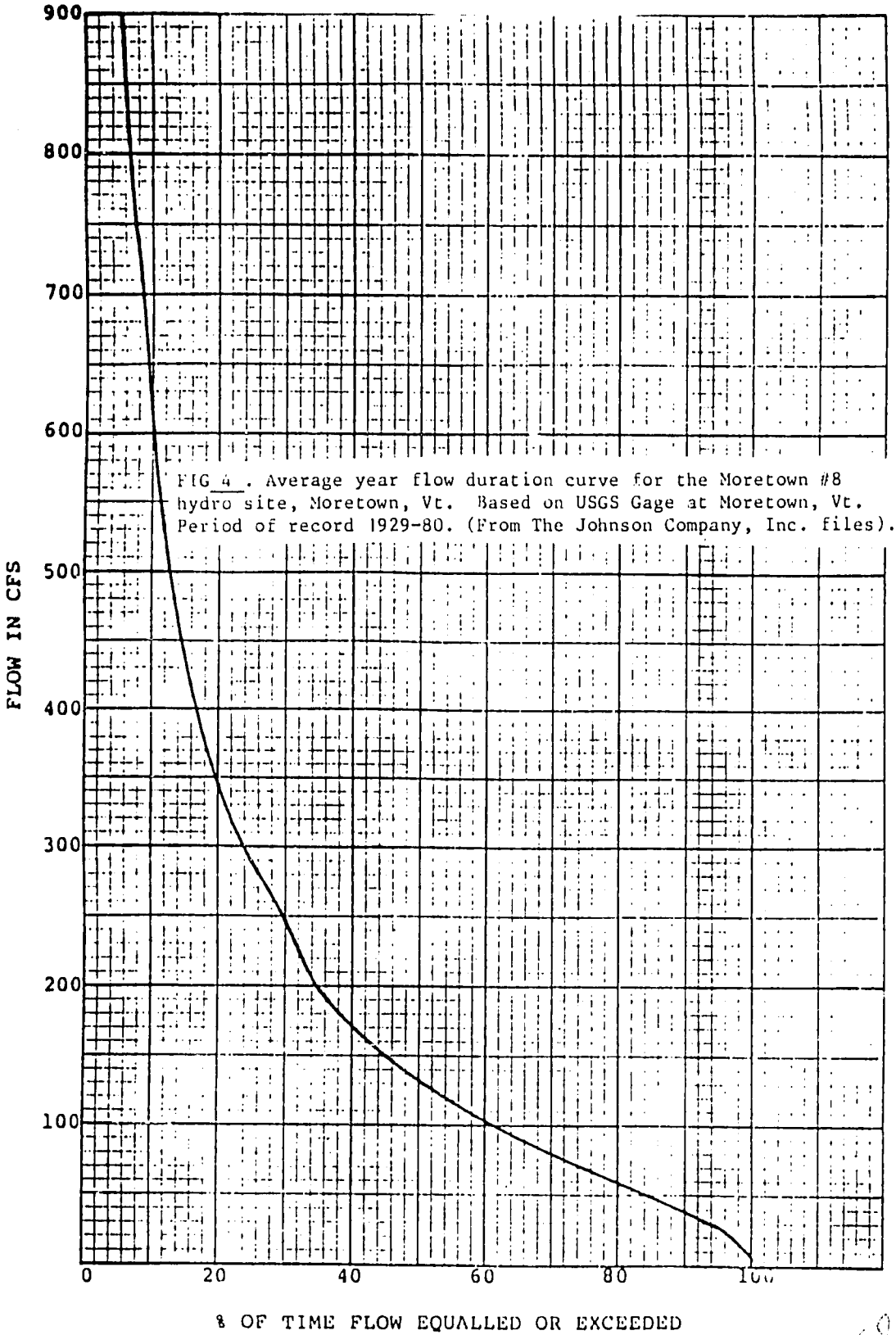


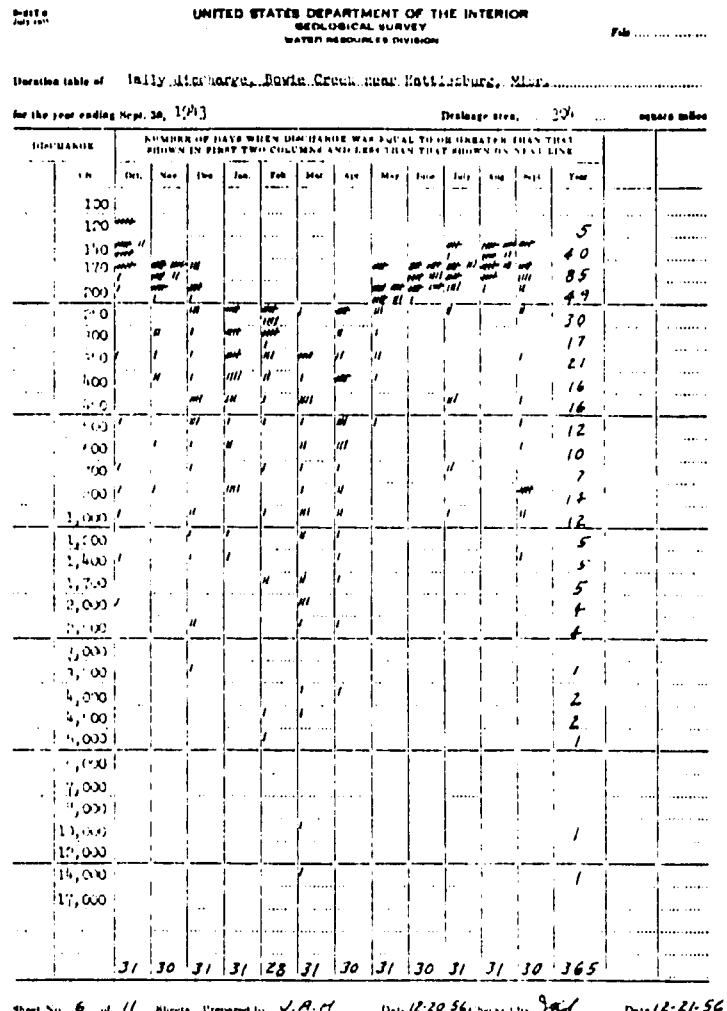
FIG 4 . Average year flow duration curve for the Moretown #8 hydro site, Moretown, Vt. Based on USGS Gage at Moretown, Vt. Period of record 1929-80. (From The Johnson Company, Inc. files).

other sites it is common to transfer such data from several gaging stations using an area weighting technique similar to the one used here. Once the basic daily flow data is prepared, it is tabulated for the duration curve. This is done using a tabulation similar to the one shown in Figure 5.

To use the tabulation the investigator first selects class limits and enters them under the discharge columns. The investigator then goes through the daily flows for each day of the year and counts the number of flows that are between each class limit, and enters that number in the appropriate box. All the days add up to 365 in both the horizontal and vertical directions. By this simple check the investigator can be certain that no days were omitted. Figure 6 shows how the data for each year are combined for all of the years of record.

This tabulation is very similar to the former one, and results in a percent of time column that is then plotted against the discharge column to produce the average year flow duration curve determined from daily mean discharge. It is important to use daily mean data because weekly, monthly or annual data will give you quite different results. This is illustrated in Figure 7.

In summary, if good flow records are available nearby, and if the tabulation is correct, an accurate flow duration curve can be constructed quickly and easily.



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Duration table of Daily discharge, Bowie Creek near Hattiesburg, Miss.

for the year ending Sept. 30, 1943 Drainage area, 296 square miles

Discharge	Oct.	Nov	Dec	Jan.	Feb	Mar	Apr	May	June	July	Aug	Sept	Year
100													
120													5
140													40
170													85
200													49
300													30
300													17
300													21
400													16
500													16
600													12
700													10
800													7
900													14
1,000													12
1,200													5
1,400													5
1,600													5
2,000													4
2,500													4
3,000													
3,500													1
4,000													2
4,500													2
5,000													1
6,000													
7,000													
8,000													
11,000													1
12,000													
14,000													1
17,000													
	31	30	31	31	28	31	30	31	30	31	31	30	365

Sheet No. 6 of 11 Sheets Prepared by J.A.H. Date 12-20-56 Checked by J.A.H. Date 12-21-56

FIG 5 . Sample work sheet for calculating the duration curve of mean daily discharge for one year of record. From USGS (4).

Form 9-1414
July 1946

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File

Duration table summary of Daily discharge, Bowie Creek near Hattiesburg, Miss.

for the years 1939-48 Drainage area 100 square miles

Discharge (cfs)	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	Total (1939-48) days	Percent of time
100	61	17		17							95	3653	100
120	68	64	10	23	5	3					173	3558	97.4
140	50	65	61	57	40	56	60	24	29	12	454	3385	92.7
170	27	47	75	48	85	53	46	70	81	99	631	2931	80.2
200	46	50	42	57	49	41	38	50	29	52	454	2300	63.0
250	18	16	53	41	30	26	47	27	34	45	337	1846	50.5
300	10	9	32	14	17	16	31	27	31	23	210	1509	41.3
350	9	14	18	16	21	26	24	20	16	17	181	1299	35.6
400	4	5	13	10	16	16	10	21	13	13	121	1118	30.6
450	11	6	7	13	16	15	15	13	5	10	113	997	27.3
500	10	11	8	11	12	18	20	20	12	20	142	884	24.2
600	10	7	9	10	10	15	19	11	20	15	126	742	20.3
700	4	3	7	4	7	16	14	14	14	6	89	616	16.9
800	12	15	6	12	14	18	10	19	13	12	131	527	14.4
1,000	7	3	5	3	12	12	10	13	11	7	83	396	10.8
1,200	4	8	3	5	5	3	5	13	9	5	55	313	8.57
1,400	6	12	2	7	5	13	4	11	9	9	78	258	7.06
1,700	3	4	3	4	5	1	3	2	10	4	39	180	4.93
2,000	2	5	1	3	4	5	5	3	7	5	40	141	3.86
2,500	1	2	6	2	4	5	3	1	7	3	34	101	2.76
3,000	2	4		4		3		3	4	1	21	67	1.83
3,500		2		2	1	3	1	2	3	2	16	46	1.26
4,000		2			2	2		1	4	2	13	30	.821
5,000				1	2				2	1	6	17	.465
6,000			1		1					1	3	11	.301
7,000			1							2	3	8	.219
8,000				1							1	5	.137
9,000									2		2	4	.109
10,000					1						1	2	.055
12,000													
14,000					1						1	1	.027
16,000													
	365	366	365	365	365	366	365	365	365	366	3653		

Sheet No. 1 of 11 Sheets Prepared by J.A.H. Date 12-20-56 Checked by JAS Date 12-21-56

FIG 6 . Sample work sheet for calculating the average year flow duration curve from ten years of record, based on mean daily discharge. From USGS (4).

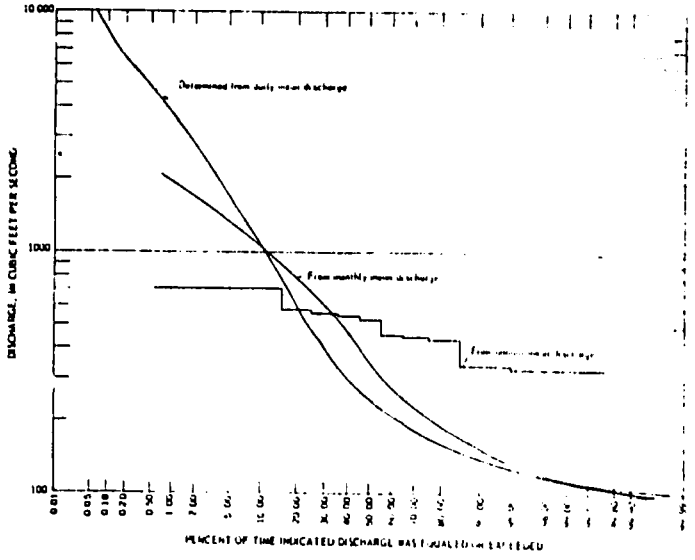

FIG 7 . Duration curves of daily, monthly, and annual flows, Bowie Creek near Hattiesburg, Miss., 1939-48. From USGS (4).

The more frequent case is the site where records are not available or where records must be transferred from some distance. The following paragraphs will deal with this problem and will describe methods for constructing the estimated flow duration curve for such sites.

In the usual flow duration curve, discharge is expressed in cubic meters per second because most daily discharges are published in those units. The discharge data could be converted to any other desired units for plotting the flow duration curve. For example, the ordinate could be cubic meters per second, millions of liters per day, kilowatts corresponding to the net head and plant efficiency, and so forth.

If the duration curve is to be used for comparing flow characteristics among streams, which is the problem we are now addressing, flow should be expressed in cubic meters per second per square kilometer or as a ratio to mean daily flow. Expressing discharge in either cubic meters per second per square kilometer or in ratio to mean daily flow eliminates the effect of size of drainage area; but to express discharge as a ratio of mean annual flow also eliminates the effect of differences in mean annual runoff per square kilometer. However, for many streams, comparisons based on cubic meters per second per square kilometer are almost identical with comparisons based on ratio to mean daily flow.

Among stream basins in which precipation differs greatly, flow duration curves based on a ratio to mean flow are much closer together than those based on cubic meters per second per square kilometer. The investigator should plot all available data that might be used using both ratios in order to see which technique will provide the best results. Figure 8 shows data from three gaging stations in the same climatic zone. The upper part of the figure shows a curve in which discharge is plotted as a rate per unit area; the lower curve shows discharge plotted as a ratio to mean annual flow. These techniques are useful conversions for hydrologic comparisons, but care should be taken to avoid the assumption that the stream with the highest yield per unit area is the best source of supply, or that the flow varies uniformly over the drainage basin.

A dimensionless flow duration curve for the mountainous regions of Lesotho is shown in Figure 9.

Such dimensionless methods can often be used to construct flow duration curves providing the investigator selects the basic data with extreme care. Attention must be paid to physiography and climatology. Records selected for use must be examined for accuracy and checked for homogeneity. A double mass curve technique may be used to do this, as shown in Figure 10.

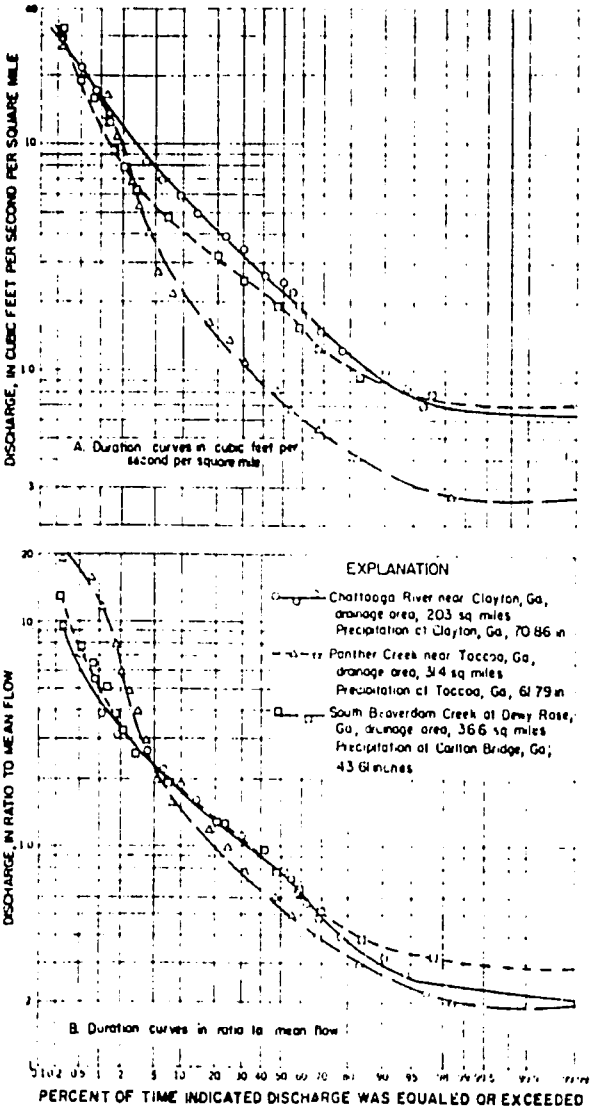

FIG 8 . Dimensionless flow duration curves. From USGS (4). Reference is Water Supply Paper 1542-A on flow duration.

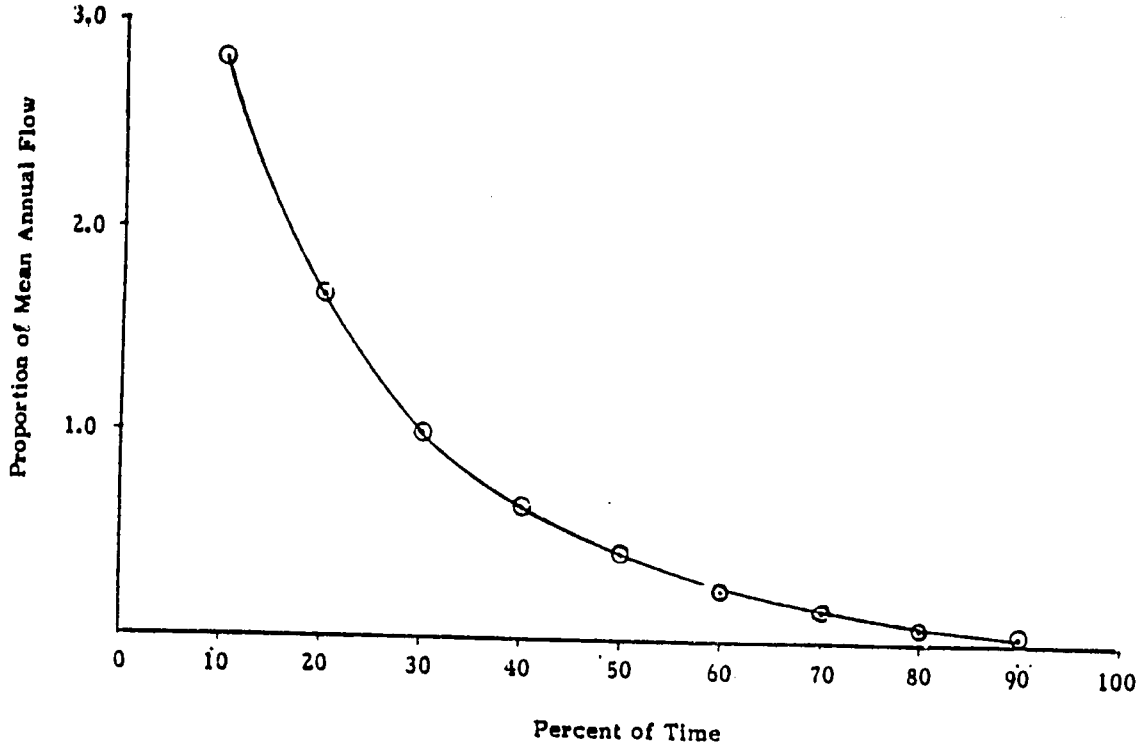

FIG 9. Dimensionless flow duration curve based upon the report by Sogreah (5). Copy reference from Lesotho.

Water year	Stream A		Pattern		Water Year	Stream A		Pattern	
	Yearly	Cumulative	Yearly	Cumulative		Yearly	Cumulative	Yearly	Cumulative
1921	19.73	19.73	19.61	19.61	1934	9.35	244.16	7.94	189.54
1922	15.80	35.53	12.29	31.90	1935	32.79	276.91	25.58	215.12
1923	17.52	53.05	8.12	40.02	1936	7.57	284.66	4.06	219.18
1924	16.58	69.63	14.39	54.41	1937	19.72	304.38	13.76	232.94
1925	5.33	74.96	3.53	57.94	1938	28.33	332.71	38.64	251.58
1926	16.45	91.41	13.80	71.74	1939	15.04	347.75	10.41	271.99
1927	30.67	122.08	24.03	95.77	1940	13.65	361.40	10.68	282.67
1928	21.22	143.30	12.40	108.17	1941	17.42	378.82	30.15	312.82
1929	21.96	165.26	19.70	127.87	1942	17.82	396.64	21.60	334.42
1930	19.34	184.60	18.10	145.97	1943	9.41	406.05	8.96	343.38
1931	9.87	194.47	5.13	151.10	1944	21.13	427.18	20.01	363.39
1932	24.81	219.28	18.30	169.40	1945	37.85	465.03	40.25	403.64
1933	15.53	234.81	12.20	181.60					

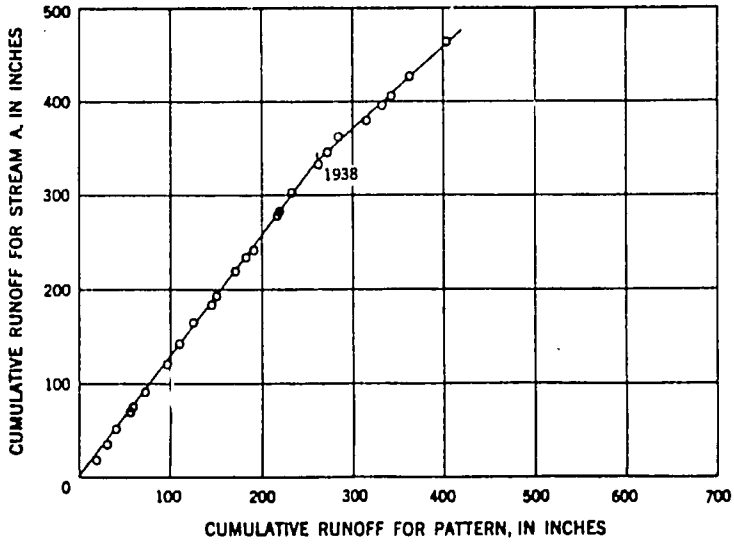

FIG 10 . Annual runoff, in inches, for double-mass curves. From USGS (6).

It is better to use accurate long term records, even if they are farther from the site to be investigated, rather than short term or inaccurate records close to the site.

Very seldom do all the gaging station records in a given area cover concurrent periods. If records are to be compared with each other, they must represent, or be adjusted to, concurrent periods in order that the differences between records will be due to differences in climatic or drainage basin characteristics and not to the fact that the records cover different periods of time. Furthermore, flow duration curves based on short records are unreliable for predicting the future pattern of flow, but they can under some circumstances be adjusted to represent longer periods.

Let us assume that we wish to extend a short term record so that we may use a short term station to estimate a flow duration curve. First we select a long term index station in the same physiographic and climatic situation as the short term station. A relation is established between the two stations for the short period of concurrent record by plotting a graph of the discharges for given duration points at one station against the corresponding data for the other station. The graph for this correlation is assumed to represent the relation between the stations for a long period. The flow available 50 percent of the time at the long term station can be used to enter the curve of the relationship in

order to obtain the adjusted long term flow available 50 percent of the time at the short time station. Adjusted flows for other frequencies at the short term station can be obtained in the same manner. By this technique even a one or two year record can be extended, but of course at some risk.

To demonstrate the method, records from two stream gaging stations in Illinois are used. The Iroquois River near Chebanse is used as the short term station with a record covering four years. The record for the long term index station on the Kankakee River at Momence is used to adjust the short term station. The data are shown in Table 3.

Figure 11 is plotted from the data in the second and third columns of Table 3. The discharges for various percent-duration points at the long term station are used to construct the relationship between the two stations as shown in Figure 11. We are now ready to adjust the discharge at the short term station. For example, the discharge of the Kankakee River (long record) at the 50 percent duration point is 1,370 cubic feet per second. Entering 1,370 on Figure 11 we find that the discharge of the Iroquois River should be 580 cubic feet per second when adjusted to the long period instead of the 750 cubic feet per second found in the short term record. In this case, then, adjustment of the Iroquois River short term record to a long term record decreases the flow values.

Percent duration	Discharge, in cubic feet per second			
	Kankakee River at Momence 1946-50	Iroquois River near Chebanse 1946-50	Kankakee River at Momence 1924-50	Iroquois River near Chebanse, adjusted to 1924-50
99.5	542	46	432	23
99	558	49	453	26.5
98	566	53	508	37.5
95	618	67	578	54
90	700	102	658	80
80	882	188	822	150
70	1,080	334	970	240
60	1,280	525	1,130	380
50	1,580	750	1,370	580
40	1,930	1,150	1,680	880
30	2,600	1,990	2,100	1,320
20	3,440	3,220	2,770	2,130
10	4,640	5,300	3,940	4,000
5	5,200	7,160	4,800	5,780
2	6,380	9,700	5,780	7,900
1	7,180	12,300	6,600	10,390
0.5	8,000	14,600	7,210	12,100

TABLE 3 . Discharge of equal percent duration on two rivers in Illinois. From USGS (4).

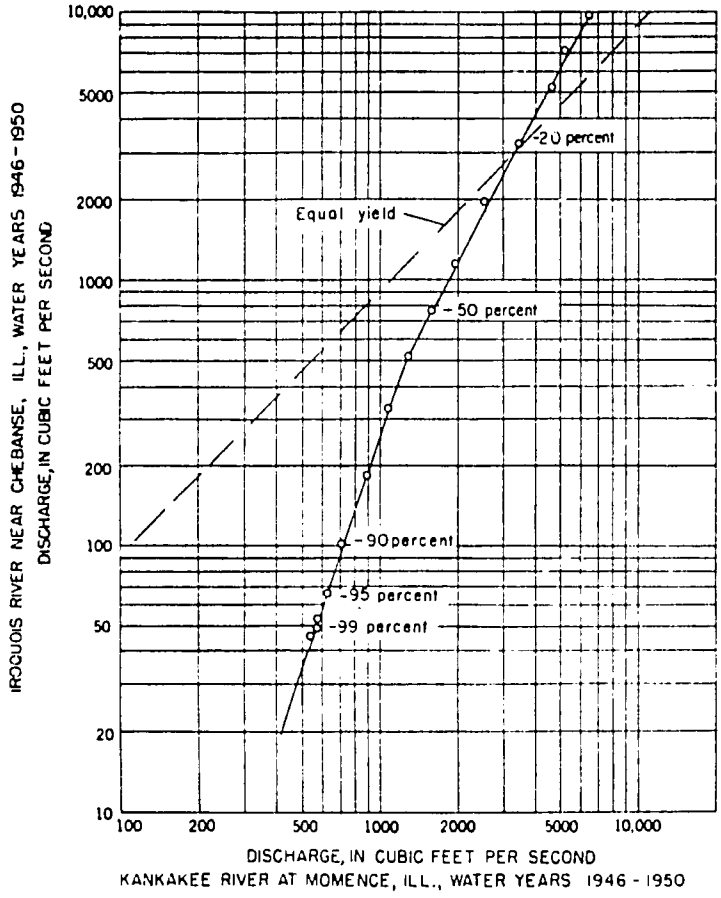

FIG 11. Correlation between the Kankakee River and Iroquois River, based on discharge of equal percent duration. From USGS (4).

The discharge for other percent-duration points is obtained in the same way, and the adjusted values are plotted to define the adjusted curve. (Figure 12).

This is a good example because the site actually does have a long term record and this method of estimating can therefore be compared with the actual record to demonstrate the accuracy of the method.

Frequently there is need for flow duration data on streams for which there are no gaging station records whatsoever. In such cases, which are all too frequent, the investigator can use several techniques which are outlined below, and which do give estimates quite satisfactory for feasibility studies providing they are properly used.

The first technique is to use, or prepare, the mean specific discharge map for the region or country in which the investigator is working. Figure 13 shows such a map for Lesotho.

This map was prepared by taking all stream gaging stations in the country, adjusting them for the same period of record, and plotting lines of equal yield or discharge on the map.

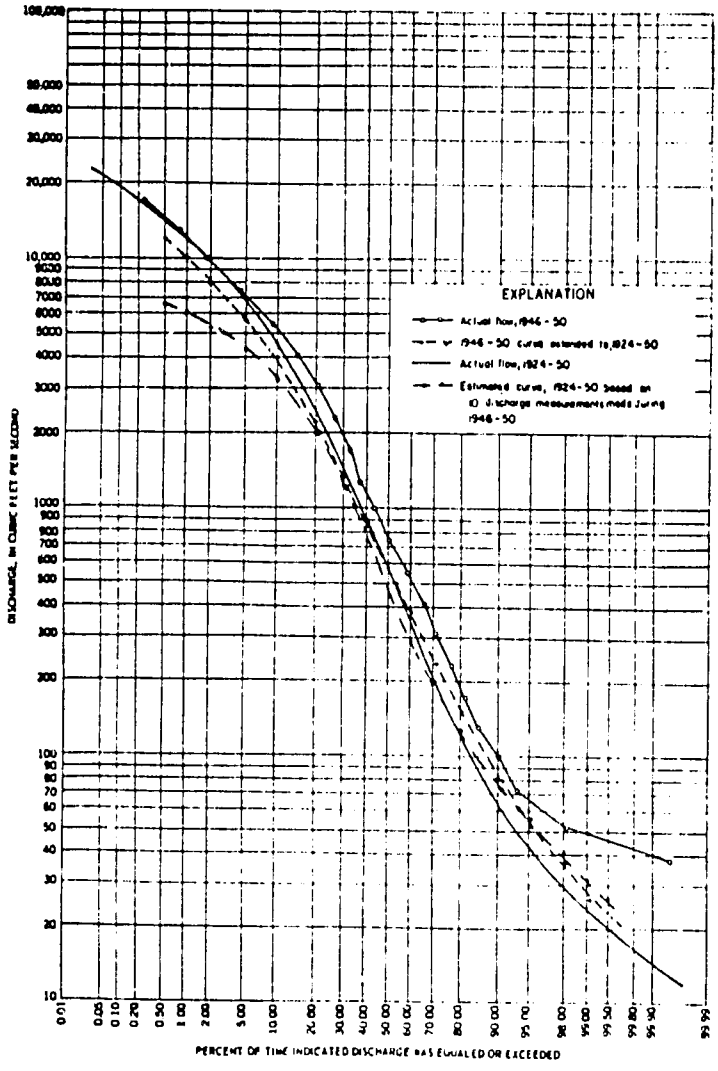

FIG 12 . Duration curves of daily flow, Iroquois River near Chebanse, Ill. From USGS (4).

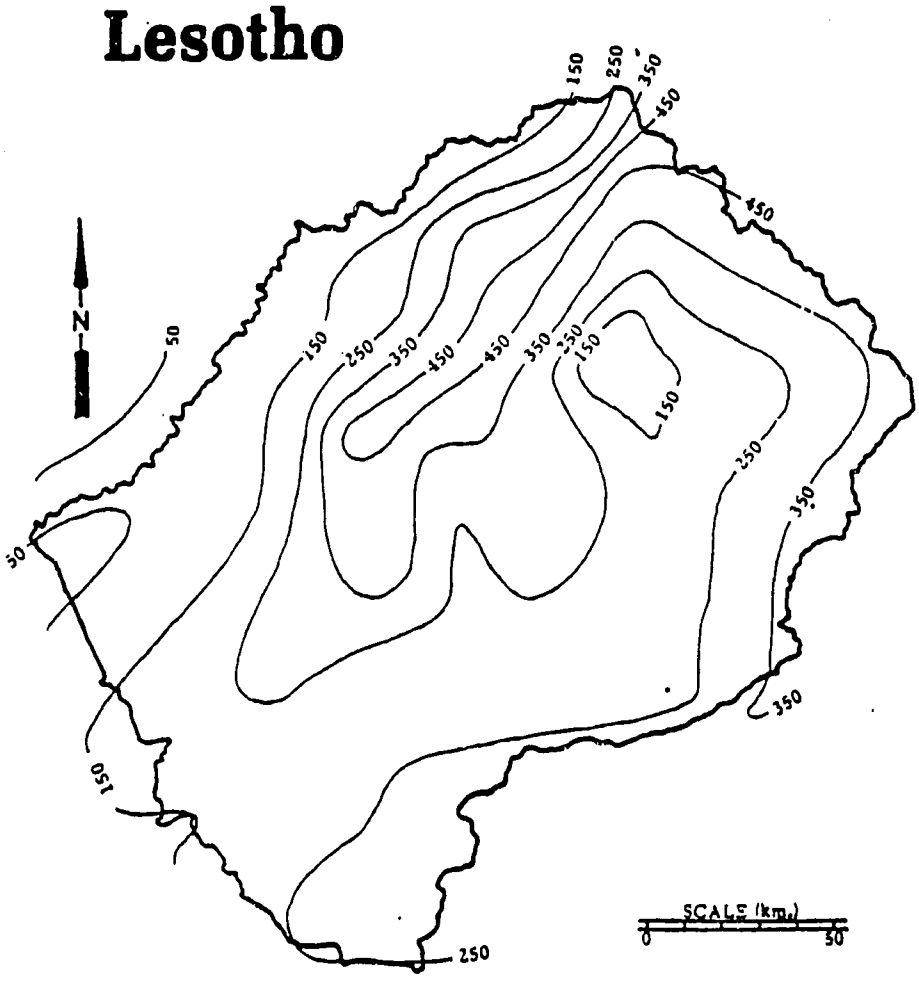

FIG 13 . Mean specific discharge, in millimeters, for Lesotho. From De Baulney (7)

Specific discharge is the mean annual runoff that can be expected from an area in an average year and is given in units of depth. A specific discharge of 100 millimeters 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 discharge for the 12 month period is the mean annual flow, which is the volume of water discharged divided by time. For a 37.5 square kilometer drainage area with a specific discharge of 100 millimeters a year the yearly volume of runoff is:

$$\text{Annual Volume} = 0.1 \times 1000 \times 1000 \times 37.5 = 3{,}750{,}000\ m_3 . \quad (8)$$

$$\text{Mean annual flow} = \frac{3{,}750{,}000\ m}{31{,}536{,}000 \text{ sec. in a year}} = 0.119\ m_3\ /\text{sec.} \quad (9)$$

Using this method the investigator may obtain an estimate of the mean annual flow for any drainage area. The investigator then applies the mean annual flow to a dimensionless flow duration curve that has been carefully prepared for the region or sub region, and thus constructs a flow duration curve for the point in question. This technique can be used to rapidly estimate the hydrologic feasibility of hydro sites. It must be used with care. In applying this method to three long term records in Lesotho, as a method of checking accuracy, errors ranged from +5.3% to +23.0%, as shown in Table 4.

Site	TLOKOENG	MOTETE	QACHA'S NEK
Drainage Area, km^2	852	261	750
Specific discharge; mm from De Baulny	200	400	200
Mean annual flow, m^3/s by Sogreah	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

TABLE 4. Accuracy check of mean annual flow and dimensionless hydrograph method, Lesotho. Values in percent. From (8).

The third and last method for constructing an estimated flow duration curve can be used at a site where absolutely no hydrologic data exists or to check the methods used and described immediately above. In this method the investigator uses relationships that exist between the geomorphology of stream channels and flow. Obviously, the channel shape and size has integrated in some complex way the rainfall-runoff relationship as well as the geology and land use of the basin, and other factors.

It has been found by numerous investigators, including this author, that a relationship exists between drainage area and bankfull discharge. Bankfull discharge is the flow in the channel when the flow has reached the very top of the bank but before water flows out of the channel over the flood plain. Flows can be calculated for the bankfull condition using the slope-area method already described. Figure 14 shows bankfull discharge as a function of drainage area for several different regions in the United States.

Many investigators have also found a relationship between mean annual flow and bankfull flow. Table 5 shows these data for a number of stations in the Green River Basin of Wyoming.

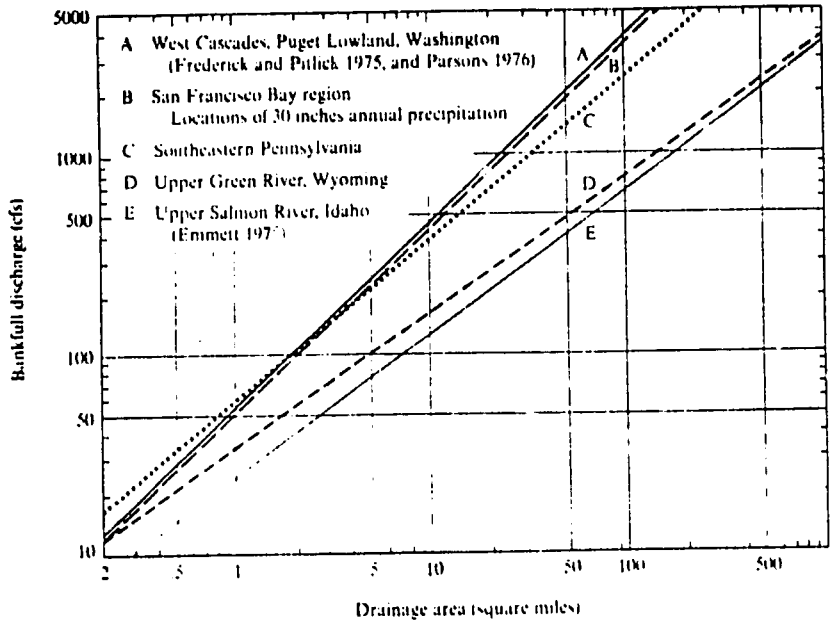

FIG 14 . Bankfull discharge as a function of drainage area for five physiographic regions. From Dunne & Leopold (1)

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	DRAINAGE AREA (SQ MI)	RATIO $\frac{Q_{bkf}}{Q_{ave}}$	PERCENT OF CHANNEL DEPTH FILLED BY Q_{ave}
LaBarge Creek near LaBarge Ranger Station	6.3	8.3	44
New Fork below New Fork Lake	36.2	6.7	50
Fall Creek near Pinedale	37.2	8.0	54
Silver Creek near Big Sandy	45.0	9.1	29
Pole Creek below Little Half Moon	87	8.1	39
Green River at Warren Bridge	468	5.3	53
New Fork near Boulder	552	4.8	38
New Fork near Big Piney	1230	6.4	39
Average		7.1	43

TABLE 5 . Ratio of bankfull flow to mean annual flow for Wyoming streams. From Dunne and Leopold (1).

Table 5 indicates that the mean annual flow is about one-seventh of the bankfull flow. Mean annual flow can then be used as the point of entry into a dimensionless flow duration curve, and thus a flow duration curve for the hydro site of interest can be estimated. The sequence is to go from drainage area to bankfull discharge to mean annual flow to flow duration. All of the relationships should be prepared for the investigators' own physiographic region. Results are often very good, but depend largely upon the skill and care of the investigator.

The flow duration curve is actually applied as follows. For the Moretown #8 site, whose flow duration curve is shown in Figure 4, the mean annual flow is 256 cubic feet per second, the net head is 45 feet and the efficiency of the turbine was assumed to be 0.82. By converting these numbers to the metric system and substituting them in equation (3) an installed capacity of 800.5 kilowatts was determined to be a reasonable first trial for the site. For this example we will assume that the installed capacity is 800 kilowatts. A cross flow type turbine was selected as being the most efficient for this run-of-the-river site, and the turbine has a maximum hydraulic capacity of 280 cubic feet per second and can operate down to a flow of 40 cubic feet per second.

When the flow is less than 40 cubic feet per second the station must be shut down for lack of water. When the flow is above 280 cubic feet per second the station will pass the excess water over the dam spillway. All flows between 40 and 280 cubic feet per second will pass through the turbine.

The amount of usable area under the flow duration curve is shown as the cross hatch portion of Figure 15. This area can then be measured and the annual output in kilowatt hours can be calculated. If an overall efficiency of 0.73 is assumed, the annual output is 3,760,000 kilowatt hours. In this way a flow duration curve is applied to accurately calculate annual energy output from the average year flow duration curve.

III. MAGNITUDE AND FREQUENCY OF FLOODS

The third major concern of the hydrologist investigating potential hydro sites has to do with the matter of flooding. To be feasible, every hydro site must obviously be capable of passing the flood without being destroyed. It is usually assumed that the 100 year flood, which is the flood that occurs on the average of once each 100 years, is the best basis for design for small hydro sites.

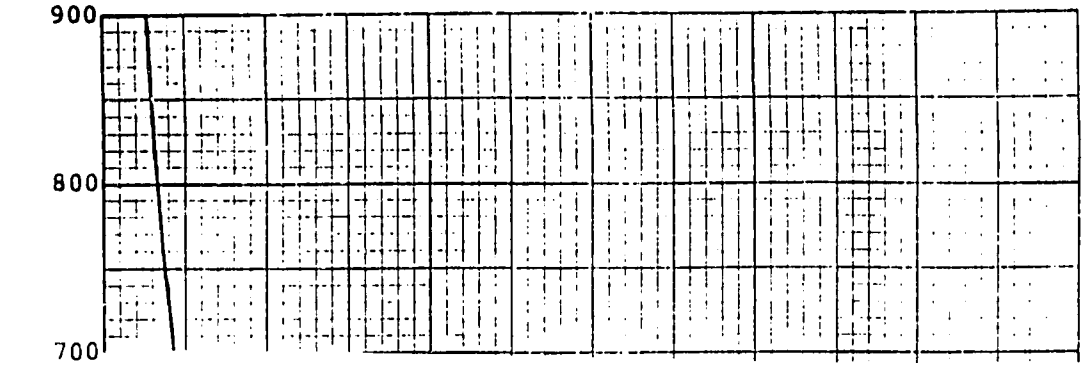
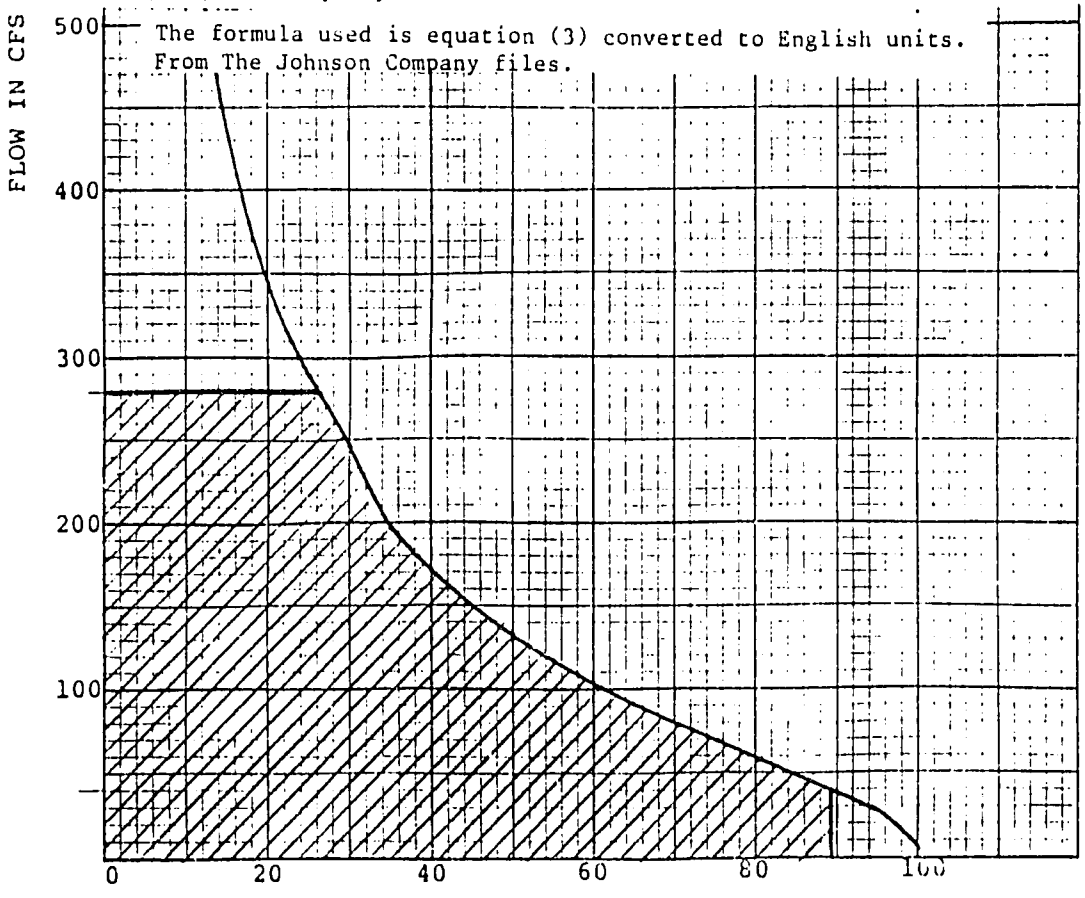


FIG 15 . Application of a flow duration curve to the calculation of annual energy output. The cross-hatched area is the usable portion of the average annual flow. There are 7.71 square inches of usable area. There are 100 small squares per square inch. Each small square is 2% of the year "wide" and 10 cubic feet per second "high". If the net head is 45 feet and the efficiency is 0.73, the output is

$$\frac{(7.71 \times 100)\ (0.02 \times 365 \times 24)\ (45)\ (0.73)}{11.8}$$

= 3,760,000 kwh per year.



To construct a flood frequency curve for a drainage area with a long term gaging record is a simple process. First, all years of record are obtained and the peak flood for each year is listed. These peak floods are then ranked in order from highest to lowest. The recurrence interval is calculated using the formula:

$$T = \frac{n+1}{m} \qquad (10)$$

in which T = the recurrence interval in years, n = the total number of years of record, and m = the ranking of the year. For example, if a record is 31 years in length, and an annual peak storm of 100 cubic meters per second ranks 8th highest in that term of record, the recurrence interval for that particular storm is 4.0.

$$T = \frac{n + 1}{m} = \frac{31 + 1}{8} = 4.0 \qquad (11)$$

The recurrence intervals thus calculated are then plotted against the annual peak discharges and a flood frequency curve is thus obtained. The following three figures (Figures 16, 17 and 18) show flood frequency curves for the Tana River in Kenya. The purpose of repeating these curves three times is to show the three most commonly used types of graph paper. The results are the same in each case.

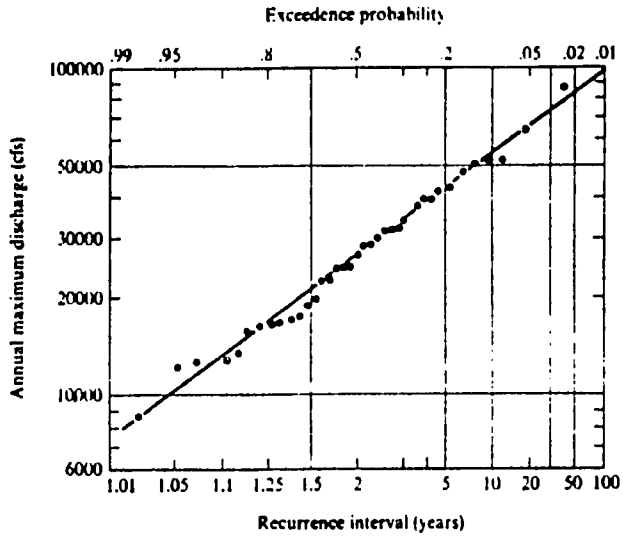


FIG 16 . Flood-frequency curve plotted on logarithmic probability paper, Tana River at Garissa, Kenya, 1934-1970. The scale at the top is the probability that the discharge is equaled or exceeded in any given year. The bottom scale, recurrence interval, is the average number of years in which the annual peak equals the discharge given on the ordiante. (Data from the Ministry of Water Development, Nairobi.) From Dunne and Leopold (1).

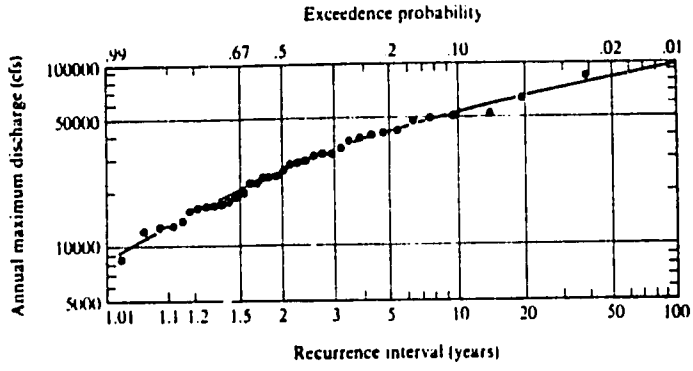


FIG 17 . Flood-frequency curve plotted on logarithmic Gumbel Type III graph paper, Tana River at Garissa, Kenya, 1934-1970. (Data from the Ministry of Water Development, Nairobi.) From Dunne and Leopold (1).

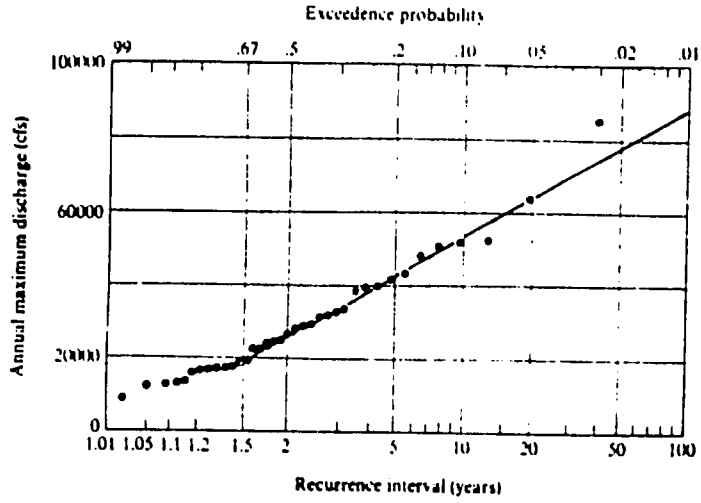


FIG 18. Flood-frequency curve plotted on arithmetic Gumbel Type I graph paper, Tana River at Garissa, Kenya, 1934-1970. (Data from the Ministry of Water Development, Nairobi.) From Dunne and Leopold (1).

Frequently long term records are not available and the investigator must again estimate the 100 year flood for a particular hydro site. A method of relating the 100 year flood to the mean annual flood can be developed for a physiographic region. Table 6 shows data for a number of very carefully measured experimental watersheds in the Northestern United States.

The T year flood is the flood of whatever return period is desired by the investigator. The data indicate that the 25 year flood is 2.5 times as large as the mean annual flood. These data can be plotted as shown in Figure 19.

The curve in Figure 19 could be extended to reach any recurrence interval desired. It is statistically invalid to use less than 100 years of record to establish a 100 year flood frequency; however everyone does extrapolate because the need for an answer outweighs the mathematical considerations.

Another variation of this approach is to correlate mean annual flood, drainage area and site altitude. This is shown in Figure 20 for an area in the Northwestern United States.

Another slight variation of this method is to develop, from long term records within the same physiographic region, ratios of the 100 year flood to the mean annual flow. This is shown in Figure 21 for an area near Washington, D.C.

DRAINAGE BASIN	W-1	W-3	W-4	W-5	W-7	W-8
Area (sq mi)	16.58	3.23	16.80	42.91	8.35	6.04
Mean annual flood	455	105	465	1000	290	157
1.1-year flood	240	67	234	770	155	93
1.5-year flood	370	86	340	880	230	122
2-year flood	430	99	420	940	270	144
3-year flood	500	117	540	1100	330	175
5-year flood	600	140	710	1400	400	215
10-year flood	720	173	1000	2000	520	280
15-year flood	780	198	1210	2500	600	330
25-year flood	860	230	1550	3050	720	400

(b)

DRAINAGE BASIN	W-1	W-3	W-4	W-5	W-7	W-8	MEDIAN
1.1-year flood	0.53	0.64	0.50	0.77	0.54	0.60	0.57
1.5-year flood	0.82	0.82	0.74	0.88	0.79	0.78	0.81
2-year flood	0.95	0.94	0.91	0.94	0.93	0.92	0.94
3-year flood	1.10	1.11	1.17	1.10	1.14	1.12	1.12
5-year flood	1.32	1.34	1.53	1.40	1.39	1.38	1.38
10-year flood	1.58	1.65	2.15	2.00	1.80	1.80	1.80
15-year flood	1.71	1.89	2.62	2.50	2.07	2.10	2.08
25-year flood	1.90	2.20	3.35	3.05	2.48	2.56	2.52

TABLE 6 . (a) Tabulation of the T-year flood for various basins taken from flood-frequency curves. The floods are expressed in cubic feet per second. The data are for 6 basins in the Sleepers River Experimental Watershed, Vermont. (b) Ratio of T-year flood to the mean annual flood for the basins. From Dunne and Leopold (1).

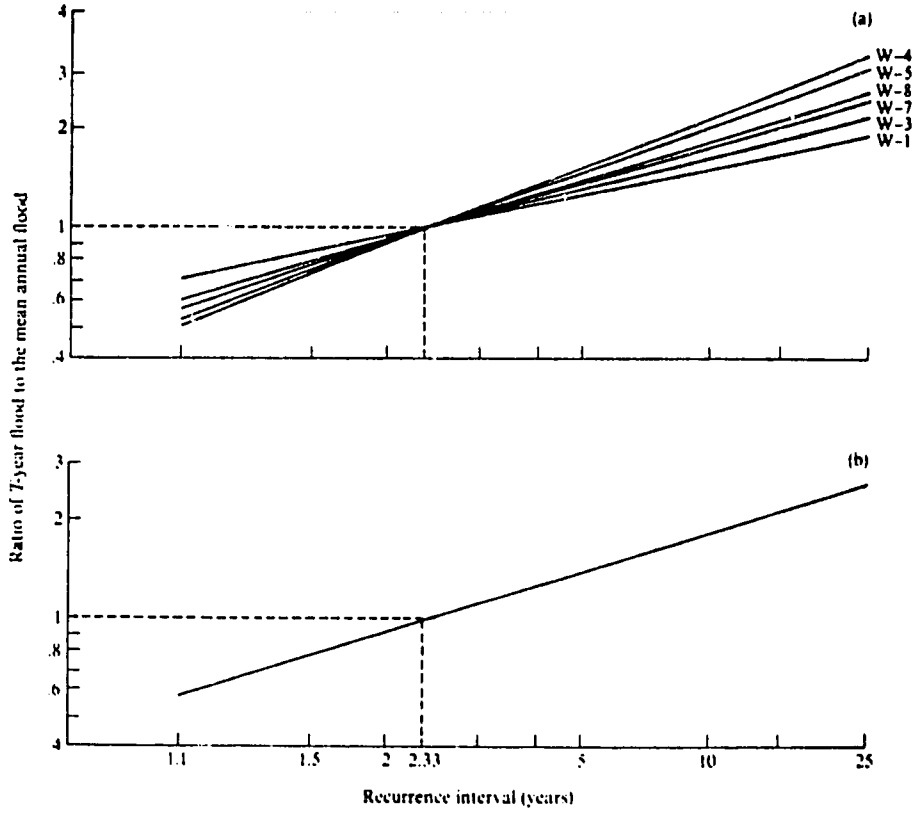


FIG 19. Flood-frequency curves from Table 6 with the discharge expressed as a ratio to the mean annual flood. (a) Individual or station curves for the six catchments. (b) Regional curve for northeastern Vermont, constructed from the median values of curves in (a) above. From Dunne and Leopold (1).

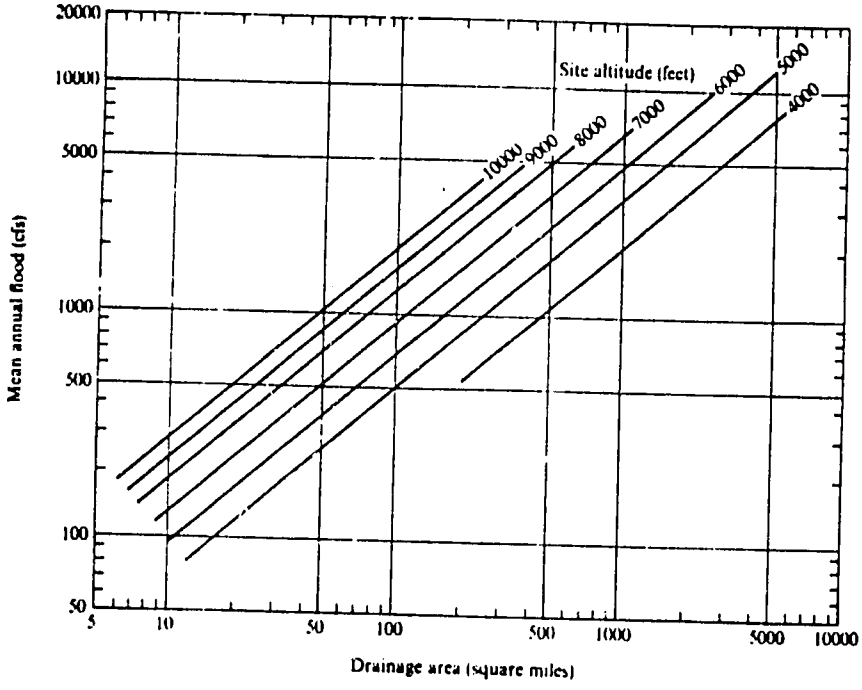


FIG 20 . Variation of mean annual flood with drainage area and altitude of the gauging site for a region in Northern Wyoming. From Dunne and Leopold (1).

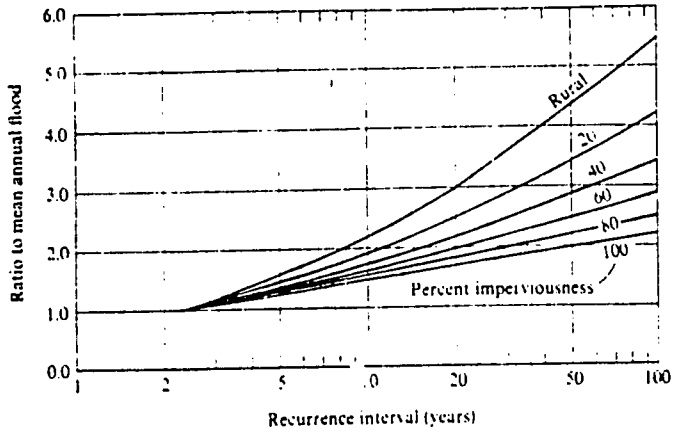


FIG 21 . Regional flood-frequency curves for catchments with various percentages of impervious area near Washington, D.C.. From Dunne and Leopold (1)

As a rule of thumb some investigators assume that the bankfull flow is the flow with a recurrence interval of 1.5 years, which is about 80% of the mean annual flood. They next assume that the 100 year flood is six times the mean annual. By this method a quick estimate can be made of the potential 100 year flood for a site.

Frequently the people who live in the vicinity of the proposed hydro station are your best source of information, and should always be interviewed. The oldest resident is not necessarily the most knowledgeable. Most people are very much aware of what is happening in the world around them, and a major flood or a major drought is a big event in their lives. A great deal of information of value to the investigator can thus be obtained from reliable and first hand sources.

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TVA AND A UNIQUE SMALL HYDRO PLANT - OCOEE NO. 2

G. L. Buchanan

History and Development

The Tennessee Valley Authority is a corporate agency of the United States Government established by an Act of Congress in 1933. It was born in the depth of the Great Depression and in the midst of the controversy over the disposition of the World War I built and Federally owned Wilson Dam at Muscle Shoals, Alabama, and two nearby nitrate plants. In requesting Congress to pass legislation creating TVA, President Roosevelt asked for "A corporation clothed with the power of government but possessed with the flexibility and initiative of private enterprise."

Further expressing his concept of TVA's responsibility, President Roosevelt said:

"It is clear the Muscle Shoals development is but a small part of the potential public usefulness of the entire Tennessee River. Such use, if envisioned in its entirety, transcends mere power development; it enters the wide fields of flood control, soil erosion, reforestation, elimination from agricultural use of marginal lands, and distribution and diversification of industry. In short, this power development of war days leads logically to national planning for a complete river watershed involving many states and the future lives and welfare of millions. It touches and gives life to all forms of human concern." This remains TVA's guiding objective and philosophy.

Organization

All powers of the corporation are vested in its 3-member Board of Directors, which reports to the President of the United States. The President, with the consent of the Senate, appoints the members of the Board to serve in 9-year overlapping terms of office. He designates one member as Chairman.

The TVA Act provided the agency with administrative freedom to meet the special requirements of its program and to adopt the methods of administration of successful private as well as public enterprise, and authorized the Board "to provide a system of organization of fix responsibility and promote efficiency."

TVA's first Board made far-reaching decisions which have guided the agency ever since. These included:

- TVA would design, construct, and operate its facilities.
- The agency would work with and through the land-grant colleges and the Extension Service in carrying out the fertilizer and agricultural programs.

TVA would build and operate the generation and transmission facilities of the power system. The retailing of electricity to the ultimate consumers would be handled by municipally-owned and rural electric cooperative systems. Contractual provisions would make these systems partners with TVA in assuring compliance with the Act's provisions that the benefits of low-cost electricity be passed on to the people of the region.

Unified Resource Development

In 1933 the Tennessee River Valley and the surrounding area was particularly depressed. It suffered from frequent floods on its unregulated rivers. Its agriculture was carried out in traditional ways that caused erosion, wasted the land, and silted the rivers. Access to markets was restricted by a poor transportation system. The population suffered from malaria and parasitic diseases and was poorly educated for life in a modern industrial society. Electric power was extremely expensive and available only in the cities.

TVA was given a broad mandate to attack these problems through coordinated and integrated development of the river and improvement in agricultural and forestry methods. With regard to river development, navigation and flood control were given priority over power generation.

The major physical showpiece of TVA is the system of dams and reservoirs on the Tennessee River and its tributaries (figure 1). This system controls floods, maintains a 650-mile (1047 km) navigation channel, and generates the maximum amount of electricity consistent with the other primary functions. This was the first large-scale demonstration of the feasibility of multiple-purpose dams, a pioneer engineering effort. Within three months after passage of the Act, work began on Norris Dam. By 1945, 16 of the Valley's network of dams had been constructed.

The agency's efforts were not limited to the huge construction program which harnessed the river. Before 1933 ended, chemical engineers and agriculturalists had fertilizer products, land reclamation, and reforestation programs underway which led to the reclamation of the Valley's land and forests.

The flow of electricity to the Valley's farms and homes, however, started at a slower pace. Time was required to build the generating facilities and transmission lines. Tupelo, Mississippi, became TVA's first customer for electicity from Wilson Dam. Later in 1934 the first rural electric cooperative, in Alcorn County, Mississippi, also began receiving TVA power.

Power System

The Act of 1933, authorizing the sale of electricity for the benefit of the region's people, gave TVA custody of two government-owned electric power plants: Wilson Dam with a capacity of 184,000 kW and Wilson Steam Plant with a capacity of 63,000 kW. From this beginning, TVA has developed its power program to provide the Tennessee Valley region with an ample supply of electric power at low cost.

Today the TVA electric power system consists of nuclear, fossil, and hydroelectric generating plants. Their locations are shown on figure 1.

The system, the nation's largest with a capacity of 32,000 MW, now serves an 80,000-square-mile (207,000 square km) area in parts of seven states with an estimated population of 6.9 million. The system is interconnected with a grid of 17,000 miles (27,400 km) of high-voltage transmission lines.

Hydroelectric System

TVA has developed the Tennessee River system into one of the most completely harnessed of any of the world's major river systems. Today the TVA integrated water control system, illustrated on figure 1, is comprised of 32 major dams--9 on the main river and 23 on tributarties. Eight of the main river dams were constructed by TVA. Of the 23 major tributary dams, 14 are TVA-built, 3 were brought, and 6 on the Little Tennessee River are owned by the Aluminum Company of America. In addition to the 32 major dams, there are also a number of minor dams in the Valley water control system. The rated capacity of the hydroelectric system is about 3300 MW.

Ocoee No. 2 Hydro Project

One of these tributary plants, Ocoee No. 2, is of special interest. The total plant capacity of Ocoee No. 2 exceeds the upper limit of that which is generally defined as small hydro. However, its two units, each rated at 10,500 kW at 250-foot (76 m) head, fall into this category. This plant is of particular interest in several aspects, some having historical significance and the incorporation of unique features. Many of these features are well suited for consideration in scaling down to site-specific needs appropriate for a small hydro installation.

This project was constructed in 1912-1913 by the Eastern Tennessee Power Company for the generation of electric power. This represented a significant step in the development of hydroelectric technology. Ocoee No. 2, combined with the companion downstream-project Ocoee No. 1, produced the first electric service for Chattanooga, Tennessee. In 1939, it was acquired by the Tennessee Valley Authority and operated almost continuously until September 1976.

Figure 2 shows the general arrangement of the project. The project consists of a 450-foot-long (137 m) rockfilled timber crib dam with a maximum height of 30 feet (9.1 m); an 11-foot-high (3.4 m) by 14-foot-wide (4.3 m), 4.6-mile-long (7.4 km) wooden flume; a forebay siphon spillway section; an extension flume section; penstock intake; two 492-foot-long (150 m), 8.0-foot-diameter (2.4 m) steel penstocks, and power plant. The power plant houses two horizontal Francis double-runner turbines. The almost 5-mile-long (8 km) wooden flume is the largest such structure known to exist in this country, and one of the oldest.

The facility was designed by William P. Creager of the J. G. White Engineering Corporation. The creation of a minimum reservoir, high-head operation and the construction of a siphon spillway were both nationally significant advancements in technology. It is believed that the siphon spillway at Ocoee No. 2 was the first constructed in America. This siphon spillway performed in a very satisfactory manner in its role of regulating the water level in the forebay and flume extension during sudden interruptions of flow through the penstocks and units. By its nature, automatic and dependable, it avoided the problem of flume overflow with no need for installation and maintenance of mechanical regulating equipment. The eight siphon spillway units were extensively tested soon after the plant went into operation, and the results were written up in the May 16, 1914, issue of Engineering Record. Included in an editorial in this same issue is the statement, "Considering that the design of siphonic spillways is still in its infancy in this country, the efficiency obtained is gratifying."

Water is diverted by the dam to the flume intake (figure 3). The flume intake is a 16-foot-high (4.9 m), 30-foot-wide (9.1 m) reinforceed concrete structure located on the right end of the diversion dam. The top is 1 foot 3 inches (38 cm) below the crest of the crib dam and the opening is provided with iron racks to prevent floating trash from entering the flume. The water admitted to the flume is controlled by a steel taintor gate that is 14 feet 1/2-inch wide (4.3 m) and 10 feet 9-3/4 inches high (3.3 m). This gate was operated solely by means of a handwheel until 1956 when it was motorized by TVA to permit remote operation from the Ocoee No. 2 powerhouse. Operation of the gate by the handwheel is still possible.

The flume itself is a partially covered wooden trough designed for a waterway 14 feet 2 inches wide(4.3 m) and 9 feet 9 inches deep (3.0 m) when carrying the maximum required capacity of 1200 cubic feet per second (34.0 cubic meters per second). The average slope is 0.064, but this slope is increased on the curves and reduced on the tangents. The drop in the flume for its entire length is 17 feet 6 inches (5.3 m).

The flume box was originally constructed of horizontal planking with vertical posts. Each post, or "bent," consisted of one 8-inch (20 cm) by 12-inch (30 cm) column on either side of the box, joined by two 3-inch (7.5 cm) by 10-inch (26 cm) collar beams across the top and two 4-inch (10 cm) by 10-inch (26 cm) sills across the bottom. Galvanized steel yokes were added in 1927 to replace the original timber columns and sill beams. The interior of the flume is lined with 3-inch (30 cm) long leaf yellow pine timber. Between 1934 and 1944, the entire exterior of the flume was reinforced with vertical planking and horizontal struts with a layer of burlap between the two.

The flume was originally supported by 42 timber trestles as it crossed the various small ravines. The wooden trestles were replaced with concrete structures around 1927. Five of the ravines, however, were too large for this kind of support and steel trestles were used. The steel trestles vary in height from 70 to 150 feet (21.3 to 45.7 m) and in length from 132 to 288 feet (40.2 to 87.8 m), the largest having a height above the valley floor of 150 feet (45.7 m) and in length of 288 feet (87.8 m).

The original power equipment consisted of two 10,000 horsepower (7460 kW) turbines running at 360 revolutions per minute, built in 1912 and furnished by the I. P. Morris Company of Philadelphia, Pennsylvania. The turbines were guaranteed to deliver 10,000 horsepower (7460 kW) at 94 percent efficiency. The turbines are inward flow, double discharge, reaction type, commonly known as "high head Francis." The turbine shafts are horizontal. In 1924, new draft tubes were installed on unit 2, improving the efficiency of the flow of water and increasing the horsepower rating to 15,000 (11,190 kW). Unit 1 was never altered and remains at its original rating of 10,000 horsepower (7460 kW).

Each turbine is directly connected to one of the two main generating units. Each of these units consisted of a 9375-kilovoltamperes (kVA), 6600-volt, 3-phase, 60-cycle alternator, running at 360 rpm. (At a later date, the generator ratings were increased by the manufacturers to 11,750 kVA, and in May 1953 unit 1 was rewound to this higher rating.) A 120-kilowatt direct current exciter is connected to each generator shaft. A 9000-kVA, 3-phase, 60-cycle transformer accompanies each generator. These transformers originally raised the potential from 6600 volts to either 66,000 or 120,000 volts. All power is now conducted at 69,000 volts. A third 8500 kVA transformer was added and all three connected in parallel to operate from the two generating units. All three transformers are used in normal operation, but the system is capable of running on only two if one is removed for servicing. In 1951, the three transformer units were modified for outdoor use and moved to the switchyard adjacent to the powerhouse.

Difficulties have been experienced at Ocoee No. 2 with short wheel life, the result of high acid and silt content in the water. Although much of this area is now heavily wooded, in 1912 there were 28 square miles (72.5 square kilometers) of denuded land caused by fumes from copper smelting plants in that vicinity, causing heavy erosion. Apparently, these problems were anticipated by the designer of the plant because the original water wheels were made of bronze. The bronze water wheels had to be replaced in less than 2-1/2 years, however, and since that time various other metals such as cast iron, white iron, welded steel, chrome nickel, and rewelded steel have been used, with no better results. Recently improved water conditions and the use of stainless steel have greatly extended the life of the wheels.

For many years following the 1939 acquisition by TVA, this project was a reliable source of low-cost energy. However, with the passage of time it became apparent that deterioration of the steel and concrete trestles which support portions of the flume was progressing to a point where major repairs would be mandatory. The downstream face of the rockfilled timber crib dam had also deteriorated.

Maintenance of the wood flume itself required a full-time carpenter crew. For access to areas requiring repair, the flume maintenance crew utilized a rail-mounted car which traveled along the top of the flume. Primarily because of concern over safety hazards to the repair crew posed by the worsening condition of the trestles, power generation was suspended in 1976.

To determine future usefulness of the plant, feasibility studies were made which ranged from plant retirement to replacement. The worsening energy situation and attractiveness of a renewable energy source made rehabilitation an economical alternative.

Originally TVA planned only to replace five badly deteriorated steel trestles and one concrete trestle, their concrete piers, and approximately 1800 feet (549 m) of the wooden flume over the replaced trestles (see figure 4) and strengthen the wood crib dam (see figure 3). However, when the operation of the project was suspended, the wooden flume deteriorated rapidly and additional study resulted in the decision to replace the entire 4.6-mile (7.4 km) flume.

A number of different alternatives for replacing the wooden flume were studied. Cost estimates were made for steel, concrete, and fiberglass flumes and for tunneling through the mountain. All of these were significantly more costly than replacement of the flume with wood. Therefore, considering the historical significance of this project, the decision was made to construct a new flume similar to the old one. The original flume had been constructed primarily of wood. The wood main framing bents had been replaced with galvanized steel in the 1920s. It was estimated that about 60 percent of the steel would be reusable with cleaning and regalvanizing. Bidders on the construction contract were given the option of salvaging the reusable steel or furnishing all new

galvanized steel. The successful bidder chose to use all new steel. The new wooden flume, a typical section of which is shown in figure 5, will be constructed of lumber and treated with the wood preservative chromated copper arsenate (CCA). The flume is supported on concrete grade beams. More than 4 million board feet (9440 m^3) of lumber will be required in rebuilding the flume. The maintenance rail car, which operates on top of the flume and is one of the unique features of the Ocoee No. 2 project, will remain an integral part of the flume.

As mentioned earlier, the downstream face of the rockfilled timber crib dam shown in figure 3 was badly deteriorated, and the dam needed to be strengthened or replaced. The dam was strengthened by placing rockfill against the downstream face covered with an approximate 8-foot (2.4 m) layer of roller-compacted concrete. Drainpipes were installed, extending from the rockfill to the downstream face of the roller compacted concrete, providing internal drainage. Strengthening of the dam was not a part of the contract and was constructed by TVA forces.

As noted earlier, corrosion is a problem; thus, both penstocks were severely pitted at the time the rehabilitation decision was made. Corrosion had eaten entirely through the steel lining at a number of localized spots. During the course of the rehabilitation program, extensive segments of these penstocks were relined with steel plates by TVA forces.

Upon completion of rehabilitation later this year, Ocoee No. 2 is expected to resume its role in providing the TVA system a reliable source of clean, low-cost electrical energy. To TVA's knowledge, there is no operating plant like Ocoee No. 2 in any power system.

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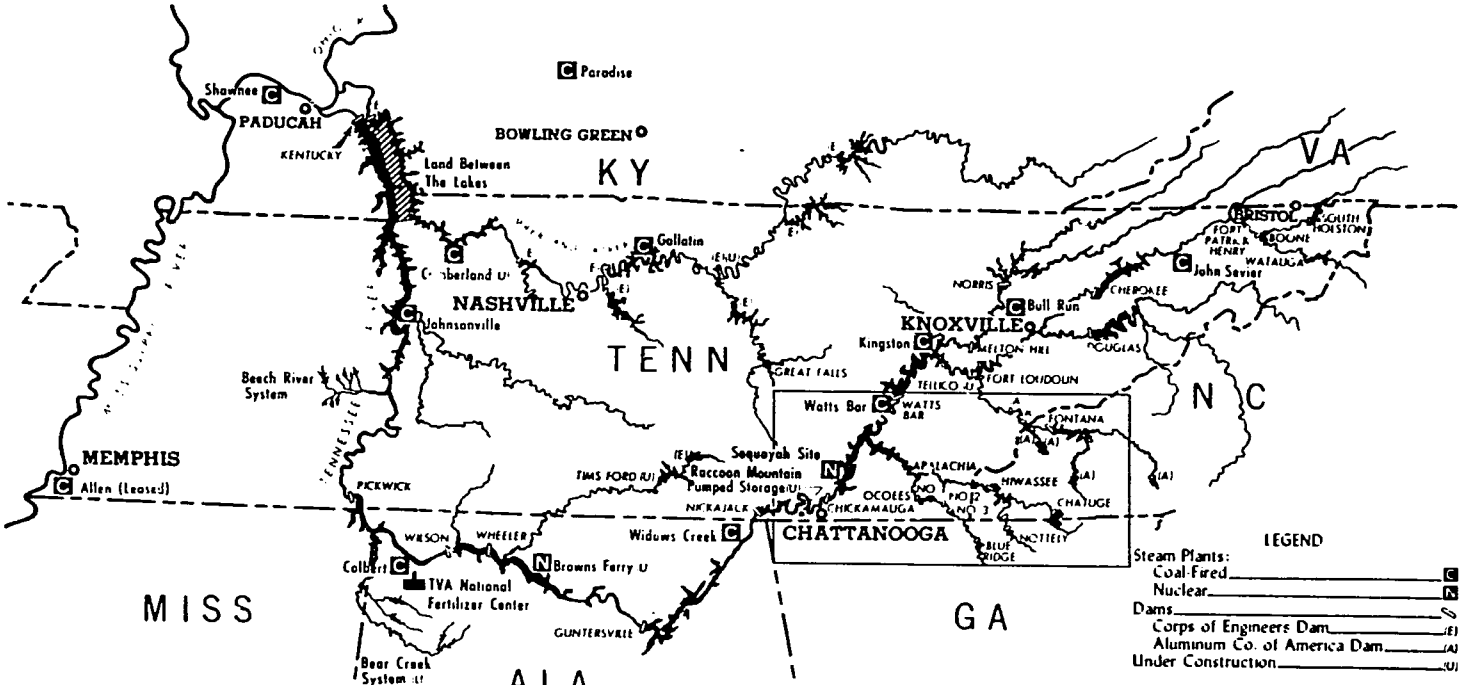
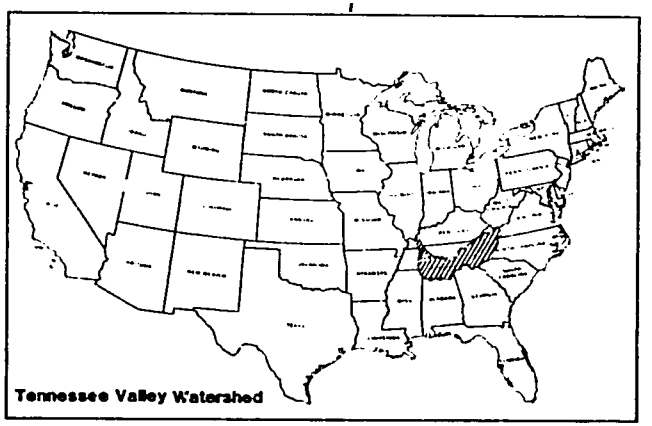
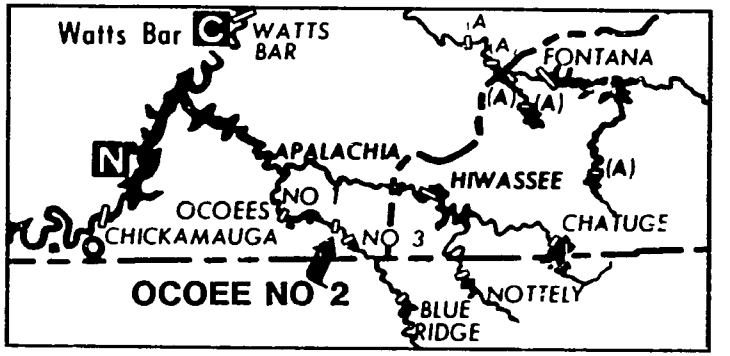


Figure 1 Tennessee Valley Region





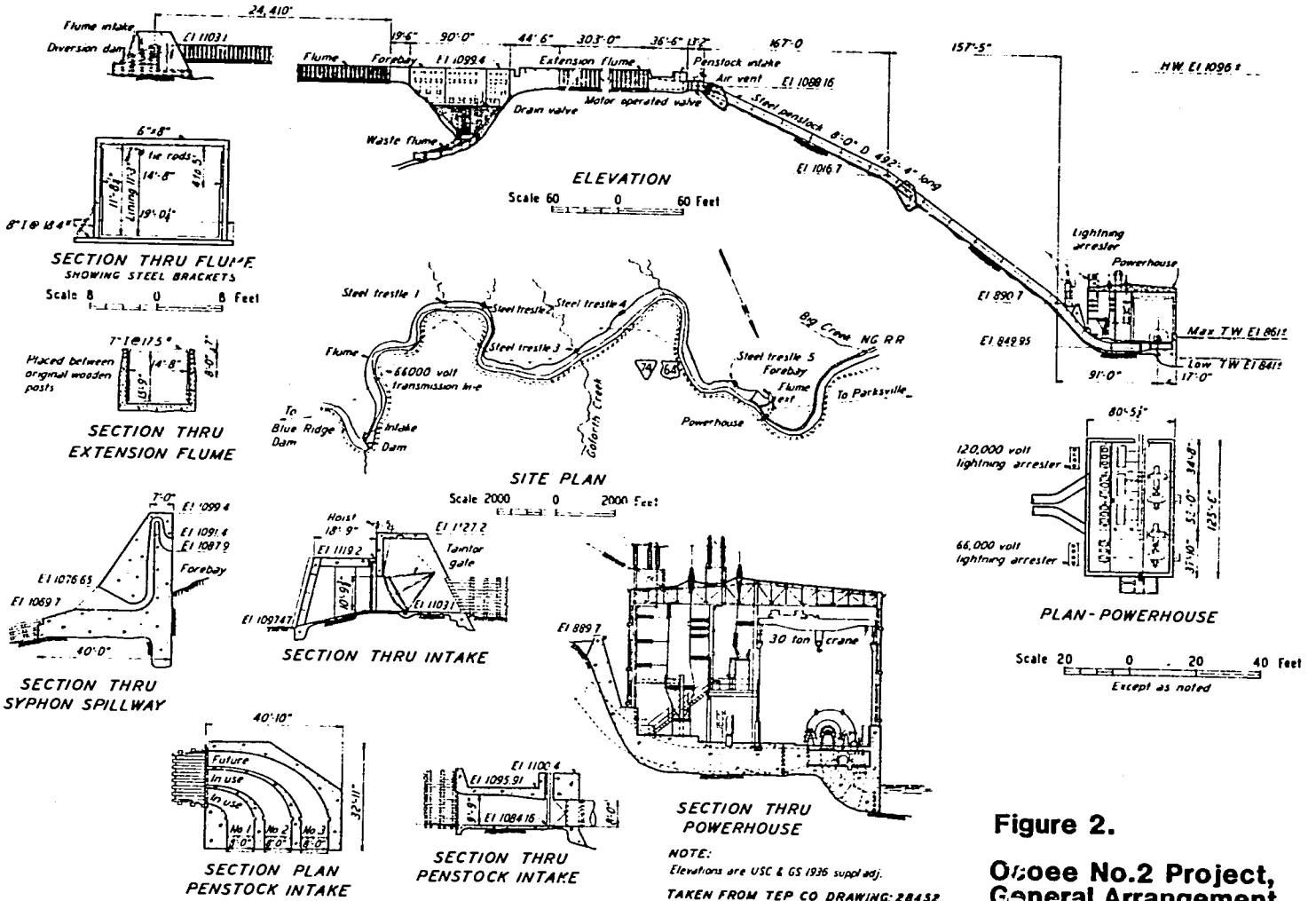


Figure 2.

Ocoee No.2 Project, General Arrangement

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Figure 4. Existing Flume over Steel Trestle

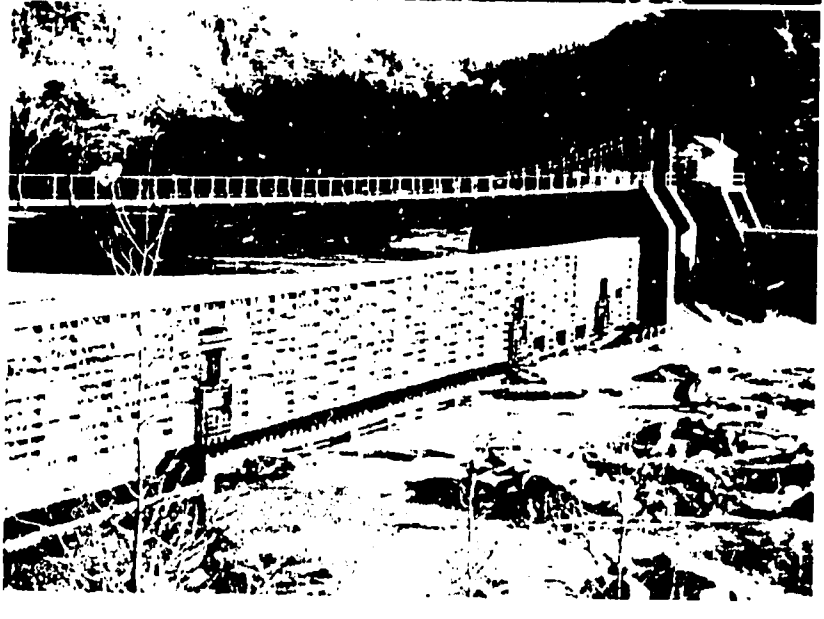

Figure 3. Rock-filled Timber Crib Dam

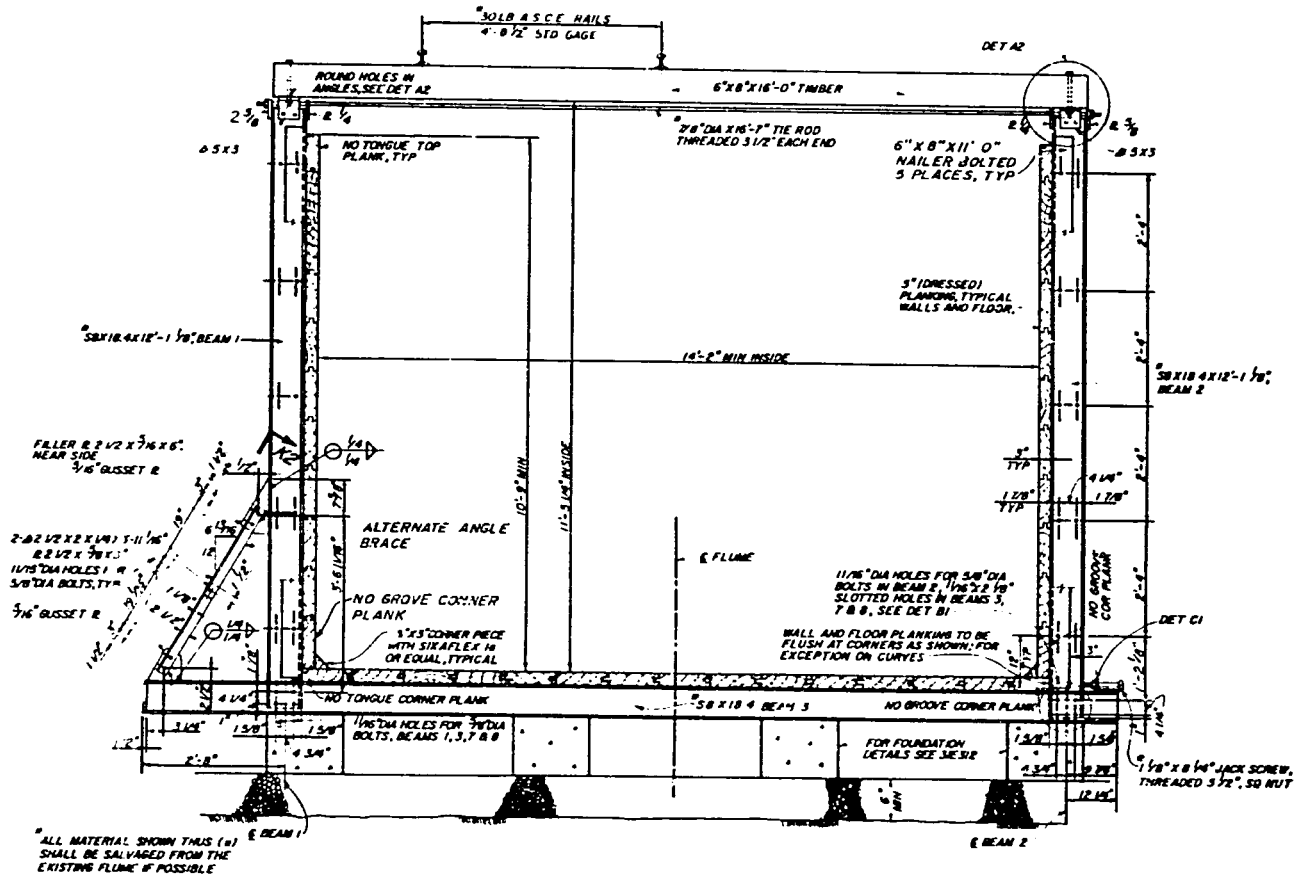

Figure 5. Typical Section of Rebuilt Flume

OPPORTUNITIES AND ISSUES IN SMALL HYDROPOWER DEVELOPMENT: AN OVERVIEW

by

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Paper presented at the regional workshop
"Small Hydropower in Africa"

Mbabane, Swaziland
June 20-24, 1983

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Biographical Sketch

Dr. Maurice L. Albertson is a professor of civil engineering at the Colorado State University at Fort Collins. He received his B.S. in civil engineering from Iowa State University in 1941 and his M.S. and Ph.D. from the University of Iowa in 1941 and 1948, respectively. In 1954 he received a Doctor of Physical Sciences from the University of Grenoble in France.

Dr. Albertson has held education, research and consultancy positions in the fields of fluid mechanics, hydraulic engineering, and water resource development over a span of 40 years. Much of this work has been with the Tennessee Valley Authority, the Iowa Institute of Hydraulic Research, the U.S. Geological Survey, the World Bank, and the United Nations Development Program. He has extensive experience in design and development of hydraulic structures, energy dissipation, alluvial hydraulics, irrigation and drainage, hydraulic machinery, and small-scale hydropower.

Dr. Albertson has written and published four books and approximately 100 papers dealing with topics related to engineering, education, research development and administration, the principles of international development, and the Peace Corps. He recently received three honorary degrees: a Doctor of Laws from the University of Peshawar in Pakistan, a Doctor of Technology from the Asian Institute of Technology in Bangkok, Thailand, and a Doctor of Humane Letters from the University of Lowell in Massachusetts.

OPPORTUNITIES AND ISSUES IN SMALL HYDROPOWER DEVELOPMENT: AN OVERVIEW

Small hydropower is a technology with many and varied characteristics, definitions, and issues offering a wide range of energy opportunities and solutions. A small hydropower plant can generate the equivalent of 50 or fewer watts of power, or it can provide up to 50 million watts of power, by some definitions. It can be used to provide mechanical or electrical power. It can draw its energy from the force of water moving in a river with no perceptible drop, or it can come from water falling hundreds of meters. Small hydropower may be generated from water stored behind dams or it can be taken from streams or rivers without the use of dams. It can provide power for a large transmission network or it can operate as a stand-alone plant serving an isolated demand center.

Similarly, a wide range of construction techniques and uses of small hydropower are possible, ranging from wooden waterwheels for simple mechanical applications to large hydroelectric systems feeding power to modern homes and industries. In between are many different types and sizes of hydropower installations, each with its own special characteristics.

In short, few generalities can be made on the subject of small hydropower, other than to say that technical specifications, costs, and applications of small hydropower tend to be very case-specific. A second general statement, which is of particular importance in the context of small hydropower in the developing countries, is that technical aspects of site development--the design, the choice of construction materials and equipment, and the scale of development—cannot be divorced from the human and economic environment in which the site exists. Issues concerning the prevailing quantitative and qualitative energy needs, the ability of the users to purchase energy, the costs of alternative energy systems, the competing requirements for water, and the means available to finance and manage projects are fundamentally related to the technical approach to development that should be used.

Indeed, one of the greatest advantages of small hydropower as an energy source is that a broad range of choices are available to the user of this technology in approaching the development of most sites. Depending on the nature of the energy requirements, a site can be developed to provide a limited source of energy for a small village, or it can be developed to its full energy potential to serve a larger power network. Moreover, a site can be developed in stages, to meet changing energy requirements. Depending on the needs for water at the site, it can also be developed in conjunction with irrigation and water supply systems, flood and sediment control, water recreation facilities, navigation systems, or fish-breeding.

History of Small Hydropower Development and Use

Small hydropower has been used to do man's work for thousands of years. Waterwheels used for grinding grain and for raising water to irrigate fields and provide water for livestock and homes first appeared in Egypt, the Levant, India, and China several centuries before the birth of Christ. Around 200 A.D. the Romans developed vertical overshot waterwheels with gears, which permitted a variation of speeds to perform different tasks. These and later improvements to waterwheels over the centuries gave man a more efficient means to saw lumber, to operate spinning wheels and looms in the

textile industry, to cut stone, to drive trip hammers, and to make wine, among other daily chores. By the fourteenth century, there were tens of thousands of waterwheels throughout Europe.

It was during the nineteenth century, however, that small hydropower became not only a source of mechanical power, but also a source of electrical power. With the invention of the turbine in 1820 by the French engineer Benoit Fourneyron, followed by the development of the reaction turbine in 1847 by Francis in Massachusetts, and the impulse turbine in 1880 by Pelton in California, the stage was set for the linkage of turbines with generators to produce electricity in Wisconsin, in 1882. The final major step was the development of alternating current by Westinghouse at Niagara Falls in 1901.

Technology of Small Hydropower

Hydropower is created by the force of falling water on a turbine. The turbine uses the kinetic and potential energy in water to cause its rotation and thereby to create mechanical energy. The power produced by a turbine is directly proportional to the product of the head and the discharge—that is, P (power) is directly proportional to H (head) x Q (flow). This means that a high head and low discharge can produce the same power as a low head and high discharge.

Site assessment. An analysis must first be performed to determine whether the water supply and head characteristics of the site are adequate to generate power. Hydrologic analysis is used to assess rainfall, groundwater, and streamflow. Topographic information is collected to determine the available head and to establish possible design parameters for the scheme. From this information, the power potential of the site can be calculated. A great deal of time and effort, requiring highly specialized expertise, may be necessary to collect and analyze this information. This is especially difficult to do in developing nations, where streamflow and topographical data is often scarce. Project costs can rise rapidly when expensive consultancy services are employed to collect and analyze data on many small, scattered sites. However, methods exist to perform site assessment at minimum cost, as we shall learn on Tuesday.

Decisions on plant size and the type of equipment to be used may not be made until an assessment of the energy requirements is made. The objective of this exercise is to ascertain what level of development is warranted in view of the demand characteristics. A knowledge of how the energy is to be used is a critical part of the planning process. End uses must be identified to ensure the plant has a sound economic basis, and a distribution plan must be developed to serve these needs. We will hear more on this topic on Tuesday, but one must not overlook the importance of load analysis and planning in determining the size and type of project to build. If the plant can be readily connected to a larger power network and the demand served by that network justifies full development, then the project should be designed to capture all of the available waterpower at the site. If the site is in an isolated setting, then other issues, involving local participation in design and construction, the local users' ability to pay for the energy and possibly to manage the plant, and present and future demand circumstances at the site - including the possible extension of the grid to the area in the future - must be taken into account. You will hear about a case study later today where local participation was the key to successful planning and implementation of such projects. Let it suffice to say that the size and type of the plant depends not only on the technical characteristics of the site, but non-technical characteristics as well.

Civil design. In a typical large hydropower station, water is fed to the turbine through a penstock from a dam, which holds back the water to both control it and to

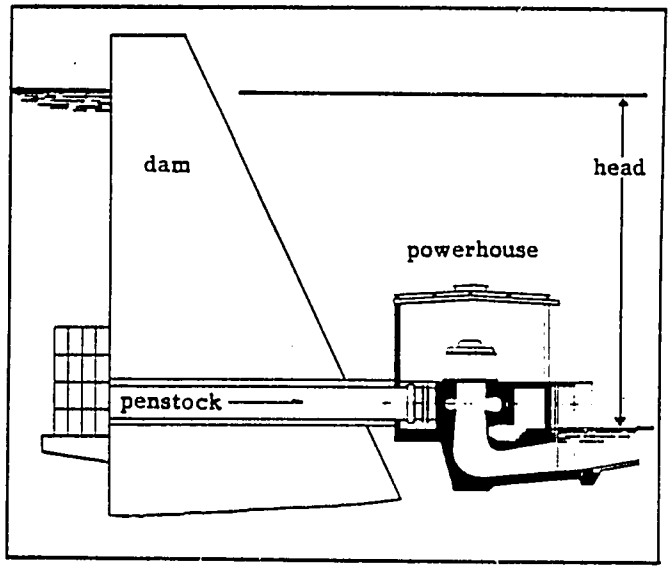

Figure 1. Typical large hydropower scheme (1).

store it for future use. The head on the turbine is the difference in elevation between the surfaces of the headwater and the tailwater (see Fig. 1).

The simplest arrangement for a small hydropower station is a "run-of-river" plant, which has no storage dam. The water is removed from a river or stream by a small diversion structure and delivered to a turbine downstream, where it rejoins the natural flow of water. The water may be delivered to the turbine by various means. In the scheme shown in Fig. 2, the water enters a canal constructed above the river and is carried along the hillside at a very gradual gradient to a point directly above the turbine. The water is then fed to the turbine through a penstock. Over more difficult terrain, where canals are not possible, a low-pressure pipe or flume may be used. Alternatively, if the river flows down a steep gradient, the water may be diverted directly into the penstock. In any case, the objective is to concentrate the head over the shortest possible distance to reduce the length, hence the cost, of the penstock.

The plant may also have a forebay and a draft tube, each of which serves an important function to increase the efficiency of the plant. The forebay helps to counter minor fluctuations in the amount of water available to the turbine by acting as a short-term water storage device. More importantly, it acts as a settling tank to remove rocks and sediment from the water before entering the penstock. The draft tube helps to convert the kinetic energy remaining in the water after it leaves the turbine into useful energy. This reduces the pressure on the downstream side of the turbine runner. Although the forebay and draft tube are desirable and increase the plant's efficiency, they also increase the cost and are not absolutely essential for plant operation.

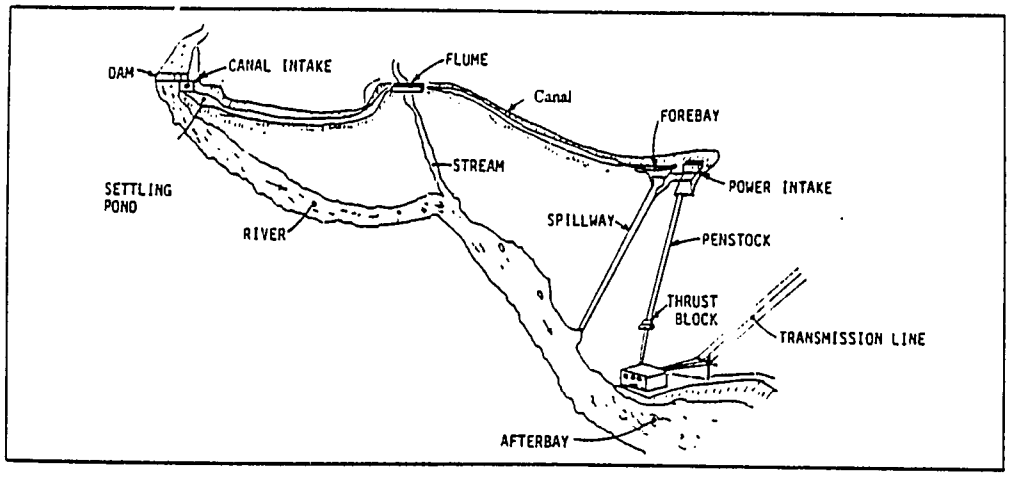

Figure 2. Typical run-of-river small hydropower scheme (2).

Civil design may be quite different for micro-hydropower plants then for plants at the larger end of the small hydropower scale. Later this week we will learn from two perspectives what these differences involve. Certain standards must be followed with larger plants to ensure that structures are adequate to capture sufficient flow and head and to withstand the higher pressures of potentially large volumes of water falling greater distances. With micro-hydro schemes, cost considerations dictate that simple structures be used. However, the opportunities to improvise are greater with micro-hydro plants than with larger plants. We shall look forward to hearing what these opportunities are.

Turbo-generating equipment. In general, a turbine, a generator, and a governor are required to produce electrical energy from water. If requirements for power may be met by means of mechanical energy, then neither the generator nor the governor are necessary. The turbine can drive machinery directly, or belts may be used to operate several machines off an intermediate shaft. A generator can be added to provide AC or DC electrical energy. For very small plants, these can be simple automobile or airplane alternators. For larger plants, a wide range of standard generator sizes are available virtually anywhere in the world.

Governors, used to regulate the turbine speed, are also generally required for electrical applications in order to maintain a constant frequency in the electricity produced. Frequency control is not always needed, however. For very small plants where lighting may be the only electrical use, fluctuations in the energy output would not be of any serious consequence, other than to dim or brighten light bulbs. With DC power, frequency is not a concern. Even where frequency regulation is necessary - as with most AC electrical motors and appliances - an electronic load controller can be used instead of a governor to regulate energy levels feeding various end-use machinery. These devices are considerably less costly than governors.

The most important component, of course, is the turbine. Turbines are generally divided into two types: impulse turbines and reaction turbines.

Impulse turbines use the velocity of the water to drive the turbine runner; they are open to atmospheric pressure and generally operate best with high heads. A good example of an impulse turbine is the Pelton turbine.

Reaction turbines are generally selected to serve lower-head sites and thus require a large volume of water to operate. Reaction turbines operate on the principle of pressure rather than velocity, and turn from the force of water flowing through the blades rather than from the water striking the blades. A good example of a reaction turbine is the Francis turbine.

A great deal more can be said about the different types of turbines and their capabilities, and fortunately we will have the opportunity to hear more about them and other equipment used in converting waterpower to mechanical and electrical energy on Tuesday. It is essential that the proper equipment is selected, and we will learn what specifications are necessary to ensure that the equipment procured meets the site conditions. We will also learn more about experience with local fabrication of turbo-generating equipment for micro-hydro plants and what is involved there. Fig. 3 provides, at a glance, the major types of turbines and their typical operating ranges.

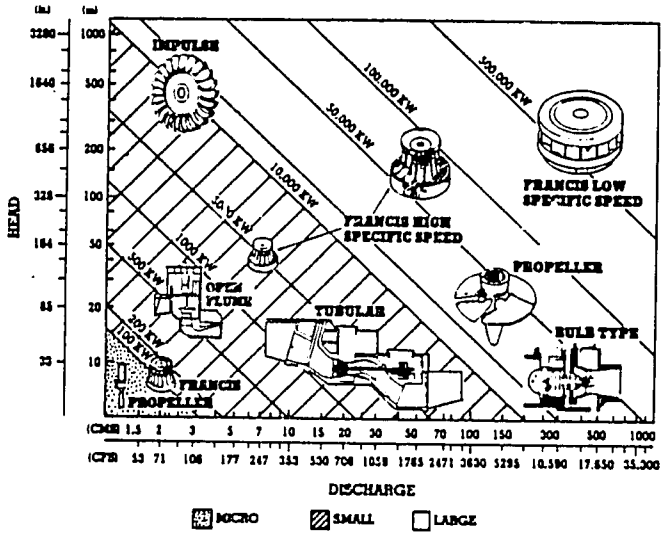

Figure 3. Typical operating ranges for various turbines (3).

Economics and Financing of Small Hydropower Projects

The economic and financial consequences of small hydropower development are found by assessing the net value of costs and benefits arising from the investment in projects. Costs are generally shown to include:

- capital costs, including planning and design, materials, labor, equipment, construction period interest, and contingencies.
- recurring costs, including operation and maintenance costs, plant replacement, and financing costs.

- indirect costs, including environmental costs, and the cost of resettling displaced populations if a reservoir is required.

Benefits arising from hydropower projects may vary according to the purposes of the project and the level of analysis. In assessing the economic consequences, they are frequently shown as cost savings to the producer or the consumer from the displacement of energy from other sources, such as kerosene and diesel fuel. If projects provide additional capacity to serve new loads, revenues from the sale of power may be counted as benefits to the producer. Indirect benefits may arise when projects serve either purpose. The cheaper energy, in the former case, may result in energy demand growth, leading to expanded economic activity. Additions to capacity may yield income in the form of cash, goods, or leisure to consumers whose productivity and well-being are improved from the use of a more efficient energy source. In conducting financial analysis of projects, benefits are shown as revenues from the sale of electricity or mechanical power.

Costs and benefits vary widely from case to case. Experience in developing nations with small hydropower has shown that for two sites of similar capacity, capital costs per installed kW may vary by a factor of five or more, depending on the circumstances. Similarly, costs (per kWh), which reflect the total benefits of the project, are dependent on how well the plant functions to meet energy demand. These issues will be examined in greater detail on Thursday.

Financial resources available for small hydropower development may also depend on the purpose of the plant, and the results of feasibility analyses. In the United States, financing is usually raised from private sources. In the developing countries, financing is most often sought from national or international financial institutions. Government institutions play an important role in attracting financial resources to support hydropower development, although local and private financing may also play an important role in the development of smaller projects. On Friday we will hear from representatives of financial institutions who will discuss the criteria which projects must meet in order to receive support.

Management of Small Hydropower Projects

Although a national government may play an important role in helping to provide the financial means of developing projects, the responsibility for implementation and management may rest more with regional, local, or private resources. Small hydropower development can be undertaken with both centralized and decentralized approaches to management. Larger projects to feed power into a power network are primarily the responsibility of centralized agencies, although regional and local participation in many of the tasks and responsibilities is possible and desirable. This was the case in the Philippines, where electric cooperatives have successfully implemented a number of projects under the guidance of a nationally-based program.

As plant capacity becomes smaller and projects become more remote from government centers, administrative cost burdens of implementing many small and scattered projects makes centralized management less tenable. Here local participation is required to reduce costs and ensure the projects will be designed and implemented to serve local needs and conditions, not some irrelevant industrial standard. China demonstrated clearly that tens of thousands of small hydropower plants could be built by local initative alone. Stimulated by leadership to be self-reliant, local populations developed various types of turbines and generating equipment throughout China. Recent

developments in Pakistan and Nepal have also shown that local initiative, with some outside assistance, can provide the necessary equipment, labor and materials required for hydropower development.

As local people build the required equipment and facilities, they also gain the skills necessary to service and maintain the equipment. Such an accomplishment leads local people to believe that they are able to solve other problems through local initiative and local resources.

During the week we will be learning more about the achievements of Nepal and Pakistan, and on Thursday we will take a closer look at how local, regional, and national resources may be applied to the management of small hydropower projects.

Different Options, with Different Problems and Issues

The foregoing discussion of the technology, economics, and management of small hydropower familiarizes the reader with the essential characteristics of small hydropower development. It has also left the reader with the impression that each aspect—resource assessment, civil design, turbo-generating equipment, economic and financial planning, and management—may be approached differently, depending on the purpose of the project and the site circumstances.

There is a basic trade-off in system performance on one hand and system cost on the other. But conditions do not always justify the maximization of energy potential of sites, particularly for small projects serving isolated loads. For example, mechanical power may be sufficient to serve the needs of a community, permitting costs for the generator, control equipment, and distribution system to be foregone. Similarly, water impoundment structures may be unnecessary where energy needs are modest. Locally fabricated turbines may replace imported custom-made turbines, which could result in lower system efficiency, but also lower costs. As described earlier, earth canals may be dug to reduce penstock costs. Water losses may result, but higher penstock costs may make the life-cycle cost of the plant unaffordable to a small rural community. Plant designs may be based on minimum flows instead of more exacting flow characteristics, since exhaustive hydrologic studies to match plant specifications with precisely measured flow parameters take time and expertise, which may not be worth the cost.

In each case, the project may be designed in such a way that incremental investment in plant can be undertaken at a future time to increase efficiency and raise output, if demand circumstances change during the life of the project, which is likely. Simple diversion weirs may be replaced by impoundment dams to capture more water. Earth canals may be lined with concrete or masonry rip-rap to eliminate water seepage. Additional turbines may be added to receive the increased supply of water. Generators and distribution or transmission facilities may be added to provide electrical power. While it may be the responsibility of local communities to develop and manage small hydropower projects initially, it should be the responsibility of centralized agencies to forecast future energy requirements—for example, when the power grid is extended to the region--and to develop plans for upgrading project designs accordingly.

Conclusion

Small hydropower can be developed to serve two fundamental policy objectives:

- national or regional energy supply development; or
- rural development of remote, isolated communities.

Intermediate objectives may also be served by the utilization of small hydropower to achieve these two basic objectives, including:

- rural electrification; and
- fuel cost and foreign exchange savings.

Each objective implies a different technological and institutional approach, in which a wide range of technical standards may be applied to achieve different results. Problems tend to arise when the same standards are applied to both project types.

The underlying objective of any energy development program should be to provide the proper form of energy at the time it is required. Among the criteria used to determine whether the energy source is appropriate is its cost. A beautifully engineered project looses its lustre if consumers are unable to pay for the cost of energy it produces. Undoubtedly, the cost constraints associated with small hydropower projects in isolated rural settings will be greater than those confronting a project serving a large power network. In such cases, experience has shown that small local communities can be very successful in adapting modern small hydropower technology to meet their needs. With some initial guidance and assistance, local populations have proven extremely resourceful in providing their own energy means through waterpower development. Not only are these systems affordable and manageable, but an enormous sense of pride and satisfaction accompanies this development, and leads local people to believe that they are able to solve other problems with local initiative as well.

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PRELIMINARY LAYOUT AND DESIGN OF CIVIL WORKS

Allen R. Inversin

Prepared for the Small Hydropower in Africa workshop held June 20-24 in Mbabane, Swaziland

INTRODUCTION

The first step in developing the hydropower potential of an area is locating a site where sufficient flow and head are available. The next step in the preliminary design of a hydropower scheme is laying out the civil works, the structures which are necessary in order to convey the water from a stream to the turbine in sufficient quantity to generate the power required and to accomplish this within the constraints set by the physical conditions at the site and the financial resources, manpower, skills, and expertise available for this task.

The first portion of this paper will provide the necessary information so that a designer of a small hydropower scheme can decide which components are necessary for the most efficient design of a specific project under consideration. In order to attain this objective, this section will:

- o describe briefly each component;
- o explain the function(s) it serves, how it serves these, and its possible interrelationship with other components; and
- o identify those factors which determine under what circumstances that component should be included as part of an overall scheme.

The second portion will, through case studies, present illustrative examples of the layout of several small hydropower schemes. These are plants in the lower portion of the small hydropower range. Other papers will present examples of layouts for larger hydropower schemes.

OVERVIEW

Once a site has been found where sufficient head and flow are available for the generation of power, the principal task is to convey this water to the turbine with minimum loss of energy. The obvious solution is to use a pipe between the source of the water and the turbine (Fig. 1). Though possible, the layout of a hydro scheme is rarely as straightforward as this. More frequently, the drop of water is not concentrated at a single waterfall but is found over a significant distance (Fig. 2). Since a lengthy and costly pipe would be required, there is a need to look into alternative approaches to convey water over relatively long distances.

In addition to a pipe or other conveyance structures, other components must be considered. For example, the source of water is usually not a pond but, more often, a stream whose discharge may vary significantly. There is therefore a need for a diversion structure to ensure adequate flow for power generation during the dry season on the one hand but which can withstand flood flows on the other. In addition, suspended bed load and debris could adversely affect the operation of a plant and, therefore, a properly designed intake structure is necessary to remove as much of this as necessary.

Fig. 3 shows how the more typical site shown in the preceding figure might be developed. Included in this figure are all the major components which might be incorporated in a hydropower scheme—whether micro, mini, small, or large. Each of these fulfills a specific purpose. At some sites, it is possible that all these components might be incorporated, whereas at others, some of these may not be necessary. Though designs of individual components might be standardized, there is no single standard design to suit all sites. If more components are included than are absolutely required, costs are unnecessarily increased and new problems might be introduced. If fewer components than necessary are included, the problems which have been left unaddressed by omitting these components, as well as the accompanying inefficiencies, might again lead to increased cost of implementation, operation, and maintenance.

The major arguments against the appropriateness of small hydropower schemes are often the high costs associated with such schemes, the relatively large efforts required in their implementation, and the continuing operational and maintenance problems which have to be met on a regular basis. If these arguments are to be countered so that small hydropower will be more widely accepted as an appropriate technology, the proper choice of which components to be incorporated at specific sites is crucial.

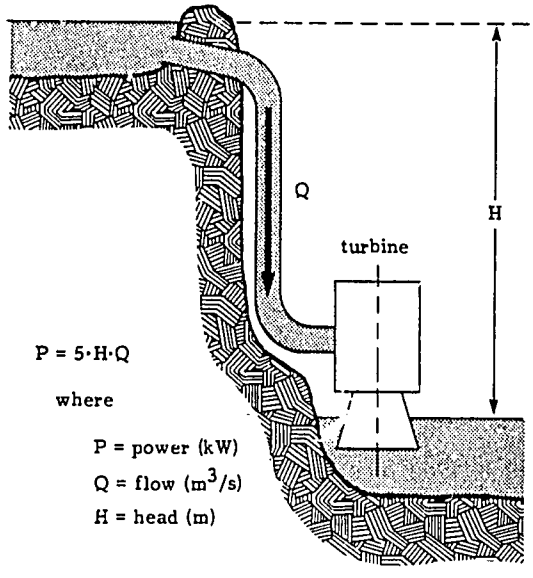

Fig. 1. Basic power equation to predict the power potential of a site (assuming 50% overall efficiency).

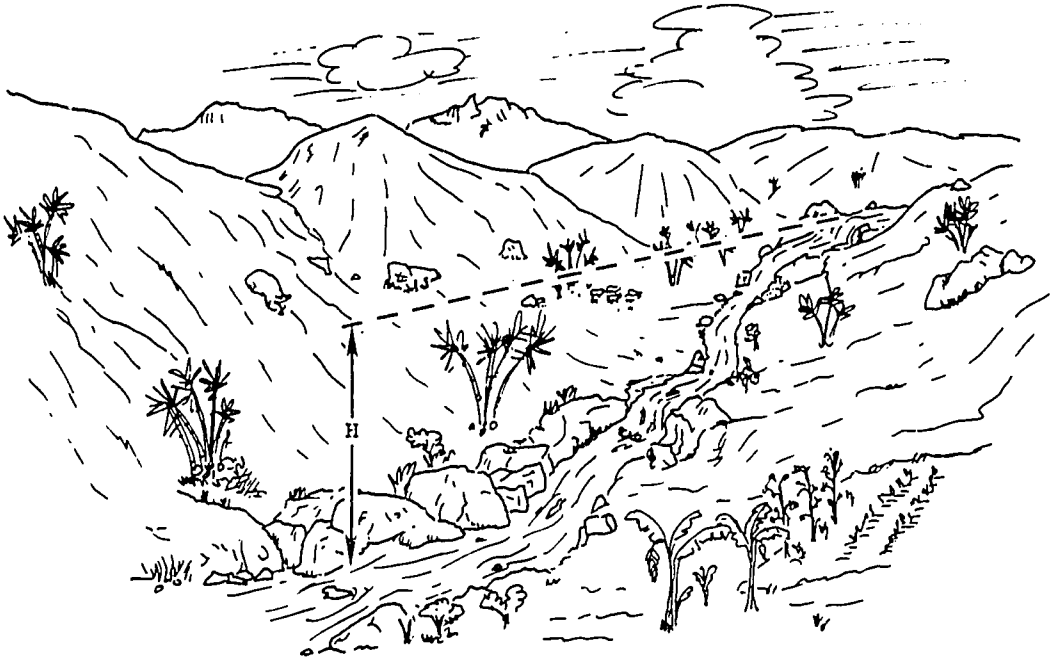

Fig. 2. A typical countryside where a small hydropower plant might be installed.

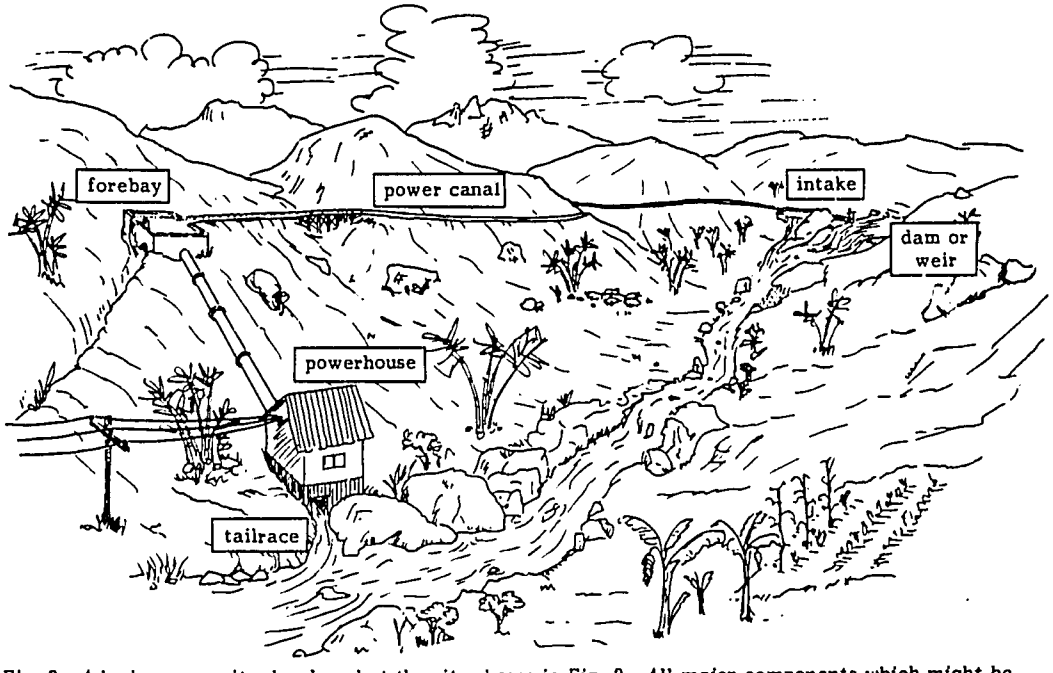

Fig. 3. A hydropower site developed at the site shown in Fig. 2. All major components which might be included are shown here.

BASIC COMPONENTS

Dam or weir

It is generally accepted that a dam is an intrinsic part of any hydropower scheme. This is indeed frequently the case with large hydroelectric projects around the world. But a dam, as with any component of a hydropower scheme, serves specific functions and it is necessary to first become familiar with these functions to determine if a dam should actually be included at all. Appropriate technical expertise is required in the design and construction of a dam. Including such a structure when it is not essential not only requires access to this expertise but also results in increased cost of the project, a longer period before the system is operational, and possibly increased problems with its maintenance. On the other hand, not including a dam under circumstances when it would be advisable may mean inadequate potential for generating the required power when needed.

The generation of hydropower requires adequate head and flow. In cases when either of these quantities is not always available when needed, a dam might be incorporated in the design. In cases when these are adequate, only a low dam or weir might then be used. This would then serve simply to divert a portion of the flow into the intake.

Let us first review how a dam might fulfill each of these three functions.

The first potential function of a dam is to increase the head available for the generation of power. With larger streamflows, where a low-head site is adequate, a dam might be incorporated since even a low dam could significantly increase the head, and therefore power potential, at that site. With higher head sites, an obvious approach to developing these sites is to utilize a penstock pipe to convey the water the entire distance. However, where the terrain is relatively flat, it might not be economically viable to exploit the potential power in a stream because the length and diameter of the penstock necessary to obtain the required head and power would be too great (Fig. 4a). This may even be true in fairly hilly terrain but where the gradient or slope of the stream itself is small. However, especially in this latter case, the topography of the area might lend itself to the construction of a dam (Fig. 4b). In this case, all the head would then be concentrated in the vicinity of the dam and powerhouse and the dimensions and cost of the penstock would be markedly reduced. However, except in cases where the dam is also used to store water (see below), a dam is rarely constructed to develop the necessary head at a higher head small hydro site since it can involve significant cost and require considerable additional effort to construct. When storage is not required, a more common solution to increasing head is to construct a power conduit (Fig. 4c). If the terrain is suitable, this will often be a more cost-effective means of increasing head than by either constructing a dam or utilizing a long penstock and will be described later.

A second function of dams is to provide for storage of water. It is more frequently the case at small hydro sites that adequate head is available but that the flow is insufficient to meet the needs when required. In these cases, a dam might be included in a scheme to store excess water in times of high flow and/or low power demand to make it available at times of low flow and/or increased demand. Though a dam similar to that shown in Fig. 4b can serve that purpose and provide additional head as well as storage, most dams associated with small hydro schemes are low and serve the sole purpose of storing water. They do not significantly increase the available head.

The third function of a dam is to divert flow for power generation. The case which is most prevalent among small hydro schemes is that where both adequate head and flow are available. Since no impoundment is then necessary, these are referred to as "run-of-river" schemes. In this case, the flow in the stream remains unaffected except that a portion of it is diverted toward the powerhouse before it rejoins the original stream. To accomplish this, a low diversion structure, commonly called a weir, is often constructed across either a portion, or the entire width, of the stream. This structure is not designed to store water but rather serves to divert the required water into the intake (Fig. 5). It might either actively channel the flow toward the intake or else simply provide the required depth of water at the intake for flow to enter of its own accord. In cases where the stream bed is susceptible to erosion, it serves the additional purpose of maintaining the level of the streambed constant in the vicinity of the intake. If no weir were constructed in the latter case, over a period of time the bed of the stream might erode to such a point that the level of the stream is no longer sufficient for water to enter the intake. These structures are straightforward to construct and can be of either temporary or permanent construction. However, it must be kept in mind that a weir or dam is not always required at a site. On occasion, a pool or other natural feature might serve essentially the same function.

Having briefly discussed the three basic functions that a dam might serve, namely, increasing available head, providing for storage, and diverting flow, let us review under what conditions a dam should be incorporated in a small hydro scheme.

For a specific project, a dam might be included for a proposed site if it is necessary to:

(1) increase head—Incorporating a dam to increase available head is only a viable option for a stream with a very low gradient where the topography in the area lends itself to the construction of a dam. This would probably mean a stream passing through an area with relatively steep banks. Such a dam would only be of use at a very low head site. With sites having higher heads, the increase in the head and power due to the height of water behind the dam would be insignificant.

Even with a very low head site, using a longer penstock or a power canal to attain the desired head is an alternative that must still be considered (Fig. 4a,c). There is a trade-off between the cost of a dam with a very short penstock and that of a long penstock or power canal with no dam. Because low-head turbines are usually more costly than those for high heads, this is an additional incentive to locate a

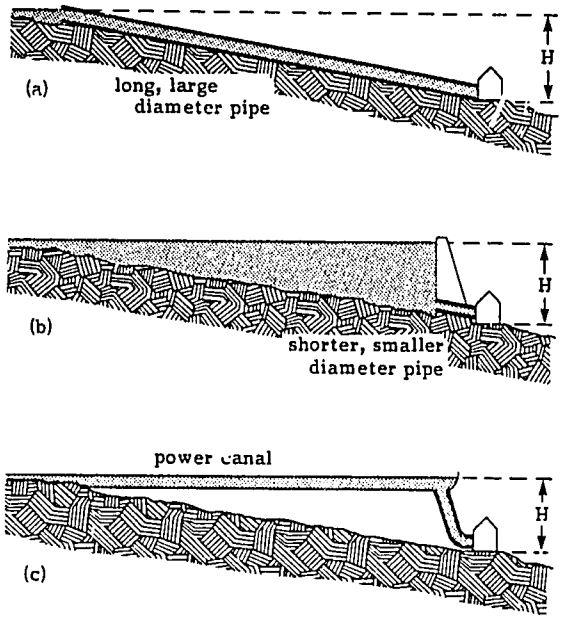

Fig. 4. Three approaches to developing a hydropower site.

Fig. 6. No permanent diversion structure is incorporated at this 100 kW hydropower scheme in Duber, Pakistan.

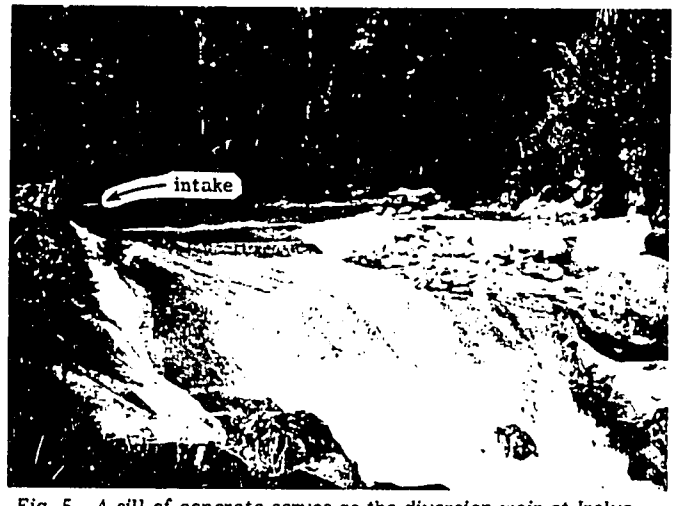

Fig. 5. A sill of concrete serves as the diversion weir at Irelya, Papua New Guinea. The left side of the weir is lower so that dry season flows are directed toward the intake.

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site with a higher head if there seems to be any prospect for such in the area.

(2) provide storage—Incorporating a dam to store water and make it available at times when water demand for power generation outstrips the flow in the stream requires careful forethought. There are at least two occasions when such an approach would be considered.

First is the case where power is only required by the consumer for a portion of the day but where the streamflow is generally inadequate to meet this demand. This might be, for example, for lighting and cooking during early evening hours. In this case, the streamflow should be adequate to provide excess water for storage during off-peak times and the capacity of the impoundment behind the dam should be sufficient to store this excess to meet these peak power demands. Based on the projected power and energy demands and streamflow, the required volume of storage and the associated dam height can be determined. In this manner, it is possible to determine whether the construction of a dam would actually fulfill the need.

The second occasion when a dam for storage might be envisioned is in areas with distinct dry seasons. In this case, the volume of the impoundment must be adequate to cover not only several hours a day as in the previous case but for weeks or possibly months. A much larger stored volume would generally imply a dam of greater dimensions. This volume can be predicted based on projected power and energy demands and streamflow. However, because of the probably large size and cost of such a dam, it might be better in this case to try to locate another site with larger head so that more power can be extracted from the same volume of water. If such a site is not available, one might have to either reconsider the load pattern to make more efficient use of the power which can be generated without an inordinately large dam or else come to the conclusion that hydropower is not a viable option under the prevailing conditions.

In considering the construction of a dam for storage, four factors must be kept in mind. First is that, since the power which can be generated is proportional to the product of net head and flow, the higher the available head, the lower the flow required to generate a given amount of power. And because lower flows are required, the storage volume behind a dam can be smaller. Consequently, the higher the head, the more effective is a given storage volume. In addition, the smaller storage volume required for higher-head scheme implies potentially fewer adverse environmental impacts.

Secondly, a dam fulfills its function of storing water only insofar as the volume behind the dam is filled with water. However, in many areas particularly in the tropics, rivers and streams contain a large silt and bed load which settles as the stream slows down upon entering the reservoir. It is not unlikely that in a relatively short time, the volume behind the dam might become full of silt, stone, and other debris and be rendered largely ineffective. Even though a dam might include a gate for scouring out this area, this will only remove the sediment in the immediate vicinity of the gate where sufficiently high velocities exist. Therefore, in areas where streams carry much debris, constructing a dam for storage should be carefully considered.

A third factor to be kept in mind when considering a dam are the adverse social, economic, and environmental impacts it might introduce. Of all the components in a hydro scheme, a dam is the one with the largest potentially beneficial, as well as adverse, impacts on the surrounding area. Though by nature generally small, a dam supplying a small hydro scheme can still contribute significantly to increased incidence of certain diseases by providing breeding grounds for disease-carrying organisms particularly in the tropics. Malaria, river blindness, and schistosomiasis carried by the anopheline mosquito, the black fly, and snails respectively are three such debilitating diseases. A dam might also affect the fish life in a stream, fish which might be a source of both food and income for a riverine population. This might be due to decreased streamflow, reduced levels of dissolved oxygen, a changed water temperature, or numerous other factors.

And finally a fourth factor to keep in mind is that, if construction of a dam is to be a major component of a small hydropower scheme, it would be well not to jump to conclusions about the advisability of including a dam without calculations based on fairly realistic streamflow information. If streamflow information is not available but there seems to be at least sufficient flow for a good part of the year, it might be best to initially design the scheme to incorporate a simple weir across the stream so that the powerplant can be on-line with the minimum delay. Then after more data is obtained, a decision can be made on the advisability of replacing the weir with a dam.

(3) divert flow—A low dam or weir is the structure most commonly used at the intake to a small hydropower scheme. As is noted in the section on intakes below, the intake to a hydropower scheme should be situated so as to prevent the river, especially during heavy rains, and riverborne debris from being funneled into the intake. But there is at the same time a need to divert an adequate flow of water toward the intake for power generation probably on a year-round basis. This is the function of a weir.

At some locations, the layout of the land and the nature of the stream may permit sufficient water to be admitted into the intake without the need for any weir (Fig. 6). This is often the case where the level of the streambed and its course have remained unchanged over the years, where the depth of the stream is sufficient year-round, and where the flow does not vary enormously from season to season. A dam or weir may also not be necessary where a pool or other natural formation fulfills the same function.

At locations where the bed of the stream is likely

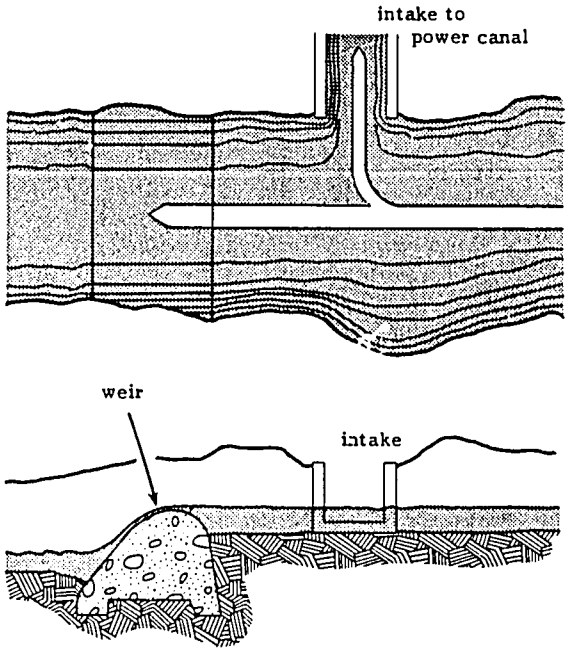


Fig. 7. A simple diversion structure presenting minimum resistance to flood flows and streamborne debris.

to erode, a weir can be included as shown in Fig. 7 so that the level of the streambed in the vicinity of the intake remains unchanged. If the streambed is of bedrock or streamflows are not so large as to erode the bed, a weir for this purpose may not be necessary.

A weir is also useful in streams where flows normally fill only a portion of a wide streambed at least during the drier seasons. In this case, the low flows may never reach the intake. A weir should be designed to deflect low flows toward the intake yet permit high flows and waterborne debris to proceed downstream unhindered. Consequently, silt, bed load, or other debris do not have the adverse impact on the life of a weir as they do on the usable life of a reservoir formed by a dam and therefore are not a major problem.

Intake

This structure permits a controlled flow of water from a river or stream to be fed into a conduit which eventually brings the water on to the turbine for the generation of power. It is a component of virtually every hydropower scheme. Since the intake serves as a transition between a stream which can, at times, become a raging torrent and a flow of water which must be controlled in both quality and quantity, its design requires careful consideration. If all factors which might impact on its operation are not properly considered, the resulting design may well be a source of continuing and frustrating maintenance and repair problems, not only with the intake but with virtually all the other major components of a scheme. The long-term success of a hydropower scheme is largely dependent on the proper design of the intake.

The task of selecting a design is somewhat complicated by the fact that there is a range of configurations which might be used. These range from simple, excavated canals opening directly onto the steam to large reinforced concrete structures (Fig. 8). They can be separated from, or be an integral part of, a weir or dam. The actual design appropriate for a specific site depends on a number of factors, among these, the quality and quantity of water required, the extremes of the stage or level of the stream, the topography and soil conditions of the site, the nature of the catchment area, whether a dam or weir is to be constructed at that site, the financial capital which is available for its construction, and the relative capital vs. labor resources available for construction, operation, and maintenance of the structure.

One of the major functions of the intake is to minimize the amount of debris and sediment carried by the incoming water. For this purpose, trashracks are often placed at the entrance to the intake to prevent floating debris and larger stones from entering. Depending on the water quality, a settling area might also be incorporated to remove some of the potentially more troublesome waterborne sediment. Without these features, the sediment and debris could settle along the power canal, eventually obstructing the flow, or else these could pass through the turbine, damaging it or reducing its effective life.

Another function of the intake is to control the flow of water which is admitted under all flow conditions. Any of several types of gates can be used to control this flow. Spillways are also often incorporated in the intake structure to serve as a backup to the gates and permit any excess water which has entered the intake gate to overflow back into the stream. If the flow of water is not controlled at the intake, excess water may cause the power canal or forebay to overflow unexpectedly and lead to serious erosion. This erosion can then undermine the canal, forebay, penstock, or powerhouse. Though the canal and forebay should be designed to prevent damage from larger flows than expected, it is still best to minimize the possibility of this occurrence by incorporating spillways in the intake structure.

Though proper design of the intake is essential for trouble-free operation of the civil works, it should be kept in mind that properly locating the intake along the stream reduces the burden placed on the intake itself. Adequate planning in the initial stages is necessary in order to place the intake in such a location that it is protected from excess water and debris which might otherwise be funneled into it during flood stage of the stream.

In locating the intake, the following factors should be considered:

- o nature of the streambed,
- o bends along the stream,

- o natural features along the stream, and
- o other uses for water in the stream.

Nature of the streambed

The elevation of the intake to a hydropower scheme is determined at the time of construction. If, because of erosion, the streambed lowers relatively quickly over time, it is possible that, before too long, the streambed might have lowered to such an extent that the level of the stream falls below the intake. To avoid this problem, the intake should be situated at a point along the stream where the level of its bed seems relatively permanent. This might be the case where a stream having a relatively constant flow, a stream, for example, originating in a spring with little additional catchment area so that heavy rains have little impact on the flow. It might be a point where the stream flows over bedrock. Or it might be along a portion of a river with a small gradient. If erosion of the streambed is a possibility, construction of a weir or dam could also resolve that problem.

Bends along the stream

One of the more common problems affecting small hydro schemes is the damage to the intake portion of the scheme due to flood waters. This often occurs at sites where the intake is placed at the outside of a bend in the stream and then also oriented upstream (as if to make sure that water will go in!).

To minimize the chance of this problem occurring, a site should be selected so that the intake structure is located along a relatively straight section of the stream. Water, like any object, prefers traveling along straight lines. This is especially noticeable at bends along a river, where the river has a tendency to go straight and does so unless forcibly constrained by its banks (Fig. 9). The area on the outside of the bend (a) is therefore subject to erosion, and stones and other waterborne debris can impair the operation of any intake structure and damage or destroy it in times of flood flows. It is therefore preferable to avoid placing the intake at such a location if at all possible. It might possibly be placed on the inside of the bends of some rivers (b). This provides the added advantage that any headrace conveying the water toward the penstock is protected from the river. However, on some streams with suspended sand and silt, this location might not be advisable since this sand will tend to accumulated on the inside of the bend and might block the intake.

Natural features along the stream

It is sometimes possible to select a site so that the intake is protected from flood waters by the natural features found along a stream. For example, where large boulders can be found along the stream, it might be possible to locate the intake at the edge of the stream but under or behind these boulders. By so doing, the water which might enter during times of high water levels is limited and large debris which might otherwise damage the intake is prevented from entering. The boulders might also provide some protection to the power canal conveying water from the intake toward the penstock. One must be alert to other similar uses of the natural features along a stream.

Other uses for water in the stream

In prospecting for suitable locations for an intake to a hydropower scheme, as well as for the entire scheme, other existing or envisioned uses for the water in the stream must be considered, especially if these uses require a sizable portion of the available water. In a number of countries, water is, for example, commonly used for irrigation. This generally represents a use of primary importance and power generation must then take a position subordinate to irrigation. If the flow of water that would be required for power generation represents a major portion of a stream and would potentially have an adverse impact on irrigation, there are several ways that both irrigation and power generation might be accommodated.

If irrigation and the proposed hydropower plant would each require a major portion of the flow, it might be possible to generate power during times when water is not used for irrigation or during the seasons when the flow is more than adequate. In either case, periods set aside for power generation would have to be carefully planned and integrated in with the needs of irrigation. Though sharing water among several uses is possible, this approach should only be used if no better options are available. Because of the importance of irrigation in most areas where it is practiced, misunderstandings and conflicts can easily arise from such an approach.

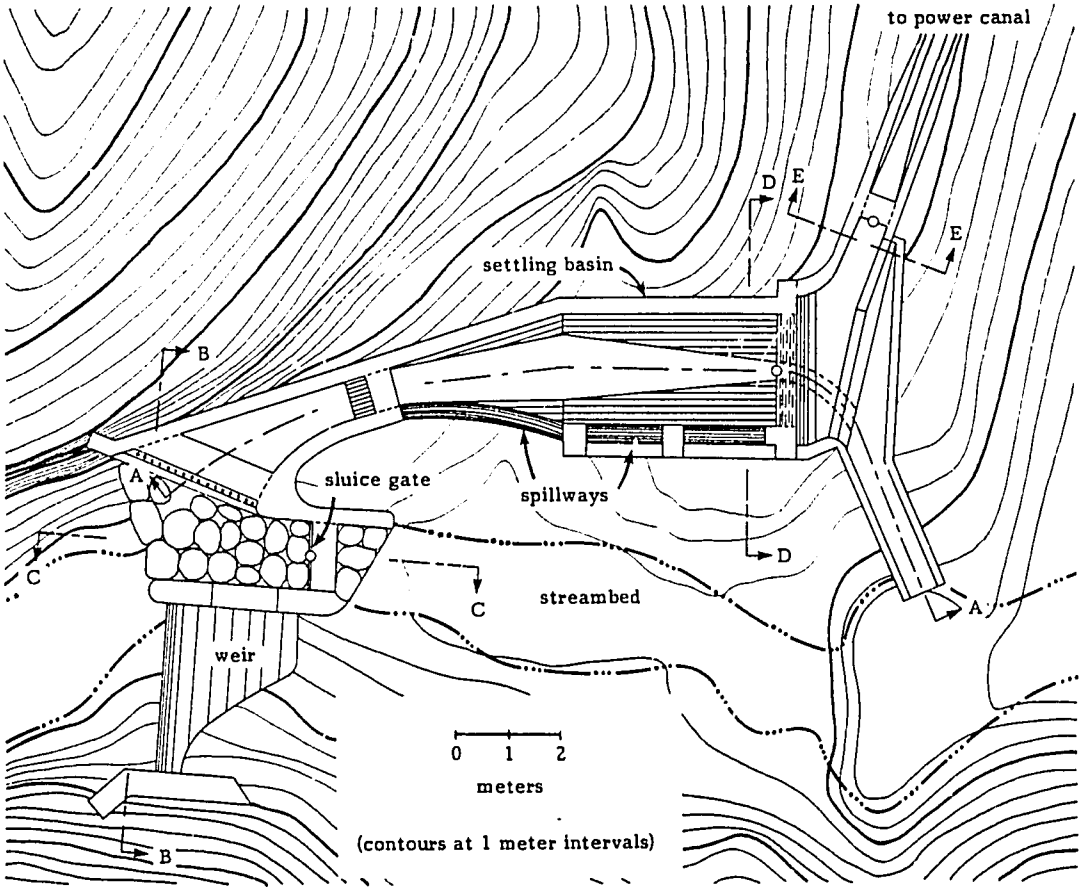
Any water in excess to that used for irrigation could be stored so that it would be available for power generation when it is required. Though this is more of a viable option for high head sites where smaller flows of water are required, constructing a storage area of the necessary volume, either behind a dam or as a separate basin, would generally be costly and problematical.

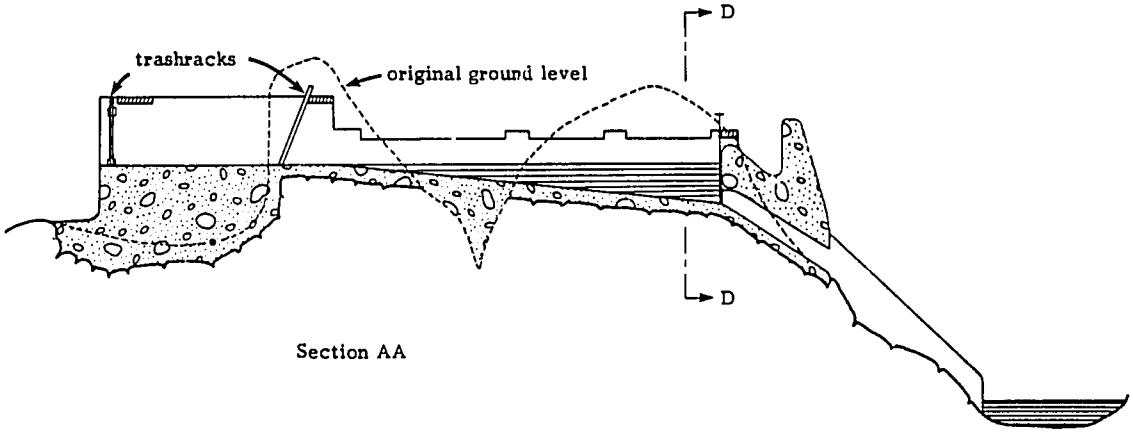
A more suitable alternative which may be possible in some circumstances is to avoid having to interfere at all with the irrigation canals in the area. This could be done by situating a hydropower scheme between two consecutive irrigation intakes along a river. In this manner, water for the hydropower plant would be taken from that remaining in the stream below the upper irrigation intake and this water would be returned to the stream below the powerhouse where the same water would be available for diversion into the next irrigation intake.

Though irrigation is the specific end use being considered above, the same arguments hold for other potential uses of the water in the area being surveyed. Other such uses may be for fisheries development and potable water supplies.

Power Conduit

This is a conduit which is used to convey water a relatively long distance with minimum loss of head and at minimum cost. Because of cost, this conduit is most frequently in the form of a canal excavated in soil. It is sometimes lined with concrete or other impervious material to reduce seepage of water which might eventually undermine the canal or to permit increased velocity and flow through a canal of given size. Or it





Section AA

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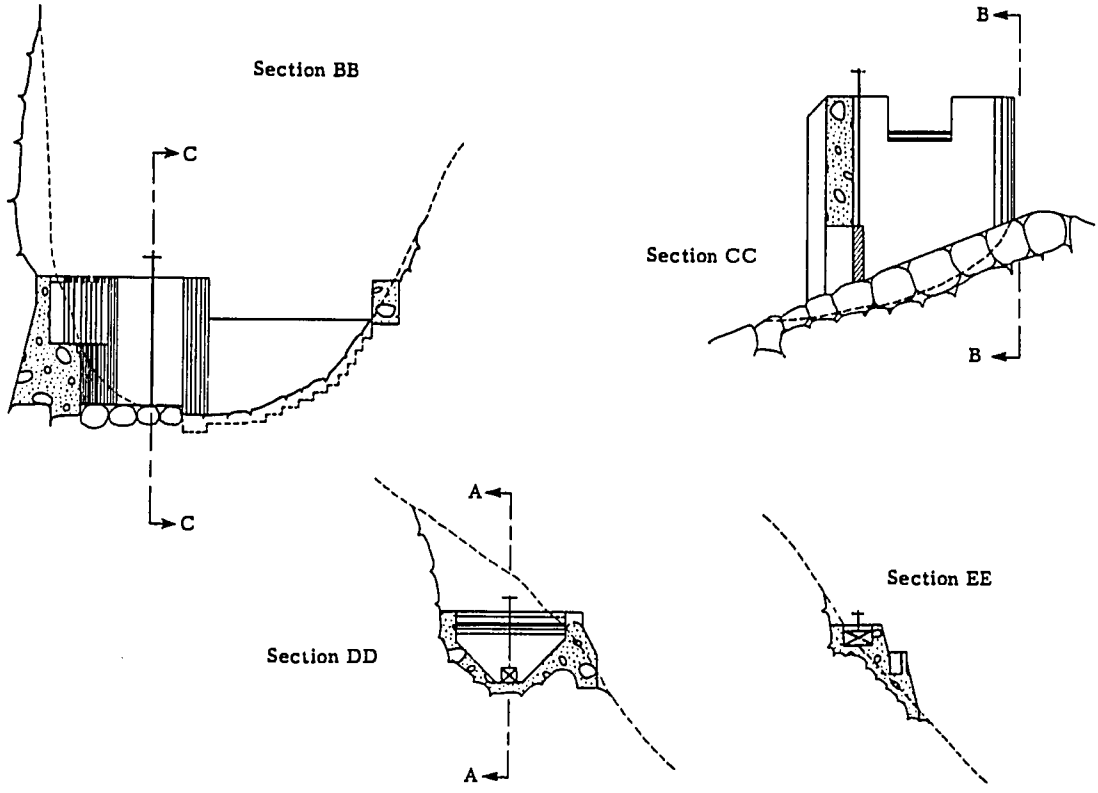


Fig. 8. Views of a weir and intake structure for a small hydroelectric project in Tabalosos, Peru (from drawings by Electroperu).

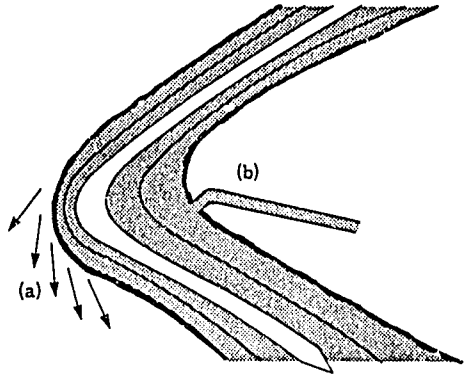


Fig. 9. Flow at the bend of a stream.

may be built of concrete or stone-concrete masonry. Canals of half-round concrete sections, wood, and sheet-metal supported above the ground have also been used. Depending on the topography of the area, portions of this conduit may be supported above the ground, as when crossing ravines, or placed underground in a pipe.

It is also possible to use a larger diameter pipe to serve as a low-pressure conduit to convey water at low velocity from the intake to the beginning of the penstock. This has the advantage over the use of a canal in that components, such as spillways, drop structures, and drainage which are usually incorporated in the design of power canals, need not be considered when a pipe is used. However, cost of large diameter pipe is generally greater than the cost for a canal, especially one excavated in earth.

With larger schemes, power tunnels are also used. These have the advantages that a more direct route is possible; that over rocky terrain, few other alternatives may exist; that the conduit is protected from landslides, heavy run-off, and debris which might otherwise be introduced along its route; and that it does not interfere with surface features (roads, gardens, houses). However, tunnels must usually be large enough to accommodate men and equipment necessary for the tunneling operations and may be too large for flows encountered with most schemes at the lower end of the small hydro range.

Unlike most of the other components described, the power conduit is not an essential part of every hydropower scheme. It is used as a means of reducing cost of the civil works in cases where there is a significant horizonal distance between the intake and the powerhouse. Then, rather than using a costly penstock pipe for the entire distance, a nearly level power conduit is used to convey the water from the intake to a point to as close to above the powerhouse as possible. The objective is to lay out the scheme so that the penstock can be as steep as possible. If this layout can be achieved, a penstock pipe of reduced diameter, length, and, therefore, cost would be required. Clearly, the cost of the conduit itself must then be added, but the conduit can frequently be constructed at a fraction of the cost of a penstock, using local materials rather than steel, concrete, or plastic pipe imported from outside the area.

To illustrate this point, consider the example where the entire scheme extends approximately one kilometer, a distance not unusual for a small hydropower scheme (Fig. 10). Let us assume that this site, with a gross head of 30 meters, requires about 300 liters/second to generate 50 kW.

Clearly, one option for developing this site is to convey the water through a penstock from the intake to the turbine. This would require 1000 meter of 600 mm diameter pipe. On the other hand, if there is a rapid drop in the vicinity of the powerhouse which would require only 100 meters of pipe to get nearly the same head, another option would be to convey the water one kilometer from the stream to the intake of the penstock with minimum head loss. This is where a power conduit in the form of, for example, a canal can play a role. With only a drop of 1 meter over its one kilometer length from the intake on the stream to the penstock, it is possible to convey the required flow with a canal cross section of about 0.2 m^2. Then, only a 100 meter length of 400 mm penstock pipe would be required to convey this flow from the end of the canal on to the turbine. In summary, the first option requires 1000 meters of 600 mm penstock whereas the second option requires 100 meters of 400 mm penstock and the excavation of 1000 meters of canal.

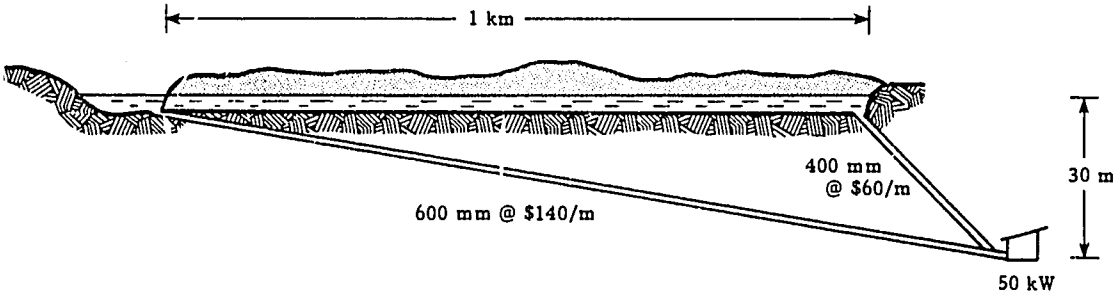
To obtain a clearer impression of what this implies in terms of cost, let us assume 400 mm steel pipe costs $60/meter and 600 mm pipe costs $140/meter. The costs for each option would be as follows:

- first option--
  $140,000 for the penstock + excavation for 1000 meters of penstock as required
- second option--
  $6,000 for the penstock + excavation for a 1000 meter canal and 100 meters of penstock as required.

Assuming an equipment cost of $1,000/kW for the 50 kW site under consideration, it is clear that, compared with the resultant cost of $50,000 for the turbo-generating equipment, the long penstock proposed in the first option would add $140,000. This would be, without question, the major cost component of the project. On the other hand, the price of the penstock proposed in the second option would contribute only marginally to the cost of the project. Of course, the cost of the canal itself must be considered. If the construction of the canal is undertaken as a self-help project, then the only material costs which would be incurred would be that for any lining which may be necessary or for a section of the canal which requires special attention (a supported section, for example). If contract labor and heavy equipment is required for the construction of a canal or if the terrain is difficult, larger costs could be incurred and the first option might prove the most appropriate.

While this example illustrates a major advantage of incorporating a power canal when the topography is suitable, it should also be noted that a power canal may not be without its drawbacks. The principal disadvantage is that, unlike the penstock, a canal is usually open, is more exposed to the elements and, therefore, requires more upkeep. Falling trees or landslides may obstruct the flow, sections might wash away due to excessive runoff uphill of the canal, or excessive sediment in the slow-moving incoming water might settle out along the length of the canal. Though a properly designed scheme can prevent many of these problems, a penstock pipe is less susceptible to these problems. Of course, as mentioned previously, a low-pressure pipe could serve as a power conduit instead of a canal but this would probably prove costlier for the same reason a penstock pipe would be costlier.

Therefore, while significant cost savings can result from using a power canal, the existence of a significant horizontal distance between an intake on the stream and the powerhouse is not a sufficient condition for including a power canal or other form of power conduit in the overall design of a scheme. It is always necessary to compare the costs of each of the two basic options, a long penstock versus a canal and short penstock, as well



OPTIONS

Direct penstock	Canal and penstock
$140,000 plus cost of excavating 1,000 meters of penstock as required.	$6,000 plus cost of excavating 1000 meters of canal and 100 meters of penstock as required.

Therefore, assuming $1,000/kW or $50,000 for equipment, direct penstock option adds $140,000 vs. $6,000 for canal and penstock option.

Fig. 10. Two options for developing a small hydropower site, one using only a penstock, the other relying primarily on a power canal.

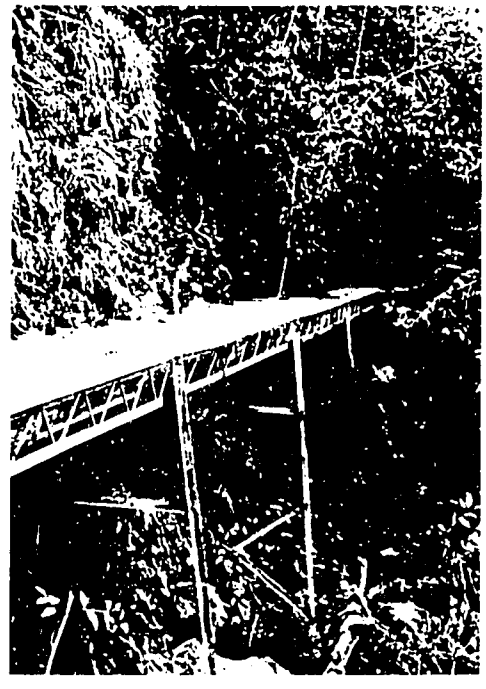


Fig. 11. A semicircular sheet-metal flume within an angle-iron frame conveys water around a cliff face (Rugli, Papua New Guinea).

as to consider the nature of the terrain to be traversed and the construction and maintenance problems which might be encountered if either option were to be adopted.

Depending on the length, slope, and dimensions of the power canal, spillways might be incorporated at appropriate intervals, with the necessary provisions to ensure that any overflow does not undermine the canal or other components. These are necessary if there is any chance that the canal might overflow either due to excess water entering the canal (though proper design of the intake should minimize this possibility) or due to an obstruction along the canal. Depending on the terrain, dirt from a landslide or other debris can restrict the flow and cause water to back up until the canal overflows.

If a canal is built on a hillside where considerable run-off could enter the canal, bringing with it debris and sediment, provision may have to be made for proper drainage around the canal.

When the power canal must cross an obstruction such as a ravine, streambed, or road, any one of several approaches might be adopted. The slope of the canal can be maintained and the canal supported above this obstruction in a flume constructed of wood, steel, or concrete (Fig. 11). Or it can be placed on or slightly below the original streambed or road, with a structure to reroute that road or stream over the canal which would then flow in a culvert. Or an inverted siphon might be used to lead the flow under the obstruction (Fig 12). This latter is a closed conduit which permits the flow in the canal to drop in elevation until it passes the obstruction and then rise again on the other side. Under certain circumstances, this might be the only viable option, but care must be taken in its design since any debris can accumulate in the siphon and eventually obstruct the flow. Adequate provision should be made at the design stage so that this debris can be removed.

Though a power canal is usually designed to minimize any head loss along its length, occasionally the terrain might make it necessary for drops to occur at points along the canal. The energy then gained by the falling water must be dissipated in a controlled manner; otherwise, it might erode part of the canal. Properly designed drop structures are used for this purpose (Fig. 19).

Forebay

This is a basin located at the end of a power canal which furnishes water to the penstock. Possible designs range from simply an excavated area or pond to a structure of reinforced concrete. Its size may vary depending on the quality of the water and whether it is to serve for storage. In some cases, it is virtually non-existent. In order to be most cost-effective, it is necessary not to overdimension the forebay but to construct it of adequate size so that it fulfills its function.

The forebay might serve several purposes. It serves as a final settling area where any waterborne debris which either passed through the intake or was swept into the canal can be removed before the water passes on to the turbine. In this case, the size of the forebay must be adequate to sufficiently reduce flow velocities within the forebay for settling to occur.

The forebay may also serve as storage. It might have sufficient active storage to supply a turbine for several hours. However, it usually provides only a small storage sufficient to make up for sudden increases in penstock flow when load on the turbine is suddenly increased. Where sufficient flow exists, it might be more appropriate to permit maximum flow into the forebay and to allow any flow not required by the turbine at times of below peak load to leave by the spillway. In cases where a load controlling device is used with the turbine, there is no need for storage to make up for transient flow variations since penstock flow remains constant.

Several important components must be included in the design and construction of the forebay. These include a spillway, scouring gate, gate(s) to penstock, trashrack, and possibly a vent (Fig 13).

It is possible that, on occasion, flow entering the forebay may exceed the flow leaving by way of the penstock. This might, for example, occur during times of heavy rains, when a gate at the intake has been improperly set, or when the valve to the turbine has been closed. For this reason it is advisable to include a spillway in one wall of the forebay. In addition, it is necessary that water over the spillway is properly diverted away to prevent any erosion which might undermine the forebay, penstock or powerhouse.

Depending on the size of the forebay, at least a portion of the sediment transported by the incoming water will settle out. Provision for a means of draining out of the forebay so that any sediment can be removed should be included. A scouring gate is incorporated for this purpose.

In addition to sediment, incoming water can carry sizable quantities of floating debris. A trashrack is often included just before the water enters the penstock. If sufficient excess water exists, it is possible to design the spillway so that most of the floating debris is automatically removed.

On occasions when it is necessary to empty the penstock in order to undertake repairs on the penstock or valve at the base of the penstock, the forebay might be emptied. However, to ensure that water which might unexpectedly enter the forebay does not cause erosion along the penstock under repair or flood the powerhouse, a gate is often placed just before the intake to the penstock. Usually a stop-log is used since this gate is infrequently used and this form of gate is less costly to construct.

As is discussed below, a vent pipe is often included as a safety measure against collapse of the penstock pipe. One design option would be to include this pipe in the wall of the forebay.

Penstock

This is a pipe conveying water, under pressure, to the turbine. Except for some very low head designs (e.g. open flume Francis (Fig. 26) and propeller turbines and traditional water wheels, it is an essential part of any small hydro plant.

Though steel is the most frequently used penstock

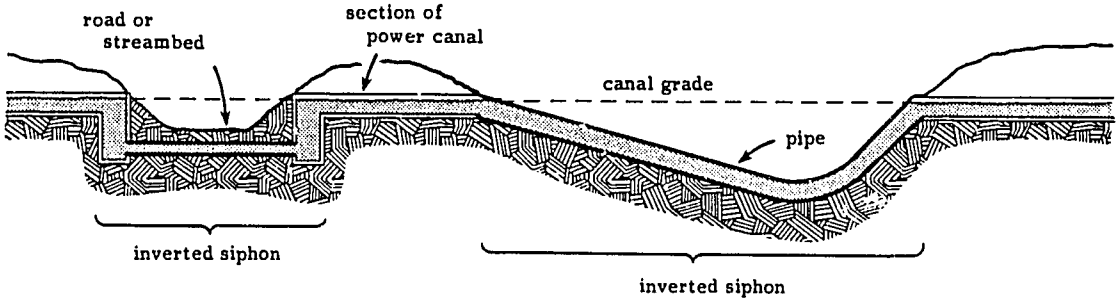


Fig. 12. Inverted siphons are used along power canals to go beneath obstacles.

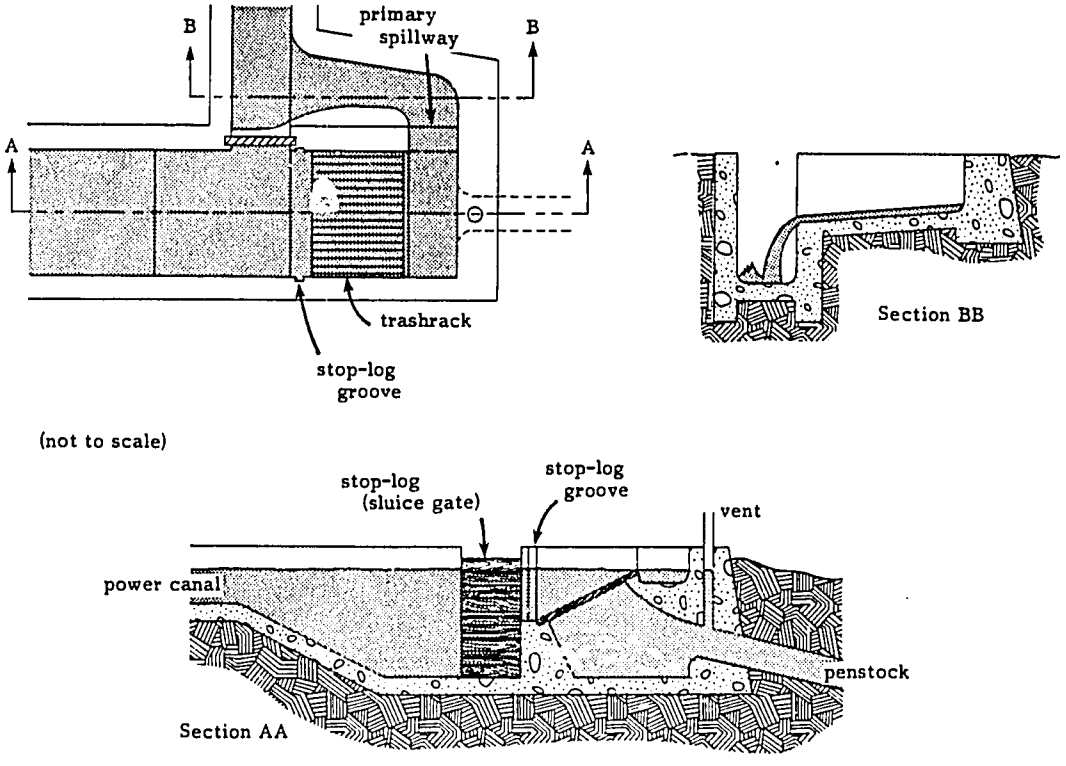


Fig. 13. A forebay design incorporating the basic features.

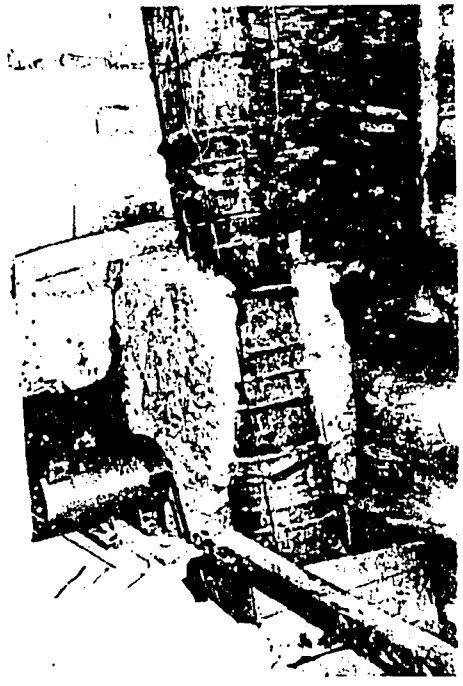


Fig. 14. Oil-drum penstock frequently used with the low-head 5-10 kW schemes in Pakistan. The turbine is belt-driven by a turbine located below floor level.

material, various types of concrete are also used. For small schemes, the low cost, low weight, and ease of installation of plastic pipe has made that an increasingly popular material. For very small self-help schemes, materials such as oil drums and timber planks have also been used (Fig. 14).

Along the length of a penstock, anchors, thrustblock and supports are generally used to prevent movement of the penstock due to forces arising from the combined weight of the water and penstock pipe, thermal expansion of the pipe, and the reaction forces due to changes in the direction of the flow of water at each bend. If the penstock is buried and depending on the magnitude of the forces involved, some of these may not be necessary.

If the penstock is above ground, it is subject to greater temperature variations than if buried. This temperature variation is even more pronounced when the turbine is not continually on. In this case, the moderating effect of the flowing water whose temperature is fairly constant would not be felt. Variations in temperature result in stresses in the pipe due to thermal expansion. If the possibility exists that these can be large, either the pipe must have sufficient structural rigidity with the help of anchors or else expansion joints are incorporated. These latter are two concentric portions of the penstock which permit relative motion with respect to each other. A gland is incorporated to prevent leaking between these concentric portions. These joints also provide the pipe some protection against earth tremors.

Because of a pile-up of trash or by the closure of a valve at the penstock inlet, flow into the penstock may be restricted. Decreasing pressure within the penstock as it empties of water might cause the pipe to collapse, requiring a major replacement job. To prevent this possibility, a vent is located at the upper end of the penstock, possibly in the forebay wall itself, to admit air into the penstock as the water is withdrawn when its inlet is closed, accidentally or otherwise. One way of minimizing the chance of this occurrence is not to include any valve at the inlet. If one is included, there may be a tendency to stop the flow in the penstock by closing this valve and , without a vent, this may well lead to the collapse of the pipe.

At the bottom of the penstock, a shut-off valve is often included. This can be used to turn on or off the turbine but is generally not used to regulate the flow. This regulation, if required, is usually done by a valve supplied as part of the turbine. Even though the valve supplied with the turbine can also be used to turn the turbine on or off, a shut-off valve is often included to shut-off the flow if the turbine or flow regulating valve has to be repaired. A lower cost, though possibly less convenient, alternative (expecially with high-head units) is to avoid this shut-off valve and simply close the gate at the intake to the penstock. Or else, the scouring gate in the forebay can be opened to drain the forebay and prevent further water from entering the penstock. The water remaining in the penstock can be drained through the turbine before repairs are undertaken.

Powerhouse

This is the structure which houses the turbo-generating equipment. In size, it can range from a simple cover over the turbine, generator, and control equipment to protect them against the elements to a structure which includes an office and workshop.

If the equipment is to be located in a building, sufficient space should be allowed on all sides to permit easy access during operation, maintenance, and repair. The foundation should be sufficiently strong to support the equipment. Proper drainage must be included to keep the powerhouse floors free of water.

Possibly most important than properly designing the powerhouse itself is the need to properly locate it. For structural reasons, as well as for reasons of safety and the need for accessibility of the equipment for proper operation and maintenance, the floor of the powerhouse must be kept above water level at all times. The maximum flood stage, the highest river level which is expected to occur over the operating life of the plant, therefore sets the lowest preferred location for the powerhouse. Lack of recorded data might make it difficult to determine precisely the flood stage of the river. However, this can be determined by piecing together informations gathered by interviewing those who have lived near the river or by seeking high-water marks on the riverbanks. Maximum expected flood stage may also be predicted using the rainfall characteristics of the region and information on the nature of the catchment area above the intake but this

may be more difficult to do properly. One must, however, be sure the information gathered is reliable as the ravages of floods, due to both the flood waters and waterborne debris, can wreak havoc along the river, especially in areas of tropical rain and even more so in regions with barren slopes caused by the removal of trees and other vegetation for firewood and gardening.

Tailrace

This canal leads the spent water from the powerhouse back into a stream (which may or may not be the same as the stream from which the water originated). As with the power canal, it may be lined or unlined.

The outlet of the tailrace into the stream should be protected from potential flood waters. To accomplish this, it is advisable to direct the tailrace downstream to prevent any water in the stream from being funneled into the tailrace during times of high streamflows.

CASE STUDIES

The following brief case studies illustrate how the major civil works components discussed above have been integrated in the layout of hydropower schemes where designs must cater to different site conditions.

The 90 kW sites at Amlapura (Indonesia) and Yaibos (Papua New Guinea) illustrate cases where all the components described above are included in their design. The former is a fairly expensive design while with the latter, costs of the civil works have been significantly reduced. The site at Musongati (Burundi) is a case where the streamflow regime made it essential to include a dam for the storage of water whereas the site at Yandohun (Liberia) illustrates a case where a dam was to be included when the need for it had no yet been established. The site at Buhiga (Burundi) illustrates a more typical small hydropower site where a power canal is used to reduced penstock costs. And finally, the last scheme illustrates a case where some components are merged into one, since several functions can be fulfilled by the same structure or omitted, since the function they fulfill is not required.

Amlapura (Indonesia)

This 90 kW scheme, which is integrated into an irrigation system, is one which incorporates each of the major components. The dam serves merely to maintain the level of water at the intake and not for the storage of water (Fig. 15). An intake at right angles to the stream conveys water into a settling area and then into a power conduit. The first part of this conduit is a tunnel since the steep banks of the river do not permit adequate space for an open canal. The second part is a masonry lined canal which leads to both the irrigated area and the forebay. A short penstock leads the water down to the powerhouse and back into the original stream (Fig. 16).

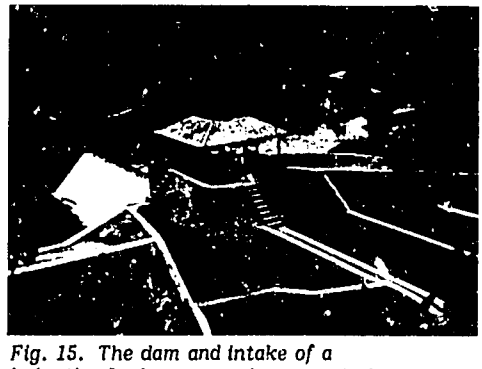


Fig. 15. The dam and intake of a irrigation/hydropower scheme at Amlapura on the island of Bali, Indonesia.

Fig. 16. Powerhouse at Amlapura, with the spillway situated to the left of the penstock.

Yaibos (Papua New Guinea)

This is another 90 kW scheme but one much less costly to implement. The weir is simply a series of gabions (rock-filled wire baskets) covered with a layer of concrete to form a sill (Fig. 17). The intake, at right angles to the stream, is well protected, and a simple sluice gate (Fig. 18) controls the flow of water into an earthern power canal (Fig. 19) and on to the forebay.

Though much less costly than the previously described sited, it must be kept in mind that the primary purpose of the scheme at Amlapura is for the supply of irrigation water. A major portion of the cost of this scheme is therefore borne by this function. Power generation is, essentially, a side benefit.

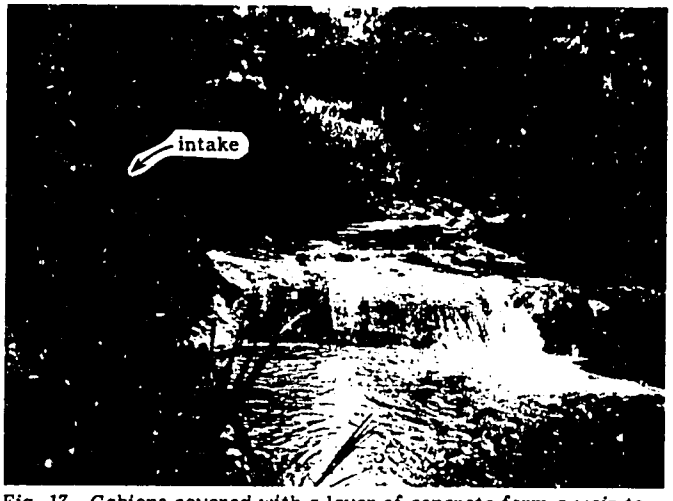


Fig. 17. Gabions covered with a layer of concrete form a weir to stabilize the portion of the riverbed near the intake (Yaibos, Papua New Guinea).

Fig. 19. The only stone-concrete masonry work along this earthern power canal is found at two canal drops (Yaibos, Papua New Guinea).

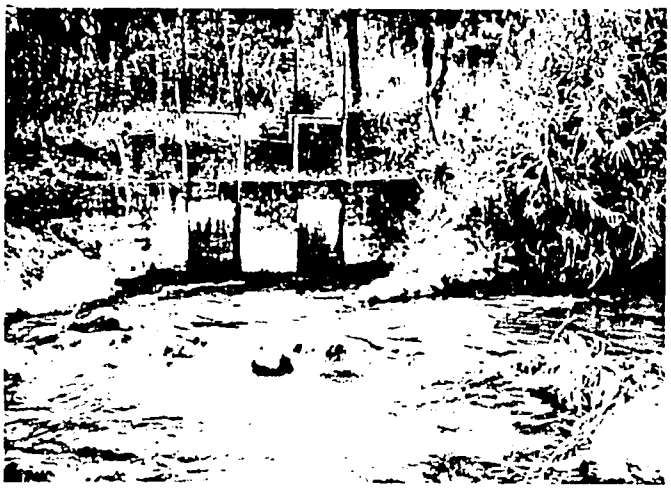


Fig. 18. Two gates control flow into the power canal. Stones have been placed cross the stream to divert flow into the intake during the dry season. The intake is well shielded from flood flows.

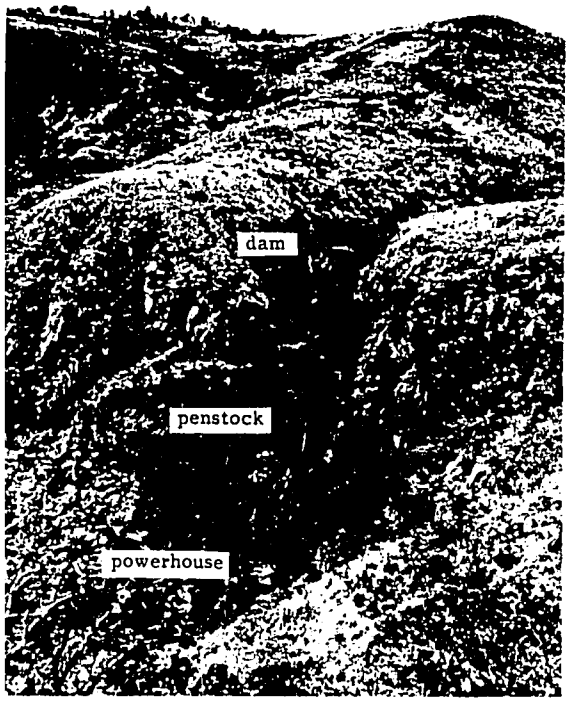


Fig. 20. The Musongati micro-hydro site (Burundi).

Musongati (Burundi)

At this site, the minimum flow in a little rivulet amounts to on the order of 3 liters/second and the available head at the top of a gorge was about 40 meters (Fig. 20). With the need for electricity for lighting and a few electric applicances, it was necessary to have a few kilowatts for several hours each evening. The power equation indicates that several times that flow would be required. At this site, it is clear that without storage, insufficient power would have been available. A dam was therefore incorporated for the purpose of storing water. Since the intake was at the top of a steep drop, a penstock is used to convey the water the entire distance to the powerhouse.

After the plant had been operational for some time, it was decided that more power would be required. This was accomplished by extending the penstock further down the gorge to gain an additional 20 meters of head, increasing the power potential by about 50%. At this site, the additional power which could be gained by extending the pentock even further downstream would have been offset by the increasing cost of the penstock.

Yandohun (Liberia)

A micro-hydro project with a capacity of 30 kW under a head of 60 meters is being implemented near the village of Yandohun in the fairly remote northern corner of Liberia. Based on occasional observations of the stream to be used and comments of the villagers, it was felt that the streamflow was above the 80 liters/second required to generate full power for all but two months of the year. The only streamflow data which existed was gathered during one week at the end of the dry season when the low flow was measured at 7 liters/second. Initial plans were therefore to build a sizable concrete and stone gravity dam 40 meters across the stream and about 2-3 meters high. This was to retain a sufficient volume of water to run the plant at half power for a 12-hour period for several days at the minimum observed flow.

When the plant was visited, work on the dam had been in progress for some time but there seemed little to show for it (Fig. 21). The construction was time-

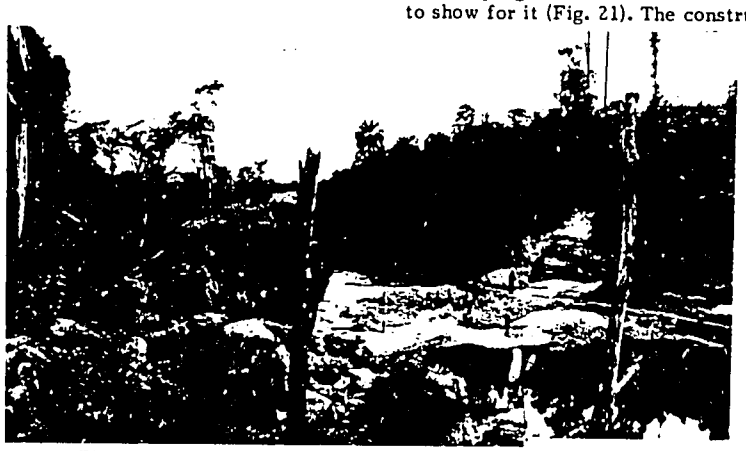


Fig. 21. Composite view of the dam site near Yandohun.

consuming. Not only was the volume of the dam large but the stone was obtained by cracking sheets of bedrock by building a fire on it. Aggregate was obtained by then breaking the stone with hammers.

It was recommended that, rather than completing the dam, it be built up only high enough for it to serve as a weir. The weir could be built up at leisure at some later date should it then prove desirable. This recommendation had the following advantages:

- It would be possible to get the plant operational with the minimum of delay. The project was ambitious enough even without the fairly massive dam and it seemed necessary that the villagers see the fruits of their labor as soon as possible.
- Based on the observations of flow, it was apparent that without a dam, sufficient flow was available 85% of the time (10 months) to generate full power and that for another 5%-10% of the time the flow would probably be sufficient to operate at half power all day. Construction of the dam would permit half power to be generated for part of the day for at least part of the remaining 5%-10% of the year. Since storage capacity would be small, it would not be possible to guarantee sufficient water for power generation at all times in any case. Utilizing a low weir rather than a dam therefore would still permit nearly full use of the plant. After putting the plant on-line, more flow data during the dry season could be gathered. At the same time, the villagers could decide whether having electricity at least for a part of the day for the remaining part of the year would be worth the additional time required for completing a dam.
- A delay in building the dam to full height would permit the operators of the plant to determine whether the silt and bed load carried down the stream and caught behind the weir would present problems in the future. Should the weir be converted to a dam at some future date, it would

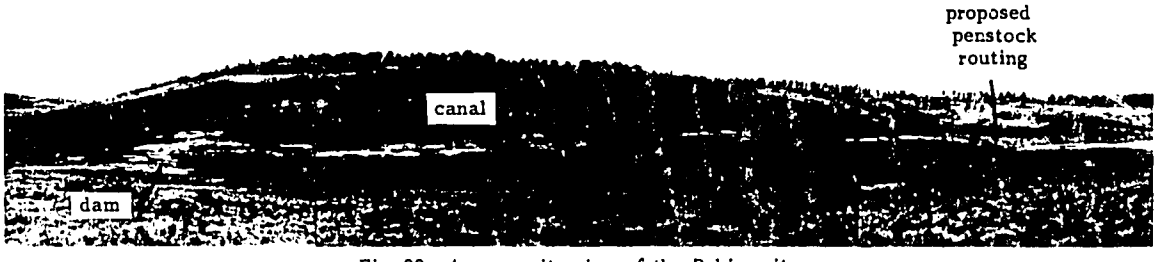


Fig. 22. A composite view of the Buhiga site.

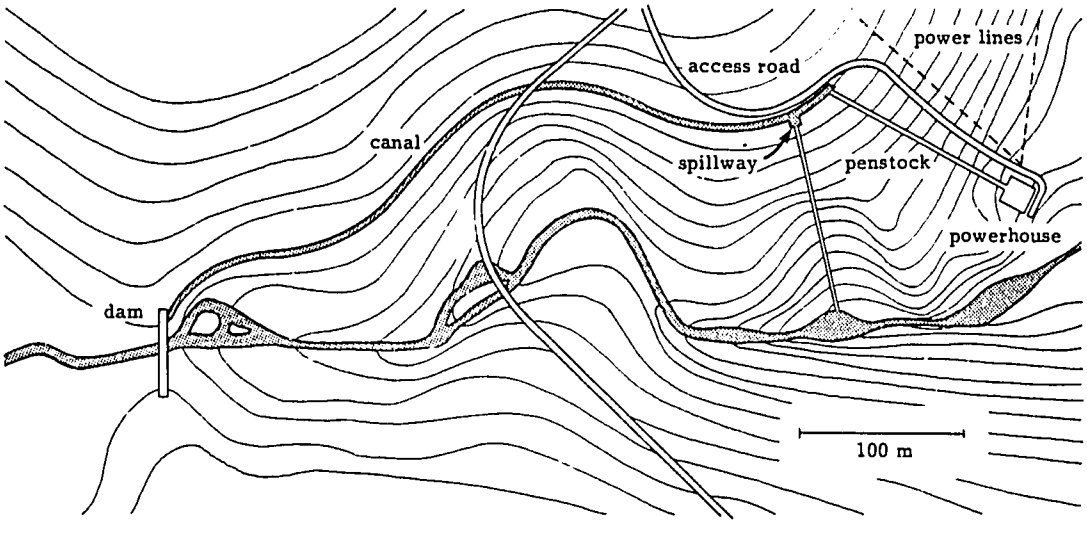


Fig. 23. Contour map (2 m contours) showing the layout of the major components at the Buhiga site (Burundi).

also permit time during which a better feel for the magnitude and duration of low streamflows could be obtained. This information would be necessary for proper dam design.

This case illustrates a situation where a component—a dam—was to be included in the overall layout of a power scheme when, on the one hand, the need for one had not yet been established, and, on the other, its construction would have placed a heavy demand on material, manpower, and time.

Buhiga (Burundi)

At this 220 kW site, a drop of 27 meters is found along a section of stream connecting two flat marshy areas (Fig. 22). This is a fairly typical small hydropower site where the head can be developed over a relatively long distance. At Buhiga, it was found that if a powerhouse were located near the lower end of this section, a much steeper incline with essentially the same drop could be found in the immediate vicinity of the powerhouse. To reduce costs and the difficulties of obtaining penstock pipe in a remote part of this land-locked country, the pipe length was reduced by 85% through the use of a canal which closely followed the contour of the land from the intake to a point above the powerhouse (Fig. 23). Since cement was expensive, imported, and in short supply, costs were further reduced by building the dam and canal of stone and concrete masonry rather than reinforced concrete (Fig. 24). Skilled masons were also easily found locally.

Wonodadi (Indonesia)

In certain cases, especially with low-head sites, it is possible to omit or merge several components. At this 230 kW site constructed along an irrigation canal, the power at an irrigation drop is harnessed (Fig. 25). In this case, there is no need for an additional diversion structure since the irrigation drop structure serves that purpose. Because of the compactness of the scheme,

Fig. 24. Stone-masonry canal being constructed at the Buhiga site.

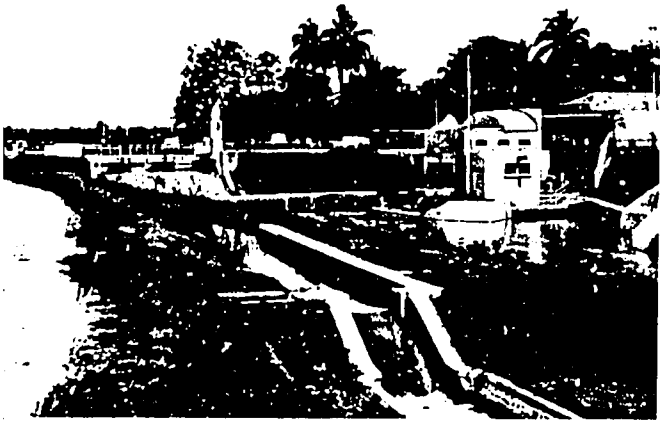


Fig. 25. With the minimum of civil works, a 230 kW plant was constructed to harness power otherwise lost at an irrigation drop at Wonodadi, Indonesia.

the function usually served by the intake, power canal, and forebay are essentially all served by a single structure. The pentock is almost non-existent.

At some sites (Fig. 26), water from the forebay can directly enter the turbine and, in that case, no penstock is required.

CONCLUSION

The dam or weir, intake, power conduit, forebay, and penstock are the principal components which can be used to convey water from a stream to the turbine for the purpose of generating power. It is essential to understand the function of each of these if a site is to be developed most cost-effectively. At the same time, it is necessary to be aware of the design and alternative materials which can be used. Then, only those components which contribute toward this purpose will be included and these will be designed and built in a fashion that meets the constraints imposed on those responsible for the task. An incomplete awareness of these factors will likely contribute to inappropriately designed schemes and frustrate efforts to exploit the small hydropower resources of a country.

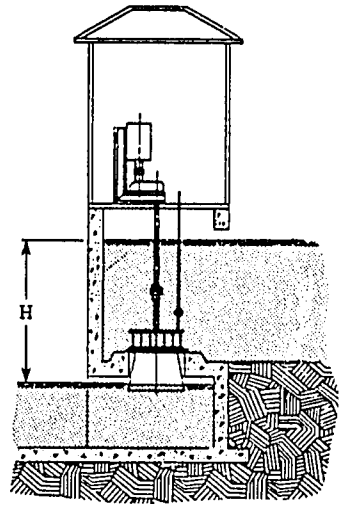


Fig. 26. An open flume hydropower plant requires no penstock.

Biographical sketch

Allen R. Inversin is a micro-hydro engineer with the Small Decentralized Hydropower Program of the National Rural Electric Cooperative Association (NRECA). Among other activities, he is presently documenting small hydropower efforts in developing countries so that lessons learned from past experiences can contribute to more effective hydropower projects in the future.

After six years in the Masters and Engineers program in aeronautics and astronautics at the Massachusetts Institute of Technology (MIT), he served six years in Laos as a professor of physics and mathematics at the National Teacher Training College near Vientiane. For the succeeding four years, he worked as an engineer with the Appropriate Technology Development Unit (ATDU) in Lae, Papua New Guinea, where he was involved in the design, development, testing, and installation of micro-hydro units.

DESIGN OF CIVIL WORKS FOR SMALL HYDROPOWER FACILITIES

by

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Muscatine, Iowa

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INTERNATIONAL CONSULTANTS IN ENGINEERING, ARCHITECTURE, PLANNING, AND MANAGEMENT

DESIGN OF CIVIL WORKS FOR SMALL HYDROPOWER FACILITIES

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Mr. Reischauer is currently head of the Water Resources Department at Stanley Consultants where he has been employed for the past 11 years. His education includes a B.S. degree in Civil Engineering from Iowa State University and an M.S. degree in Civil and Environmental Engineering from the University of Iowa. Professional experience includes studies, reports, and detailed design of civil works associated with hydroelectric facilities including dams, diversion works, penstocks, and power houses. Recent experience includes supervision and review of the final design of the civil works portion of the recently completed Malaysian small hydro program. During that effort, designs were prepared for 41 sites with capacities ranging from 50 kW to just over 1,000 kW with broad spectrum of hydraulic heads from 2 to over 400 meters.

Introduction

The civil works required for development of a small hydro facility normally make up a significant portion of the construction cost of the project. In order to minimize these costs, careful consideration must be given to project layout, design criteria used to size facilities, and materials of construction. Maintenance costs must also be considered since hydropower facilities are normally designed with a service life of 40 to 50 years and are generally operated for much longer times.

This paper is based primarily upon development of small hydro facilities in the country of Malaysia. The Government of Malaysia has embarked on a small hydro development plan with the objectives of acceleration and expansion of their ongoing rural electrification program and to reduce dependence on expensive diesel fuel for power generation. Previous rural electrification in Malaysia has been accomplished by extensions of major grid systems into the rural areas and installation of isolated diesel generators in remote villages. While the isolated diesel generators provide an important function, they have some significant limitations. Typically, the diesel plants are operated to provide electricity only 12 hours per day (6 p.m. to 6 a.m.), thus restricting development of full economic and social benefits. Difficulties with fuel delivery in addition to ever-rising cost and scarcity of fuel provided stimulus for developing alternative energy sources.

Small hydropower offers distinct potential for supplementing rural electrification in Malaysia. The hydro plants are small and adaptable to steep mountainous streams which are typically found in the remote areas.

Minimal transmission line lengths are required to serve nearby villages and fuel delivery problems become nonexistent. Because of limited natural resources, small hydropower does not provide the total answer to rural electrification or elimination of fuel oil dependency. However, it does contribute significantly to the solution.

Stanley Consultants was contracted by the Government of Malaysia to identify potential sites for small hydro development, conduct initial screening of these sites, prepare feasibility studies, develop international tender documents for 41 selected small hydro projects, prepare detailed cost estimates, and develop an implementation program for the 41 projects. Stanley Consultants was assisted in this work by Tudor Engineering Company of the USA and Sepakat Setia Perunding and SCM Perunding, both of Kuala Lumpur, Malaysia.

Overview

Small hydro for this program was defined as water power developments ranging from 50 to 500 kW installed capacity, with consideration also given to a few plants ranging up to 1,000 kW. Most of the 41 installations fall within the 200 to 400 kW ranges as shown below:

50-100 kW	2 Sites
100-200 kW	4 Sites
200-300 kW	11 Sites
300-400 kW	11 Sites
400-500 kW	4 Sites
500-750 kW	6 Sites
750-1,070 kW	3 Sites

The small hydro projects were designed for eventual interconnection with a regional or national grid. Sixteen of the plants will operate isolated for five to ten years before the grid tie. All grid tie sites will tend to support the grid at remote locations where low voltage problems have often been encountered.

In Malaysia, most streams have a fairly high base flow throughout the year and emphasis was therefore given to "run-of-river" installations. Most power house sites were positioned near the base of a waterfall or a steep series of rapids, with the diversion point located near the top of these features. A broad range of hydraulic heads was encountered as follows:

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Gross Head Meters	Number of Sites
2-10	3
10-15	2
15-30	4
30-50	5
50-60	9
60-80	6
80-100	7
100-130	4
425	1

Typical small hydro installations in Malaysia include a low diversion weir, intake chamber with trash rack, settling basin, penstock, power house, and tailrace. Penstock sizes range from 300 to 1,800 mm diameter; lengths range from 0.1 to 1.8 km with an average length of 0.8 km. Three types of turbines were recommended, depending upon the head and flow conditions: tubular for heads up to 20 m, crossflow for heads between 20 m and 30 m, and impulse for heads above 30 m. Necessary controls are provided for automatic operation of each plant following manual start-up.

Economic studies were performed to meet review standards of the World Bank. Small hydropower represents the least expensive means of providing 24-hour electricity to 38 of the 41 approved sites. The other three sites could theoretically be served more cost effectively by a 24-hour rural diesel station or direct connection to the grid.

Site Identification

A large portion of the small hydro study effort was expended in the identification and evaluation of potential sites. This effort was broken down into two phases. During the first phase, potential locations for small hydro development were identified. These sites were evaluated in the office, then a brief site visit was made to verify the overall suitability of each proposed project. Unsuitable sites were eliminated from further study. During the second phase, detailed investigations were made of each site recommended for development. This included field visits to select locations for principal project features, conduct field surveys of the site, and assess the power market.

During the site identification process, suitable sites were selected for small hydro development based upon their physical characteristics. These characteristics included sufficient hydraulic head and stream flow and adequate stream slope and other acceptable physical site characteristics. The sites had to be located within reasonable proximity of a potential power market and in an area where access to the site could be obtained.

Available topographic maps and geological survey maps were used to identify sites with suitable physical characteristics. For each potentially attractive site located, estimates of the gross head and stream slope were measured on the topographic maps. Topography, tributary stream intersection, and length of the penstock route were assessed. The surface area, dimensions, topographic character, and land use patterns of the drainage basin upstream of the proposed diversion point were also determined. Existing access roads and nearby villages were noted. For many of the proposed sites, several alternative development schemes were identified for comparative evaluation.

An attractive medium- or high-head site required a stream with at least 30 meters of fall and an average gradient greater than five to ten percent. Other desirable features included an existing access road at or near the site; a power market located within five to ten km from the site; and topographic features suitable for constructing a small diversion weir, a penstock, and a power house. The stream had to have a catchment area upstream from the diversion site greater than 10 km^2, and the catchment could not be a highly developed area. Low-head sites were judged similarly except that a lower head and larger catchment area were required, and an abrupt falls or existing dam was desirable.

Initial map studies and office screening identified 163 possible small hydro sites which were visited during the initial field reconnaissance. Each site was investigated to determine or confirm the following:

- Accessibility and type of access
- Possible locations for diversion weir and power house
- Approximate hydraulic head available between diversion weir and power house
- Estimated stream flow
- Topographic, geologic, and soil conditions examined for engineering feasibility and constructibility
- Information on site clearing and other characteristics that would facilitate site reconnaissance and survey efforts
- Proximity of the proposed market and any existing power plants or transmission lines
- Approximate number of households within the market communities

A revised estimate of the average plant output for each site was made following these field visits. The sites were then ranked according to desirability for future small hydro development. Each site was placed into one of the following catagories:

1. All site characteristics including accessibility, power potential, market, proximity, and geology indicate good likelihood for feasible small hydro development.

2. One or more of the site characteristics are marginal, but feasibility seems probable.

3. One or more of the site characteristics are in doubt for feasibility. However, the site is still attractive enough that further assessment is recommended.

4. One or more of the site characteristics preclude feasibility.

Of the 163 sites visited, 113 were found to lie generally within category 4, four sites were within catagory 3, and the remaining 46 were included in catagories 1 or 2. Sites included in catagory 4 were eliminated from further study; those in catagory 3 were examined further and then eliminated. The 46 sites in catagories 1 and 2 were retained for detailed site investigations.

Site Investigation

A detailed investigation was made for each of the 46 selected sites. This included development of detailed site hydrology, completion of site specific power market surveys, preliminary office optimization, field engineering investigations, and topographic surveys.

The preliminary office optimization consisted of assessing the optimum installed capacity of each small hydro site. This analysis used approximate hydraulic head, a computed flow duration curve, and market study interim results for each site. A brief optimization was then made to evaluate alternative project capacities and layouts. Alternative locations for the diversion works and power houses were evaluated to determine which configuration would yield the desired hydraulics with the shortest penstock length.

During the detailed field investigations, field teams visited each site for several days to select locations and prepare preliminary layouts for the principal project features. They also evaluated potential problems for project development and flagged the area for subsequent surveying. An important aspect of the field investigations was selecting the best available sites for the diversion weir and power house. In the case of sites at waterfalls, the diversion weir was normally located just upstream of the falls and the power house just below the falls. In most

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instances, however, the sites were located along a series of rapids which extended for several kilometers. In this situation, the facilities were normally located along the steepest portion of the rapids, and where practical, downstream of any major stream confluences. For sites serving isolated power markets, the hydraulic head of the proposed project was limited to that required to give a potential power production equal to the maximum demand of the market area. In most instances, however, the hydraulic head available was limited by physical constr.ints including obstructions along the penstock route making a longer penstock infeasible, a lack of good diversion weir or power house sites beyond the location selected, a gradual flattening of the stream slope beyond the selected project limits such that an extension of the project would be uneconomical, or a major stream confluence along the rapids requiring that the diversion weir be located below this confluence.

Field soil conditions were examined by observation of stream banks, canyon side slopes, stream channel upstream and downstream of the project features, existing excavations, and road and timber track cuts in the vicinity. These observations provided valuable information for judging stability of soils and assessing feasible construction methods for the penstock, access road, and other project features.

Detailed instrument surveys of each site were then made to develop topographic coverage at the locations of the diversion weir and the power house. Instrument surveys were also made of the stream and proposed penstock route between the diversion weir and the power house sites. This survey information was then used for developing final construction drawings.

Project Design

Following completion of the detailed site investigations, designs were prepared for each small hydro project. The location, orientation, overall dimensions, and critical elevations for the diversion weir, intake structure, settling basin, and power house were developed. The size, alignment, and grade of the penstock were established at this time. Turbine and generator type, installed capacity, and average annual energy production were also established. The alignment, size, and type of transmission line, substation, and access roads were developed. In some cases, economic comparisons of several design alternatives were made to determine the least costly layout. The end product of the design phase consisted of several sets of construction drawings, specifications and bidding documents for the 41 sites.

Standard Design

When several similar projects are being implemented simultaneously there are advantages associated with the development and use of standard designs. One of the main advantages is that the number of manhours and the

length of time required to develop bidding documents can be minimized. This helps hold down engineering costs and also gets the projects into the construction phase in as short a time as possible. Early construction will tend to reduce inflation-related costs and will also get the facilities into use at an early date. Another advantage of standardization includes minimizing the number of spare parts required for any mechanical equipment. Standardization will also simplify the training of operation and maintenance personnel. Well developed standard designs can also serve as a good basis for the development of future projects.

Care must be taken when developing standard designs to avoid grouping project features in such a way that some facilities are oversized and/or overdesigned. For example, all settling basins should not be constructed the same size based on the flow rate of the largest facility. Also, foundation designs for the various project features will differ depending upon whether the facilities are located on soil or rock. The layout and orientation of civil features associated with small hydro facilities are heavily dependent upon topography and other site specific characteristics. Standard designs for civil works must be developed with enough flexibility that they can be adapted to the unique features which exist at each site.

During the final design stage of the Malaysian project, standard designs were developed and adapted to each site. A total of 65 standard drawings were developed covering items ranging from diversion weirs and settling basins to penstock saddles, anchors, and thrust blocks. These standard designs were developed for this project based upon conditions which generally exist in the project area and would need to be modified if applied in other areas. The standard designs were developed to provide dependable facilities and to minimize design and construction effort on the project.

Site specific drawings were developed for each of the 41 project sites showing location, orientation, elevations, and similar information for principal project features. Appropriate standard drawings were then selected to supplement the site specific drawings and form a complete bidding package.

Photos showing the diversion weir site and power house site for a typical project are shown on Figure 1. Figures 2 through 6 present site specific drawings for the principal project features for this project. Figures 7 through 11 show some of the standard drawings which were used. Design criteria and features of the civil works portion of the project are discussed in the following sections.

Diversion Weir

The diversion works include the diversion weir or dam, an intake structure, and a settling basin. In a few instances where large ponding areas

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were created behind the weir, no settling basin was provided. Layout and sections of the diversion works at a typical site are shown on Figures 2 and 3. Diversion weirs were designed as concrete gravity structures with varying cross-sections depending upon the type of foundation available. The height of the diversion weir was designed to be the minimum required for proper functioning of the intake structure, settling basin, and penstock. Adequate head was provided for the following:

- Hydraulic head losses through the trash racks and bar screens at the penstock inlet
- Velocity head in the penstock at maximum discharge
- Sufficient submergence of the penstock intake to prevent vortex formation

An empirical formula for the minimum submergence to prevent vortex formation at the penstock entrance is as follows:

$$S = C\ V\ D^{0.5}$$

Where: S = required submergence from the water surface to the top of the penstock inlet, in meters.

C = coefficient ranging from 0.5 for intakes with symmetrical flow to 0.7 for intakes with lateral approach flow.

V = water velocity at the penstock entrance, in meters per second.

D = penstock inside diameter, in meters.

The diversion weir was designed with a normal overflow section across the stream and a raised section at the intake structure. The height of the raised section was selected to prevent overflow in this area until flows exceed the average annual peak flood discharge. Abutments subject to erosion were protected with rip rap. For rock abutments, no special treatment was provided. The only mechanical equipment provided at the diversion weir was a sluice gate to allow flushing of sediment that accumulates behind a weir. The sluice gate was located close to the intake structure to remove as much sediment as possible from the intake area.

Special emphasis was placed on location of the weir to minimize its height and related construction cost. In most cases, the weirs were sited on bedrock or connected to large boulders of adequate size to make movement during maximum flood flows unlikely. The diversion weir design depended upon the type of foundation in the stream channel. If the weir

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was to be constructed on a bedrock foundation, it was designed as a concrete gravity section and anchored into the bedrock. The gravity weir was lightly reinforced on the upstream and downstream faces. In instances where the diversion weir was located on sand or gravel foundations, a larger concrete gravity section was used. Upstream and downstream aprons with shallow cutoff walls were also provided to minimize the foundation pressure and increase the flowpath beneath the weir. This was important to decrease seepage and minimize potential for piping of water under the weir. The cutoff walls were designed for either concrete or steel construction. A standard drawing for a diversion weir located on soil is shown on Figure 7.

Intake Structure

The intake structure includes a trash rack and a concrete intake chamber constructed integrally with the diversion weir structure. A steel pipe was used to connect the intake structure to the downstream settling basin. The trash rack is designed and located on the side of the structure so that it is parallel to the stream flow. This arrangement permits a side inlet into the trash rack to minimize plugging with floating debris during high flow conditions. A standard drawing for an intake chamber is shown on Figure 8.

The design approach velocity for the trash rack is 0.5 m/s through the total gross opening located below minimum water surface. This low velocity allowed for some trash coverage of the rack between cleanings. Actual water velocity under partially plugged conditions could reach as high as 1 m/s without significant head loss through the racks. Orientation of the steel bars is in a vertical plane to facilitate cleaning with a hand rake. On this project the trash racks were mounted in a steel frame and slid into place in vertical channels. Another desirable arrangement would be to place the trash racks in an inclined position. This would be more costly to construct but the racks would be easier to clean. The trash racks can be removed and replaced by stop logs when closure is desired for maintenance or repairs of downstream structures. A cleaning platform was provided and located slightly above the average annual flood level.

Settling Basin

The settling basins were located downstream from the diversion weirs as near to the weirs as topography would permit. The shape and layout of the settling basins were arranged to best fit the site conditions and still function effectively. The reinforced concrete basins include an entrance chamber, settling chamber, exit chamber, and bypass channel. The function of the entrance chamber is to direct the flow either through the settling chamber during normal operation or through the bypass channel while the settling chamber is being flushed or cleaned out. Simple

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stop logs in alternate positions are used to direct water into the desired course. An overflow weir was provided on the stream side wall of the entrance chamber to control any water overspillage. A standard drawing for a settling basin is shown on Figure 9.

The settling velocity in the basin depends primarily upon the surface area and consequently on the surface loading or overflow rate of the basin. A larger surface area will result in a slower settling velocity and smaller particles will be removed. The settling basins were sized to allow sand particles larger than about 0.5 mm in diameter to be removed. In some cases, where streams carried a heavy sediment loading, chambers were sized larger to settle out particles smaller than 0.5 mm in diameter.

The settling velocity of a settling basin is given by the following formula:

$$V_s = 60 \frac{Q}{A_s}$$

Where: V_s = basin settling velocity, meter per minute.

Q = flow rate through basin, cubic meters per second

A_s = surface area of basin, square meters

Any particle with a settling velocity greater than the basin settling velocity will theoretically be removed. The settling velocity of a partial depends primarily on its size and material. The settling velocity of quartz particles in water ranges from approximately 1.0 meter per minute for a 0.15 mm particle to approximately 5.0 meter per minute for a 0.85 mm particle. A 0.5 mm particle has a settling velocity of about 3.0 meters per minute.

A gated sluiceway one meter square was located in the side wall of the settling basin. This gate is normally closed but can be opened to flush out sediment and aid in cleaning out the structure. A bar screen was provided at the settling basin outlet to remove any small floating debris which may have passed through the primary trash racks. Also branches or twigs falling into the settling basin will be removed prior to entrance into the penstock.

The settling basins are typically located in areas subject to inundation during major floods. The structures have been designed to withstand uplift pressures during flood conditions. At sites where the basins were located on sand or gravel, care was taken to avoid high velocity zones in the floodplain where underscouring could be a problem.

Penstock

Several materials were considered for penstock construction. Prestressed concrete pipe was rejected because of the excess weight and difficult handling in the rugged terrain. Different types of plastic and fiberglass reinforced materials had possible application because of their light weight and ease of handling. These materials were not readily available in Malaysia and they did not have a proven history for penstock applications. Ductile iron pipe was considered an acceptable material for buried applications. However, due to cost and lack of availability, it was not used on this project. Steel was considered to be the best penstock material to meet the rugged and varying small hydro applications in Malaysia and was selected for use on all of the projects.

The exterior of the steel penstock is coated for above and below ground protection, and the interior is lined to prevent corrosion and to maintain low friction losses. The penstock is normally constructed aboveground in rock areas and buried where soil conditions permit. Low concrete piers are used for most aboveground supports. For sections crossing ravines, the penstock is supported with steel supports where concrete piers are not practical. Sections located near the diversion weir which might be endangered by flood debris or rocks are encased in concrete for added protection and to resist flotation if the penstock is dewatered during a flood. Flexible joints are specified for exposed penstock where required to allow expansion and contraction capability between anchor points.

Air release and vacuum valves are provided at intermediate high points along the line to prevent air binding due to trapped air and to release air during penstock filling. They are also required to prevent possible collapse of the penstock during draining operations. Drain valves are provided at intermediate low points to allow the penstock to be drained and flush any trapped sediment from the pipe. Where possible, the penstocks have been placed to avoid intermediate low and high points, thus minimizing the need for the air release and vacuum valves and drain valves. Anchor blocks and thrust blocks have been located at changes in direction and on steep slopes to hold the pipe in place. Penstock plan and profile drawings for a typical site are shown on Figures 5 and 6. A standard drawing for horizontal thrust blocks located on rock is shown on Figure 10.

The optimum penstock diameter was selected based on a series of calculations comparing energy production with penstock costs. The nearest commercial size to the optimum diameter was used as the penstock size. A detailed analysis of pipe wall thickness was made to determine class of

pipe required to accommodate anticipated stresses. The following empirical formula which was developed for this project can be used to determine the optimum penstock diameter for steel penstocks:

$$D = 1.33\ (Q^{.50}/Hg^{.25})^{.53}$$

Where: D = optimum penstock diameter, in meters.

Q = design flow rate, in cubic meters per second.

Hg = gross head, in meters.

Power House and Yard

The power houses were sized to contain the turbine, generator, governor, turbine shutoff valve, oil pressure set, fly wheel when required, control cubicle, and speed increaser. The equipment is designed for indoor installation. A stepup transformer and transmission line takeoff structure were located outside the power house. The top of the power house floor slab was set with a minimum of 0.5 meters freeboard above the 50-year flood level. The power house foundation consists of reinforced concrete footings with a concrete slab on grade placed on level soil or rock. A separate equipment foundation is provided for the turbine-generator unit. A terminal penstock anchor/thrust block was provided in conjunction with the power house foundation. Floor trenches were provided for main power and control cables in the power house to minimize overhead obstructions. Other wiring was routed in galvanized conduit.

The power house superstructure was designed with adequate height and access to accommodate the anticipated equipment. Provisions are included to permit dismantling of equipment within the building by means of a movable hoist mounted on a portable jib. Where size and arrangement permit, the turbine and generator are proposed for skid mounting.

Buildings are constructed of readily available material normally used in the area. Steel roof trusses carry the roof which slopes in two directions. Corrugated coated steel roofing was used. The roof trusses are supported on reinforced concrete columns firmly tied by ground beams and roof beams. The panels between columns are filled with masonry. Louvers are provided for natural cross ventilation of the power house. Sanitary facilities are not provided because the power house does not require regular operator attention. A standard drawing for a power house is shown on Figure 11.

The power house yard was designed with adequate space for turning and parking vehicles. The area will be surfaced with a layer of crushed rock and a fence will be constructed around the power house and yard. A station grounding system is provided in the power house yard around the

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power house and switchyard and along the fence for equipment protection and personal safety. A power house and yard layout for a typical site is shown on Figure 4.

Access Roads

Many of the projects are located in remote areas. Access to the project site is required for construction, equipment delivery, operation, and maintenance. A properly designed permanent access road will be constructed from the nearest adequate public or private road. An easement of approximately 10 m is required, suitably widened in hilly terrain where cut and fill sections occur. Whenever possible, existing logging tracks or other nearby access roads will be upgraded and used for the permanent site access.

The permanent access roads are designed to be approximately three meters wide and cross sloped for proper drainage. Road surfacing includes a 100 mm layer of gravel to minimize maintenance. The roads are designed for very low speed traffic with grades as high as 15 percent. Curves have a centerline radius of not less than 15 m and rock cuts are avoided where possible. Ditches and culverts are placed as needed, and all the stripped areas are seeded for stabilization. In some areas, small bridges are required. These are designed for simple timber construction. For some of the wider streams, low water crossings are used. In such cases, vehicle access is possible only during low flow conditions when the stream can be forded. In these instances, small suspension bridges or cableways are provided for foot traffic to the site during high flow periods.

Construction Cost Estimates

Care must be exercised when preparing cost estimates since the future of a proposed project is at stake. If the estimates are too high, the project may appear to be infeasible and development will not occur even though a more accurate estimate might have shown the project to be feasible. Conversely, if the cost estimates are substantially below the low construction bid, sufficient money may not be available for project construction and the project future may be in doubt.

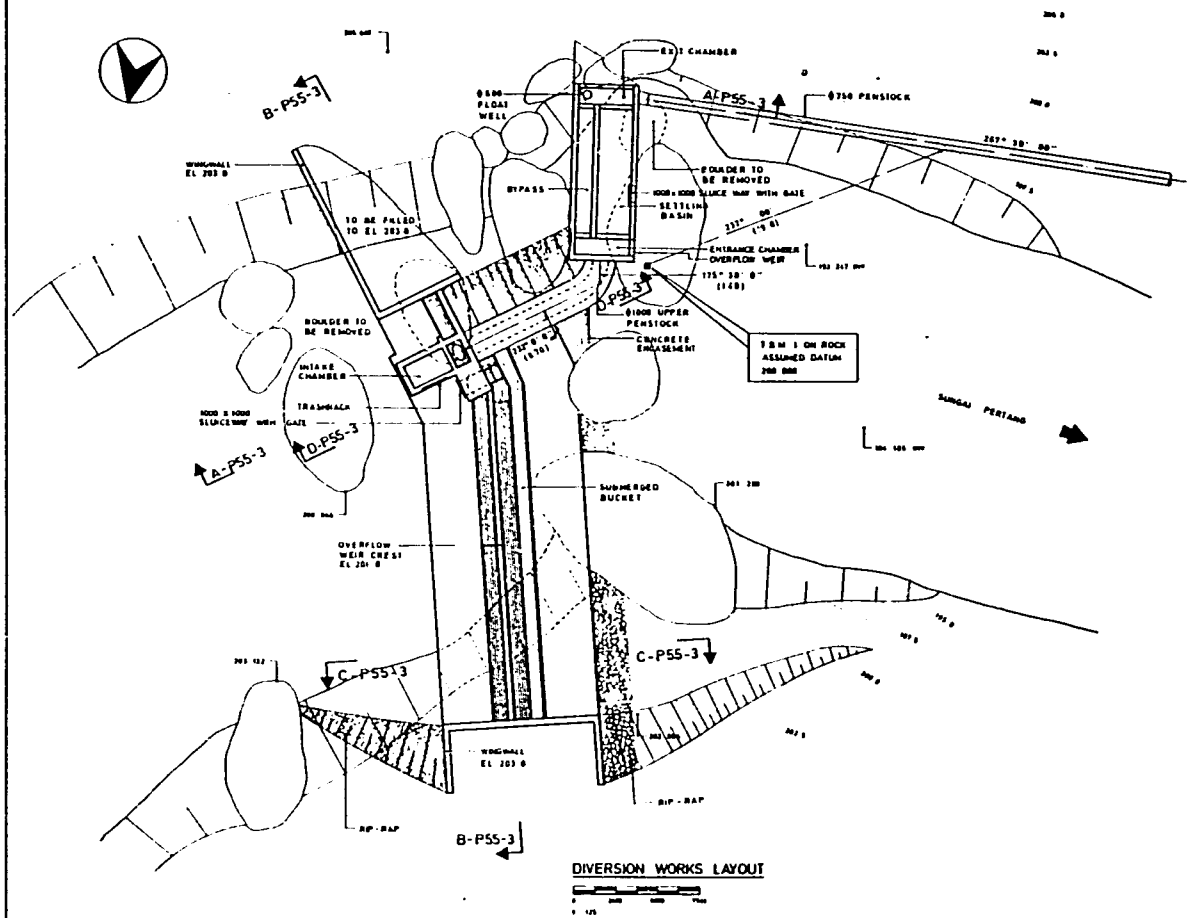
Construction cost estimates for civil works are normally developed by estimating quantities of various work items and then applying unit costs to each item. Typical civil work items include site clearing, earth excavation, rock excavation, concrete, reinforcing steel, backfill, rip rap, penstock pipe, stop logs, trash racks, etc. Unit costs are usually based upon recent bids for similar work in the project area. The construction cost estimates normally include allowances for mobilization and contingencies.

DIVERSION WEIR SITE (LOOKING UPSTREAM)

POWERHOUSE SITE

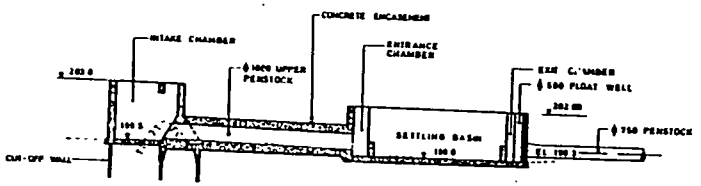
RAPIDS BETWEEN DIVERSION WEIR
AND POWERHOUSE

SITE PHOTOS
Figure 1

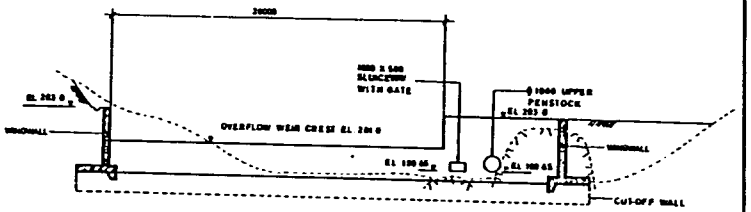


DIVERSION WORKS LAYOUT

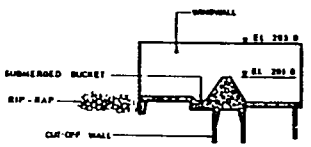
Figure 2



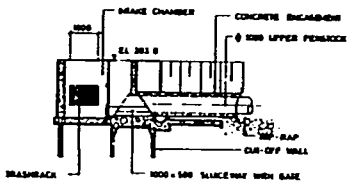
SECTION A-P55-3 / P55-2



SECTION B-P55-3 / P55-2



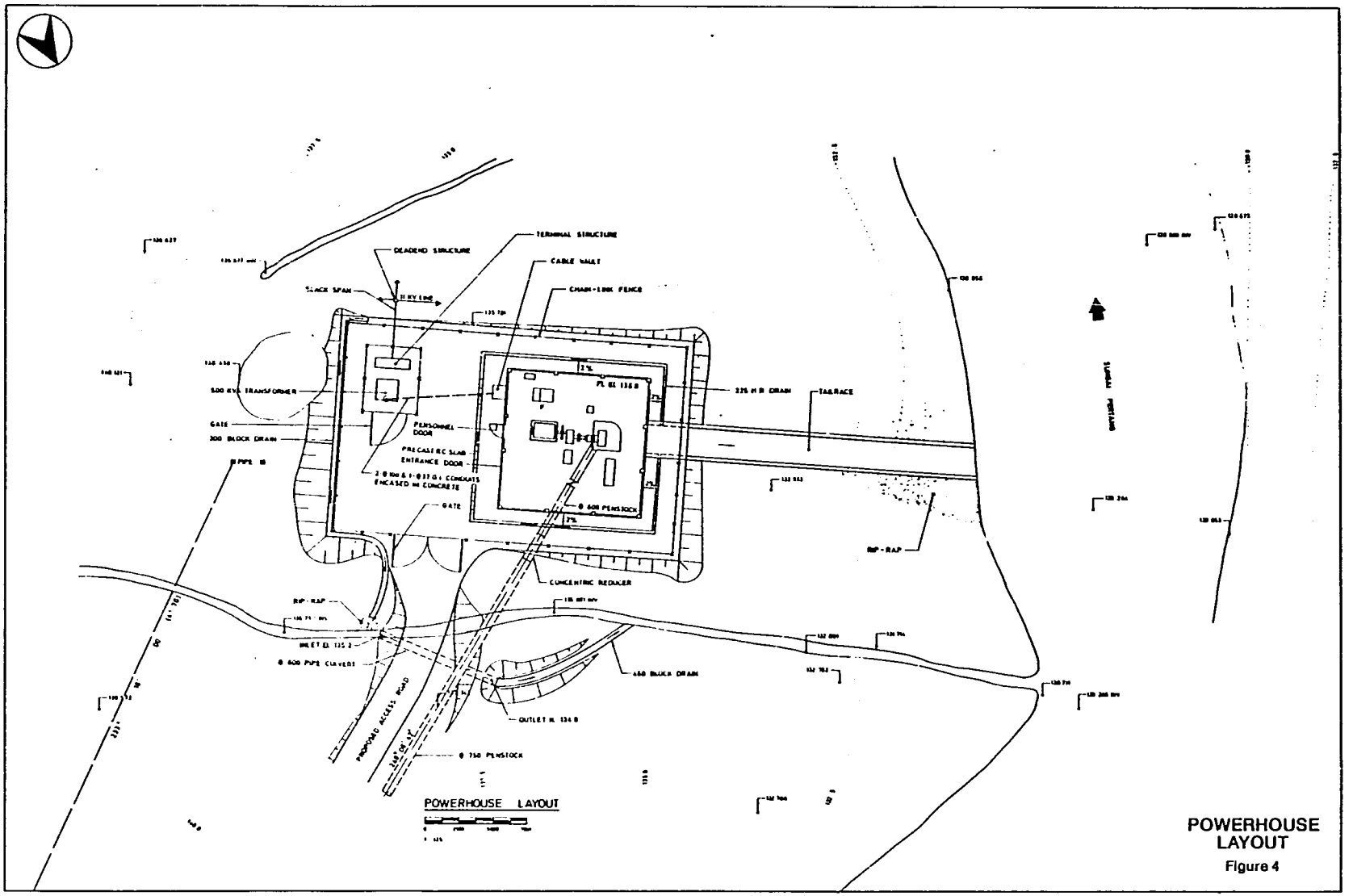
SECTION C-P55-3 / P55-2



SECTION D-P55-3 / P55-2

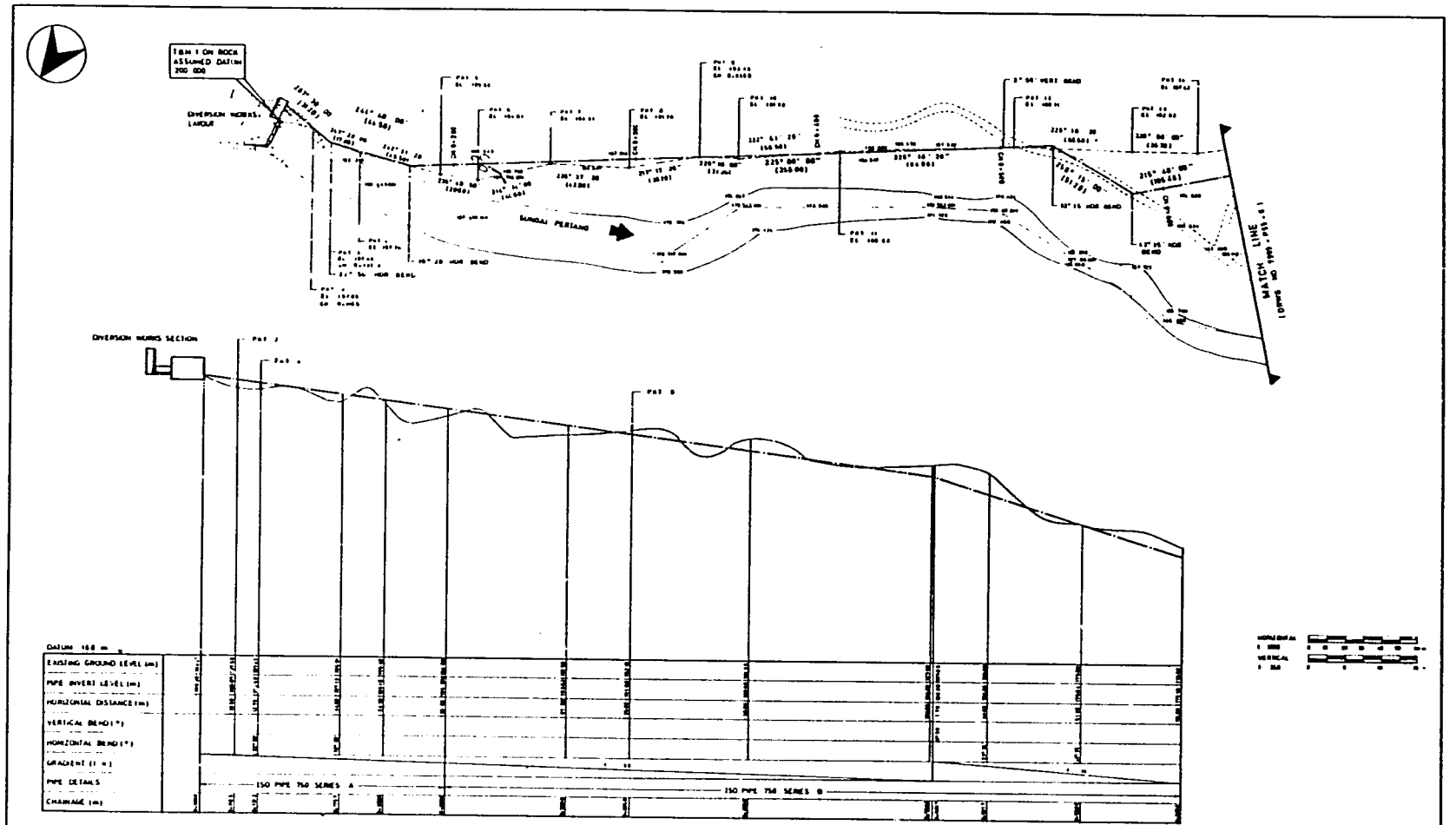
DIVERSION WORKS SECTION

Figure 3



POWERHOUSE LAYOUT

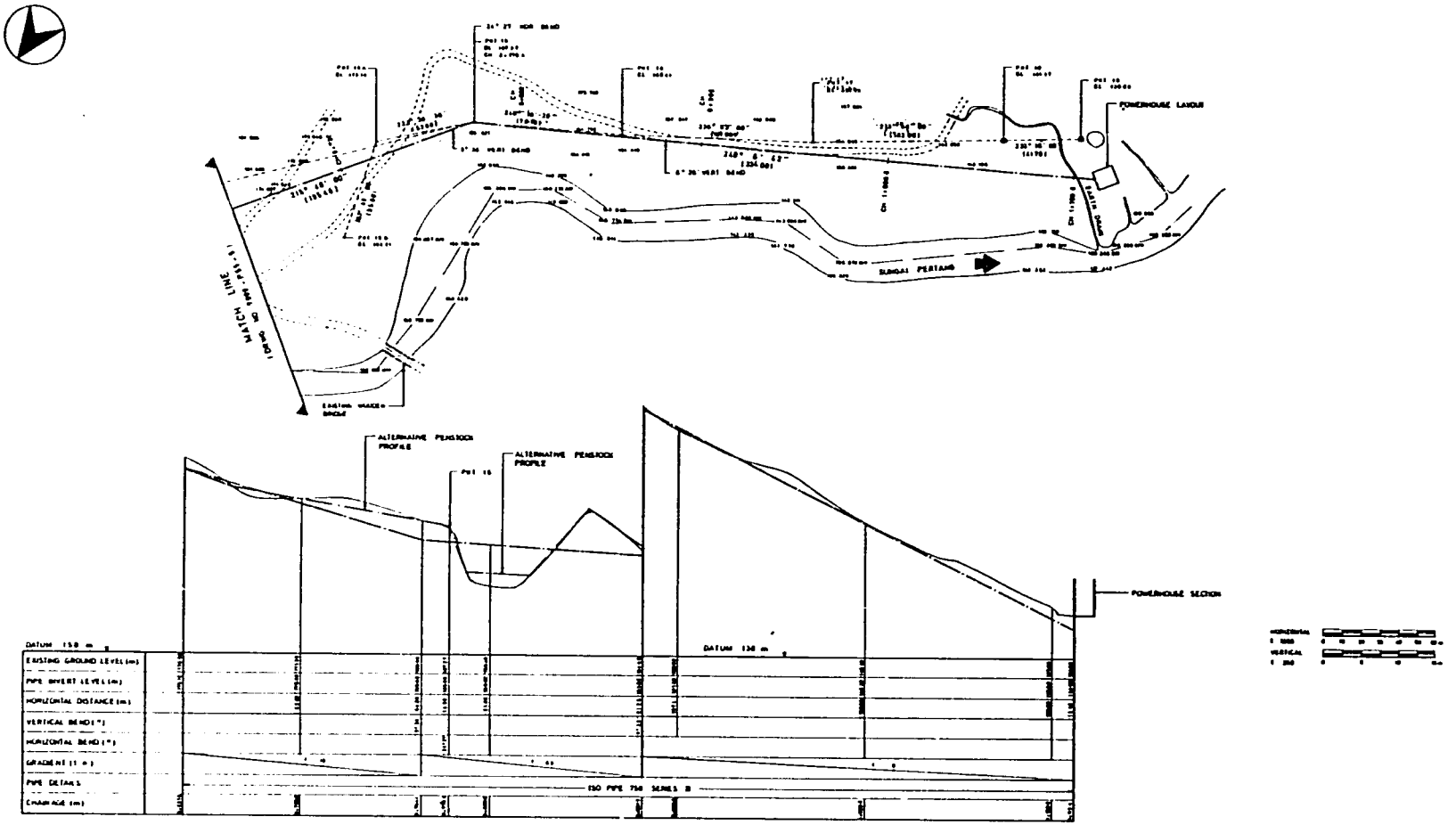
Figure 4



PENSTOCK PLAN AND PROFILE
SHEET 1

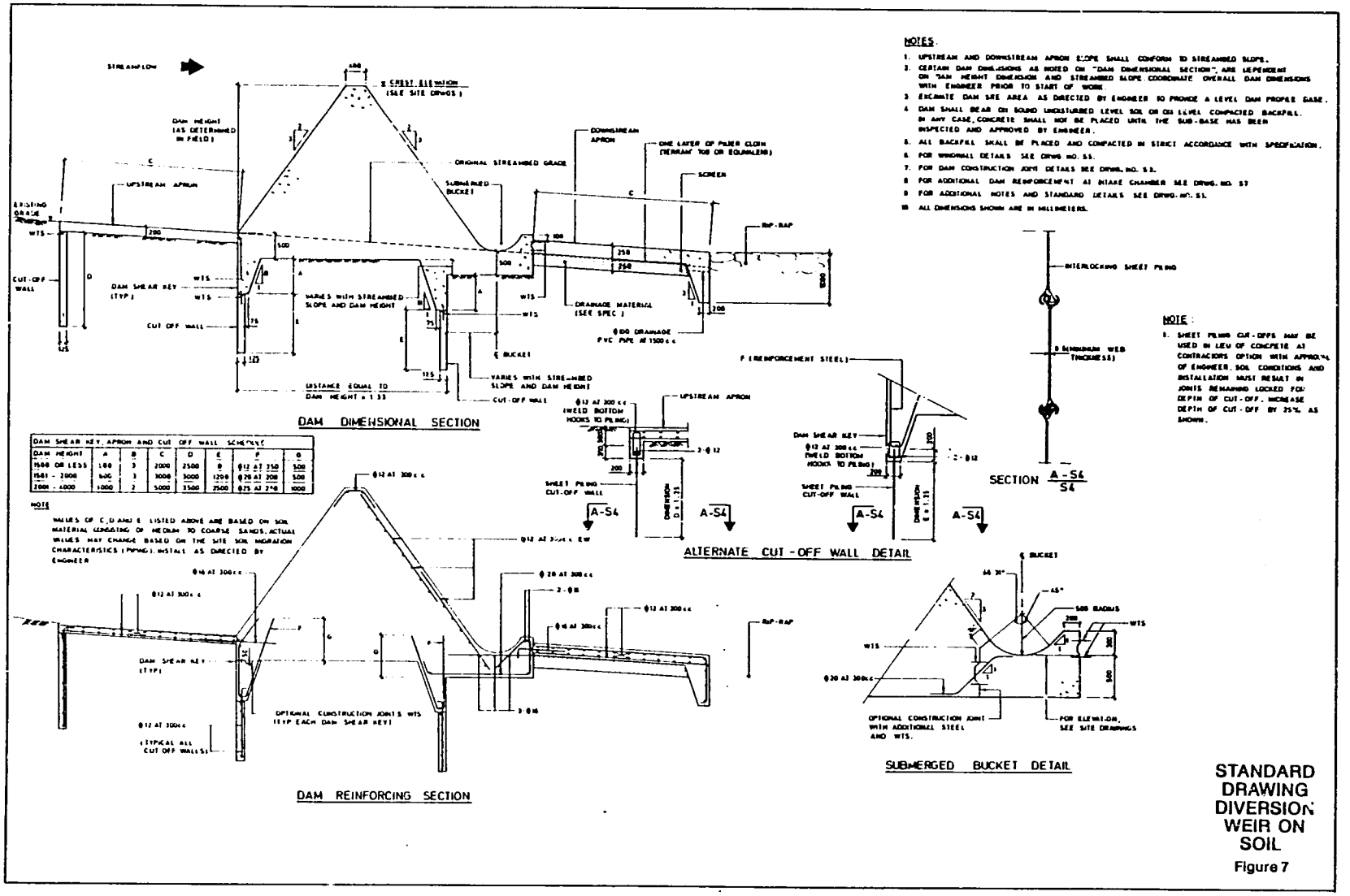
Figure 5

7999



PENSTOCK PLAN AND PROFILE
SHEET 2

Figure 6



NOTES:

1. UPSTREAM AND DOWNSTREAM APRON SLOPE SHALL CONFORM TO STREAMBED SLOPE.
2. CERTAIN DAM DIMENSIONS AS NOTED ON "DAM DIMENSIONAL SECTION", ARE DEPENDENT ON DAM HEIGHT DIMENSION AND STREAMBED SLOPE. COORDINATE OVERALL DAM DIMENSIONS WITH ENGINEER PRIOR TO START OF WORK.
3. EXCAVATE DAM SITE AREA AS DIRECTED BY ENGINEER TO PROVIDE A LEVEL DAM PROFILE BASE.
4. DAM SHALL BEAR ON SOUND UNDISTURBED LEVEL SOIL OR ON LEVEL COMPACTED BACKFILL. IN ANY CASE, CONCRETE SHALL NOT BE PLACED UNTIL THE SUB-BASE HAS BEEN INSPECTED AND APPROVED BY ENGINEER.
5. ALL BACKFILL SHALL BE PLACED AND COMPACTED IN STRICT ACCORDANCE WITH SPECIFICATION.
6. FOR WINGWALL DETAILS SEE DRWG. NO. S5.
7. FOR DAM CONSTRUCTION JOINT DETAILS SEE DRWG. NO. S5.
8. FOR ADDITIONAL DAM REINFORCEMENT AT INTAKE CHAMBER SEE DRWG. NO. S7
9. FOR ADDITIONAL NOTES AND STANDARD DETAILS SEE DRWG. NO. S1.
10. ALL DIMENSIONS SHOWN ARE IN MILLIMETERS.

NOTE:

1. SHEET PILING CUT-OFFS MAY BE USED IN LIEU OF CONCRETE AT CONTRACTOR'S OPTION WITH APPROVAL OF ENGINEER. SOIL CONDITIONS AND INSTALLATION MUST RESULT IN JOINTS REMAINING LOCKED FOR DEPTH OF CUT-OFF. INCREASE DEPTH OF CUT-OFF BY 25% AS SHOWN.

DAM DIMENSIONAL SECTION

ALTERNATE CUT-OFF WALL DETAIL

SUBMERGED BUCKET DETAIL

DAM REINFORCING SECTION

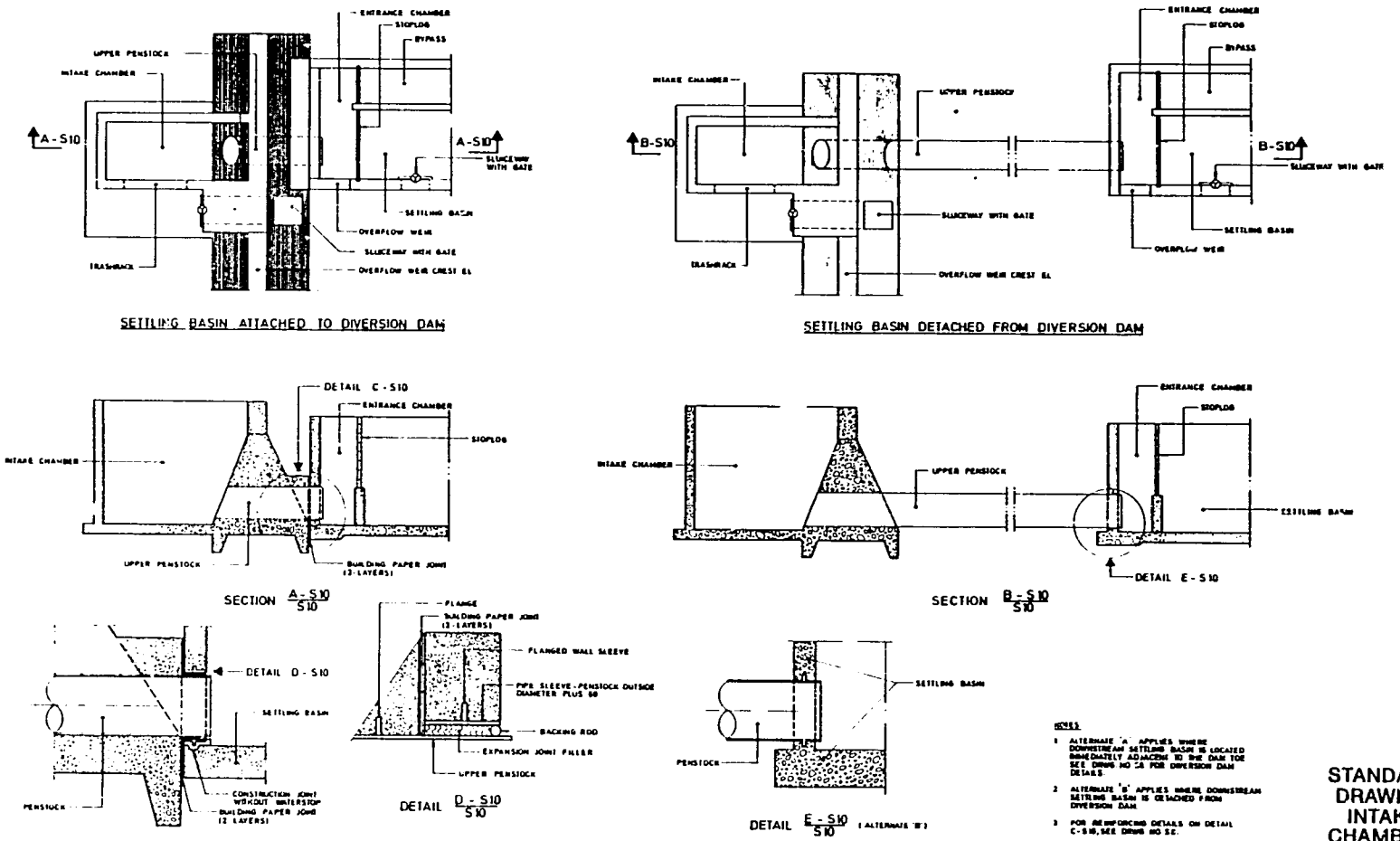
DAM SHEAR KEY, APRON AND CUT OFF WALL SCHEDULE								
DAM HEIGHT	A	B	C	D	E	F	G
1500 OR LESS	100	3	2000	2500	0	Ø12 AT 350	500
1501 - 2000	600	3	3000	3000	1200	Ø20 AT 200	500
2001 - 4000	1000	2	5000	3500	2500	Ø25 AT 250	1000

NOTE

VALUES OF C, D AND E LISTED ABOVE ARE BASED ON SOIL MATERIAL CONSISTING OF MEDIUM TO COARSE SANDS. ACTUAL VALUES MAY CHANGE BASED ON THE SITE SOIL MIGRATION CHARACTERISTICS (PIPING). INSTALL AS DIRECTED BY ENGINEER

STANDARD DRAWING DIVERSION WEIR ON SOIL

Figure 7

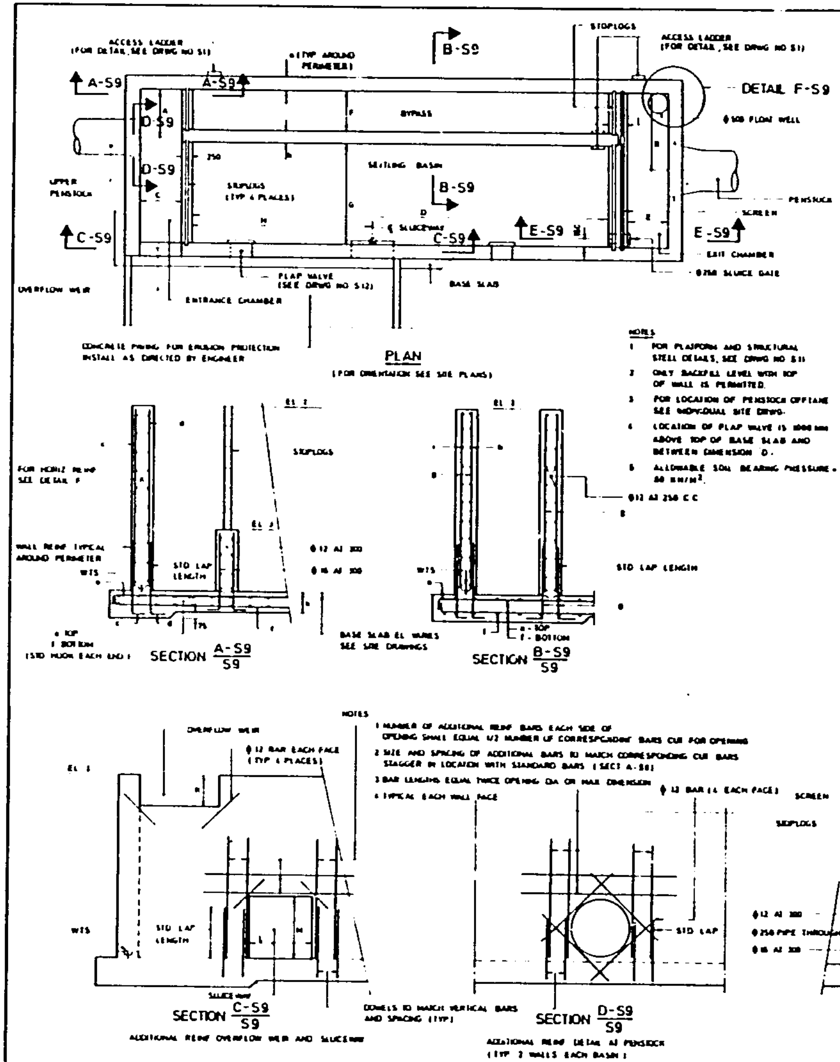


NOTES:

1. ALTERNATE "A" APPLIES WHERE DOWNSTREAM SETTLING BASIN IS LOCATED IMMEDIATELY ADJACENT TO THE DAM TOE SEE DRWG NO 2A FOR DIVERSION DAM DETAILS.
2. ALTERNATE "B" APPLIES WHERE DOWNSTREAM SETTLING BASIN IS DETACHED FROM DIVERSION DAM.
3. FOR REINFORCING DETAILS ON DETAIL C-S10, SEE DRWG NO 5E.

STANDARD DRAWING INTAKE CHAMBER

Figure 8



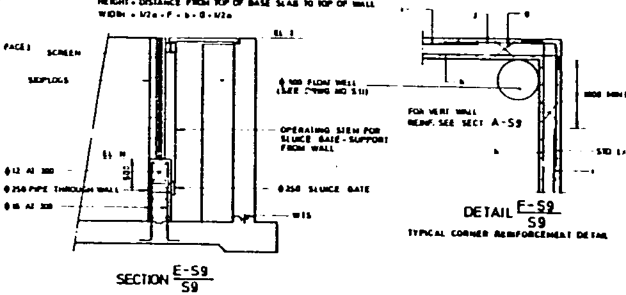
SETTLING BASIN SITE SCHEDULE

SITE	TYPE	A	B	C	D	E	F	G	H	I	J	K	L	M	N	COMMENTS
J-12	1	1.2	1.2	1.0	8.0	1.0	1.0	1.0	2.7	203.00	210.50	0.5	1.0	1.0	210.50	
J-14	2	1.3	1.2	1.0	4.0	1.0	1.0	1.0	1.3	182.00	90.50	0.5	1.0	1.0	90.50	
J-20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	EXISTING DIVERSION WORKS
K-2	3	2.1	0	1.5	12.5	2.0	1.0	3.0	12.0	300.00	207.50	0.5	1.0	1.0	207.50	[illegible]
K-6	3	2.6	[illegible]	1.0	13.0	2.0	1.0	4.0	4.0	101.50	88.00	0.5	1.0	1.0	90.00	[illegible]
K-7	1	1.5	1.5	1.0	7.0	1.0	1.0	1.5	2.3	272.00	280.00	0.5	1.0	1.0	280.00	
K-10	2	1.0	1.0	1.0	11.0	1.0	1.0	2.0	3.7	180.50	126.00	0.5	1.0	1.0	166.00	
K-13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	NO SETTLING BASIN
N-10	3	3.3	3.3	1.5	10.0	1.5	1.5	5.0	5.3	184.50	182.00	0.5	1.0	1.0	182.00	
N-21	3	0	0	1.5	11.0	1.5	1.5	3.5	3.7	58.70	48.70	0.5	1.0	1.0	48.70	[illegible]
N-42	1	1.6	1.3	1.0	6.5	1.0	1.0	1.0	[illegible]	500.70	480.00	0.3	1.0	1.0	480.00	
N-44	1	1.7	1.7	1.0	9.0	1.0	1.0	2.0	3.0	201.00	191.50	0.3	1.0	1.0	191.50	
N-54	1	1.7	1.4	1.0	8.0	1.0	1.0	1.5	2.7	203.00	200.40	0.5	1.0	1.0	201.00	
N-63	2	2.2	1.7	1.0	10.0	1.0	1.0	1.5	3.3	152.40	140.00	0.5	1.0	1.0	140.00	
N-64	1	1.2	1.2	1.0	8.5	1.0	1.0	1.0	3.2	302.00	200.50	0.5	1.0	1.0	200.50	
P-6	2	2.3	1.0	1.0	11.5	1.0	1.0	2.5	3.0	282.50	300.00	0.5	1.0	1.0	200.00	
P-21	1	1.6	1.6	1.0	5.5	1.0	1.0	2.0	1.6	151.00	140.00	0.5	1.0	1.0	140.00	
P-22	4	1.3	1.2	1.0	3.0	1.0	1.0	1.0	1.0	100.00	90.50	0.5	1.0	1.0	90.50	
P-36	4	1.2	1.2	1.0	10.0	1.0	1.0	1.0	3.3	320.00	325.00	0.5	1.0	1.0	325.00	
P-50	6	3.6	3.6	2.0	14.0	2.0	2.0	6.0	6.0	200.00	187.00	0.5	1.0	1.0	187.00	
P-52	3	1.3	3.5	1.0	7.0	1.0	1.0	3.5	3.3	304.50	301.50	0.5	1.0	1.0	301.50	
P-54	6	6.0	4.0	1.5	14.0	6.5	1.5	6.0	6.7	53.30	54.30	0.5	1.0	1.0	54.30	
P-55	1	1.6	0	1.0	8.5	1.0	1.0	3.0	3.0	302.05	300.00	0.5	1.0	1.0	300.00	[illegible]
P-57	4	2.2	2.3	1.0	10.0	1.0	1.0	2.0	3.3	251.50	240.00	0.5	1.0	1.0	245.50	
P-60	1	1.6	1.6	1.0	12.0	1.0	1.0	2.0	4.0	454.00	448.00	0.5	1.0	1.0	448.00	
P-68	5	1.0	1.0	1.0	8.0	1.0	1.0	3.0	3.0	303.30	300.70	0.5	1.0	1.0	300.70	
P-72	1	2.3	2.6	1.0	10.0	1.0	1.2	2.0	3.3	205.00	201.00	0.5	1.0	1.0	201.00	
P-76	5	1.4	1.4	1.0	5.5	1.0	1.0	1.5	1.0	201.00	190.50	0.5	1.0	1.0	190.50	
P-81	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	NO SETTLING BASIN
T-1	3	0	3.5	1.5	12.5	1.5	1.5	5.0	4.3	132.00	130.00	0.5	1.0	1.0	130.00	[illegible]
T-5	1	1.6	1.3	1.0	7.5	1.0	1.0	1.5	2.6	301.00	[illegible]	0.5	1.0	1.0	300.00	
T-7	1	2.6	1.0	1.0	8.5	1.0	1.6	2.0	3.3	100.00	87.30	0.5	1.0	1.0	87.30	
T-13	2	1.5	1.4	1.0	7.0	1.0	1.0	1.5	3.3	101.00	98.50	0.5	1.0	1.0	98.50	
T-16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	NO SETTLING BASIN
T-20	1	1.3	1.4	1.0	8.5	1.0	1.0	1.0	2.0	202.00	200.20	0.5	1.0	1.0	200.20	
T-24	3	3.0	2.3	1.0	8.0	1.0	1.0	3.0	2.7	152.00	100.00	0.5	1.0	1.0	100.00	
T-29	2	1.5	1.5	1.0	11.0	1.0	1.0	1.5	3.7	101.00	99.70	0.5	1.0	1.0	98.70	
T-30	5	1.0	1.0	1.0	9.0	1.0	1.0	2.0	3.0	200.00	106.00	0.5	1.0	1.0	106.00	
T-35	2	1.0	1.0	1.0	11.0	1.0	1.0	2.0	3.7	307.00	200.70	0.5	1.0	1.0	200.70	
T-36	3	2.0	1.7	1.0	14.0	1.0	1.0	2.0	3.7	102.30	100.20	0.5	1.0	1.0	102.30	
T-37	1	1.5	1.5	1.0	8.5	1.0	1.0	1.5	2.0	102.30	100.30	0.5	1.0	1.0	100.30	

SETTLING BASIN DETAIL SCHEDULE

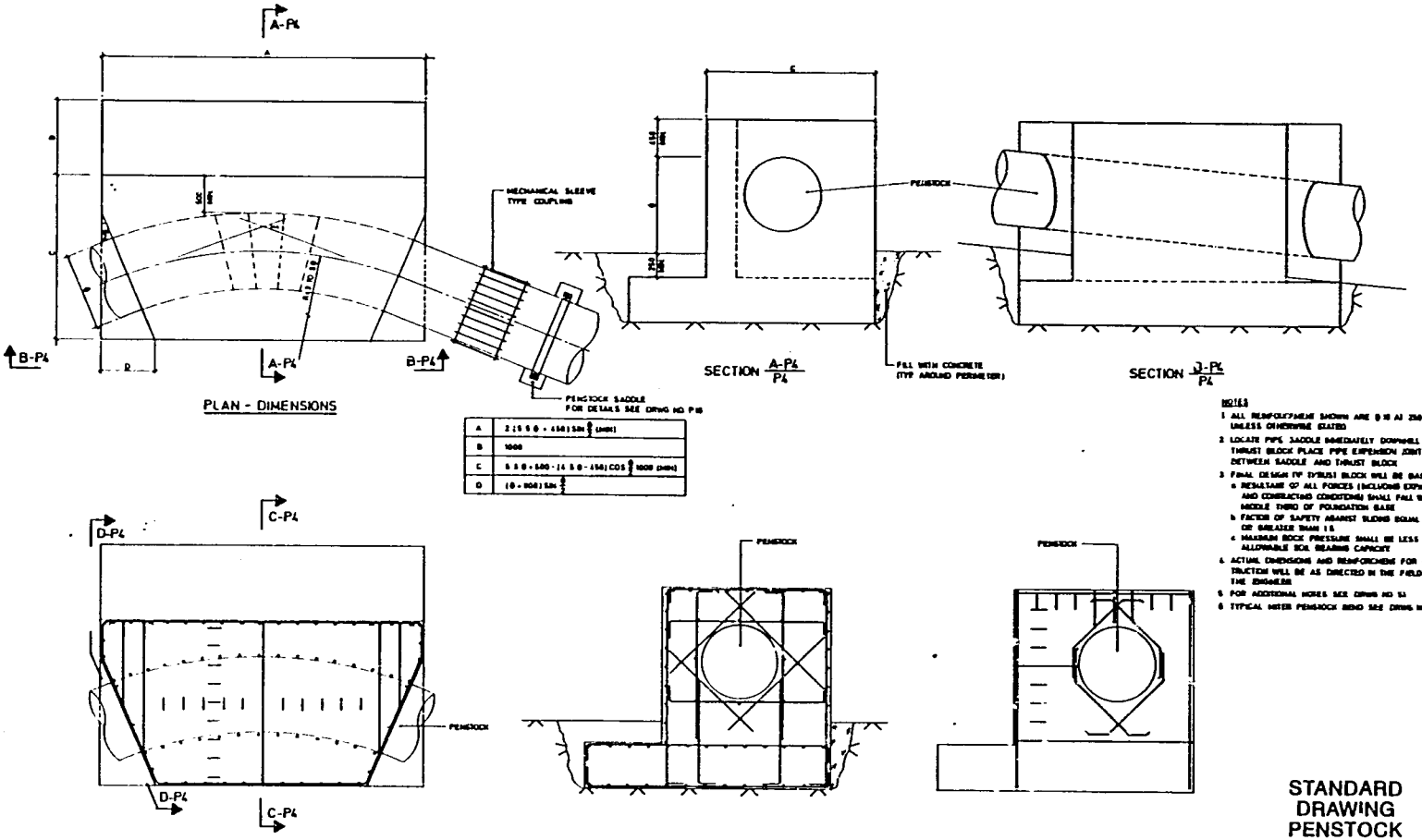
TYPE	HEIGHT	WIDTH	a	b	c	d	e	f	g	h	i	j	k	l	REMARK
1	3000	3000	300	300	Ø20 AT 150	Ø20 AT 150	Ø20 AT 150	Ø20 AT 150	Ø20 AT 150	Ø12 AT 200	Ø12 AT 200	Ø12 AT 150	350	400	WITHOUT BACKFILL
2	4000	3000	400	400	Ø25 AT 150	Ø25 AT 150	Ø25 AT 150	Ø25 AT 150	Ø25 AT 150	Ø12 AT 175	Ø12 AT 175	Ø16 AT 175	450	400	
3	4000	7000	400	400	Ø25 AT 150	Ø25 AT 150	Ø25 AT 150	Ø25 AT 150	Ø25 AT 150	Ø16 AT 175	Ø16 AT 175	Ø20 AT 175	450	400	
4	3000	3000	300	300	Ø20 AT 125	Ø20 AT 125	Ø20 AT 125	Ø20 AT 125	Ø20 AT 125	Ø16 AT 200	Ø16 AT 200	Ø16 AT 200	350	400	WITH BACKFILL
5	4000	3000	400	400	Ø25 AT 125	Ø25 AT 125	Ø25 AT 125	Ø25 AT 125	Ø25 AT 125	Ø12 AT 150	Ø12 AT 150	Ø16 AT 150	450	400	
6	4000	7000	400	400	Ø25 AT 125	Ø25 AT 125	Ø25 AT 125	Ø25 AT 125	Ø25 AT 125	Ø16 AT 175	Ø16 AT 175	Ø16 AT 175	450	400	

HEIGHT = DISTANCE FROM TOP OF BASE SLAB TO TOP OF WALL
WIDTH = 1/2a + F + b + G + 1/2a



STANDARD DRAWING SETTLING BASIN

Figure 9



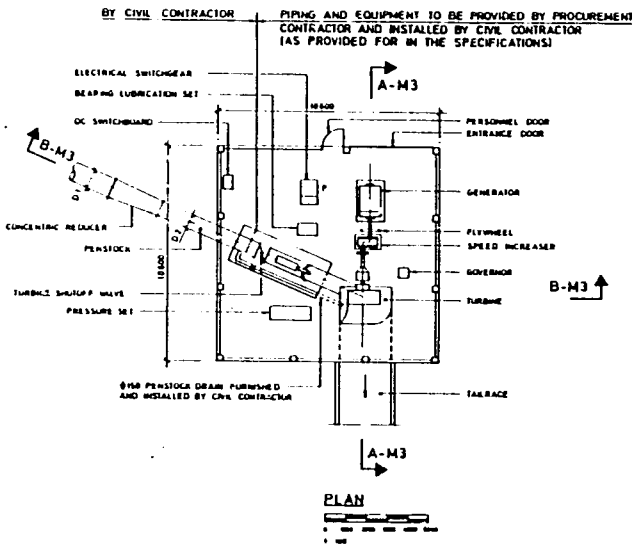
A	2 (5 5 0 + 150) SIN θ (MM)
B	1000
C	5 5 0 + 500 - (4 5 0 - 150) COS θ 1000 (MM)
D	(0 + 900) SIN θ

NOTES

1. ALL REINFORCEMENT SHOWN ARE Ø 16 AT 250 c c UNLESS OTHERWISE STATED
2. LOCATE PIPE SADDLE IMMEDIATELY DOWNHILL OF THRUST BLOCK PLACE PIPE EXPANSION JOINT BETWEEN SADDLE AND THRUST BLOCK
3. FINAL DESIGN OF THRUST BLOCK WILL BE BASED ON
   a. RESULTANT OF ALL FORCES (INCLUDING EXPANDING AND CONTRACTING CONDITIONS) SHALL FALL WITHIN MIDDLE THIRD OF FOUNDATION BASE
   b. FACTOR OF SAFETY AGAINST SLIDING EQUAL TO OR GREATER THAN 1.5
   c. MAXIMUM ROCK PRESSURE SHALL BE LESS THAN ALLOWABLE SOIL BEARING CAPACITY
4. ACTUAL DIMENSIONS AND REINFORCEMENT FOR CONSTRUCTION WILL BE AS DIRECTED IN THE FIELD BY THE ENGINEER
5. FOR ADDITIONAL NOTES SEE DRWG NO S1
6. TYPICAL INTER PENSTOCK BEND SEE DRWG NO P2

STANDARD DRAWING PENSTOCK HORIZONTAL THRUST BLOCK ON ROCK

Figure 10



DIMENSION SCHEDULE										
SITE	D1	D2	A(1)	B(1)						
J - 12	600	450	1300	1150						
J - 16	500	500	1230	1000						
J - 29	(2)	350	1000	800						
K - 4	750(3)	600	2150	1800						
K - 7	600	450	1300	1150						
K - 1[illegible]	800	600	2300	2000						
K - 4[illegible]	450	300	1000	2300						
K - 44	750	600	1800	1500						
K - 51	600	450	1530	1270						
K - 53	800	600	2250	1000						
K - 64	600	450	1300	1150						
P - 21	600	450	1300	1150						
P - 22	300	250	1220	1000						
P - 30	500	450	1300	1150						
P - 53	700	500	1300	1150						
P - 55	750	600	2150	1800						
P - 57	600	500	2150	1600						
P - 68	700	500	1300	1150						
P - 69	600	500	2150	1600						
P - 72	800	600	2300	2000						
P - 76	600	450	1300	1150						
T - 5	750	500	1530	1270						
T - 7	800	600	2150	[illegible]						
T - 13	500	450	1530	1270						
T - 20	600	450	1300	1150						
T - 24	900	700	2600	2400						
T - 26	800	600	2150	1800						
T - 30	600	500	1730	1450						
T - 35	750	600	1900	1600						
T - 36	800	600	2300	2000						
T - 37	700	500	1730	1450						

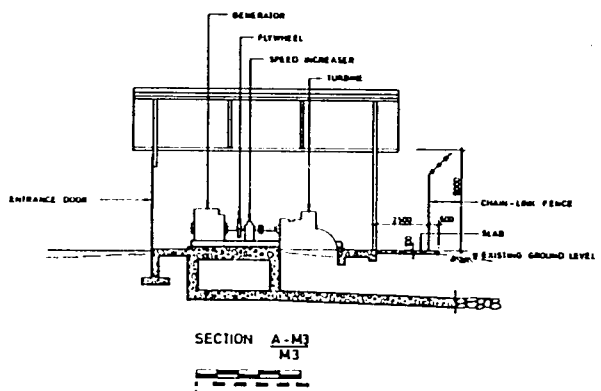
(1) ASSUMED DIMENSION WHICH MAY BE ADJUSTED TO SUIT EQUIPMENT FURNISHED. FINAL DIMENSIONS ARE SUBJECT TO REVIEW OF ENGINEER

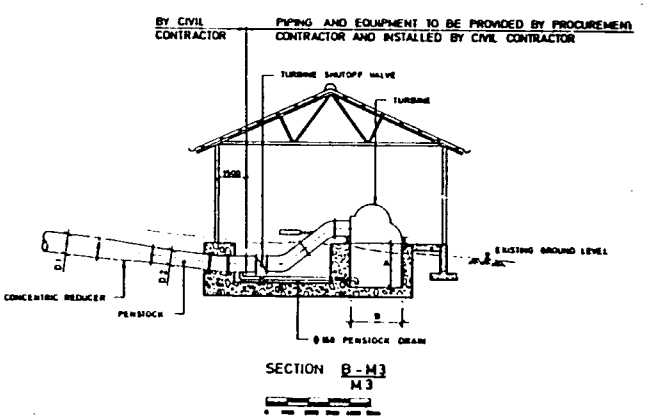
(2) CONNECT TO EXISTING PIPE AT SITE J - 29

(3) FOR UNIT 1 ONLY

NOTES

1. THIS DRAWING SHOWS TYPICAL GENERAL ARRANGEMENT AND LOCATION OF IMPULSE TURBINES AND ASSOCIATED EQUIPMENT. LOCATION AND ARRANGEMENT CAN BE ADJUSTED TO SUIT EQUIPMENT PROVIDED
2. REFER TO POWERHOUSE LAYOUT DRAWING FOR EACH SITE FOR ORIENTATION OF BUILDING, PENSTOCK, TAILRACE, DOORS AND OTHER SIMILAR ITEMS
3. REFER TO DRAWINGS S17 AND S18 FOR POWERHOUSE FOUNDATION DETAILS
4. FILLET WELD BETWEEN PENSTOCK AND SECTION FURNISH BY PROCUREMENT CONTRACTOR TO BE MADE BY CIVIL CONTRACTOR
5. FLEXIBLE COUPLING WILL BE PROVIDED BY EQUIPMENT PROCUREMENT CONTRACTOR IF REQUIRED FOR HIS EQUIPMENT
6. FOR DETAIL OF CHAIN-LINK FENCE SEE DRWG NO C4





STANDARD DRAWING POWERHOUSE FOR IMPULSE TURBINE

Figure 11

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End-Use and Electrical Distribution Planning For Isolated Hydropower Systems

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May 1983

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Cost estimates.

Summary and conclusions

Hydro in general and small hydro in particular are becoming increasingly important as sources of generation for central station electric power systems and for isolated subsystems. The prime reason for this situation is that hydro is a renewable energy resource whereas fuel resources are limited and increasingly costly.

While considerable attention is given to the characteristics of the generation plants, the distribution plant and its function in electrical energy end use development is not always adequately emphasized. This paper analyzes those aspects of a 400 kW hydropower project in northern Zaire based upon the design, construction, operation and economic criteria contained in a feasibility study under which the project was financed. Pertinent features of the project include:

- a religious mission with defined electrical loads consisting of their hospital, church, residences, machine shop, and schools,
- a nearby river which has been observed for many years and the minimum flow of record has established accordingly,
- much of the time, the minimum flow during a year exceeds the minimum flow of record,
- a sufficient pool for 24-hour regulation of the minimum flow of record is to be formed with a small dam and spillway,
- this pool enables conformance of the generation with the hourly load variations,
- flows above the minimum could provide energy for secondary loads on a seasonal basis,
- generation and distribution capability has been established to make use of secondary energy potential,
- alternative distribution system designs should be considered including open line on wood, steel or concrete poles and buried cable,
- the loads for this project justified application of normal criteria of voltage drop and losses in line voltage, conductor size and line configuration.
- secondary load possibilities include two villages, one of which has some commercial potential such as a cold storage plant and stores plus street lighting,
- the U.S. standard of 7.2/12.5 kV three-phase plus neutral using single-phase taps is appropriate for this system and sufficient capability has been included in the system design to properly serve secondary loads in the area.

I. Introduction

Small hydroelectric plants can be used to supply power to a large electric power grid, or used to serve a smaller, isolated local load. For grid-connected systems, the sites are usually developed for the optimal energy output which is used by the grid to either displace higher cost energy sources or supply load growth. In this case, the small hydropower plant is treated as another alternative f . supplying the grid and the technical issues, economics, and evaluations are done in comparison to conventional power supplies.

Planning for isolated systems, however, requires analyzing not only the power supply, but the entire system operations. Rather than simply adopting the national or regional standards for load growth, rates, ownership, operations, maintenance, and line extensions, such issues should be addressed for each isolated system. Isolated small hydro systems are usually expensive in terms of per kW or kWh cost. Therefore, to obtain the necessary financing, the planners must maximize the benefits and minimize the costs. Such planning criteria will impact the electrical distribution planning probably more than the civil and mechanical aspects.

In planning the electrical distribution system, the engineer is faced with several conflicting objectives. He must:

- minimize the initial capital cost,
- minimize the life cycle cost,
- maximize load and plant factors,
- maximize the social benefits of electrification, and
- maximize the political objectives of electrification.

The final distribution plan is often a balance among these objectives. One indication of a proper balance is when all the parties in the electrification project are a bit unhappy (the sociologist thinks that the plan is insensitive, the bankers feel that the rate of return should be increased, the economist recommends deleting some unproductive loads, and the politicans want more consumers connected).

This paper looks at the major steps in planning distribution systems for isolated areas, especially the relationships of the end-uses and the availablity of the power. A small hydropower scheme in Karawa, Zaire is used throughout as a case study to illustrate these steps. The Karawa hydropower site is located in north central Zaire on small tributary of the Libala River which flows eastward towards its confluence with the Zaire (formally the Congo) River. The site has up to 400 kW of potential and is about 11 km from Karawa, where there exists a Protestant Christian mission hospital, shops, and residences. The hydropower system is about 80 percent completed.

II. End Uses and Load Characteristics

Project Framework

Since most international development banks have adopted the "logical framework" method for project analysis, it is used in this paper to illustrate the distribution-planning process for small hydropower projects. In the logical framework, the highest objective is the "project goal." For electrification schemes, project goals are usually stated in terms of either improving the quality of life for a particular target group, or for improving their economic productivity. Projects may have more than one goal, but how successfully the project meets its goal(s) can be measured by either quality of life indicators (health facilities, higher levels of education, increased longevity) or by economic indicators (higher per capita income, exports, decreased imports).

Next in the relative levels of objectives is the "project purpose" which is a statement of conditions required to accomplish the goals. For small hydropower projects, common purposes are to produce low-cost hydropower for either supplying power in areas without existing power supplies, displacing existing higher-cost power supplies, or supplying an additional power source for new loads. Hydro is selected when it it is identified as the lowest cost alternative power supply. Generally, successful projects have only one project purpose. Measureable indicators of successfully meeting the project purpose are the amount of kWh used or the amount of higher-cost fuel saved.

The third level of objectives is the project output which is the direct product of the financial assistance. For a small hydropower project, it is generally the physical installation and operation of the electric system. Measureable indicators of project output include the number of consumers connected, the operational capacity and production of the unit, or increased system capacity.

The Karawa small hydro project was designed to provide the mission with low-cost hydropower to displace the use of diesel fuel and to provide additional capacity for new hospital loads. Building the small hydro plant permits the mission to decrease its dependance on fuel supplies, lower its operating costs, and provide improved medical services. Over a period of years, it will increasingly serve the goal of improving the quality of life for the rural population surrounding the Karawa Mission.

Primary Uses

The first step in planning a distribution system is to identify the target loads or the consumer loads, that meet the purpose of the electrification project. If the project purpose is to provide human services and thereby increase the quality of life, then loads such as lighting, hospitals, community centers, schools are the primary loads. If the purpose is to increase the economic activity and productivity of an area, then consumers such as cottage industries, commercial enterprises, and farms would be the primary loads.

The primary loads are summed to determine the load characteristics of a minimum system. These characteristics can then be compared to the energy available and the amount of excess energy needed to serve secondary loads.

At Karawa, the primary loads are those that are now served by existing diesels plus the capacity needed to serve additional hospital equipment. The mission's entire electrical energy requirements were supplied by several small diesel units. Mission loads

include 20 kW for lights, small appliances, and about 10 horsepower of shop tools including saws, drills, a lathe, and a planer. These tools draw large starting currents which cause voltage drop problems. A reliable electric power supply will permit better lighting, improved sanitation, storage of refrigerated supplies, X-rays, and a blood bank.

Lighting in the hospital's operating and maternity rooms, laboratories, and patient wards will be upgraded and in many cases replaced with more efficient and longer lasting fluorescent lamps which require a steady source of power. Hospital operations require autoclaves and boilers for sterilizing instruments and supplies. This was being done by a very old kersone-fired unit. Electric sterilizers are more reliable, safer, and less costly to operate.

The Mission doctor believes that air conditioning will greatly reduce the surgical infection rate and improve the accuracy of laboratory analyses. Therefore, air conditioning is planned for operating rooms and laboratories to control humidity and limit the amount of outside air entering sterile areas.

An electric load estimate was made to compare the Karawa Mission requirements to the hydropower site potential to determine the appropriate generating capacity of the turbo-generating equipment. This estimate is given in Table 1. All connected loads are not taking power at the same time which is accounted for by applying diversity factors which represents the composite probabliity of various loads being on during the peak load period. A large diversity factor was applied to shop connected load of 15 kW since there are more machines than men to use them.

Since the site is near the equator there were no seasonal variations of demand. Hospital routine is the same every day of the week which minimizes differences for weekends and holidays. Losses were calculated by assuming a 16% loss of capacity on peak demand and 10% loses of energy (kWh).

Table 1
Primary Mission Loads

Facility	Coincident Demand(kW)	Energy (kWh) Per day	Energy (kWh) Per year
1. Hospital and related housing	40	433	158,000
2. Mission staff housing	65	400	150,000
3. School	2	16	6,000
4. Shop	5	17	6,000
Sub totals	112	866	320,000
Losses	18	88	32,000
Total	130	954	352,000

The load factor for the above requirememts is the ratio of the average annual usage to the peak coindcident demand or:

$$\text{Load Factor} = \frac{352{,}000 \text{ kWh}}{130\text{kW} \times 8{,}760 \text{ h}}$$

$$= 0.31$$

The hourly demands were derived and graphed as shown in Fig. 1.

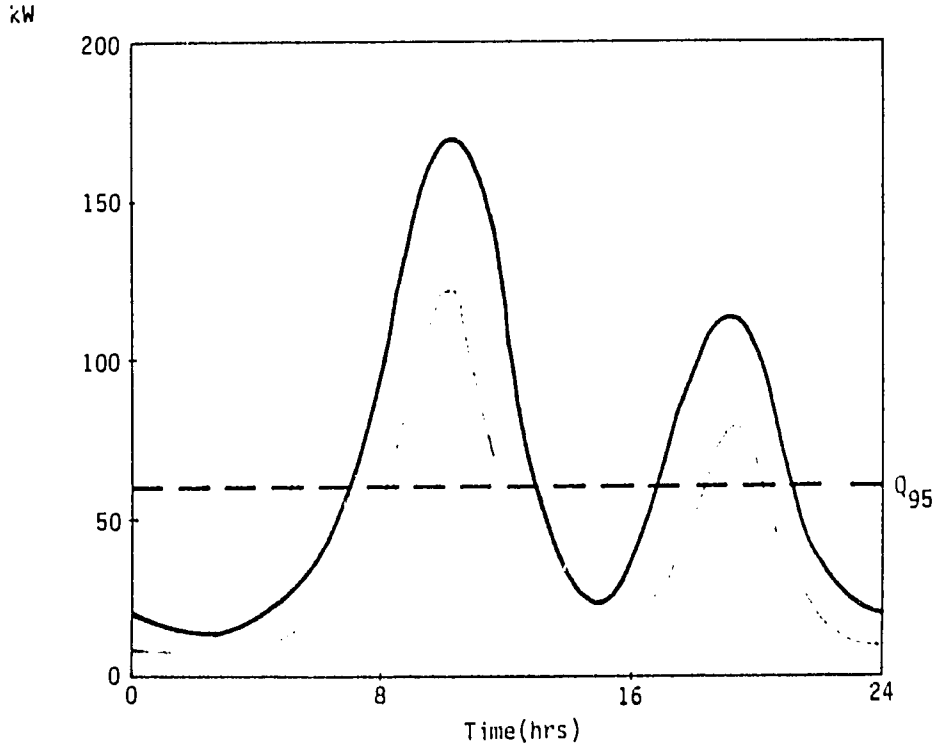

Fig. 1. Karawa Daily Load Characteristics

Energy Availablity

After the primary loads have been identified, the power sources are investigated to determine the best alternative and if there is additional energy to supply secondary loads. For isolated hydropower systems it is necessary to test the energy availablity during dry season conditions and ensure that priority loads can be served. Then the energy available to serve secondary loads can be determined throughout the year.

In the Karawa example, the power output for a flow of 1.08 m^3/s, corresponding to approximately Q_{95}, is 60 kW, which is shown on Fig. 1. Obviously the demand could not be served during the dry-season by run-of-river hydropower alone. However, the minimum output of 60 kW is capable of producing 60 x 24 hours or 1440 kWh over a 24

hour period which exceeds the 954 kWh daily primary energy requirements.

A site survey indicated that a 3.5 m high wier located directly above the falls would impound an active storage potential of 52,000 m^3, roughly equivalent to 800 kWh. With this amount of storage plus the minimum in-flows, the daily load demand variations could be easily met.

Secondary Loads

In addition to meeting the project objectives, small hydropower installations usually must also meet certain finanical criteria in order to receive funding. Since the capital costs of hydropower schemes are relatively high, meeting the financial criteria generally requires maximizing the return, or energy usage, for the unit installed. Standard methods used in the US and other central grid (power limited) programs are to promote the development of productive uses and off-peak energy uses which increase the system load factor. However, at isolated small hydropower sites the system can often be energy limited with little potential for increasing the load factor.

Productive uses of electricity will usually increase the overall productivity of the target area thereby increasing the local per capita income and the ability of the local population to pay for electric service. Recent studies have indicated that in order for rural electrification to be finanically viable, approximately 25% of the load should be commercial uses.

Rural residential loads are characterized by low load factors, often below 20%. Increasing the load factor increases the amount of energy used with the same capital investment. Loads that can be managed to operate during off-peak hours will increase the daily load factors. Some loads to consider for off-peak applications are; irrigation pumping, cold storage, water heaters, fertilizer production, and calcium carbide pellet production.

Load growth should be encouraged if the initial demand is below the optimal power production potential of the hydropower site. It has been NRECA's experience that areas first receiving electric power will experience a large load growth rate during the first few years of operations usually, from commercial consumers. The growth then slows and becomes a function of the economy of the region. Typical growth rates are 10% per year for the first 5 years, and 6% through the planning horizon- usually atleast 10 years. Generation and distribution facilities are then constructed to be easily up-graded to serve this forecasted load. It also is NRECA's experience that consumers need a source of credit in order to purchase the electrical devices that will make the system viable. In several programs, consumers must pay the cost of household wiring in addtion to the devices they like would to purchase. The implementing agency must either be willing to finance such ventures, or identify sources of financing for the overall project to be successful. The estimates for the secondary loads are added to the primary loads and again compared to the energy availablity.

At Karawa there were potential secondary loads identified in the mission complex and nearby villages. An electric hammermill to be installed near Zulu Falls to grind corn and manioc to produce flour for the surrounding community was felt to be a useful additional load.

Most homes at the mission have kersosene fueled refrigerators which do not work effectively in the hot climate. Replacing kersone units with electrical units will assure the the safety of costly and hard to obtain supplies in the hospital and avoid frequent

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spoilage of food in the mission households.

Additional demand may come from mission load growth or electrification of near-by villages. Two areas were considered as possible loads, the first one a village located between the powerhouse site and the mission, and the other the village of Karawa located approximately 4 km to the south of the mission (see Fig. 4).

The first village consists of approximately 35 houses and a school. There were other clusters of mud house in the area that appeared to be temporary structures. Potential loads were lighting the school and a village meeting center, a total of about 3 kW.

The village of Karawa consisted of approximately 35 houses, a few stores and a school, all comprising a population of perhaps 200. A commercial shipping company operates a cold storage facility powered by a 50 kW diesel-electric generator which also supplies the office, employees residences, street lights, and few stores. These uses produce a peak load on the diesel unit of about 12 kW which means the unit is operated at inefficent partial loads.

Due to the lack of a source for funds for the purpose, it was decided to not include electric service to the two villages as part of the initial construction project.

The "secondary" mission loads then are added to the primary load yield the total demand and energy requirements as shown in Table 2.

Table 2
Total Mission Loads

Facility	Coincident Demand(kW)	Energy (kWh) Per day	Energy (kWh) Per year
1. Hospital and related housing	40	463	168,000
2. Mission staff housing	100	680	247,000
3. School	2	16	6,000
4. Shop	5	19	6,000
5. Hammer mills	3	48	18,000
Sub totals	150	1,226	445,000
Losses	24	120	44,000
Total	174	1,346	489,000

A rough analysis of the reservoir inflow/outflow/storage operations was done to determine if the total load could be served with the potential storage. This was done by representing the daily volume of water flowing in and out of the reservoir in terms of the equivalent energy (kWh) the water could produce, and comparing this to the reservoir active storage capacity. This daily operation during the dry season is graphed on the mass curve shown in Figure 2.

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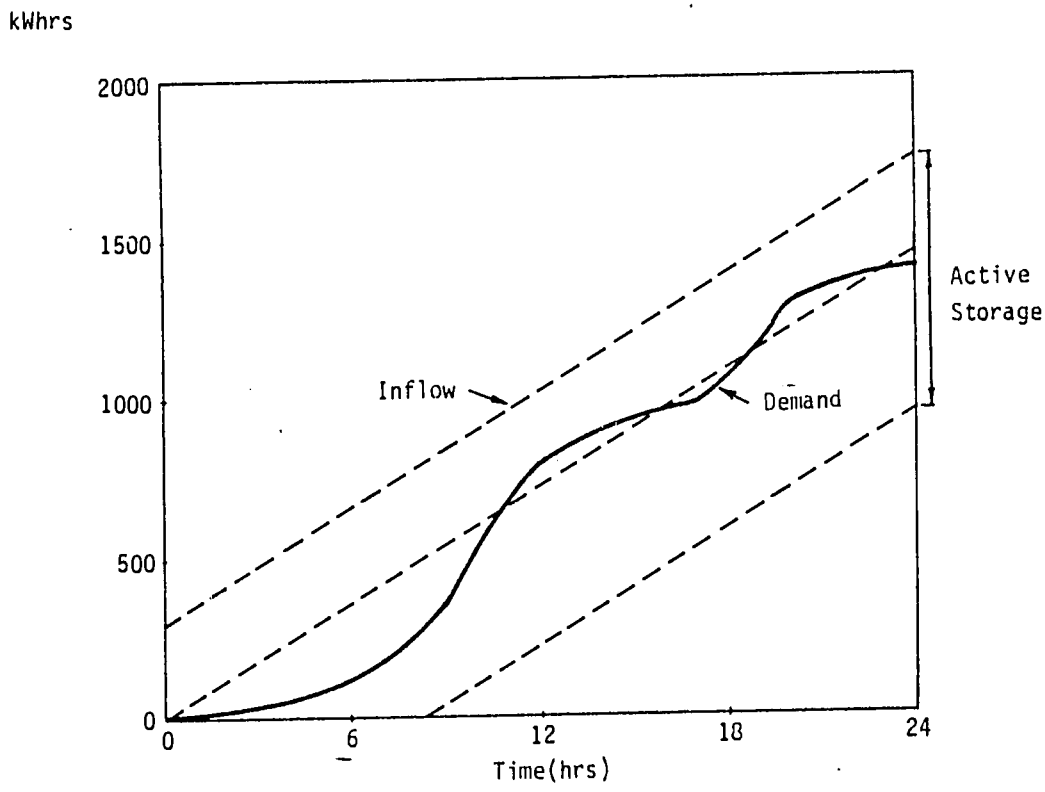

Figure 2. Mass curve for Karawa system

The mass curve shows that the 800 kWh of storage is sufficent to meet the hourly energy variations during the dry season days. However, since the flow will go as high as 4 m^3/s at other times, there is appreciable seasonal energy potential at the site. The mission believes they can utilize this seasonal potential and have sized the generators based upon optimizing the river potential rather than the local projected demand. From the flow duration curve analysis they decided to install two units; a 150 kW propeller and a 250 kW crossflow turbine.

Accordingly, the mission will investigate other load possibilities which can use seasonal energy. The cold storage facility is an example as it could run most of the year on hydropower and revert to the diesel capacity during the minimum flow periods. The hammermill could be considered a seasonal load as sufficent corn could be milled during periods of high flow to last the community through the dry season.

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Fig. 3. Karawa dam site under contruction - 1982. The 7 m falls is to the left and the reservoir area to the right of the dam.

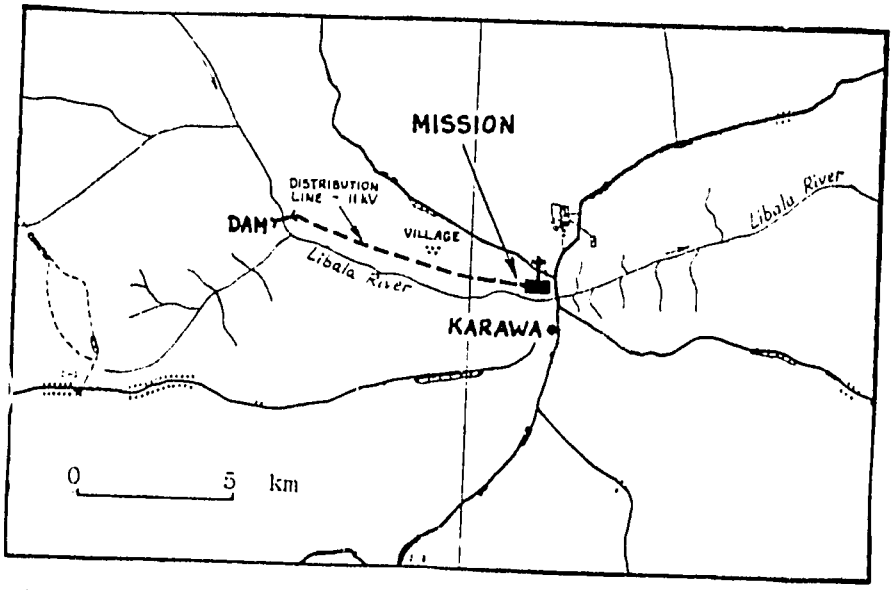


Fig. 4 Map of Karawa.

III. Distribution Design

Since distribution costs can account for as much as 30 percent of the total small hydropower system cost, electrical facilities should be carefully planned. A well designed distribution system minimizes the cumulative annual cost which includes amortization of capital cost, the value of energy losses, operations, maintenance, and the future construction cost when building for system growth. There usually is more than one combination of voltage, conductor size and system configuration which will supply power and meet the design criteria. However, when factors such as reliability, safety, access to spare parts, and land use impacts are considered one choice usually stands out as the best. This section offers some guidelines for selecting the most appropriate distribution system.

Design Voltage Selection

Typical small hydropower projects have three voltage levels; the generator voltage at the powerhouse which can be stepped-up to a higher primary distribution voltage and then transformed back down to the secondary voltage for utilization by the consumers. In rare cases power from a small hydro source can be distributed directly at generator voltage to nearby loads without incurring voltage drops in excess of about 10 percent. For a micro-hydro plant within about a kilometer from its load, a higher generator voltage such as 480 v could be sufficient to keep the voltage drop within limits and avoid transforming up to a primary voltage level. Generally, medium voltage systems (2.4-10 kV) can distribute the power from a small hydro unit without excessive voltage drops. However, the medium voltage system has greater energy losses and requires larger conductors to distribute the same amount of power than higher voltage lines. Most countries do not have national standards for medium voltage system and hence it will be more difficult to find spare parts or interconnect into large systems in the future. In such cases, the national standard high voltage should be used for the primary distribution voltage.

Secondary (consumer) voltages are usually either 120/240 v, three wire single phase or 220/380 v three-phase systems as used widely in Africa. The choice depends largely upon the voltage rating of available electrical devices such as motors, lamps, etc.

Configuration

Two configurations widely used for the distribution system are the three-phase ungrounded (delta) system, and the three-phase/single-phase, multiple grounded neutral system. The advantage of the latter is that single-phase taps can be run at primary voltage to small loads at lower cost than running all three phases or two fully insulated phase wires for single phase. Also, single bushing transformers can be used, further reducing the system cost. NRECA recommends use of the three-phase/ single-phase configuration which is increasingly being applied to rural electrification programs.

At Karawa the distance between the powerhouse and load center is 11.2 km and hence it is necessary to step up the generation voltage to a distribution voltage level. In Zaire the national standard distribution voltage is 11 kV so a voltage in this class was selected. The three-phase/single phase configuration was selected because: (1) single-phase taps could be run at a lower cost; (2) the equipment was partically donated from US sources which use the multiple grounded system; and (3) the mission has many single phase motors already in use on the initial diesel electric system. A 7.2/12.5 kV mulitple grounded system was chosen to distribute the power from the powerhouse to the mission

load center.

Conductor Selection

Choices for conductor type include bare overhead conductors insulated suspended aerial cable, underground cable, or a combination of cable and bare conductors.

The advantages of overhead conductors are that they are generally less expensive for primary voltages, are easily to splice and tap as new loads develop, and line faults can be readily located. Poles can be either wood, steel, or concrete. Where timber products suitable for manufacture of wood poles are available, a full pressure treated wood pole may be produced for 50 percent less than the equivalent concrete support structure. The average concrete pole of comparable size is generally twice the weight of a wood pole with one-third less tensile strength. In urban electrification where poles are spaced at intervals of less than 50 m, the strength is of little concern and the economics of wood versus concrete are not too pronounced. However, in rural electrification, with spans of 150 to 200 m, the tensile strength is a major consideration. Also, breakage in transportation over country roads is minimal for wood poles, attachments are cheaper, and the foundations requirements are simpler than for concrete poles.

The advantage of cables are that they do not require heavy poles and pole-top hardware, trenches can be dug with local labor, and buried cables are less susceptable to fire, storm, and lightning damage. Rights-of-way require only minimal maintenance.

The primary conductor should be sized to limit the voltage drop during peak load conditions to under 5%. The number of different conductor sizes should be held to a minimum to reduce warehouse stocks and maintenance procedures. The following is a system that has worked well for overhead construction:

- for main three-phase primary feeders utilize 1/0 aluminum conductor with six strands of aluminum wire and one strand of steel (6/1 ACSR) along with #4 7/1 ACSR as the neutral conductor. (Anything larger requires heavy construction standards with related additional cost.)
- for all taps, except where loads necessitate a larger conductor, use #4 ACSR for both the primary and neutral conductors.
- for secondary lines, match 1/0 ACSR and #4 ACSR with the transformer capacities.
- for service drops, use ACSR duplex, triplex, and quadruplex in order not to mix material types (aluminum and copper).

At Karawa, an underground cable was selected primarily because of the difficulty of importing poles and hardware to the site, and the high incidence of lightning and brush fires along the line route. A three core, #2 aluminum, 15 kV cable with a neutral shield was selected which will yield a voltage drop of 1.43% during the evening peak load period. This cable is oversized for the initial load but could handle the full 400 kW potential of the site if needed in the future.

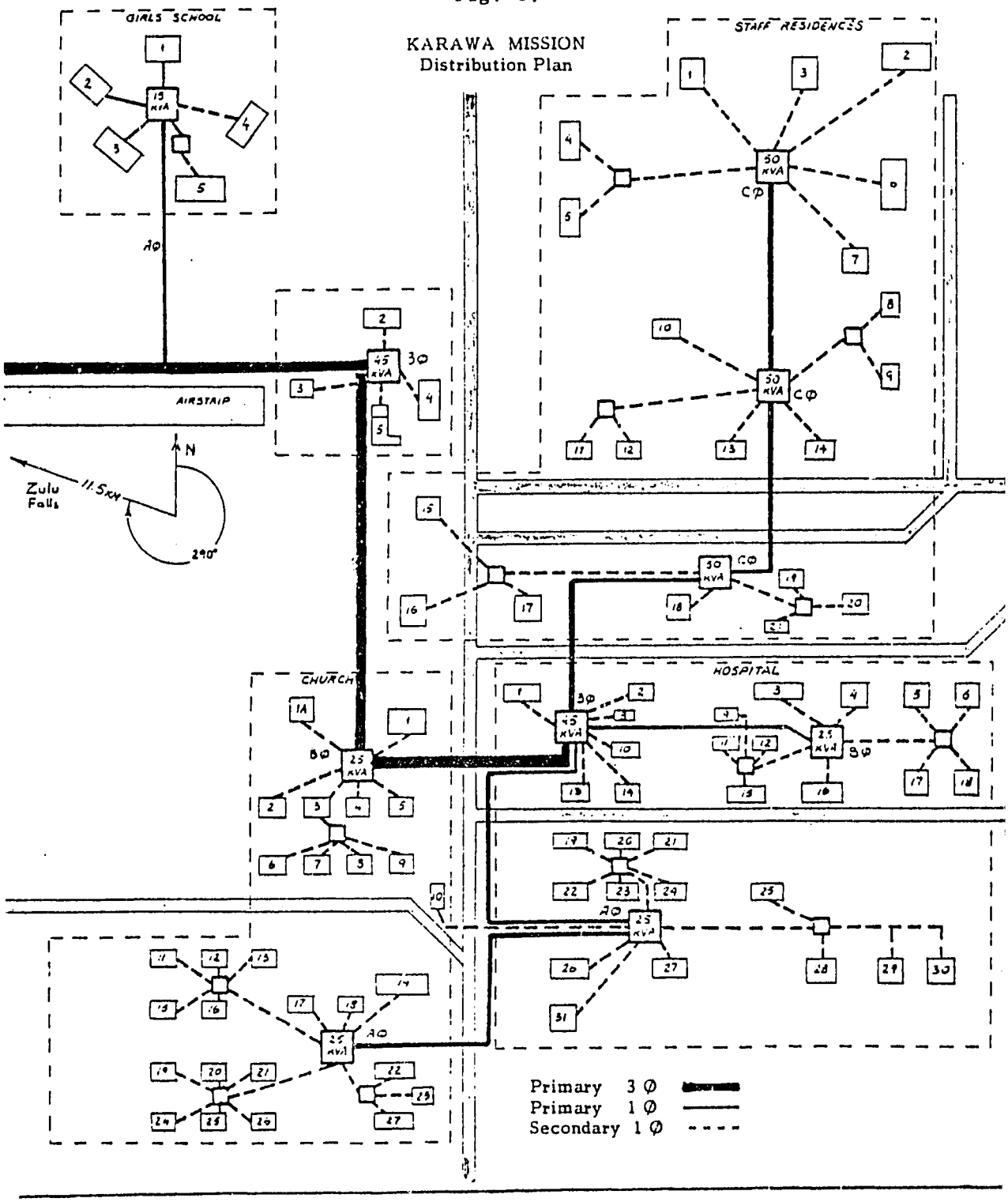
Route Selection

The following criteria should be considered in selecting routes for distribution lines:

- the existence of all weather-roads for main three phase feeders,
- the existence of at least seasonal roads for single-phase taps,
- consumer density.

Fig. 5.

KARAWA MISSION
Distribution Plan



At Karawa the route for the primary cable extends along the road from the river to the mission. A map of the Mission is given in Fig. 5 and a preliminary layout of three-phase and single-phase circuits marked from which approximate lengths of primary and secondary lines were scaled. Most of the services are single-phase except for the shop where there are some three-phase motors. The hospital load is large enough (95 kW) to warrant a three-phase feed although the loads are all single-phase. Line taps were selected in a manner to balance the loads on all three phases from the generator.

Transformers

The largest source of losses in a typical distribution system comes from transformers losses. Hence, selection of proper transformer will include consideration of the value of the losses over the life of the transformer. The step-up transformer can be either one three-phase transformer, or three single phase transformers. The single-phase transformers are easiler to handle, transport, and adapt to changing conditions. A fourth single phase transformer can serve as a system spare. Step-down transformers are located close enough to loads to keep voltage drops on the secondary under 1 volt. This still leaves a choice of installing several small step-down transformers, or fewer larger transformers. A guide for making this determination is to: (1) install a single transformer bank for all priority loads such as a hospital; (2) do not install any transformers less than 10kVA, and (3) do not employ transformers larger than what can be handled by local crews with basic tackle.

At Karawa the transformers were donated. Accordingly no analysis was made of the energy losses. Five load sub-areas where identified to be served by step-down transformers:

(1) the hospital	95 kVA
(2) technical service	45 kVA
(3) girl's school	15 kVA
(4) staff residences	150 kVA
(5) church	50 kVA
Total	355 kVA

Protection

The level of protection should be kept simple, yet adequate to avoid catastropic failure. A few suggestion are:

- o use simple line fuses rather than automatic reclosers and sectionalizers in isolated, inaccessable areas.
- o either purchase self-protected transformers or fuse all transformers.
- o install surge (lightning) arresters along the main feeders.

Meters

Meters may be deleted on small hydropower systems if there is sufficent power to serve all loads and the cost can be recovered by a fixed monthly fee. On other systems, meters are recommended.

REA Standards

The United States Rural Electrification Administration (REA) has published numerous specifications, standards, and instructions for planning, designing, and operating rural electric power systems. Over one-third of the electric distribution lines in the US were

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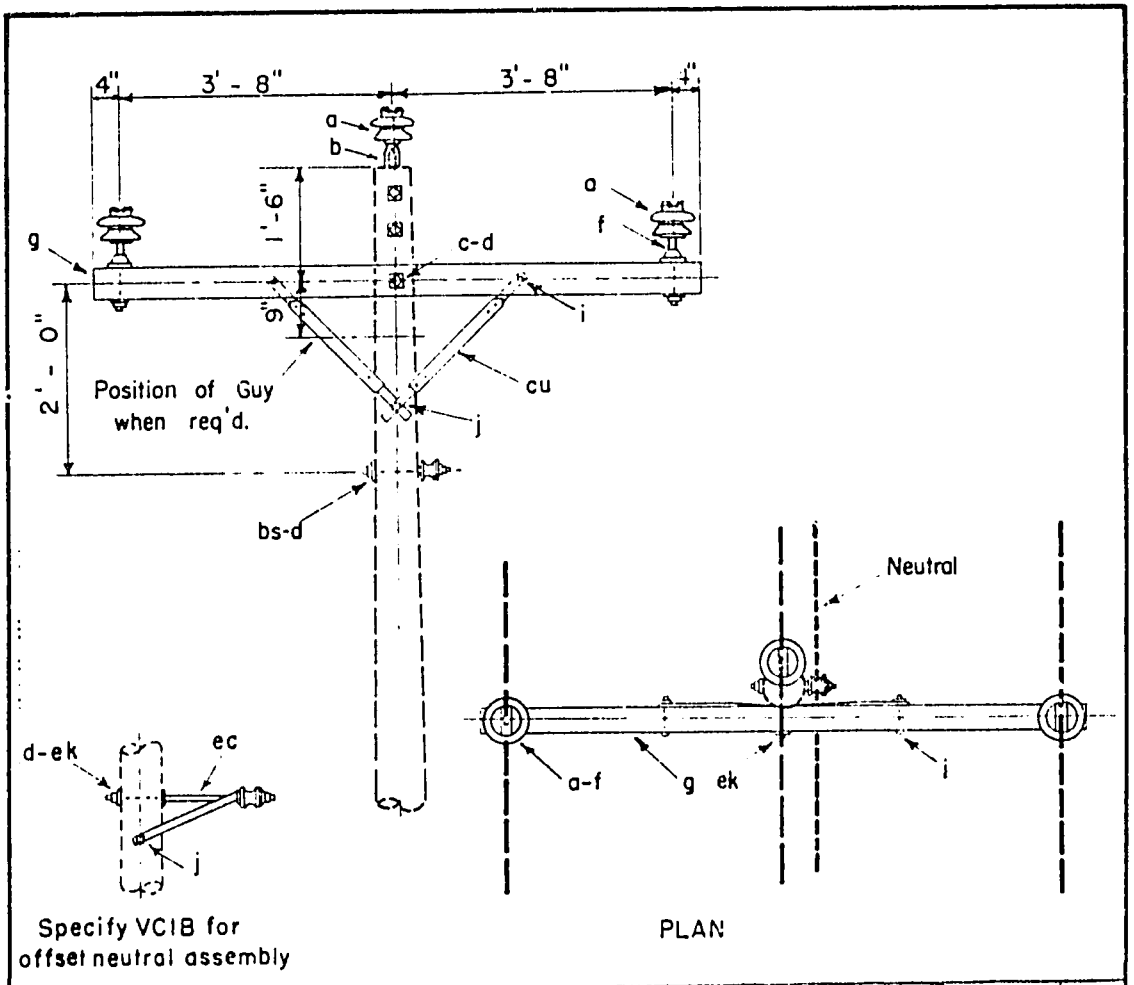

ITEM	NO.	MATERIAL		ITEM	NO.	MATERIAL	
a	3	Insulator, pin type		cu	2	Brace, wood, 28"	
b	1	Pin, pole top, 20"		i	2	Bolt, carriage, 3/8" x 4 1/2"	
c	3	Bolt, machine, 5/8" x req'd length		j	1	Screw, lag, 1/2" x 4", (VCI only)	
d	4	Washer, square 2 1/4"		bs	1	Bolt, single upset, insulated, (VCI only)	
f	2	Pin, crossarm, steel, 5/8" x 14"		ek		Locknuts	
g	1	Crossarm, 3 1/2" x 4 1/2" x 8'-0"		ec	1	Bracket, offset, insulated, (VCIB only)	
j	3	Screw, lag, 1/2" x 4", (VCIB only)					

14.4/24.9 KV, 3-PHASE
CROSSARM CONSTRUCTION-SINGLE PRIMARY SUPPORT
0° TO 5° ANGLE

Jan 1, 1963

VCI, VCIB

Figure 6

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built to these specifications. Operating instructions include a management model, accounting systems, materials records management procedures and numerous recommedations for safe line maintenance. Copies of theses documents are available for a small fee from the Superintendent of Doucuments, US Government Printing Office, Washington D.C. 20402.

Cost Estimates

All distribution construction should be planned, bid, constructed, and paid for on the basis of assembly units. An assembly unit is a collection of materials to serve a specific function. For example Fig. 6 illustrates the VC-1 assembly unit for a three-phase crossarm support. The number of assembly units required per kilometer of line can then be estimated, and the material and labor cost based upon the number of assemblies.

At Karawa the distribution cost were estimated as shown in Table 3.

Table 3

Karawa Electrical Distribution Cost Estimates

($ US)

Item	Unit	Per Unit Cost Material	Per Unit Cost Labor	Quantity	Total Cost
15 kV cable -main	m	5.76	2.68	11,200	94,528
15 kV cable - 1/c	m	1.96	0.38	1,200	2,808
15 kV cable - 3/c	m	4.96	0.40	700	3,752
Transformers-	kVA	30.53	12.40	355	15,240
Service cables	m	0.83	0.37	5,000	6,000
Secondary cables	m	2.07	0.40	1,000	2,470
Service entrance and meters	each	121	5	90	11,340
Pedestals	each	153	91	4	976
Misc.				1,700	
Sub- Total					138,814
Shipping					20,000
Contingencies					15,000
Total					173,814
For cost estimates					$ 174,000

Notes:
1. Above material cost are 1978 US catalog prices and no not include ocean or inland freight, customs.
2. Cost escalation varies with each material but increases since 1978 will generally be around 40%.
3. Labor costs represent what imported labor by multi-skilled journeymen would cost. Permenent Mission staff would do much of this work and supervise local laborers.

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Protection and Automatic Control For Small Scale Hydroelectric Plants

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June 1983

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PROTECTION AND AUTOMATIC CONTROL FOR SMALL-SCALE HYDROELECTRIC PLANTS

I. INTRODUCTION

Energy development in the rural areas of developing nations has, in the recent past, become a significant part of energy planning for the nation as a whole. The social, economic and technical complexities in pursuing a rural electrification program are considerable. The technical solutions range from extension of the existing electrical grid to installation of isolated diesel generation units to installation of small-scale hydroelectric units. Often no single solution is satisfactory when the problem is projected into the future to account for load growth and system expansion. A system capable of flexibility and expansion as well as providing a means of data collection and resource optimization should be considered when specifying a rural electrification program involving small hydro.

Small-scale hydroelectric development refers to a wide range of capacities from a few kilowatts to several megawatts. It is important to recognize that the technical approach to hydro development will vary widely within this range particularly on the low end of the scale (less than 100 kW) where the degree of complexity and automation of the system is drastically reduced. At the larger end of the small hydro power spectrum, from 500 kW to 5 MW and up, a greater degree of complexity is inherent in the electrical control design of the station. It is this end of the spectrum that will be the focus of the discussion.

Regions that are suitable for small hydro development are often remote from the electric grid system and from any substantial load center. Furthermore, it is often found that the geography and hydrologic characteristics of an area will support more than one hydro plant, either on the same river or stream or within the same drainage area. In these cases in particular, automatic control is indicated as an alternative to manned operation along with some form of supervisory control.

Automatic and supervisory control are generally considered to be only cost effective in large (5 MW or over) generating stations, but reduced costs due to standardized hardware and flexible software render them an economically viable choice for incorporation in small-scale development. This paper will address in general terms the application of automatic and supervisory control to a small hydro station

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in the U.S., and discuss the benefits and potential cost savings that may be applicable to a similar system incorporated in hydro installations in developing nations.

II. THE SANDERS PLANT - A CASE STUDY

The Sanders Plant is an unmanned small scale hydroelectric plant located in northern rural Vermont approximately seven miles from the Village it serves. The powerhouse was built at the base of an existing dam that impounds water from a drainage area of approximately 14 square miles thus permitting it to be used as a "peaking" installation. Control and monitoring of the plant is accomplished from a manned hydro plant located in the Village itself. An operator at this plant is able to stop, start and monitor the plant, as well as change load levels and the power factor.

The powerhouse contains two identical 900 kW vertical Francis turbines direct connected to two synchronous generators with brushless excitation. The turbines are regulated by hydraulic speed governors manufactured by the Woodward Company. The generator switchgear, one of the most critical pieces of equipment in the powerhouse, encompasses all the equipment necessary to connect the output of the generator to the electric power system. Switchgear is a general term covering switching and interrupting devices and their combination with associated control, instrumentation, metering, protective and regulating devices. For the purposes of this discussion the switchgear will be divided into protection equipment and control equipment both automatic and supervisory.

Protection Equipment

A crucial part of any small hydro plant deals with safety of personnel and machine protection. The devices needed to accomplish this can be very extensive in scope or relatively straight forward depending on the protection scheme to be employed. It should be emphasized that more than one solution is possible and the scheme described below while suitable and sufficient for the plant in question may vary considerably for another installation.

A one-line diagram for the protection scheme of the Sanders Plant is given in Figure 1. A brief description of various critical protective devices and their function is as follows:

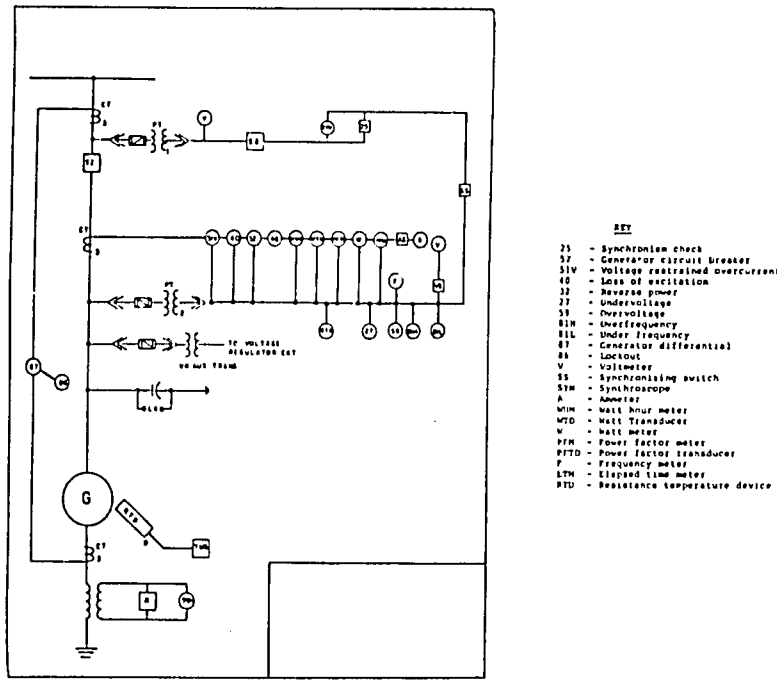

Figure 1
One-line Diagram

Device #52 - Generator Circuit Breaker - This is the main switching device in the small hydro plant and must be designed and built so it can open the line in case of a fault without destroying itself. The continuous current rating is based on the rated output of the generator while the short time rating is based on the available fault current from the utility network. For the Sanders Plant these ratings are 4.16 kV, 1200A continuous, 29000A short circuit rating, 250 MVA. This is a standard 5 kV breaker. The generator circuit breaker is tripped by the various protective relays as the control scheme dictates.

Device #87 - Generator Differential Relay - is used to detect internal faults within the generator by comparing the currents on each phase on both sides of the generator. Differential relays, among others, are connected to Device #86, the lockout relay, which always requires a manual hand reset action. Also, the differential relay must disconnect the excitation from the generator to prevent further generator damage.

Device #51V - Voltage Restrained Overcurrent Relay - This senses the line current and line voltage and adjusts the tripping time proportionally to the line voltage. Thus, the tripping time becomes shorter as the line voltage droops. This relay is used in conjunction with Device #46, the phase unbalance relay, to detect an overcurrent situation on any phase.

Device #32 - Reverse Power Relay - It senses power flow into the generator from the system: A situation which would occur with a governor failure, or immediately following synchronization before the turbine can respond to a signal to pick up load.

RTD - Resistance Temperature Device - Used to detect an abnormal rise in generator stator temperature or bearing temperature. This is usually linked to the lockout relay and requires an operator inspection before restart is permitted.

Protective device operation initiates rapid shutdown of the unit involved, independent of the programmable controller as follows:

(1) An emergency shutdown with lockout is provided to immediately trip the generator circuit breaker, and bring the unit to a stop. The unit may not be restarted without a manual reset.

(2) A normal shutdown with lockout first unloads the unit, then trips the generator circuit breaker, and brings the unit to a stop.

(3) An emergency shutdown without lockout provides an immediate trip of the generator circuit breaker and brings the unit to a stop but allows the unit to be restarted again remotely if desired.

The above protective devices are recommended for a small hydro installation particularly if operated remotely. Again, the number and types of protective relays vary between installations and the addition or deletion of particular protection functions are dependent on the design scheme.

Automatic Control

A typical small hydroelectric plant consists of the following components:

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Hydraulic turbine equipped with a flow control device such as wicket gates.

Generator of either the synchronous or asynchronous (induction) type.

Speed governor or load control device.

Circuit breaker.

Protective Relays.

Synchronizing equipment.

Electrical control equipment.

The proper interaction and sequencing of valves, motors, pumps and protective devices associated with the above listed components must be monitored and verified during a startup or shutdown procedure whether the plant is in a automatic or manual control mode. Interlocking relays and annunciator lights indicate to an operator if the various systems are functioning properly and if the plant is ready for startup. As the number of auxiliary relays increases to interlock systems and prevent operator error, the reliability decreases and maintenance costs increase. To remedy this situation, a programmable controller can be used as an effective substitute for auxiliary relays.

The programmable controller (PC), in its simpliest sense, is a replacement for convential electromechanical relays for electrical logic control. It is a microprocessor based system that allows a relay logic program in ladder diagram format to be entered into the constant memory. The logic program is constantly executed and turns real world outputs on and off according to the status of real world inputs and the internal logic. In addition to digital status signals, the PC is also consistant with analog signals allowing the control scheme to include adjustable setpoints.

The Sanders Plant employs two General Electric Series Six programmable controllers to control each generating unit individually. Although one PC could be used for both units, the incremental cost for a duplicate system was readily justified by the increased reliability and a low incremental cost. The PC's monitor the status of all inputs, direct the status of all outputs, and sequentially start-up or shutdown the plant either locally or remotely. In addition to automatic operation, a manual mode is provided in which the PC

is bypassed and all startup and shutdown procedures can be affected by operation of control switches on the front panel of the switchgear.

An automatic synchronizer and automatic voltage regulator are also necessary components of the automatic control scheme. The automatic voltage regulator used in conjunction with the brushless excitation system is equipped with a motor operated control rheostat (MOC). The MOC will receive pulses for raise or lower voltage commands and adjust the voltage regulator accordingly. In the automatic mode the pulses are of a predetermined duration and issued by the automatic synchronizer prior to synchronization with the line to bring the incoming voltage equal to the running bus voltage. Once the unit is "on-line" the remote operator will send raise or lower commands to the MOC to adjust the power factor.

The automatic synchronizer is a solid state device that will automatically sense speed, voltage and phase angle differences between the running bus and the incoming unit and adjust the latter. When the unit is ready to synchronize (speed and voltage matched) a close command is issued to the generator circuit breaker in anticipation of zero phase angle, taking into account the closing time of the breaker. The close command is either permitted or blocked by the synchronizing relay (Device #25) as a double check before closing the breaker.

Supervisory Control

Supervisory control generally implies remote operation of a system where it is impractical to direct wire the controlled device. The supervisory equipment provides an operator at a remote location with enough information to determine the status of a generating facility and to cause actions or operations to take place without being physically present. A supervisory system can range in size from multiple master stations and multiple remote stations to a single master with a single remote. The latter system is what will be discussed here as remote control of a small hydro plant.

The programmable controller that is used for automatic operation of the plant is used for the supervisory control function as well. The remote operator can accomplish all the functions in the automatically controlled plant that are necessary for starting, stopping, and adjustment of load level and power factor. In addition, the operator monitors the water level of the impoundment, the status of the generator circuit breaker and the status of the high voltage

recloser located in the switchyard. The operator's console is shown in Figure 2. The electronic totalizer shown on the operators' console is independent of the programmable controller. It's function is to totalize the net system demand thus providing the operator with information as to when to run the remote plant. Because the plant is intended as a peak following installation, it can be run at the most economical times (i.e., when it is displacing the more expensive alternative) by using the system data. An annunciator panel, similar to the panel at the plant, is provided for the operator enabling him/her to monitor all protective relays, all modes of shutdown, and the status of station alarms, such as: fire, intrusion, and emergency power system fuel level. A photograph of the remote annunciator panel is shown in Figure 3.

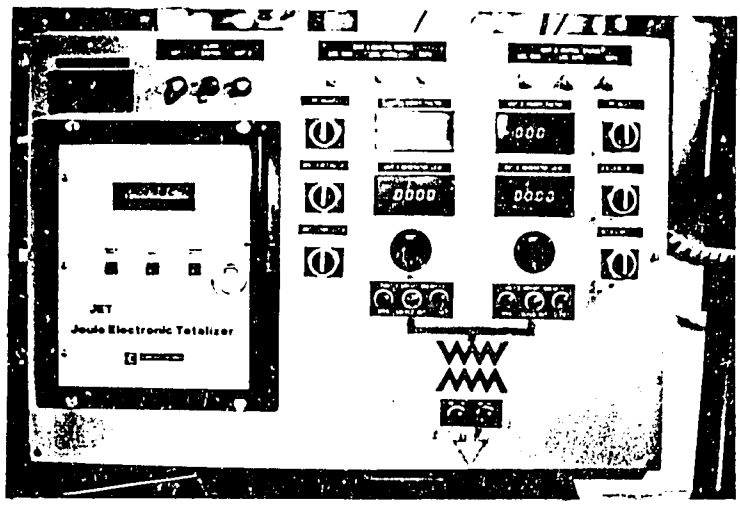

Figure 2
Operator Console

The addition of supervisory control for remote operation of the automatically controlled hydro plant was a very small step both technically and economically. All the logic functions necessary to arrange data are inherent in the PC. To serialize data for communications through a modem, the addition of one more output module (Remote I/O Driver) was required. In the remote control location an I/O rack with a Remote I/O Receiver and other modules, the operator's console, and annunciator panel completed the system. A simplified block diagram of the system is presented in Figure 4.

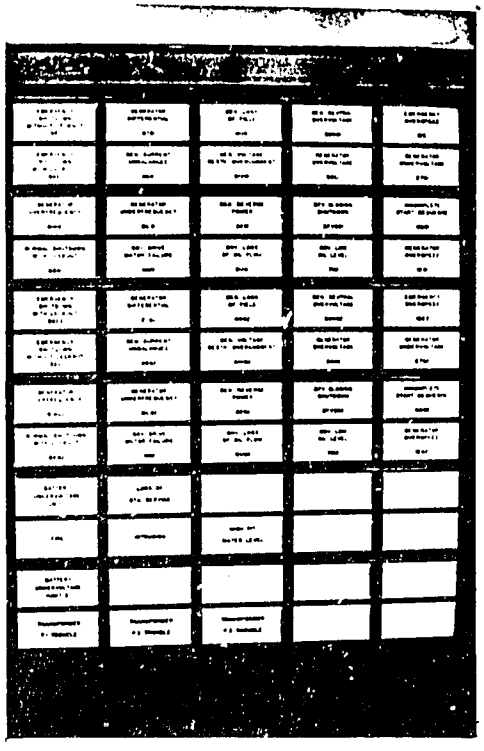

Figure 3
Annunciator Panel

Future additions will include a small independent microprocessor with floppy disk drive and a hard copy device. This will be used for two main functions. (1) It will record all generation from local hydro plants record purchased grid power from three remote delivery points, provide a sequence of events record and store, correlate, and summarize the data for a monthly report format. (2) It will make available a dynamic profile of the purchased power entitlements of the village and use this as the criterion for automatically operating the hydro unit as a peak following facility. By entering daily or hourly updates on the various components of their power mix, the village can further optonize thier hydro resource.

III. SUMMARY AND CONCLUSIONS

Switchgear is perhaps the most critical component of a small hydro installation. It's first function is to protect the major equipment from internal failure, external faults and operator error. The protective devices included in the switchgear scheme should be studied carefully and selected

to be applicable to the individual plant. Some of the variables to be considered are type of generator (synchronous or induction), type of excitation and type of hydraulic turbine control. Each of these variables will influence the number, complexity and time characteristics of the protection scheme.

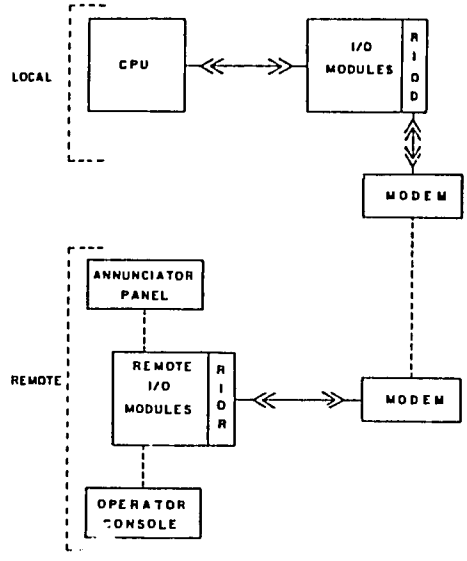

Figure 4
Block Diagram
Programmable Controller Configuration

The second function of switchgear is to provide a control scheme for the plant. The minimum control scheme must dictate the startup and shutdown sequences whether in a normal or emergency situation through the use of interposing relay logic or, as suggested here, the use of a programmable controller. Some of the advantages of incorporating a PC in the control function of the switchgear are as follows:

- It eliminates the need to construct large relay panels and to design extensive interconnection diagrams.

- It provides a flexible aspect to the control scheme where on-site changes to the program for operating or protection procedures can be made in minutes.

- The PC includes basic logic functions that permit an optimization routine to be part of the control parameters. This is most valuable when multiple units are

employed or planned, or alternate generation such as diesel fired base load equipment is used.

- The present state of the art in programmable controllers provides a high degree of reliability. Discrete plug-in printed circuit cards are arranged to facilitate troubleshooting and repair by interchanging or replacing the troubling card.

- System expansion or the inclusion of future isolated installations in the area can be accounted for and incorporated in the overall control scheme without major changes or physical re-design.

- Remote supervisory control and data acquisition can easily be incorporated into the system.

A coherent "systems" approach to rural electrification in developing nations is an option that should be considered in the earliest stages of planning. Modern technology has simplified the programming, and operation and maintenance of programmable controllers while increasing their flexibility and reliability and decreasing the cost. In addition to the advantages in control given above, the following benefits that may be realized in a national rural electrification program are suggested:

- A centrally located supervisory control system for a series of small plants in a region would decrease the technical training requirement. A staff of professional operators would be trained for employment at the central control and part-time maintenance personnel would be located at the remote sites.

- Generation data, maintenance records and inspection schedules would be available in a central location in a standard format. Maintenance would be co-ordinated on a "preventive" basis and generation and load data correlated to provide an overall view of electrification.

- In situations where cascaded plants are viable, the time delay between facilities can be used in conjunction with minimal impoundments to produce constant gen-

eration levels as well as peaking requirements for the regional system.

- An economic benefit can be realized by standardizing remote control operation of dissimilar plants. While the individual control scheme of remote plants will vary, the man-machine interface will be constant at the control location.

- By providing a relatively "high tech" involvement in small-hydro development, university trained nationals may be induced to remain in the country.

The item to be stressed in the development of a rural electrification program is that of permitting flexibility of control and the capability of incorporating future changes into the present plan with a minimum of cost and re-design. This system described here is a move toward that concept.

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John M. Bogert was born in New Jersey, USA on January 29, 1946. He received his BSE degree in Basic Engineering from Princeton University in 1968 and his MSE in Electric Power Engineering from Rensselaer Polytechnic Institute in 1980. Mr. Bogert is employed by the consulting firm of James Hansen and Associates in Vermont and has been working in the small hydro field for five years. He is particularly involved with small substation design, switchgear and control design and small utility systems.

Mr. Bogert is a registered professional engineer in the States of California and Vermont.

EAST AFRICA SMALL HYDROPOWER WORKSHOP IN MBABANE, SWAZILAND: 20 - 24 JUNE 1983

NATIONAL SMALL HYDROPOWER ACTIVITIES IN KENYA

INTRODUCTION.

Kenyas installed capacity in 1982 stood at 348.5 MW This is excluding 30MW imported from Uganda. Kenya has a total of 11 power stations, out of which 5 stations have an installed capacity of 2MW or less and 2 stations have a capacity of 0.4 MW or less. The total hydro generation in 1982 is 1589 GWh. Further Kenya just commissioned its second phase of a geothermal power project. It now has a 30 MW geothermal plant and a 98 MW thermal station. Total generation in 1982 was 1946 GWh. Kenya expects to be self sufficient on hydro and geothermal power by 1988 when some 2 on-going hydro-power projects will have been commissioned. Kenyas goal of being tot totally dependent on hdro and geothermal power is aimed at reducing the oil import bill.

As long as Kenya can produce sufficient energy in the large hydro-stations implementation of small hydros will remain unviable from an economic point of view. About 88 - 90% of Kenyas population live on a narrow high potential belt which spreads from the coast of Kenya to Lake Victoria. This area also happens to be the best suited belt for small hydro development due to its favourable catchments grounds. In this belt the grid is fairly well developed and it is therefore more economical to extend the grid than implement small hydros. The already existing small hydros were developed over 20 years ago by companies requiring power in isolated areas. They were however handed over to the National distribution agent and are now connected to the main grid.

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Kenya has a National Master Plan which also covers all activities in hdropower. In addition there are some consultants report on mini-hydros for various parts of the country. Some of the sites studied are very promising for small and mini-hydro implementation had it not been for the neighbourhood of the main grid. There is one site however which lies on the slopes of Mt Kilimanjaro and which happens to be far from the main grid. Plans are under way to construct a minihydro power plant here to serve a hospital. Still even for this one it would have been a lot cheaper and convinient for he local people if the area was to be connected to the National grid. Site identification, measuring of water flow and precipitation still continues.

The Ministry of Energy is the one charged with the duty of Energy Planning. Kenya Power Company (KPC) and Tana and Athi River Development Company (TARDC) plus Regional Development Authorities execute the implementation while East African Power and Lighting (EAPL) does the operation and maintenance of the plants together with power distribution.

Kenya has a moderate potential of hydro-electric power. When fully implemented the capacity will meet the demand up to the year 2000. Mean annual rainfall in Kenya ranges from less than 250mm in the arid north and eastern region to more than 2000mm near the high mountain ranges. The country is divided into 5 main catchment areas of which Tana River (The largest river in Kenya) area comprises the largest potential for hydro power development. The lake Basin, part of the Rift Valley, Athi River areas also have suitable areas for hydropower development.

Tariff is similar for the whole country. It tends towards cheaper unit prices for higher consumption and also has lower

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rates for off-peak supply for water heating. Total consumption of electricity in 1982 was 1631 GWh. Out of this 28% was in the domestic and small commercial use, 64% for large commercial and industrial, 7% for off-peak and 1% for street lighting. The main consumption took place in the urban areas. For the rural areas the use of electricity is very sparse due to the fact that transmission and distribution net-work is not well developed. The situation has however, been changing fast since a rural electrification programme was launched in 1973. In total only 2% of Kenyas energy consumption comes from electricity, more energy contribution comes from woodfuel with a share of 75%. All public supply except for 5 remote minor towns comes from the main grid. The quality and reliability of supply is therefore high. Operation and maintenance requirements are met by the power company's own staff (of engineers and technicians) which is locally trained.

Capital costs for small hydros in Kenya show a wide variations from one project site to another. Investment costs for about 17 investigated sites in Western Kenya and Upper Tana areas varies from 1400 to 8500 US $/kw (1982 prices). Of this the share of civil works and generator equipment consists of above 50%. The recurrent cost of capital is usualy based on 30 years life time and 11% interest rate, while operating and maintenance cost are estimated at about 2% of the capital costs.

The large scale hydros are financed through soft loans from donors or through the world Bank and also by local contribution. No small scale hydros have been implemented in the last 20 years. Design work is done by locally trained engineers and technicians. The Power Company (EAPL) consists mainly of Kenyans. The power company runs courses for technicians every year.

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CONCLUSION.

Kenya recognises the fact that her potential for large dams is limited and will soon be exhausted. The government therefore takes keen interest in the subject of mini-hydros. Already discussions are under way to formulate a policy on mini-hydro electric power development. Regional development authorities have been given the mandate to look into ways of implementing some of the small hydro electric power projects which are relatively more economic and which lie within their jurisdiction. Still, more has to be done in the way of coming out with a clear policy on matters such as commercialisation of this energy, tariffs as well general guidelines on management, operations and maintenance.

Thank you.

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EAST AFRICA SMALL HYDROPOWER WORKSHOP

JUNE 20TH - 24TH 1983

MBABANE SWAZILAND

CONDUCTED BY NATIONAL RURAL ELECTRIC COOPERATIVE ASSOCIATION

SMALL HYDROPOWER ACTIVITIES IN MAURITIUS

PRESENTED BY

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CENTRAL ELECTRICITY BOARD

MAURITIUS

June 1983

SMALL HYDROPOWER ACTIVITIES IN MAURITIUS

Mauritius is a small island of volcanic origin and it covers an area of about 1864 km^2. It is not as mountainous as, say, a nearby island, Reunion, but it cannot be classified a flat country. The appropriate sites for hydro power development are found in the mountainous southern parts of the island and most of the major sites have been exploited. The station with the highest head is at Tamarind Falls, namely, 292 m.

The major factor which has retarded hydro power development is the extent and importance of irrigation in the sugar industry, this industry being the backbone of the islands economy. There has been recent emphasis on the optimisation of our irrigation system which will permit the use of more water for power development. This policy has received a boost with the introduction of water saving irrigation methods e.g drip irrigation.

The total hydro power production of the country is around 20% annually, this represents a mean value of 70 GWh. (The Champagne Project which is due to be completed by the beginning of next year, will increase the production by about 32 GWh). Statistics based on studies made by firms such as OVE ARUP, SIGMA - SOGREAH and SMEC indicate a possible hydro potential of about 50 GWh annually. If the implementation of such projects were to prove successful to, say, 10%, this would mean an increase of 50% in the hydro production. (See annexure 1 and 1.1 for a list and sites of possible hydro schemes). The generation costs for the month of February 1983 were as follows:

Average Cost/kWh Rupees	Energy Source
0,89	Diesel
0,07	Hydro
0,52	Coal (Estimate)

These figures show that substantial savings can be made not only by the producer of electricity.(The Central Electricity Board, C.E.B) but also by the consumer since the cost of energy depends on the relative thermal (Diesel) production as compared with the total production. It must also be remembered that the useful life of a hydro scheme is much longer than that of a thermal scheme.

A recent mission of 2 experts sponsored by UNDP visited Mauritius last year (from the 12th of October to the 6th of November) in order to evaluate the small hydro power potential of the island. The latest information indicate that the report was still under preparation. The sites visited by the experts were in the Marc-Aux-Vacoas/Mare Longue/Tamarind Falls area, the Chamarel area and the Black River area. The possible annual production from these sites would be 3,6 GWh, 0,1 GWh and 0,6 GWh respectively. All the proposed sites could not be investigated because of the limited time available. Other projects worth mentionning are the Diamamouve/Champagne Scheme and the La Ferme Scheme. The first scheme proposes a possible potential of 21 GWh, this would increase the expected production of the Champagne project by 50%. In this region, a mean flowrate of 1,34 m^3/s of the water available is being diverted northwards for irrigation purposes. It is worth quoting from a report made by the Snowy Mountains Engineering Corporation (SMEC).

"It is significantly more economic to use the Grand River South East water resources for hydro power generation than to use them in the Northern Plains Irrigation Project".

The La Ferme Power Station, has seen its output reduced and finally stopped owing to an unreliable water supply from the Rivière du Rempart. In 1964, diversion of water from the higher grounds into La Ferme reservoir was studied by the C.E.B. The scheme was not followed up at that time because of the cost of civil works involved in relation to the cost of diesel fuel, however, the present situation shows that drastic changes have taken place. A report from SIGMA-TIGREAN indicates an availability of over 250 l/s of water, this water, if diverted would improve the inflow to the feeder and enable the re-instatement of La Ferme power station with an improved output of some 4,6 GWh as compared with 3,6 GWh previously. It must also be remarked that a careful study of the economics of the allocation of water to irrigation against the allocation of water to energy would appear advisable because a substantial part of the flows of the two main feeders in that region are being used for irrigation. The Quilles project is programmed as follows:

Stage I	1985	5,0 GWh
Stage II	1992	7,1 GWh
Stage III	1995	12,6 GWh

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The Banque Africaine de Développement has accepted to finance the complementary studies for the Guibies project in its 1983 programme. The Central Water Authority (CWA) now schedules the commissionning of the first of three stages of the project in 1987/88.

The list of hydro power potential sites is by no means exhaustive and the preceeding comments highlight the immediate possibilities for a development programme. The imminent presence on site of specialists for the study of proposed sites and eventual ones would undoubtedly boost the efforts of the Central Water Authority and the Central Electricity Board who, with the support of the Ministry of Energy and Communications are already devoted to the country's interest.

We would deeply welcome the inflow of very long term loans with low rates of interest from friendly overseas organisations, which take an unselfish interest in our well being. These loans would enable us to implement immediately our plans in the development of our remaining hydro resources and also in the optimisation of our existing sites. In particular we would welcome studies for the Eau Blanc Reservoir, where losses by infiltration through adjacent flows of lava on one of its banks represent an average of 13,4 mm^3 per year. These losses are indeed significant when they are compared with a total yearly average inflow of 30,4 mm^3. One must not forget that water costs us nothing and the earlier a project is implemented the lower the cost usually is.

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ANNEXURE 1

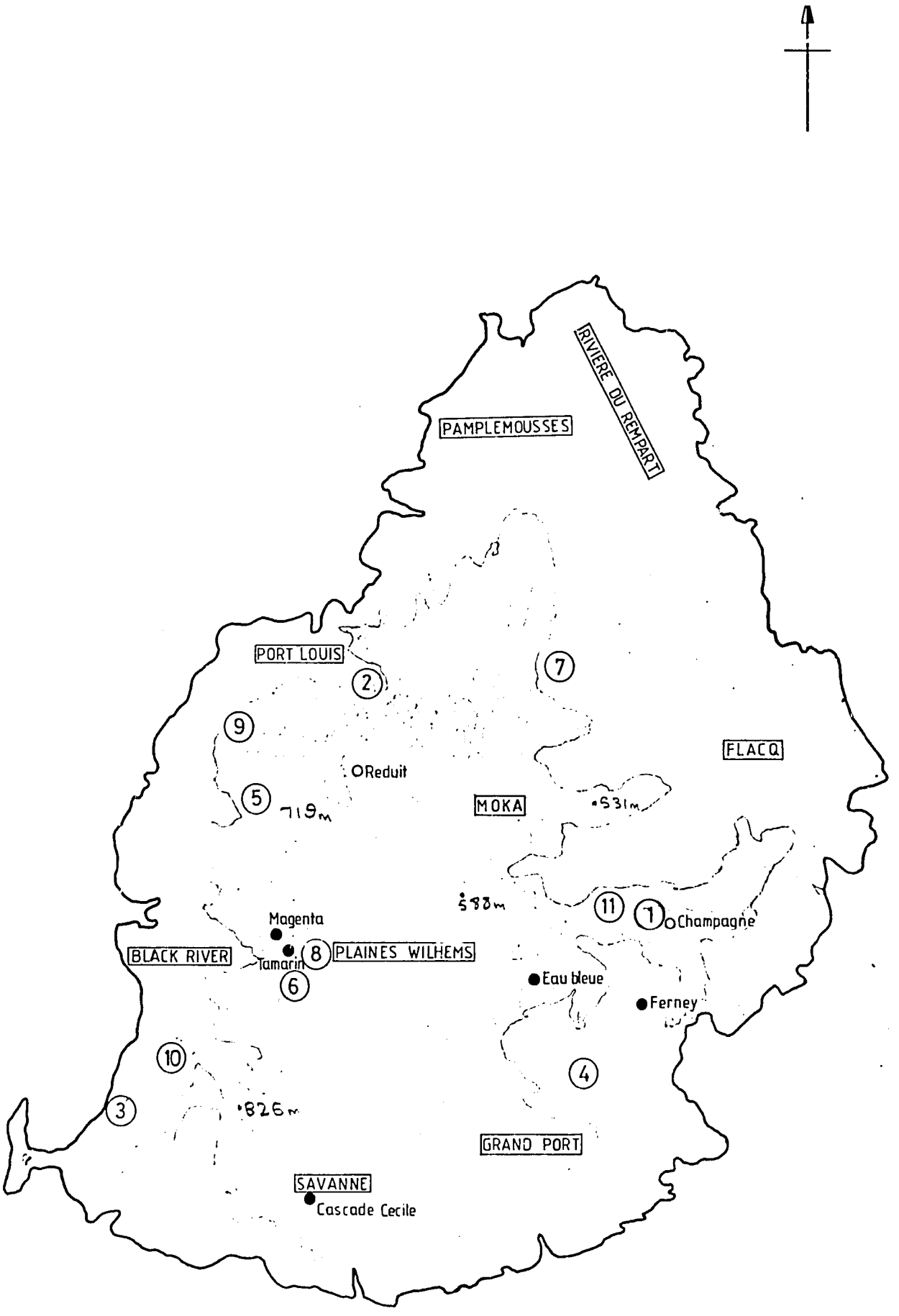
SUMMARY OF FURTHER HYDRO POTENTIAL IDENTIFIED

	SITE	POTENTIAL GWH/YEAR
1.	Diamandouve-Champagne: Additional Potential	21
2.	Guibies Project	12,6
3.	Chamarel	6,1
4.	Astrea	4,7
5.	La Ferme	4,6
6.	Mare Aux Vacoas/Mare Longue/Tamarind Falls	3,6
7.	Nicolière Feeder Canal (1,5 GWh/year) only if item (1) is not to be implemented	-
8.	La Marie treatment plant	?
9.	Pierrefonds Petite Rivière Pipeline	0,8
10.	Black River	?
11.	Grand River South East, downstream of La Pipe	?
		53,4 + ?

Note: The figures given above are tentative and would need confirmation from feasibility studies.

The numbers indicated correspond to the approximate situation of the sites in Annexure 1.1.

SG/



● EXISTING

O UNDER CONSTRUCTION

ANNEXURE 1.1

0 1 2 3 4 5 miles.

EAST AFRICA SMALL HYDROPOWER WORKSHOP

20 - 24 JUNE 1983: MBABANE, SWAZILAND

Discussion Topics

On

Small Hydropower Development in Lesotho

1. INTRODUCTION

The Leseotho Electricity Corporation (LEC) which was established under the Electricity Act of 1969 is responsible for all matters related to the generat on, trasmission, distribution and supply of electricity in the country; while all policy issues are under the juristiction of the Ministry of Water, Energy and Mining.

The LEC imports all electrical power from the South African Electricity Supply Commission (ESCOM). Some small diesel generators serve as stand-by-units or provide electricity to isolated small towns.

A number of Hydropower Schemes have been proposed and investigated more or less thoroughly since the early 1950's; and the sad fact has always been that the cost per kwh power transmissioned to the Central Distribution Area is twice higher than the cost per kwh imported from the RSA.

2. LESOTHO ELECTRICITY CORPORATION (LEC)

The participant from this Corporation will give an overview of the activities of the LEC. Topics to be covered shall include:

- Organizational Structure
- Staff and Training

- Capital and recurrent costs
- Load description and quality of power.
- Tarifff structure
- Operation and maintenance

3. ALTERNATIVE SOURCES FOR ELECTRICITY SUPPLY

Besides importing electricity from ESCOM, the Government has been actively Studying alternative sources for electricity supply. In 1977, a Hydropower study was carried out. This study resulted in a register of possible schemes with their main characteristics as regards hydro-power production.

At present, there are three active project proposals on hand, namely:

a. The Lesotho Highlands Water Project which seeks to sell surplus water to the RSA and simultenously to utilize that diversion scheme to generate hydro-electric power for the country. The enery output is estimated to be 450 GWh.

This participant is an engineer working in this project.

b. The Jordane Multi-power scheme The scheme is to provide hydropower. water supply for drinking and irrigation. A pre-feasibility study has been done.

c. Three Small Hydropower Projects - preliminary designs have been prepared and funds secured for detailed design and implementation.

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4. SMALL HYDROPOWER DEVELOPMENT ACTIVITIES

4.1 Definition

The question often posed is: What are the characteristics of a small hydropower plant? Maybe we are thinking of plant capacity of 500 - 1000 kw

Apparently there should be some consistency in referring to small, mini, micro or big hydropower!

4.2 Constraints and problems associated with Small Hydropower Development

In Lesotho, generally there have been three main problems, namely that:

a. The development of all hydropower has been the responsibility of a single government agency (LEC) and therefore, small hydropower is often neglected.

b. In the mountain areas, the rivers have generally cut down into narrow valleys in the hard basalt rock, resulting in an ample number of natural possible dam sites; and also the slopes are steep. But the catchment is small and the amount of water available is relatively small.

In the Lowlands where the rivers have collected more water, the slope is flat and the valley wide, making a development of head more difficult.

c. We have dry winter seasons and therefore storage must be provided for. Storage costs are high. In the summer, we have flash floods which must be catered for by building spillways. Again spillways are expensive.

4.3 Evaluation of existing sites

Perhaps the most particular characteristic is that no two potential sites are alike.

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The approach has been to select sites which require low investment and are able to cover immediate energy demand. Of course, one of the assumptions is that the project itself will lead to increased demand. Experience in areas such as transportation projects in developing countries demonstrates that this point of view is not erroneous.

These considerations have led to the choice of:

a. Installations with minimum water storage facilities.

b. Secondary rivers with adequate flow conditions and flood peaks which do not require large-scale spillway arrangements.

c. Easy-access sites, as near to the centres to be supplied as possible.

4.4 Small Hydropower projects under implementation

A study (May 1981) carried out by SOGREAH Consulting Engineers of France has indentified 9 sites and indicated for each site:

- the proposed installed capacity,
- the potential production,
- the minimum guaranteed power output,
- the production time at minimum output,
- the estimate of investment cost,
- the cost price per kwh potential production.

The Gvernment has selected 3 of these 9 sites for further detailed study and subsequent implementation as priority schemes.

These sites are:

1. Motete on the Motete river, to supply the Kao mines.
2. Tlokoeng on the Khubelu river to supply Mokhotlong town.

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3. Qachas' Nek on the Tsoelike river to supply Qachas' Nek town.

Using an average discount rate of 8% and assuming an average of 80% comsumption of the potential production, the following results are obtained:

	Tlokoeng	Motete	Qachas'Nek
Installed power (kw)	708	524	482
Investment Cost (M)	2.22 million	2.45 million	2.567 million
Cost of kwh (cents)	8.1	12.7	12.3

1 M = U.S. $0.92

4.5 Project Financing

Funds for studies on Small Hydropower development have been made available by the German, Chinese, French, American and Norwegian Governments.

The French Government has gone a step further to provide funds for a detialed design and subsequent implementation of the three priority projects.

4.6 Management of the Small Hydropower Projects

There is no organizational structure and procedures tailored to handle Small-hydro development. All previous studies have been conducted using the services of one expatriate in the Headquarters of the Ministry in conjunction with the LEC management.

This set-up has worked mainly due to good faith from both sides.

It is now imperative that an organizational structure with specific terms of reference should be established in order to adminster the implementation of these projects.

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Guidelines are being prepared and we hope that the workshop will shed some light on this subject.

5. PARTICIPANT:

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EAST AFRICA SMALL HYDROPOWER WORKSHOP 20 - 24 JUNE 1983,
MBABANE SWAZILAND

HYDROPOWER ACTIVITIES IN LESOTHO

1. Introduction

Lesotho is dependant on the Republic of South Africa (R.S.A.) for electric power. The Lesotho Electricity Corporation (L.E.C.) which is responsible for the generation, transmission, distribution and supply of electricity in the country receives supply from the Electricity Supply Commission (R.S.A) at three points.

Water happens to be the important resources of Lesotho which has been the subject of many reports since the early 1950's. Recently a number of projects have been identified to develop Lesotho's hydropower potential.

2. Identified Projects

(a) Lesotho Highland Water Project which seeks to divert water from the Lesotho Highlands to the Vaal system (R.S.A) and to include hydropower development in Lesotho.

The scheme would ultimately give a continuous delivery 35.1 m^3/s of water to the vaal, and produce 450 GWh of electrical energy each year. It is proposed that work proceed in four phases designed to suit the forecast R.S.A. demand for water.

(b) Jordane Scheme The net annual energy production of the Jordane Scheme would be 155 GWh. Installed capacity if based on a load factor of 0,45 would be 42 MW in three units each of 14 MW.

Jordane is a multi purpose scheme offering benefits to Lesotho other than power. These are:-

(i) a perennial flow in the Senqunyane which will allow irrigation,

(ii) a perennial flow in the Senqunyane, or piped from the power station, which would also provide a reliable long term water supply for Maseru without a need for another resevior.

(iii) a reliable flow at the discharge of a power station which would provide an opportunity unique in Lesotho for fish farming. Unit cost of energy for the Jordane scheme is shown in table 1.1

(c) Mohlakeng Scheme is situated on the Senqu River upstream of the confluence with the Qomoqomong River.

The size, capacity and output of the Mohlakeng Scheme depends on the layout of the Highland Water Project to be chosen.

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2. (c) continued.

Three possibilities exist and are detailed in Table 1.1 which also shows the energy production, proposed installed capacity, capital cost and loss of potential output for each.

The unit cost from the Mohlakaneng schemes is given in Table 1.2, also shown is the unity electricity cost for Mohlakaneng Phase 2, as originally conceived by SWECO, with no diversions of water to the R.S.A. The Highland Water Project reduces the total energy potential of Mohlakaneng and thereby increases the unit cost of electricity it generates. The increase depends on the layout chosen.

(d) Mini-Hydroelectric projects. There are proposals to proceed with small hydroelectric projects of 500 KW or 1MW to 3MW. These are to be situated at Mohale's Hoek and on the Senqu River near the border with Transkei.

These hydroelectric projects are intended to supply isolated system and concern distribution voltage levels only.

The hydroelectric stations should be located such that power generated would be utilized with minimum technical and economic constraints.

A participant from Ministry of Water, Energy and Mining will give detailed information on small hydroelectric project development in Lesotho.

3. Effects of the Lesotho Highland Water Project on the Lesotho's hydropower potential. Without the L.H.W.P, Lesotho Hydropower potential would have been mainly concentrated in four projects with the following approximate energy output:-

Tsoelike	300 GWh/yr
Mohlakaneng	550 GWh/yr
Motebong	240 GWh/yr
Jordane	160 GWh/yr
Total	1250 GWh/yr

With the Lesotho Highland Water Project, Lesotho's hydropower potential would become:-

Mohlakaneng	210 GWh/yr
Jordane	160 GWh/yr
L. H. W. P.	450 GWh/yr
Total	820 GWh/yr

Figures are of gross energy, including transmission losses. Implementation of the L.H.W.P. will not relieve Lesotho of its dependence on the R.S.A. for its power needs, this will help cheapen the power by "chopping off" the peak demand which is pronounced during winter months. Table 1.3 shows relationship between L.H.W.P. and L.E.C. demands.

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4. Tariff structure of Lesotho Electricity Corporation

L.E.C. has classified its consumers in the following categories, namely:-

A. Small domestic consumer "whose maximum current taken at any one time is limited to 1 Amphere" The supply is unmetered, controlled through loadlimeter and is subject to a fixed charge of M5-00 per month. This tariff is not available to new consumers.

B. Domestic consumer for purely residential purposes.

First 300 units per month at 0.066 M per unit. All further units per month at 0.046 M per unit.

In addition a fixed monthly charge is payable calculated as follows:-

For the first 1 or 2 living rooms	M3.85 per month
For each addition living room	M3.85 per month.

C. General purpose tariff for all consumers other than private residences which have a demand of less than 50 KW for commercial purposes and less than 25 KW for industrial purpose. This tariff applies to most shops, offices, garages,workshops, schools and churches

The first 100 units per month at 0.13 M per unit All further units per month at 0,0725 per unit.

In addition a fixed monthly charge applies. The amount charged depends on total area of the installatio supplied. There is a minimum charge of M5.50 and a maximum of M78-00 per month.

D. (1) Commercial Maximum Demand: applicable to consumers other than industrial, "regularly having a Maximum Demand of 50 KW measured during a 30 minutes period in the course of the meter reading period.

All units consumed are charged at 0,0483 M per uni A demand charge of M8.9 per KW for all 6 units of Maximum Demand for each meter reading period with a minimum charge of M200 per month.

(2) Bulk supply to non-industrial consumers at H.T. Transformer and gear supplied and financed by consumer.

Demand charge is M7.8 per KW for all units of Maximum Demand for each meter reading period.

The charge is 0,0483 M per unit for all units consumed.

4. E. (1) Applicable to large industrial consumers having a maximum demand in excess of 25 KW, measured as in case of tariff D (1).

A demand charge is M7.72 per KW for all units of Maximum Demand for each meter reading period with a minimum charge of M190-00 per month.

All units consumed are charged at 0,0412 per unit.

(2) Applicable to large industrial consumers taking supply at H.V. Transformer and gear supplied and financed by consumer.

Demand charge is M6.72 per KW for all units of the maximum demand for each meter reading period.

All units consumed are charged at 0,0412 M per unit.

F. An off-peak tariff, available for not less than 8 hrs. a day. The charge is 0,0336 M per unit, for all units.

Cost of supply is composed of three parts namely:-

(a) Demand related charge, its constituants are:- interest charges, depreciation charge on fixed assets, salary and wages etc.

(b) energy related charges, e.g. cost of fuel etc.

(c) consumer related charges e.g. cost of meter reading, billing, service charges etc.

Current Escom tariff to L.E.C. is as follows:-

(i) Maximum Demand - 7.00 Rands/KW

(ii) Unit charge - 1,201 cent/KWh

(iii) A discount of 10% after deducting an amount of 1500 Rand from the sum of maximum demand, energy and service charge.

(iv) Service charge - 25 Rands

(v) Surcharge of 47,5% over the nett amount. It is not clear what this represent, since the escalations in cost of fuel is taken care of by increasing the energy charge.

Training

L.E.C. which is corporate with an autonomous status created by the Government under the Electricity Act 1969 was assigned "to make such provision as appear to it to be appropriate for advancing the skill of its employees by education, training and otherwise".

There is a negative attitude on the part of higher echelon within the L.E.C. to train.

Training continued

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References : (1) Lesotho Highlands Water Project
Preliminary feasibility Report May 1979.

(2) Tariff structure of Lesotho
Electricity Corporation BY A.S. SRIVASTAVA.

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TABLE 1.1

COST OF ENERGY IN CENTS/KWh FOR MOHLAKENG AND JORDANE SCHEMES

SCHEME		DISCOUNT RATE				
		4%	6%	8%	10%	12%
Mohlakaneng	A	2.45	3.33	4.37	5.56	6.87
	B	2.20	2.98	3.92	4.98	6.15
	C	2.11	2.85	3.74	4.75	5.87
ditto Phase 2 SWECO		1.39	1.90	2.49	3.16	3.89
Jordane		3.68	4.95	6.43	8.09	9.89

TABLE 1.3

RELATIONSHIP BETWEEN LHWP OUTPUTS AND L.E.C. DEMANDS

YEAR	LHWP PROJECTED OUTPUTS		LEC PROJECTED DEMANDS	
	MW	GWh	MW	GWh
1994/5	68	195	129	521.5
1998/9	82.5	304	194	780
2002/3	122.5	506	284	1142
2006/7	202.5	450	416	1672

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TABLE 1.2

ALTERNATIVE SCHEMES AT MOHLAKANENG

Mohlakaneng Scheme	H. W. P. LAYOUT NUMBERS	MAR available at Mohlakaneng $m^3 \times 10^6$	Capital cost Rand $\times 10^6$	Net annual firm energy production GWhr	Proposed installed capacity MW	SWECO net firm energy production GWhr	Loss of net firm energy GWhr
A	1,2,4,5,6,7,10, 11,12,13,15,17, 18,19	1,425	85.6	193	52	518	325
B	3, 9, 14	1,685	88.2	221	60	518	297
C	8	1,815	89.5	235	64	518	283

WATERS OF LESOTHO

Most of Lesotho's rivers that have sustainable flows are on the eastern and north-western region; the Senqu head waters and the Caledon basin head waters with the ~~flows~~ towns of Mokhotlong, Thaba-Tseka and Quthing. The most populated western region along the Caledon Basin has rivers with medium flows, becoming dry in the dry season, however the flows are very ~~hing~~ high during the wet summer season. The rainy season covers the months of October to April, the dry season is in the months of May to September.

Sediment loads are very high on the western region, the Caledon lowlands, due to high activity which covers agricultural land use and dust roads. The Eastern highlands have very little sediment loads due to the very scarce population, hence low activities.

The precipitation and evaporation distribution follow the west to east pattern. The eastern highlands have very high rainfall and the distribution is more or less uniform throughout the water year with snow supplement in the winter months from June to August. The evaporation is comparatively low due to low temperatures. The Caledon lowlands have low rainfall with the southern part having the lowest rainfall throughout the country. The evaporation potential is very high in this region due to the high temperatures.

To illustrate the above points, a tabulation of hydrological parameters as experienced throughout the country are given below.

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STATION NAME	REGION	PERIOD OF RECORDS YEARS	ANNUAL AVERAGE FLOW M^3/s	MAX. FLOW M^3/S	MIN. FLOW M^3/S	SEDIMENT LOAD TONS/YEAR 10^6	CATCHMENT AREA Km^2	PREC. MM	EVAPORATION mm/YEAR
TEBE-TEBENG	2	14	0.66	112	0.00	-	172	700-1200	2000
HOLOLO	2	17	1.38	71	0.01	0.016	212	900-1300	2000
HLOTSE	2	12	6.68	540	0.06	0. 575	728	860-1300	2013
MASIANOKENG	2	15	4.19	399	0.00	2.047	945	650-1150	2048
MOLIMO-NTHUSE	1	18	1.26	61	0.04	-	86	550-1320	1800
KOLONYAMA	2	10	6.69	272	0.06	0.881	905	700-1200	2000
PARAY	1	15	26.19	845	0.54	0.205	3240	550-1320	1500
SEMONKONG	1	17	2.35	45	0.00	-	231	750-1100	1500

REGION ONE IS THE EASTERN HIGHLANDS REGION, REGION TWO IS CALEDON LOWLANDS.

MINISTRY OF INDUSTRY
AND COMMERCE

JIRO SY RANO MALAGASY

SMALL HYDROPOWER ACTIVITIES IN MADAGASCAR

1. GENERALITIES

1.1. Geographical situation

Madagascar is a big island located in the Indian Ocean and separated from the Africa by the Mocambic Channel (390 Km).

Its area is 587 041 square Km (1 500 Km from North to South and 450 to 570 Km from East to West).

The Capricorn Tropic crosses the Island at its South part.

A North-South dividing ridge long of 1 200 Km (three times nearer of the Indian Ocean at the East than Mocambic Channel at the West) divides the Island into two zones :

- zone with very accidental relief on the High Plateau and at the East.

- zone with plat relief at the West.

Rivers are :

- Short and torrential at the East : Mangoro 300 Km, Mandrare 270 Km, Maningory 260 Km.

- Longer and more regular in the West : Mangoky 821 Km, Ikopa 664 Km, Betsiboka 605 Km, Mania 525 Km, Sofia 328 Km.

1.2. Climate and vegetation

- In the South-East, East and North, the climate is tropical type, hot and wet (average day time temperature varying from 19,1°C to 29,9°C - 1 000 to 4 000 mm of rain a year). Vegetation is formed in its major part of dense forests and secondary bush in the deforested zones.

- On the Central High Plateau, the climate is continental type, fresh and dry (9,2°C to 23,8°C - 1 222 to 1 430 mm of rain a year). Secondary bush constitues its vegetation.

- In the North-West, West and South-West, the climate is tropical type with long and dry season, hot and dry (18,9°C to 33,9°C - 744 to 2 095 mm of rain a year). Vegetation is almost constituted by the savanna with dense forests in some areas of North-West and the West.

- In the South, the climate subdesert type, hot and very dry (18,8°C to 29,9°C - 342 mm of rain a year). The vegetation is essentially constituted of fleshy and thorny bush.

1.3. Population

Actually, the population of Madagascar is about 8 500 000 whose 85% live in rural areas.

The Malagasy economy is basically agricultural.

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2. ELECTRIC POWER GENERATION, TRANSMISSION AND DISTRIBUTION IN MADAGASCAR

2.1. Organizational system of electric power generation, transmission and distribution in Madagascar.

The National Company JIRAMA (JIRO SY RANO MALAGASY or MALAGASY ELECTICITY AND WATER) have the onus of public electric power generation, transmission and distribution for the whole malagasy territory.

However, there is still more industrial self-producers, essentially in extracting industries (mica of the South, graphite of the East, chromite of the Center and the North, cement-factory of the North-West), agricultural (North NorthWest and East sugar-refineries, sisal of the South, big rice output centres of the Center North-West and SouthWest), mechanical (Antsiranana naval works site) as also common state exploitations (in process of disappearing)

For JIRAMA, Madagascar is divided into two regions :

- Interconnected Zone (Z.I) which includes approximately the central part of the country, where the grid, like its denomination, is interconnected.

- Exterior Zones (Z.E) which regroup all the lonely exploitations outside the Z.I.

2.2. Actual situation of the electric power production and consumption in Madagascar

Electric power production and consumption in Madagascar can be summarized by the following board (Source JIRAMA 1982 for the public distribution and 1980 situation for self-producying which has not very much progress until now).

		Public Distribution		Self-producing	Total
		ZI	ZE		
Equiped power kvA	Thermic			61 468	
	Hydraulic			619	
	Total			62 077	255 050
Production MWh	Thermic	10 742	103 618	77 430	191 790
	Hydraulic	198 638	29 682	1 052	229 372
	Total	209 380	133 300	78 482	421 162
Consumption and MWh	Industries High voltage			77 493	
	Low voltage			-	
	Total			77 493	

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In December, 31-1982, JIRAMA counts 56 diesel power plants (gas-oil and fuel-oil) and 10 hydropower plants.

At last, it should be observed that self-generation is essentially thermic whose advantage is to have reccurse to steam-power plants feeded by agricultural waste (waste of sugar refineries)

In 1980, situation was caracterized by the following percentage

	Equipped power	Generation
Hydraulic	1%	1,3%
Thermic with steam	37%	40,5%
Other thermics	62%	58,2%
	100%	100 %

2.3. Caracteristics of electric current

- Standardized voltage in Madagascar
  - . for transmission line : 138 kV, 63 kV and 35 kV
  - . for medium voltage distribution lines : 20 kV ar 5 kV
  - . for low voltage distribution lines : 220/380 V

Yet, we also find in some JIRAMA exploitations, old distribution lines with medium voltage of 30 kV, 15 kV, 10 kV and 5,5 kV ; so is the low voltage 127/220V in the center of big towns.

- Caracteristics of electric current
  - . frequency : 50 Hz
  - . Number of phases : 3
  - . Number of wires :
    - + High and medium voltage : 3 (insulated neutral)
    - + Low voltage : 4 (3 phases and neutral which is grounded) for service lead and 5 on the public grid (the 5th wire used to public lighting)
  - . Tolerance :
    - + of frequency : ± 2%
    - + of voltage : ± 3% for the High and medium voltage grid and ± 7% for the low volatge grid.

3. SMALL HYDROPOWER PLANTS DEVELOPPEMENT TOWARDS THE 2000'S

3.1. Hydroelectric potential of Madagascar

Generaly speaking, in order to valorize national ressources and to reduce in the same time the oil dependance of Madagascar, and as the country disposes of sites and an hydrological condition suitable to hydropower installation, the National energy Policy is moving more and more towards hydraulic solutions any time there exists sites, on the one hand to replace the existing Diesel power plants or to satisfy every important increase of demand, on the other hand for rural electrification.

So, JIRAMA established a systematic inventory of waterfalls existed on 1/100 000 and 1/50 000 topographic maps as well as corresponding hydrological data furnished by different agencies (Nacional Meteorology Agency, ORSTOM, Rural Engineering, JIRAMA) in order to value the hydroelectric potential of the Country.

The first phases will lead to a preselection of sites for reconnaissance survey and/or preliminary studies.

3.2. Studies and realizations

The national activities in the field of small hydropower plants are summarized in the following 3.1. Schedule.

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SCHEDULE N° 3.1

SMALL HYDROPOWER PLANTS

RECAPITULATION OF EXECUTED AND PROJECTED STUDIES AND WORKS MADAGASCAR

PHASIS / NUMBER	EXECUTED	PROJECTED	SOURCE OF DESIGN EXPERTISE	OBSERVATIONS
RECONNAISSANCE SURVEY AND/OR PRELIMINARY STUDIES	92	10 per year	local	
PRELIMINARY PLAN AND/OR (1) FACTIBILITY STUDIES	27	5 per year	local	
DETAILED DRAFT SCHEME	3	1 per year	overseas firms	local after formation of local staff
WORKS OF REALIZATION	1 (1)	1 (2) and 1 per year	(1) Dumont Camille et Cie. France (2) B.C.E.O.M.	(1) located at SAHAMADIO(Fr) 107 kW-807 MWH (2) located at BEZAHA (Tu) financed by FAC and CCCE 100 kW-700 MWH

(1) According project importance

3.3. Financial aspects

The small hydropower cost varuies with the project size and the civil engineering difficulties. The average parts are : 60% of the total cost going to civil engineering and 40% to hydromecanic and electric equipements.

The following schedule shows a few samples of costs concerning recent projects studied by B C E O M in Madagascar.

FEW SMALL HYDROPOWER PLANT COST IN MADAGASCAR (basis 1981)
(Withour power transmission line and exit way costs)

SITE	DEZAHA+	ANTARALAVA	MANABO+	NIBATOBE
Head (m)	13	30	2,5	5
Equipped power (kW)	100	320	76	51
cost in millions of FMG				
Civil engineering	37,5	145,1	32,6	45,3
Hydromecanichal Equipements	43,0	122,5	39,4	21,2
Electical Equipments	37,7	75,2	14,4	13,7
Total cost of (million of FMG)	118,2	342,8	86,4	80,2

1 FMG = US $ 0,004

+ Hydropower plant arranging on irrigation-ditch

The rentability of small hydropower plants can be affected by two supplementary facts, such as :

- the electric power transmission line which cost between US $ 18,000 to US $ 20,000 per Km.
- the exit way and roads whose cost vary with the geological data of the ground, the vegetation and the topographic difficulties.

At last, the financial rentability of small hydropower plants compared to a reference thermic solution is generally insured for annual using-hours of the electric power point superior to 2,500 hours per year.

A few basis statements for financial and economical analysis of projects are given by the schedules 3.2 and 3.3.

SCHEDULE 3.2.

LIFE OF EQUIPEMENTS

	Small hydropower plant	Diesel power plant
Civil Engineering	40 to 50 years	40 to 50 years
Hydromecanichal equipements	30 Years	
Electrical equipements	15 to 20 years	15 to 20 years
Generating set		15 000 hours

Using-hours of the electric power point = $\frac{\text{consumption in kWh}}{\text{equipped power in kW}}$

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. Juridical :

More particulary, insuffisciency of legislative texts about the water ressources permitting an arbitration between the different users and the control of a rational using of the water.

. Financial

Only preliminary studies are realized by the local staff.
Besides, the electromecanical equipements in its totality and one sum of civil engineering equipements are imported.

That state of things necessarily leads to expenses of currency which is against the actual conjuncture, and constitues serious problems.

On the other part, the existing tariff structure doesn't allow to constitue a suffiscient provision for self-financing of studies and investissment works.

Lastly, Madagascar oftly receives from some industrialized countries, trading proposals without any insurance of its socio-economical integration in the country.

5. CONCLUSIONS

The small hydropower plants development will certainly contribute to the rural countries electrification and at the same time, to the development of agro-alimentary and cottage industries, to the training and the amelioration of the countrymen life level, whose as it was said on the begining, constitue 85% of the population.

So efforts must be led, more particulary on the following points :

. Hydrology :

It's necessary to accomplish a systematic study of drainage-basin type per per region, operation as much justified that small hydropower plants are generally installed in isolated centers.

. Development of substructure roads

. Creation of a special organization for the small hydropower plants promotion.

. Suffiscient financial mounting as for studies as for realization works (grant, viable condition loan, self-financing by an adequat tariff structure)

. Formation of local staff in order to insure the relief of oversea firms that will reduce total cost of initial investissment.

. Transfert of technology in order to permit local manufactiring of some parts of equipements and to use local materials.

HYDRO-POWER DEVELOPMENT IN MALAWI

WITH

REFERENCE TO MINI-HYDRO PLANT

SMALL HYDRO - POWER WORKSHOP - SWAZILAND

20TH - 24TH JUNE, 1983

PREPARED BY: L.F. SONDHI & B.W.B. JALI
ELECTRICITY SUPPLY COMMISSION OF MALAWI

DATE: 17TH JUNE, 1983

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1. INTRODUCTION

Each process used in producing electrical energy has its advantages and disadvantages and the appropriate process must be employed to generate the desired electrical power, which is vital to economic development.

Malawi has abundant water resources. The rapids and falls of numerous rivers offer a source of power which could be harnessed to provide electrical energy at low operational cost without depending on expensive imported fuel.

As a land-locked country, Malawi has to import diesel fuel and other items of plant and equipment through the sea ports of Nacala in Mozambique. The expense of transporting this fuel over long distances and the high cost of diesel itself is reflected in the high cost of electricity in those isolated areas which are electrified by diesel generators. These extremely high rates deter development of the areas. Small hydro plant development in these areas would therefore not only replace existing uneconomical diesel plant, but would go a long way towards development of demand for power to the stage that it would be appropriate to connect these centres to the main grid.

The entire generation, transmission and distribution of electricity in the public sector within Malawi is the responsibility of the Electricity Supply Commission of Malawi which is a parastatal organisation of Malawi Government.

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2. LARGE HYDRO-POWER PLANT DEVELOPMENT

Malawi's principal river and major source of power potential, the Shire River, is classfied into three sections:

i) Upper Shire drops about 7m for 132Km from the southern extremity of Lake Malawi - the country's gigantic reservoir - to Matope. Hydro power development in this region has not been possible.

ii) Middle Shire stretches for about 94Km from Matope and drops 384m in a series of rapids known as the Murchison Cataracts. It is in this region of the river that hydro power development has taken place and more will take place in years to come.

iii) Lower Shire has a gradual slope and therefore no hydro power development is expected in this region.

The first hydro power station, Nkula Stage I, was commissioned in 1966 and the third generating unit was installed and commissioned in 1967. The power station has 3 x 8MW units and operation is at a net head of 45m. Since 1967 the peak demand for power and energy rose from 17.5MW to 66MW in 1981 and from 66GWh to about 380Gwh respectively.

Hydro generation was further augmented by construction of Tedzani Power Station eight Kilometres downstream from Nkula Power station. Stage I of Tedzani Power Station has two units, each of 10MW capacity and were commissioned in 1973. Stage II which also has 2 x 10MW units was commissioned in 1976 and 1977. The fourth 10MW unit commissioned in 1977 raised the total hydro capacity from Shire River to 64MW. Tedzani Power station operates at a net head of about 40m.

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With a forecast rise in power peak demand from 66MW in 1980 to about 170MW up to the year 1992, a third hydro power station was constructed and the first phase of Nkula Stage II was commissioned in 1981. This comprises 3 x 20MW units and operation is at a net head of 57M. When the second phase is completed in the near future the station will have a total capacity of 5 x 20MW.

The present hydro power harnessed from the waters of Shire River now stands at 124MW.

2.1 Future Development

The next stage of development after phase II of Nkula Stage II, which will give an additional 40MW, will be Kapichira on Shire River. This will have a total capacity of 4 x 30MW. The first unit is to be operating by the end of 1989.

Investigations have shown that with a firm discharge of about $170m^3/S$ the middle Shire river has a hydro potential of about 500MW at five identified sites.

Central and northern regions of Malawi also possess considerable hydro potential which is proposed to be developed when necessary.

2.2 Transmission Network

The major power stations on the Shire river supply bulk power to the southern, parts of the central and northern regions of the country through transmission lines at 132kV and 66kV for main grid lines and by spur lines at 33kV for primary distribution and 11kV for secondary distribution.

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Some sections of the transmission lines constructed to operate at 132kV and 66kV are operating at 66kV and 33kV respectively. In the near future these lines will be operating at the design Voltages.

Distribution to the consumers is either at 230V single phase or 400V three phase at a frequency of 50Hz.

3. EXISTING MICRO, MINI AND SMALL HYDRO PLANT

Two 300kW pelton sets exist in the old capital of Malawi, Zomba, in the southern region. The station is connected to the grid but only operates on standby basis.

Other units varying from 35kW to 520kW also exist, but are privately owned by Tea Estates and other institutions. Some of these operate as standby plant and those in isolated areas are primarily planned and implemented to meet the basic needs of electricity for local purposes.

Owners of these hydro plants are required by law to apply for a licence to generate electricity through ESCOM if the capacity of the plant exceeds 20kW (See table 2).

4. SMALL HYDRO POWER - POTENTIAL SITES

Although the benefits of comparatively low cost hydro power from the Southern region have reached many parts of the country, there still exist areas such as Karonga and Chitipa in the northern region which are unlikely to reap the benefits of an interconnected power system for many years for economic reasons. However, studies conducted by the United Nations Department of Technical co-operation for Development have shown that there exists potential for small hydro power in Karonga, which if harnessed would replace the uneconomical diesel

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generation which electrifies the area at present. For Chitipa, unfortunately, the investigations indicated that the stream flow is inadequate and the site is not suitable for development either through diversion structure or by any impounding structure for creation of a significant head.

4.1 Site I - Karonga Project

The town and its adjoining localities are supplied from a diesel station with two generating units each of 120kW capacity. The 1981 peak demand of about 100kW in Karonga will no doubt rise to about 500kW in a few years. The development of a mini-hydro plant in the vicinity would replace the existing uneconomical diesel power station.

Investigations carried out by UNDTCO identified a site after the confluence of the North Rukuru river with its tributary river Sere. Their report entitled "Evaluation of Small Hydro Power Sites in Malawi" states that it should be possible to harness about 500KW at this site by utilising a design discharge of 0.84m^3/s and by developing a net head of 75m. This will have an annual energy content of 2.34GWh at an average load factor of 60%. More potential exists should it be necessary to expand.

4.2 Site II - Chilumba Project

This town situated about 77kM from Karonga has not been electrified as yet and there are no plans for its electrification either by diesel power or extension of the main grid. In 1981 the demand for power was estimated to be between 30 to 40kW.

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The UNDTCO report states that a potential hydro site exists after the confluence of rivers Manchewe and Kazichi, the tributaries of river Chitimba. This site should be able to produce about 200kW of power with an annual energy content of 1 Gwh at an average load factor of 60%. This is based on a design discharge of $0.09m^3/s$ at a net head of 275m. This power would serve areas Chitimba, Chilumba, Khwawa and Livingstonia.

4.3 Site III - Mazamba

Investigations have been carried out to ascertain the potential at Mazamba. These investigations were carried out when Mzuzu was being electrified by a diesel station, with a capacity of 380kW, with a view to meet the growing power energy requirements of the area. Now the area has been connected to the national grid.

A suitable development of the hydro-electric potential at Mazamba would comprise a reservoir at Mazamba Bridge for over-annual storage created by an earthfill design of dam. This reservoir would provide a reliable continuous flow of about $1.6m^3/s$.

The power station would be located about 0.8Km downstream on the north side of the river. An open aqueduct leading to a head pond on the hill side adjacent to the power station would enable power to be produced from a net head of about 47m. This would give an annual energy output of about 5.4Gwh.

The proposal was to use three horizontal bedplate-mounted water turbine alternator sets, the turbines being of the Francis type operating at 750rpm and connected directly to 450KW 530kVA 0.8p.f. alternators generating at 3.3kV. 400V generators could be considered but would require the use of heavy duty, low voltage switches and

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heavy interconnecting cables to the switchgear and outdoor transformers.

This station when developed would be interconnected with the grid.

4.4 Other Sites - General

There are numerous sites with hydro potential on other rivers which have a reliable continuous flow throughout the year - South Rukuru, Dwangwa, Bua, Lilongwe, Linthipe, Livulezi, Ruo and Luchenza are just some of the rivers. Some of these have been investigated and others are yet to be investigated, but upon grounds of economy, not all sites can be developed. However, sites previously considered to be very expensive to develop will have to be reconsidered.

Bua River has a potential of about 18.5MW. The harnessing of this power and its interconnection with the national grid would, besides increasing the national hydro capacity, reduce transmission losses due to transmission from the south and would also improve the system reliability in the central and northern areas.

South Rukuru scheme is also another of significance in the northern area.

5. CONCLUDING REMARKS

Electrification of remote rural areas by extension of the national grid is impractical because of unfavourable cost/benefit ratio and system operation at low loads that do not justify maintenance cost for that extension. Low load factors can also make it difficult to design the capacity of generating facility properly. Electrification by diesel is also expensive to run and as a result the charges would not attract consumers.

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Development of small scale hydro systems where the potential exists can therefore go a long way in meeting the energy requirements of the remote rural areas.

Malawi has many rivers where water flows throughout the year. There is, therefore, a case for thorough investigations to be carried out on these and other rivers to ascertain the sites and potential for future development of hydro power. It should be noted that once the middle Shire river has been fully developed, other locations will have to be sought to meet the future demand. The interconnection of all such small stations with the grid will also improve the overall reliability of the system.

The Government of Malawi working hand in hand with ESCOM is continuing its efforts in developing its hydro electric potential wherever it is feasible in order to satisfy the economic and social development of Malawi.

Three more sites are to be developed on the Shire River with a total of 360MW, but the small hydro schemes will supply the very remote, isolated areas of Malawi.

REFERENCES

UNDTCO : "Report of the Mission to Evaluate Small Hydro-Power Sites in Malawi" June, 1981.

ESCOM : "Annual Report, 1981"

ESCOM : "Feasibility Report on the Mazamba Hydro-Electric Development," March, 1972

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TABLE 2.

POTENTIAL HYDRO - ELECTRIC SITES

SITE	MEAN GROSS HEAD (M)	DAILY ENERGY CONTENT (MWH)	CONTINUOUS OUTPUT (MW)	AVERAGE DISCHARGE (M^3/S)
NKULA +	54	1728	114	170
TEDZANI +	40	1272	40	170
MPATAMANGA *	64	2112	120	170
KAPICHIRA *	62	1992	120	170
KHOLOMBIDZO *	69	2184	120	170

\+ developed or partially developed.

* for future development.

TABLE 2.

PRIVATELY OWNED MICRO, MINI, AND SMALL HYDRO PLANT

LICENSEE	AREA	CAPACITY (KW)
1. Lujeri Tea Estates Ltd.	Mulanje	i) 520 ii) 252 iii) 35
2. Nchima Tea & Tung Estate	Thyolo	145
3. Christian Service Committee	Livingstonia	145
4. Blantyre & East Africa Ltd.	Mulanje	80
5. Seventh Day Adventist Mission	Neno	30
6 Diocese of Southern Malawi	Kasupe	35
	TOTAL	1242

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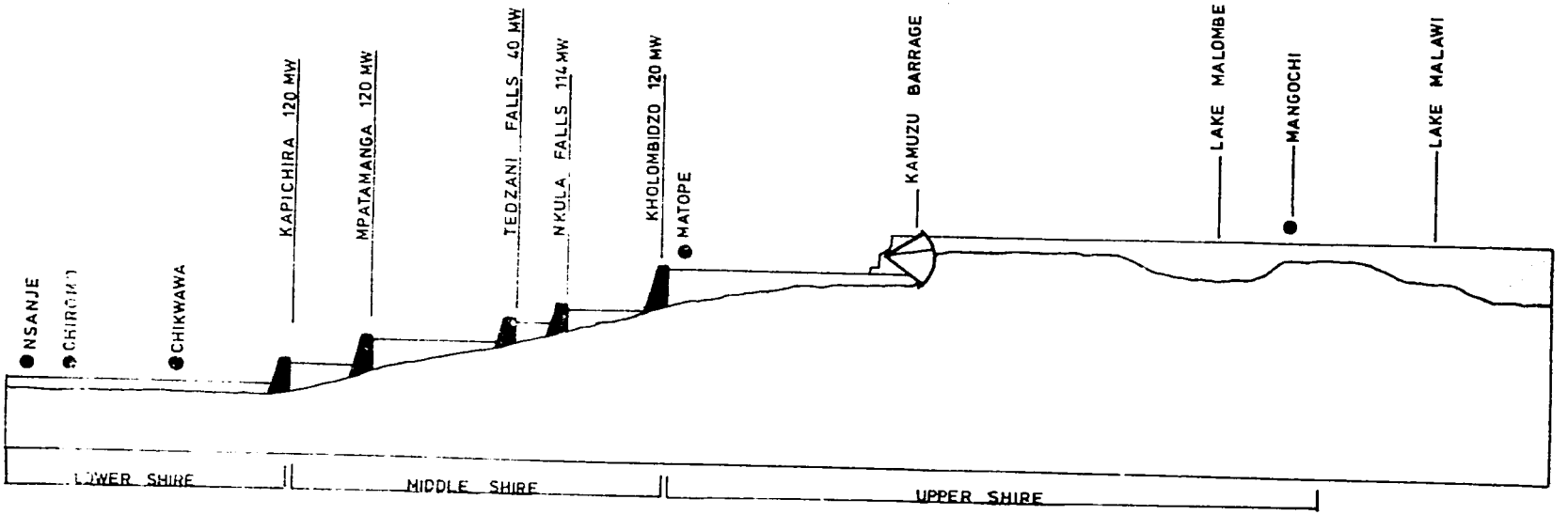


THE SHIRE RIVER

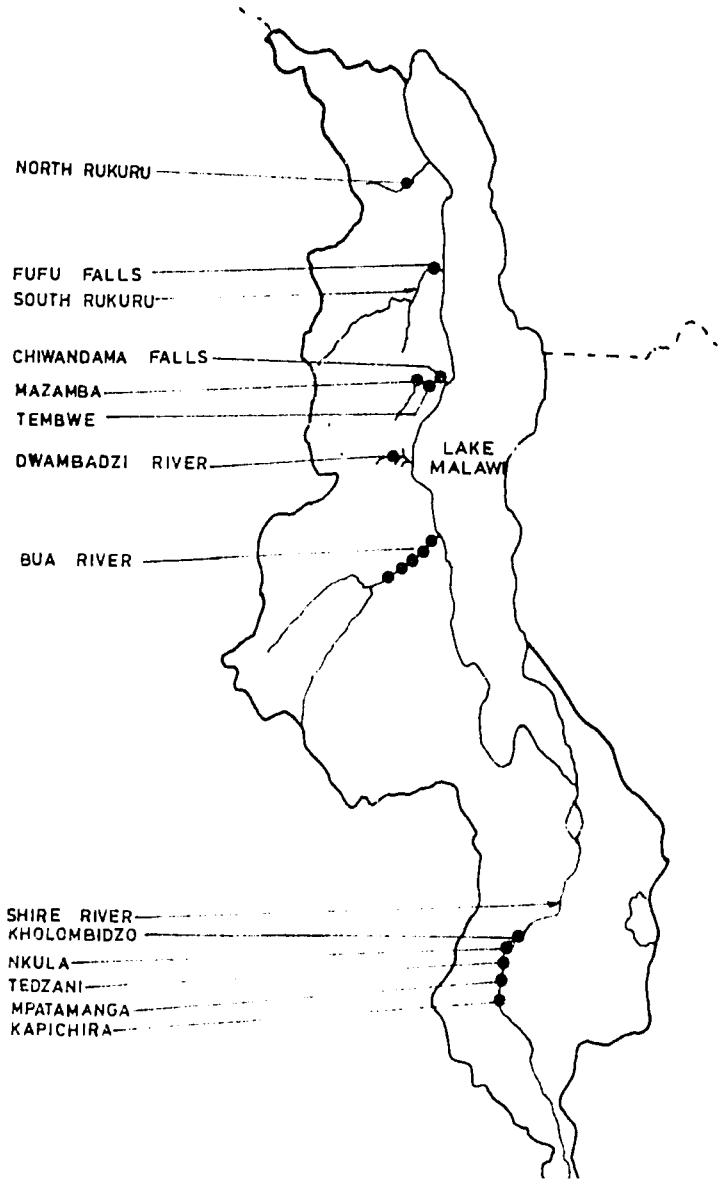
THE UPPER SHIRE FALLS ONLY 7METRES IN THE 132km BETWEEN THE LAKE AND MATOPE. SIMILARLY THE LOWER SHIRE FALLS VERY LITTLE BEYOND CHIKWAWA.

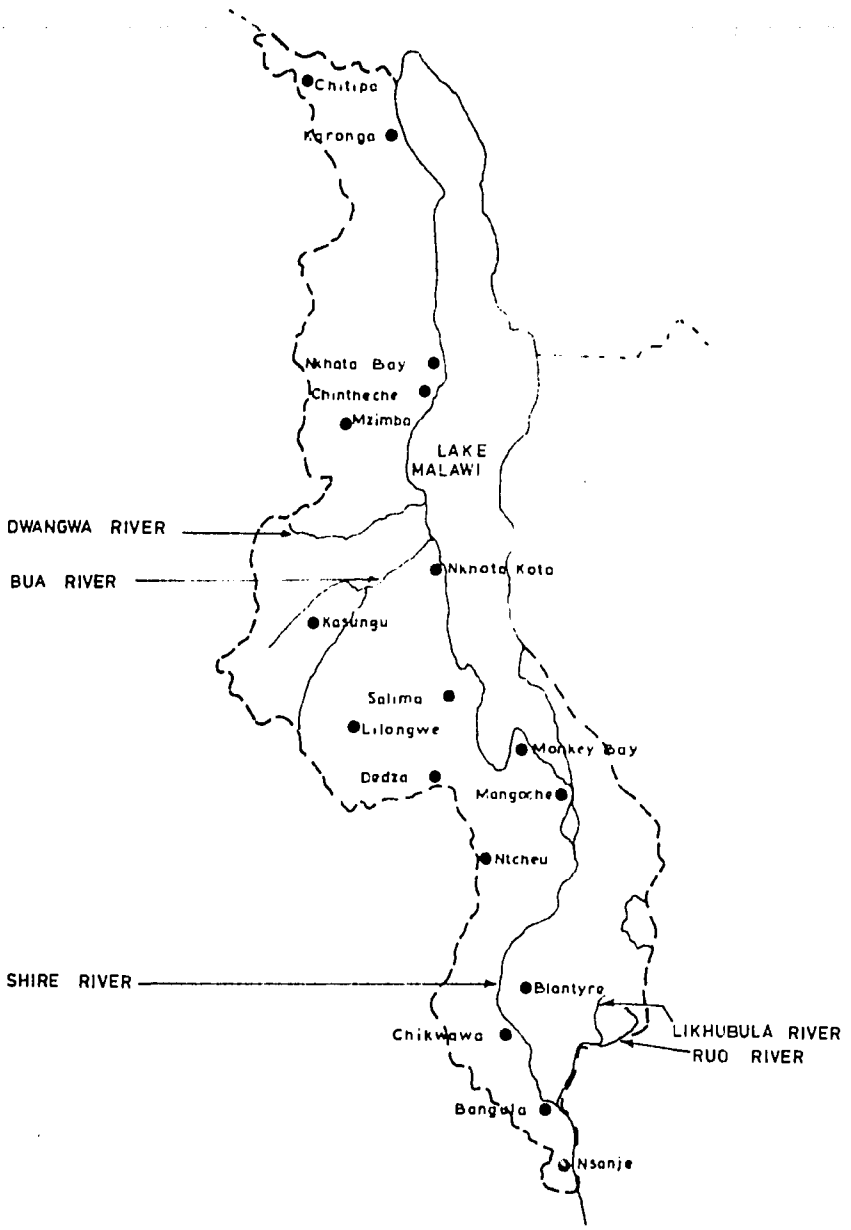
IT IS IN THE MIDDLE SHIRE WHERE IN 84km THE RIVER PLUNGES 384 M IN A SERIES OF RAPIDS KNOWN AS THE MURCHISON CATARACTS, THAT SUFFICIENT HEAD ! AVAILABLE FOR HYDRO-POWER.

WATER QUANTITY AS WELL AS HEAD AFFECTS THE AMOUNT OF POWER AVAILABLE KAMUZU BARRAGE COMPLETED IN 1965 WAS CONSTRUCTED TO PERMIT CONTROL OF LEVEL OF MALAWI IN ORDER TO ENSURE THAT AN ADEQUATE DISCHARGE WILL ALWAYS BE AVAILABLE I THE SHIRE FOR HYDRO-ELECTRIC GENERATION.

IT IS ECONOMICALLY IMPOSIBLE TO HARNESS THE FULL THEORETICAL POWER OF THE SHIRE RIVE BUT DETAILED STUDIES BY E S C O M AND THEIR CONSULTING ENGINEERS HAVE LED TO A NU OF PRACTICAL PROPOSALS WHERE BY CONSTRUCTION OF HYDRO ELECTRIC POWER STATIONS W DAMS OR BARRAGES AT THE FIVE SITES SHOWN IN FIGURE 2, MOST OF THE AVAILABLE POTENTIAL CAN BE DEVELOPED.

POTENTIAL SITES FOR HYDRO ELECTRIC DEVELOPMENT IN MALAWI




Chitipa
Karonga
Nkhata Bay
Chintheche
Mzimba
LAKE
MALAWI
DWANGWA RIVER
BUA RIVER
Nkhata Kota
Kasungu
Salima
Lilongwe
Monkey Bay
Dedza
Mangochi
Ntcheu
SHIRE RIVER
Blantyre
LIKHUBULA RIVER
RUO RIVER
Chikwawa
Bangula
Nsanje

Regional Workshop on Micro Mini Hydro Electric Systems

20 - 24 June 1983 SWAZILAND

Country Paper - Seychelles by R WEBER M.Sc.

Micro/Mini Hydel potential in Seychelles

1. Introduction

1.1 General

The Seychelles archipelago lies between latitudes 4° and 10° South and longtitude 46° and 56° East and has a land area of 444 square kilometres. It consists of 115 islands scattered over 1.15 million square kilometres in the Western Indian Ocean. Forty four of these islands are geologically granitic and the rest are coralline.

The total population of the Seychelles is 65,000 of which 60,000 live on the main island of Mahé.

Mahé, the largest island has an area of 148 square kilometres. It is approximately 27 km long in the North - South direction and varies in width from 3 to 8 km. Victoria the capital city is the only port. Most of the habitation and agricultural development in on the narrow coastal strip all along the periphery of the island. Hydro Power Potential only exists for Mahé and one or two other granite islands sites for hydropower development.

1.2 Topography and Geology

The central mountain range on Mahé rises steeply from the sea and coastal plateaus to heights of between 460 and 900m. The average slopes are in the 1 in 5 to 1 in 6 range. Running down these slopes are numerous stream with small catchments of areas varying from 1 sq km to 5 sq km. There are no major rivers in the conventional sense.

Mahé is a granitic island and boulders well rounded varying from a few centimeters to several metres in diameter occur in different concentrations at many places on the slopes and in the river valleys. In some cases, the boulders are so densely packed to form an almost impenetrable maze. This coupled with dense vegetation, steep slopes and exposed hard rock make it economically unfeasible to divert flows of adjoining streams for utilization under one hydro scheme and hence individual small scale hydro power schemes on several streams have to be planned.

1.3 Climate

The climate is of the tropical humid type with a marked seasonality influenced by the prevailing pressure conditions. During the dry season, May to October, the island is under the influence of the South-East Monsoon, from November to March, the wet season, the North-East Monsoon blows. The relative humidity is high throughout the year averaging 75 to 80%. Average annual rainfall is as high as 3500 mm in the central high lands, dropping down with elevation to 2000 to 1700 mm in the coastal regions. During the wet season the monthly average exceeds 200 mm and in the dry season this is in the range 70 to 90 mm.

Temperature is almost uniform over the year with mean daytime values ranging from 66°C to 28°C, the maximum of 30°C being in April and May. Night temperatures average 24°C.

2.0 Seychelles Energy Programme

Apart from the coprah and cinnamon industries, the Seychelles meets its energy requirements through the importation of oil. Statistical figures regarding oil imports into the Seychelles tell the following story:

- Between 1975 - 1979 the volume of oil imports for domestic consumption has increased 1.8 times whilst the cost of these imports has trebled.
- By the year 2000 the Seychelles is likely to consume three times as much electricity as it does now and its peak power demand is likely to increase by as much.
- Seychelles earnings from its domestic exports is inefficient by a large margin to meet the costs of its domestic import of oil clearly highlighting the precarious dependence of Seychelles economy on the tourism sector. The trend is an increasing proportion of the country's revenue going towards meeting the cost of its oil requirements: between 1976 and 1981 the figure rose from 13.9% to 25%.

It is in response to the above picture that the Seychelles Government drew up the Seychelles Integrated Energy Project (SIEP) with the following development objectives.

- the development of an alternative energy system which will enable the principal island of Mahé to satisfy its total electrical energy requirement from non-fossil fuel sources
- the development of individual integrated energy systems which will be fed either by other renewable forms of energy or by other locally available materials, capable of providing the entire electrical energy requirements of the remaining islands of the Republic of Seychelles.

- the development of an energy management programme involving:
  - energy economy
  - energy substitution
  - energy consumption pattern control in order to:
    - reduce projected future oil imports for electricity generation
    - reduce capital outlay on additional generating capacity by the more efficient use of existing plants.

The energy problem has thus to be addressed at two levels:

(i) the requirements of the outer coral islands, where a small integrated energy package of the order of (100 - 500) kW is required

(ii) the requirements of Mahé where a large system of the order of 20 mW is required.

The sources of alternative energy that have been identified are as follows:

- conservation and efficiency
- hydroelectricity
- biomass
- biogas
- solar
- wind
- ocean thermal energy conversion

In order to carry out the SIEP, the Seychelles Government created in October 1979, the Research and Development Unit within the Ministry of Planning and External Relations. The SIEP is divided into three phases of 3, 10 and 7 years respectively and may be considered to have begun since 1980. Phase I is designed initially to provide a power supply of the order of 50 - 100 kW for each of the outer islands which are earmarked for development.

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Sources that have been identified and on which the small energy packages will be developed is based on producer gas, biogas, wind and solar energy.

For the energy requirements of Mahé, of (10 - 20) mW the most promising sources on the short term are hydro electricity and conservation measures. Solar water heating systems have an important contribution in meeting the low and medium temperature hot water requirements. Biogas may have possibilities on the larger farms and National Youth Service villages. The wind regime on Mahé does not seem to hold out much promise for wind energy conversion system unless their performance should improve and their costs come down significantly.

In the long term, photovoltaic system and Ocean Thermal Energy Conversion systems hold a lot of promise. The cost of the former seems to be coming down, figures of US $1/ watt by the end of the century. In so far as the Ocean Thermal Energy Conversion System is concerned, the potential sites are available but there is still quite a way to go with regard to its economical viability.

The Seychelles Government has been successful in obtaining funds to begin executing the first phase of its Integrated Energy Project: however financial and technological assistance will be needed in considerably greater amounts to ensure the completion of the project over the whole project period of some 20 years.

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3.0 Power Supply

The present Electricity supply of Mahé is by diesel generation from two power houses Huteau Lane (Station A) and New Port (Station B) both situated in the main town of Victoria.

The capacity of the generating sets at these stations are given in Table 1 below.

Unit No	Capacity (mw)	Year of Installation
Station A		
1	1.00	1969
2	0.46	1963
3	0.46	1966
4	0.46	1966
	2.38	
Station B		
1	2.5	1972
2	2.5	1972
3	2.5	1976
4	2.5	1978
5	5.0	1981
	15.0	
TOTAL	17.38	

TABLE II

Seychelles Electricity Cooporation Limited

	1981	1982	1983	1984	1985
Installed Capacity (MW)	17.38	17.38	17.38	22.38	22.38
Peak Demand (MW)	9.0	9.3	10.0	10.2	10.6
Load Factor (%)	63.8	62.3	61.1	61.1	59.3
Gas Oil (L)	13,960,325	11,357,741	3,064,336	3,114,553	3,129,389
Fuel Oil (L)	-	2,242,956	10,787,256	10,964,030	11,016,259
Fuel Cost (RS)	39,926,529	37,641,937	33,574,688	34,124,890	34,287,447
Units Generated	50,324,940	50,787,324	53,700,000	54,580,000	54,580,000
Transmission Losses (%)	8.75	8.17	8.00	8.00	8.00
Generation Losses (%)	3.44	4.29	4.50	4.50	4.50

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Table II illustrates clearly the Seychelles Electricity Coorporation current position and projected developments up to 1985.

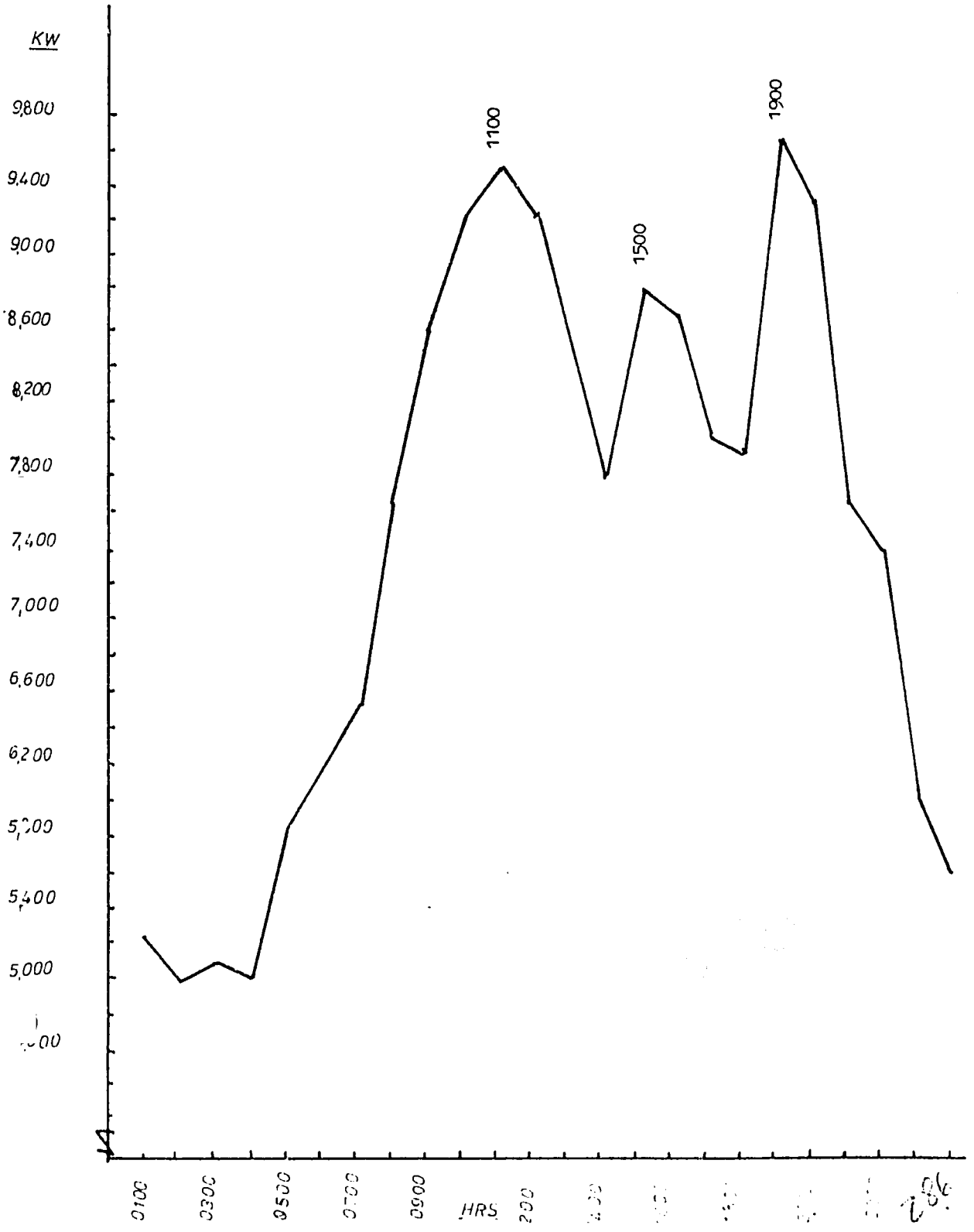
In 1982 Seychelles Electricity Cooporation introduced the substitution of gas oil for fuel oil at a substantial decrease in cost of imported fuel from SR 40 million (6 m $) to SR 33.5 million (5 m $). However fuel imports for electricity generation contributes up to 10% of our total import bill and consequently any possibilities of developing energy sources alternative to the actual generators could provide a saving on the import bill.

The electricity network on Mahé is quite extensive. A 11 kV transmission line runs all along the coastal road of the island except for a short distance at the North West tip. In addition there are cross connections linking east and west coasts. A 33 kV trans island transmission line runs east-west across the island. Generating voltage is 11 kV and 6.6 kV. Low voltage distribution is at 240/415 V AC. Tanalised wooden (Pinus Radiator) poles are used for transmission and distribution lines and step down transformers are pole mounted. The whole island is well covered by the transmission/distribution system.

The present average annual power demand is around 45 million units. A typical daily demand curve (see Fig. 1) is characterized by two distinct peaks of 9.5 MW at 11.00 and 9.7 at 19.00 hours. A minimum demand of 5 MW occurs at around 3.00 hours. There is no appreciable variation over the months in a year in daily power demand. Out of the total demand 30.5% is domestic demand, [illegible]% street lighting and the remaining [illegible]% is industrial and commercial demand. The estimated increase in demand [illegible] MW per year.

Fig. 1

Typical Daily Load Variation (Mahé 30/4/83)



4.0 Hydro-electricity Potential in the Seychelles

In 1982 the TATA Consulting Engineers Bombay undertook a pre-feasibility study on micro/mini hydro electricity schemes on the island of Mahé to determine the possibilities for hydro electric power. The results of this study is as follows:-

1. The topography and geology of Mahé island indicate that storage schemes are not economically feasible and hence run of the river schemes are best suited for generation of hydro power.

2. Net heads at the different schemes are in the range of 50 to 150 m. For heads in this range and flows of such small magnitude (design draft of less than 500 lit/sec) and varying widely from month to month, radial impulse type cross flow turbines (Banki-Mitchell) are the most suitable. Such turbines which have guide vanes built in multi sections make it possible to run the unit at optimum efficiency for flow variation from full to one fifth of the design discharge. For deciding size of the unit, net head is assumed to be 90% of gross head to account for friction and other losses. The combined efficiency of generator and turbine is assumed as 81%. For schemes with maximum power potential less than 100 kW only one unit is proposed and for bigger schemes two units each of capacity equal to 50% power potential are proposed. Accordingly minimum flow upto which a power station can run will be 1/5 of the design draft in case of single units and 1/10 of the design draft with two units. With these criterias, the power stations will be able to operate for 80 to 90% of the time in a year i.e. for 10 to 11 months in a year.

3. Comparative cost analysis made for determining the optimum installed capacity at typical power stations indicated that installed capacities corresponding to 10% to 15% duration flows appear to be optimum and ensure maximum hydro energy generation. The power stations will generate power at varying rate over the months in a year depending upon the flows in the river. The Seychelles Electricity Cooperation anticipate no problems in feeding power to the grid.

4. The most likely sites with hydropower potential which can be developed economically will be those where the cost of generation per unit will be less than the corresponding cost by diesel generation, currently 0.2 US $/kWh (SR 1.30/kWh). It was observed that sites with potential less than 100 kW tend to have a higher unit generation cost compared to diesel generation, due to higher cost of civil works in comparison to schemes with higher installed capacities.

5. There are six rivers with unit cost of power generation lower than the present diesel generation cost of US $ 0.20 (SR 1.29) /kWh. Two other rivers have unit generation cost marginally higher and will have to be studied in greater detail before ruling them out as uneconomical.

6. The 8 rivers studied have potentials ranging from 150 kW to 300 kW. The total hydro potential including the two marginal schemes is 2105 kW with a generating potential of 7.152 million units which is 15% of Mahé's present annual electrical energy requirement.

7. Cost analysis has been made on the basis of US $ 3,360/kW (SR 22,500/kW) worked out for a typical 200 kW scheme. In view of the procedure adopted for costing, cost of unit generation depends very much on annual plant

factor (Power Generated/Power Capacity) which in turn depends upon flow characteristics of different streams. The higher the plant factor, lower is the cost of unit generation. A detailed cost estimation of each scheme has not been carried out and will need to be carried out under detailed feasibility studies. A rough estimate of capital cost for the total hydro scheme is US $ 6.8 million.

8. Some of the proposed schemes have part of these civil structures, infrastructure readily available, the construction period as well as cost can be appreciably reduced.

9. Being run of the river schemes, the hydro power generation will vary from month to month depending upon the stream flow. The maximum generation will be in December and January and the minimum during June - August. The hydro power stations will run for about 9 to 11 months in a year.

10. During the low flow period when the flow is too low to be within permissible range of flow for the turbines, power stations will be shut down for annual maintenance and repair if any and hence the entire low flows will be available for local water supply and or irrigation during this period.

5. Recommendations

5.1 Hydrologic Data Collection

(a) For rivers without gauging stations, gauging data has been generated by assuming the river basin hydrologically homologous with adjacent river valleys for which observed data is available. For a more realistic analysis, it is recommended that gauging stations be established on those rivers which have no gauging data. It is realized that data collected will only be of a short duration but at least some data will be available at the time of detailed planning and designs.

(b) It is also necessary to establish rain gauge stations in the upper regions of the catchment areas.

5.2 Feasibility Study

In view of the encouraging results of the pre-feasibility study, it is essential that a detailed feasibility study for the development of hydro potential on Mahé island be taken up on a priority basis as an essential step towards implementation.

The basic objectives of the feasibility study will be

(a) evaluation of hydro resources available for generation of electricity on various streams identified as potential sites for hydro power development

(b) deciding the optimum storage capacities at the head works

(c) deciding the optimum type and size of generating units.

The economic viability of a scheme should be judged by the comparision of unit generation cost with alternative diesel generation cost.

The studies should also indicate the priorities in which different schemes can be taken up for development depending upon the construction work involved and also the returns.

6. Conclusion

In Seychelles there is a large potential for mini hydro electric power in the range of 2.0 mW, total installed capacity, comprising of 100 - 200 kW units. Up to 15% (7.2 million units) of the total annual consumption of electricity in the Seychelles can be substituted for. It could save up to 750,000 US $ per annum in fuel bills at current prices. The cost of the total scheme has been roughly estimated at US $ 6.8 million giving a pay back period of around 9 to 10 years.

The type of turbine most suitable for the Seychelles is the BANKI-MITCHELL, cross flow radial impulse type. The possibility for local manufacture could be looked into.

Consequently the needs of the Seychelles as far as investment into micro hydro power can be listed as follows:

(i) Funding for a feasibility study into micro hydro for Seychelles costing around US $ 150,000.

(ii) Further funding to meet capital cost of installation of micro hydro schemes in the Seychelles estimated at US $ 7 million.

HYDROPOWER DEVELOPMENT IN THE SUDAN

• Introduction

The recent focus on renewable energy resources, which has resulted from a growing awareness of the energy problems facing many countries, has generated significant attention in hydropower development. The technology is relatively more established than those of other renewables and hydropower has been successfully competing with the fossil fuel-based power even when the latter was cheaper than it is today.

Sudan has faced a particularly growing energy crisis eversince the early seventies. Severe shortages of generated electrcity and essential petroleum fuels, which are wholly imported, have adversely affected every economic activity. Transport, household, industry and agriculture are particularly hurt. Agricultural and industrail production have been droping year by year creating evermounting socio-economic problems. The per capita energy consumption is one of the lowest in the world, about 0.2 kw available over the 24 hours a day from all sources. Most of the energy consumed is supplied by thermal sources which are mainly firewood and imported petroleum. Large scale unplanned firewood cutting has accelerated a serious deforestation problem and imported fuels make above 65% of the total imports of the country which suffers a chronic trade deficit problem.

Hydropower already provides 57% of the public generated elecricity. However, over 90% of the hydropower potential in the country has yet to be developed. This potential is mainly of the large scale class, see Table (1). Existing, planned and potential hydrosites are shown in Fig.(1).

The development of large scale hydropower, which requires large capital and relatively high technological level that are at present not within the Sudan capability, will have to be achieved mainly through foriegn technical and finance bodies. For these potential schemes the cost is estimated to range from $300 to $3500 per kw installed capacity. In view of the present economic situation of the country, the development of large scale hydropower may prove difficult to attain in the near future.

Small decentralized hydropower (50 kw to 5 Mw) to serve local needs in rural areas where electricity is not readily available, would have great advantages for many parts of the Sudan, particularly in the South. In the North attractive sites of these capacities seem to be few and only some of these are reported to be economically feasible. The main problems limiting the number of appropriate sites in the North are heavy siltation, great seasonal flow variation, relatively small heads and the usual primacy of irrigation purposes over other

uses. In the South distances between suitable sites and potential users also limit opportunities to develop sites of these capacities. Nevertheless, promising sites exist in many parts of the country that can be developed in the near future.

The development of mini-hydropower (5 kw to 50 kw) requiring low technology and practically no infrastructure seems to be most appropriate. Isolated mini-hydro units, namely current turbines of simple design that can be locally manufactured, would provide power for agricultural and domestic uses in rural areas where power demand is modest.

2. Small Scale Decentralized Hydropower

Activities on development of decentralized hydropower in the Sudan are still in the feasibility study phase. One major problem in this phase has been the lack of adequate and precise data and consistent information on potential and demand. Nevertheless, the following are generally considered most attractive small hydropower sites:

(I) Retrofit of Existing Facilities:-

(i) Major Irrigation Canals (Gazira, Managil, Rahad, Elgirba etc): Substantial flow is available in these canals almost throughout the year, typically 3 to 5 Mm^3 per day. However, available head is low, less than 2 m. Yet, considerable potential exists due to the large flow rates.

(ii) Jebel Awlia Dam :

About 50 Mw capacity of an annual out-put of about 240 GWH has been considered feasible by a number of investigators. Low head machines (maximum 7.5 m head) of up to 1.5 MW each are proposed to be installed per sluice opening. Further cost analysis of the project is required.

(II) Proposed New Facilities :-

(i) Bahr El Gebel (Fola Rapids upstream of Juba on Main Nile) : Over and above the large scale hydropower potential of this river (estimated capacity of up to 400 MW) a small scale project has been proposed at Upper Fola Rapids which would provide from 5 MW to 10 MW on stages from about 10 meter head, but without a dam. This should meet power demands in both Juba and Nimule in the short term plan.

(ii) Kinyeti River (at Katire) :-

A proposed facility at Katire of 3-5 MW in four phases is reported to be best suited for development to supply power to towns of Katire and Torit.

(iii) Jebel Marra (west of Sudan)

In a 1968 FAO study, it has been estimated that 100 kW could be developed from streams of Jebel Marra. The lakes there could provide

a bigger potential of 3 MW. However, an updated feasibility study is needed.

A number of other sites in Southern Sudan are reported to be potentially attractive for small scale hydro projects. These include sites on rivers Assua, Ateppi, Kit, Kaia, Yei, Naam, Tonj and Busseri.

3. Mini-Hydropower

A Mini Hydropower Research and Development Project is underway in the Department of Mechanical Engineering, Universuty Of Khartoum. The main purpose has been to demonstrate and evaluate the use of water current energy for powering small-scale pumping units and for generating electricity. Power requirement for pumping water for irrigation on typical small land holdings in the Sudan will be of the order of 5 kW to 10 kW. The same range of power should sufficiently meet domestic needs of isolated homes.

A vertical shaft impulse turbine of simple design has been built to extract energy from water current of canals, rivers or streams. Field trials of the model are currently being planned and will be carried out in the Blue Nile.Detailed information on the system design and performance await experimental findings.

4. Management and Training

Recent reorganisation of the National Government has meant that local authorities, through Regional Ministries of Housing and Public Utilities, will be expected to handle management and operation of electricity generation facilities in their respective areas and regions. However, management and technical training has been of a general nature: specific programs of training are lacking.There is a clear need for a comprehensive manpower development and training program for hydropower planning, generation, transmission, distribution and commercial staff. This may be achieved in coopration with Universities and International Agencies both in-country and abroad, for example the United States Agency for International Development.

5. References

(1) Nile Water Study, Vol. 4 " Power Development in the Southern Region" Sir Alexander Gibb & others, 1979.

(2) Sudan: An Assessment of Decentralized Hydropower Potential NRECA, July, 1982.

(3) Development of Hydropower Potential in the Southern Region BONIFICA S.P.A. Jan. 1983

(4) Eastern Equatoria Hydroelectric power Study Hafslund, 1981.

Table (1): Existing and Planned Hydropower sites

Facility	Present Capacity (MW)	Planned or Addition (MW)
Roseries	1. 132	200
Sennar	15	30
Elgerba	12	-
Romela	-	20
Merawe	-	600
Sabaloka	-	120
Shereik	-	240
Sherri Island	-	450
Dal	-	600
Beddan Rapids	-	250
Fola Rapids	-	120
Total	159	2630
Percentage	5 %	95 %

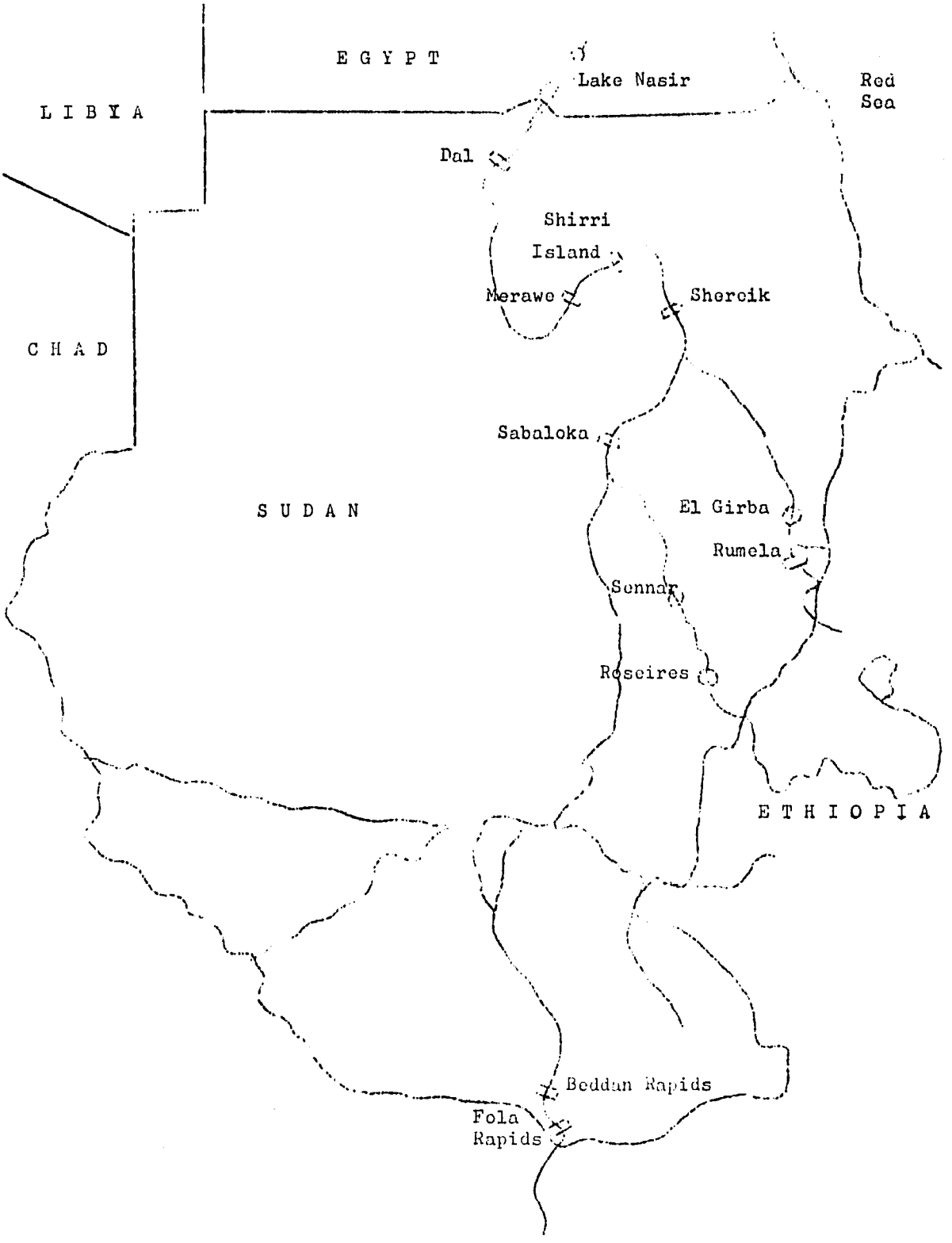


Fig. (1): Hydropower Sites In The Sudan

Existing Hydroelectric Facility

Planned Hydropower Development

20TH JUNE 1983

HYDROPOWER IN SWAZILAND

Introducing Swaziland

When considering hydropower anywhere one must look at the geography of the country.

Swaziland is a country with three levels. The west is just on the edge of the Southern African plateau at an altitude of about 1200m. There is a sharp drop of up to 600m to the Swaziland Middleveld which then slopes down to the Lowveld at elevations dropping from 300 to 100m. Finally, at the eastern edge of the country there is a sharp rise to the Lubombo Mountains at 500m.

Rainfall varies fairly uniformly from 1400mm per year in the west to 600mm in the east. Lightning intensity at over 11 strikes/km^2/year in the west is the highest in Southern Africa.

Drainage is by rivers all running west to east: The Komati in the North, the Umbeluzi in the centre and the Usuthu system in the Southern half of the country. The Usuthu and all its major tributaries rise in the Republic of South Africa as does the Komati. On both river systems there are control and abstraction works upstream of the border so Swaziland gets only a portion of the run-off from the upstream catchments. There are internationally agreed outflows from Swaziland on the Komati and Umbeluzi.

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The land near the mountainous western borders has only fairly thin soil cover and was planted with conifers between about 1950 and 1970. These commercial forests are markedly reducing the run off.

Whilst the well drained profile of the Highveld to Middleveld region and the good Highveld rainfall seem ideal for hydro electric generation and are so used, there are limitations.

In this part of the world the virgin Mean Annual Runoff (M.A.R.) was about 22% of the precipitation.

Rainfall is seasonal and so is the run-off. At the Highveld/Middleveld boundary half of MAR flows in the period December through March. The rainy season is expected to start in October but sometimes does not begin until December. The river flows decrease from June onwards and if the rains are late the October and November flows are very low indeed. So some storage is necessary for any but the smallest hydro-electric scheme if it is to operate in the dry season.

One effect of increasing cultivation and urbanisation in the upper catchment areas appears to be a shortening of the lag time between rainfall and runoff. This could have the effect of decreasing the base flow. It is definitely increasing the sediment load of the rivers. Silting of reservoirs is now causing mechanical wear of turbine parts(due to carry-over)and reduced water storage for peak lopping.

Electricity Requirements

For many years Swaziland's electricity demand increased by about [illegible]% a year. This growth has now slowed to about 10% a year. By the mid 1990s the annual growth is expected to be in the 5% class.

This year's total electricity consumption in Swaziland will be approximately 650MWh. About 130MWh of this is generated and used internally by timber and sugar mills from process steam raised by firing waste products. The remaining 520MWh come through SEB's network.

Until now only about 130MWh per year of good rainfall could be generated by SEB's 21MW of hydro electric stations. SEB also has 9MW of diesel generators which are expensive to run and are used only for short term peak lopping. All the rest of the demand is met by imports from a neighbouring country. The proportion of total requirements which is imported varies continuously but is getting uncomfortably high. The 3 year drought has not helped matters. To reduce dependence on imports and the limitations of two highly loaded [illegible] 2000 financial year [illegible] electric scheme is due to come into [illegible] next January.

The Maguga project was the most cost effective of [illegible] schemes studied. Its [illegible] per annum output is [illegible] by water [illegible]. So [illegible] dependence on [illegible] imports.

Best Available Document

An earlier speaker pointed out that SEB's proposed 8MW, Lower Scheme able to generate 50GWh per annum was deferred. It was a good project intended to be built at the same time as the Lupohlo-Ezulwini scheme. When money became available for only one of the two schemes, the Lower Scheme was shelved. Since then the load has risen to the extent that the next source must provide 30 to 40MW of power. Swaziland has opted to build a relatively cheap third 132kV import link.

This should secure the electricity needs unti about 1990. Studies for the power source to contribute from 1990 onwards have been instigated. Other hydro sites exist but are very expensive to develop. None have the capacity of producing more than about 100GWh per annum alternatively 30MW at quite low load factors. Present feeling is that the 1990 supply source is likely to be a steam station starting with 2-40MW sets sited on or near the Mpaka coal field. When this is in service and if there is any money left over it will be well worthwhile to install small hydro plant - including the Lower Scheme - wherever it can be shown to be economic. This plant will provide energy (i.e. kWh) only. The growth in power demand (MW) will be too high for any useful contribution to be made by the relatively small hydro schemes being looked at.

The economic value of such small schemes could be limited to the fuel cost replacement and this is unlikely to justify a project whose only purpose is to generate electricity. Only if there is some associated objective, such as an irrigation storage reservoir which could share the civil engineering costs, is new small scale power generation plant likely to be commercially viable.

THE SWAZILAND ELECTRICITY BOARD

This is the parastatal organisation which handles and distributes all public electricity requirements. The Board consists of a part-time chairman and five members appointed by Government. The only Government money involved in the Board's operation is a £2 million loan for the new hydro electric scheme. All other capital is either self generated or comes from long term loans from international agencies guaranteed by Government but whose guarantees have never, to date, had to be called upon. The Board sets its own tariffs and in general operates on a commercial basis.

There are 400 employees on generation, distribution, administration, construction and maintenance. The distribution staff operate from depots in 9 towns and serve 12 500 consumers. This figure includes 450 irrigation and industrial consumers, who account for 70% of the electricity sold. 9500 domestic consumers account for 20%. The rest goes to small commercial consumers taking up to 20kVA.

There are now about 2300km of lines at voltages up to 132 000 volts. SEB designs and builds its own lines using locally grown and impregnated wood poles.

The diagram shows SEB's 11kV system reaching to most parts of the country. Most rural dwellers live in scattered homesteads. Rural electrification does not yet affect many of these homesteads but is gaining some ground. Where it happens it is often alongside Government sponsored power lines to facilities such as schools, clinics, police stations and rural development centres.

As mentioned earlier, SEB can now bring a power supply to most parts of the country at a cost likely to be less then any but the very simplest small hydro installation. By the same token any future small installation is likely to be connected to the national system and this points to the use of induction generators. One is due to be installed later this year near the Edwaleni Power Station in a 300kW mini hydro generously donated by the Canadian International Development Agency. This will be put in an almost ideal situation where water from a farm canal falls through 13m in a set of artificial cascades.

The Edwaleni Power Station draws its main feed from the reservoir formed by Mkinkomo Weir on the Usushwana where the MAR is 370Mcm. The canal between the reservoir and the head pond is about 12km long and carries up to $14m^3/s$. From the head pond conduits and penstocks drop the water through 130m head to the total of 15MW of Francis turbines in the power station.

A tailwater canal leads to the 6MW head Maguduza power station which is controlled by Edwaleni.

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The Lupohlo/Ezulwini scheme involves building a 45m high rock fill embankment to create a 20Mcm reservoir in the valley of the upper Usushwana, diverting the water into the Ezulwini Valley by a 4,5km tunnel through Lupohlo Peak between the valleys and leading the water to 2-10MW Pelton wheels. The average head will be 250m. Tailwater will flow into streams which rejoin the Usushwana before the Mkinkomo Weir so sensible operation of Ezulwini will give some regulation to the downstream water supply and enable Edwaleni to generate an additional 3 to 5GWh per year from water which would otherwise spill over the weir in the wet season.

Finally, four possible small projects.

The possibility of fitting a 400kW turbo-generator to the compensating discharge of the Mnjoli Dam has been looked at and rejected as being uneconomic. The pattern of release is such that a potential of only 150kW is available for at least half the year.

A sugar cane grower with 1500kW of pumping plant is seriously investigating installing a 900kW Osberger turbine driven generator. He has a large co-operatively owned canal running through his land near a steep drop to a river bed. He is prepared to enlarge the canal from intake to the penstock site. The tailwater would still be available to downstream users.

In the north-east of the country the Umbeluzi makes a spectacular meander. Seen from the air it looks almost as if an oxbow lake is soon to be formed. In fact, at the narrowest part of the loop there is a 30m head difference between the two limbs which are separated by a hard rock ridge only 200m wide. The farmer working this land grows sugar cane and citrus fruit and uses over 4MW of power. To replace some of this he is looking at tunnelling through the ridge and putting a turbine at the outfall. Various hydrological and silt disposal problems must still be examined but if they are cleared it should be possible to generate at least 500kW for much of the year.

The most attractive small hydro electric project likely to fit into a multi purpose scheme would be at the projected 60Mcm regulating dam at Lozitha. This dam will hold back summer flood flows for winter irrigation use but since the SEB reservoir at Mkonkomo requires $10m^3/s$ or the free flow of the Usushwana at the point a fairly constant discharge would be maintained. It should be possible to install a 2,5MW turbine to generate about 13GWh per annum at relatively low cost.

A few negative comments on the comparative costs of hydro electric plant have been made in this short paper. Its high manufactured cost is just a fact of life. SEB believes that if the capital for well thought-out scheme can be raised at reasonable money cost such a project will prove a long term benefit. Once the scheme is in service its costs remain substantially constant. Hydro-electricity must be one of the few steady cost products at a time of world wide inflation.

TANZANIA ELECTRIC SUPPLY COMPANY LIMITED

SMALL SCALE HYDROPOWER DEVELOPMENT IN TANZANIA - JUNE 1983

1. INTRODUCTION

The Republic of Tanzania, in East Africa, is fortunate in having many sizeable identified potential sites which could be developed to satisfy the country's power demands well into the 21st century. The known hydropower potential of the country is estimated at 3800 MW with about 19000 GWh of annual energy. The total hydropower installation capacity stands at about 250 MW, accounting for about 6.6 percent of the country's known hydro-potential.

1.1 PRESENT ELECTRIC - POWER GENERATION

Hydro and diesel are the main sources of electric power generation in the country. The Tanzania Electric Supply Company (TANESCO) is a parastatal organisation wholly owned by the Tanzanian Government and is responsible for the generation, transmission and distribution of commercial electricity in the country. TANESCO owns 7 hydroelectric power stations with a total of 249.22 MW installed capacity and 27 thermal power stations with total of 130.11 MW installed capacity. The distribution of the power station/s is as shown on map in appendix 1. Most of the generation is concentrated in the COASTAL GRID with an installed capacity of 247.66 MW hydro and 66.14 MW thermal. Away from the Coastal Grid there are three minihydro power stations (sub-section 2.1) the rest being diesel power stations serving big regional and district centres.

1.2. EXTENSION OF THE COASTAL GRID

Plans are well underway to extend the existing coastal grid by interconnecting the other major load-centres which presently run on expensive diesel (ref: appendix 1). This has to be done in a phased manner.

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Simultaneously, studies are in progress on other big potentials to determine the appropriate development sequences and additions to the expanding grid system.

1.3. REASONS BEHIND MINIHYDRO DEVELOPMENT

Even if the grid system will be expanded to cover a larger part of the country, economics of power transmission and transformation will make it prohibitive to supply from the grid, isolated townships and villages. Thus the majority of the population (about 85% of the country's population live in the rural areas) will not benefit from the extended grid. The ever-escalating fossil fuel prices, the unreliability of fuel supply in future and the added transportation costs of the fuel to upcountry areas make the operation of diesel-generating sets very expensive and unreliable. Small hydropotentials have been identified in many areas around the country in the vicinities of townships and villages. Many such sites could be developed economically either to replace the existing diesel generating sets in those areas or for power supplies to unelectrified towns and villages, or both. The Government has given serious consideration on the development of the minihydro pontial sites and currently a good number of such sites are being studied by TANESCO (ref: sub-section 3.2).

2. EXISTING MINIHYDRO INSTALLATION

2.1. OWNERSHIP

Appendix 2 shows the minihydro installation in the country. Three of these are owned by TANESCO at Iringa, Moshi and Mbeya townships, the hydro-generation being supplemented by diesel generating sets in those towns.

The majority of the other minihdro installations are owned and run by Christian Missions in the rural areas where the power is used for lighting in mission Schools, Churches, hospitals, etc. and for supply

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to small scale industries being run by the missionaries. Where the power supply is sufficient the communities surrounding the missions are also connected and from the outlook it is evidently a notable example why electricity is a social amenity even to the rural pupulation.

2.2 LAY-OUT

Most of the minihydro installations in the country bear a common layout consisting of:

1. diversion weir (concrete, earthfill, etc.)
2. headrace canal (in a few cases lined)
3. headpond
4. penstock(s)
5. powerhouse
6. tailrace canal.

Almost all materials for civil works are locally abtained and cheap labour-force readily availed by the local pupulation.

2.3. THE TURBINES AND WATER FLOWS:

The turbines are of Pelton, Francis and Cross-Flow types depending on the heads utilized, the majority of the turbine sets being cross-flows of Ossberger make. Despite the fact that most of the turbines were installed very long time back (the oldest set was installed in 1928), their operational reports to-date are quite satisfactory. Most of the minihydro schemes were built with very short or no flow record at hand and as such they were liable for under-or over-installation. None of them has a regulating reservoir as project component and as result too much water is wasted during most of the months and some few installations are partially closed down during driest months due to lack of water. Most of them have stand-by diesel- generating sets and one of them has diesel-set for peaking.

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3. STUDIES ON MINIHYDROS

3.1. The Ministry of Water and Energy (MAJI) has conducted/is conducting studies on the country's water resources. Most of these studies concentrated on big-scale projects, and as such minihydro potentials were not included in some of the reports submitted.

Back in 1974 MAJI launched the Western Tanzania Project (WTP) to assess the water resources potentialities of the western and south-western parts of the country, infact on the rivers draining to lakes Tanganyika, Rukwa and Nyasa. As these three lakes are in the Great Rift Valley (the western branch) the rift-escarpments create good hydropower potntials near the river outfalls to the lakes. The WTP identified many minihydro potentials in those areas and hydrometric stations were established to monitor the river flows.

Other studies have identified minihydro sites along the escarpment of the eastern-branch of the rift-valley in Mbulu Distric.

Many other minihydro sites have been identified randomly around the country. So far, about eighty (80) potential minihydro sites have been identified and the majority of them are gauged.

3.2. CURRENT STUDIES ON MINIHYDRO

The map on appendix 1 also shows the minihydro projects currently being studied or earmarked for studies by TANESCO. The details of these projects are tabulated in appendix 3. The study-sites have been selected out of the more than eighty (80) identified sites around the country, the criteria being to choose the potentials which appear to be readily exploitable, not far from potential power users and / or as a replacement of existing installed sets running on expensive diesel. The Regional Headquarters of Songea, Sumbawanga, Kigoma and Bukoba which are currently supplied with power from diesel generating sets and about 10 district headquarters will benefit from these minihydro developments. Other prominent settlements and villages

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will also be considered for electrification wherever economics justify. For the studies on minihydros, financial and technical assistance is provided by some of the developed countries. The studies are conducted by competent foreign consultants but much emphasis is put on much local participation during the course of the studies. The consultants do also prepare tender documents, detail designs and provide supervision during construction.

3.3 IMPLEMENTATION SCHEDULE

Once a project has proved to be feasible and decision made upon for its implementation, funds have to be sought from developed countries and financial institutions. The project is then executed on a turn-key basis which involves detailed designing, procurement/supply/ installation of equipments, the execution of civil works and erection of local transmission network. TANESCO'S contribution is limited to the distribution network. Local participation and on-job training of counterparts is insisted upon to the maximum level.

4. PROBLEMS/CONSTRAINTS

4.1. FINANCIAL:

Many poor countries fail to raise the funds required for minihydro development due to the apparent high initial costs of such projects. Other development projects like basic education, health centres, water supply, etc. may rank above electric power supply. As such developed countries and /or international financial institutions have to be approached to provide funds for minihydro projects, a process which may be time consuming.

4.2 TECHNICAL:

Many countries which provide funds for studies or implementation require as a precondition that the consulting and /or construction

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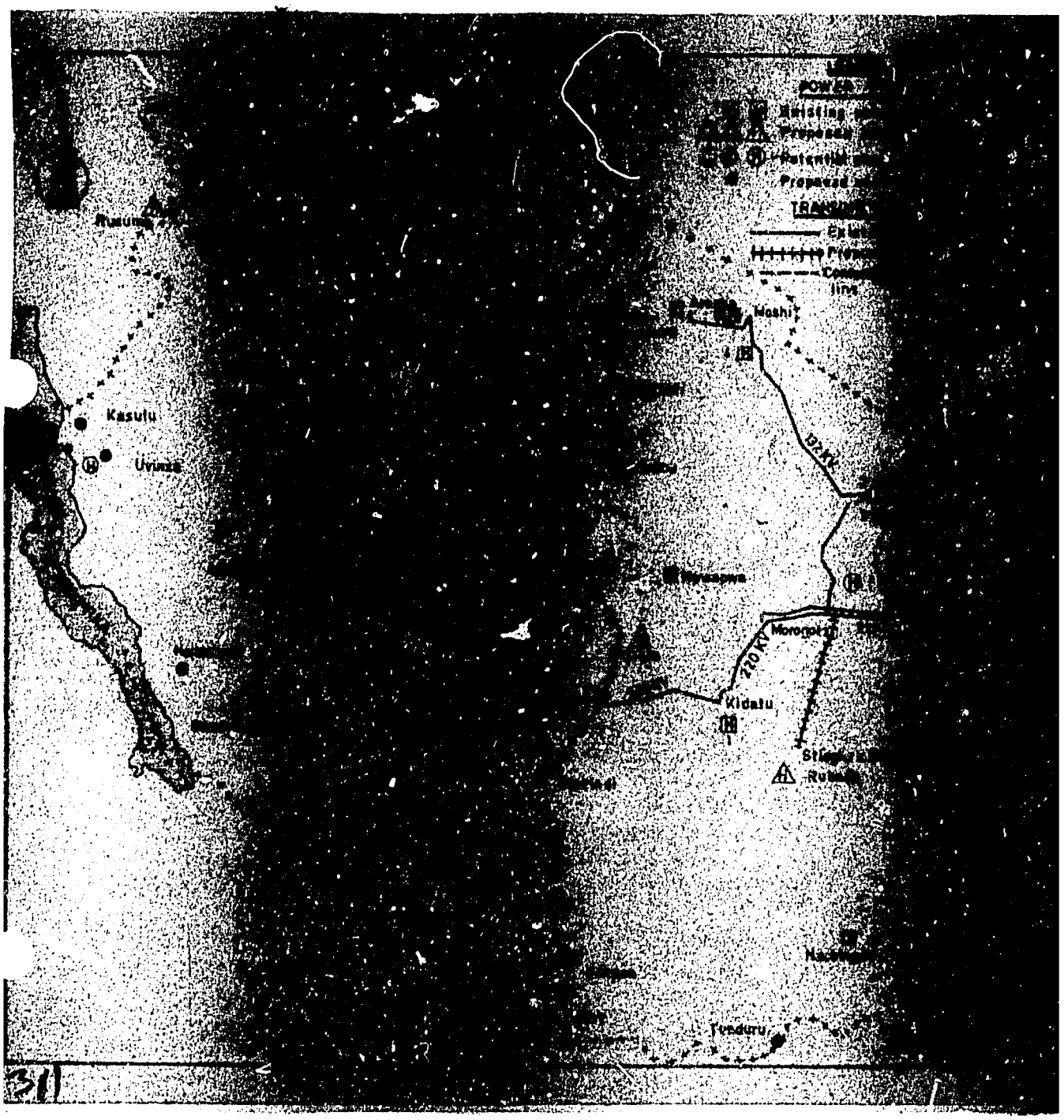
firms should come from their own countries. Even for very trivial studies or construction works the developed countries will doubt the capabilities of the local people. As such the project costs become very high due to the expensive foreign personnel.

5. SUGGESTIONS AND CONCLUSIONS

Minihydro schemes ought to have as simple a layout as possible i.e. like run-of-river but also not involving expensive civil structures like dams, tunnels, underground power stations, etc. The construction requirements of minihydro schemes could thus be adequately met by local construction firms or a consortium of local firms. Likewise, the studies on minihydro development need not be as extensive as those necessary for major hydro projects. Given a chance and motivation, local technical personnel (engineers, economists, surveyors etc.) could organize themselves to carry out the studies on minihydro development. Very few expatriates would then be involved say, to act as project supervisors. This kind of approach could have the projects' costs both the local and foreign components reduced drastically. The know-how of the local technical personnel involved could be highly expanded and self-confidence built up.

To make this approach more realistic close cooperation should be maintained with the local Missionaries (subsection 2.1) who have already gained experience from installing several minihydro plants in the country.


Kasulu
Uvinza
Moshi
Morogoro
Kidatu
Tunduru

EXISTING MINIHYDRO INSTALLATIONS

Appendix 2.

OWNER/LOCATION	TURBINE TYPE/ MANUFACTURER	INSTALLED CAPACITY (KW)
TANESCO		
Tosamaganga (Iringa)	Gilkes & Gordon/Francis	1220
Kikuletwa (Moshi)	Boving and Voith Reaction	1160
Mbalizi (Mbeya)	Gilkes & Gordon/Francis	340
Others*		
Kitai (Songea)	Cross Flow/Ossberger	45
Nyagao (Lindi)	"	15.8
Isoko (Tukuyu)	"	15.5
Uwemba (Njombe)	"	101.0
Bulongwa (Njombe)	"	180.0
Kaengesa (S'wanga)	"	44.0
Rungwe (Tukuyu)	"	21.2
Nyangao (Lindi)	"	38.8
Peramiho (Songea)	"	34.6
Isoko (Tukuyu)	"	7.3
Ndanda (Lindi)	"	14.4
Ngare Sero (Arusha)	Gilbert	15.0
Sakare (Soni)	Geiselbrecht	6.3
Mbarari (Mbeya)	Chinese	200.0
Ndolage (Bukoba)	B. Maier	55.0
Ikonda (Njombe)	CMTIP	40.0

* Source: Exploiting Minihydro Plants Potential for Rural Development in Tanzania

By: M.G. Hassanali and R. Reichel.

CURRENT MINIHYDRO SITES UNDER STUDIES

Appendix 3

Name of River	Minihydro Location	Installed Capacity (KW)	Supply to	Study Level Reached to Date
Ruvuma	Sunda	3,000	Tunduru(D)*	Feasibility
Ruvuma	Lupilo	1,400	Songea (R)+	"
Luaita	Mbinga	300	Mbinga	Prefeasibility
Luwika	L. Nyasa shore	1,400	Mbamba Bay	Reconnaissance
Several	-	-	Rudewa	Not yet surveyed
Lupalilo	Lupalele	-	Makete (D)	"
Ruhudji	Njombe	3,000	Njombe (D)	Prefeasibility
Lupa	Rukwa Valley	2,800	Chunya (D)	Reconnaissance
Kiwira/Mbaka	Kyela	3,000/4,000	Tukuyu (D)	Prefeasibility
Luiche	Escarp	3,000	S'wanga (R)	"
Luanfi	Musoro	1,200	Namanyere(D)	Reconnaissance
Mtambo	Ugalla	2,400	Mpanda (D)	"
M'garasi	Uvinza	6,400	Kigoma (R)/ Kasulu (D)/ Uvinza	Feasibility
Luiche	Nkugwe	4,000	"	Prefeasibility
B'nulo	Game Reserve	200	B'nulo (D)	Reconnaissance
Igono	Kalebe	2,500	Bukoba (R)	Re-feasibility
Iainu	Mbulu	1,500	Mbulu (D)/ Babati (D)	Prefeasibility
Ito wa Simba	Mto wa Mnbu	1,500	"	"
Magafiro	Uwemba		Uwemba	Prefeasibility
Several	W. Lake Region	?	Villages	Identification
	Lindi Region	?	"	"

* (D) = District headquarters

\+ (R) = Regional headquarters.

SMALL HYDRO POWER GENERATION

WORKSHOP

MBABANE, SWAZILAND

20TH - 24TH JUNE 1983

EXPERIENCE IN ZAMBIA

Presented by:

S MUNDIA N S MWALE G MWINANYAMBE

ZAMBIA ELECTRICITY SUPPLY CORPORATION LTD.
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LUSAKA
ZAMBIA

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EXPERIENCE WITH SMALL HYDRO GENERATION IN ZAMBIA

Zambia Electricity Supply Corporation Limited (ZESCO), which is a State owned organization charged with the responsibility of generation, transmission and distribution of electricity, operates four small hydro stations in rural areas where interconnection with the national grid has hitherto been uneconomical. This paper outlines briefly experience on the operations of the stations with a detailed description of one of the schemes.

INTRODUCTION

Zambia is located in Central Africa and is roughly bound by latitudes 8° and 18° South and longitudes 22° and 33° East. It has a total area of $750,000km^{2}$ with a population of 5 8million. It boarders with Zimbabwe in the South, Malawi in the East, Tanzania and Zaire in the North and Angola and Namibia (SWA) in the West.

The country is fairly flat being a plateau at 1 000 metres altitude interrupted only by Muchinga escarpment which rises from the centre of the country and runs into the North-eastern direction at an altitude of up to 2 000 metres. The country is cut by Zambezi river in the West and its tributaries Kafue and Luangwa in the centre and East respectively. It abounds in small rivers and has adequate rainfall during the months of November, December, January and February.

BACKGROUND TO SMALL HYDRO GENERATION

The urban areas of the country which roughly follow the railway system from the south to the north are fed from the country's national grid system comprising the major generating stations of Victoria Falls, Kafue Gorge and Kariba Hydro power stations interconnected through 330 kV transmission lines to the major load centres in Lusaka, Kabwe and Copperbelt in the north.

The vast size of the country however precluded early connection of rural community centres to the national grid and there was need for alternative source of supply to these centres as early as the late 1950s. There were administrative centres with population of between 2 000 and 5 000 each for the rural provinces ie. Western Province, North-Western Province, Eastern Province, Northern and Luapula Provinces. Preliminary estimates of the largely domestic electricity requirements indicated that these would be small and there was the need therefore to devise simple electrical schemes which could be economically matched to initially small loads yet be capable of extension in future years.

cont....

BACKGROUND TO SMALL HYDRO GENERATION (CONT'D)

Two alternatives presented themselves, that is diesel generation and small hydro generation where suitable perennial rivers existed. Studies indicated that simple hydro schemes close to the load centres, though initially requiring more capital investment than diesel stations, were more economical due to the high cost of diesel and maintenance costs. Assessment of firm energy of hydro scheme proposals were necessarily based on assumptions from rainfall run-off calculations in the catchment areas and spot gaugings of the rivers as hydrological data was scanty.

At Mbala, Kasama and Mansa conditions existed for exploitation of small rivers at small river falls where the head and assessed average annual discharge were sufficient for electricity generation to meet immediate and future load demands. By 1960 investigations had been completed and tenders advertised for execution of civil works and supply of machinery and equipment.

The hydro stations conceived were simple, run-of-river schemes with only diurnal storage above the diversion weirs to reduce the cost of civil engineering works although the design of individual items usually allowed for future extensions when upstream storage to utilize the full potential capacity of the river became necessary.

At Chishimba Falls some 40 km west of Kasama town on Luombe river a power station was established and commissioned in 1960 by building nearly 1½ km of a canal from the diversion weir and two penstocks to deliver water to four horizontal shaft Francis turbine-generators rated at 300 kW each. Power was generated at 3.3 kV and transmitted through 33 kV wood pole line from the nearby outdoor step-up sub-station. The power station was upgraded in 1970 and in 1975 with the addition of 4 x 1.2 MW turbine-generators. The extensions entailed raising the diversion weir, the construction of 1.5 km of 2 m diameter concrete low pressure conduit, a surge chamber, and two penstocks 450 m long with internal diameter ranging from 1.2 m to 0.6 m at the power station end.

Another, even smaller station was established at Lunzua Falls near Mbala town some 200 km north of Kasama. The station was initially of 2 x 250 kW Francis turbine-generators at a head of 40 m on a run-of-river basis on Lunzua river. The power station was upgraded in 1969 by the addition of the third 250 kW machine.

The largest of the four stations is Lusiwasi which was established 80 km east of Serenje town where the Lusiwasi river cuts through Muchinga escarpment before emptying in Luangwa river, creating a head of 500 m. Two impulse type Pelton turbo-generators were installed in 1970 each of 300 kW rating. The station now has two additional machines of the same design bringing installed capacity to 12 MW.

The power station comprises a storage dam 60 km upstream for seasonal water flow regulation, a diversion weir, intake gates for the 1 km canal, headworks and the two 12 MW penstocks. A haulageway runs along the one km penstocks to the power station.

MUSONDA FALLS POWER STATION

Investigations were carried out in 1956 on the feasibility of a power station on Luongo river to supply power to Mansa township and sorrounding areas. The place of interest was Musonda Falls 57 km north of Mansa and 16 km from the confluence of Luongo with Luapula river.

There was no stream flow information available at the time but hydrological assessments had established that on run-of-river basis the discharge during average rainfall years was sufficient to maintain an output of 1 MW firm capacity at 60% load factor.

The power station was established by diverting the river at the falls into a canal 800 metres long to a forebay where two steel penstocks, each of 1.4 m diameter, led water to the power station creating a total head of 29 metres.

The machines are of horizontal shaft Francis turbine type with cast stainless steel runners driving salient pole synchronous alternators with a brushless exciter generating 1 000 kW power at 3.3 kV. Journal pedestal bearings are provided between the runners, flywheel, the alternator and exciter.

The turbines are provided with automatic mechanical hydraulic governors with a centrifugal head driven by a motor supplied from a permanent magnet generator mounted on the exciter, capable of adjusting turbine speed within ± 6%, provision being made for manual and remote electrical control of the turbine.

The machine assembly incroporates automatic shut down of the turbine and exciter against excess bearing temperature, excess generator and exciter air temperature, turbine overspeed and low governor oil pressure.

The power station has since been extended by the two 1 000 kW turbo-generator sets with separate penstocks of similar design to the other two. The extensions to create a 3 MW capacity required the construction of a concrete gravity dam 8 km upstream for seasonal regulation, the provision of additional steel radial gates for the headworks, the raising of canal walls, additional structures at the forebay and construction of two penstocks.

The power station building houses four 1 000 kW turbine-generator sets, control panels for each set, asynchronising panel, 3.3 kV switchgear, a battery room and a workshop. An outdoor sub-station adjascent to the power station steps up the voltage to 33 kV for transmission along the 400 km Luapula valley. A schematic arrangement of the power station is attached.

ELECTRICAL PROTECTION

None of the small hydro electric stations available in Zambia have generating units of more than 3 MVA. As such these units are directly connected to the system, that is, they are not connected to the system through individual transformers.

ELECTRICAL PROTECTION (CONT'D)

There are many techniques available for protecting generating plants against various faults and abnormal conditions which my occur. In view of the range of possible protective systems it is necessary to realize that the design of a complete and comprehensive protective scheme is governed by economic considerations. Smaller generators such as those available in our hydro-stations are not so comprehensively protected. Below is given a typical protective scheme of a mini-hydro electric station at Musonda Falls.

The main generator protection is a Merz-Price circulating current protection. This protection provides for phase and earth fault protection of the stator windings. As a generator protection back-up overcurrent relay of the inverse definite minimum time (IDMT) type are applied. Overvoltage protection is also provided on these machines. The stator protection is supplemented by an earth fault alarm system.

Protection associated with severe electrical faults is arranged to trip the high voltage circuit breaker, the field circuit breaker and stops the turbine. The speed governor is designed to prevent a dangerous speed rise even with a 100% load rejection, but nevertheless an additional centrifugal overspeed trip device is provided to stop the turbine if the synchronous speed is exceeded by 10%.

The main transformer protection is the bucholz. This is supplemented by earth fault protection. The feeders have overcurrent and earth fault protection using IDMT relays.

OPERATION OF THE POWER STATION

The power station is manned by Zambian trained staff consisting of an electrical technologist (Power Station Superintendent) a Station Mechanical Fitter, a senior Plant Operator, eleven Plant Operators (plant attendants), and twenty-six general workers. They are responsible for the day-to-day running of the power station including routine maintenance. Major construction and repair work when necessary is however carried out by outside personnel. The establishment also includes nine security personnel, a medical assistant and a station driver.

The power station has performed satisfactorily since its establishment, with only occasional replacement of minor equipment and maintenance work on civil engineering structures requiring attention. Personnel could be substantially reduced with corresponding savings on salaries and wages but such action is not possible in a country where labour lay-offs are not politically acceptable.

THE ECONOMICS OF GENERATION

A schedule of capital costs for Musonda Falls is shown on the attached sheet One, which also gives the running costs, excluding finance charges. A rough estimate from the figures indicates generation costs of the order of 1.6n per kwh, as compared to average revenue of 2.7n per generated kwh using 1979/80 fiscal year figures.

PROSPECTS FOR FUTURE SMALL HYDRO STATIONS

There are possibilities for developing further mini-hydro stations in the country's remote areas. The economics of such investment depends largely on physical conditions obtaining at the proposed sites and therefore the cost of development, the distance from the load centre to the nearest transmission line and level of electricity loads expected.

Zambia Electricity Supply Corporation recently commissioned a study to examine the feasibility of replacing diesel stations in the North-western Province with either small hydro stations or inter-connecting the four towns in the provinces to the national grid. The results of the study indicate a desirability of small hydro stations. These are cheaper in capital costs than inter-connecting for the loads obtaining in the foreseeable future. Diesel generation is, however, still cheaper at present prices and level of generation but this alternative is considered uneconomical in the long run.

These findings will no doubt apply to other parts of the country as yet to be electrified. With the country's emphasis on agricultural development and rural electrification more efforts will be made at establishing small hydro operating stations, the constraints being availability of capital funding and suitable, cheap designs of turbines to utilize low heads with high discharges.

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SHEET I

MUSONDA FALLS POWER STATION

GENERATION COSTS

(K'000 K1 = SUS 0.85)

A. HISTORICAL				
Value of Assets	1976/77	1977/78	1978/79	1979/80
Fiscal year				
Civil Works	1522	1522	1544	1544
Plant & machinery	454	500	661	661
Transformer	26	26	26	26
Switch gear	35	35	35	35
	2037	2033	2256	2256
B. GENERATION				
MWh'000	13 333	14 923	17 646	16 525
C. LUAPULA SYSTEM SALES				
K'000	244	328	390	450
D. OPERATING EXPENSES				
Salaries and Wages	58	60	76	87
Maintenance of Civil works	1	2	1	10
Maintenance of Plant	2	3	4	8
Small equipment	1	1	1	1
Domestic Supplies	-	-	-	-
Transport	3	3	4	4
Administration	2	1	1	3
Depreciation	46	46	47	52
	113	116	134	165

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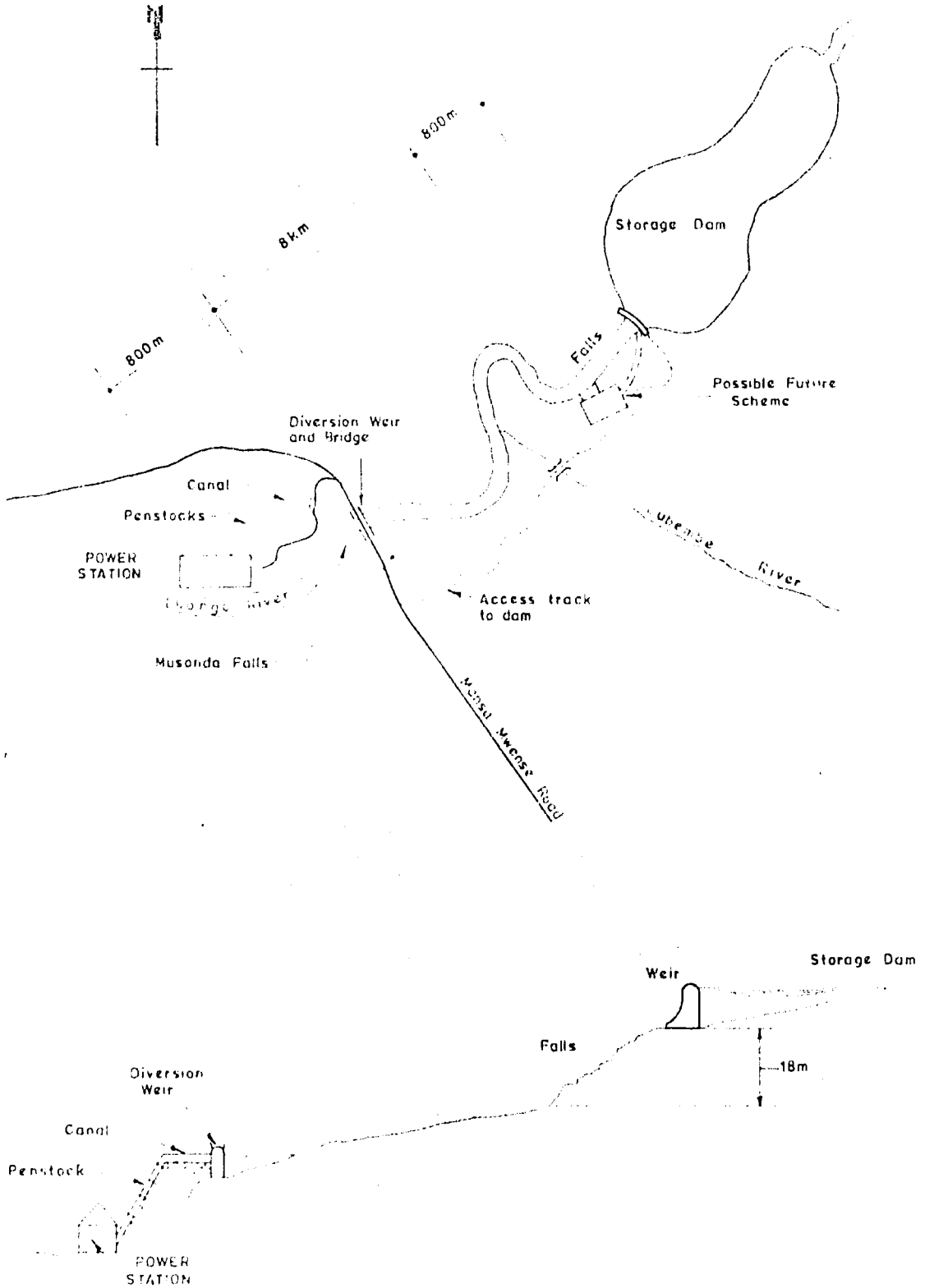
HYDRO POWER STATIONS IN ZAMBIA

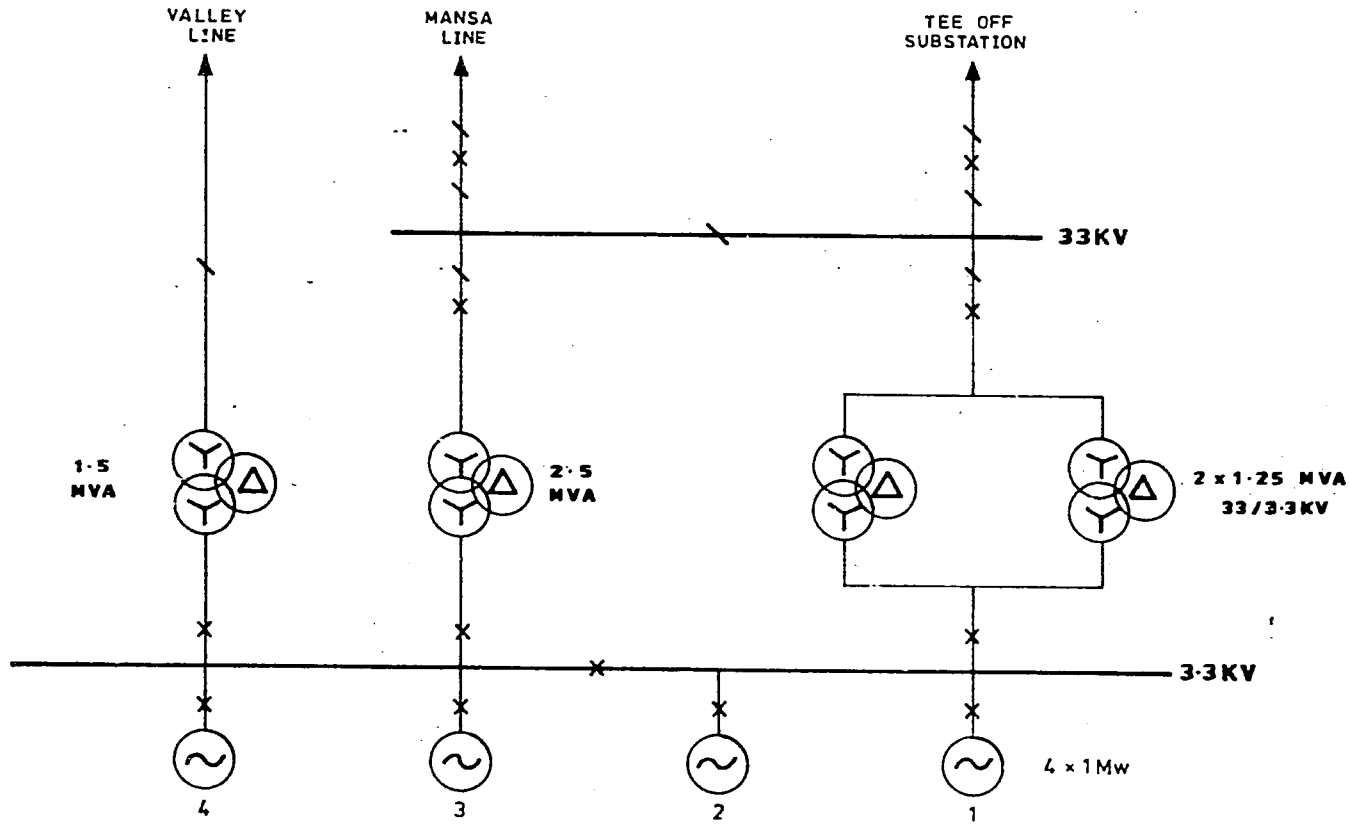
	NAME	CAPACITY M.W	NO. AND SIZE OF UNITS	HEAD METERS	TYPE OF TURBINE	POTENTIAL MEAN ANNUAL PRODUCTION Gwh
1.	Kafue Gorge	200	6 x 150	390	Francis	4090
2.	Kariba North Bank	600	4 x 150	480	"	3320
3.	Victoria Falls	108	2 x1 + 2x 3 + 10 x10	108	"	699
4.	Mulungushi	20	1 x 2 + 3 x 6	366	"	75
5.	Lunsemfwa	18	3 x 6	107	"	118
6.	Lusiwasi	12	4 x 3	500	Pelton	36
7.	Chishimba Falls	6	4 x 0.3 + 4 x 1.2	70	Francis	17.5
8.	Musonda Falls	4	4 x 1	30	"	16.5
9.	Lunzua	0.75	3 x 0 . 25	130	"	0.4



Description:

SCHEMATIC PLAN AND ELEVATION OF MANSA HYDRO ELECTRIC DEVELOPMENT

Modification		Zambia Electricity Supply Corporation Limited (N.A.)
		District
		Drawn: Mwalunga — Drawing No.
		Date: 14/6/82 — LP/04/6-395
		Approved



Description:

SCHEMATIC DIAGRAM FOR MUSONDA FALLS POWER STATION

Modification	

Zambia Electricity Supply Corporation Limited (N.A.)

District

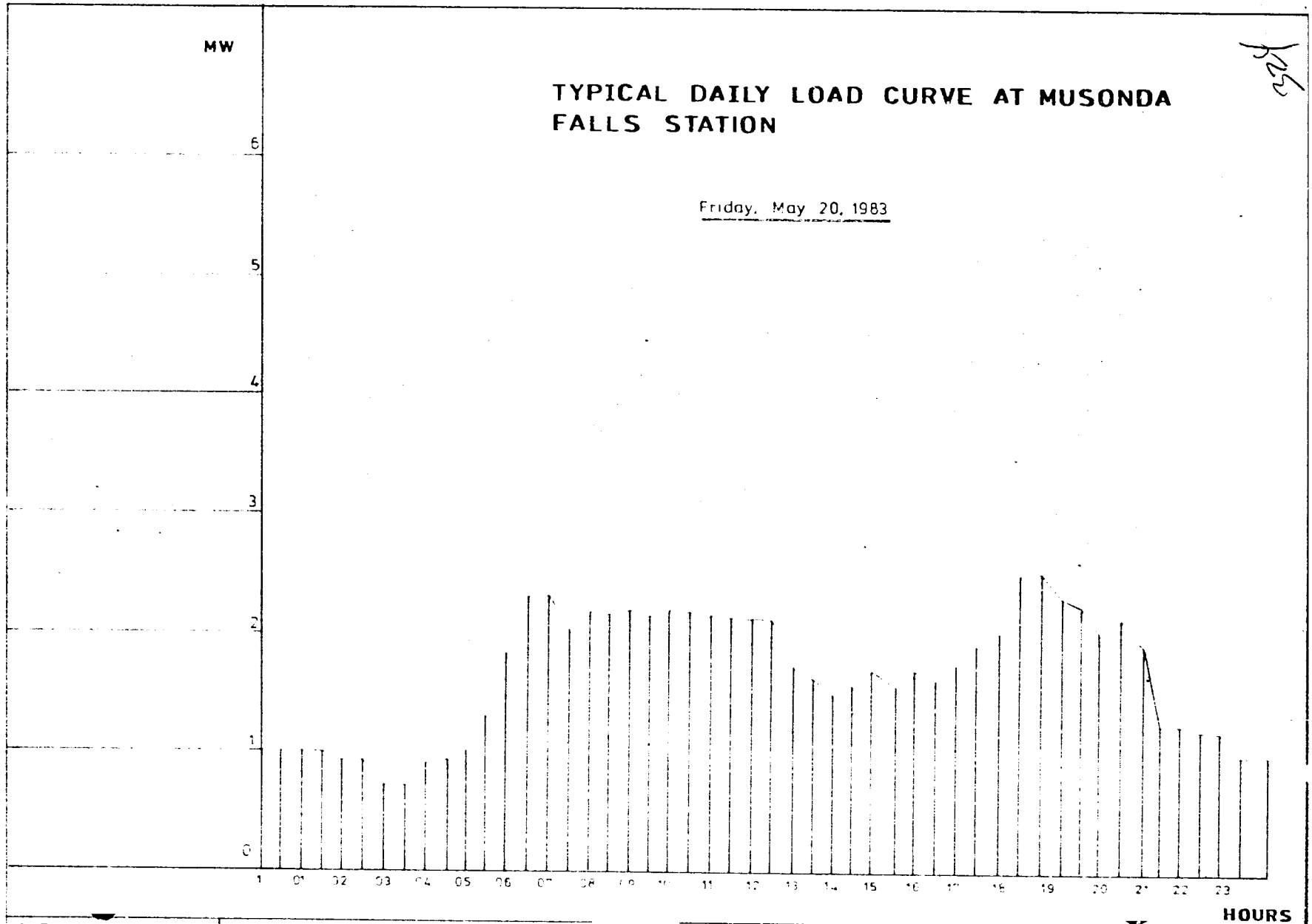
Drawn

Date 12/6/92

Drawing No.

TYPICAL DAILY LOAD CURVE AT MUSONDA FALLS STATION

Friday, May 20, 1983



LP/04/10-265

ZAMBIA ELECTRICITY SUPPLY CORPORATION LIMITED

INCREASE OF ELECTRICITY TARIFFS

In accordance with Section 12 of Electricity Act. Chapter 811 of the Laws of Zambia, notice is hereby given that from 1st May, 1983 maximum demand and energy charges will be as given below. The bills based on the new charges should therefore be received by consumers in June, 1983.

Tariff E1 - Energy Tariff restricted to 5 Amperes single phase
Fixed monthly charge in Kwacha - 0.75
Unit charge in Ngwee - 2.13

Tariff E2 - Energy Tariff restricted to15 Amperes single phase
Fixed monthly charge in Kwacha - 1.50
Unit charge in Ngwee - 2.13

Load Limiter Rating in Amperes											
1	1½	2	2½	3	5	6	7	7½	10	12½	
Monthly Charge in Kwacha											
1.4	1.6	1.9	2.0	2.3	3.4	4.5	4.9	5.3	6.6	7.9	9.0

Tariff E3 - Energy Tariff for unrestricted single phase and three phase supplies up to 15 KVA for domestic purposes only
Fixed monthly charge in Kwacha - 4.50
Unit charge in Ngwee - 2.13

Tariff E4 - Energy Tariff unrestricted single phase and three phase supplies up to 15 KVA for commercial purposes
Fixed monthly charge in Kwacha - 16.25
Unit charge in Ngwee - 2.38

Tariff D - Maximum Demand Tariff

(a) **Tariff D1** - Consumers Maximum Demand in KVA below 300
Fixed monthly charge in Kwacha - 21.13
Maximum demand charge per KVA per month in Kwacha - 3.63
Unit charge in Ngwee - 1.63

(b) **Tariff D2** - Consumers Maximum Demand in KVA 300 to 2000
Fixed monthly charge in Kwacha - 406.25
Maximum Demand charge per KVA per month in Kwacha - 3.25
Unit charge in Ngwee - 1.25

CONT/.....

(c) Tariff D3 - Consumers Maximum Demand in KVA over 2000
Fixed monthly charge in Kwacha - 4062.50
Maximum demand charge per KVA per month in Kwacha - 2.78
Unit charge in Ngwee - 0.82

Surcharges for Supplies from Isolated Systems Other than on Tariff E1 & Tariff E2

Consumers of Tariffs E3, E4 and D will be subject to the following surcharges:-

(a) The 20% surcharge on consumers supplied from isolated systems with mainly hydro electric power generation remains unchanged.

(b) The 150% surcharge on power and energy supplied from isolated systems with only diesel electric power generation remains unchanged

SECURITY DEPOSITS - The new standard deposits for the supply of electricity are now as follows:-

(a)	Restricted supply (maximum load 5 amperes)	K13.00
(b)	Restricted supply (over 5 amperes)	K25.00
(c)	Unrestricted Domestic	K63.00
(d)	Other consumers (excluding maximum demand consumers)	K88.00

Existing consumers will remain on their previous deposits. However, in the event of any default in payment of bills resulting in disconnection, deposits will increase to the rates shown above. It should be noted that the new Reconnection charge is K25.00.

SALES TAX - A Government Sales Tax of 12½ remains unaltered.

R.G. MITI
GENERAL MANAGER

DATE: 31st March, 1983.

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Background

Historically Zimbabwe depended for its electricity supply on small coal fired power stations built to be local supplies either for cities or major mining centres. In January, 1960 the Kariba hydroelectric power station was commissioned with 666 MW (Zimbabwe's half share then was 333) of installed capacity mainly as a response to power demand by the mining industry. To-date the Kariba has been boosted to a Zimbabwe-half-share installed capacity of 633 MW complemented by a farely advanced national power grid network which currently serves a broad area of mining, industrial, commercial, domestic and agricultural (rural) activities as illustrated in Map 1 - ELECTRICITY SUPPLY COMMISSION.

With present government emphasis on rural development, power development schemes must be extended to include the establishment of an effective rural power supply sytem. It is in this sphere that small hydropower systems must be useful. Small hydropower technology alone, or in combination with other small scale systems may be used as isolated generation systems to supply rural centres too expensive to be serviced by grid extension.

A summary explanation of Zimbabwe's rural development strategy is shown in Map 2 - GROWTH CENTRES, DISTRICT SERVICE CENTRES, AND RURAL SERVICE CENTRES FOR PSIP. It is intended to supply power to these growth centres and to allow for network expansion to the ultimate development of a fully interconnected national power grid.

Existing Small Hydropower Systems

The development of hydropower in general in Zimbabwe has been limited to the Kariba while the development of power in general tended to be centralised. This may be attributed to the development of large scale industries in the country and the streamlined industrial location structure. Thus there are no existing small hydro stations in the country yet. The haphazard nature of the location of rural activity centres, however, calls for investigation of decentralised systems.

New Development In Electricity Supply

Boosting power generation capacity with the Hwange project may give Zimbabwe enough electricity for both rural and industrial consumption. However, the cost of extending the transmission network to some rural area justifies the adoption of localised small scale systems for rural power supply.

Zimbabwe is, therefore, seeking to do a study to provide rural centres with the most suitable power supply technologies. Rudimentary consideration of candidate technologies for rural

isolated power generation is underway but it is felt that consultancy and the relevant funding must be sought to carry out an indepth nation-wide rural electrification feasibility study with technology selection as a major exercise.

Resources For Small Hydro

Map 3., HYDROLOGICAL ZONES, shows rivers with falls or rapids, lakes, and dams. No effective study has yet been done on sites for small hydropower but the obvious areas of interest are covered by hydrological zones D, E and F. Zone F and eastern E have the greatest potential because they have perennial waters, high gradients, and the highest rainfall in the country.

However, flows and evaporation figures are not available for possible sites since these have not at all been identified. Available figures were collected for purposes other than small hydropower development and may thus be irrelevant in this case.

There are also a number of dams which could provide possible sites if their use for power generation is not in competition with water supply for irrigation, or drought control.

Again, any hydropower development has to match intended rural development. Thus site selection will be determined not only by hydrological factors but also by:

1. the location of the rural centre for which supply is intended.

2. the comparative cost of grid extension or other autogeneration systems.

Expertise and Training

The rural electrification feasibility study mentioned above would also be used as a training exercise for locals who would be seconded to the study team.

The running and maintenance of the stations would be done by the Electricity Supply Commission which trains its own personnel.

MINISTRY OF INDUSTRY AND ENERGY DEVELOPMENT: ZIMBABWE

No.1 TARIFF URBAN DOMESTIC

This tariff applies to all Domestic premises situated in an area within the boundaries of a Local Government Authority, or Rural Council Urban Ward, which, in the opinion of the Commission, should be classed as an Urban area. The tariff covers supplies to all apparatus normally used in such premises, including any number of motors up to 2,2 kW, and to any other apparatus which the Commission may, from time to time, decide upon.

a) The first 45 kWh per month at 8,5c per kWh.
b) The next 155 kWh per month at 2,5c per kWh.
c) Balance of monthly energy consumption at 1,1c per kWh.

This tariff is subject to surcharges, details of which are given in the attached schedule, and is also subject to a guaranteed minimum monthly account which will be related to the capital cost of providing the supply, but which will never be less than $2,00 per month.

No.2 TARIFF RURAL DOMESTIC

This tariff applies to all Domestic premises situated in an area outside the boundaries of a Local Government Authority, or Rural Council Urban Ward, which, in the opinion of the Commission, should be classed as a Rural area. The tariff applies to all apparatus normally used in such premises, including any number of motors up to 4 kW, and to any other apparatus which the Commission may, from time to time, decide upon.

a) The first 115 kWh per month at 8,5c per kWh.
b) The next 285 kWh per month at 2,5c per kWh.
c) Balance of monthly energy consumption at 1,2c per kW.

This tariff is subject to surcharges, details of which are given in the attached schedule, and is also subject to a guaranteed minimum monthly account which will be related to the capital cost of providing a supply, but which will never be less than $2,50 per month.

No.3 TARIFF URBAN BLOCK POWER

This tariff applies to all Commercial, Hotel, Institutional, Mining, Industrial, or other supplies having a supply capacity not exceeding 300 kVA, which are situated in an area within the boundaries of a Local Government Authority or Rural Council Urban Ward, which, in the opinion of the Commission, should be classed as an Urban area.

a) For single phase supplies, the first 50 kWh per month at 8,5c per kWh.
For three phase supplies, the first 100 kWh per month at 8,5c per kWh.
b) For both single and three phase supplies, the next 40 kWh per month, or 8 kWh per month per kVA of supply capacity, whichever is the greater, at 8,5c per kWh.
c) For both single and three phase supplies, the balance of monthly energy consumption at 1,1c per kWh.

This tariff is subject to surcharges, details of which are given in the attached schedule, and is also subject to a guaranteed minimum monthly account which will be related to the capital cost of providing the supply, but which will never be less than $3,00 or $1,00 per kVA of supply capacity, whichever is the greater.

No.4 TARIFF RURAL BLOCK POWER

This tariff applies to all Commercial, Hotel, Institutional, Mining, Industrial or other supplies having a supply capacity not exceeding 300 kVA and which are situated in an area outside the boundaries of a Local Government Authority, or Rural Council Urban Ward, which, in the opinion of the Commission, should be classed as a Rural area.

a) For single phase supplies, the first 190 kWh per month at 8,5c per kWh.
For three phase supplies, the first 340 kWh per month, at 8,5c per kWh.
b) For both single and three phase supplies, the next 50 kWh per month, or 10 kWh per month per kVA of supply capacity, whichever is the greater, at 8,5c per kWh.
For both single and three phase supplies, the balance of monthly energy consumption at 1,2c per kWh.

This tariff is subject to surcharges, details of which are given in the attached schedule, and is also subject to a guaranteed minimum monthly account, which will be related to the capital cost of providing the supply, but which will never be less than $5,00 or $1,00 per kVA of supply capacity, whichever is the greater.

No.5 TARIFF FARMING

This tariff applies to all farm supplies where the area of the farm exceeds 20 hectares and the occupier holds a current farmer's licence.

a) The first 340 kWh per month at 8,5c per kWh.
b) The next 50 kWh per month, or 10 kWh per month per kVA of supply capacity, whichever is the greater, at 8,5c per kWh.
c) Balance of monthly energy consumption at 1,1c per kWh.

This tariff is subject to surcharges, details of which are given in the attached schedule, and is also subject to a guaranteed minimum monthly account which will be related to the capital cost of providing the supply but which will never be less than $13,00 per month.

In the case of plot holders occupying land less than 20 hectares in area, the following conditions apply :—

a) Where the supply is used solely for domestic purposes, either No. 1 or No. 2 Tariff as appropriate.
b) Where no farming licence is held but produce is sold, either No. 3 or No. 4 Tariff as appropriate.
c) Where a farming licence is held, the occupant may have the choice between No. 5 Tariff and the appropriate one of No. 3 or No. 4 Tariffs.

No.6 TARIFF INDUSTRIAL DEMAND

This tariff applies to Commercial, Hotel, Institutional, Mining, Industrial, or other supplies over 300 kVA supply capacity and not exceeding 10 000 kVA supply capacity.

a) The first 300 kVA of monthly demand at $2,20 per kVA.
b) The next 700 kVA of monthly demand at $1,80 per kVA.
c) The balance of monthly demand at $1,55 per kVA.
d) The first 200 kWh per month per kVA of monthly demand at 1,1c per kWh.
e) The next 200 kWh per month per kVA of monthly demand at 0,7c per kWh.
f) Balance of monthly energy consumption at 0,3c per kWh.

This tariff is subject to surcharges, details of which are given in the attached schedule, and is also subject to a guaranteed minimum monthly account which will be related to the capital cost of providing the supply, but which will never be less than $1,00 per kVA of supply capacity.

No.7 TARIFF MUNICIPAL AND LARGE INDUSTRIAL

This tariff applies to Municipal, Industrial, Mining or other supplies over 10 000 kVA of supply capacity.

a) The first 10 000 kVA of annual demand at $43,50 per kVA.
b) Balance of annual demand at $33,00 per kVA.
c) The first 2 400 kWh per annum per kVA of annual demand at 0,4c per kWh.
d) The next 2 400 kWh per annum per kVA of annual demand at 0,3c per kWh.
e) The balance of annual energy consumption at 0,2c per kWh.

This tariff is subject to surcharges, details of which are given in the attached schedule, and is also subject to a guaranteed minimum annual account which will be related to the capital cost of providing the supply, but which will never be less than $15,00 per kVA of supply capacity.

No.8 TARIFF LIGHTING

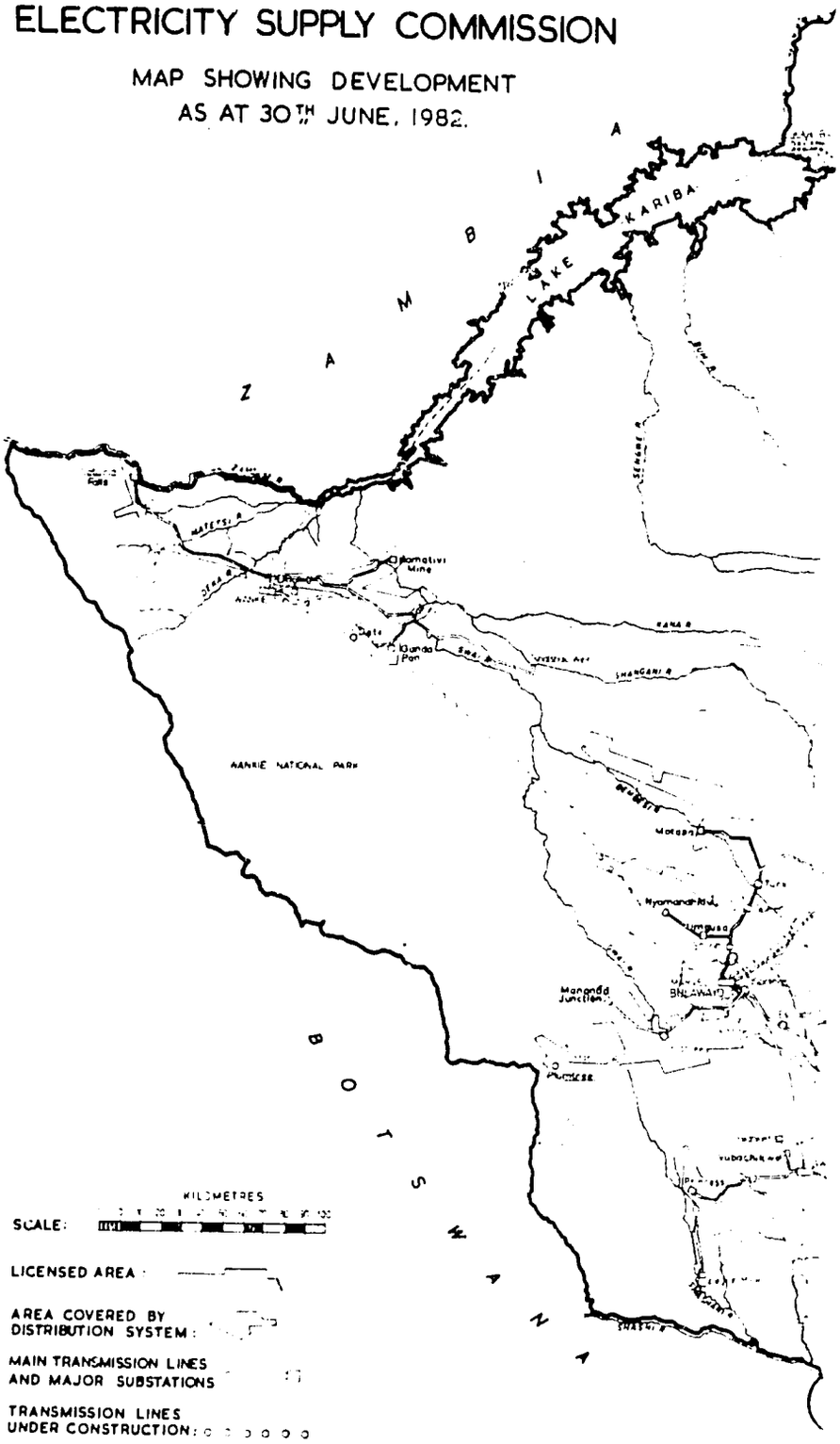
This tariff may apply as an alternative to Tariffs No. 3 or No. 4 for Women's Institutes, Scout and Sports Clubs, Farmers' Halls, Libraries, Churches and other such consumers as the Commission may from time to time decide.

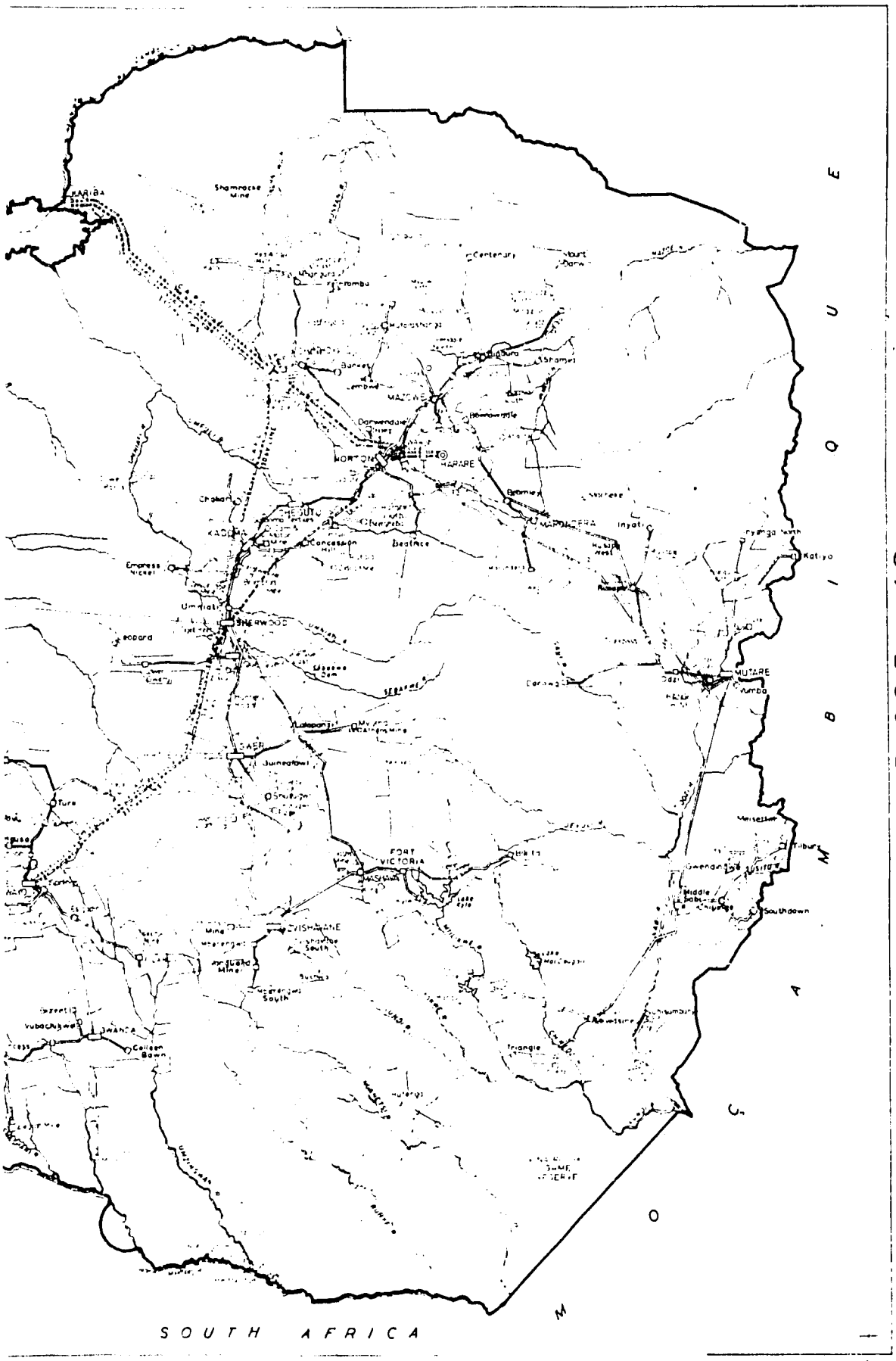
All monthly consumption at 10c per kWh.

This tariff is subject to surcharges, details of which are given in the attached schedule, and is also subject to a guaranteed minimum monthly account which will be related to the capital cost of providing the supply, but which will never be less than $1,00.

ELECTRICITY SUPPLY COMMISSION

MAP SHOWING DEVELOPMENT AS AT 30TH JUNE, 1982.




KARIBA
Shamrocke Mine
Centenary
Chromba
Bindura
Shamva
MAZOWE
Darwendale
NORTON
HARARE
Chakari
CHEGUTU
KADOMA
Concession
Beatrice
WAROWERA
Inyati
Nyanga North
Katiyo
Umvuma
SHERWOOD
Bepard
Ussewe Dam
SERAPHIN
MUTARE
Umtali
Lusapont
GWAERI
Gwenoro Dam
Turle
FORT VICTORIA
MASVINGO
Triangle
Mersetton
Tribur
Gwendor
Middle Sabi
Chipinge
Southdown
CHISHAWASHA
Mine
Wenengeni South
Mutubo Mine
Wenengeni South
Bennetsine
Umbumbur
Vubachikwe
GWANDA
Colleen Bawn
SOUTH AFRICA
M O Z A M B I Q U E

P 685 - 4C

Workshop on Small Hydropower in Africa

20 - 24 June 1983

Mbabane, Swaziland

Microhydropower Development in Pakistan

Mohammad Abdullah
Professor & Chairman
Department of Electrical Engineering,
NWFP University of Engg: and Tech:
Peshawar

and
Consultant to A.T.D.O
Government of Pakistan.

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INTRODUCTION.

Electricity plays a very important role in the development of a country. In a developing country like Pakistan, electrical energy is needed for meeting the basic need of energy in the domestic sectors of urban and rural population as well as for development in agricultural and industrial sectors. The generation system of Pakistan is a thermal-hydro mix, the present installed capacity is 4064 MW. 13000 villages out of a total of 43000 have so far been electrified. Most of energy needs of the people in rural areas are met from non-commercial fuel available locally.

In order to accelerate the pace of supplying electricty to rural people in remote areas, the Appropriate Technology Development Organization of the Government of Pakistan is implementing a program of rural electrification utilizing small hydroelectric potential. The program emphasises primarily on developing and promoting indigenous technology and using local resources. Forty schemes of 5-30 KW capacity have so far been completed at a cost ranging from Rupees 3000 to 5000 per Kw installed. The paper describes selected features of the schemes, mainly hydropower equipment, local fabrication, management and tariff. Experiences gained on the maintenance and repair of the plant is highlighted. Areas of research, design and development are pointed out.

Best Available Document

I. RURAL ELECTRIFICATION OPTIONS.

Since a large population of the country lives in villages, it is essential to accelerate the rate of rural electrification. Rural areas are being electrified by extending the national grid. This system is quite expensive for areas where load density is low and distances are long. The average cost of electrifying a village under the present system is about Rs. 500,000/- (1 U.S $ approximately = Rs. 12.50). This does not include the cost of providing additional generation capacity and cost of transmission lines and grid station. In view of high cost of this system it is imperative to look for a suitable option for electrifying the villages at a lower cost.

Decentralized electricity generation systems offer an attractive solution for remote, isolated and sparsely populated areas. Since no extensive transmission and distribution systems are needed, substantial saving in capital cost is possible. Decentralized generating stations, using renewable sources of primary energy are most suited to oil importing developing countries. Among the various sources of renewable energy, hydropower is the one whose technology is well established. In rural areas, water power has been used by people since ancient times. Simple water sheel are common sights in many parts of Pakistan even today.

In pakistan, decentralized hydroelectric schemes are being implemented under two different approaches. In one case, small plants of capacities 100-200 KW are installed under conventional method. These projects are executed by contractors, who follow the conventional designs of civil works. The turbine is imported and the generators and transformers are made by local firms. These projects are being

installed at a cost of Rs. 50,000/- - 70,000/- per KW. Since the revenue returns are low, the schemes are heavily subsidized by the Government.

In the other schemes, adapted and promoted by the Appropriate Technology Development Organization (ATDO) of the Government of Pakistan, projects are being executed with participation of the local community. Plants of capacities in the range of 5-30 KW have been installed in a number of villages in the northern areas. The installed cost of these plants range from Rs. 3000/- to Rs. 5000/- per KW. A brief description of these schemes is given in the following paragraphs.

2. MICROHYDRO SCHEMES OF A.T.D.O.

NEED FOR ELECTRICITY AND POWER IN RURAL AREAS.

The plants are developed to serve communities which are living in isolated for-off areas in mountaneous regions. Most of these locations are difficult to reach, and due to snow fall they remain cut-off for few months. People are mostly uneducated and have a low income. They possess village level skills in masonary and carpentary . Skills in installation and operation of any kind of machine is uncommon. The cash income is either from the sale of agricultural products or salary of family members working in town or on some government projects around their villages.

Basic need of lighting is met by using kerosine lamps by those who can afford it. Rest of the people either use oil-wick lamps or burn firewood for obtaining light. In the regions under consideration, kerosine oil is quite

expensive. It is sold at about Rs. 16/- per gallon. A well-to-do family may have to spend about Rs. 100/- per month for purchase of kerosine oil for lighting purpose. An average family spends about Rs. 25/- per month for this purpose. Transport and storage of oil poses some problems too. In most of the villages, motive power for grinding mills is produced from ancient type of wooden water sheels run on vertical shaft. Though they are very cheep and simple, they are highly inefficient and slow. Some enterprenuers install a diesel engine to run their mills.

The basic needs of the community can be satisfied by modest level of electricity. A couple of bulbs in each house is all that is needed. The climatic conditions are such that cooling fans are not required. In addition to residential building there are a couple of other places, e.g religious centres, community centres, schools, police station, dispensary etc which require electricity for lighting purpose.

The requirements of mechanical power to run the usual agricultural processing units is also quite low. The units commonly needed in a rural area include flour milling, rice husking, cotton ginning, sawing, drilling and lathe etc. Since the demand of the products is low, machines of small capacities are installed. All the units do not operate simultaneously and as such the maximum demand of power is only a few horse-power.

CURRENT PRACTICE.

In the earlier stages, plants of smaller capacities, mainly in the range of 5 - 10 Kw were installed. These sites have a head in the 5 - 10 m range. Penstocks were made

from wooden planks and at some places old oil drums were assembled to make penstocks. The Banki type rotors were made from steel sheets bent manually to give the desired curvature of the vane. A detailed account of the schemes have been given earlier (1-4).

The recent installations are relatively larger in capacity, 10 - 30 Kw and sites with higher heads, 10-40 m have been developed. Steel pipes penstocks are invariably used and a gate valve is installed at inlet to the turbine. Fabrication of the turbine rotor has also been improved. The vanes are cut from a pipe of appropriate diameter, which has resulted into stronger and uniformly shaped vanes.

The breakdown of the cost of a typical 20 Kw plant at a site having a head of 20 m is as shown below :-

a)	Civil works including penstocks	Rs. 15,000
b)	Turbo-generator equipment	Rs. 30,000
c)	Technical services	Rs. 10,000
	Total	Rs. 55,000/-

In the initial stages, the entire expenditure of a plant was borne by ATDO. Later on the cost was shared between the ATDO and the provincial government. Currently there is a greater contribution made by the provincial government and local councils. The cost of material and equipment is borne by the provincial government, the local council or the cooperative society is responsible for supplying wooden poles for distribution lines and labour and local material for the civil works. The ATDO provides all the technical services needed to implement the scheme.

Since the installation of the first demonstration plant in 1976, 40 plants with a total capacity of 360 Kw have been installed to-date. Another 20 projects are at various stages of implementation.

3. MICROHYDRO-POWER PLANTS.

In the micro-hydro program of the A.T.D.O, the selection of the type of turbine is based on the following criterion :-

1. Indigenous know-how should be developed and promoted. The turbine must be simple enough to be built in a small local workshop.

2. Material and components used must be available locally.

3. It shouldbe substantially cheaper than imported turbine. Its cost should be within the reach of individual/community.

4. It should be easily portable.

5. Repairs should be easily carried out in a local shop.

6. It should be fairly reliable.

7. It should be fairly efficient.

Purely on technical grounds, for the range of head (5m to 25m) and flow (50 l/Sec to 500 l/Sec), Francis type turbine appears most suitable. However,this turbine has the following disadvantages :-

a) The design of the turbine is complicated and hence it is very expensive.

b) Different flow-head combination needs a different runner diameter which demand entirely a new design of the turbine.

c) The part-load efficiency is very low. This is a great disadvantage for smaller streams and in run-of the river plants.

Reaction turbines are usually more suited for very large installation.

The cross-flow turbine is free from the above mentioned drawback. It has the following main advantages :-

a) The design procedure and fabrication are simple and therefore it is not expensive.

b) The design is well suited to different combinations of flow and head. Runners of varying widths but a fixed diameter can be made to suit the requirement.

c) The part-load efficiency of a cross-flow turbine is fairly high. A good design will have an efficiency of nearly 80 % at water flow from 20 % to 100 % maximum flow.

d) The bearings have no contact with the flow.

e) No sealed housing is needed as the rotor operates at atmospheric pressure. The operation and maintenance of a cross-flow turbine is simple. Because of its design, it is self-cleaning. They are not affected by cavitation.

In view of these advantages and with a view to developing indigenous know-how the cross flow turbine was chosen by A.T.D.

3.1 LOCAL DESIGN AND FABRICATION.

TURBINE.

In order to meet the objective of scheme, complex structures and manufacturing processes are avoided. No casting is involved, rather locally available sheets and pipes are used in the fabrication of the rotor, nozzle and the housing. The machine can be easily manufactured in a simple workshop having facilities of sheet cutting, drilling and welding. The turbine dimensions are worked out from the values of available head and flow at each site. No effort is made for standarizing any of the rotor dimensions. The rotor speed is designed to be in the range of 300-500 rpm in most of the plants. Exceptionally, at very low heads speed of about 200 rpm have been obtained. The rotor diameter ranges from 30 cm to 50 cm and the width from 20 cm to 60 cm. Most design have 28-30 blades.

The turbine rotor is assembled by a simple process. End plates of specified diameters are cut from 6 mm thick mild steel plates. Rotor vanes are cut from a suitably sized steel pipe. Blades are then welded electrically to the end plates. The rotor has a through shaft. The nozzle is made from 3 mm thick mild steel sheet. It is fixed at the lower end of the penstock and is independent of the turbine. No automatic governor is included in the design. The flow is controlled manually.

The rotor is supported by three ball bearings which are secured on railings grouted on concrete pads. Cast iron pullies of suitable diameter are used to couple the turbine to the generator through V-belts. Both locally made and imported bearing and belts are available in the market.

Penstocks are made locally by rolling mild steel sheets to the desired diameter and welding the seam. Pipes are usually made in diameters of 25-40 cm and length 2.5-3 meters. Thus they are easily portable.

GENERATORS.

Imported alternators, available in the local market are currently used in the scheme. These are standard 220/380 V, 1500 rpm, 50 Hz synchronous generators. Since the generator is the single most expensive item of the scheme, a program of local design and fabrication of generators has been initiated by the A.T.D.O. Prototype units are undergoing trial and the results are promising.

DISTRIBUTION SYSTEM.

The distribution system operates at the voltage at which power is generated at the machine. Thus step-up and step-down transformers are not needed. This results in saving of capital cost as well as in reduced maintenance. Bare copper wires are used as distribution lines which are supported on wooden poles. Each house is properly wired, with switches and protective fuses, additionally pole-mounted fuses are also used. All materials used in the distribution system are made locally and are available in most of the market.

4. PLANT AVAILABILITY.

The micro hydro power plants are designed and constructed to give uninterupted service under normal conditions of operation. Since the local technology and material is used as far as possible, no claim can be made for acheiving a perfect design and construction. Some element of risk of failure

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is accepted in all the components of the system i.e intake and power channel, penstock, turbine and its accessories, generator and distribution system. The experience gained in regard to failure of each of these elements is presented.

The intake is built with loosely held pieces of boulder meant only to divert a portion of water from the main stream to the power channel. The channel is in most cases unlined, although in some cases where the length is short and funds were available, lined channels have been made. The forebay, in the form of a small size tank is made with cemented sides and floor. No measures are taken for any special reinforcements.

Under normal conditions the civil works in the form described above are quite safe. The water flowing through the channel is in the range of 3-10 cusecs, having a velocity of 2-4 ft/sec. No soil erosion has been experienced in the channel and the forebay have shown no signs of damage.

However, in case of heavy floods in the stream and heavy rains, the unlined channel do suffer damage, and the sides are washed away at some places. The intake may also be damaged. No damage has been reported to the forebay. As a result of damage to the intake and the channel, the plant remains closed for periods varying from few hours to a couple of days, depending upon the extent of damage and the availability of the local people to do the repair. In case of widespread damage, a team of volunteers come forward to do the job. In addition to rain and floods, channels have also been damaged due to snow fall. At some places, the sliding rocks from the mountain slopes have damaged the channel. Irrespective of the cause, the nature of the damage is such that it is taken care off by the local people and we are not even informed.

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The penstock at most places is made up of mild steel pipes, although in some of the earlier designs wooden channel and at one place concrete pipe have been used. Plants with steel pipes penstock are fitted with a control valve at its outlet. The valve is operated manually and consequently water hammer of serious nature is not generated. The wall thickness of pipes is suitably designed to withstand such pressures. No damage of penstocks has been reported so far. Even the wooden penstocks have operated without damage, although water leakage has posed problems at some places. The experience with concrete pipe has been quite interesting. On the first operation of the plant, a portion of the pipe at the lower end burst and gave in. The damaged portion was plastered and it is working well for about two years.

The turbine consists of the rotor, nozzle, shaft, bearings, pully and belt. The turbine rotor and the nozzle are fabricated in a local workshop and the pullies of required size are also fabricated locally. The other components e.g. shaft, bearing and belt are purchased from the market. Turbine damage has been reported at some places. Mainly the blade breaks at the joints to the end plates. Examining the damage it was observed that it resulted from the failure of the welded joint. Blades are joined to the end plates by means of electric welding. Since the blades are curved, and the clearance between adjacent blades is small, it is difficult to make a good joint manually. Failure of joints are more common on long rotors. In the event of such a failure, the rotor is brought to a nearby village or town for rewelding. Welding facilities are commonly available in towns. It may involve closure of the plant for a day or two depending upon the location of the plant and transportation facilities. Some plant managers keep a spare rotor for such eventualities.

Other items of turbine failure are bearing and belt. The housing provided on the rotor is not water-tight, consequently leakage of water takes place which affects the bearing and the belts. Secondly misalignment of the shaft and pullies cause damage to belt and bearing. The plant managers are advised to keep spare set of these items and in that situation replacement is done quickly. However, in case where stocks are not kept, they have to be purchased from the town, which may involve a day or two for travelling.

Failure of turbine is taken care off at the local level, since welders are available locally and people are familiar with the purchase of belt and bearing. They can also replace and install these items.

Electric generator is the most complicated machinery in the micro-hydroelectric plant. No technical skill is available locally for the repair and maintenance of generators. Generators have been damaged on few occasions in the past. In some cases, the rectifiers in the field systems were damaged and in others th winding was damaged. Usually, the generator failure is reported to ATDO. In some cases the people bring the generator to the ATDO office in Peshawar and it is checked by our staff. Minor faults e.g burnt rectifier or lost magnetism are taken care off quickly. However, if the winding is damaged, the generator is given to an electrical shop in the town for rewinding. In some cases, people take the generator to shop directly without contacting ATDO and get the work done. A generator failure leads to closure of the plant for longer period particularly if it needs rewinding. A period of one or two weeks is quite common. Besides it involves large expenses which includes cost of repair, transport of generator, boarding and lodging of persons carrying the generator. Nonavailability of plant resulting from failure of r machinery or due to any other cause is of no great concern t the people. A more ..

important issue is the availability of funds to meet the expenditure on major repair e.g rewinding of generator. Since the plants are not run on commercial lines, the income from the sale of electricity to domestic consumers is barely sufficient to meet the cost of operation and replacement of minor components e.g belt, bearing etc. In case of heavy expenditure, special collections are made from the beneficiaries which is not easily forthcoming. Some people request a spare generator but ATDO can not meet the demand.

5. MANAGEMENT.

Small hydropower schemes can be implemented in more than one ways. In one approach, a central agency of the government is entrusted with the responsibility of planning, designing, executing, operating and maintaining the schemes. The particular agency becomes fully responsible for all phases of the work. The local community then buys electricty at a rate fixed by th Government. Such schemes are usually electricty-generating sch mes only. In the decentralized approach, participation of local government and local people is invited at various stages of the work. The community can be actively invloved in discussions, planning, data collection, execution and remain involved upto the hand-over stage.

In Pakistan, both approaches are being followed. Small hydro schemes of 100-200 KW are being implemented in conventional patterns used with large schemes:- capital-intensive designs, imported hardware and construction firms. The result is a huge capital cost of investment. In addition, the cost of operation is also high and often needs heavy subsidy. In a 200 KW scheme under implementation, the scheme is estimated to cost Rs. 7800000/- . In view of a low revenue, a subsidy of nearly Rs. 10,00000/- per annum has to be provided by the Government.

In the decentralized approach, followed by ATDO, local people are associated from the identification of the site to the installation of the plant. Upon the receipt of a request from a village, a team of ATDO staff visits the area and discusses all aspects of the project with the village leaders to inform them of their obligations and the responsibilities of the Government. Construction of civil works are undertaken by the villagers. The turbine is fabricated by ATDO in a town. The turbo-generating set is installed by the villagers under the guidence of the ATDO staff. Thereafter the plant is handed over to the local community. The village leaders hire an individual from the village to operate and maintain the plants. Decisions regarding the operating hours and tariff are made by the community No taxes or revenues are collected by ATDO or any other agency of the government.

In a number of schemes implemented recently, District Councils and Cooperative Socities of the provincial government have participated and provide financial support and leadership. The ATDO maintains a close liaison with the village leaders in all the project areas. The staff makes occasional visits to the plant and share experiences. Only in case of major technical problems, the village leaders approach the ATDO for guidence and assistence.

6. TARIFF.

Matters relating to tariff are discussed with the leaders of the local community taking part in the project. The cost of the project is shared by ATDO, provincial Government and the local community, the latter contributing mainly in the form of labour and arranging for the wooden poles for the distribution lines. After the work is completed and the plant made operational, it is handed over to the local people. Neither ATDO nor the provincial government collects any

revenue or taxes from the sale of electricity. The ATDO staff explains to the community the need of generating funds for sucessful operation of the plant. They are informed of the components that may have to be replaced over a period of one year. They are also told to depute one person foroperating the plant and arrange funds for his salary. Estimates of likely expenditure are worked out and some additional amount is included as a reserve for unforeseen expenses. The community is then advised to collect this amount on a monthly basis in a suitable manner. There is no fixed tariff which is applied at all places, the arrangement is quite flexible. At one or two places, people preferred to install energy meters at their premises and pay according to the consumption recorded on the meters. A rate of Rs. 1/- per KWH was charged. This system is not encouraged by ATDO and the people are informed of its difficulties. Firstly it is expensive to purchase a meter. Secondly an educated person has to visit each home every month and note down the reading. Thirdly it is difficult to ensure the correctness of the meter. Possibility of damage to meter and pilferage can not be ruled out.

A more common system adopted by the people is based on charges per bulb connected in a house. At the time of domestic fittings, people are advised about the number of bulbs which they can install at their premises. Usually lamps of 25 W, 40 W and 60 W ratings are allowed, and a flat rate of Rs. 4 - 5 per bulb charged. This system has an inherent drawback in that the tariff does not take into account the number of hours the bulbs are used. Some families may be using the lamps for longer hours without paying any additional amount. Keeping in view the habits and social life in a village, the working hours of the families do not vary to any significant extent. A more important consideration in this tariff is a check on the number of lamps andtheir rating. Some families try to use more powerful lamps and also use electric heaters of 1000 W rating. Such cases are detected by the plant manager/

operator who pursuades such consumers not to use these devices. In case of non-compliance, they are disconnected from the line. Because of a close relationship among the residents, misuse of electric power can not remain a secret for long time.

The fact that people to pay a fixed rate per bulb rather than having an energy prefer in their houses shows that it is acceptable to them. The collection is made by the plant manager or his nominee. Either consumers come to the power house and make the payment, or the manager moves around the village and collects the money. Cases have been reported of default or delay in payment, a fact which is accepted in every society. The manager maintains a record showing the name of consumers and the payment received. Occasionally the ATDO staff checks the record for information purposes only.

7. COMMERCIAL MANUFACTURE OF EQUIPMENT.

Some years back a scheme of installing small hydro-electric plants was initiated by the Government of Pakistan. The scheme envisged the installation of 100 small units, in capacities of 50 KW or 100 KW each in various parts of the country. A number of major industrial units and equipment suppliers participated in the program.

The penstock pipes and other hydraulic structures were fabricated in local factories. Two types of hydraulic turbines were selected. Francl Spiral Turbine and Ossberger Cross-flow turbine. Dress Francis turbines of capacity 85 HP and 170 HP alongwith automatic hydraulic speed governer and other components were imported from abroad. The cross-flow turbines of 83 HP and 151 HP were supplied with imported main components e.g turbine runner and oil pressure governor. Other components such as sluice-valve, draft tube, oil bath gear box, flywheel and elastic couplings were made locally.

Three phase, four-wire alternators of 50 KW and 100 KW, 440/254 volts with voltage regulation of ± 2.5 % were fabricated locally. Switchgears for the alternators with necessary built-in components including transformers, circuit breakers, wire and cables, poles and insulators and energy meters were all made locally.

No detailed study has been made to identify the potential of manufacturing complete units of hydraulic turbines. There are a number of industries manufacturing heavy mechanical plants in Pakistan. It seems likely that they may have the facilities to fabricate turbines. Since the demand of such turbine has been quite low, commercial production was not attractive. With increasing interest in the microhydro technology, chances of turbine manufacturing are bright.

There are a number of industries that have well established facilities for design and fabrication of electrical equipments, such as generator, motor, transformer, switchgear, wire and cable. Complete range of 11 KV distribution equipment is made locally. Generators upto 750 KVA and transformers upto 20 MVA are being made in Pakistan. Electrical sheet, steel, copper and insulating materials are however imported, Relays and indicating instruments used on switchgear panel are also imported.

8. RESEARCH, DESIGN AND DEVELOPMENT.

Small hydropower should not be considered as a miniaturised version of major hydro-power. It has been recognised as source of energy which can be harnessed at a lower capital investment and maintenance cost, the equipment needed could be fabricated in many of the developing countries and it has the potential of electrifying remote rural areas.

In order to make small hydropower schemes successful, design and developments should continue in a number of areas.

In Pakistan, design and development work in the field of small hydropower equipment are being carried out mainly by Engineering Universities and National Institute of Power. Currently the following activities are in hand:-

a) Improvement in the design and fabrication of the cross-flow turbines.

b) Design and development of very low head and heavy discharge turbines.

c) Design and development of alternators.

d) Design and development of appropriate control and protective devices.

Other promising areas for research and development include designs of simple turbine for head varying between 2 m and 50 m and flow varying from 20 l/Sec to 500 l/Sec. Looking at all the components of a small hydroelectric scheme, the electricity distribution system may become the most expensive part, depending upon the location of the plant and the area to be served. In some of the schemes in Pakistan, the electrical energy from the micro-hydroelectric plants is supplied to consumers at a distance of about one mile or so from the power house. In such a situation, the cost of the distribution becomes very high and even exceeds the total cost of installation. There is a need, therefore, to look into the possibilities of developing inexpensive distribution systems.

The author is not aware of any R & D work by the private sector in the field of water turbine. Since there is no commercial production of these equipment, it is unlikely

that any research is being undertaken by industries. Design and development work are being carried out in those industries which manufacture electrical equipment such as generators, transformers, motors, switchgears, cable and wire.

A micro-hydropower plant offers a suitable means of providing a motive power, not only for running electric generators, but also for operating directly small agricultural processing units. The utility of the plant can thus be greatly enhanced and its economics will be substantially improved. A number of schemes in Pakistan are dual-purpose. During night, electricty is supplied to the community and during the day, the turbine is coupled to a line shaft which drives a number of processing machines e.g flour-mills, rice-hullar, cotton-gins, saw-mill, wooden-lathe. The local people are encouraged to install these industrial units where ever possible. In addition to generating income, such plants also provides employment to a couple of local people. Both locally made and imported units are available in the market. There is a need to develop small and efficient units which can match the power available at the microhydropower plant. It is proposed to initiate R & D in this direction too.

9. EDUCATION AND TRAINING.

For proper planning and designing of small hydro-electric sheemes, knowledge in various disciplines of engineering is needed. Knowledge in fluid mechanics and hydraulics is required in the assessment of potential and design of hydraulic structures. Proper understanding of the principles of operation, selection and design of water turbine is required. A knowledge in mechanics and mechanical engineering is useful for selection and design of turbine and its components e.g bearing and drive mechanisms. For the selection of generator, design of distribution system, control and protection equipment , education in the field of electrical

engineering is necessary.

The entire spectrum of education and knowledge can be made available in two ways. A team of civil, electrical and mechanical engineers is engaged for the scheme, a practice which is followed in most of the medium and large hydropower schemes. However for small schemes it may become expensive to employ a team of highly qualified engineers. The other alternative is to educate and train an engineer (Civil/ Electrical/Mechanical/Agricultural) with additional knowledge needed for planning and designing of these schemes. A good interdisciplinary education is needed. This can be achieved by special courses in the related subjects.

10. CONCLUSIONS.

Small hydroelectric schemes implemented under conventional approach are too expensive particularly when electricity is used primarily for domestic needs. Decentralized micro-hydropower is a viable option for electrifying isolated rural areas. By utilizing local resources and involving local people, these schemes can be implemented at a low cost and can be instrumental in rural development in true sense.

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BIOGRAPHICAL SKETCH.

Mohammad Abdullah obtained Ph.D and M.Sc degrees in Electrical Engineering from University of Manchester, England. His major areas of academic interest are electric power engineering, dielectrics and high voltage engineering. He possesses 28 years experience in electrical engineering education and research. At present he is Professor & Chairman of Electrical Engineering Department, NWFP University of Engineering & Technology, Peshawar, Pakistan. He is coauthor of a book, " High voltage Engineering " and has published several articles in national and international journals. He has visited a number of countries in Asia, Europe and Noth America. He is a member of the Institution of Electrical Engineering, England.

For the past ten years he has been interested in alternate sources of energy and energy conservation. He has worked on a number of national panels and working groups on energy and power. As a consultant to the Appropriate Technology Development Organization, Government of Pakistan, he is currently engaged in the design, development, demonstration and dissemination of micro-hydro-electric technology in rural areas.

HIGH HEAD SITES

— **SITE:** Mountain streams having a series of rapids or waterfalls, such that the gradient is not less than one metre in ten. The best sites are often found in glacial areas where a side stream enters a main river valley as illustrated above.

— **UTILISATION:** A small weir is all that is required to divert the flow into the penstock, making these sites very cost effective. The small diameter penstock is easy to install and conceal if the area is of great natural beauty.

— **FACTORS:** The higher the head you can obtain, the smaller and cheaper the installation becomes. It will also perform better under low water conditions.

THE 'Falls' SERIES
Water Turbine

400 Leaving for Scotland

800 Runner for Sri Lanka

400 Horizontal for Cornwall

YOUR HIGH HEAD SITE can produce abundant cheap power using one of our 'Falls Series' of water turbines. There are seven sizes to choose from, ranging from 1/2 a kW to over 150 kWs.

GREAT FLEXIBILITY results from using multiple jets and high efficiency belt drives. Installers can hold standardized components in stock and make up a plant to suit a specific site. It also enables you to change the output at a later date if for example the head is increased. The lack of accurate site data will not cause problems with this system.

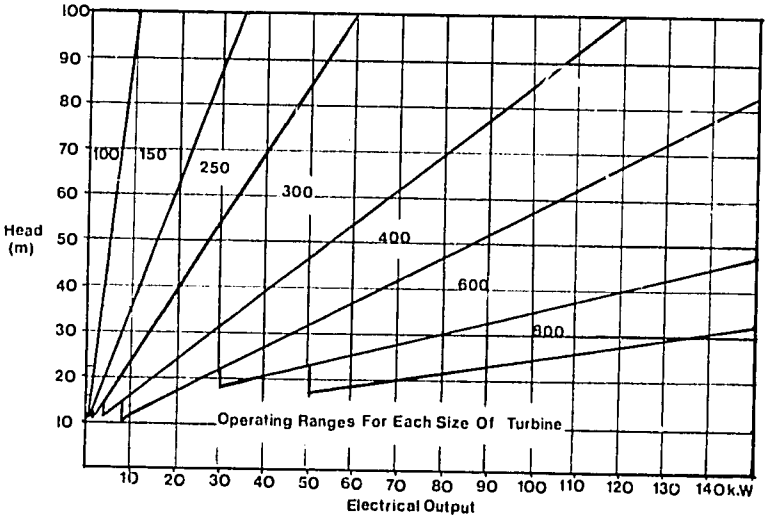
SIMPLE AND ROBUST steel construction means that these machines are easy to assemble and with our excellent corrosion proofing, they require virtually no maintenance. Components can be made light enough for transport into remote areas.

THE ARRANGEMENT can be vertical which lends itself to electricity generation, or horizontal for mobile (skid mounted) plants for temporary use e.g. mining operations, or to drive machinery.

THE EFFICIENCY of the turbine drive and alternator are all very good so that where water is limited, every drop counts. We also supply economiser systems to conserve water where there is water storage.

BRUSHLESS ALTERNATORS with static or permanent magnet excitation are fitted as standard to reduce maintenance still further.

ELECTRONIC GOVERNING systems are fitted on all machines as standard and give a level of accuracy and reliability previously unknown in the field. We supply a range of control panel and protection systems to meet every requirement.



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SERVICES AVAILABLE TO OVERSEAS CUSTOMERS

EQUIPMENT.

We design and build a range of Small Hydro Generating sets, with outputs of a few hundred watts up to over 200KW, for heads from as little as 500mm to over 300 metres. Being of a simple but robust design, our machines are ideal for remote locations in Developing Countries, and we maintain that they are the least expensive turbines currently on the market. As a guide,the ex-works price of a 60KW plant for a head of 70 metres, consisting of Turbine, Alternator and Electronic Governing System is in the region of £8,000.

By careful selection of materials for penstock,etc.,and the use of interchangeable components such as jets, we can supply complete Hydro Generating Sets that are portable; these are particularly suitable for applications such as mining exploration and forestry, where the plant can be moved to a different location when worked has ceased in one area.

ELECTRONIC LOAD CONTROL

We are the pioneers of Electronic Load Control for Micro Hydro, and the only UK manufacturer, and can offer a complete range from 5KW single phase (£350 ex-works) up to 120KW three Phase (£2100 ex works). A new system of Electronic Control for applications above 120KW has now also been developed and prices are available on application. We can supply complete Alternator/Controller packages to your requirements.

CONSULTANCY

Having considerable experience in the field, we can offer a consultancy service covering all aspects of Micro Hydro, from site survey of individual projects, to overall planning and feasibility studies for multi site projects.

ENDUSER ADVICE.

In conjunction with our consultancy service, we can offer advice on the utilization of Hydro Power, including the setting up of local small industries such as Sawmilling and Ice Making Plants. Many local industries can be made possible by the installation of Micro Hydro Power plants.

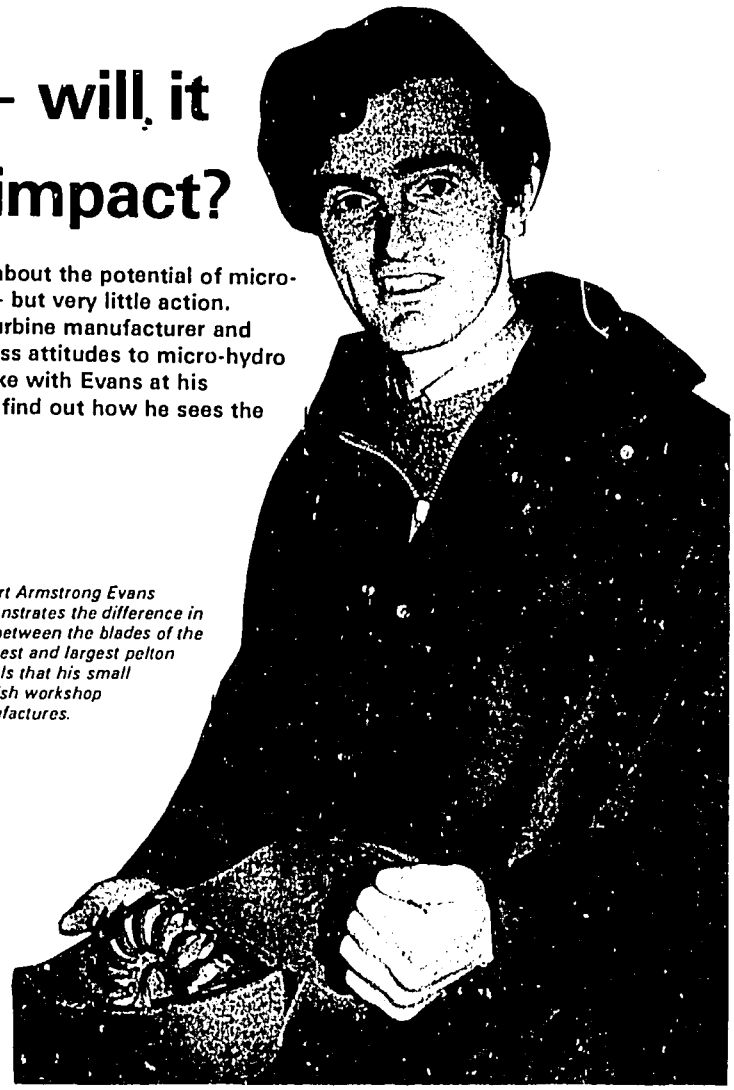
Our charges for both these services are very modest, particularly if they are in conjunction with Development Aid Agencies.

LOCAL MANUFACTURE

In Developing Countries with good hydro potential, where it can be shown that there is sufficient interest to make local manufacture viable, we welcome any opportunity to assist small, locally owned Engineering Companies to manufacture or part manufacture, install and maintain Hydro Electric plant to our specification.

Micro-hydro — will it ever make an impact?

The past ten years have seen a lot of talk about the potential of micro-hydro as an alternative source of energy — but very little action. Rupert Armstrong Evans, a micro-hydro turbine manufacturer and specialist sees this pattern continuing unless attitudes to micro-hydro development change. Garry Charnock spoke with Evans at his engineering workshop in Cornwall, UK, to find out how he sees the way forward.



Rupert Armstrong Evans demonstrates the difference in size between the blades of the smallest and largest pelton wheels that his small Cornish workshop manufactures.

Few people would disagree that Rupert Armstrong Evans is an expert on micro-hydro development — but a lot might argue against his views on how this potentially vast energy source should be developed.

Besides running the largest manufacturing company of micro-hydro turbines in the UK, Evans has also spent a great deal of time over the last ten years looking at micro-hydro schemes in places as far apart as India, Malaysia, New Guinea, Colombia, Dominica and Kenya. He now believes that the future of micro-hydro lies in the type and attitude of organisations carrying out the projects.

"The biggest single problem of micro-hydro is politics," says Evans, who believes that government red tape, poor planning and political bias have hampered the successful development of micro hydro. But he also lays some of the blame at the engineer's door.

Civil engineers are blamed for giving micro-hydro undeserved bad publicity over the past few years. "If you ask a civil engineer to design a small-scale hydro plant he will always err on the side of safety and also try to build a structure to be proud of," says Evans. In fact, highly expensive engineering skills are not needed on most small-scale hydro projects, and should be avoided in order to make the schemes cheaper and less complex.

"Of the 3,000 or so water mill structures that exist in Cornwall and Devon, most have weirs built entirely out of local materials without the use of cement. The majority are intact today and some are absolutely perfect even though they are 500-600 years old. My argument is that if local people could build these structures such a long time ago, then the same can surely be done now," says Evans.

He is angered by civil engineers who claim that the problem with installing low- and medium-head hydro is the high cost of building the concrete intake channel. "I haven't yet built a hydro station with a concrete channel," he claims. "If I built one using stone walling, I would consider it luxurious. The Cornish ones are built simply and cheaply out of earth and slate and have worked well for hundreds of years."

"Small-scale hydro is as different to large-scale hydro as putting up a garden shed is to building a skyscraper. It is just about the simplest mechanical technology you can come across. Bringing in a consulting engineer to carry out a one-off micro-hydro project will kill the project. I can think of several overseas schemes where the cost of the feasibility study has been more than the hydro installation."

Most of Evans' criticism is directed at governments, who he believes have been ultimately responsible for most of the micro-hydro failures. His experience in numerous countries has led him to conclude that there are several common approaches to micro-hydro development and most of them lead to failure.

He describes one of the most common faults as the "pilot project problem," in which governments interested in small-scale hydro tend to install a pilot scheme which is made to work regardless of cost. "Quite often the local university is called in to help and all it does is to try to re-invent the wheel by carrying out performance tests on various turbines." Evans says that all the necessary technical information has been available for years and points out that what are needed are simple, reliable machines and not complex new inventions.

He also claims that these pilot projects result in other micro-hydro programmes being shelved. "Many governments believe that if they 'Rolls Royce' the pilot project they can then concentrate on cutting costs of subsequent schemes — but in reality this approach never works. Accountants assessing pilot project cost benefit figures see that only a few kilowatts have been produced at very high cost and refuse to fund subsequent projects." It is far better, in Evans' opinion, to start off with a very cheap project and be "floundering around in the mud" to find out what some of the real problems are.

Long-term planning of micro hydro also

be independent of the local grid and use the micro-hydro generated power. Evans argues that the grid is not "losing a customer" by allowing the hydro station to continue operation as without the cheap power the industry would probably not exist at all.

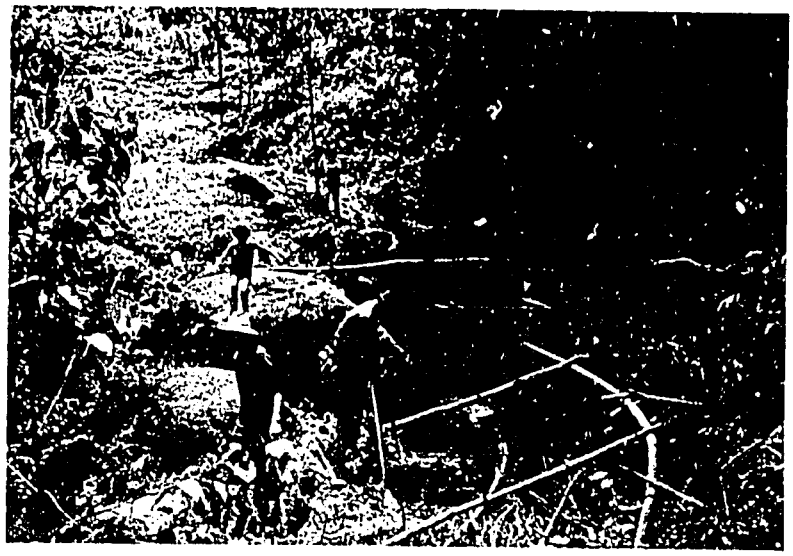
A final and very cheap option is to install micro-hydro plants on a temporary basis using packaged equipment similar to that used on irrigation work. Evans claims that the technology for this type of hydro is almost identical to that used in irrigation. He points out that there is no engineering reason why hydro plants need be permanent installations and says that many turbines could be skid mounted and moved to different sites.

"I prefer to regard small-scale water power as just another item of farm machinery — as simple as buying a petrol or diesel generator," comments Evans.

Supplying power to widely dispersed communities which are too far from the national grid to contemplate connection, could be achieved using micro-hydro, but not by the conventional system of using expensive power cables. He suggests adopting what he calls a 'bottom-up' approach. A simple turbine is initially installed to drive machinery in a local mill.

Evans quotes the Chinese approach to micro-hydro as an example. In some areas, small-scale hydro is brought in to power rice-milling machinery. Once the local people have become accustomed to the simple hydraulics of running the turbine they can then think about using the turbines' excess generating capacity for providing a local community power source.

As an alternative to installing electricity cables the local inhabitants are encouraged to collect their 'power' from the mill. In some areas of China, centralised water heating has been set up using hydro power. Local villagers bring cheap thermos flasks to the mill site and collect hot water in return for a payment of a very small fee.



In Colombia, Evans has studied a successful scheme which uses hydro power for battery charging. The local population uses charged batteries for household lighting and when the battery runs out of power they simply exchange it for a fresh one at the battery charging station.

Evans points out that by using small-scale water power in this way no-one in the community is discriminated against. In conventional schemes, which deliver power via cables, only the wealthier and more influential inhabitants tend to benefit, leaving the isolated rural dweller no better off.

While hydro power does not provide a real alternative to wood as a household cooking fuel, Evans believes that it could be useful as a fuelwood replacement for small industries. In this way it could help stave off the rate of deforestation in some countries.

In one area of Nepal the local soap factories used to cut down more wood than that used by all the local inhabitants. By using the mechanical energy of a small water turbine to drive an air impeller to heat air to 200°C, which is then used to heat the soap boiler, about 7,000 trees a year have been saved.

Evans enthusiastically churns out numerous ideas on the vast potential of hydro power and says that, when you look at the economics of installing turbines, there are few better investments.

"A plant can pay for itself in three years and then you can have free power for life," he says. But he realises that competition with diesel plants, which have smaller initial capital costs, is always going to be fierce.

Evans is developing a system-building approach to micro-hydro. He eventually hopes to have a small number of 'off the shelf' turbines covering the needs of most high and low head locations. He is also trying to build turbines which are simple to maintain and which cannot fail suddenly and catastrophically.

Despite his enthusiasm for hydro, Evans foresees that its development will continue much the same way as before. "Some countries will use it successfully, but an awful lot of projects are going to fall flat on their faces. I'm worried that the failures will be used to smear small-scale hydro-power with a bad reputation."

Left: This old 2.5-3kW turbine in Colombia has been locally made to a very low cost design. Total cost of the turbine, including the rudimentary intake works pictured above, is about $450, according to Evans. An old rubber tyre has been converted into a turbine casing and, although makeshift, it is an easily replaceable component. Similarly, the intake channel could easily be rebuilt by local workers if it were to be washed away.

This rudimentary, locally made turbine, provides sufficient power to run a wool processing plant in Northern India. It is of poor design and inefficient, but it works and can be maintained locally.

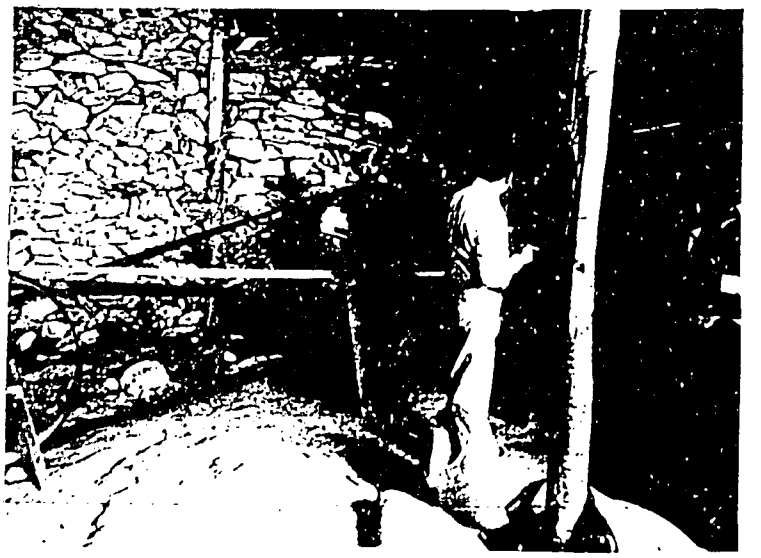
comes in for criticism. Many countries have a national grid which only feeds electricity to a relatively small developed area — usually an urbanised coastal plain. Eventually the grid is planned to be extended into the rural hinterlands as funds become available.

"As a result of political pressure, rural power stations (either diesel or hydro) are built as stop-gap measures before the grid connection is made. Diesel stations are quick to install and non-site-specific and their running costs grow with the load. The traditional hydro plant is, by comparison, capital intensive and immobile and just when the load factor has grown to an economic level the plant is replaced by the grid and usually shut down," says Evans. This is a fantastic waste of energy in a fuel hungry world, when there are thousands of derelict plants which bear witness to this type of planning policy. In Colombia, he says, there are some 6-7,000 derelict small hydro stations.

Evans believes that an alternative approach to micro-hydro installation is needed and he has developed several ideas.

First, plants could be designed for automatic operation so that they could be integrated into the grid system when it is eventually installed. Governments should realise that every kilowatt generated by a hydro station is a kilowatt saved on the balance of payments, as it reduces the amount of imported fuel needed to power the large national grid generating stations.

Second, positive efforts could be made to establish local industries which would



Mini-hydro motors on move to Sri Lanka

Two mini-hydro turbines, with outputs of 55kW and 100kW have been sent to Sri Lanka from the UK where they will be used to provide electricity to power machinery in two tea factories at Kataboola and Alupolla in the central highlands. The turbines will supply a cheaper and more reliable power supply than that provided by the present national power grid which is prone to frequent power cuts.

The new machines, manufactured by Evans Engineering & Power of Launceston, Cornwall, will replace the 50 year old Francis turbines which used to generate DC electricity until the national grid was introduced.

The mini-hydro turbines incorporate multi-jet vertical pelton wheels which enable the plant to operate efficiently down to very low flows. The turbines drive brushless alternators and are governed by the recently launched electronic load controller developed by Evans Engineering & Power *(World Water, December 1982)*. The load controller has minimum maintenance — a factor of paramount importance in Third World countries.

The turbines have runner pitch circles of 600mm and 800mm and, according to the manufacturer, have been supplied for just over $55,000, half of which has been provided by the UK's Overseas Development Administration. Brown & Company of Sri Lanka is providing the rest of the finance for the equipment which is due to be operational later this year. Brown & Company is also planning to take over the manufacture and installation of the turbines to meet Sri Lanka's needs.

Left: The largest diameter pelton wheel measuring 800mm before installation into the turbine housing. Far Left: Turbine under construction at Launceston.

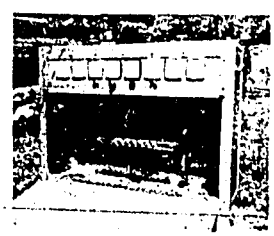
UK mini hydro group invited

A team from the Intermediate Technology Development Group (ITDG) and its collaborators, Evans Engineering and GP Electronics, UK, were the guests of the Ministry of Water Conservancy and Electric Power at the Hangzou Regional Research and Training Centre for Small Hydro Power, China, in September.

ITDG has been supporting the development of a unique electronic controller and simplified hydroelectric turbines by two small companies, Evans Engineering in Cornwall and GP Electronics in Devon. These developments promise to dramatically reduce the costs of providing remote areas with electricity, which is vital in increasing the productivity of small, rural industries and agro-processing.

The concept of the electronic controller was first put into practice by Rupert Armstrong-Evans of Evans Engineering, and Gerry Pope, the designer, of GP Electronics. Over 50 single phase controllers have been in operation over the last six years, and three phase controllers have been installed in Colombia, Sri Lanka and Thailand, with no recorded failures.

An initial order for 13 controllers in the 5 to 100 kW range has been secured from the China General Electric Corporation. This is the first step in a collaborative programme to utilise the controller with Chinese manufactured turbine generator sets for their internal and external markets. In addition, three Chinese turbine gensets will be purchased for use with the controller in the UK and for demonstration in developing countries.



The electronic controller works on a new principle of load control. As the demand for electricity varies the controller instantly adjusts the amount of power fed into a secondary "ballast" circuit while keeping the primary circuit absolutely steady and the speed of the turbine generator constant. This eliminates the expensive mechanical equipment and all the associated maintenance problems used to control the flow of water through the turbine, and allows for the use of much simpler and cheaper turbines.

The combined savings with the electronic controller and the simple turbine could halve the costs of a small hydroelectric plant. There are over 100 000 small scale hydroelectric plants in operation in China. □

SMALL HYDROPOWER IN AFRICA, MBABANE

Daily Evaluation Form

Friday, June 24

Please rate the overall quality of each presentation, using a scale of 1 (poor) to 5 (excellent). Please circle only one number of each line that corresponds to the quality of the presentation in terms of:

(1) the applicability of subject matter,
(2) the presentation of the subject matter, and
(3) technical substance.

	POOR				EXCELLENT
1. Financing Small Hydropower Schemes thru an Agricultural Development Bank					
applicability of subject matter.....	1	2	3	4	5
presentation of subject matter.....	1	2	3	4	5
technical substance.....	1	2	3	4	5
2. Financing of Small Hydropower Schemes In Africa					
applicability of subject matter.....	1	2	3	4	5
presentation of subject matter.....	1	2	3	4	5
technical substance.....	1	2	3	4	5

AFRICAN DEVELOPMENT BANK GROUP

FINANCING OF SMALL HYDRO POWER PROJECTS IN AFRICA

BY

S. DESAI

SMALL HYDRO POWER WORKSHOP

MBABANE - SWAZILAND

JUNE 1983

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Shashi C. Desai has been Principal Power Engineer at the African Development Bank's headquarters in Abidjan, Ivory Coast, since November 1980, where he is responsible for evaluating power projects which the BAD is considering financing. He received his B.E. in electrical engineering in 1961 from Rajasthan University in Pilani, India and received his M.Sc.Tech. in electrical engineering from Manchester University in 1963. From 1964 to 1980, Mr. Desai held various positions with the Central Electricity Board in Mauritius, including systems control engineer, electrical engineer (generation), and commercial engineer, where he was engaged in the design, construction, and commissioning of a 10 MW small hydropower station. Mr. Desai has published numerous papers on electricity tariffs.

AFRICAN DEVELOPMENT BANK GROUP

FINANCING OF SMALL HYDRO-POWER PROJECTS IN AFRICA

1. INTRODUCTION

The African Continent is endowed with abundant hydro-electric resources, which according to various estimates account for nearly 33% of the world's potential. Since the energy crisis of the year 1973, African countries have become conscious of their vast sources of renewable energy and are now looking forward to their gradual development. In this context, the African Development Bank (ADB) Group is now playing an important role in assisting member countries in the identification, preparation and financing of projects aimed at utilizing the locally available resources of energy. This paper briefly reviews the ADB Group and its lending policy in the energy sector with special reference to small hydro-power projects in Africa.

2. AFRICAN DEVELOPMENT BANK GROUP

The ADB Group is composed of the African Development Bank (ADB), the African Development Fund (ADF) and the Nigerian Trust Fund (NTF), as described hereunder.

2.1. The African Development Bank

The African Development Bank was established by 30 independent African States in August, 1963 to stimulate economic and social development in order to raise the living standards of the peoples in the African Continent. To-day it has grown up into an international development finance institution comprising 50 African Member Countries and 22 Non-Regional Countries. The Bank's main function, as outlined in its charter, is to use the financial and technical resources at its disposal for the promotion of projects and programmes which would contribute to the economic and social welfare of its member countries. In addition to the subscribed capital, it can mobilize financial resources for regional development projects by borrowing on international capital markets and by cofinancing with other international institutions, organizations and governments.

.../2.

At the end of the year 1982, the authorized capital of the Bank amounted to US $ 6.3 billion, and its cumulative lending stood at US $ 2.0 billion. In addition, the ADB is authorized to establish or be entrusted with the administration of special funds which are consistent with its objectives. At present there are two such special funds, as described below.

2.2. The African Development Fund (ADF)

The ADF was established in the year 1972 with the participation of Non-Regional Countries. The funds' resources are subscriptions which are specifically used to give assistance to the poorer regional members of the ADB through interest-free long term loans. Presently, there are 25 Non-Regional Countries participating in the Fund. The resources of the Fund are obtained by periodic replenishments from the participants. At the end of the year 1982, the cumulative lending of the ADF stood at US $ 1.7 billion.

The bulk of ADF loans is allocated to Member Countries whose GNP per capita is below a periodically-adjusted minimum 'low income' level. A smaller share of its resources goes to those with moderate GNP per capita, while relatively higher income countries are normally ineligible.

2.3. The Nigeria Trust Fund (NTF)

The NTF was established by an agreement between the Nigerian Government and the ADB in the year 1976. Its resources are wholly contributed by the Government of Nigeria. The main objective of the NTF is to assist the development effort of ADB members by extending loans at less onerous terms than the conventional ADB terms. At the end of the year 1982, the cumulative lending of this Fund amounted to US $ 92 million.

3. LENDING POLICY IN THE ENERGY SECTOR

Since the rapid increases of petroleum prices, particularly the shocks of 1973 and 1979, renewable resources and in particular hydro-electric resources have regained their importance. The changed conditions have a considerable impact both on the member countries that are endowed with abundant oil reserves and on those that depend heavily on imported fuels.

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The ADB Group has initiated a re-examination of its energy policies in the light of its previous experience and future realities in this sector.

The new ADB energy policy emphasizes increasing use of local energy resources. For Bank Group financing, it sets the following priorities for the near future:

(i) Development of hydro-electricity, including large, medium or small scale

(ii) Development of electricity production projects using other local energy resources such as coal, lignite, peat, geothermal energy, wind or biomass.

While giving priority to projects that directly produce energy, the ADB Group will also finance studies or programmes aimed at providing efficient use of energy in domestic or industrial applications.

The ADB Group's energy policy is consistent with the Lagos Plan of Action which gives high priority to the financing of small or large hydro-electric projects that use already known and proven technology easily adaptable to local conditions. This strategy is principally aimed at reducing the amount of imported energy, mainly in the form of petroleum products.

4. FINANCING TERMS AND CONDITIONS

The ADB Group provides financing for energy projects or other projects on the following terms and conditions:

ADB Loans

Interest rate	:	9.5%
Statutory Commission	:	1%
Commitment charges on undisbursed amount	:	1%
Grace period	:	Maximum of 5 years
Repayment period	:	12 to 20 years excluding the grace period for the implementation of the project

ADF Loans

Interest rate	:	nil
Commitment charges	:	0.75% p.a.
Repayment period for projects	:	50 years including grace period of 10 years
Repayment period for studies	:	10 years excluding 3 years' grace period.

NTF Loan

Interest	:	4% p.a.
Commitment Charge	:	0.75%
Repayment period	:	25 years including 5 years' grace period.

For the ADB loans, the loan amount is generally available only for the foreign exchange or off-shore cost of the project. It is therefore necessary that the borrowing member country should finance all the local or on-shore costs of the project. In the case of ADF Loans, foreign exchange may be made available to finance local costs for projects provided that the recepient country is allocating its resources efficiently among the various projects forming part of its development programme.

5. FINANCING OF HYDRO-POWER PROJECTS

The ADB Group has so far participated in the financing of the following hydro-power projects

YEAR	COUNTRY	PROJECT	
1969	Malawi	Tedzani falls	3 million UA
1977	Malawi	Nkula falls	4.7 million UA
1977	Mali	Selingue	5.0 million UA
1980	Swaziland	Lupholo Ezulwini	6.5 million UA
1982	Burundi	Rwegura	14 million UA
1982	Mali/Senegal	Manantali	10.9 million UA and 8.6 million F UA

The Bank Group has also financed two studies under bilateral aid from Non-Regional members:

(i)	Cavaly River Project	Liberia/Ivory Coast
(ii)	Micro-hydro power stations	Comoros

Among the large hydro projects, the Bank Group is actively considering the co-financing of hydro-electric projects in Kenya, Ivory Coast, Benin, Togo and Upper Volta with other financing Institutions and Organizations.

6. FINANCING OF SMALL HYDRO-ELECTRIC POWER PROJECTS

Although small hydro-electric power projects fall within the spectrum of the ADB's energy lending policy, their financing presents some practical problems. For example, if the cost of the proposed project is below one million US dollars, the preliminary costs of the ADB's intervention (preparatory mission, appraisal mission, loan negotiations etc.) would be quite high in relation to the cost of the project itself. Such projects are therefore more suitable for financing under lines of credit granted to National Development Banks. However, if several of these projects are grouped together as a package, an ADB or ADF loan may be made to finance part of the costs of the combined project.

For projects costing above one million dollars, loans may be made directly by the ADB Group to the borrowing country. It is understood that the projects submitted to the Bank must be technically sound, economically and financially viable. To ensure that projects satisfy these criteria, they must be well prepared, preferably by reputable consulting engineers. The Bank Group may assist the member countries in the preparation of the terms of reference of studies to be carried out by the consulting engineers and also in the financing of these studies.

Apart from the cost of the project, the Bank Group also provides assistance in the financing of components related to the project such as distribution network, purchase of tools and equipment, training programme for the power station staff and management training.

The following paragraph outlines the general requirements for the feasibility studies of a small hydro-power project.

7. PROJECT PREPARATION

A feasibility study of a small hydro-power project should examine the following essential points:

(i) Hydrological and climatic conditions

(ii) Geological and seismic conditions

(iii) Topography of the area

(iv) Selection of site

(v) Type of scheme - run of river or storage reservoir

(vi) Type and height of dam

(vii) Design of power station, equipment, auxiliaries, intake and discharge works

(ix) Cost estimates in local and foreign exchange

(x) Market survey and tariffs

(xi) Economic and financial analysis

(xii) Management of the proposed scheme during construction and after completion.

After completion of the study on the above guidelines, the potential borrowing country should apply to the ADB Group for project finance, stressing its priority ranking in the National Energy Development plan and submitting all the relevant information, technical and financial, on the project and the Executing Agency which would be implementing the project. The ADB Group then examines the request in relation to its lending programme to ensure that adequate funds are available for the country concerned and also to ensure that the project is the least cost solution to meet the desired objectives. Generally, the processing time for the financing of a project varies from six (6) months to eighteen (18) months, depending upon the status of the project at the time of the loan application.

.../7.

CONCLUSIONS

The ADB Group has adopted as its policy to give a high priority to financing hydro-power projects, small or large, in the member countries. Such projects offer various advantages, namely, the use of a renewable source of energy, import substitution, energy independence, and well proven technolo easily adaptable in the African environment.

It is hoped that Member Countries would avail of ADB Group financing facilities to promote such projects which very often aim at improving the economic and social conditions of the most underprivileged populations of th African Continent.

Small Decentralized Hydropower Program
International Programs Division
National Rural Electric Cooperative Association
1800 Massachusetts Avenue N.W.
Washington, D.C. 20036

Telephone: 202-857-9622
Telex: 64260 Cable: NATRECA

Small Hydropower in Africa

Mbabane, Swaziland

Program Schedule
June 20-24, 1983

Cosponsored by:

Swaziland Electricity Board
Ministry of Works, Power, and Communications
U.S. Agency for International Development
National Rural Electric Cooperative Association

Monday, June 20

First Plenary Session: Welcome and Keynote Address

8:00 a.m. Registration

9:00 a.m. Call to Order by Workshop Moderator

9:00 a.m. Welcome Speeches

W. M. Magongo, Acting Minister, Ministry of Works, Power and Communications, Mbabane, Swaziland

Kenneth Thomson, General Manager, Swaziland Electricity Board, Mbabane, Swaziland

Robert G. Huesmann, Director, United States Agency for International Development, Mbabane, Swaziland

Anthony Pryor, Energy Officer, Regional Economic Development Services Office/East Africa, Nairobi, Kenya

Dr. David Zoellner, Program Manager, Small Decentralized Hydropower Program, National Rural Electric Cooperative Association, Washington, D.C.

10:00 a.m. Coffee Break

10:30 a.m. Energy Initiatives for Africa

Michael Bess, Deputy Director for East Africa Region, Energy Initiatives for Africa, Nairobi, Kenya

11:30 a.m. African Country Papers

12:00 p.m. Lunch

Second Plenary Session: Introduction and Case Studies

2:00 p.m. Call to Order by Workshop Moderator

2:00 p.m. Opportunities and Issues in Small Hydropower Development: An Overview

Dr. Maury Albertson, Professor of Civil Engineering, Colorado State University, Fort Collins, Colorado

2:30 p.m. Pakistan: Villager-Implemented Micro-Hydropower Schemes

Dr. Mohammad Abdullah, Chairman, Department of Electrical Engineering, NWFP University of Engineering and Technology, Peshawar, Pakistan

3:15 p.m. Nepal: Private-Sector Approach to Mini-Hydropower Schemes

Edward Kramer, Manager, Himal Hydro Construction Pvt. Ltd., Kathmandu, Nepal

4:00 p.m. Coffee Break

4:30 p.m. Irrigation and Small Hydropower Schemes
David Willer, Vice President, Tudor Engineering Company, San Francisco, California

5:30 p.m. Introduction to Working Groups
Allen Inversin, Micro-Hydro Engineer, Small Decentralized Hydropower Program, NRECA, Washington, D.C.

6:00 p.m. Adjournment

6:30 p.m. Reception hosted by Robert Huesmann, USAID Mission Director

Tuesday, June 21

Third Plenary Session: Resource Assessment and Preliminary Design

8:00 a.m. Call to Order by Workshop Moderator

8:00 a.m. The International Finance Corporation and Private-Sector Development of Small Hydropower
V.S. Raghavan, Regional Representative for Eastern Africa, International Finance Corporation, Nairobi, Kenya

9:00 a.m. Hydrologic Assessments for Small Hyropower Schemes
Dr. Martin Johnson, President, The Johnson Company, Montpelier, Vermont

10:00 a.m. Coffee Break

10:30 a.m. Preliminary Layout and Design of Civil Works
Allen Inversin, Micro-Hydro Engineer, Small Decentralized Hydropower Program, NRECA, Washington, D.C.

11:15 a.m. Design of Civil Works and Small Hydropower Facilities
Bennett D. Reischauer, Head, Water Resources Department, Stanley Consultants, Muscatine, Iowa

12:00 p.m. Lunch

Fourth Plenary Session: Electromechanical Equipment and Electrical Distribution

2:00 p.m. Call to Order by Workshop Moderator

2:00 p.m. Electromechanical Equipment for Small Hydropo · Schemes
Rupert Armstrong Evans, Micro-Hydro Engineer, Evans Engineering, Launceston, England

3:00 p.m. End-Use and Electrical Distribution Planning for Isolated Hydropower Systems
Bard Jackson, Principal Engineer, Small Decentralized Hydropower Program, NRECA, Washington, D.C.

4:00 p.m. Coffee Break

4:30 p.m. Working Groups (planning session for field trip)

5:30 p.m. African Country Papers

6:00 p.m. Adjournment

6:30 p.m. U.S. Equipment Manufacturers' Presentations

Wednesday, June 22

8:00 a.m. Field Trip (to nearby small hydro sites)

2:00 p.m. Working Groups (begin working on workshop exercises for first four lectures)

4:00 p.m. Coffee Break

4:30 p.m. Working Groups (continued)

6:00 p.m. Adjournment

7:30 p.m. Banquet
Guest Speaker:
U.S. Ambassador Robert H. Phinny

Thursday, June 23

Fifth Plenary Session: Economic and Management Issues

8:00 a.m. Call to Order by Workshop Moderator

8:00 a.m. Economic Issues in Small Hydropower Development
Paul Clark, Training and Information Specialist, Small Decentralized Hydropower Program, NRECA, Washington, D.C.

9:00 a.m. Coffee Break

9:30 a.m. Management and Institutional Issues
Dr. David Zoellner, Program Manager, Small Decentralized Hydropower Program, NRECA, Washington, D.C.

10:30 a.m. African Country Papers Madagascar

12:00 p.m. Lunch Zimbabwe, Lesotho Kenya

2:00 p.m. Working Groups (continue with workshop exercises from previous day and exercises for economic issues)

4:00 p.m. Coffee Break

4:30 p.m. Working Groups (continued)

6:00 p.m. Adjournment

Friday, June 24

Sixth Plenary Session: Financing Issues

8:00 a.m. Financing Small Hydropower Schemes thru an Agricultural Development Bank
Kiran Man Singh, Agricultural Engineer, Agricultural Development Bank, Kathmanda, Nepal

8:45 a.m. Financing of Small Hydropower Schemes in Africa
Shashi C. Desai, Principal Power Engineer, African Development Bank, Abidjan, Ivory Coast

9:30 a.m. Working Group Presentations

10:30 a.m. Coffee Break

11:00 a.m. Working Group Presentations (continued)

12:00 p.m. Lunch

Seventh Plenary Session: Summary and Conclusion

2:00 p.m. Call to Order by Workshop Moderator

2:00 p.m. African Country Papers

2:30 p.m. Time for Additional Paper Presentations/Field Trip

4:00 p.m. Coffee Break

4:30 p.m. Summary Remarks
Dr. David Zoellner, Program Manager, Small Decentralized Hydropower Program, NRECA, Washington, D.C.

5:30 p.m. Adjournment