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"Small Scale Hydropower in Africa"

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GLOSSARY OF HYDROLOGY

AND RELATED TERMS

IN

ELECTRICITY, ENVIRONMENT, ECONOMICS, ETC.

FRENCH--ENGLISH

18

A

abutment protection	structure de protection a culée
ammeter	ampèremètre
arc-welding	soudage à l'arc
alternate sources of energy	sources d'énergie de substitution

B

bed(canal,etc.)	lit(canal,etc.)
basin	bassin
balance	
water --	bilan hydrologique
energy --	bilan énergétique
ball bearings	roulements à billes
belt	courroie
biota	biota;faune et flore
blade	aube,palette
bottom-dwelling organisms	organismes benthiques
breast wheel	roue de côté, de poitrine
breaker	disjoncteur
bus bar	barre omnibus,ligne barre

C

capacity (turbine)	puissance,capacité rendement(turbine)
capital intensive	à fort coefficient de capitaux
catchment area	bassin versant
cavitation	cavitation
centerline (nozzle)	axe(de tuyère)
checklist	liste de vérification,contrôle
cost effective	rentable
cost sharing - basis (on a)	participation aux frais à frais partagés, à parité de frais
capital costs	frais d'investissement
operating costs	frais d'exploitation
crest (for a weir)	crête (déversoir),seuil,sommet
cross section	section transversale
curvature	courbure
custom-made	fait,fabriqué sur commande,demande

D

dam	barrage
arch -	barrage-voûte
buttress -	barrage à contreforts
diversion -	barrage de dérivation
earth -	barrage en terre
gravity -	barrage-poids
rockfill -	barrage en enrochement(s)
timber crib -	barrage à caisson
dam up (to)	contenir, endiguer un cours d'eau ou lac, construire un barrage en aval d'une vallée

D (suite)

design	
- flood	crue nominale,crue utilisée pour un calcul
- recurrence	récurrence de calcul
dielectric	diélectrique
discharge (rate)	débit (valeur)
dissolved oxygen	oxygène dissous
downsteam (flow)	(écoulement) d'aval
drainage	
- area	bassin hydrographique,surface de captation des eaux, bassin d'alimentation
- basin	bassin hydrographique, aire d'alimentation, aire de drainage

E

efficiency (turbine)	rendement (turbine)
effective	efficace, utile, effectif, réel
energy balance	bilan énergétique
environmental	environnemental(e)
evaporation	évaporation
evaporation pan	bac évaporatoire

F

flood	crue, inondation
- discharge	débit de crue
flow	écoulement, débit
return -	écoulement restitué
subsurface -	écoulement souterrain, hypodermique
- duration	durée des débits
- duration curve	courbe de durée des débits

F (suite)

forebay	chambre(bassin) de mise en charge
frequency meter	fréquencemètre
fuse wire	conducteur fusible

G

gage, gauge	jauge
generator	générateur, génératrice
induction -	génératrice asynchrone
governor	régulateur
gradually varied flow	écoulement graduellement varié
grid	réseau électrique national
ground cover	couverture végétale

H

head	hauteur de chute
net -	" " nette
gross -	" " brute
headgate	vanne motrice (ou de tête), porte d'amont
headrace	canal d'amenée
hydrograph	hydrogramme
hydrosulphide	hydrosulfate

I

impounding	endiguement, captage des eaux
impoundment	eaux captées(par un endiguement)
inflow	venue (d'eau)
inlet	entrée, arrivée, orifice d'admission, d'entrée, d'introduction
intake	prise d'eau; admission
- area	aire d'alimentation
- screen	crépine, grille d'entrée
installed capacity	puissance installée
insulator	isolateur
pin-type -	" à tige

L

load	charge
- curve	courbe,diagramme de charge
lignt point	point d'éclairage
lightning	
- protection	protection contre la foudre
- protector	parafoudre

M

mini-hydro plant	mini-centrale hydraulique
micro-hydro plant	micro-centrale hydraulique
moisture	humidité
soil -	humidité du sol
money	
price, cost of -	le loyer de l'argent
- rate	taux de l'argent
motive power	force motrice
(surface) mulch	couverture d'humus

N

nullah	cours d'eau, lit de rivière, de torrent
nozzle	tuyère, jet, ajutage
- centerline	axe de tuyère

O

open circuit	circuit ouvert
overcurrent	surintensité
- protection device	dispositif de protection à maximum de courant
overfrequency	
- protection	dispositif de protection à maximum de fréquence
overvoltage	surtension
- protection	dispositif de protection à maximum de tension

P

panel board	tableau, panneau de commande,contrôle
pad	rembourrage , rembourrement
penstock	conduite forcée
phase	phase
single -	monophasé, uniphasé
three -	triphasé
pipe	tuyau, conduite, canalisation
plate	plaque
pondage	retenue, endiguement, captage d'eau, accumulation, emmagasinement
ponding	retenue, stockage d'eau (par étang artificiel)

P (suite)

power	puissance, énergie, capacité
- canal	canal usinier
- house)	
- station)	centrale électrique
- plant)	
- unit	unité, bloc, module d'alimentation
precipitation	précipitation
put up (to)	construire, bâtir, ériger, installer, monter

R

rain gauge	pluviomètre
record	relevé
recording rain gauge	pluviographe
recording river stage	équipement de limnigraphie des fleuves
regulation	régularisation
release	décharge, libération, délivrance, relâchement
return period	période de retour
rotor (turbine)	rotor (de turbine)
route	itinéraire, trajet
r.p.m.	tours/minute
rules of thumb	méthodes, procédés empiriques
runner (turbine)	roue mobile (de turbine)
run-off	écoulement
surface -	écoulement de surface
run-of-the-river	au fil de l'eau

S

section	section
cross -	section transversale
sediment load	charge sédimentaire
seepage	infiltration,suintement
setting (turbine)	emplacement (de turbine)
settling basin	bassin de décantation
shaft	arbre
silt	vase
siltation	envasement
site	site
sluice gate	vanne
- - valve	vanne de vidange
spill	déversement
- surge chamber	réservoir compensateur à déversoir
- - tank	chambre d'équilibre avec déversoir
spillway	passe-déversoir, déversoir, évacuateur
- dam	barrage à déversoir
- design flood	crue nominale du déversoir
stage (stream, river)	hauteur d'eau, hauteur limnimétrique (d'un cours d'eau,etc.)
flood -	- du niveau de crue
staff gauge	échelle limnimétrique
steel	acier
mild -	- doux
stop log	batardeau
survey	levé de terrain
SWG (Standard Wire Gauge)	calibre de fil standard
switch	interrupteur, commutateur
switch-fuse	commutateur-fusible
spawning	frai
streamflow	écoulement (d'un cours d'eau)

T

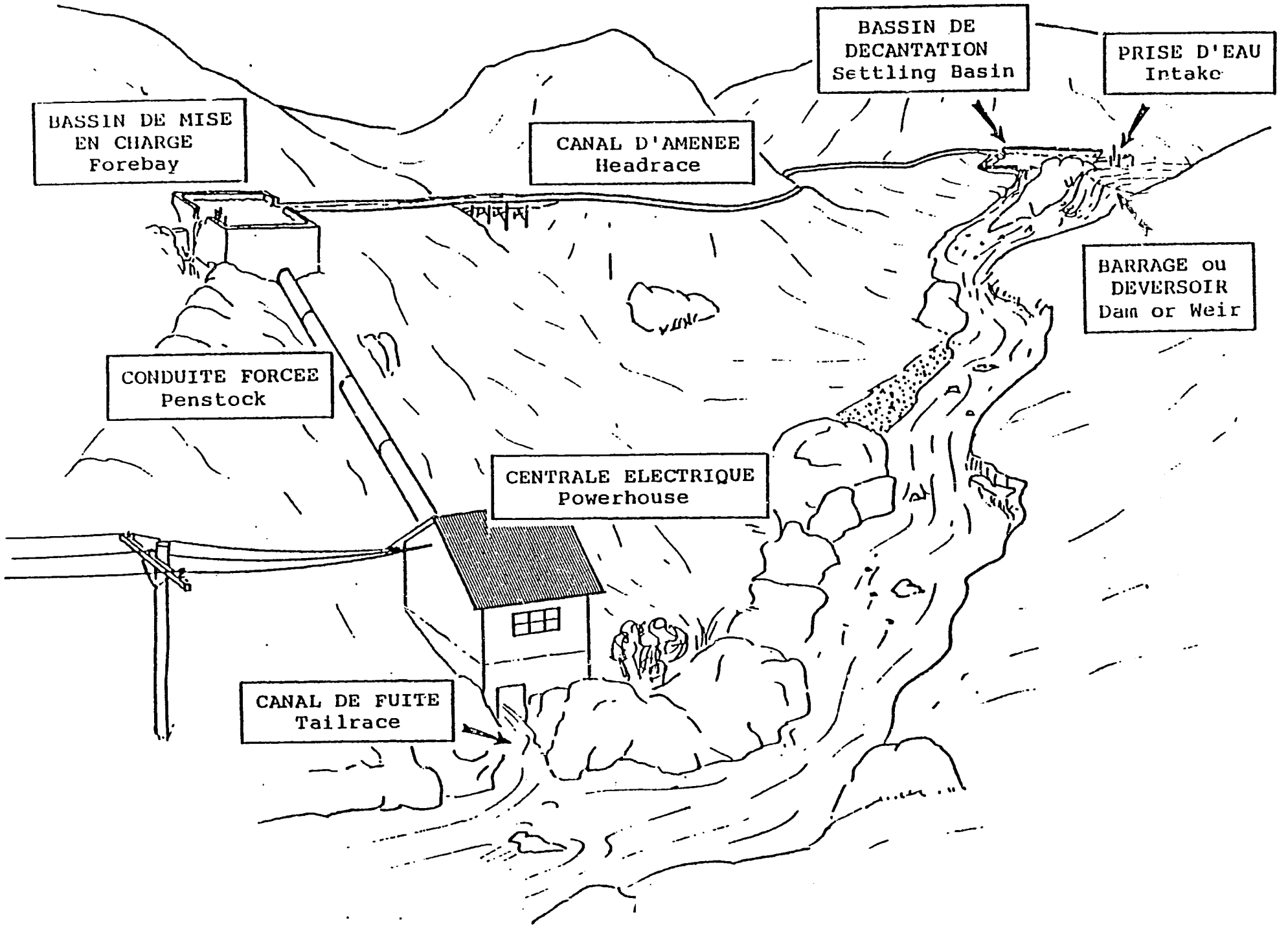
tailgate	vanne de garde aval
tailrace	canal de fuite
tailwater	eau d'aval
- elevation	élévation de l'eau d'aval, niveau d'aval
through shaft	arbre traversant
time-consuming process	processus de longue haleine
tipping-bucket	à benne basculante
trade-off	concession,compromis,échange
trapping	capture, prise
- efficiency	capacité de prise de sédiments
trash rack	grille grossière, grille de protection
tributary	tributaire, affluent
turbine	turbine
reaction -	- à reaction
impulse -	- à impulsion (ou à choc)

V

valve	vanne, soupape
inlet -	vanne de prise d'eau
vacuum-breaker -	soupape casse-vide
vane	palette, aube
velocity	vitesse
- head	charge de la vitesse
discharge velocity head	charge cinétique du débit
volatility	volatilité

W

waste	
- heat	chaleur perdue
solid -	déchets solides
processing -	déchets industriels
water	eau
- balance	bilan hydrologique
- year	année hydrologique
- quality	qualité de l'eau
- level gauge	limnimètre
- - - recorder	limnigraphe
- - graph	limnigramme
- - staff	échelle limnimétrique
watershed	bassin hydrographique, aire d'alimentation
weight-driven	à poids
weir	barrage, déversoir
wetlands	marécages
wheel	roue
impulse -	- à impulsion


BASSIN DE DECANTATION
Settling Basin
PRISE D'EAU
Intake
BASSIN DE MISE EN CHARGE
Forebay
CANAL D'AMENEE
Headrace
BARRAGE ou DEVERSOIR
Dam or Weir
CONDUITE FORCEE
Penstock
CENTRALE ELECTRIQUE
Powerhouse
CANAL DE FUITE
Tailrace

INTRODUCTION TO SMALL HYDRO TECHNOLOGY AND DEVELOPMENT

BY

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Paper presented at the regional Workshop
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Abstract

Small-scale hydropower has been used around the world for thousands of years. Water wheels provided mechanical power for grinding grain and raising water to higher elevation for water supply and irrigation primarily in Egypt, the Middle East, India, and China. In 1802 the first turbine was invented, and with the linkage of the turbine to the generator, electricity was produced from water power in 1882. The development of alternating current by George Westinghouse in 1902 was the final step in setting the stage for modern hydropower development.

A common hydropower installation involves a generator driven by a turbine. The water is fed to the turbine through a penstock from a dam which holds back the water both to control it and to store it for future use. However, the simplest hydropower arrangement is the run-of-river which has no storage dam. Hydrologic analysis along with topological data is necessary to determine if water supply is adequate for hydropower, and to determine the appropriate size of the turbine and generator.

Economic analysis to determine the benefit/cost ratio should precede the decision to build a hydroelectric power plant. Analysis should include other factors as competing water uses, and the social, cultural, political and institutional environments.

Small-scale hydro may have fewer negative impacts than projects involving large dams and resevoirs. Nonetheless, it is critical to anticipate and evaluate these impacts in advance.

Small plants can be built through local initiative which can promote self reliance and self sufficiency. When the project is financed locally, and the equipment is fabricated locally, costs can be reduced.

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Ft. Collins, Colorado

March 1982

Small-scale hydropower has been in use in the world for thousands of years. In fact, it was in use many centuries B.C. with water wheels for grinding grain and for raising water to a higher elevation for irrigation or water supply. These very early developments took place primarily in Egypt, the Middle East, India, and China. About 200 A.D., the Romans built a complex of 16 flour mills with vertical overshot waterwheels and gears which permitted a variation of speeds. This provided 28 tons of flour per day. With various types of improvements over the centuries these water wheels, some having a vertical shaft and others having a horizontal shaft, provided power to grind and mill various grains, to saw lumber, to operate spinning wheels and looms in the textile industry, to cut stone, to drive trip hammers, to make wine, and to raise water, see Fig. 1. By the fourteenth century, there were tens of thousands of water wheels which were providing mechanical power in Europe.

It was during the ninteenth century, however, that hydropower became not only a source of mechanical power, but also a source of electric power. With the invention of the turbine, by the French engineer Benoit Fourneyron, in 1820, the development of the reaction

turbine by Francis in Lowell, Massachussetts, in 1847, the development of the Pelton Wheel in California, in 1880, see Fig. 7, combined with the linkage of turbines with generators to produce electricity in Wisconsin, in 1882, that water power was finally used to produce electricity. The final major step was the development of alternating current by George Westinghouse at Niagara Falls in 1901. It was these developments through the first nineteen centuries that set the stage for the more recent developments in hydropower.

The hydropower potential of the world is enormous, being more than 2.2 million MW, but only 13.6% of this has been developed, see Table 1 from Goodman et al 1981. Of this total capacity, Africa has a potential of 0.437 million MW (nearly 20% of the world capacity) of which less than 2% has been developed. Half of that which has been developed is at Aswan on the Nile, Kariba in East Africa, and Akosombo in Ghana, see Deudney 1981. In other words, the hydropower potential of Africa has hardly been tapped at all. By proper planning from now on, it is likely that hydropower can provide most of Africa's power requirement, as it develops and moves into the 21st century.

Hydropower has been variously termed as large-scale, small-scale, mini-scale, and micro-scale hydropower. The definition of these terms, however, is far from a settled matter. Nevertheless, a survey of the literature shows that the range of definitions is as follows:

Micro-scale: Less than 100 KW, head $<$ 3m

Mini-scale: 100 to 500 KW

Small-scale: 500 KW to 50 MW

Low-head: $<$ 20m

Large-scale: Greater than 50 MW

It is usually neither desirable nor economical to have water resource development for hydropower alone. In other words, it is usually most desirable to have a multi-purpose development including several of the following purposes:

1. Hydropower
2. Irrigation
3. Flood control
4. Municipal & industrial supply
5. Navigation
6. Sediment control
7. Recreation
8. Fisheries

How much emphasis to place on each of these purposes in the planning and design of a single project can be determined most easily and successfully by a process of water resource systems engineering, see Hall and Dracup 1970. With the advent of the electronic digital computer, this process of simulation, optimization, and maximization has become an indespensible tool.

Technology of Hydropower

A common arrangement for a hydropower station is illustrated by Fig. 2 from Goodman et al 1981. The electricity is created by the generator which is driven by a turbine. Water is fed to the turbine by a penstock through the dam which holds back the water both to control it and to store it for future use. The head on the turbine is the difference in elevation between the surfaces of the headwater and the tailwater.

The simplest arrangement of a hydropower station is the run-of-river plant which has no storage dam. The water is diverted out of the river into an open channel or a pipe to be carried for some distance at a flatter slope than the river slope in order to gain elevation before the water is then dropped down through a penstock into the turbine at river level downstream, see Fig. 3 from NRECA 1980. With this arrangement, there is no need for an expensive diversion dam. At the upstream intake there is need only for a diversion dam that will stabilize and control the water entering the intake. When the river flow is large, the intake must be protected against being washed away, and during very low flows most of the water may need to be diverted to the intake to obtain the discharge needed for power generation.

Generally speaking a hydropower plant is arranged as illustrated in Fig. 3. Here the plant has a forebay, a draft tube, a turbine and generator unit, and an afterbay. Each of these serves an important function which increases the efficiency and effectiveness of the entire power plant operation. The forebay allows for minor fluctuations in water entering the forebay and short term fluctuations in the flow of

water through the turbine. Likewise, the afterbay provides for temporary storage which is needed because of the fluctuations of demand through the turbine. The draft tube helps to convert the kinetic energy remaining in the water after it leaves the turbine into potential energy which reduces the pressure on the downstream side of the turbine runner. Although the forebay, the afterbay, and the draft tube are desirable and increase the efficiency, they also increase the cost and are not absolutely essential to power plant operation. Likewise, the penstock is not always essential-- depending largely upon the quantity of water and the head involved. For truly low-head, low-discharge plants, the arrangements shown in Fig. 4 can be used. Here the forebay and penstock are combined and the water goes directly into the turbine from a chamber. Likewise, there is no draft tube and the water discharges into a pool which serves as an afterbay but does not perform all of the temporary storage functions.

The arrangement illustrated in Fig. 3 will usually result in an efficiency of 60% to 70% which, at first, might seem highly undesirable However, if there is an adequate supply of water and a satisfactory head can be developed, then a 50% efficiency simply means that twice as much water is used as that for nearly 100% efficiency. Communities in Pakistan and China, for example, have recently built thousands of these types of units which have low efficiency but do provide electricity that otherwise would not be available.

In order to determine whether the water supply is adequate for hydropower, and to determine the desirable size of generating units, it is necessary to make a hydrologic analysis. Fig. 5 shows the hydrologic cycle where the water comes from precipitation such as

rainfall or snow and then runs in streams to the ocean. Large quantities of water, however, are likely to seep into the soil where it is stored either for later use or to seep out at a later time into a surface water stream. This water can be stored and diverted for irrigation, hydropower, navigation, flood control, domestic and industrial uses, and for recreation.

The hydrologic analysis consists of analyzing streamflow and groundwater together with precipitation records. The data produced from these analyses are the data that are necessay, together with topographic information, for determining the maximum size of turbine and generator that can be used. The demands of the community, however, may not require that the maximum size be utilized. Therefore, it is necessary to take into consideration the potential load or demand for hydropower.

There are various types of generators and electrical equipment which can be used for small-scale hydropower. Since these are standard for a given area for steam or petroleum engines and generators already in use, there is no need to discuss it further in this paper. Suffice it to say, that it may or may not be possible or desirable to connect a given small-scale plant into a regional or national electrical grid.

Governors are commonly used in hydropower plants to control the frequency of the electricity produced. For micro-scale units, however, this expense may not be necessary. A load control system can be used.

Most of the more developed countries of the world have been obsessed with obtaining the highest possible efficiency in the turbine and other equipment.

This matter of efficiency, however, has far less importance for

small-scale hydropower where there is usually an excess of flow or a limitation on cost of the plant. Usually, low efficiency can be easily overcome by simply increasing the quantity of discharge passing through the turbine.

Water Wheels and Turbines

The various types of water wheels and turbines are illustrated in Figs.6 and 7. The vertical water wheel, see Fig. 6, with a horizontal shaft is slow moving and best adapted to: grinding and milling processes; operating tools such as a drill press, a lathe, or a saw; and operating pumps and electrical generators with a gearing mechanism to increase the shaft speed. Although its efficiency is much less than the turbine, it is simpler and less expensive. Furthermore, it can be built, serviced, and maintained with local non-technical personnel. For the Undershot Wheel and the Poncelet Wheel the water is introduced at the bottom of the wheel and for the Breast Wheel and the Overshot Wheel the water is introduced at the top of the wheel.

The Undershot Wheel is the most elementary wheel. Its action is much like the side wheels on the early steam ships. It can operate with as little as 30 cm of head, but the optimum head is 2 to 5 m A common diameter of the wheel is 5m. It has a very low efficiency.

The Poncelet Wheel is a modification of the undershot wheel. The blades, however, are curved and the water enters through a two-dimensional nozzle operating under a head of 3 m or less. The diameter of the wheel is usually about 5 m and has a greater efficiency than the Undershot Wheel. Much closer tolerances are required; therefore, the floor and walls around the Poncelet Wheel are made of wood, masonry, or concrete.

For the Breast Wheel the water enters the wheel near the top and is held in the buckets all the way to the bottom. They usually operate at heads less than 3 m and their diameter is usually two to three

times the head. The maximum efficiency is usually about 65%.

In the Overshot Wheel the water is fed to the wheel through a flume. A sluice gate controls the discharge of the water. The head is the same as the wheel diameter and is usually a maximum of about 10 m. The efficiency is high.

A turbine is a machine which uses the kinetic and/or potential energy in water to force the machine to rotate and create mechanical energy. It can be connected directly to mechanical equipment such as lathes, grinders, or mills, or to a generator to produce either a.c. or d.c. electricity.

The amount of power produced by a turbine is directly proportional to the product of the head and the discharge-- that is, $P \sim HQ$. This means that a high head and low discharge can produce the same power as a low head and high discharge.

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, and it is open to the atmospheric pressure. A good example of an impulse turbine is the Pelton Wheel, which is a more confined and refined extension of the Poncelet Wheel.

Another example of an impulse turbine is the Crossflow Turbine which has curved blades and is shaped much like a squirrel-cage air blower (which acts as an air pump). The water enters the Crossflow Turbine much like it does in the Breast Wheel but the blades are shaped so that as the water enters the turbine on one side it gives them a downward thrust and then the water is directed across the inside of the turbine to strike the blades on the other side to give them an

upward thrust before it drops into the pool below. It can operate under heads as low as 1 m and its efficiency is usually about 60 to 70% with a maximum of 80%.

The Pelton Wheel is a disc wheel with ball-shaped bucket blades around the outside edge of the disc. A high velocity jet of water strikes the buckets which deflect the water into a reverse direction and the change in momentum flux causes a force against the bucket which drives the wheel. The Pelton is for high heads and can have an efficiency as high as 90%.

The Francis Turbine is a reaction turbine wherein the flow is completely confined inside the turbine. The water flows against and along the blades and the force caused by a combination of the ambient pressure and the change in momentum flux drives the blades to rotate the runner. The flow into the runner is from either an open chamber or a scroll case which may first flow through wicket gates that are operated by a governor to control the amount of water flowing into the turbine.

The blades of a Propeller Turbine are similar to those of a propeller which drives a boat, except that the propeller and blades are confined --whereas with a boat the propeller is not confined and is open to the ambient pressure. The Kaplan Turbine is a special type of propeller turbine with adjustable blades which makes it efficient over a wider range of heads and discharges.

The Bulb Turbine is a recent development wherein the generator and turbine are encased within the flow and the water flows around the unit and through the propeller blades to generate the electricity. The Tubular Turbine and the Straflo Turbine have similar characteristics.

A general summary of efficiency ranges is given in the following table:

Typical Efficiency Ranges for Small Water Wheels and Turbines

(From Alward et al 1979)

Water Wheels		Turbines	
Undershot	25-45%	Reaction	80%
Breast	35-65%	Impulse	80-85%
Poncelet	40-60%	Crossflow	60-80%
Overshot	60-75%		

In recent years, several turbine manufacturers have been standardizing their various sizes of turbines so that some of the advantages of assembly line and mass production can be taken to reduce the cost of turbines. This has already been the case for pumps for many years.

The possibility of using pumps as turbines by reversing the flow is another possibility which is gaining momentum. Such a unit has reduced efficiency but this disadvantage can sometimes be overcome by the advantages of simplicity, ease of servicing, lower initial cost, and pumped storage for peaking power.

Basically the Pelton Wheel is for relatively high heads and low-discharge installations and the Kaplan Propeller Turbine is for low head and high discharge, see Fig. 7. The Francis Turbine is an intermediate turbine that is most efficient in operating between the extremely high head and extremely low head, see Fig. 9.

Economics

Whether or not to build a hydroelectric power plant is a decision that should be preceded by an economic analysis so that the benefit/cost (B/C) ratio can be determined and there will be no (or fewer) surprises ahead as the project is designed, built, operated, and maintained. The items to be included as benefits and costs will depend upon the kind of analysis being made and the nature and wishes of the sponsoring organization, see Tudor 1980.

The benefits from a hydropower project are composed of the present value of future benefits resulting from the project and may include one or a combination of the following:

1. The presence of firm capacity and energy which allows other power projects to be deferred.
2. The saving of fuel costs in exsisting thermal generating plants, if available.
3. The saving of costs of power the owner may now be purchasing from other sources.
4. The saving in cost of construction, operation, and maintenance of the most economical alternative source of power if none is now available.
5. The social benefits.

The cost portion of the analysis is composed of the present value of the initial cost plus the future costs as follows:

1. Initial costs of planning, design, and construction.
2. Future repairs or replacement costs.
3. Operation costs.
4. Maintenance costs
5. Inflation costs.

Various reference materials are available to obtain the details of these benefit/cost items and calculations. For example see: Tudor 1980, Corps of Engineers 1979, and Tudor 1981. Examples of information available are Table 2 giving Principal Technical and Economic Factors for Feasibility Studies and Fig. 10 which gives a rough "reconnaissance" idea of costs for a hydro plant.

In addition to these economic considerations, it is necessary to consider such factors as competing uses of water, social and cultural considerations, political considerations, and institutional considerations before making a decision to proceed with a hydropower project.

Constraints, Problems, and Motivations

When considering a hydropower project, engineers and planners frequently give little or no attention to the socio-cultural impact the project will have on the local community and the region. If the project involves a large dam and resevoir, or if irrigation, flood control, or navigation are involved, there are both favorable and unfavorable impacts that can result, see Deudney 1981. Small-scale hydro may have fewer negative results, but it is very important to anticipate and evaluate these results in advance instead of having them come as surprises after it is built and in operation. Some of the factors needing prior study include effects on:

1. Agriculture
2. Fisheries
3. Forestry
4. Mining
5. Health
6. Employment
7. Income distribution
8. Political factors
9. Standard of living
10. Ecology and Environment
11. Self reliance of local people
12. Erosion and sedimentation

Once electricity is available, it can greatly reduce the drudgery of an enormous amount of hand labor. In this way people are freed from the time consuming hand labor and are made available to carry out other tasks to help improve conditions in the community.

In order for a community to have an interest in progressing to hydropower and electricity there must be an interest culturally and politically in having this advancment take place which will permit the use of mechanised equipment as well as having electric lights to increase the hours that work can be done and to improve lighting conditions for recreational and other activities.

Although there is always the temptation for a government to borrow money (from the World Bank for example) in order to provide funds for

small-scale hydropower in rural areas, this is not always in the best interests of the people themselves. China demonstrated very clearly that tens of thousands of small-scale hydropower plants could be built by local initiative alone with no funding being provided by the central government. This is a case of the people being stimulated by leadership to be self-reliant and thereby self-sufficient. The various types of turbines and generating equipment were developed by local initiative throughout China.

Recent developments in Pakistan have also illustrated rather clearly that local initiative can fabricate the necessary equipment together with the facilities and funding required for hydroelectric power. There are several advantages to this type of approach as follows:

1. If a project is financed entirely by local funds it will not be so costly that future financial commitments will work a hardship on the community.
2. Having fabricated and built all of the equipment and facilities required by local people, these same people then have the capability for servicing and maintaining the equipment to keep it in working order.
3. There is an enormous satisfaction that comes from solving one's own problems with local resources and a great deal of pride results from having accomplished this.
4. Such an accomplishment then leads to the conviction on the part of the local people that they have the capability of solving other problems as well through local initiative and local financing.

Although there may be other competing uses for the water that is used to generate hydropower, if the plant is "run-of-river" then the water stream is diverted for only a relatively short distance and it is never held for any period of time to prevent use downstream. Consequently, there are very few situations where a "run-of-river" plant would conflict with the environment or uses of the water supply.

In case there is storage of water in order to provide peaking capability or to provide carry over water in order to generate electricity during dry periods, then there is greater likelihood that the hydropower requirements will compete with other uses such as irrigation and flood control.

References

Alward, Ron, Sherry Eisenbart, and John Volkman, 1979, "Micro-Hydropower: Reviewing and Old Concept", National Center for Appropriate Technology, Butte, Montana, USA.

Boese, Gerald W. and Judy A. Kelly, 1981, "Developing Hydropower in Washington State" Office of Water Programs, Department of Ecology, State of Washington, Olympia, Washington, USA.

Corps of Engineers, 1979 "Feasibility Studies for Small Scale Hydropower Additions" U.S. Corps of Engineers Guide Manual, Hydrologic Engineering Center, Davis, California, USA, July, 1979.

Corps of Engineers, 1979 "Waterpower '79: An International Conference on Small-Scale Hydropower" Proceedings of a Conference, October 1979 sponsored jointly by the U.S. Army Corps of Engineers and the U.S. Department of Energy, Washington, D.C. USA.

Corps of Engineers, 1981, "Waterpower '81: An International Conference on Hydropower", Proceedings in 2 volumes of a Conference June 1981, U.S. Corps of Engineers, Washington, D.C. USA.

Deudney, Daniel, 1981 "An Old Technology for a New Era" Environment, Vol, 23, No. 7, September 1981.

Goodman, Louis J., John N. Hawkins, and Ralph N. Love, "Small Hydroelectric Projects for Rural Development" Pergammon Press, New York, 1981.

Hall, Warren A. and John Dracup, 1970, "Water Resources Systems Engineering", McGraw-Hill Book Company, New York.

NRECA 1980 "Small Hydroelectric Powerplants" Proceedings of a Workshop, August 1980, in Quito, Ecuador, National Rural Electric Cooperative Association, Washington, D.C. USA.

NRECA 1981 "Small Hydropower for Asian Rural Development" Proceedings of a Workshop held in Bangkok, Thailand, June 1981, National Rural Electric Cooperative Association, Washington, D.C. USA.

Rouse, Hunter and Simon, Inc. 1957, "History of Hydraulics" Iowa Institute of Hydraulic Research, Iowa City, Iowa, USA.

Tudor 1980 "Reconnaissance Evaluation of Small, Low-Head Hydroelectric Installations" a report prepared by Tudor Engineering Co. for the U.S. Bureau of Reclamation, Denver, Colorado, USA, July 1980.

Tudor 1981 "Simplified Methodology for Economic Screening of Potential Low-Head, Small-Capacity Hydroelectric Sites" a report prepared by Tudor Engineering Co. for the Electric Power Research Institute, Palo Alto, California, USA, January 1981.

USBR 1976 "Selecting Hydraulic Reaction Turbines" Engineering Monograph No. 20, Water Resources Technical Publication, U.S. Bureau of Reclamation, Denver, Colorado.

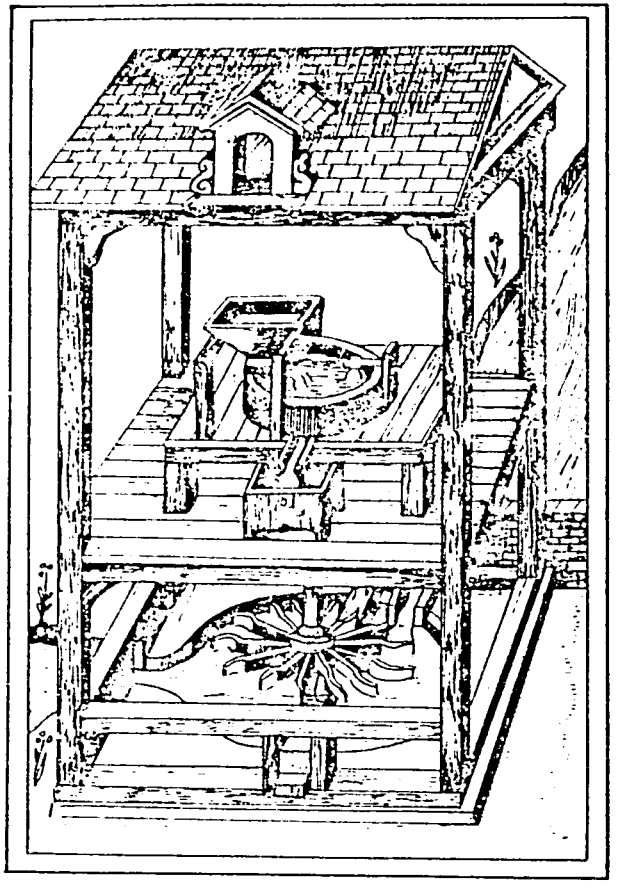


Fig. 1. Ancient Water Wheel

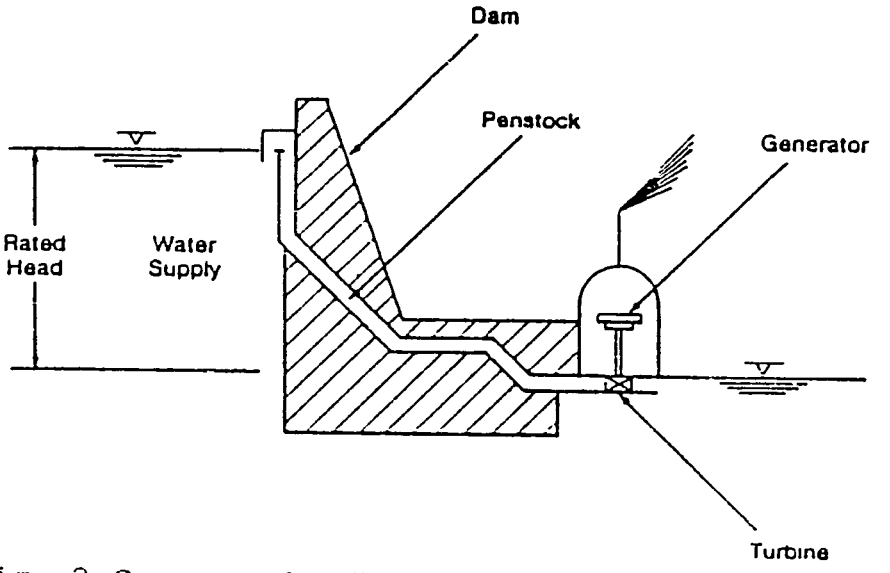


Fig. 2. Components of small hydroelectric system.

Table 1. World Hydroelectric Power Capacity and Production Capability, 1974

Continent or area	Total capacity (MW)	Percent of total world capacity	Developed capacity (MW)	Percent capacity developed	Average annual production capability (GWh)	Percent of total world production capability	Developed average annual production capability (GWh)	Percent production capability developed
Africa	437,104	19.3	8,154	1.9	2,019,934	20.6	30,168	1.5
Asia (less USSR)	684,337	30.3	47,118	6.9	2,638,169	26.9	198,433	7.5
Europe (less USSR)	215,407	9.5	103,998	48.3	722,368	7.4	382,317	52.9
USSR	269,000	11.9	31,500	11.7	1,095,000	11.2	123,000	11.2
North America	330,455	14.7	90,210	27.3	1,487,847	15.2	453,334	30.5
South America	288,289	12.7	18,773	6.5	1,637,031	16.7	91,415	5.6
Oceania	36,515	1.6	7,609	20.8	202,071	2.0	28,897	14.3
Total	2,261,107	100.0	307,362	13.6	9,802,420	100.0	1,307,564	13.3

Sources: World Energy Conference, Survey of Energy Resources, New York, 197[illegible]; Energy Perspectives 2, U.S. Department of the Interior, June 1976.

Table 2.

PRINCIPAL TECHNICAL AND ECONOMIC FACTORS FOR FEASIBILITY STUDIES

- Collect and review existing data.
- Survey site to obtain river profile, cross sections, and topography, as necessary.
- Investigate foundation conditions and site geology.
- Perform hydrologic and hydraulic studies.
- Define range of development alternatives.
- Identify types of turbines suited to site and obtain vendor data.
- Prepare conceptual layouts and preliminary cost estimates for alternatives.
- Evaluate capacity and energy potential of site.
- Select alternative(s) for more detailed study.
- Research and confirm ownership of land and water rights.
- Prepare project financing plan.
- Research tax implications.
- Perform preliminary environmental assessment.
- Prepare drawings of the selected development alternative(s).
- Estimate project licensing, engineering, construction and operational costs.
- Prepare project schedule covering licensing, engineering construction, and startup.
- Prepare a power marketing plan and determine power and energy values.
- Perform an economic/financial analysis of the project.
- Prepare feasibility report.

Derived from "Design & Economic Considerations," Raymond E. Cunningham, The Energy Bureau Conference, Washington, D.C., April 27-28, 1981, page 4.

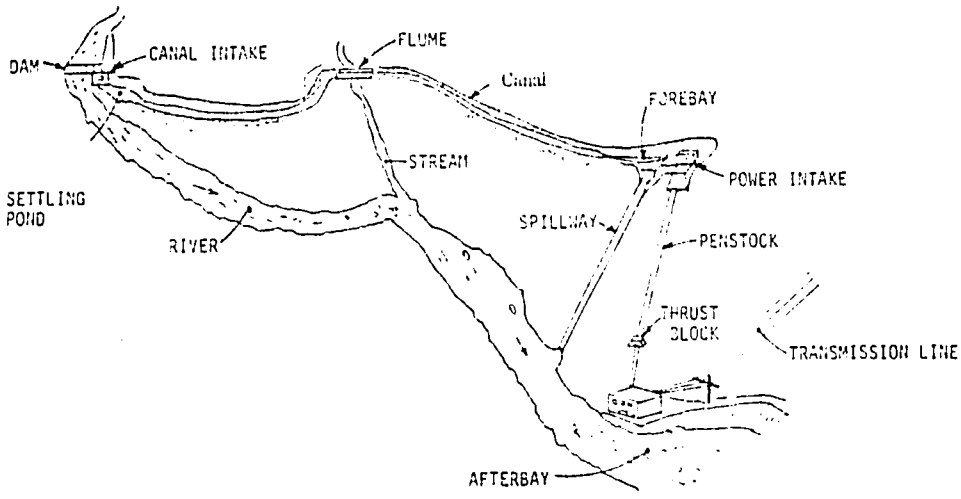


Fig. 3. Run-of-River Hydropower (from NRECA, 1980)

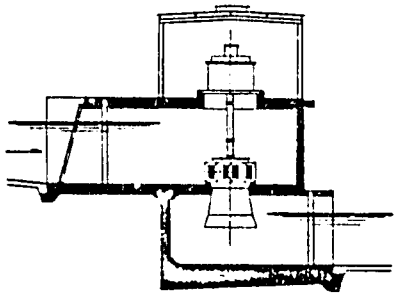


Fig. 4. Open flume with Francis or Propeller Turbine

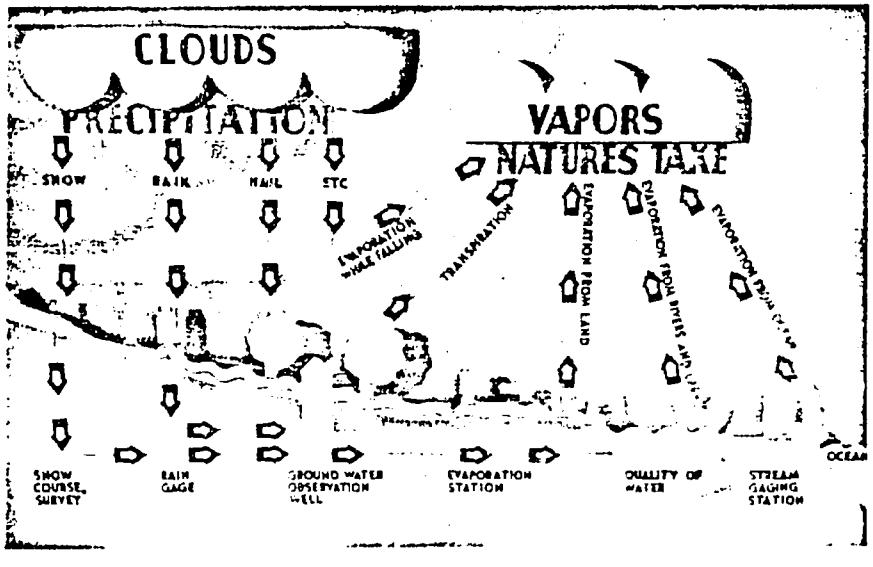
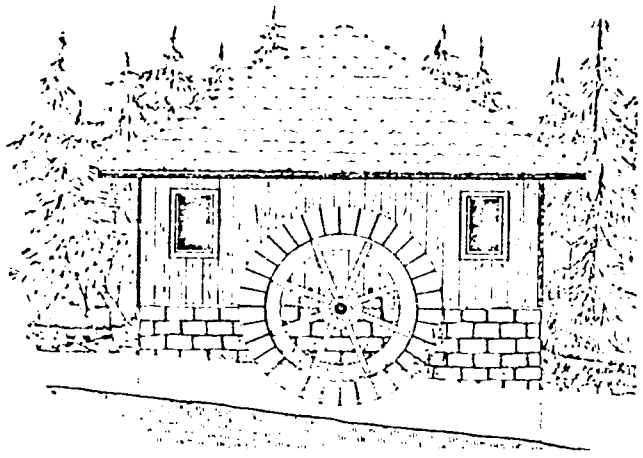
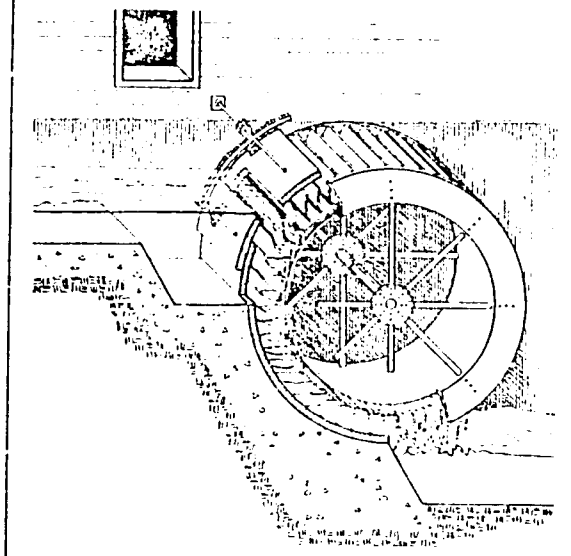


Fig. 5. The Hydrologic Cycle (courtesy U. S. Geological Survey)



Undershot Wheel:

This is the most basic of water wheels. Water passing under the wheel strikes the blades or paddles, causing the wheel to rotate. It can operate on a minimum of one foot of head (producing almost no power at this head), and has a low efficiency. The optimum head range is 6 to 15 feet, with minimum wheel diameter being about 15 feet.



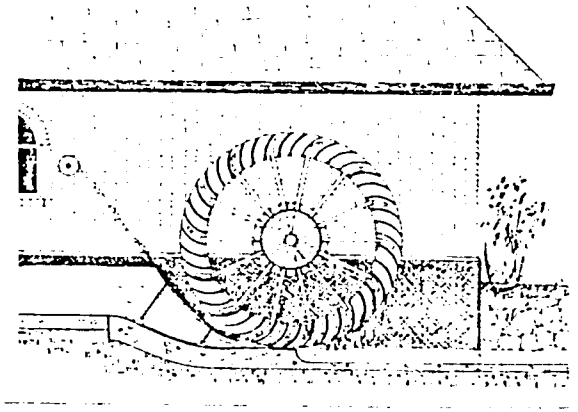
Breast Wheel:

Water enters the breast wheel below the top of the wheel and is kept in the buckets by a close fitting breastworks until it discharges at or near the lowest point on the wheel. Breast wheels operate best with heads less than 10 feet, and wheel diameters usually range between the head and three times the head. High breast wheels (water entering above the center shaft) have efficiencies that can approach 65 percent. Low breast wheels (water entering below the center shaft) usually have efficiencies between 35 and 40 percent.

Breast wheels require somewhat complicated, curved breastworks. In addition, the buckets have to be ventilated to allow air to escape to the next higher bucket as each bucket fills. The close tolerances of the breastworks give the same disadvantages in terms of water-borne debris as for the Poncelet wheel. The complicated construction techniques and the lower efficiencies, particularly in the low breast wheels, usually make other types of water wheels more attractive.

Poncelet Wheel:

This is an adaptation of the undershot wheel, in which the blades are curved to provide more efficient water interaction with the wheel. This wheel makes use of the velocity of the water which has been held back and forced through a narrow opening. Minimum diameter of a Poncelet Wheel is about 14 feet and they usually operate best with heads of 7 feet or less. Efficiencies are higher than for the undershot wheel. These wheels require a breastworks of concrete fitted close to the run of the wheel in order to help retain water in the buckets. The close clearances necessitate the use of trash racks to keep stones and wood from entering the system and causing damage.



Overshot Wheel:

Water is supplied by a nearly horizontal chute to the top of the water wheel. The weight of the water in the run buckets causes the wheel to turn. The entering water usually strikes the buckets with a velocity somewhat greater than the run speed so as not to be struck by the back of the buckets and be splashed off the wheel. The water supply, and thus the power output, is controlled by a hand operated sluice gate. Overshot wheels are generally the most efficient of the water wheels. They can operate on any head above 10 feet. Today, the upper limit on the head is around 30 feet because of the cost of constructing a wheel of that diameter.

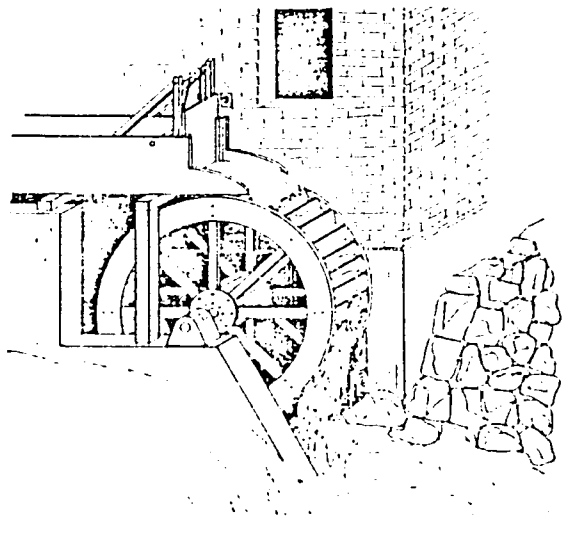
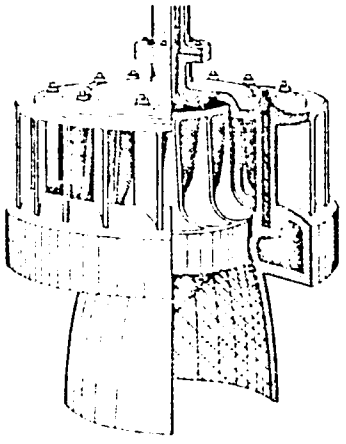
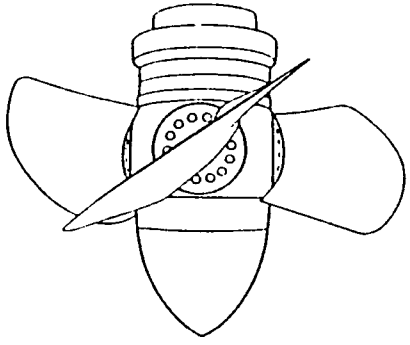


Fig. 6. Water Wheels (from Alward et al. 1979)

The Francis Turbine:

Francis units are typically installed in very large hydro power developments. The water is introduced just above the runner and all around it and then falls through, causing it to spin. Francis units are designed very specifically for their intended installation, use a complicated valve system, and thus are not generally used in micro hydro applications.





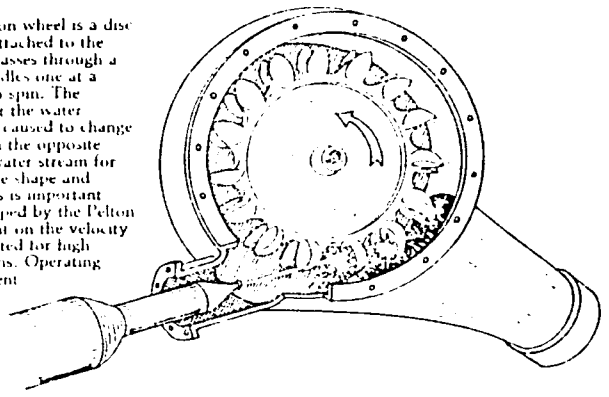
Kaplan turbine

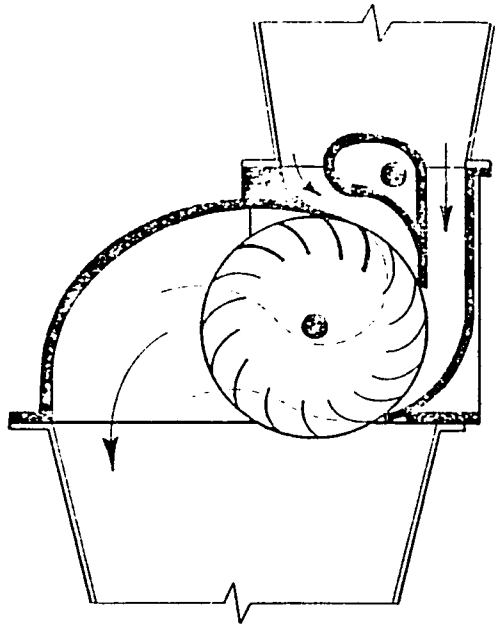
Propeller Turbines:

This design resembles a boat propeller running a tube and operates on a similar principle. As wit the Francis, the water contacts all of the blades constantly and it is thus imperative that the pressure in the cross section of the pipe be uniforn It, for example, the unit were operating horizontally and the pressure at the top of the tut were less than at the bottom, the runner would be out of balance. There are several variations on ho the principle is applied, i.e., the *bulb turbine* in which the turbine and generator are a sealed unit placed directly in the water stream; the *straflow* in which the generator is attached directl the perimeter of the turbine; the *tube turbine* in w the penstock bends just before or after the runner, allowing a straight line connection with the genera which is located outside of the pipe. The *Kaplan*, a variation on all of these, has adjustable blades on propeller to allow for variations in flow rates. Depending on site conditions, the unit can be inst in any position from horizontal to vertical. The m common reaction turbine design used in micro-hyc is the tube, sometimes with the Kaplan blade arrangement.

The Pelton Wheel

In general terms, a Pelton wheel is a disc with paddles or buckets attached to the outside edge. The water passes through a nozzle and strikes the paddles one at a time, causing the wheel to spin. The buckets are shaped so that the water stream is split in half and caused to change direction, heading back in the opposite direction to the original water stream for the greatest efficiency. The shape and smoothness of the buckets is important. Because the power developed by the Pelton Wheel is largely dependent on the velocity of the water, it is well suited for high head, low flow installations. Operating efficiencies in the 80 percent range are common and micro units using the Pelton Wheel are produced by several firms in North America.





The Crossflow Turbine:

A crossflow runner is drum-shaped with the blades fixed radially along the outer edge. The unit, open in the center, resembles a "squirrel cage" blower. When looked at from the end as though it were a clock face, the water enters at 8 o'clock, crosses the center and exits at 4 o'clock; thus the name crossflow. Most commercially available crossflows are made by Ossberger of West Germany or by someone else under their license. Because of its design, the crossflow is said to be largely self-cleaning and is well suited to low head applications. Ossberger has in fact installed them successfully in situations with only 39 inches (1 meter) of head. The Ossberger crossflow uses a metering vane at the intake side and maintains high efficiency over a wide range of flow rates. Because the runner and housing fit fairly close, a draft tube is used on the down side of the turbine, allowing some flexibility in installation relative to turbine placement and tail water level. The crossflow is used widely around the world, although it is less common in the United States.

Fig. 7. Turbines (from Alward et al. 1979)

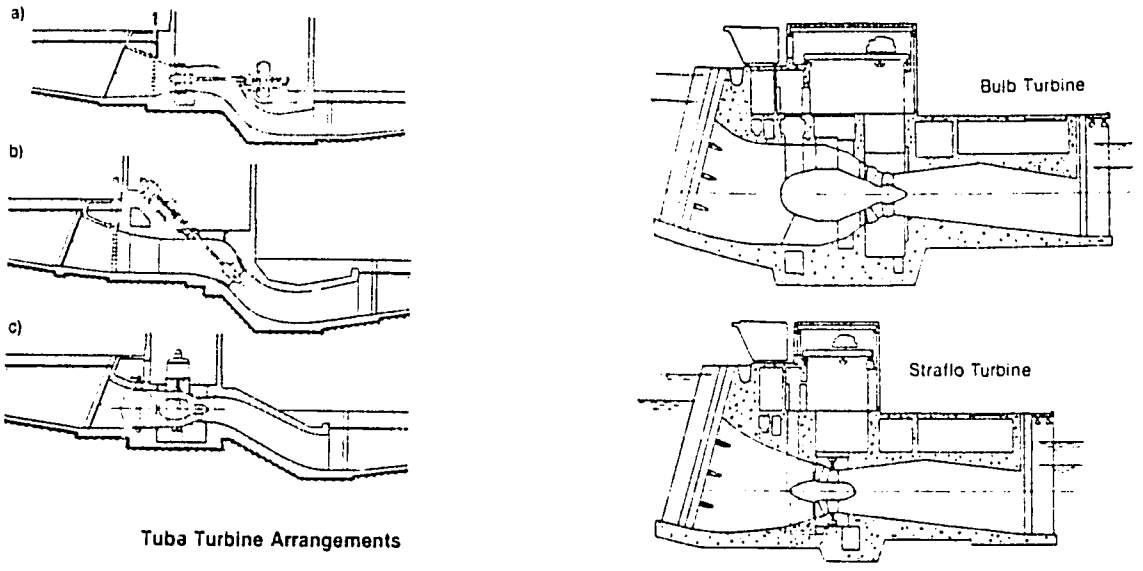
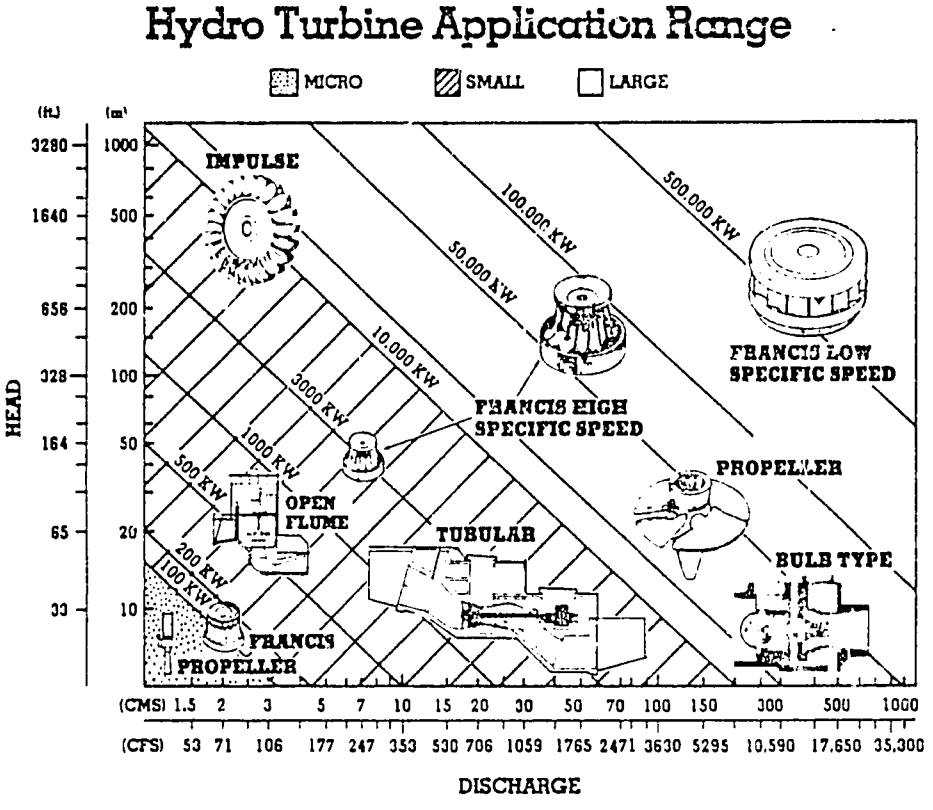
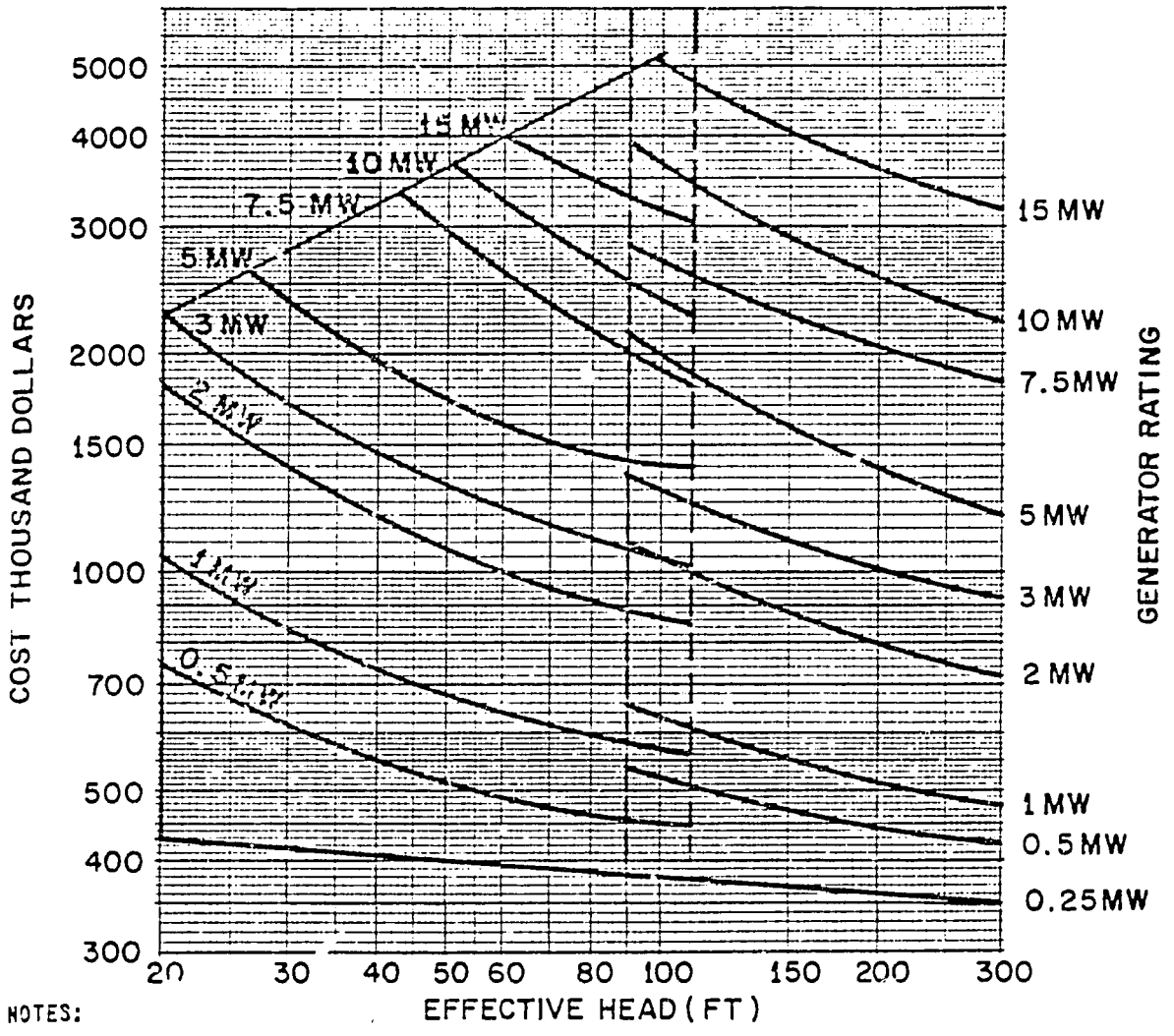


Fig. 8. Comparison of Tube, Bulb, and Straflo Turbines (from NRECA, 1980)



The selection of a water turbine is dictated by the head and flow characteristics of a particular site. Since its invention by Lester A. Pelton in 1880, the Pelton wheel or impulse turbine has dominated in high head, low flow applications. Tube and bulb turbines are recommended for low head, high flow conditions. The majority of large projects are equipped with Francis or adjustable blade Kaplan (propeller) turbines.

Fig. 9. Hydro Turbine Application Range (from Boese and Kelly, 1981)



NOTES:

1. Estimated costs are based upon a typical or standardized turbine coupled to a generator either directly or through a speed increaser, depending on the type turbine used.
2. Costs include turbine/generator and appurtenant equipment, station electric equipment, miscellaneous powerplant equipment, powerhouse, powerhouse excavation, switchyard civil works, an upstream slide gate, and construction and installation.
3. Costs not included are transmission line, penstock, tailrace construction and switchyard equipment.
4. Cost base July 1978.
5. The transition zone occurs as unit types change due to increased head.
6. For a Multiple Unit powerhouse, additional station equipment costs are $20,000 + $58,000x(n-1) where n is the total number of units.
7. Data for this figure was obtained from figures and tables in Volumes V and VI.

RVD 5/80

Fig. 10. Power Features Cost
(from Corps of Engineers, 1979).

THE FUTURE OF SMALL HYDROPOWER IN IVORY COAST

S Y N O P S I S

Small capacity hydropower plants are a new energy source among others. Instead of competing with other new energy sources, their contribution rather completes the role of these sources. With a potential exceeding 1.000 GWh, the small hydroplants delay the exhaustion of hydropower in the Ivory Coast, thus allowing the optimum use of waterways.

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THE FUTURE OF SMALL HYDROPOWER IN IVORY COAST

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Despite the fact that hydropower techniques were mastered long time ago, small hydropower appears nowadays as a "new" source of energy, together with solar energy yet known and even sometimes cleverly exploited since the ancient times. This is due to the fact that in the field of hydropower, in the developed as well as developing countries, the huge power ressources required for the industrial progress of the modern world have for a long time, focussed the attention of the competent authorities, public powers and specialists, on the exclusive equipment of the sites with great energy potential. As a result of this trend, the small structures built in Europe and elsewhere have been relegated to the background, and sometimes just simply discarded as the extension of high and medium voltage is implemented.

The Ivory Coast which, in spite or because of its young age is experiencing some rapid economic growth since its independance, did not escape the rule. Therefore, the Ivory Coast stated the installation of its hydroelectric equipment by developing the sites which, even though small scale, cannot be termed small hydropower plants. Thus AYAME-I and AYAME-II with

respectively 20 and 30 MW were operated in 1957, then in 1965, followed in 1972 by KOSSOU, 175 MW, in 1976 by TAABO 210 MW, and in 1980 by BUYO 165 MW. The SOUBRE project for which the bids are now being launched shall enter into operation in 1985, with an installed capacity of 328 MW.

Yet, as early as 1975, upon the recommandations of E.E.C.I. and considering the world energy crisis resulting from the first oil shock in 1973, the public authorities took the decision to carry out what is now unanimously termed the hydro turning point of the Ivory Coast thus stating the political will of the Ivory Coast to tap its hydro potential in priority for the supply of electrical power. The E.E.C.I. then decided to make an inventory of the hydroelectric available on the national territory, and to denote a special interest to the small hydropower sites as a normal procedure, but also to the purely agricultural sites, because of the possible consequences of uncontrolled equipment of such sites on downstream hydroelectric schemes. The inventory revealed an important hydro power potential and it increased the early interest shown for this power range and at the same time it initiated the E.E.C.I.'s "small hydropower plants" program designed to develop gradually all the small hydropower sites which had been identified by the inventory.

As the exploitation of such energy sources is generally related to the development of isolated rural areas, it is not surprising that this seminar was designed to be an appropriate

forum for the exchange of information, experience and views on issues and subjects related to the development of small hydropower plants in the isolated rural areas of Africa.

So, with your permission, we shall first of all examine together, the situation of small hydropower among the other non conventional energy sources available in the Ivory Coast. Then, I shall describe some of the most interesting sites and state the future role of such small hydropower in the country.

With your permission, I would like to speak first of all on the rural energy context of the Ivory Coast and to remind you briefly of the rural electrification methods practiced by the E.E.C.I. so far in order to be better adapted to this context.

The Ivory Coast is in many ways crossed in the middle by a V line, which, in the hydropower context, runs along the Bafing in the South, cuts through the Marahoué at its immediate junction with the Béré North of Zuenoula and goes slightly down to the South of the Dimbokro region before going up to the Ghana border at the East and after crossing the Comoé. We shall see shortly that the quasi-totality of the small and large hydropower sites are located South of the V line, whereas the Northen area is almost except for a few sites. Therefore it is quite normal that for each of these two large zones, the choice of the E.E.C.I. production means derives from this natural

distribution or rather from this localization of the national hydropower ressources. Thus the South is being equiped gradually with hydroelectric schemes whereas the North is dotted with isolated diesel plants as you can see on the slide which is being shown now.

In terms of electrical power, the ivorian rural areas are characterized by a considerable dispersion of demand in general and by the low level of such demand for each consumption point considered.

The low level of economic development in some areas is certainly an explanation to this situation and so is the traditional inclination for agriculture of the populations concerned.

In this context, what are the special arrangements made by the E.E.C.I. for rural electrification ? A quick examination of the past shows that this company, taking into account the geographic, economic and social criteria mentionned above, has always endeavoured to adapt to this context in the most appropriate way, through its rural electrification methods in general, its production means and its distribution techniques in particular. Thus it adopted various techniques in turn and is still experimenting other techniques which shall demonstrate shortly.

Rural electrification in the Ivory Coast is primarily

based on isolated diesel plants, installed in each consumption center scheduled in the program of a specific year. These installations were termed local centers because they served only the district where they are installed, they have been increasing very rapidly between the years 1960 and , thus adding to the number of electrified cities and villages during the same period. Yet as the fuel used in these power stations is the DDO(1), the proliferation of such units because economically unattractive after the 1973 oil crisis.

Henceforth, the local networks, experimented since the end the 60's rapidly drew more interest from the planning managers of the company. Thus, they were established throughout the country side to serve not only new districts but also electrified villages, thus making it possible to discard existing sets and to reduce the equipment budget in this field, because the procurement of new diesel units has been considerably reduced. The 33 KV network increased from km in 1960 to km by the end of september 1981.

In addition to the discarding of some plants and the elimination of the need to build other plants, this approach has another advantage which contributed to its spreading. As a matter of fact, it guarantees a better continuity of service by making it possible the supply of one single center by several

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(1) DDO : Distilate Diesel Oil

power stations, as is the case for the 33 KV Daloa - Gagnoa - Divo line, which was supplied by both Daloa and Gagnoa stations, when first operated. As goes the saying the more you get, the more you want. The experiment with local networks was so successful that their number increased and covered more geographical areas. Since then the idea of "spider web centers" germinated in the minds.

Such centers, termed "spider web" because of their space configuration evolve from the extrapolation of the local networks idea. These centers are the most recent stage of progress of the rural electrification methods practised by the E.E.C.I. As these centers are designed to serve the remote geographical areas, they rely mainly on either an important diesel generating station of a few megawatts or an HV/MV station of appropriate capacity. The number of power stations discarded through this approach is more important than that of local networks. Unfortunately, the development level of the areas served, the scattering out of consumption centers and the low level of demand at each of these points contribute to the reduced load of the MV network of the "spider web" program. Quite often, the load capacity per kilometer per line is about 1 kVA. For that reason, experiments with new techniques is scheduled in thus program. It is aimed at reducing the investment costs by adopting simple but confirmed techniques anywhere where the conventional threephase networks appear to be more sophisticated, at least during

the first stage. One of the most attractive simple techniques seems to be the Single Wire Earth Return (SWER) system, the experiment of which is scheduled in the rural electrification program of the relacated villages in the KOSSOU lake area. At this stage, I must point out that simple techniques does not imply a reduction in the reliability of the structures, as the good quality of service must be maintained and the safety of people guaranteed. In the case of the SWER, a special attention is given to the quality of earthing.

For the same reason, the E.E.C.I. is carrying out some experiments in the field of new energy sources. In this respect the Solar Experimental Rural Electrification program ERES should make it possible, by 1986, to determine to what extent solar energy, and particularly in the photovoltaic line, is likely to provide an appropriate solution to the low consumption rural areas.

This short review of the rural electrification methods practised so far or considered by the E.E.C.I. demonstrates that there is no miracle solution. On the opposite, the ideal solution should not only adapt to the rural context envisaged, but enable the electricity company of the country to reach a certain autonomy in the field of energy considering the constant increase of oil fuel prices.

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Therefore, the issue is to know whether the small hydropower are likely to meet this requirement. The answer to the question, will mainly depend on the attractiveness of these small hydropower plants as compared to other energy sources likely to meet the needs considered. I am refering especially to agricultural and forest wastes, solar energy and biomass.

The Ivory Coast has a large potential of agricultural and forest waste which could supply a large quantity of electrical power, if processed adequately. Coffee wastes, molasses, sawdust or hevea trees, too old to be productive, constitute hundreds of tons of energy wastes which, so far, have been simply discarded every year by the rice husking plants, sugar mills and plantatations. The experience of other countries and the successful tests carried out in the Ivory Coast by the local research institutes make it possible henceforth to assess the energy value and attractiveness of such wastes.

The flattering centers provide a large quantity of raw material necessary to generate electricity from methanol produced by appropriate digesters.

Refering to the tests carried out elsewhere, it can be stated that the valorization of vegetal and animal wastes appears as a safe means to produce electricity in the rural environment. Yet it is important to note that these wastes are

profitable only when use locally, as the transportation cost will increase the real cost of one kilowatthour produced.

Solar radiation appears as the universal energy source because it is available everywhere, free of charge. Such a large scope makes it more appropriate than all other conventional or new energy sources, to be adapted to the scattering of demand in rural area. Besides, the capacities likely to be developed under the current technological conditions are in the range of the rural consumers requirements.

What is the situation of the hydropower plants among these various energy sources. This question raises three other issues relating first to the availability of such small hydropower, secondly to their cost and thirdly to the technical conditions of their operation.

Regarding the availability, we have mentioned earlier, that, except for a few areas, the hydropower development sites are all located South of the V line defined above. In fact as compared to the V line there is no hydropower site as such in the North, except for the Missouli site on the Marahoué river. The production ratio is 1 over 123 for the South as the real values are respectively 100 and 12.305 GWh. As for small hydropower, there is a slight advantage of the North compared to the South, because the North has 28 sites providing a total of 706 GWh against 22 sites representing 449 GWh for the South.

The production capacity ratio equals 1.65 per 1 for the South. The slides which are to be shown now describe the distribution on the map of the various sites over the national territory.

It evolves from this situation that, in opposition to the large sites of hydropower development, the 50 small hydropower sites identified are fairly equally distributed all over the country.

Apart from the considerations on the availability, the small hydropower plants are also characterized by a higher investment cost, in general, as the cost for the various sites identified in the inventory ranges from about 1 million to 2.750 millions F.CFA per kilowatt installed. For the same sites, the price of the kWh ranges from 100 to 550 F.CFA. The following table which is being shown describes the total range of such prices.

TABLE N° 1 : Cost of Energy produced by the main small hydro-power sites

NAME OF SITE	F.CFA/KW (x 1000)	F.CFA/kWh-YEAR
1 San Pédro	350	87.6*
2 Aboisso	360*	78*
3 Koundisso	1 264	215
4 Sambadougou	2 500	549
5 Missouli	940	235
6 Ile-aux-Palmiers	2 750	314
7 Tahibli	590	113
8 Ghadio	2 000	467
AVERAGE **	1.674	315.50

* To be checked ** Outside Aboisso and San Pédro

By comparison, I suggest that you examine now a similar table on the larger hydro power basins in the Ivory Coast.

TABLE N° 2 : Cost of installed KW and price of kWh-year of the large hydropower basin in Ivory Coast.

NAME OF BASIN	F.CFA/KW (x 1000)	F.CFA/kWh-YEAR
BAFING	619.2	94.5
SASSANDRA	287.0	59.5
BANDAMA	277.0	72.2
COMOE	330.3	51.7
AVERAGE	378.4	69.5

A comparison of the two tables demonstrates that the development of small capacity sites is four times more expensive than that of larger sites, this ratio applies to both the price of a kWh-year and the price of the kWh installed.

A comparison of costs between the small capacity hydropower and other new sources of energy can only be based on the quality factor, as the costs calculation is, in most cases, vitiated by an excess of publicity biases is favour of these new energy sources. So, I shall only point out that the costs mentioned on table 1 above can be compared to those of photovoltaic solar energy only as most of the other costs are estimated to be lower than the figures on table 1.

Now we come to the operational problems of small hydropower plants. You are certainly aware of the fact that the problems result mainly from the necessity to connect the hydro plants to the MV network, because their production capacity is mostly higher than the local requirements. This is particularly true in the case of the Ivory Coast. But such problems are not unsolvable. However it is important that they should be pointed out for a more accurate comparison. The special measures to be taken in order to solve these problems shall be prescribed by some guiding principles based on the necessity to maintain the quality of service, to limit the constraints and to guarantee the safety of people.

Indeed, it would be inadmissible to let the quality of service deteriorate due to the connection of small hydropower plant at any point of the system. Instead, it is important that the quality of service should be equivalent to that of the network suscribers in the absence of this plant. Special provisions must be made to this end. The maintainability of the quality of service requires therefore the protection of the MV network against any fault likely to affect the small hydropower plants connected to the system, thus it is necessary to isolate systematically these plants. It is also necessary that some steps be taken to maintain voltage and frequency within a reasonable range, in the case a small hydropower plant is isolated over a certain portion of the MV network. Besides undue tripping and false coupling are constraints which are likely to affect the efficiency of a normal operation. The necessity to guarantee the safety of people is obvious. It is particularly required in the case of energizing operations or when a fault occurs while the small hydropower plant is isolated over a portion of the system.

Most of these problems can be avoided with solar generators or generating sets fed by animal or vegetal gaz, because these installations can be sized according to the local requirements, and therefore, do not need to be connected to the system.

To conclude the comparison on these new energy sources, I will point out that the Ivory Coast potential for small hydropower plants is relatively high as it is amounts to 1000 GWh a

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year. Moreover the 50 sites identified which make up this potential are fairly well distributed over the country, in so far the Northern region apparently desolate owns 60 % of such potential. Therefore, despite the high amount of investment required a and the operational problems the small hydropower plants, rank fairly high among the new energy sources available in the Ivory Coast. Yet the various new sources of energy mentioned here should not be considered necessarily as competing entities. Each one of them can be adapted to a specific context, according to its nature, availability and the technical conditions of its use. Henceforth, the effective role to be given eventually to the small hydroplants is not so much related to the availability of other power sources in the Ivory Coast, but rather depends on the new power ressources distribution policy to be eventually adopted by the E.E.C.I. and the public authorities of this country.

But before outlining this policy on which the future of small hydropower will lie, we shall see how the sites of the small capacity hydropower plants are laid out.

The general inventory of the hydroelectric ressources of the Ivory Coast, carried out between october 1976 and july 1979 revealed the existence of some fifty small capacity sites distributed throughout the country. It must stated immediately that this type of sites are those whose annual production is below or equal to 100 GWh. This, of course, is an arbitrary

criterium. But it allow the grouping of all sites whose estimated capacities are far below those of the larger hydropower structures of the E.E.C.I. Thus except for some six sites whose capacities exceed 10 MW, all the other sites have a capacity ranging from 1.5 to 5 MW. The lowest capacity is at about 500 KW. A few of them deserve some special attention.

First, the Grah Rapids site, because of the advanced stage of its construction. In fact the dam and the units have been completed and the erection of the electromechanical equipment shall be completed by the end of march 1983, in one year time. The installed capacity is 5 MW supplied by 2 with a unit capacity of 2,5 MW, under a fall ranging from 8,9 m to 11 m. The flow is 60 m^3/s. Apart from electricity generation which is to supply annually some 20 Gigawatthours on the 33 KV system, the dam provides a catchment basin which will need of the city of San Pedro and of various industrial and agricultural customers close to the city. More specifically, the catchment will have to supply water to the paper plant to be built in the immediate vicinity of the dam, about 2.7 m^3/s to start, then 4.5 m^3/s during full operation. The water needs of the city and other customers amount to a total of 2 m^3/s.

The Aboisso site lies in the heart of the city and is characterized by a natural level variation of 4.5 m which will be raised to 5 m by a concrete sill. The flow of 125 m^3/s will make it possible to install a total capacity of 5 MW.

The main characteristics of other sites are as follows :

TABLE N° 3 : Main characteristics of some small hydropower sites

NAME OF SITE	HEIGHT OF FALL (m)	RATED FLOW	INSTALLED CAPACITY (MW)
FERKE	11	100	8
AGBOVILLE	4	16	0.5
DALOA	4	25	0.8
LA PALEE	-	16	2.5
ZEGBERI	24	30	11

The capacities of most small hydropower sites identified exceed considerably strict local needs. Therefore, their connection to the MV distribution network is preliminary condition for their development. In this respect it is worth noting that many of these sites are located at less than 15 km from the existing network as shown on Table 4 below.

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TABLE N° 4 : Distance between small hydropower sites and existing MV network

NAME OF SITE	DISTANCE FROM SITE TO MV NETWORK (km)
PALEE	15
DROU	3
ABOISSO	2
DALOA	1
AGBOVILLE	2
FERKE	16
ZEGBERI	45

The future of small hydropower plants depends not only on the attitude of the authorities and experts towards micropower, as stated earlier, but also on the performance of such plants and primarily on the quantity of energy that they can supply to the system.

The process of pondering over the future of small capacity hydropower plants, leads to some issues relating on the one hand to the general attitude of the ivorian authorities in the context of the world energy crisis and to the real magnitude of the small hydropower plants potential on the other hand and eventually to the behaviour of such plants in the system.

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Regarding the first issue, it is well-know that since 1975 and upon the recommendations of the E.E.C.I., the Government decided to exploit exclusively its hydroelectric sites and by the same taken to delay the installation of thermal plants. Since then, "the hydro turn" made possible by this decision has enabled the country to save a large amount of foreign currencies by producing hydroelectrical power in priority. The contribution of hydro to the production of electricity amounted to 76 % in 1979-1980, then 92 % in 1980-1981. This contribution is expected to rise to 90 % by 1988-1989 at least, if the hydro option decided in 1975 is maintained. The exploitation of small capacity hydro-pwer sites is part of this policy to save foreign currencies and achieve some autonomy in the field of energy, so, it is obvious that the political opinion is in favour of the development of the sites.

As regards the behaviour of small hydropower plants in the system it has been stated that the difficulties pertaining to their operation can be solved.

Therefore, there is no obstacle to small hydropower sites exploitation which is not only perfectly in line with the energy option adopted for some years now by the public authorities, but which would render numerous and various services ranging from electrical power production to the regulation of streams with a view to developing some valleys which would be otherwise improfitable, the supply of water to some cities and the protection

of some lowlands against the permanent risks of flooding, in Man and Aboisso for instance.

The multiple functions expected from small hydropower plants is a good enough reason to believe that the authorities of this country will become fully aware of the value of such schemes, lest they be condemned by future generations who will hardly admit that the previous generation may have neglected an important national energy source, at a time when the world energy crisis was rampant.

As a conclusion to this paper, I wish to express my own firm belief. I have always believed that this possible condemnation from the generations to come will really be dismissed only in so far as today's authorities will be able to master all the factors involved in the processing of the national energy ressources in general, and water ressources in particular. I think first and foremost about the human factor. Plainly speaking, it is important not only to exploit the hydropower ressources, but to me, it appears as a national duty to do so with national technical skills as well. In view of their relatively simple operation and the short period required for their implementation small hydropower plants, provide a special opportunity to build up such skills. In addition to the kilowatthours to be generated and beyond thousands of hectares made productive through the regulation of streams this contribution would be the most worthy and most significant of any program designed for the exploitation

of these sites. In the absence of such factor it would be deluding to expect any autonomy in the field of energy some day.

I thank you for your patient attention.

THE MICRO-HYDROELECTRIC GENERATION PROGRAM OF ECUADOR

by

EDUARDO MORAN

ABSTRACT

Although Ecuador has abundant hydropower potential, barely 1.5% of that potential has been developed. Hdyroelectricity was the first source of energy for many cities and towns since the beginning of the century. When the National Electrification Authority (INECEL), created in the late sixties, realized its National Interconnected System (NIS) in 1979, a considerable number of micro-hydroplants serving small towns located in the range of NIS were disconnected or abandoned. When analyzing its National Electrification Master Plan which included the objective of rural electrification by 1984, INECEL discovered that 40% of the national population, due to geographical dispersement, could not be integrated into NIS. In search for a better approach to energy development, the National Energy Institute (NEI) was established as the entity responsible for overall national energy planning. NEI has developed a national program of micro-hydro generation and a whole systems approach to energy planning, in general. Specialized technical groups were created to work specifically to develop alternative sources of energy for rural areas for which micro-hydro is a priority. NEI assembles and discusses plans with INECEL and other prospective executors, thereby making possible the identification of objectives between planners and executors of energy policies. To develop a national technological capacity, NEI works jointly with specialized institutions by allocating funds, specialized personnel and by defining objectives of each joint program. NEI is establishing a center for technological development which will serve to develop local expertise and institutions for continued research, development and training in hydropower technology.

BIOGRAPHICAL SKETCH

Eduardo Moran, as Advisor to the National Energy Institute of Ecuador since 1979, has specialized in the fields of renewable sources of energy, energy conservation, and technical assistance. He is currently a doctoral candidate in energy and economics at the University of Grenoble, France. He received his chemical and industrial engineering degrees from the University of Idaho in 1969; his M.B.A. in 1973 from the American Graduate School of International Management; and his Master of International Management in 1974. From 1974-1976, Mr. Moran was the Manager of Industrial Safety and Technical Inspection of the N&C Oil Company (CEPE) in Ecuador. His publications include: "Industrial Energy Consumption in Developing Countries" (methodology and analysis), RFF, Washington, D.C., 1981; "Rural Energy Consumption in Rural Areas" (methodology and analysis), MRNE, 1980; "Methodologies for Planning and Implementing the Use of Renewable Sources of Energy," INE, 1979; and "Possibilities of Use of Alcohol as Fuel in Ecuador," INE, 1979. Mr. Moran is presently working on two articles, "Terms of Reference for Alcohol Programs in Developing Countries," and "The Economics of Micro-Hydrogeneration."

The Micro-Hydroelectric Generation Program of Ecuador

Similar to all the mountainous countries situated in tropical areas, Ecuador is a gifted country in hydraulic resources. Hydroelectricity was the first source of energy for many cities and towns since the beginning of the century. Small (up to 5,000 kW) and micro-hydroelectricity (up to 500 kW) plants were spread around the country, creating in this form a decentralized system still partially in operation. The national hydropower potential is estimated at 22,000 MW; we are not even using 1.5% of this potential. In fact, 76% of the energy presently produced is by thermoelectric equipment.

The development of thermoelectricity, due to the accelerated economic growth and the availability of cheap oil during the last ten years, was also a consequence of the lack of rational energy planning and the need to satisfy the needs of energy supply as they appeared, especially in the urban areas.

A National Electrification Authority (INECEL) was created in the late sixties, starting also the era of grand hydroschemes, big thermoelectric plants, and the National Interconnected System (NIS). By law only INECEL or any of their regional enterprises were able to produce, distribute, and sell electricity. The interconnected system became a reality in 1979. The National Electrification Master Plan prepared by INECEL indicates that one of its objectives is, by 1984, to provide electricity to 700,000 inhabitants of the rural areas, through a rural electrification program consisting especially of installations of small powerplants, substations, transmission and distribution lines, most of them branching out of the NIS. When analyzing this plan, where for the first time, rural electrification had an important role, a striking reality appears - that is that 40% of the national population, the majority of which lives in rural communities geographically spread in such a way as to prevent their integration into the NIS, will suffer the lack of electricity - a fact that accentuates their marginality even more. Therefore, it was evident that, within the framework for harmonious development of

these areas, a different and more suitable solution than traditional electrification had to be found.

The Role of the National Energy Institute (NEI)

In 1979 the National Energy Institute (NEI) was created as the entity responsible for the overall national energy planning.

For the first time, energy was treated in a whole systems approach, treating it as a factor of social and economic development, intimately related to other factors as technology, social organization, etc. The realization by NEI of the problems imposed on the supply of electricity to the rural areas by the socio-economic characteristics of the small population and their dispersed nature became a preoccupation of the Institute which was expressed by the creation of specialized technical groups whose work was centered in the study and development of alternative sources of energy for the rural areas, and where micro-hydroelectricity generation was a priority. The NEI, as the national coordinating entity for energy planning, has access to all the organizations of the country. Therefore, when designing the alternative energy planning system, all the institutions that were going to be involved in one way or other in the different phases of the plan were called to work with the NEI group.

The creation in NEI of the micro-hydro Group was followed immediately by a similar action in the rural electrification and planning divisions of INECEL. Their similar objectives started the spread of the national program of micro-hydro generation.

All that was mentioned above is important to note in order to point out the relevance of the intervention of NEI that made possible, for example, the creation of planning systems where most of the important extra-energy factors were considered and the assembling and discussion of the plans with INECEL and other prospective executors - actions which made possible the identification of objectives between the planners and executors of the energy policies. Also the planning system was adopted by the same

regional electric enterprises. A synthetic diagram of the principal points of the system are shown in graphic 1.

What is relevant in the planning system is that, in each one of these phases, more than one institution plays an important role, creating in this form an organizational interdependence that makes possible the disappearance of a program due to violent institutional changes or even partial financial problems.

National Micro-Hydroelectricity (MHE)

The study of the electric sector showed that one of the consequences of the start up of the functioning of the NIS was the disconnection and, in certain cases, the abandoning of a considerable number of micro-hydroplants that were serving small towns presently located in the range of the NIS.

A preliminary inventory showed 68 plants in this situation. Therefore, the principal task of the INECEL micro-hydro group was the in-depth study and inventory of this equipment.

This particular situation gave the country a great opportunity to start up a micro-hydroelectricity program through the study and evaluation of all the characteristics of the not-in-service equipment and installations. Also the reallocation of this equipment requires a considerable amount of work that at this moment is seriously performed by INECEL. This group is also working in the identification of all the population centers which will not be tied to the NIS and identifying those best fit to receive the existing plants.

Meanwhile NEI started to think and work in the standardization of study and evaluation procedures for site selection, equipment selection etc. and also in the possibilities of manufacturing equipment locally. The NEI program of MHE was gradually reinforced in the areas of study of local manufacturing possibilities and standardization of resource assessment and civil works.

The state of the art in different developed and developing countries was studied and, at the same time, contacts were made with persons and institutions capable of carrying out successfully the idea and plans of national production of partial, or even complete, micro-plants. The coincidence of the realization of a workshop-seminar similar to the present one during the first stages of the program in August, 1980, permitted NEI to invite to the event all the persons and entities that will in one way or other play the roles of executors, users, researchers, constructors, etc. and, at the same time, weigh the real possibilities of our plans. The contact with the foreign researchers, field workers, company representatives, etc. was an enriching and valuable experience that also gave the NEI the opportunity to meet the technicians and consultants who were later hired by the U.N. for helping the institution in the accomplishment of the proposed technological plans.

Development of a National Technological Capacity

Instead of increasing the technical bureaucracy in order to develop its energy programs, the NEI has chosen to work jointly with the specialized institutions by allocating funds, specialized personnel, and clearly defining the objective of each joint program.

With the National Polytechnic School (NPS), the agreement contemplates the construction of micro-turbines of the Banki and Pelton types and all the technical work for the transformation of pumps into turbines; with the Electrical Engineering Department and a local manufacturer of electronic panels, the development and construction of electronic load controllers and the adaptation of the generators to the turbines. A contract with the U.N. has permitted us to bring in a recognized and very experienced consultant in micro-hydro equipment construction, operation and installation who worked together with the NEI and the NPS in the turbine construction and also in all the other aspects of programs. The importance of the international expertise should be

noted. We consider that, for some time to come, only by working with and learning from those who have gained a firm knowledge, whether in the field or in the workshop, can a group of inexperienced but capable national technicians effectively acquire this expertise. What has been the cost of the NEI-NPS program for the development of the three turbines, the transformation of pumps into turbines, and the construction of electronic-load controllers? Disregarding the technical manpower that in one way or another has to be assigned a cost, the disbursement has been close to US $15,000. At this point, it is necessary to consider the time and effort given by the research team of the Polytechnic School to the project. Had the project, in which all the materials, parts, and foreign expertise were given by NEI, not existed, the micro-hydro team or a similar one would have been employed in projects or thesis work generally not useful and apart from the national reality.

In the case of the electronic-load controllers, a cost was assigned to manpower by the company working together with the NPS in the development of the designs and equipment. The total cost of a typical control for a 50 kW turbine was close to US $2,000. Concerning the civil works, different alternatives are being considered for the construction of the different elements of an installation and special attention is able being given to the possibility of using local labor and materials. What appears to be able to reduce the costs substantially is the use of plastic pipe for the penstock; a suitable manufacturer of this type has been found.

Project of the Center for Research, Development and Training in Micro-Hydro Technologies

When studying the development of micro-hydro in Ecuador, immediately a question arises. Why, in a country where there have been installed more than 100 operating micro-plants and where even the construction of simple equipment has been done, is there a lack of expertise in this field?

The answers to this question could be synthetized in the following statements:

- o there has been a dispersion of the projects in time and space that didn't allow any national counterpart to acquire experience in this field;
- o there has been a total dependence on foreign companies and expertise for the calculations, designs, installation, etc. of the plants.
- o there has been an absence of a group or groups of national engineers or companies working in the field in a continuous form; and
- o there has been a lack of institutions where the experience could be kept and the technological development pursued.

The NEI thinks that the implementation of a center for technological development, where the applied research will be complemented by practical training, will help avoid repeating negative experiences as the ones enumerated above.

The NEI has envisaged the functioning of the Center in the following manner: a group of engineers (mechanical, civil, and hydraulic) belonging to NEI will constitute the permanent personnel of the Center. The local electric company (QUITO) will provide the place, services, and water for the Center having at the same time an engineer in the work group. The other institutions of research and universities could assign personnel to work in the Center, permanently or by project. The electrification companies, in the same manner as the universities, will have the choice to assign personnel to the Center. The material, personnel, and economic support for the operation will be borne almost completely by NEI, which will also direct, operate, and maintain the Center.

The projected physical installations will permit the testing of equipment up to 200 kW, having all the facilities to test different types of turbines, controllers, and electrical systems. A mechanical shop with basic tools will permit the assembling, disassembling, repair, transformation, and reproduction of certain pieces or parts of equipment. A

small administrative building with offices and a classroom for seminars, meetings, and training stages will also be built.

The projected Center will have the principal types of equipment for MHG sold on the international market: the locally-manufactured equipment and the occasional equipment for repair. When talking about equipment, what is comprised is turbines, controls, generators, and the electric panels.

Three main types of activities are envisaged for the Center:

1) applied research in operation of the systems, the testing and reproduction of parts and pieces, and testing of equipment produced locally;
2) training in installation and operation of MHG equipment to groups of engineers belonging to public or private entities that will be in charge of design, construction, and/or operation of this type of equipment;
3) training in operation and control of equipment to personnel engaged in these tasks (this could belong to the electric companies, communes, and/or private entities) and training in repair and installation of equipment of the personnel of the electric companies.

In the prefeasibility study of the Center, an approximate cost of US $560,000 was calculated. At the present, the definite studies are still in process.

A contract was signed in December, 1981 with the Electric Enterprise Quito for the construction of the Center; but what is also important to mention, is that, at this moment a provisional facility has been finished adjacent to the future facilities. This permits the NEI-NPS group to test turbines of a capacity up to 70 kW, which is especially useful for testing the transformed pump and the Mitchell-Banki units already finished. The cost of this provisional facility, where the majority of mechanical works were done by the Municipal Water Company, is about US $15,000. At this point, it is important to comment on the work of the Municipal Water Company where we found a lot of piping, valves, and the capacity and experience for the mechanical works similar to the one

needed for our provisional installation.

SUMMARY

As a brief summary, it can be said that after the realization by the Ecuadorian Government of the importance that micro-hydro generation could have for the development and upgrading of the standard of living of the rural areas, the program started by NEI and INECEL has been given the necessary support. A more rational and appropriate planning system is in operation at the highest levels of energy planning. The assignation of specific personnel to work in the programs of NEI, INECEL, NPS, and at this moment, two regional enterprises, shows increasing and sustained interest. There are 12 full-time engineers of the different institutions working in this field. The programs are well financed and the resources for the development of the different programs are already allocated.

International interest has been demonstrated in the Ecuadorian MHG program, especially for the installation of pilot facilities. In this sense, AID will work with INE - INECEL in a small program for the provision of electricity to two rural villages. In these projects, all the methodologies for planning, execution, and operation will be applied. Governments and international entities have also shown interest in financing programs for MHG, but our experience shows that, if a country does not prepare suitable counterparts and does not create permanent groups, there is no possibility for technical and technological advancement.

Our program, that started two and a half years ago, has reached the present status due to all the favorable circumstances that exist in the country. We still have a long road to cover, but we have realized our possibilities and we hope we will be able to make this source of energy one of the elements that will permit better economic and social development of a vast sector of the Ecuadorian rural population.

Only through the acquisition of consciousness of the importance of this alternative

source of energy by the highest authorities can a national plan be successful, especially if the direction of this is given to motivated and capable personnel supplied with the financial and material elements to assure full success.

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Micro-Hydroelectric Schemes in Pakistan

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Micro-Hydroelectric Schemes in Pakistan

Abstract

For the rural areas of Pakistan, there is a pressing need for accelerating the pace of electrification utilizing appropriate sources of energy. The paper describes the salient features of the schemes of the Appropriate Technology Development Organization. The presentation includes the need of developing a non-conventional approach to schemes of rural electrification. The paper describes the technology, fabrication, financing, management and end-uses of the schemes. By proper use of local resources, schemes have been completed at a cost of US $250-400 per kW.

Biographical Sketch

Mohammad Abdullah holds a Ph.D. degree from University of Manchester England in Electrical Engineering. His academic interests are in the field of electrical power engineering with specialization in dielectrics and high voltage engineering. He has 25 years experience in education and research in electrical engineering. Presently he is professor and Chairman of Electrical Engineering Department, Engineering University, Peshawar, Pakistan. He is the coauthor of a book, "High Voltage Engineering", and has published several articles in national and international journals.

For the past ten years he has been interested in alternate sources of energy and energy conservation. He has served on a number of national panels and working groups on energy and power. Lately he has been actively engaged in the design, development and demonstration of micro-hydroelectric plants for rural areas.

Introduction

Pakistan is primarily a rural country; two thirds of the total population live in villages. Like most of the developing countries in that region, most of the energy needs of people in rural areas are met from the non-commercial sources available locally. Only 10,000 out of a total of 43,000 villages have so far been electrified. Within the electrified villages, the consumer saturation is nearly 14% which compares well with figures quoted by international agencies for developing countries.

Most of the people in rural areas use wood, forest and crop residues and dung as a heat source for cooking and space heating. Forest wood and kerosene oil are used as a source of light. The cost of kerosene oil in the mountainous areas is higher than that in towns. Typically a 4-gallon can of kerosene in a hilly area will cost about Rs 40/= * (nearly $4.00). A household generally uses Rs 20= worth of kerosene per month for lighting purposes. In areas close to forest, a rural family uses forest wood worth Rs 10,000/= annually to meet its heating and cooking energy needs.

Options of Rural Electrification

Electricity supply in Pakistan is the responsibility of the federal government. The generation system is a thermal-hydro mix; the installed capacity is 3350 MW (1980 figure). Rural areas are electrified by extending the national grid. Preference is given to those areas which are close to an existing transmission line. Due to limited resources, 1,000 villages per year have been electrified in the recent past. Typically a village electrification costs Rs 500,000/= (=$50,000).

* (US$1.00 = Rupees 10)

In some of the areas, diesel generating plants have been installed. These plants are a drain on the national economy as Pakistan imports nearly 90% of its oil requirement. Secondly these plants need care and maintenance.

In order to meet the local electricity needs, the Government initiated a scheme of mini-hydroelectric plants. The turbo-generator plants (50/100kW) were manufactured in Pakistan in collaboration with foreign manufacturers. The project was planned and implemented along conventional lines, which resulted in a cost of about Rs 50,000-60,000 per kW. In view of this high cost, the schemes could not be implemented on a large scale.

The existing systems of rural electrification are not suited as they are capital intensive and have high operational costs. Financial returns are low and nearly 95% of electricity is used for domestic purposes. Consumer saturation is low which further adds to social inequity.

Micro-Hydropower Plants of the ATDO

Hydroelectric plants, irrespective of their capacities, have several features in common. Each plant has a water storage/diversion system, a turbine-generator plant and a transmission system. However, when mini- and micro-hydroelectric plants are designed, installed, operated and managed on the same system as large hydro plants, costs are too high. Experience in Pakistan and information from other countries indicate a wide range of cost values, mostly in the range of $800 to 5000 per kW. A detailed analysis may indicate the breakdown of the cost for various components, material, technology, fabrication, labour, energy, etc. Only such a detailed analysis can explain a wide range of the cost of such schemes.

It is for the people and the government of a country to decide the price at which they would like to have electricity. Where resources are unlimited and there are no constraints, cost does not matter and electricity could be generated by harnessing potential in the conventional manner.

However for Pakistan, and to several developing countries, constraints of resources--financial and technical know-how--control the programs of harnessing hydropower projects. If mini- and micro-hydroelectric projects are to be established viably, it is necessary to look for a different approach to the whole issue. Electricity in rural areas is mainly used for domestic purposes. For this end-use, is it worth supplying electricity at a cost of say $2000 per kW?

In the approach adopted by the Appropriate Technology Development Organization (ATDO) of the Government of Pakistan, reliance is placed on the local resources -- men, material, finance and technology. In addition to meeting the desired objective at a reduced cost, this approach leads to the overall development of the community. Local people participate in all phases of the scheme. So far 25 plants of capacities in the range of 5 kW to 15 kW have been installed at a cost in the range of US $250-$400 per kW.

Objective

Development of a suitable technology and system -- simple and inexpensive -- for meeting the electricity needs of the rural people is the main objective of the ATDO schemes. To meet this objective, suitable technologies have been developed and appropriate implementation and management procedures have been adopted. The salient features of the schemes are described in the following paragraphs.

Approach

In the mid-1970's, we recognized the possibilities of running electric generators on the sites where local people were running grinding mills by diverting a small quanity of water. On visits to several existing grinding mills, it was estimated that the mills were operating on a water flow of a couple of cusecs and a head of 5-10 feet. An open wooden channel was used to drop the water head and wooden wheels having radial blades were driven by the water jet. On the vertical shafts of the wheel, grinders were placed. Some of these sites were in operation for 20-25 years without any major failures. The only replacement needed was the blades of the wheel. The waterways, wheel and grinders are all built by the local people without any assistance from outside.

The first pilot plant was put up in a village near Peshawar. The village had electricity from the grid, but the houses near the water mill were not electrified. The owner of the mill allowed us to put up the experimental plant at his site; in return for the local labour, they received electricity. Encouraged by promising results, we took the technology to an area which was a remote village and did not have electricity at all. Six kilowatts of power was generated and about 60 houses were electrified. The successful implementation of the first scheme attracted several villages around that area. People used to visit the plant and they showed interest and enthusiasm in having a plant in their village. The approach proved contagious and we started receiving applications from a number of villages. In most cases, a group of persons from a village, 100-200 miles away, came to us with a request for putting up a power plant.

On the receipt of a request, our technical staff visits the village. A fairly large number of people -- (20-30) -- meet with our staff, who explain to them the technical, financial and managerial aspects of the scheme.

They are informed how various aspects of the scheme are implemented and how the expenses of the scheme are shared between the Government and the local community. Our staff stays in the village for a day or two and matters are discussed mutually. The power potential is assessed and the people are told of the extent to which the power can be beneficial to them. They are also told of the likely expenditures on the operation and maintenance of the plant. This information helps them in deciding on a tariff.

Technology

The power output is estimated by measuring the discharge and the head available at the site. The location of the powerhouse is determined by taking into account the head which can be created for a given length of the power channel and the lengths of distribution lines needed to supply electricity to the remote portions of the village. Frequently the decision is dictated by such considerations as the route of the power channel, ownership of the land on which the channel will pass, and the ownership of the land where the powerhouse is to be constructed. All these issues are kept in mind while making a decision about the location of the civil works and hydraulic structures. The flow is estimated by using a "float" which has been found as the only appropriate method and it gives fairly good results. The fall is determined by measuring the difference of elevation between the penstock entrance and the turbine inlet. Reference tables have been prepared giving the power available for different combinations of flow and head. These tables can be used by the rural people for making an estimate of the available potential.

The waterway system is similar to the one which has been used by the village people for irrigation purposes. They are familiar with this technology which has been used for ages. The intake is a low stone weir which raises the water level and diverts the flow into an unlined power channel. The power channel terminates into a forebay structure which is built of dry rubble masonry lined with concrete. The forebay has necessary openings for inlet and outlet and overflow wooden gates are provided at the inlet and outlet openings.

For heads up to 20 feet, non-conventional but readily available materials such as wood and oil drums are used. For higher heads, 30-100 feet, steel pipes are used and a valve is included just before the nozzle. Such pipes and accessories have to be purchased from a city which may be nearly 400-500 miles away from the project site. Transportation of material is difficult and expensive.

The size of the powerhouse is selected to accommodate the turbo-generator unit and other machinery. Generally a room 10' x 12' is sufficient for a 10 kW plant. At those places, where motive power is used to drive processing units, the size of the room may be 15' x 40'. It is constructed of rubble masonary with timber roofing.

No critical dimensions or designs are followed in the waterways and the civil works. The villagers are encouraged to use their skills and the materials available to them locally. The ATDO staff visit the work occasionally and give the instructions wherever required.

The selection of the prime mover is dictated by the site condition, simplicity of operation and fabrication, and cost. The cross-flow "Banki" turbine has been found to be a suitable prime mover for these schemes.

A simple process has been adopted for the fabrication of the turbine rotor. End plates of specified diameter are cut from a 1/4" thick mild steel plate. Rotor vanes are either cut from a suitably-sized pipe or shaped to proper curvature by hammering mild steel plates 1/8" thick. Rotor blades are then welded electrically to the end-plates. For each installation, a turbine rotor of designed dimensions is fabricated. The rotor has a through shaft. The nozzle made from sheet steel is fixed at the lower end of the penstock and is independent of the turbine. The rotor is supported by three ball-bearings which are secured on concrete pads. No automatic governor is included in the design. Instead the power input is controlled with a gate or valve. The rotor shaft supports a V-type pulley which couples the turbine to the generator.

Single- and three-phase 50 Hz, 1500 rpnm, 220/380 volt electric generators made in Peoples Republic of China are purchased from the market. Since the generators are expensive in relation to the cost of other items of the scheme, a program of local design and fabrication has been initiated by the ATDO. A panel board containing voltmeters, ammeters, switch-fuse units, and over-current protective devices, is provided with each generator unit. An overvoltage relay is also fitted to avoid overvoltages in case of an accidental open circuit of the generator load or on very low loads.

The powerhouse is located close to the village; the distribution is therefore at the generation voltage. Usually 8 and 10 SWG bare copper conductors, supported by pin-type insulators, are laid on wooden poles.

Cost

The breakdown of costs for a 10 kW micro-hydro scheme is given below

1.	Civil works	U.S. $ 800.00
2.	Turbine	200.00
3.	Generator	1500.00
4.	Technical services	400.00
	Total	$2,900/=

The cost of the distribution system depends upon the extent of the area served. Typically a cost of about $800 - 1000 may be taken for a 10 kW plant. For heads in the range of 40-100 feet, the cost of long lengths of iron pipe penstock may increase the cost of civil work to about $1500.00. The unusually low cost of $250-400 per installed kW results from such factors, as:

a. low administrative cost

b. labour contributed by villagers

c. use of local materials

d. local fabrication wherever possible

e. appropriate system design.

The cost/kWh generated is about 25 mills. (1 mill = US$.001).

Financing

In the initial stages, the ATDO financed all the machinery and components needed for the plants. This was necessary to establish and demonstrate the viability of the schemes, particularly the new approaches in the design, fabrication, installation, operation and management of the plants. Presently, the schemes are implemented on cost-sharing

basis. ATDO and local governments share the cost of turbine and generator. The cost of civil work including penstock and distribution system is shared by the community or local enterpreneurs. Technical services are provided by the ATDO. The investment made by an enterpreneur is recovered by running cottage-level industrial units e.g. band saw, flour mill, rice huller, cotton gin,etc. A number of banks have introduced schemes of loans to farmers for agro-based industries. It is expected that loans could be arranged for multi-purpose micro-hydroelectric plants.

Management and Operation

The success of the micro-hydro schemes in Pakistan is a result of the involvement and participation of the local people. Decentralized energy schemes intended for isolated communities must have the interest and participation of the people for whom the scheme is designed. In the ATDO projects, local people are associated from the identification of the site to the installation of the plant. During the course of the construction of the waterway and powernouse, technical staff of the ATDO makes only occasional visits, just to ensure that the work is progressing well and the quality of the work is good. The installation of the machinery is carried out jointly by the ATDO staff and local technicians. The plant is run by the ATDO staff for a few days during which period a local technician learns the various aspects of the operation of the plant. Thereafter the plant is handed over to the local community who operate, maintain, and manage the plant.

Usually one or two persons are selected by the community from among themselves who are assigned the duties of operation and maintenance of the plant. Decisions are made by the community regarding

giving electricity to the residents. First preference is given to those people who had made any contribution to the project. Then people living close to an existing distribution line are given connection. Public places e.g. religious places, schools, dispensaries, street lighting and shops are also connected to the line.

In order to meet the running expenses, the community decides on the charges to be collected from the consumers. Usually a fixed rate of $0.30-0.40 per light point is charged per month. No taxes are collected by the Government; their contribution is an aid to the people.

The local people are managing the system well. Necessary spare parts e.g. belt, bearings and fuse wires are kept in stock so that they need not have to come to the town for purchasing these items when replacements are needed. They also attend to the social problems resulting from the supply of electricity. Only in case of major problems do they approach the ATDO. There is a close link between the local community and the ATDO staff who also monitor the projects frequently.

End Uses

The micro-hydroelectric power programs are primarily planned and implemented for meeting the basic needs of electricity for domestic purposes. However, people are advised and encouraged to use the power for cottage industries. Most of the electrical load is lighting, with three or four incandescent bulbs of 40-60 watts in most homes. Those who can afford to use fluorescent tubes. The maximum power available is shared by the community in such a way that all are benefitted fairly equally. The level of consumer saturation in the villages electrified by the schemes is about 80-90%. Some well-to-do villagers have also

installed television receivers at their homes.

The industrial application of the power so produced depends upon the agricultural products of the locality and the existing methods of processing. Usually, the agricultural products are processed at the traditional grinding mill or taken to a town. Both these systems are inconvenient and time consuming and also expensive if products are taken to the town. The micro-hydropower plants at a number of places are supplying power to cottage industries and agricultural processing units. In most cases, the motive power of the turbine, through a suitable pulley-belt system, drives a variety of devices. These include band saws, flour mills, rice hullers, cotton gins, corn shellers, wooden lathes, and grinders.

At one installation, an electrically-driven wheat thresher/corn sheller is operated in the field. It is moved to convenient locations around the field and electricity is tapped from a nearby distribution line. At another site an arc-welding unit is used. At one place it is proposed to lift water at an elevation of 60 feet.

These industrial activities are a great help to the local people. They provide an easy and convenient place for people from the nearby villages to get their agricultural products processed. To the owners of the plants, it is a source of income. It also provides employment to a few people.

Conclusion

Conventional method of rural electrification is too expensive particularly when electricity is used only for social benefits and for running village-level cottage industries. Decentralized micro-

hydropower offers a viable option for electrifying isolated rural communities. By utilizing the local resources, these power schemes can be implemented at a low cost. The ATDO schemes in Pakistan have brought socio-cultural reformation. Some aspects of this reformation are summarized below:

(a) Sense of participation in development schemes

(b) Sense of pride

(c) Increased awareness of need for development

(d) Increased hours of study and work

(e) Smokeless lighting, leading to healthy environment

(f) Reduction in tree cutting

(g) Introduction of small-scale industrial activity

(h) Employment generation and increased income.

Data on Selected Micro-Hydroelectric Power Plants

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, wooden 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, wooden 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		

DEPARTMENT OF HIGHER AND UNIVERSITY EDUCATION
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SMALL HYDROELECTRIC POWER DEVELOPMENT IN ZAIRE

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February 1982

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SMALL HYDROELECTRIC POWER DEVELOPMENT IN ZAIRE

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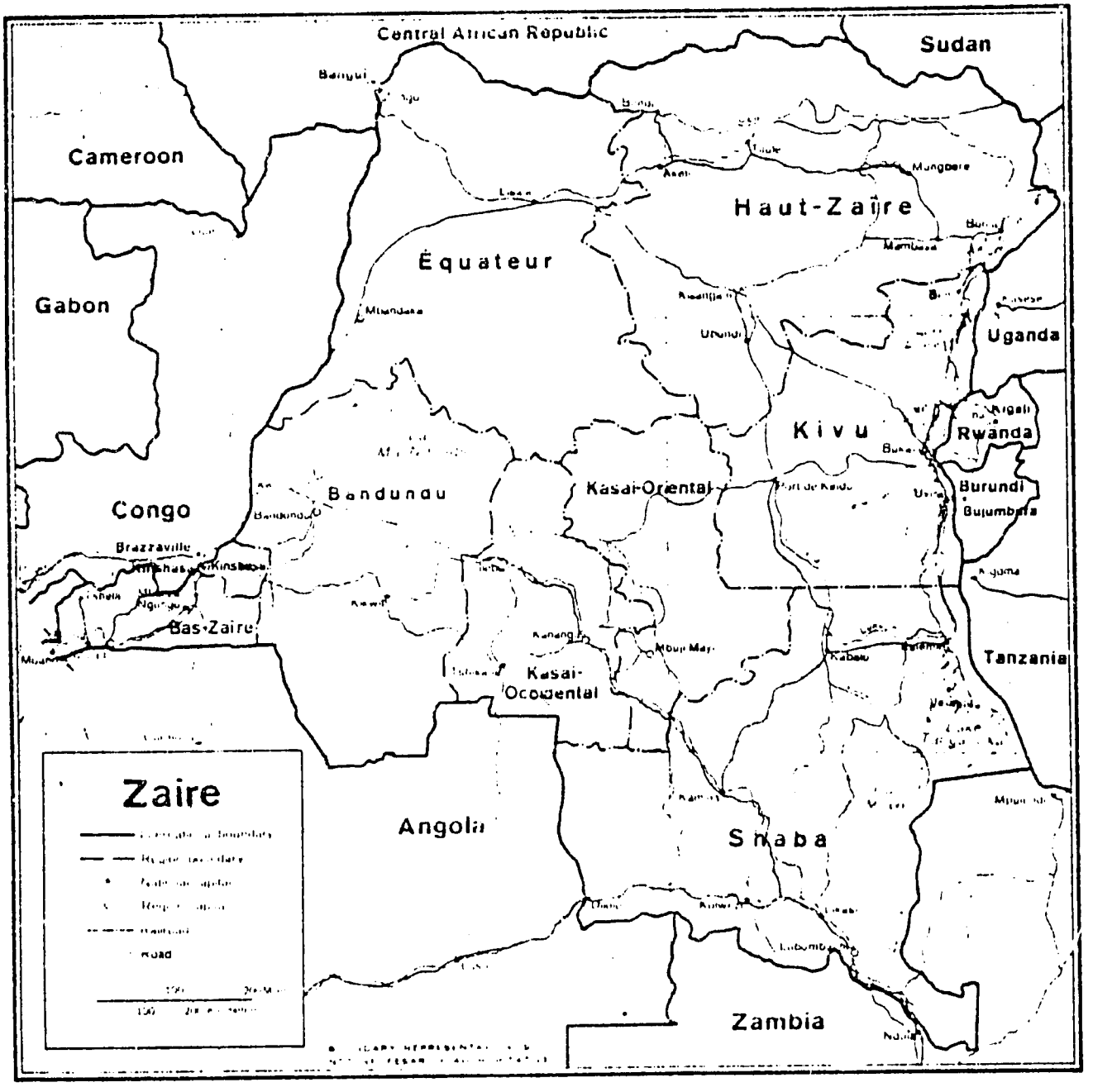

Figure 1. Carte generale du Zaire.

General map of Zaire.

SMALL HYDROELECTRIC POWER DEVELOPMENT IN ZAIRE

INTRODUCTION

Electrical energy is at the heart of world economic development. The sources of electrical energy are numerous including coal, oil, natural gas, water, wind, wood, steam and solid waste. These energy sources are drawn upon to power various types of motors that transform input energy into mechanical energy. Fed into generators, this energy is transformed into electrical energy. Each process utilized in producing such energy has advantages and disadvantages. The appropriate process must be selected to generate the desired electric power.

Hydroelectric power potential depends on the quantity of water provided and its head. Power-plants utilized in generating hydroelectric power fall into two general groups (ref.1)[1]: large-scale and small-scale. A large-scale hydro-plant generally is considered to have a minimum capacity of 3000 to 5000 KW; it is usually constructed to serve the electrical needs of large urban areas. Small-scale hydro-plants, on the other hand, usually are built for the needs of rural areas and farms. They have a capacity ranging from 0-3000 or 5000 KW. This paper addresses small-scale hydropower development in the rural electrification program of the Republic of Zaire.

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[1] References are listed at the end of the text.

1. HISTORICAL BACKGROUND

The Republic of Zaire is a largely landlocked country centrally located in equatorial Africa. With an area of 2,344,885 sq.Km. (905,365 sq.M), it is the third largest country in Africa and is roughly equal in size to the United States east of the Mississippi.

Its 1979 population (Ref.2) has been estimated at 27,048,000. The population growth rate has increased from an average annual rate of 2.0% between 1950 and 1955 to about 2.9% today.

1.1) Large-scale Hydro Power-plant Development

The production of energy by large-scale hydroelectric facilities is one of the main productive uses of water in Zaire. Zaire's hydroelectric power potential (Ref.2 p. 20) is estimated at over one million megawatts (MW). The largest existing site is on the lower part of the Zaire River where its course takes it past the Inga plateau about 40 km upstream from the port of Matadi in Bas-Zaire region. The first phase of the Inga hydroelectric development (Inga I) began in 1968 and went into operation in 1972. The Inga I plant has a reliable generating capacity of 300 MW. Work is underway on Inga II, which will furnish 1,272 MW; an 1800 Km, high-voltage, direct-current transmission line links the plant to Shaba region to provide the energy necessary for expansion of copper mining. There are three other hydroelectric generating stations in Bas-Zaire region two on the Inkisi River, south-

west of Kinshasa, with combined capacity of 87 MW, and a small 2 MW plant near Matadi. Presently Bandundu and Equateur regions do not have any significant hydroelectric installations due to their generally flat terrain, although a facility is under construction on the Bangui River in northern Equateur. In Haut-Zaire, Kisangani is supplied by a 12.3 MW plant on the Tshopo River, and in Kivu a 12.6 MW station on the Ruzizi River supplies power to Bukavu.

Shaba Region still has the largest hydroelectric power generation capacity with some 530 MW installed. Four major installations serving the mining and industrial complex of GECAMINES have a combined installed capacity of 467 MW. Two of these plants are on the Lualaba River north of Kolwezi, and the other two are on the Lufira River northeast of Likasi. Other Shaba stations are comparatively small, including a 17.5 MW station that furnishes power to the urban center of Kalemi on Lake Tanganika.

Shaba consumes almost three-quarters of Zaire's total hydroelectric production; the western part of the country, including Kinshasa, Bas-Zaire, and parts of Bandundu, consume about 23%; the remainder is accounted for by the rest of Zaire. The mining and metallurgical industries use about 68% of the total output, and other industrial sectors some 18%. Home consumption, together with street and other public lighting, account for about 11% of the total output.

1.2) Diesel Power-Plants

Some cities, missionary stations, and private establishments are using diesel power-plants. Most of these are operated only several hours a day because of the unrealibility of the expensive diesel oil supplies. Others are not running at all due to a complete lack of fuel.

1.3) Small-scale Hydro-power-plant development

There has been only one small hydropower plant installed by the Government This is the 2 MW plant near Matadi. Until recently the GOZ has not been very concerned with small-scale hydropower installations. However, as the costs of petroleum funds have continued to rise, increasing the totals of import bills even as export earnings have faltered, the GOZ has revised its national energy policy to give priority to the exploitation of Zaire's potential for small hydropower development.

2. EXISTING SMALL HYDROPOWER PLANTS

2.1) Small Hydro Power Potential

The potential for hydropower development in Zaire has been estimated at about 13% of the total world hydroelectrical potential (Ref. 3). The number of feasible sites for small hydropower development probably exceeds one thousand.

2.2) Assessment of the Existing Plants

A number of private firms and religious groups have installed small hydropower plants around the country. These plants are enumerated below:

2.2.1) KATALE, northern Kivu.

Apparent power: 50 KVA

2.2.2) RUANGURA, Rutshuru, Kivu.

Apparent power: 200 KVA

2.2.3) BIBANGA, Katanda zone, Kasai Oriental

Apparent power: 14 KVA

2.2.4) IDZIM, Idiofa, Bandundu

Power: 108.9 KW; Head: 28.55; Flow

Flow: 470 l/sec

2.2.5) OSSO, Bas-Zaire.

Power: 190 HP (141.7 KW),

Head: 8.6 m; Flow: 2000 l/sec

2.2.6) NIOKA, Bunia, Haut-Zaire,

Power: 26.6 HP (19.8 KW)

Head: 5 m; Flow 500 l/sec

2.2.7) PERES TRAPISTES, Kikwit, Bandundu

Power: 76 HP (56 7 KW);

Head: 15.8 m; Flow: 450 l/sec

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2.2.8) RAEDECK, Bukavu, Kivu Region

Power: 23.9 HP (17.8 KW)

Head: 64 m; Flow: 35 l/sec

2.2.9) FRANZ, Bukavu-Kivu.

Power: 64 HP (47.7 KW)

Head: 10 m; Flow: 600 l/sec

2.2.10) ROBERT, Bukavu. Power: 19.7 HP (14.7 KW)

Head: 14.2 m; Flow: 130 l/sec

2.3. Construction Materials and Equipment

Structures involved in small hydropower facilities include dams, powerhouses, canals and penstock supports. Reinforced concrete, rock masonry and reinforcing bars are required. to undertake this construction. These materials are available locally in Zaire and can be purchased with local currency. Their average cost is estimated at about one-half the equipment cost (see Appendix A).

Equipment to be considered in a small hydro plant includes penstock with accessories, turbines and generators with accessories, high tension electric towers, conductors with insulators, transformers and meters. For Zaire and probably for most countries in Africa, this equipment must be imported since no local manufacturers exist. The cost of these items generally must be borne in foreign exchange (dollars).

2.4) End Uses of Power Generated

Power generated by missionary hydro-power facilities in Zaire has been used mainly for hospitals and maternities, dispensaries, machine shops, schools, and home appliances and lighting purposes. The individual and small business facilities have been used to run commercial equipment, machinery, mills, and appliances, as well as for domestic needs such as home lighting and appliances.

2.5) Role of Small Hydropower plants in the National Electrification System

These small hydropower plants are not interconnected; they are installed in remote areas, generally widely separated and serving different load centers. There exist no interconnections between these small hydropower systems and the national electrical system network.

3. PRELIMINARY NEW SITE ASSESSMENTS

Preliminary assessment of sites capable of providing sufficient hydropower for rural areas has been conducted by both the Government of Zaire and by various donors, the latter including especially USAID.

3.1) GOZ Assessments

The GOZ's energy policy working group, steered by the Service Presidentiel d'Etudes (SPE), has made a partial inventory of the small hydropower sites to be considered in the future development of Zaire's rural electrification program.

A list of these sites is presented in App. B. Ref. 4. The GOZ defines a "mini" hydroelectric plant as one with an installed capacity of 2000-10,000 KW. Plants with capacity below 2000 KW are considered "micro-hydro".

3.2) USAID Assessments

Other small hydropower sites have been investigated by USAID/Zaire in response to requests by various parties interested in financial and technical assistance in developing rural hydroelectric power potential.

A summary of the available information on these sites is provided in Appendix C. According to USAID criteria, small hydropower plants may be subdivided into two groups: micro- and mini-hydropower plants. Micro hydro plants are those with a capacity for power output ranging between 0 and 100 KW; mini hydro plants are defined as having a capacity ranging between 100 and 1000 KW (or, depending on circumstances, up to several megawatts in some cases).

3.3) Criteria for Site Selection (Ref. 3, p. 32)

A preliminary set of criteria for evaluating sites for further consideration has been developed. Evaluations are based on the analysis of data provided in requests for developmental assistance, site inspections, and reviews with government officials and sponsoring communities. These criteria are presented below.

3.3.1) Social and Economic Impact - This is measured in terms of population, schools, medical facilities,

commercial enterprises, and agro-industrial facilities to be served. It includes an assessment of community capacity to generate revenues sufficient to amortize installation and operating costs.

3.3.2) Existing Availability of Electric Power - Consideration is given to whether hydroelectric power is the best alternative for meeting the electrical energy requirements of the area. Areas within the service radius of a transmission grid (existing or being planned) would not be considered unless it would be impractical to tap existing lines (as when step-down transformers would be too costly or imcompatible with the major system).

3.3.3) Potential Power - The electrical potential at a site is considered in terms of both capacity (KW) and energy (KWH). Sites where water resources exist, but the electrical potential is too low or too unreliable due to seasonal flow fluctuations, are not suitable.

3.3.4) Head Available - A minimum acceptable head is set to eliminate potential sites that may have sufficient water resources but, due to the low head available, would be too costly to develop. A head of less than three meters generally is considered impractical to develop.

3.3.5) Compatibility with Regional Development Plans - Each site is checked for compatibility with the development program of the Government of Zaire. Certain agricultural production centers receive a higher priority for development by

the GOZ.

3.3.6) Environmental Impact - An assessment o the environmental impact of site development is considered. For most small hydro facilities, environmental impact is expected to be low.

3.3.7) Distance to Load Centers - The distanc from the generating plant to load centers determines the exte of transmission lines needed. Very long lines serving a smal load are not practical.

3.3.8) Favorable Geological Conditions - An initial assessment of geological conditions at the site should be favorable.

3.3.9) Availability of Skills - The availabili of local personnel to help install, operate and maintain the hydroelectric plant is considered. At a minimum there should be sufficient managerial and technical personnel capable of absorbing appropriate training and technical assistance.

4. PLANS FOR FUTURE DEVELOPMENT

Following a national energy colloquium in 1980, SPE wa designated to head a GOZ working group charged with developing a national energy policy. The first drafts of that policy have given the development of small rural hydropower priority. SPE now is proceeding with regional surveys to lay the foundation for a national rural hydroelectric development plan. Initial thinking for that plan envisions a series of pilot projects to

develop an experiential base of information regarding technical, managerial, and financial requirements at both the national and local levels. The GOZ has requested USAID assistance in operational studies for rural hydroelectric development.

The GOZ and USAID/Zaire now are beginning the planning for a project to undertake operational feasibility studies through demonstration projects. In 1981 USAID requested the assistance of NRECA to conduct a preliminary survey for such an undertaking. The NRECA report (ref. 3) endorsed the concept and outlined a range of options for initial planning. The costs of a national pilot program tentatively have been estimated at $15 million.

The project concept focuses on institution building and technology transfer in the process of establishing a base upon which the long-term development of Zaire's rural hydroelectric potential can be founded. It is anticipated that principal operational responsibility will be seated with the national electricity company (Societe' National d'Electricite' SNEL). Under the project SNEL would establish a Rural Minihydro Division staffed with engineering, economic, administrative, and logistics specialists. The Division would be trained and supported over the life of the project by a technical assistance team of experienced professionals representing those several disciplines. Training of key managerial and technical personnel would be carried out in-country and abroad.

The project would undertake the installation of a number of minihydro facilities to test feasibility in different geographical regions and under various socio-economic conditions. Development of

these facilities would provide opportunities for practical experience for SNEL personnel and would help refine the criteria for site identification within a long-term national energy development program.

As a result of the project, SNEL would develop the institutional capacity to provide the essential technical, managerial, and logistical support for future minihydro electrification in rural areas. Specific support capacities would include:

Civil engineering for the design and construction of water control structures, hydrology (water supply and flood estimation), turbine selection and installation, geologic assessments, and environmental impact assessments.

Electro-mechanical engineering for the design and construction of electrical systems and installation of generation, control and transmission equipment for small hydroelectric systems.

Economic and social analysis to assess and assist community organization, planning for power distribution and use, financing for installation and operation, and amortization of costs.

Administrative and logistical support to facilitate planning and to reduce constraints to timely and effective implementation of plans.

It is expected that the project would explore the possibilities for establishing financing mechanisms to provide resources for the sustained growth of Zaire's rural electrification. The roles of cooperative associations, local savings institutions, regional and national development banks, and donor assistance would be considered.

5. SUMMARY AND CONCLUSION

Because the GNP of a developing country bears a close relationship to the quantity of energy consumed (ref. 5), it is clear that continued efforts to develop hydroelectric potential whenever it is economical can play a vital role in the economic and social development of any country.

Small-scale hydroelectric power can meet the needs of isolated rural communities; it combines the unlimited future of a renewable resource with the reliability of a proven technology; it is available now; and it can be integrated with other energy sources and technologies. (Ref. 6).

With the impetus provided by ever-increasing oil costs, more attention is being directed toward the design of hydroelectric equipment packages for cost-efficient systems. Small-scale hydroelectric systems falls into two categories Ref.7): micro-hydro, (0-100 KW) and mini-hydro (100-1000 KW). Whether an installation falls into the category of microhydro or mini-hydro is determined primarily by the amount of potential energy available at the site. The physical principles involved are

the same for all hydroelectric systems. System design and development must be tailored to the potential. Methods must be developed to reduce commensurately the costs of design installation, and operation in accordance with the amount of energy expected to be generated by smaller minihydro projects.

With the availability of new materials (e.g. bearings, small generators, and electronic controls) it has become possible to effect small-scale hydropower systems with installed costs of $2000 or less per kilowatt and that require less than 5% of invested capital per year for operation and maintenance. Such systems can have useful economic lives of 30-40 years. They also can be installed in a matter of months by essentially unskilled labor with a modicum of technical assistance and supervision. Further refinement of such systems, reducing costs and complexities from start to finish, should be the goal if the potential for rural hydroelectrification is to be fully and rapidly exploited.

REFERENCES

1. ZERBAN A. and NYE, E.P.: Power Plants, International Textbook Company, Scranton, Second Edition p. 41

2. SCIENCE AND TECHNOLOGY DIVISION, Library of Congress, Washington D.C.: Phase I Environmental Profile of the Republic of Zaire AID contract No. SA/TOA 1-77 with the US Man and the Biophere Secretariate, Department of State, Washington, D.C., June 1980

3. NATIONAL RURAL ELECTRIC COOPERATIVE Association, 1800 Massachusetts Avenue, N.W. Washington D.C.: Small Hydropower and Rural Electrification Project for Zaire. SDH Program - International Programs Division. July 1981

4. SERVICE PRESIDENTIEL D'ETUDES (SPE): Colloque National sur l'Energie-Potentialites Energetiques. Nsele, 25 au 28 fevrier 1980. P. 22

5. GLADWELL, J.S. and WARNICK C.C.: LOW-Head Hydro, An examination of an alternative energy source. Idaho Water Resources Research Institute, Moscow, Idaho 83843, U.S.A. June 1979

6. NATIONAL RURAL ELECTRIC COOPERATIVE ASSOCIATION 1800 Massachusetts Avenue, N.W. Washington D.C. 20036: Small Hydroelectric Power Plants, an information Exchange on Problems, Methodologies, and Development. P.6

7. Advisory Committee on Technology Innovation, Board on Science and Technology for International Development - Commission on International Relations - National Research Council: Supplement Energy for Rural Development. National Academy Press, Washington D.C. 1981 p. 48

APPENDIX A

KODA HYDROELECTRIC PROJECT

Summary Cost Estimate

February 1982

ITEM	TOTAL COST	
	Z	$
Materials	1,017,500	-
Equipment	248,900	361,000
Training & Supervision	14,800	45,000
Contingency	380,000	40,000
GRAND TOTAL	1,661,200	446,000

NOTE: These estimates are based on a study prepared by USAID/Zaire for the Koda Falls Project in Haut Zaire Region. The estimates exclude costs of design. Combining local and foreign exchange costs yields a total project cost of approximately $600,000 ($1=Z5.5 at the official rate and approximately Z10 at the current market rate). Planned capacity for the Koda Falls installation is 250 KW.

APPENDIX B

SITE ASSESSMENT SUMMARY I
(Government of Zaire)

Region name	River name	Zone name	Fall name	Head (m)	Flow (m^3/s)	Theoretical Power (KW)
Kasai Occidental	Tshibashi	Demba	Tshibashi	4.00	5.00	160.0
"	Miao	Kazumba	Tshibuayi	4.26	66.5	2,266.32
"	Lulua	Karanga	Bombo	10.00	100.00	8,000.00
Kasai Oriental	Katsha	Lupatapata	Katsha	17.14	0.56	76.80
"	Mbuji-Mayi	Mwene-Ditu	Katambaye	13.80	126.00	13,910.40
"	Luilu	Gandajika	Kafumbu	10.05	92.01	7,397.85
"	Muovo	Miabi	Muovo	20.00	2.92	467.20
Kivu	Rutshuru	Rutshuru	Rutshuru	23.00	14.00	2,576.00
"	Fuku	Rutshuru	Rutshuru-Fuku	25.00	1.40	280.00
"	Musosa	Lubero	ITAV-Butembo	7.60	1.50	91.20
"	Semliki	Lubero	Semliki	20.00	90.00	14,400.00
"	Luhulu	Lubero	Mugomba	140.00	10.00	11,200.00
"	Mweso	Masisi	Ngingwe	15.00	18.00	2,160.00
"	Mweso	Masisi	Binza	25.00	12.80	2,560.00
"	Nyakisuma	Masisi	Nyakisuma	172.00	0.50	688.00
"	Osso	Masisi	Osso	15.00	25.80	3,096.00
"	Luberizi	Uvira	Luberizi	28.00	1.50	336.00
"	Mutambala	Baraka	Malitchia	6.50	11.20	582.40
"	Ulidi	Mwega	Mwega	30.00	27.50	6,600.00
Bas-Zaire	Luasi	Mbanza-Ngungu	Gombe-Matadi	10.00	2.20	176.00
Haut-Zaire	Lindi	Banalia	Bengamisa	12.00	500.00	48,000.00

GOZ Site Assessment Summary I (continued)

Region name	River name	Zone name	Fall name	Head (m)	Flow (m^3/s)	Theoretical Power (kW)
Kivu	Lutulu	Lubero	Butembo	174.00	3.10	6,000.00
Ki	Butahu	Beni	Ruwenzori I	180.00	3.10	6,000.00
Kivu	Lusilube	Beni	Ruwenzori II	180.00	2.50	6,000.00
Kivu	Kilita	Uvira	Kiliba	545.00	2.00	15,000.00
Kivu	Lubero	Lubero	Lubero	45.000	2.50	1,700.00
Kivu	Talya South		Muhuma	280.00	8.10	25,000.00

APPENDIX C

SITE ASSESSMENT SUMMARY II

(USAID/Zaire)

Region	Zone	River	Fall	Head (m)	Flow m^3/sec	Power (KW)
1. Equateur	Gemena	Libala River Tributary	Zulu-Karawa Karawa	7.0	5.00	200.00
2. H. Zaire	D'jungu	Koda	Koda	94.00	0 28	254.59
3. Shaba	Kamina	Lulelwe	Songa	11.20	24.00	2,104.76
4. Bas-Zaire	Luozi	Ngudi	Sundi-Lutete	16.50	24.00	3,106.00
5. Bas-Zaire	Mbanza-Ngungu	Lunionzo	Sona-Pangu	--	--	20.00
6. Kivu	Rutchuru	Putchurce	Rwanguba	--	--	125.80
7. Bas-Zaire	Mbanza-Ngungu	--	Gombe-Matadi	--	--	140.00
8. Bas-Zaire	Mbanza-Ngungu	Notake	Nkamba	30.00	0.07	15.00
9. Bas-Zaire	Madimba	--	Sona-Bata	--	--	40.00
10. Haut-Zaire	Irumu	Notake	Tshabi	17.00	0.30	50.00
11. Haut-Zaire	Irumu	Ababiba	Tshabi	30.00	0.12	40.00
12. Kivu	Shabunda	--	Katchungu	--	--	12.00
13. Kivu	Fizi	--	Nundu	--	--	100.00
14. Kivu	Pangi	--	Kama	--	--	--
15. Kasai Occ.	Dibaya	Lubi-Mpata	Lubi-Mpata	--	--	180.00
16. Kasai Occ.	Dibaya	Lukula	Tshidimba	8 13	2.30	154.46

Slide Presentation: Small Hydropower Schemes

by

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Biographical Sketch

Allen 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 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 science 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.

TEXT

The purpose of this presentation is to illustrate, with slides, what is involved, on the physical plane, in small hydropower installations and then to describe some aspects of small hydropower which make it an attractive option.

A. Let me briefly review the range of hydropower projects encountered around the world to see where small hydropower fits in.

1. Most people are more familiar with large hydroelectric projects generating hundreds of megawatts and beyond. Not only are these impressive showpieces but they can make a major contribution to the electric power available for the development activities of a nation. For those oil-importing nations, developing large hydroelectric projects brings the promise of reducing the drain on foreign exchange. But these developments are not without their drawbacks. Not infrequently, they introduce adverse environmental impacts, including the spread of disease carriers and the flooding of agricultural land, and social dislocations. They generally require a heavy radiance both on costly outside expertise for their design, construction, and maintenance and on costly imported equipment and materials.

2. Smaller hydroelectric schemes allow for greater local inputs and therefore greater financial returns and benefits to a nation. This 3 MW plant near Fang in northwestern Thailand, for example, was designed by Thai and constructed by local companies with only the turbogenerating equipment and associated hardware being imported.

3. Because of the increasing cost of oil, there is an increasing interest in even smaller plants which until recently would not have been cost effective compared to diesel. These are often in more remote areas at some distance from the national grid, serving small population centers and often replacing existing diesel generating sets.

4. And finally, near the bottom of the power range are even smaller hydropower plants. While these have no significant impact on the total power available to a country, they do meet specific needs and perform a valuable service. Among these are, for example, a 90 kW plant providing power to a hospital and staff housing in the central highlands at Papua New Guinea, a 12 kW plant furnishing power to a forestry station and tribal village in northwestern Thailand, and a 1 kW plant providing lighting to a very remote mountain village in Papua New Guinea. These smaller plants permit even greater local inputs, even local fabrication of a portion of the turbogenerating hardware and community participation in the installation and management of the schemes. They can make a direct contribution to rural development.

B. Let me briefly describe what is involved when one talks of small hydropower plants.

1. Though there is a wide range of sizes and designs, all hydropower plants perform the same function - by means of a turbine, they harness the energy lost by water as it drops in elevation.

2. To accomplish this end, there is a variety of different turbines that can be used to cover the entire range of heads and a range of designs for hydropower

schemes which are determined by conditions at the proposed site. However, all hydropower schemes include some or all of the following components (Fig. 1):

a. The first step is to divert water from the stream toward the powerhouse. This might be done by building a dam as was done at this 1 MW locally constructed project in Nepal. But whereas dams are generally associated with large hydroelectric plants because excess water can then be stored, one tries to avoid dams in designing small schemes because heavy rainfalls in the tropics, often coupled with hillside slopes made bare for agriculture, contribute to heavy silting and large flow variations and create potential problems. Also, dams often require a costly series of thorough engineering studies of the site as well as the structure. Small schemes are generally run-of-the-river designs where water is used as it flows downstream and none is stored for later use. In this case weirs or other diversion structures are placed across the stream to deflect water into the intake. The intake from the stream is generally equipped with a metal grill or trashrack to prevent floating or other large debris from entering. A gate for controlling the flow toward the powerhouse is also often included.

b. Near the intake may be a settling basin to permit any water-borne sand and gravel to be deposited there and prevent their being deposited in the canal on the way to the powerhouse, gradually hindering the flow of water, or carried through the turbine where it causes rapid deterioration of the turbine.

c. Though it is sometimes advisable to convey the water directly from the intake or settling basin to the turbine by means of a pipe, this often leads to excessive costs. An alternative to reduce these costs is to bring the water

as close to above the powerhouse as possible by means of a canal which nearly follows the contour of the land. This power canal can be of a variety of materials including concrete, wood, or earth.

d. This canal carries water to the forebay, a basin located just before the intake to the pressure pipe to the turbine. It serves (1) as an area where any suspended matter in the water can settle out and (2) as storage for small volumes of water to accommodate initial changes in flow through the turbine.

e. The water then flows through the penstock, a pipe conveying the water, under pressure, to the turbine in the powerhouse. There the water power is harnessed and the spent water is returned, usually to the original stream.

3. The following sequence of slides of a hydropower scheme on the island of Bali in Indonesia illustrate how these components are integrated into an overall scheme. As with many hydropower schemes in Indonesia, this scheme is integrated into an irrigation system. Water is therefore used either for irrigation or power generation or both. In this manner, since costs are shared, the cost of the hydropower plant itself can be reduced.

In this scheme, the dam is used to maintain the water level and not for the storage of water. The intake takes water in at right angle to the river and leads into a settling area. For here, a canal first leads the water through a tunnel and then into an open canal. Then a portion of the water is used for irrigation and another portion is carried off to the forebay, and then down the penstock to the powerhouse where a drop of 11 meters generates about 80 kW.

C. Although all serve the same purpose, hydropower plants have different layouts and require different turbines depending on the actual site. The actual turbine used is primarily a function of operating head. This may range from one to two meters to a thousand or more meters. An approximate relationship between the power generated in a hydroelectric scheme and the head and flow available at the site is shown by the equation in Fig. 2.

1. An example of a low head site is located at Wonodadi on the island of Java in Indonesia. It is similar to other schemes in the country which are integrated in existing irrigation network. The slides from the island of Bali seen previously used excess water from an irrigation canal whereas this one makes use of a drop along a major irrigation canal. When operating, water is diverted by a short canal just upstream from the 3-4 meter drop through the powerhouse where 230 kW is generated. Because of the low head, a large flow must pass through the turbine and this latter is large.

2. An example of a higher head site is a new site located at Nam Dang in northern Thailand. Under a higher head of 79 meters, it requires less water to produce a 50 kW, and consequently a much smaller turbine. In this case, the turbine is fabricated in a local workshop and is of the design shown here.

D. Until recently, only large hydroelectric schemes attracted the attention of developing countries. But increasing interest is being placed on small decentralized hydropower schemes. Some of the reasons for this are the following:

1. Whereas large projects rely largely on imported materials, equipment and expertise, smaller projects permit a larger use of locally available materials and

labor. In Pakistan, for example, penstocks are not only fabricated of steel when necessary, but also of discarded oil drums and even timber from the local forests.. Also with smaller schemes, there is a greater possibility of local manufacture of at least some of the turbogenerating equipment.

2. Whereas large schemes uniquely generate electrical power, small hydropower schemes permit, in addition to electricity generation, direct mechanical drive for workshop equipment, small industries, and agro-processing equipment. All these can be directly run off the turbine without electricity, reducing the costs and complexity of hydropower plants. This is especially appropriate in rural areas where power can increase productivity but where technical skills necessary to maintain electrical equipment are not highly developed.

3. Whereas large schemes generate a large quantity of power, little finds its way to the rural areas because the high cost of transmission makes this uneconomical. Compounding this problem is the fact that the load in rural areas is not developed, being used only for lighting, and the economic base to pay for the electricity from the grid does not exist. On the other hand, small decentralized hydropower plants permit power to be generated near the rural customers, avoiding the enormous costs due to transmission. Small plants, in conjunction with end-use programs can encourage the development of economic growth in these areas. If the local needs eventually exceed the capacity of a small plant, the higher load factor which will have developed will make the power transmitted from large centralized schemes less costly and the customers, because of economic activities which have developed, will be in a better position to meet these costs.

E. A number of organizations and governments are undertaking small hydropower programs. A few, like Indonesia, have been involved for numerous years and manufacture turbines into the megawatt range. However, most developing countries have virtually no experience with small hydropower projects and therefore begin their program more modestly. Nepal is an example of such an approach.

Traditionally in Nepal the hulling of rice, milling of grain, and the expelling of oil required manual inputs. Centuries ago, the grinding of grain was mechanized through a rudimentary water-powered mill. More recently this has been replaced by diesel engines powering the hulling, milling, and oil expelling equipment. In the last four years, one company in Butwal, Nepal, has fabricated and installed turbines for more than fifty sites in remote parts of the country to replace the costly processing by diesel engines. These installations are virtually unsubsidized with costs being kept down by maximizing local manufacture, minimizing pre-installation studies, using local labor and appropriate designs.

This series of slides of one of their installations illustrates one approach to implementing small hydropower schemes. After receiving an inquiry from an entrepreneur or group in a village, one or more staff from the company visit and investigate the proposed site and discuss with the villagers the various aspects of how work at the site would proceed, what obligations they have in implementing the project, and what financial costs would be involved. If the decision is then made to undertake the project, a downpayment for the turbine and equipment is made and fabrication work is undertaken in the company workshop. At the same time, the villagers undertake the necessary excavation for the canal, powerhouse and forebay, and collected stones, sand, and other necessary materials which are locally available. Once the villagers feel they have completed their work and are ready to

proceed, they make arrangements for all the machinery and other materials to be transported to the site. Once all the materials have been assembled, a three-man team from the company goes to the site and provides the necessary expertise and guidance to the villagers to install the equipment. The penstock, turbine, anal draft tube are first assembled and as a unit, moved into place and secured. Then the huller, grinder, and oil expeller are then installed. The three-man team is paid by the day and this encourages the villages to maximize their inputs. In two to three weeks, the plant is completed and operational.

Though the activities of this company in hydropower began slowly, work is now proceeding at an increasing pace as more villagers become aware of the potential of water-driven equipment. Though initially the plants were installed for mechanically driving agro-processing equipment, there is growing interest in using the power in the evening to generate electricity. A large workshop in Kathmandu, Nepal, has also been undertaking similar work and also have about 50 plants installed. This approach is appealing because it is replicable. It can be copied by others in the country and have a more wide-spread impact in the countryside. In Nepal, several small workshops, seeing the potential for hydropower in the mountains because of the example set by these two larger companies have initiated local fabrication of turbines on their own.

This represents just one small example of an approach to the implementation of such schemes as will be covered during this workshop. It is hoped that the presentations and discussions which follow will make you more aware of the options which are open to each country, some of the problem areas which must be addressed, as well as some of the contributions to development that small decentralized hydropower can make.

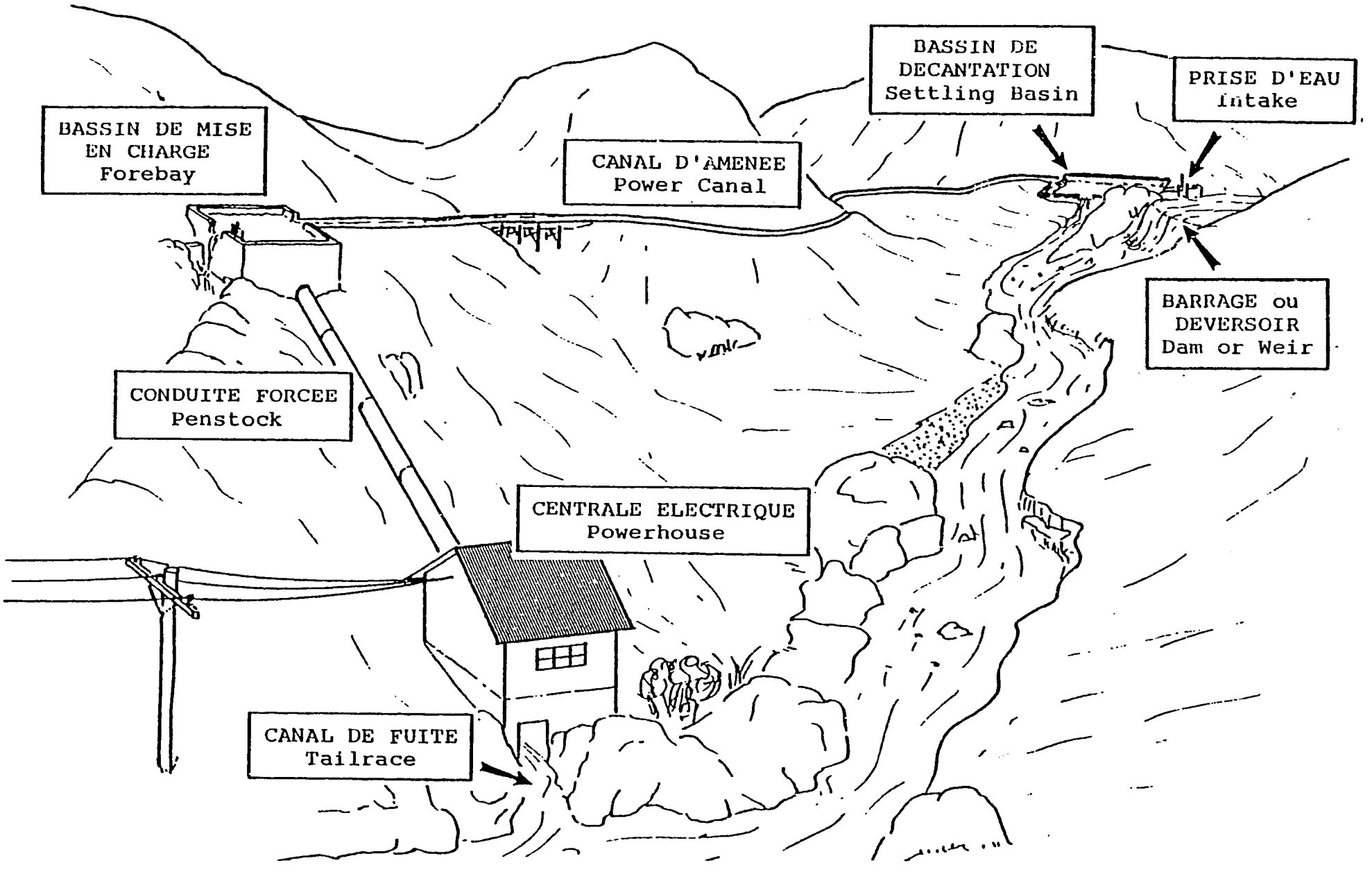
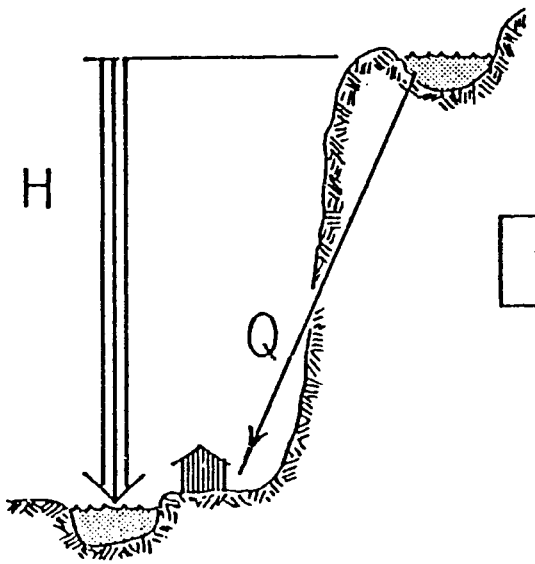


Fig. 1. Les principaux éléments d'un projet de centrale hydraulique.
Principal components of a hydropower scheme.



HIGH HEAD

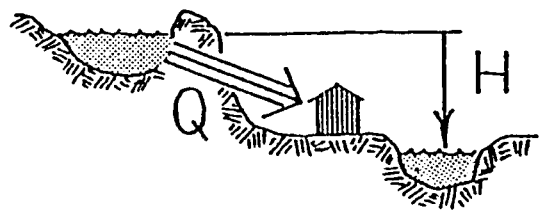
$$P \doteq 6 \cdot Q \cdot H$$

Where

P = power (kilowatt)

Q = flow (m^3/sec)

H = gross head (m)



LOW HEAD

Fig. 2. Basic parameters affecting power production. (The above equation assumes a 60% overall efficiency.)

HYDROLOGIC ASSESSMENT METHODOLOGIES

by

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ERRATA SHEET

HYDROLOGIC ASSESSMENT METHODOLOGIES

by

P.H. Kirshen

In the "Procedure" on the top of Figure 2, Number 3 should read:

"3. The average energy available each month is equivalent to the area of the hydrograph under the maximum flow line except in the case when the average monthly flow does not exceed the minimum flow. In these month, no energy is considered available."

Hydrologic Assessment Methodologies

Abstract

The hydrologic, environmental, and geological factors to be analyzed in siting mini-hydroplants in prefeasibility and feasibility studies are presented. Both simple and complex methods of analysis are discussed. Appendices on quality and augmentation of hydrologic data and measurements of flow and head are also included.

The major purpose of hydrologic studies is to estimate power and energy potential by discharge and head studies. Related analyses include tailwater elevation changes, flood discharges, and evaporation and transpiration losses.

Environmental studies should be conducted concurrently with other hydropower studies so that particularly adverse environmental impacts can be mitigated by design or operational changes. It is also possible to enhance positive aspects. Environmental impacts should be presented to decision-makers by category of impact. The single most important factor in assessing the impact of a mini-hydro project is whether there is water impoundment or not.

The three major geological factors to consider are sediment loads in streams, conditions of valley sidewalls and foundations at dam sites, and earthquake conditions.

Biographical Sketch

Dr. Paul Kirshen is a consultant working in all aspects of water resources planning and engineering. Mini-hydro projects include technical assessments in New England, Togo, and Nepal. He has also been involved in major studies of the social, legal, institutional, environmental, and economic impacts of mini-hydro. Dr. Kirshen has also worked on projects concerning the collection and use of real-time hydromet data, flood management, international, integrated river-basin planning, water quality, and water supply. He has published about 30 reports and papers.

Dr. Kirshen has worked in private industry and has taught at Dartmouth College and Virginia Polytechnic Institute and State University. He received his degrees from Brown University and the Massachusetts Institute of Technology. He is a member of the American Society of Civil Engineering, the American Geophysical Union, and the American Water Resources Association.

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Appendix A. Quality and Augmentation of Streamflow Data

Appendix B. Measurements of Head and Discharge

I. INTRODUCTION

When a mini-hydro project comes on line, it represents the successful completion of the planning process shown in Figure 1. Initially a broad-scale country assessment of mini-hydro is done. The results of this are identification of areas where mini-hydro best meets the needs of a country. Prefeasibility studies are then done to reduce the large number of potential sites in the region or country by coarse-grained analysis to a much smaller number of candidate sites (for example, 25 to 50 sites). The last step in site selection is the feasibility study where the candidate sites are studied in greater detail and final sites selected (for example 1 to 5 sites). These sites then go through the site approval, planning, design, and construction steps.

At each step in the process, a range of factors must be considered. These include hydrologic, environmental, geologic, economic, financial, social, and energy policy factors. Ideally, all factors should be simultaneously considered at each step but, in practice, usually hydrologic factors initially dominate (to ascertain the magnitude of the mini-hydro potential) and then other factors are considered and used to adjust the results of the hydrologic analysis.

Presented in this paper is a discussion of the hydrologic, environmental, and geological factors that affect site selection. The general emphasis is upon the prefeasibility and feasibility levels of analysis. Within each section, both simple and complex methods of analysis are presented. The reader should also remember that all methods and analyses need to be adjusted for local factors and data availability.

II. HYDROLOGIC ANALYSIS

Introduction

The major purpose of hydrologic studies is to estimate the power and energy available at a site through discharge and head studies. Other related studies include: (1) the change in tailwater elevation so that the net head fluctuation can be determined, (2) the magnitude of the flood discharge so that the spillway can be designed, and (3) the evaporation and transpiration rates to account for storage losses and head changes. Each of these topics is addressed in this section from a prefeasibility and then a feasibility analysis point of view. Seepage losses and sedimentation effects are discussed in the section on Environmental and Geological Factors.

The section concludes on adjustments to the methods when hydropower production is not the primary purpose of the project.

In many parts of the discussion, it is assumed that sufficient and high quality data are available at site to do the analysis. Methods of studying data poor sites are discussed in Appendix A. The various types of hydrologic studies and their purposes are summarized in Table 1.

Power and Energy Potential

The well-known formula for power at a site is

$$P = 9.81\ QH_n e \qquad (1)$$

P = power (Kw)

Q = discharge (m^3/sec)

H_n = net head (m)

e = efficiency of turbine and generator

In English units it is

$$P = \frac{QH_n e}{11.81} \qquad (2)$$

where Q = discharge (ft^3/sec)

H_n = net head (ft)

and other variables are the same. Energy is determined by multiplying the power by time of operation.

Therefore to estimate the power and energy potential at a site, both discharge and head must be known.

Prefeasibility Study. In prefeasibility studies, it is necessary to estimate the average energy production resulting from the installation of one or several turbine/generator units. In this manner, average annual energy value can be compared to the average annual costs.

The simplest manner to select turbine capacities that may be feasible for a site and the corresponding annual average energy production is to assume the net head and efficiency are constant and storage affects are negligible, and to use "rules of thumb" developed for an area. For example, in one part of the world, it was found that designing for the mean annual discharge and a 40 percent capacity factor (capacity factor is defined as actual annual energy production divided by theoritical energy production if plant operated all year at design discharge) usually produced economical designs. Therefore in prefeasibility studies, this method was used to estimate power and energy production . In another part of the world, it was found that capacity and energy production could be estimated by sizing the turbines at 50 percent of the mean flow and assuming such a plant operated at full capacity for 5 months of the year and produced an additional energy output of 10 percent during the remaining 7 months.

Other rules of thumb are based upon precipitation values and drainage areas. Obviously, the analyst must review how the rule of thumb was derived and accept it. It is entirely possible that for many prefeasibility studies, such rules of thumb will not exist. To develop such rules of thumb, prefeasibility or feasibility studies of

mini-hydro in hydrologically similar areas (see Appendix A for discussion of "similar" areas) can be reviewed and the results generalized. An alternative is for the analyst to conduct several prefeasibility or feasibility studies using the more complex methods described below and then generalize the results.

One of these more complex methods is to plot the monthly annual hydrographs of a few actual years whose annual discharge approximates the average annual discharge at the site. The one most representative of a typical year can be chosen and the annual energy production that would occur if a particular turbine size was selected can be estimated. (The method of calculation is discussed in Figure 2.) While estimates of energy production found from these above methods are very approximate, they are satisfactory for prefeasibility studies.

The most accurate but time consuming method to estimate annual average energy production for a prefeasibility study is to construct a monthly or daily annual flow duration curve. (See any standard hydrology book on how to do this, for example, Viessman et al (1977) or Gladwell (1980).) Figure 3 shows how to use the curve to estimate energy production for a possible turbine size.

As was discussed earlier, net head is usually assumed constant in mini-hydro prefeasibility studies. Discussed in this part of the report are how net head can be estimated at site. For a reaction turbine net head is the elevation difference between the forebay water surface and the tailwater surface minus friction losses in trash racks, intakes, penstocks etc (depending upon the configuraton these range from negligible to 10 percent). For an impulse turbine, the discharge velocity head must also be deducted, which is the elevation difference between the nozzle centerline and the tailwater surface.

There are many ways head or elevation drop can be developed at a site. Some of these include using an existing dam or repairing a damaged dam, taking advantage of natural falls with penstocks, damming up steep-walled valleys, using irrigation dams, canals, and drop structures, and using penstocks to connect different sections of a steep river "bend" or to divert water from one river to another. In conducting a prefeasiblity study, it is best to first view a potential

site on a topographical map to determine different possible configurations and then measure the head during a site visit using one of the survey methods in Appendix B.

Unless high tailwater conditions will prevail for more than 10 percent of the year and the head is relatively low, it is usually not necessary to study high tailwater effects in prefeasibility studies of power and energy potential. It may, however, be necessary to adjust net head estimates for reservoir evaporation and transpiration losses if such losses are significant (see the section on Evaporation and Transpiration Losses).

Feasiblity Study. Since the economic value of the energy produced at a site depends upon the value of the energy it replaces in a regional load curve, the temporal distribution of the energy production at a site must be determined in a feasibility study. Whether it is necessary to know, however, the hourly, daily, monthly or annual distribution of that energy really depends upon the complexity of a region's energy demand load curve and the amount of storage available at the site. For example, if little storage is available (for example, less than a few hours), and the demand pattern is not complex and/or all energy has approximately the same value, it may be sufficient just to know the average annual energy production. On the other hand, if significant storage is available (for example, 12 hours) and the demand pattern is complex (i.e. clear periods of base, intermediate and peak), daily or even hourly energy production must be known.

At this level of analysis, at least an annual flow duration curve with assumed constant net head and efficiency must be used to estimate annual average energy production. If monthly distribution of energy must be known, monthly flow duration curve analysis can be used. If the monthly net heads vary considerably because of tailwater effects and/or evaporation and transpiration losses, it may be necessary to also assume a monthly distribution of net heads and efficiencies. The most accurate method to determine the average annual energy production and temporal (for example, daily or hourly) distribution of energy at a site is the use sequential simulation of the operation of the

plant. This is usually necessary at sites with significant storage. In this method, a computer model of the reservoir, turbine and generator is built, and the operation of the system with 10 to 100 years of historic or synthetic data on a time step of a few hours to a month is simulated. Indicators of system performance such as average annual energy production, temporal distribution of energy with specified reliability, average volume of spills etc. are measured. In the most complex cases, reservoir volume-area-elevation, turbine head-discharge-efficiency, and downstream flow-tailwater elevation curves are used. For a more detailed description of sequential analysis see Volume III of U.S. Army Corps of Engineers (1979).

At the feasiblity study level, the net head (the other major factor in the power equation) must be adjusted for the type of turbine under study (impulse or reaction), changes in reservoir elevation (for example, due to evaporation and transpiration losses or releases for another purpose such as irrigation), and changes in tailwater elevation if they are significant and persistent. Tailwater effects are discussed next.

Tailwater Elevation

Prefeasiblity Study. It is usually not necessary to study tailwater effects in prefeasibility studies unless the tailwater is persistently high during one or two periods of the year. Quick estimates of tailwater elevations can usually be obtained by speaking to local residents or applying the equation of Gradually Varied Flow (see Chow (1959) for a discussion of this) to average monthly flow conditions.

Feasibility Study. Since reasonably accurate costs and design criteria must result from feasibility studies, tailwater effects must be studied in some detail. It must be known how it varies throughout the year, and the lowest that will ever occur under turbine operation. The latter information is necessary to insure that a reaction turbine will not have cavitation damage. Monthly variation in tailwater elevation can be estimated by assuming a downstream flow

condition, a reservoir and/or spillway release and then applying the equation of Gradually Varied Flow to estimate the resulting flow profile. A similar method of analysis can be used to estimate the lowest tailwater elevation that will most likely exist when the turbine is operating (note: this will probably not be minimum flow of record at the site because under these conditions the turbine will probably not be operating).

Flood Discharge

Prefeasibility Study. In this level of analysis, it is usually not necessary to estimate the magnitude of the spillway design flood. Rather, to develop the broad analysis of cost needed at this step, it is only necessary to estimate the type of dam and spillway needed.

Feasibility Study. In a feasibilty study, it is necessary to estimate the magnitude of the spillway design flood. The method of analysis used and level of safety sought really depends upon the consequences of the spillway capacity being exceeded. For example, if an earth dam is used and there is activity below the dam that can not be flooded or damaged, high design safety and very accurate analysis should be used. On the other hand, if a concrete dam is to be built and designed to serve also as a spillway and there is little important activity below the dam, a lesser degree of safety and accuracy is needed. Since dams and reserviors for mini-hydro are small, in most cases a design recurrence not exceeding 50 to 100 years should be used.

If there is 20 to 30 (n) years of annual flood data for a site, the design flood can be estimated in several ways. The simplest is to plot the annual flood on semi-log graph paper assuming the largest flood has a n-year return period and then extrapolate the graph (see Figure 4).

A slightly more complex method is fit a commonly accepted extreme value probability distribution to the flood data. Examples of these are the Log-Pearson Type III and the Extreme-Value Type I distributions. These are described in any hydrology book such as Linsley et al (1975).

If such streamflow data are not available, but rainfall intensity-frequency-duration data are available, Crawford and Thurin (1981) in a report prepared for NRECA present a variation of the rational method to estimate the peak flow.

In places where there are insufficient streamflow or precipitation data, there are several alternatives. One is to find a hydrologically similar watershed (see Appendix A for description of "hydrologically similar watershed") with sufficient data and find the peak flow per unit area and/or unit annual rainfall. This information can then be applied to the site under study. Another alternative is to estimate the height of the peak flow through site observations and discussions with local residents and then convert this to discharge. Crawford and Thurin (1981) discuss this method in detail. The drawback to this method is that it is not possible to estimate the recurrence interval of the peak flow. In most cases, this is not particularly severe as long as the depth estimate is indeed an extreme value. This is because at the higher recurrence intervals (greater than 30 or 40 years), there is not a great difference between the recurrence intervals of peak flow values. For example, as shown in Figure 4, the peak flow increases by 100 percent between the one and ten year recurrence intervals. Between the 40 and 50 year recurrence intervals, the flow only increases by 5 percent. Therefore whether the actual depth measured corresponds to a 40 to 50 year period does not make a significant difference.

Evaporation and Transpiration Losses

Reservoirs can go dry during extended periods of no precipitation if surface evaporation and transpiration losses from phreatophytes bordering the reservoir are large.

Prefeasibilty Study. Generally such data are not needed at the prefeasibility level of study. All that is needed to be known is if there are significant losses during extended dry periods. If there are such losses, it means most shallow reserviors will go dry and over season storage is not possible.

Feasibility Study. In areas where there are significant annual losses (perhaps greater than 50 percent of the annual precipitation), average annual and monthly losses must be estimated.

If such data are not available at the site or nearby similar areas, estimates will have to be developed. Evaporation can be measured with evaporation pans or calculated using methods such as the energy balance approach and the Penman method (see Linsley et al (1975)). Transpiration losses from bordering phreatophytes can best be estimated from local agricultural transpiration data.

Energy Potential at Sites Where Hydropower is Secondary Purpose

As was described earlier, hydropower facilities can be located at dams and other structures designed for such primary purposes as water supply or irrigation. The major impacts of this are that the stream discharges are not naturally occurring. Therefore the pattern of dam releases (known as the operating policy) must be learned from reviewing project documents and interviews with dam operators and owners. Once this pattern of flow is known, methods similar to those discussed previously can be used. For particularly complex operating policies, sequential simulation may be the only method to estimate energy output for feasiblity studies.

III. ENVIRONMENTAL ANALYSIS

Introduction

As stated earlier, a range of factors must be considered in the design of a mini-hydro project. Technological, social, economic, financial, hydrologic and envionmental considerations are several of them. A decision to implement a project must be based upon the trade-offs between these factors. Presented in this section is a discussion of the environmental effects of mini-hydro development and how to incorporate them in prefeasibility and feasibility studies. Environment effects only include changes to the natural or physical environment as a result of a program or project, not the social or human effects. Because euvironmental impacts are very site specific, not all the environment impacts discussed in this section may be significant or occur at a particular site.

Because any decision to implement a mini-hydro program or project must be compared to other energy technologies, this section starts with a summary of some of the positive aspects of mini-hydro compared to other technologies. This is followed by the necessary environmental studies at the prefeasibility and feasibility levels. The last part of the section is a methodology for extending environmental impacts to human or social impacts. Most of the material in this section is from reports prepared for NRECA by Zoellner (1980) and Cada and Zadroga (1981). It is recommended that both of these be read.

Positive Impacts of Mini-Hydro

Zoellner (1980) presents a precise description of the comparatively positive aspects of small hydro. It is presented below and summarized in Table 2.

"Small-scale hydropower is considered to be an environmentally clean technology relative to nonrenewable technologies. It has the advantages of large-scale hydro, that is, using a renewable, fuelless resource and generating no process residuals. It is also touted as

being an appropriate technology for small developers with relatively low capital and maintenance costs. It requires very short transmission distances, has decentralized capability and engineering innovation potential. The principal environmental advantage of small-scale hydropower is the relatively small size of the facility and the relatively small scale of any attendant impacts from construction and operation, particularly for sites utilizing run-of-river, diversion, or irrigation drops. In the case of impoundment, there is a mitigating advantage. The potential exists around the reservoir for economic and recreational development.

Generally speaking, hydropower generation does not consume water in any way, so that with the possible exception of very large impoundments, hydropower is not a source of water loss to the system. In fact, hydropower development may be complementary to other water uses such as irrigation and water supply. It can provide power for these uses. The capital costs may be also lowered considerably in cases of such integrated development.

In comparing the environmental impacts of small hydropower to small scale conventional technologies, there is, as mentioned above, the absence of process residuals such as waste heat, air emissions, solid waste, and toxic substances. From a regional development standpoint where many small plants are concerned, the aggregate advantage of this may be significant. This is doubly important when considering the environmental impacts of fuel extraction, processing and shipping--events which do not occur for renewable energy technologies" (pg. 93-43).

Prefeasibility Study

As noted previously, the objective of a prefeasibility study is to reduce a large number of potential sites to a smaller number for more detailed analysis. Cada and Zadroga (1981) state that there are four basic issues of concern at this level of analysis (pgs 3-7). They are summarized in Table 3 and discussed below.

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1) The impact of the development induced by the project upon the resource base. If a project is to be build in a relatively undeveloped area or is likely to change land use or occupations in a developed area, it must be determined how the changes will effect the resource base. For example, the construction of a mini-hydro project may result in local development in an area with poor soils and fragile groundcover that is best left undeveloped. Unless mitigating measures are taken, such a site might be removed from further consideration.

2) The availability of water of adequate quantity and quality. It is obvious that there should be sufficient water flowing for power production (see Hydrology section). This, however, addresses the broader question of the possible competition between various water uses at a site. These other users must be determined so that potential water-use conflicts can be avoided. If there are too many conflicts, it may be necessary to no longer consider the site.

   It is also necessary to consider the present quality of the water at the site. If the quality is already poor or the site is in a water-related disease area, development of a project may further deteriorate the quality or increase incidence of disease.

3) Proximity of the site to a legally protected area or an area that should be declared or treated as wildland. It may not be possible to develop mini-hydro in some legally protected areas such as National Parks. It should also be noted in a prefeasibility study if a potential site will impact any rare or endangered species.

4) Level of interest and support from local community. It is essential that the project be beneficial and useful to the impacted local community and, in turn, that they support the project. This support is necessary because they may have to make some lifestyle changes to accomodate the project (e.g., no longer swim in certain parts of the river, have some land flooded, adopt certain public health measures, etc.).

Feasibility Study

Introduction. As stated earlier, environmental effects are one of the many factors that must be considered in a feasibility study (hydrologic, technological and economic are examples of other factors). An environmental assessment must be conducted for each potential site. The purpose of an environment assessment is to identify the potential impacts of the project upon the environment,

identify alternatives to the project, and propose mitigating measures for some of the negative impacts. The environmental assessment should be conducted as concurrently as possible with other studies (e.g. technological) so that particularly adverse environmental impacts can be identified early in the planning process and perhaps mitigated by design or operational changes (for example, not constructing sluice gates below a certain elevation to prevent low dissolved oxygen water from going downstream or not flooding a certain wildlife habitant).

While it is difficult to quantify many environmental impacts, the assessment information must be presented to decision-makers in an accurate, understandable, and concise manner. This will help decision-makers to make the necessary trade-offs between the various considerations in mini-hydro siting.

Since mini-hydro can have many diverse environmental impacts, it is suggested that the information be presented to the decision makers by category of impact type (for example, aquatic organisms, disease etc). The impacts within each category should be identified and further described as short or long term, reversible or irreversible, and construction or operation related. Mitigating measures should also be discussed.

Having described a methodology for conducting an environmental assessment for a feasibility study, the reminder of this section describes possible environmental impacts by category (summarized in Table 4) and concludes with a check list designed to help the analyst organize data, and identify and assess the relative significane of impacts. The majority of this information is from Cada and Zadroga (1981).

Initially, Cada and Zadroga (1981) note that the single most important factor in assessing the impact of a mini-hydro project is whether the project has a water impoundment or not. With significant impoundment of water, there will be more physical, chemical, and biological changes in the stream than with no impoundment. They also note that the magnitude of the impacts depends partly upon the relative size of the plant. A large plant will generally have more serious impacts than a smaller one, and a small plant on a small river may have more severe impacts than a moderate plant on a large river.

Flow Disruption. These impacts include channel degradation downstream, downstream sedimentation, and, if water is diverted from one basin to another, a net loss of water from one drainage basin and a gain in another. Other possible impacts include decreased downstream flooding and subsequent loss of fertilization of downstream agricultural land, variation in groundwater levels, and upsetting salt and fresh water balances in estuaries. If pond elevation fluctuates a lot because of peaking power production, there may be shoreline erosion and habitant destruction. The least disruptive operation is "run of the river, no water storage, and return of diverted water back to the same stream at a lower elevation" (pg 11).

Sedimentation. Sedimentation results from both project construction and operation. The impacts of sedimentation are many. Examples include turbine damage, burying fish spawning areas and bottom dwelling organisms, and shifting the composition, abundance, and distribution of aquatic biota. Associated with sedimentation effects is the retention of sediment by reservoirs. This can result in premature siltation of the reservoir. An associated impact is trapping of nutrients in the reservoir. Since normally these nutrients would have traveled to downstream wetlands and estuaries, the nutrient balance may be upset. The increased nutrients, in the reservoir may lead to the growth of aquatic weeds and algae—both of which lead to decreased dissolved oxygen and other water quality problems.

Water Quality. Generally, a run-of-the-river operation with no impoundment "will have little or no effect on water quality in streams" (pg 16). Water quality impacts may occur, however, if there is diversion from one watershed to another (particularly if it is of poor quality or changes the chemical composition of the receiving water), or there is an impoundment. The impoundment can impact water quality if it undergoes thermal stratification causing a temperature differential as well as decreased bottom dissolved oxygen and "greater concentrations of hydrosulfide and reduced ionic forms of iron and manganese" (pg 17). Impoundments of water can also increase the

exposure time of organisms to contaminants. In impoundments some pollutants may be adsorbed to suspended settling particles and eventually be buried on the bottom of the impoundment. Water quality may also be impacted by oils, greases, and chemicals entering the stream from the construction site.

Aquatic Organisms. Possible impacts to aquatic organisms are many. Examples include turbine damage to fish; blockage of upstream migrating fish; impingement (trapping of organisms against intake screens); destruction of downstream habitats due to decreased flow; damage downstream due to reservoir releases containing suspended material, low dissolved oxygen, toxic contaminants, and being of low temperature; changes in species composition and abundance due to change from flow to reservoir habitat (particularly important to study for economically important fisheries); and gas bubble disease to fish caused by supersaturation of water by atmospheric gas as water is released from spillways.

Waterborne Diseases and Parasites. Water impoundments provide breeding grounds for mosquitoes (which carry such diseases as malaria, encephalitis, yellow fever, and dengue) and snails (which are part of the chain of schistosomiasis and other diseases). Impoundments also decrease the natural purifying elements of running water of turbulence, sunlight penetration and oxygenation. A positive aspect of impoundments is the decreased flow in certain sections of a stream and a possible localized reduction in onchocerciasis (river blindness).

Land Use and Development. The direct land use impact of a mini-hydro project is the loss of land for access roads, canals, turbine/generator buildings, transmission lines, and reservoir pools. Perhaps a more significant land use impact may occur, however, due to development created by the project. For example, colonization in the headwaters region of project may lead to increasd erosion and subsequent siltation of the reservoir (see later section for fuller discussion of such induced impacts).

Terrestrial Impacts. Terrestrial impacts (in addition to land use and development impacts) may include alteration of wildlife habitat (due to land use changes and creation of an impoundment), and interference with nesting activities of birds due to construction noise. Construction and maintenance of transmission lines can disrupt natural land forms and vegetation, and hinder wildlife migrations.

Environmental Checklist

Cada and Zadroga (1981, pgs. 33-36) present a checklist designed to help the analyst organize the data, and identify and assess the relative significance of impacts. With the use of the checklist, it should be possible for the analyst to organize the impacts by the categories previously presented. The checklist is in Table 5.

Induced Impacts Upon the Human Environment

Because a mini-hydro project provides electricity to a region, it will have direct impacts upon the human environment. Examples may include increases in population, more light industry, changes in land use patterns, increased educational opportunities (due, for example, electric lights and radio) etc. Impacts upon the human environment will also occur indirectly because of the environmental impacts of the project. For example, fish losses due to sedimentation may result in economic losses to commercial fisherman. Zoellner (1980) presents a framework of analysis for these induced impacts.

1) Identify the cause of an impact - for example, construction of an impoundment.
2) Describe the changed condition - for example, flooding of an area.
3) State the effect - for example, improved wildlife habitant.
4) Derive the impact - for example, more hunting opportunities.

Obviously, this is a simplified example because a changed condition may be the result of several causes, and effects may be due to several changed conditions. Its application to more complex situations, however, is straightforward.

IV. GEOLOGICAL FACTORS

Introduction

Three major geological factors need to be considered in siting mini-hydro projects; (1) sediment loads in streams; (2) conditions of valley sidewalls and foundations at dam sites and (3) earthquake conditions. Siting considerations in regard to the first two factors are discussed in this section and summarized in Table 6. Earthquake conditions will not be discussed here except to note that they should be considered in the structural design of dams.

Sediment Loads in Streams

Sediment loads in streams result in accumulation of sediments in reservoirs, turbine damage, and increased potential for environment damage due to sediment releases from reservoirs (see Environmental Section).

Sediment loads in streams can be estimated by especially designed sampling devices, empirically derived sediment rating curves, or comparisons to similar watersheds.

Sediment accumulation in reservoirs result because of decreased flow velocities as rivers enter reservoirs. The trapping efficiency of a reservoir is related, in the simplest manner, to the ratio of capacity to annual inflow volume. Shown in Figure 5 is a general relationship of this. The volume of sediment trapped is determined by multiplying the weight of the trapped sediment by its specific weight. A small reservoir with a low detention time will trap less sediment than a large reservoir.

Reservoir siltation problems can be mitigated by land use control to prevent sedimentation, providing for sediment storage, discharging sediment-laden discharges through sluice gates, and dredging.

Prefeasibility Study. In a prefeasibility study, it is usually only necessary to note from visual observation whether sedimentation effects are likely to be severe.

Feasibility Study. It will usually be necessary during a feasibility study to estimate the sediment load in the stream using one of the measurement methods, previously described. With this estimate, reservoir siltation, turbine damage, and environmental effects can be studied.

Conditions of Valley Sidewalls and Foundations at Dam Sites

The type of sidewalls and foundation composition at a potential dam site are, in addition to the cost of materials and labor, the major factors in dam design.

Gravity dams require solid foundations, generally on rock but may be on sound alluvial foundations. Arch dams require strong, steep valley sidewalls. Buttress dams are usually designed for wide valleys with rock or sound alluvium foundations. Seepage characteristics are particularly important in the design of earth dams as they are usually built on earth foundations. The foundations of rockfill dams are usually rock or sound sand or gravel. Timber crib dams can be built on a variety of foundations.

Prefeasibilty Study. In a prefeasibility study, it is only necessary to broadly assess sidewall and foundation conditions from visual observatons and other means. At this level of analysis it is only necessary to determine the feasible types of dams.

Feasibility Study. Since one result of a feasibility study is the selection and approximate size of the dam, detailed investigation of sidewall and foundation conditions must be undertaken. If a large dam is planned, borings may be necessary.

V. REFERENCES

1. Alward, A., Eisenbart, S., and Volkman, J., Micro-Hydro Power: Reviewing an Old Concept, Prepared for the U.S. Department of Energy under Contract No. ET-78-S-07-1752, by the National Center for Appropriate Technology, Butte, Montana, 1 January, 1979.

2. Cada, G.F., and Zadroga, F., Environmental Issues and Site Selection Criteria for Small Hydropower Projects in Developing Countries, Environmental Sciences Division Publication No. 1712, Oak Ridge National Laboratory, Oak Ridge, TN., March 1981.

3. Chow, V.T., Open-Channel Hydraulics, McGraw Hill Book Compan;y, New York, 1959.

4. Crawford, N.H., and Thurin, S.M., Hydrologic Estimates for Small Hydroelectric Projects, prepared for National Rural Electric Cooperative Association, Washington, D.C., by Hydrocomp, Inc., September, 1981.

5. Fiering, M., and Jackson, B., Streamflow Synthesis, American Geophysical Union, Washington, D.C., 1971.

6. Gladwell, J.S., "Hydrologic Studies for Hydropower Assessment", Proceedings of Small Hydroelectric Power Plants, Quito, Ecuador, Co-sponsored by National Rural Electric Cooperative Association, Washington, D.C., 19-21 August, 1980.

7. Lawrence, W.D., Kirshen, P.H., and Lanou, T.E., Togo Small Decentralized Hydropower Study, Prepared for National Rural Electric Cooperative Association, Washington, D.C., July, 1981.

8. Linsley, R.K., and Franzini, J.B., Water-Resources Engineering, 3rd Edition, Mc-Graw Hill Book Company, 1979.

9. Linsley, R.K., Kohler, M.A., and Paulhus, J.L., Hydrology for Engineers, 2nd Edition, McGraw-Hill Book Company, 1975.

10. National Rural Electric Cooperative Association, A Methodology for Prefeasibilty Studies of Candidate Mini-Hydro Sites, Washington, D.C., no date.

11. U.S. Army Corps of Engineers, Feasibility Studies for Small Scale Hydropower Additions, Hydrologic Engineering Centr, Davis, Calif, and Institute for Water Resources, Ft. Belvoir, Va., July, 1979.

12. U.S. Bureau of Reclamation, Reconnaissance Evaluation of Small, Low Head Hydroelectric Installations, Denver, Co., 1 July, 1980.

13. Viessman, W., Knapp, J.W., Lewis, G.L, Introduction to Hydrology, 2nd Edition, Harper and Row, 1977.

14. Zoellner, D., "Environmental Assessment of Small Scale Hydropower", Proceedings of Small Hydroelectric Power Plants, Quito, Ecuador, Co-sponsored by National Rural Electric Cooperative Association, Washington, D.C., 19-21 August, 1980.

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Table 1

Types of Hydrologic Information Needed for Mini-Hydro Studies

Type of Information	Methods
	Prefeasibility Study
Average Annual Energy Production and Turbine Capacity	1. Rules of Thumb 2. Sequential Simulation of Typical Year 3. Annual Flow Duration Curve
Net Head	1. Topographical Map 2. Site Visit (perhaps adjust for high tailwater and/or evaporation and transpiration losses).
Tailwater Effects	1. Speak to local residents 2. Apply equation of Gradually Varied Flow (usually not necessary to estimate in Prefeasibiltiy Studies)
Flood Discharge	1. Only need to consider that spillway may be needed.
Evaporation and Transpiration Losses	1. Only need to estimate whether losses are large enough that reservoirs may become dry during dry seasons.
	Feasibility Study
Temporal Distribution of Energy and Turbine Capacity	1. Annual Flow Duration Curve 2. Monthly Flow Duration Curves 3. Sequential Simulation of Historic or Synthetic Flows
Net Head	1. Must consider type of turbine, tailwater elevations, and evaporation and transpiration losses.

Table 1 (Continued)

Type of Information	Methods
Tailwater Effects	1. Monthly elevations using equation of Gradually Varied Flow
Flood Discharge	1. Plot Annual peak flow data on semi-log graph paper and extrapolate 2. Fit extreme value distribution to data 3. Use rainfall intensity-frequency-duration curves and runoff analysis 4. Comparison with similar types of watersheds 5. Site visit
Evaporation Losses	1. Use data from similar area 2. Measure 3. Calculate
Transpiration Losses	1. Use data from similar area 2. Measure 3. Calculate
Other Project Purposes	1. Review operating policy of reservoir or structure

Table 2

Positive Aspects of Mini-Hydro

1. Renewable, fuelless resource

2. Generates no process residuals such as waste heat, air emissions, solid waste, and toxic substances

3. Low capital and maintenance costs

4. Proven, straightforward technology

5. Decentralized technology adaptive to local conditions

6. Relatively small scale environmental impacts - particularly if run-of-river

7. Unless there are large impoundments, no consumation of water

8. Complementary to other water uses such as water supply and irrigation

Source: Zoellner (1980)

Table 3

Environmental Issues in Prefeasibility Studies

1. The impact of the development induced by the project upon the resource base.

2. The availability of water of adequate quantity and quality.

3. Proximity of the site to a legally protected area or an area that should be declared or treated as wildland.

4. Level of interest and support from local community.

Source: Cada and Zadroga (1981)

Table 4

Categories of Environmental Impacts of Mini-Hydro

1. Flow Disruption
2. Sedimentation
3. Water Quality
4. Aquatic Organisms
5. Waterborn Diseases and Parasites
6. Land Use and Development
7. Terrestrial Impacts
8. Derived Impacts upon Human Environment

Table 5

Environmental Checklists for Feasiblity Studies

1. Obtain topographical maps (1:25,000 if possible) which show the location of the mini-hydro facility components and, if a water impoundment is planned, the bathymetry of the future reservoir.

2. Obtain low-level aerial photographs of the site and watershed.

3. Obtain recent stream flow data for a number of years in order to ensure both the maintenance of minimum flows in the stream and reliabiliy of mini-hydro operation.

4. Obtain rainfall data for the study area. Do rainfall intensity values also exist?

5. Determine water withdrawal rates for mini-hydro operation and the location of the intake and discharge structures.

6. If a water storage impoundment is part of the design, determine the timing of reservoir releases on a daily and seasonal basis.

7. Determine the alternative water uses in the area, the location of all water intakes or discharges in the affected areas, and flow rates and nature of all effluents.

8. Locate important wetlands that could be affected (for example, drained or filled with sediment) by construction and operation of the mini-hydro.

9. Locate important alluvial floodplains that will no longer be seasonally flooded due to reservoir flow regulation.

10. Locate other water bodies (lakes, reservoirs, etc) that are associated with the surface waters of the study area.

11. According to the life zones (ecological) map of the country, determine what life zones occur in the watershed under study, what runoff distribution could naturally be expected from each Life Zone (or other appropriate ecological classification unit) according to water balance estimations, and how many effectively dry months are there in each water year.

12. Obtain a map of actual land use for the area. Determine the predominant land uses.

13. Obtain land-use capability or land-use potential maps developed for the general study area. Determine what resource-use potentials exist for the watershed of concern.

14. Determine what land-use and watershed protection plans can be developed in order to minimize adverse secondary impacts.

Table 5 (Continued)

15. Determine what important soil, geological, historical, cultural, or archaeological resources will be lost by site construction, access road construction, transmisson line construction, or impoundment.

16. Determine whether the site is near a protected area (preserve, sanctuary, refuge, dedicated area) that may require special consideration.

17. Determine whether stream waters near the site are used for fish spawning, nursery, or feeding areas, or as fish migration routes.

18. Determine whether any rare, endangered, or commercially or recreationally important species are present in the region.

19. Identify the principal aquatic species present in the area affected by construction and operation.

20. Determine what species are harvested for sport or commercial purposes in the area, the harvest level and seasonality of harvest, and what fishes or shellfishes are harvested from the stream for food by the local community.

21. List the waterborn diseases or parasites that are endemic to the area and determine the possiblity of spreading or accentuating disease problems by mini-hydro development.

22. Identify species of aquatic plants in the area that could interfere with hydroelectricity production and alternate water uses.

23. Identify any preexisting (natural or man-induced) environmental stresses in the area and any future developments planned for the area that might add additional stresses. Characterize and, if possible, quantify these stresses.

24. Estimate the nature and size of suspended sediments in the stream as well as the bedload of the stream.

25. Obtain water quality data, especially regarding temperature, dissolved solids, salt, nutrient, and dissolved oxygen levels, or the presence of toxic materials or disease organisms.

26. Identify projected or active mining activities in the study area. Are these open-pit or tunnel mines and how are wastes handled?

Table 5 (Continued)

27. Consider any unique plant design features (impoundment, trans-basin diversion) which would necessitate special consideration with regard to environmental impacts.

28. Determine the possibilities for avoiding, reducing, or mitigating environmental impacts of site development by adequate prior planning.

Source: Cada and Zadroga (1981)

Table 6

Geological Factors in Mini-Hydro Siting

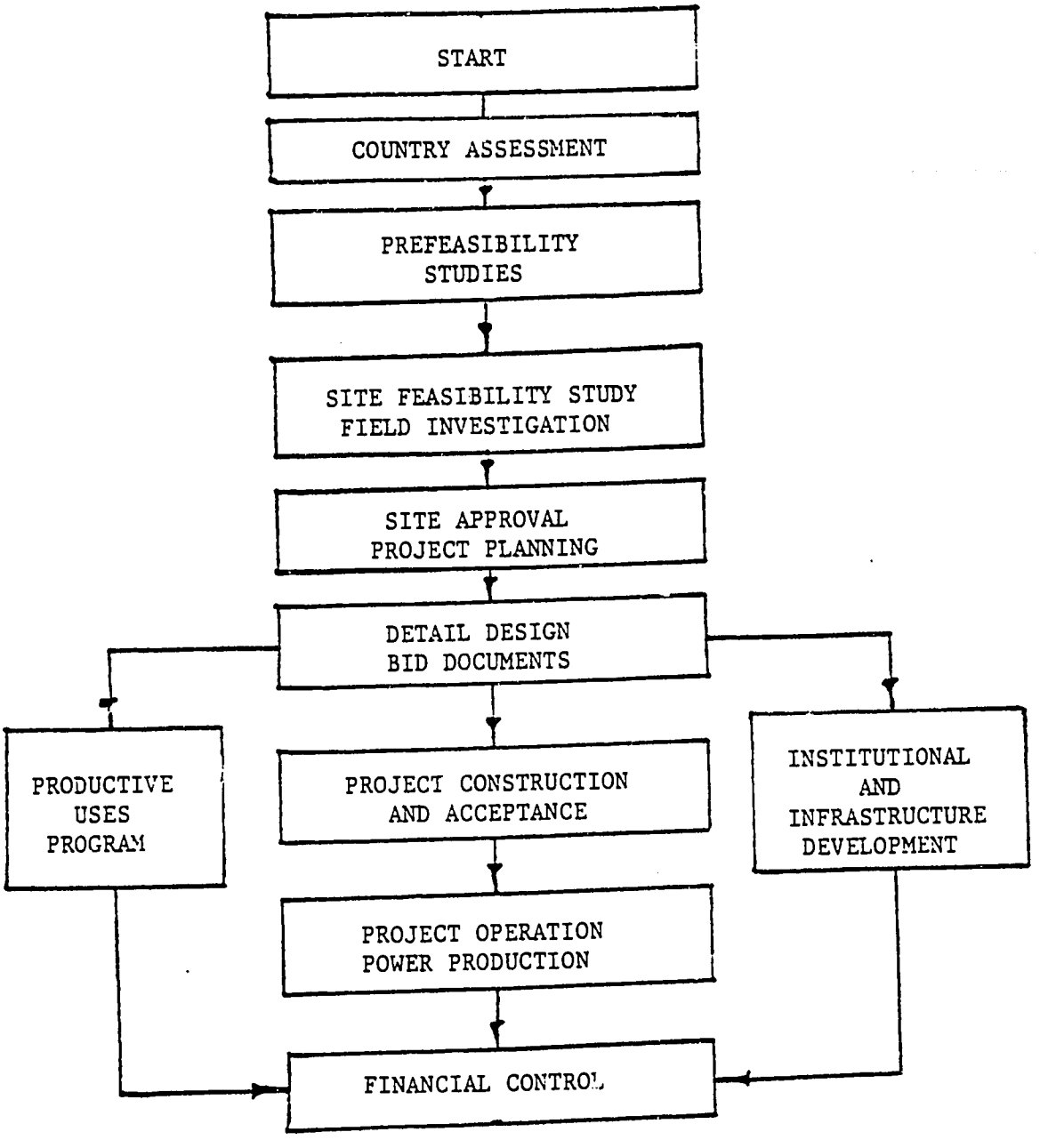
1. Sediment Loads in Streams

   Reservoir Siltation
   Turbine Damage
   Increased Potential for Environmental Damage

2. Conditions of Sidewalls and Foundations at Dam Sites

   Major Factors in Dam Design

      Gravity
      Arch
      Buttress
      Earth
      Rockfill
      Timber Crib



STAGES OF PROJECT DEVELOPMENT

Figure I

Source: Jackson, Bard, A Methodology for Prefeasibility Studies of Candidate Mini-Hydro Sites, National Rural Electric Cooperative Association, 1981.

Figure 2

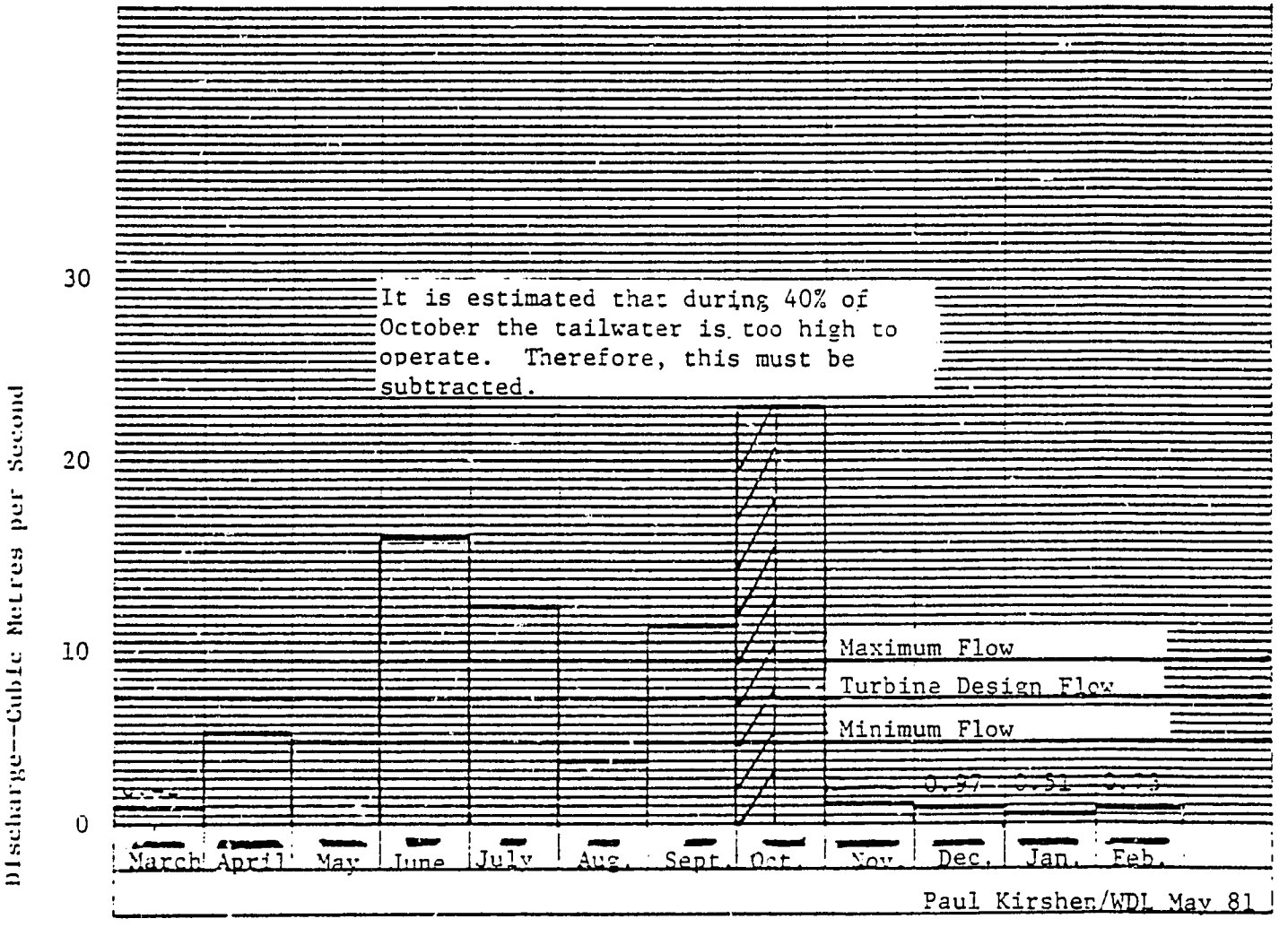
ESTIMATING MEAN ANNUAL ENERGY PRODUCTION USING MEAN FLOW SEQUENCE

PROCEDURE

1. Select turbine design, maximum, and minimum flows.

2. Assume constant net head and efficiency.

3. Calculate area of hydrograph between maximum and minimum flows and convert to energy using standard formulae. If necessary, subtract area occurring during high tailwater periods.



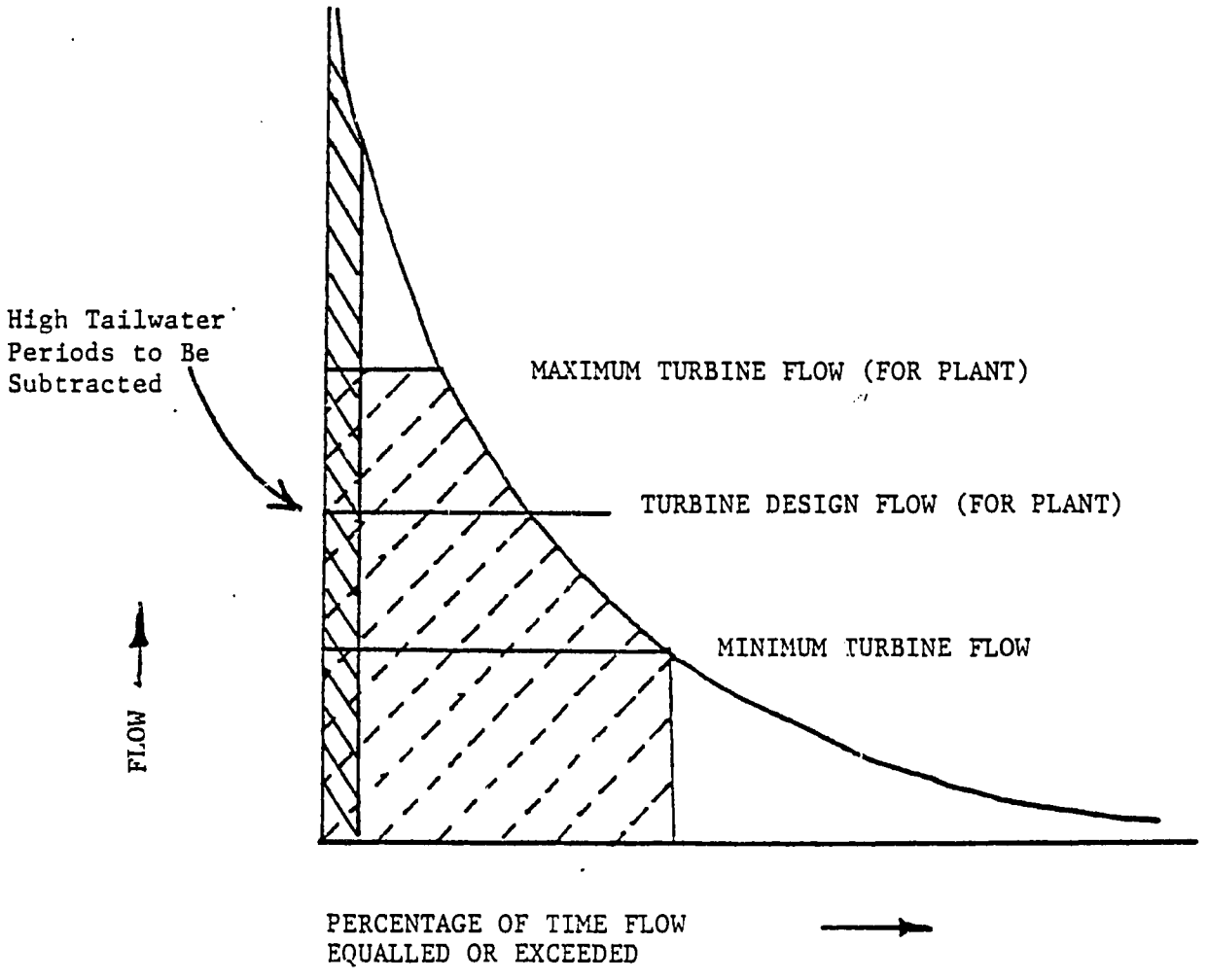
Source: Lawrence, Walter D., Kirshen, Paul H., Lanou, Tobie E., Togo Small Decentralized Hydropower Study, National Rural Electric Cooperative Association, 1981.

Figure 3

ESTIMATING MEAN ANNUAL ENERGY PRODUCTION USING FLOW DURATION CURVE

PROCEDURE

1. Select turbine design, maximum, and minimum flows.
2. Assume constant net head and efficiency.
3. Convert ordinate scale to hours per year.
4. Calculate area of shaded portion and convert to energy using standard formulae. If necessary, subtract area corresponding to high tailwater periods.

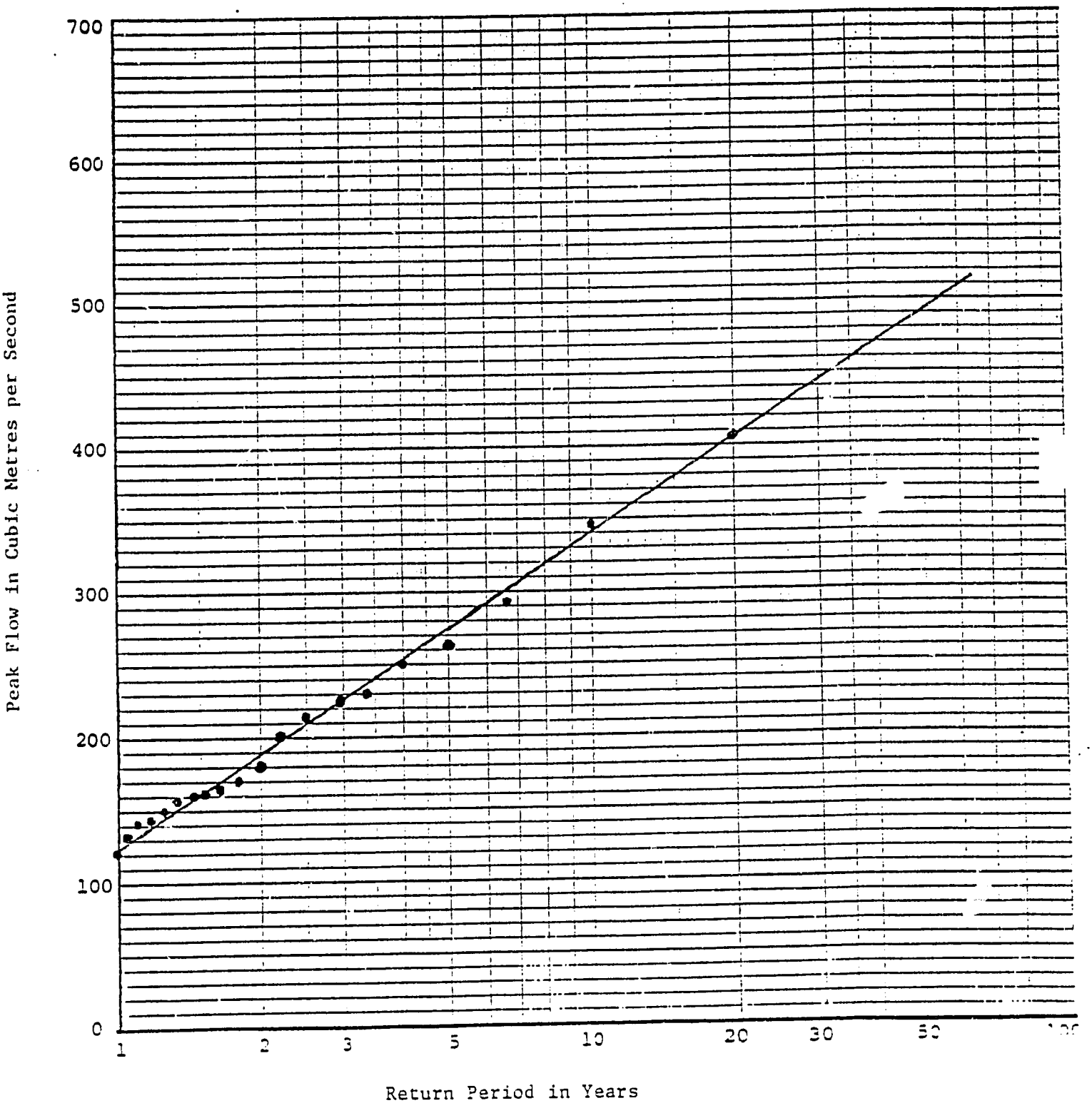


FLOW DURATION CURVE

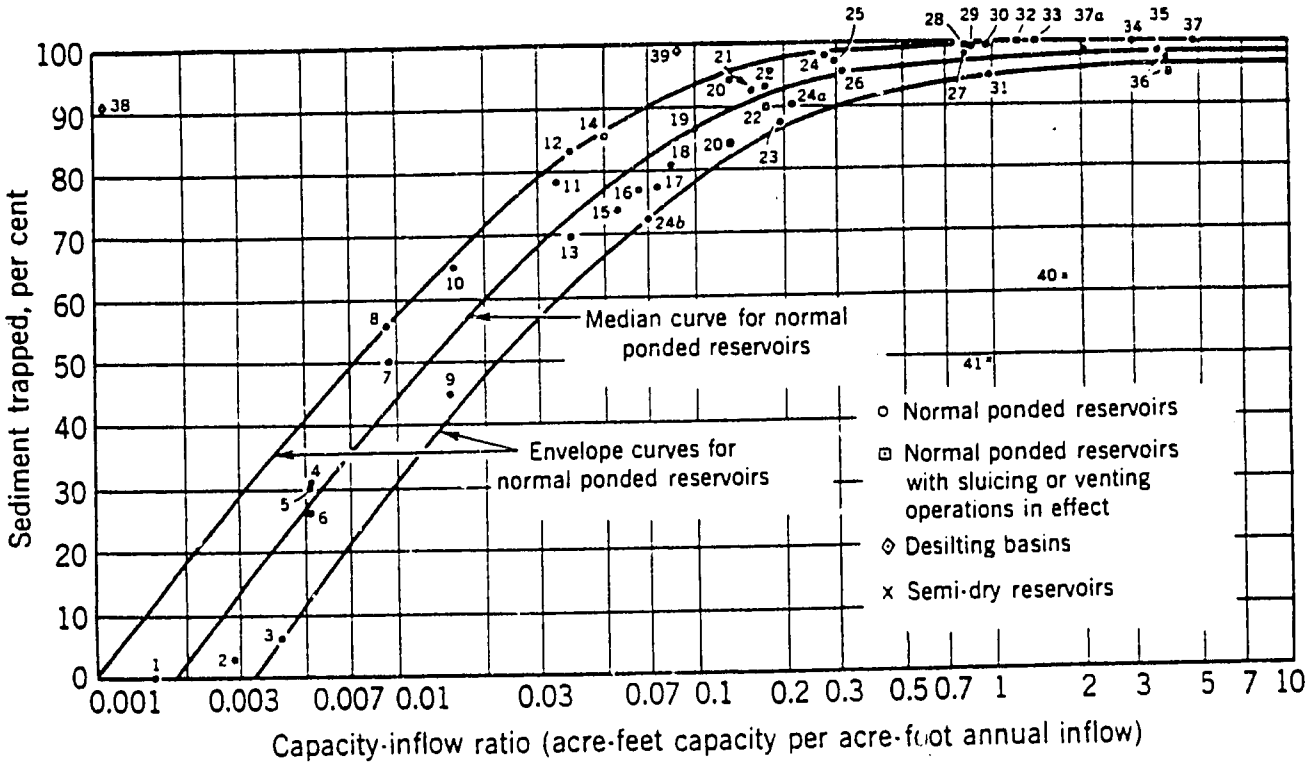
Source: Jackson, Bard, A Methodology for Prefeasibility Studies of Candidate Mini-Hydro Sites, National Rural Electric Cooperative Association, 1981.

Figure 4

FLOOD FREQUENCY: PEAK FLOW VS. RETURN PERIOD



Source: Crawford, Dr. Norman H., Thurin, Steven M., Hydrologic Estimates for Small Hydroelectric Projects, National Rural Electric Cooperative Association, 1981.



Reservoir-trap efficiency as a function of the capacity-inflow ratio

Figure 5

Source: Linsley and Franzini(1979)

APPENDIX A

QUALITY AND AUGMENTATION OF STREAMFLOW DATA

Introduction

Two problems frequently arise in the analysis of water resources projects; (1) the need to examine the quality of streamflow data (does it really represent what is likely to happen at the site over the projects' expected lifetime) and (2) the data are insufficient or lacking at a site. Presented in this section is a discussion of how to study the quality of streamflow data and how to augment or extend such data from other sources. Additional material on this subject can be found in Viessman et al. (1977), Fiering and Jackson (1971), the U.S. Bureau of Reclamation (1980), Gladwell (1980), and Crawford and Thurin (1981).

Data Quality

Data quality can be considered to be measured by the data's homogeneity and the length of the record. A time series is homogeneous "if the identical events under consideration in the series are equally likely to occur at all times and places" (pg. 3-6, U.S. Bureau of Reclamation, 1980). A record is long enough if it contains the expected variations and extreme values of the streamflow or these can be inferred from it at least in sufficient accuracy for the scale of the project. The end result of having "high" quality data is that the project can be designed for all conditions that will likely impact it over its lifetime.

Non-homogeneity in streamflow data is caused by collecting data from an area whose characteristics are changing with time and by trends and cycles in the data. The major cause of change is usually human activities, such as diversions and deforestation. As noted by the U.S. Bureau of Reclamation (1980), such inconsistencies can be noted by plotting the cumulative values of one affected variable (i.e., streamflow) versus the cumulative value of a related variable

such as streamflow in an unaffected watershed or precipitation. Once an inconsistency is determined, it can be "corrected" by interpolating and extrapolating from the cumulative plot or by adjusting the past records with the known quantities of diversions, etc. Trends and cycles in data can be determined from visual inspection of time series or by plotting, for example, 5-year moving averages to smooth the data. It is important to be aware of trends and cycles in the data if only a short segment of the data is to be used in analysis or if records of different lengths are being used in a study.

The length of record needed for a study depends upon the study purpose and the regional hydrologic characteristics. The regional hydrologic characteristics are probably the most important variables. If the precipitation and streamflow in an area do not vary considerably from year to year, then 10 to 15 years is probably suitable for all levels of analysis. If there is considerable variation in these values, then 30 to 60 years is needed to accurately capture the variability. As an example of this, consider the level of Lake Chad, which behaves similarly to a streamflow in a river. Over a 30-year period, the mean volume of Lake Chad is 30 billion cubic meters. Over two different 10-year periods, the calculated means are 17 billion and 50 billion. Obviously, designs for these three "mean" values will have different implications. In conducting a comparison study between sites, it is usually desirable to use records covering the same periods; in this manner consistent comparisons can be made between the sites. If records of different periods and/or lengths have to be used, some records should be either extended or "filled-in". This and related topics are discussed next.

Data Augmentation

Streamflow data can be augmented (or synthesized) by extending or filling-in records at gaged sites or by developing flow estimates and parameters at ungaged sites. Such synthesized data must be used carefully. Gladwell (1980) provides the following warning for fill-in data which also applies to estimates at ungaged sites; "Attempts to fill-in missing data can create false security if one is not extremely

careful. First it must be realized that the use of correlation or regression analyses dilutes the value of the data ...The fill-in data can only be considered an approximation of what actually occurred. Furthermore, if the data are to be used in statistical analyses, the use of simple regression analyses will only produce estimates of the means of missing vlues. In such cases, the natural variations about the mean will be eliminated and the overall variance, thus, diminished" (pp. 31-32).

Record Extension and Fill-In. The simplest method to extend or fill in streamflow data is to establish a correlation between the flows at a data poor site and a data rich data. Of course, the two sites must be located reasonably close to each other and have similar hydrologic characteristics (see section on ungaged sites for discussion of "similar hydrologic characteristics"). In many cases, it is only necessary to use the ratio of mean flows in the regression equation as shown in Equation (A1).

$$\text{Daily Flow at } i = \frac{\text{Mean Flow at } i}{\text{Mean Flow at } j} \times \text{Daily Flow at } j \qquad \text{(A1)}$$

More sophisticated regressions may contain parameters such as basin slope, precipitation, etc. or temporally lagged parameters. If the random variations between the flow at the sites is important to maintain, it is necessary to add a random number component to the regression (see Fiering and Jackson (1971) for a clear discussion of this). Another simple method of data extension or fill-in is to use double mass curve analysis. This has the serious disadvantage, however, of eliminating some of the natural variation in streamflow because the plotted line only represents mean conditions.

Stream Flow Estimates for Ungaged Sites. One of the rules of thumb in hydrology is that if watersheds are located near each other, are at approximagely the same elevation, and have similar land use, area, topography, geology, and similar precipitation patterns, then the flows (daily in some cases) are related by the ratios of drainage

areas, precipitation, and slope (in some cases). Two such watersheds can be considered to be "hydrologically similar". The practical value of this is that if the flows are unknown at a site but are known at a similar site, then estimates of flow at the ungaged site can be determined by multiplying the flow at the gaged site by ratios of drainage areas or precipitation. Slope ratios may be necessary to also include if peak discharge information is needed. If it is important to maintain the natural variation in flows between the gaged and ungaged sites, a random component might be added to the simple regression.

This procedure even works for "transferring" a flow duration curve from a gaged site to an ungaged site; the flow ordinates of the curve can be multiplied by the ratios of drainage area and/or precipitation.

Methods for estimating flows at ungaged sites in areas where there are not hydrologically similar gaged sites are presented in an NRECA report by Crawford and Thurin (1981). The methods are based upon physical observations and simple rainfall and streamflow routing procedures.

APPENDIX B

MEASUREMENTS OF HEAD AND DISCHARGE

It is necessary during field investigations to measure the head and, often times, the discharge of a site. Alward et al (1979) present an excellent discussion of measuring techniques in a report prepared for the National Center for Appropriate Technology (NCAT) (pgs 10-18). The relevant sections are presented below.

How to measure stream or spring flow:

1) For small mountain streams or for springs, temporarily dam up the water and divert the entire flow into a container of known size. Carefully time the number of seconds it takes to fill this container.

   For example:

   If it takes 40 seconds to fill a 55 gallon barrel, the flow rate is 1.375 gallons per second, or 82.5 gallons per minute, or 11 cubic feet per minute.

2) For larger streams, the float method can be used. If done carefully, and repeated several times, it can give results accurate enough for most calculations. In order to use this method, you need to know the cross-sectional area of the stream and the stream velocity.

   The cross-sectional area should be determined at some easily measured spot in the stream, preferably in the middle of a straight run of the stream. Measure the width (w) of the stream in feet. Then, using a stick, measure the depth in feet at equal intervals across the width of the stream (see Figure A). Record the depth at each interval and calculate the average depth.

For example:

With a stream cross-section as in Fig. A,

d = depth

d1	= 1.0 feet
d2	= 1.3 feet
d3	= 1.2 feet
d4	= 1.8 feet
d5	= 1.0 feet
d6	= 0.8 feet
d7	= 1.1 feet
d8	= 1.8 feet
d9	= 1.3 feet
d10	= 0.7 feet
Total	= 12 feet

$$\text{Average } d = \frac{12}{10} = 1.2 \text{ feet}$$

Next, multiply the width (w) by the average depth (d) to get the cross-sectional area (A) of the stream in square feet.

For example:

In the above stream, say the width at the point of making the depth measurements was 8 feet, then the cross-sectional area (A) is

A = w X d

A = 8 feet x 1.2 feet

A = 9.6 square feet

The stream velocity can be determined by choosing a straight stretch of water at least 30 feet long with the sides approximately parallel and the bed unobstructed by rocks, branches or other obstacles. Mark off two points, say 30 feet apart, along the stream. On a windless day, place a float upstream of the first marker, in midstream. A pop bottle, partially filled with small stones so that it rides

with its neck out of water, is a good float. Carefully time the number of seconds it takes the float to pass from the first marker to the second. Repeat this process several times and average the results.

For example:

The average time for a float to travel between two markers placed 30 feet apart is 15 seconds. The velocity of the float is thus

$$\frac{30 \text{ feet}}{15 \text{ sec.}} \approx 2 \text{ feet/second}$$

This float velocity does not, however, represent the velocity of all the water in the stream. The water at the sides and bottom of the stream flows less quickly than that at the center or near the top due to stream bed friction and channel roughness. A correction factor, depending on the roughness or smoothness of the stream bed, is usually inlcuded to give an estimated average stream velocity. This correction factor can vary from 0.6 for a rocky hill stream, to 0.86 for a stream with very smooth bed and sides.

For example:

Taking the float velocity computed above, the stream velocity (V) for a fairly rough hill stream is

$$V = 2 \text{ feet/second} \times 0.65 = 1.3 \text{ feet/second}$$

or $V = 78$ feet per minute.

The flow rate of the stream can now be calculated by multiplying the cross-sectional area of the stream (A) by the stream velocity (V).

For example:

Flow = A x V
Flow = 9.6 sq ft x 78 ft/min
Flow = 748.8 cubic feet/min

Now, depending on what portion of the stream flow you can or want to use, you can now determine the usable flow. Simply multiply the stream flow rate you have just calculated by the portion of the flow you will be using.

For example:

If you will only be using 25% of the minimum stream flow, and the stream flow you have determined above is 748.8 cubic feet per minute, then the usable flow is

Usable Flow = 748.8 cfm x 0.25
Usable Flow = 187.2 cfm

3) There is a third method for determining stream flow. This is called the Weir Method. This method is accurate and can be used to measure the flow rate of any stream. It is particularly advantageous for flow measurements in shallow streams where a weighted float would have difficulty floating freely. However, it is also a more complicated technique for measuring flow.

Essentially, a temporary dam structure is built across the stream perpendicular to the flow, with a rectangular notch or spillway of controlled proportions located in the center section. This notch has to be large enough to take the maximum flow of the stream during the period of measurement, so make some rough estimate of the stream flow prior to building the Weir. The notch width (W) should be at least three times it height (h) and the lower edge should be

perfectly level. The lower edge and the vertical sides of the notch should be beveled with the sharp edge upstream. The whole structure can be best built out of timber with all edges and the bottom sealed with clay, earth and sandbags to prevent any leakage. A typical Weir is illustrated in Figure B.

In order to meausre the flow of water over the Weir, you have to set up a simple depth gauge. This is done by driving a stake in the stream bed at least 5 feet upsteam from the Weir, until a pre-set mark in the stake is precisely level with the bottom edge of the notch. The depth of the water on this stake, above the pre-set mark, will indicate the flow rate of water over the Weir. You will need to refer to a "Weir Table" in order to determine this flow rate. A typical "Weir Table" follows.

To use the table, determine the depth of water in inches over the pre-set stake mark. Take this value to the Weir Table and read off the flow rate in cubic feet per minute per inch of notch width. Multiply this volume flow rate by the width, in inches, of your Weir notch. This will give you the stream flow rate in cubic feet per minute.

For example:

On a particular stream you have built a Weir with a notch width of 30 inches. The depth of the water on the stake above the pre-set marking is 6 1/4 inches. On the Weir Table, read opposite 6.25 inches to the flow rate of 6.28 cfm per inch of notch width. The flow rate of the total stream is then

6.28 cfm x 30 in.

or 188.4 cfm

When you have the Weir in place, you can easily take readings at your convenience. If you are going to use the Weir for any extended period of time, it is important to frequently ensure the watertightness of the sides and bottom.

Head Measurement

The greater the vertical distance that water falls, the more potentially useful power there is available in the water.

How to measure head:

1) For high head systems, detailed topographical maps of your area may give some indication of the vertical height difference between proposed intake and tailwater levels. However, the accuracy of map reading is limited so this technique should only be used for very preliminary estimations.

2) For those who are acquainted with photographic surverying techniques, this method can give fairly accurate results. Pictures taken in the field can be developed and the elevations scaled on the photographs. But caution--this is not a method for amateurs. Photographic surveying requires some skill and training.

3) Pocket altimeters can give you preliminary estimations of the elevation difference between intake and tailwater locations on proposed high head systems. However, the accuracy of measurement is not suitable for any serious calculations.

   There are some larger portable altimeters on the market, which tend to be very expensive, that can enable you to make elevation measurements within an accuracy of a couple of feet. These instruments are suitable for engineering

calculations; however, they do not give as precise measurements as do the following three methods.

4) Any good surveyor can be hired to determine the head for you. Ask the surveyor to simply find the vertical distance between your water source, or proposed intake location, and the proposed location of the power plant. Hiring a surveyor is going to be somewhat expensive, so if this is your only alternative, you want to reasonably sure that you intend to carry through with the project. If your head is less than 25 feet, you need very precise measurements, so a surveyor may be advisable.

5) If you know how to use standard surveying equipment, for example a transit or a surveyor's level and leveling rod, borrow or rent the appropriate pieces and get a friend to help you make the necessary measurements.

6) Another technique involves a do-it-yourself approach. The equipment required is a carpenter's level, some sort of stand to raise the level a few feet off the ground, and a tape measure. You may or may not use someone else to assist you. The method is described below in relation to Figure C:

   a) Set the level on the stand; make sure the level is horizontal (level) and that its upper edge is either at the same elevation as the water source, or a known vertical distance above the water surface.

   b) Sight along the upper edge of the level to a spot on a nearby object (tree, rock, building) that is further down the hill and which can be reached for measuring.

c) Note this precise spot on the object and mark it (Point A in the diagram).

d) Move your level and stand down the hill slope and set it up again so that this time the upper edge of the level is at some Point B below Point A on the first object, as in the drawing. Mark this Point B and measure and record the vertical distance A to B. Now sight along the upper edge of the level in the opposite direction to another object that is further down the hill.

e) Repeat this procedure until you end up at the same elevation as the proposed power plant site.

f) If more than one set-up was required, add all the vertical distances A-B. If your first set-up was above the water surface, subtract the vertical distance between the water surface and the upper edge of the level from the sum of the vertical distances. You now have the total head.

In undertaking the above measurements there are a few things you should remember:

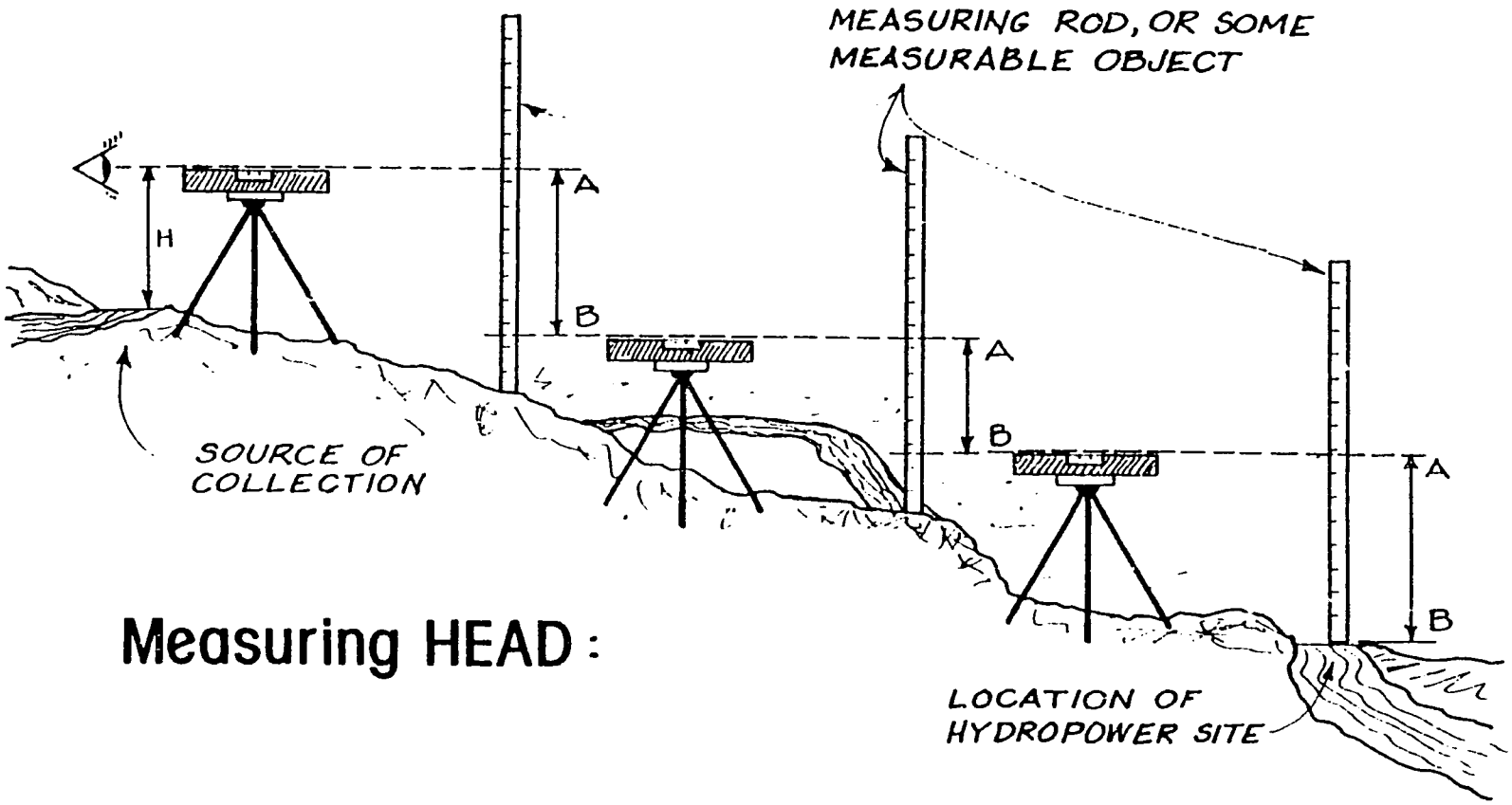
- You do not need to be concerned with horizontal distances for head determination.
- Every time you re-set the level, its upper edge should be at precisely the same level as Point B (sight back to check).
- You need not travel in a straight line.

WEIR TABLE

Depth on Stake in inches	c.f.m. per inch of notch width
1	0.40
1.25	0.55
1.5	0.74
1.75	0.93
2	1.14
2.25	1.36
2.5	1.59
2.75	1.83
3	2.09
3.25	2.36
3.5	2.63
3.75	2.92
4	3.22
4.25	3.52
4.5	3.83
4.75	4.16
5	4.50
5.25	4.84
5.5	5.18
5.75	5.54
6	5.90
6.25	6.28
6.5	6.65
6.75	7.05
7	7.44
7.25	7.84
7.5	8.25
7.75	8.66
8	9.10
8.25	9.52
8.5	9.96
8.75	10.40
9	10.86
9.25	11.31
9.5	11.77
9.75	12.23
10	12.71
10.25	13.19
10.5	13.67
10.75	14.16
11	14.67
11.25	15.18
11.5	15.67
11.75	16.20
12	16.73
12.25	17.26

Depth on stake in inches	c.f.m. per inch of notch width
12.5	17.78
12.75	18.32
13	18.87
13.25	19.42
13.5	19.97
13.75	20.52
14	21.09
14.25	21.65
14.5	22.22
14.75	22.70
15	23.38
15.25	23.97
15.5	24.56
15.75	25.16
16	25.76
16.25	26.36
16.5	26.97
16.75	27.58
17	28.20
17.25	28.82
17.5	29.45
17.75	30.08
18	30.70
18.25	31.34
18.5	31.98
18.75	32.63
19	33.29
19.25	33.94
19.5	34.60
19.75	35.27
20	35.94
20.25	36.60
20.5	37.28
20.75	37.96
21	38.65
21.25	39.34
21.5	40.04
21.75	40.73
22	41.43
22.25	42.13
22.5	42.84
22.75	43.56
23	44.28
23.25	45.00
23.5	45.71
23.75	46.43
24	47.18

Note: one inch=2.54 cm., one cfm=28.32 liters/min.



Measuring HEAD:

FIGURE C

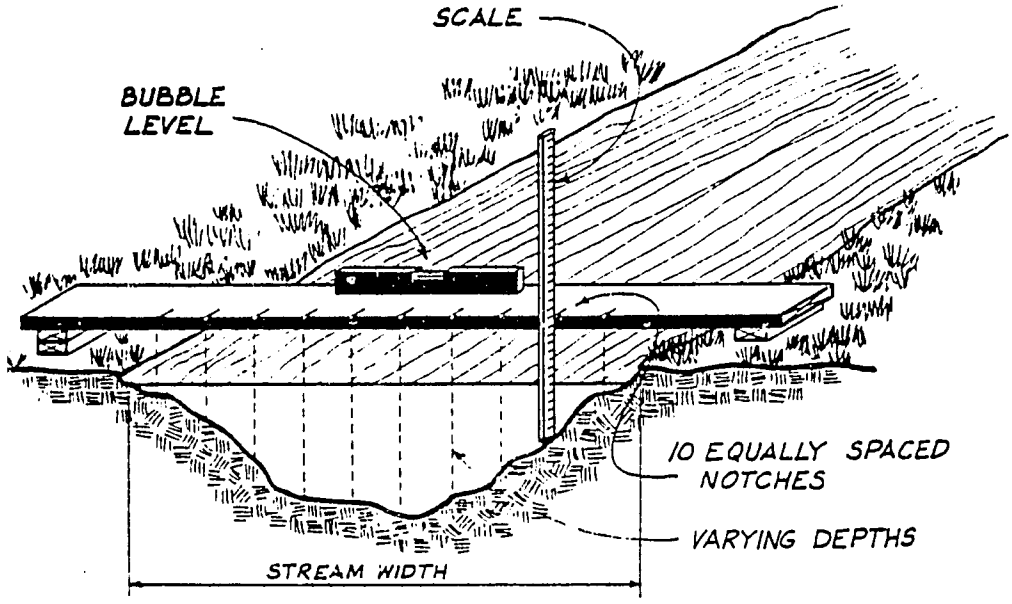


FIGURE A

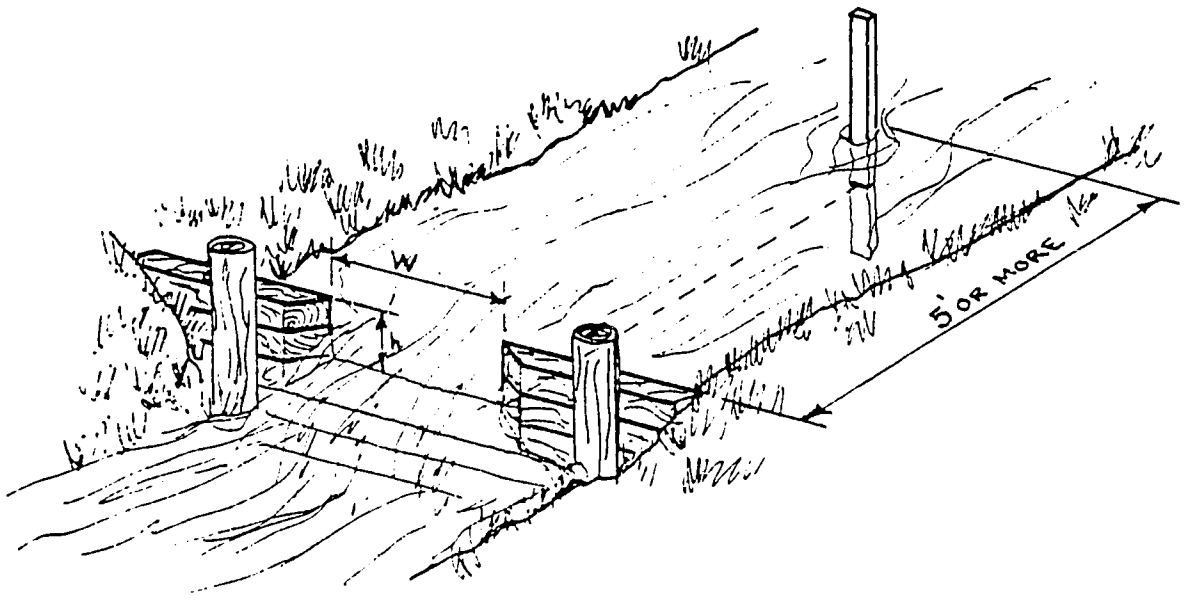


FIGURE B

REGIONAL WORKSHOP ON "SMALL HYDROPOWER IN AFRICA"

ABIDJAN, IVORY COAST

MARCH 1-5, 1982

RESOURCE ASSESSMENT AND SITE SELECTION

BY

WALTER D. LAWRENCE

N.C

RESOURCE ASSESSMENT AND SITE SELECTION

In developing countries and particularly in the case of small hydro, there is often a lack of topographic, geologic and hydrologic data from which the physical and electrical features of the power sub-system are supposed to be determined. The following presents some thoughts on acquiring preliminary data of prefeasibility scope on small hydro sites. In such studies, interpolation and extrapolation of very rough data are necessary to determine if a site is worthy of more detailed analysis and what the focus of such analysis should be.

Hydrologic data (precipitation and stream flows) frequently are limited in time and area coverage, or are not reliable or sometimes not available at all. How to fill in some of these gaps is of interest here. In the Small Hydropower for Asian Rural Development workshop report is a paper entitled Hydrological Methodology Without Streamflow Data by Norman H. Crawford. The workshop was in Bangkok June 1981. This paper presents methods of deriving stream flows from available rainfall, evaporation and other data without establishing rainfall/streamflow correlations requiring gauging of stream flows.

Two results of precipitation are considered. First, the flow during and immediately after precipitation is short-term in nature and if the precipitation is high enough it results in flood flows.

Second, water absorbed by the soil moves as sub-surface flow and a portion emerges further down into streams. The latter flow usually is an important component of the total stream flow since there is a significant time interval from the time that portion of the precipitation soaks into the ground and when it shows up as return flows in the lower areas of the basin. The resultant stream flows in the lower parts of the basin are much more uniform due to the effective ground storage and diversity of the sub-surface channel lengths and flow capacities.

The process described in Crawford's paper considers the basic water balance equation: precipitation minus actual evapotranspiration plus storage change equals runoff. Storage includes soil moisture and ground water aquifers. Crawford goes on to consider watershed characteristics and coefficients showing soil moisture storage capacity, the fraction of runoff that enters sub-surface water courses and a factor showing the ratio of groundwater storage that emerges as surface return flows. The effects of recent rainfall patterns (high, low or typical) on soil moisture and resultant surface runoff (high if soil is saturated - low if dry) are considered.

Flood flow predictions are covered also in terms of rainfall intensity as related to rainfall duration (somewhat of an inverse relationship), catchment area, channel length and gradient and watershed loss rate as affected by the soil characteristics. A table showing six soil types and related loss rates is made even more useful by showing the predominant general types of vegetation which may be found on each type of soil to assist the reconnaissance

personnel in making soil classifications.

Crawford's procedures require topographic, geologic and soils information and these usually are available in one form or another. Required also are rainfall data which are not always available for the catchment areas of interest. Naturally, the longer the period of record, the more reliable are the significant flow figures such as for the minimum month. However, even a year or two of daily rainfall data are better than none at all and could be obtained while much of the other reconnaissance work is going on. Most of the rain gauge for that purpose could be the simple funnel type, read and recorded by responsible villagers. Often, the upper catchment areas are not heavily inhabited or access to suitable gauge locations is difficult and recording gauge might be considered. Such gauge will operate over periods of months. Radio reporting gauges are reasonably portable, simple to install and maintain and useful in the less inhabited catchment areas - frequently in the higher elevation areas where much of the total precipitation occurs. Normally, the simple weight-driven, clock-operated, tipping-bucket rain gauge with a strip chart will provide a record of rainfall distribution over a period of time. The main benefit of the radio-reporting gauge is that it provides real time information which is more useful to an operating water resource project than it would be for a project in the reconnaissance stage.

Stream stage information can be obtained from staff gauges located at points in the streams where a stable cross section exists

which can be calibrated. Other gauge location criteria include whether or not tributary flows should be included and if correlations are to be established between catchment area rainfall and stream flows.

Staff gauge for river stage measurements are simple to install and to read - the problem is to get people sufficiently intelligent, interested, responsible and well enough paid to really read the gauge at prescribed times and also at time following abnormal precipitation. Recording river stage equipment is also available, the extra cost of which could be justified for very inaccessible or very important locations or where the data must be as reliable as possible.

The foregoing methodology requires some rainfall data, but in some cases there are no such data from which stream flows could be predicted. Everyone likely has his own methods of estimating stream flows and the few mentioned here are intended to inspire discussion of those methods. Years ago in the hydraulic laboratories of the US Bureau of Reclamation, the writer observed known discharge rates of water over weirs of different sizes and over irregular crests and developed the ability to look at a flow of water and make a reasonably accurate estimate - within perhaps plus or minus 15 percent. Such an ability can be developed by observing flows at a weir and in channels below the weir.

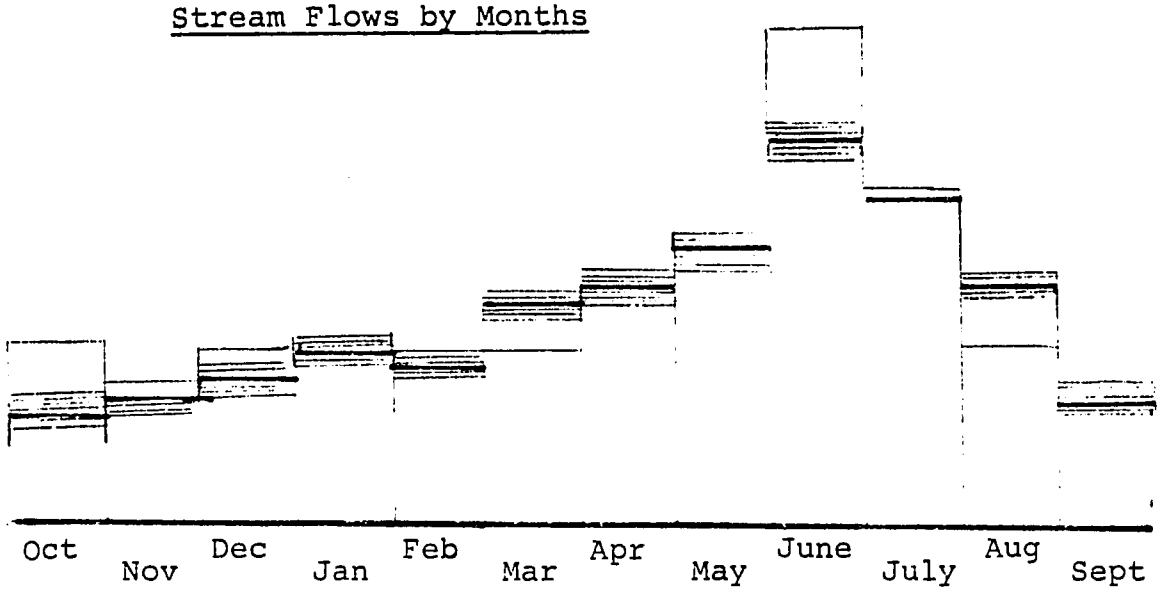
Many rural roads use a masonry or concrete structure built through the stream at bed level with sloping approaches instead of a bridge.

If you are dealing with a stream that always has some flow, these nullahs offer a smooth cross section and smooth water flow where the water velocity would be easy to measure and the flow quantity could be readily calculated.

Minimum flow values are the most significant for hydropower studies since they establish the base power capability of the system. Assuming that flow or rainfall data are available by months for a number of years, a flow duration could be derived therefrom. Another form of graphic presentation is useful to the writer and that is a year-by-months (calendar or hydrologic year) bar graph of flows with all the flows put onto one graph. See Figure 1 below:

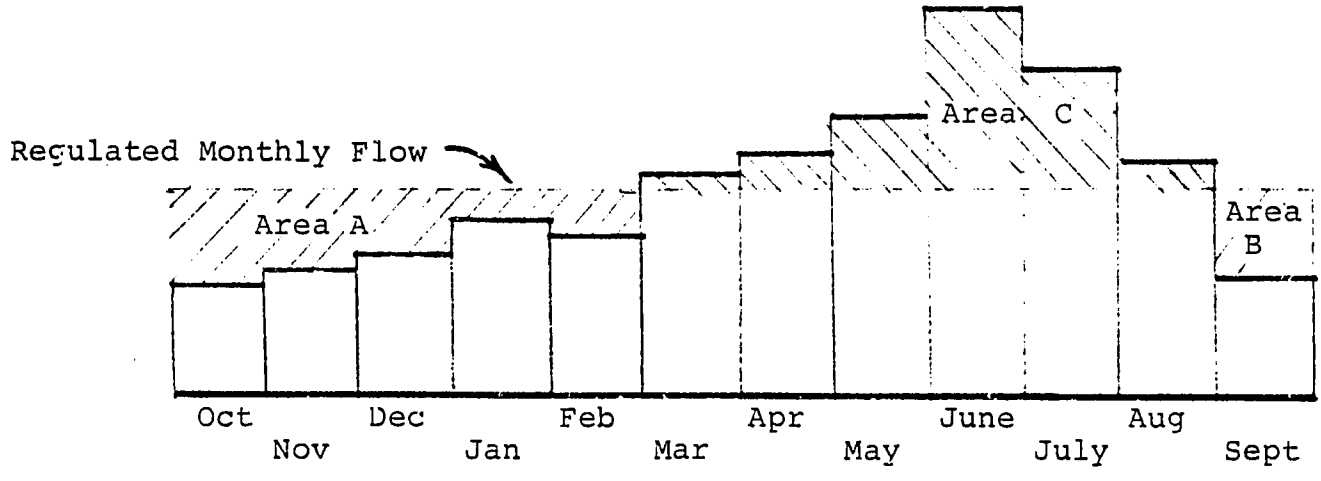
Figure 1

Stream Flows by Months



This graph is a sort of frequency of occurrence pattern from which some very preliminary hydrologic information can be obtained. Suppose a hypothetical water year is needed to determine the power capability of a potential project. The monthly flows could be averaged, but that process frequently includes some values that are greatly different from the others - which distorts the average. In Figure 1, the fine lines are the plots of monthly flows over the period of record and the heavy line represents the values which are mostly likely to occur. The heavy line is drawn in by inspection. From the writer's experience, it usually is possible to find an actual year of flow record which closely matches the derived year. Call this the "typical year" and use it for determining the monthly water supply. See Figure 2.

Figure 2
Stream Flow by Months -- typical year



For a run-of-the-river hydro project, such a graph would enable a preliminary estimate of the water volume to be used in calculating the power plant capacity. This will not necessarily be the minimum month. Actually, it would be prudent to set the value at a somewhat higher monthly figure to enable the power plant to utilize greater than minimum quantities of water when they are available. The rationale for this recommendation is not very technical - it is simply that excess power usually finds a load to use it.

So far, runoff data have been considered in terms of monthly quantities, mostly because hydrologic records are typically in that form and accordingly presume a constant flow throughout the month. For those months where the available water is in excess of power requirements or the power plant capability, daily flow variations are not of concern. However, during the low flow months, it is possible that there could be daily or random variations in the flow. A series of observations during several days would be necessary to determine if that is the case. Actually, a river system (defined here as combining a number of tributaries) would not be likely to show much daily variation due to the diversity effect of different surface and return flow sources above the point of diversion for power. However, a small stream, with relatively little catchment area above it could show considerable flow variations, with rapid and sharp responses to precipitation in the catchment area.

At this point it is necessary to relate power water requirements to the load requirements. The typical small hydro system

initial load tends to be low during the day hours and higher during night lighting hours. Around-the-clock loads (refrigerators domestic and commercial) and other commercial or small industry (food-processing, grinding, etc.) loads are developed as rapidly as possible to make full use of the hydro potential. In any event, the typical 24-hour load curve shape will be lowest in the first quarter (midnight to 0600), rising from 0600-1200 hours, more or less steady from 1200-1800 and peaking during the 1800-2400 quarter. Generation then has to conform to the changing load pattern and several possible ways of doing that may be considered.

First, if the water source as determined by the typical year monthly run-of-the-river flow is sufficient to develop the power required through some future year (say the tenth year), the turbine-generator control could be of the "water wasting" type where the turbine-generator runs at rated speed and constant (rated) output at the generator terminals. The difference between rated output and the variable load requirements is diverted by an electronic switching device to passive resistor loads. Several makes of this so-called electronic load controller are represented to be in production for single phase machines up to 60 kW and three phase machines to 180 kW. One version uses an induction generator which receives its excitation from capacitors. Within the limitations of the size of machine they can control, the electronic load controllers have some cost advantage over the conventional mechanical or hydraulic governor. Literature seen so far by the writer has not indicated how the electronic controllers are adapted to automatic

start up or shut down. When these controllers get into quantity production, they should be built of modules such that spares for the electronic components could be kept in stock and plugged in in place of defective units. The passive load resistors are simple and should be quite reliable.

If power (kW) and energy (kWh) requirements and daily water flow are such that all the available water must be utilized, storage for daily regulation or monthly holdover or both may be necessary. A forebay pondage capable of storing at least one or two days of the typical daily flow should be located if possible. A conventional governor now would be necessary since the generator must follow the load variations and there would be no water to be wasted by an electronic controller. The additional cost of the conventional governor should be justified by the additional power and energy that could then go to active loads.

Holdover storage to fill in low-flow months from high month flows generally is more justifiable for larger hydro projects - in the megawatt range. However, if such storage for small hydro can be found, a rough estimate of storage volume requirements can be made by using Figure 2 where a horizontal line can be constructed by eye to make the areas A plus B equal to area C. The height of the line above the axis indicates the value of a uniform monthly water release which can be the starting point for a regular reservoir operation.

There are several methods for estimating peak or flood flows, but then the flow has to be routed through the stream channel and water stage levels calculated. Actually, the flood flow rate (ft^3/second or M^3/second) is not as significant as is the flood stage. In many cases, the stream channel can be examined for high water indicators such as bank erosion, debris along the banks, bridge overtopped, marks on rocks or trees and such. Area residents can be a good source of flood stage data.

Preliminary designs and related cost estimates for diversion dams should include abutment protection well above such high flood stage indicators. Turbine settings must take account of flood stages at the powerhouse location. The reaction turbine with a submerged runner is affected only by a reduction in net head by high tailwater during floods. However, the impulse wheel must always be above tailwater level.

EQUIPMENT DESIGN AND LOCAL MANUFACTURING OPPORTUNITIES

Paper presented at the regional Workshop
on "Small-Scale Hydropower in Africa"

Abidjan, Ivory Coast
March 1-5, 1982

by
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Technical University Furtwangen
Fed. Rep. of Germany

ABSTRACT

China and Nepal are two countries with huge hydropower potential, but with quite different experiences in using this valuable resource. China has gone a long way in developing its water resources since liberation in 1949 with approximately 100,000 small hydropower stations to date. Anybody trying to start out on small hydro development (SDH) should try to profit from China's vast experience in this field. Nepal is at present making big efforts to develop its water resources, but has not yet fully defined its policy concerning SHD. Thus, Nepal is representative of those countries with hydro potential, but only beginning to develop their own ways concerning SHD.

The first part of this paper discusses some aspects of the Chinese way of self-reliance concerning SHD. It seems that the most important prerequisite for successful SHD is to build up a "climate" - an infrastructure in which indigenous programs are able to grow.

With the help of the Chinese standardization, the different types of machines and their design features are shown, covering the range of flows and heads encountered in SHD.

The second part of the paper tries to evaluate Nepal's experience with SHD. Imported machinery does not guarantee successful programs since this machinery is often expensive, difficult to maintain, and often not designed for the rural areas. In choosing equipment, criteria other than price only must be considered.

The possibility of a "golden middle way" between complete self-reliance and full import dependency is examined.

Experience gained from the "Small Turbine and Mill Project" in Nepal suggests that it is imperative to build up an indigenous know-how in manufacturing SH equipment. Without it even maintaining imported equipment is impossible. It is suggested that imports should only have the role of bridging the gap of not yet available

manufacturing capability which can slowly be built up with the undertaking of small enough projects.

BIOGRAPHICAL SKETCH

Reinhold Metzler was born on July 4, 1950 in Heidenheim, West Germany. After secondary education, he entered a two year industrial practice as an employee of the Voith Company, manufacturer of water turbines and paper-making machines. Completing his studies at the Technical University of Ulm, West Germany, he received his Diploma in mechanical engineering in 1971. Until 1976, he gained practical experience in mechanical engineering as a technical designer and leader of a design group in manufacturing companies in the field of packaging machinery and industrial washing machines.

In 1976 he began working with Butwal Technical Institute in Nepal. This work was under the United Mission to Nepal and employment was by Services Overseas - an organization of the Protestant Churches in West Germany. As preparation, he received six months' training in different companies covering the fields of hydraulic and electric machines.

From 1977 to 1981, he was responsible for the R&D Department of Butwal Engineering Works - an associate project of United Mission to Nepal. This work included the develoment of a small water turbine, which could be completely manufactured in Nepal and the development of appropriate machinery to be powered by this turbine. Results of these efforts have been published in the GATE-module 1/13 "Small Waterturbine" with the German Appropriate Technology Exchange.

In August, 1980, he was a member of a group of 12 specialists visiting the People's Republic of China to study the small hydro development efforts of China.

Since July, 1981, he has acted as project leader of R&D project at the Technical University of Furtwangen, West Germany. The aim of this project is to develop a heat generator capable of converting the mechanical energy of a water turbine

directly into heat for processes in cottage industry thereby avoiding the costly and more complex production of electricity.

The prototype is planned to power a small soap factory in Nepal. This two year project is financed by the Baden-Wurttemberg State Ministry of Economics of West Germany.

Equipment Design and Local Manufacturing Opportunities

1. Prerequisites for Indigenous Manufacture

1.1 China - An Example

1.2 General Aspects of Water-Resources Development in China

1.3 Policy in Rural Electrification in China

1.4 The Role of Small Hydropower Stations in China

1.5 The Standardization of Equipment in China

1.5.1 The Role of Standardization

1.5.2 Turbines

1.5.3 Generators

1.5.4 Governing

1.5.5 Turbine-Pump

1.6 Conclusions

2. Efforts of Small Hydropower Development (SHD) in Nepal

2.1 The Import-Oriented Approach

2.2 Building Up Indigenous Know-How

2.2.1 The Project

2.2.2 Choosing the Turbine Design

2.2.3 The Application

2.3 Conclusions

3. Appendix

3.1 Bibliography

3.2 List of Manufacturers of SH Equipment

1. Prerequisites for Indigenous Manufacture

1.1 China - An Example

Many countries have realized the need to develop their waterpower resources and have gone different ways in doing so. Many thought it best to let "specialists" do it and imported know-how and machinery. Often enough they had to find that in this way the plants become too expensive and difficult to maintain, since know-how and spare parts were not available in the country. Others made "do-it-yourself" efforts and tried to develop their own designs to produce locally the otherwise expensive machinery. But even so spare parts where available now, most of the projects still seem to be too expensive and difficult to operate and maintain economically.

These two problems - on the one hand expensive and imported know-how and equipment and on the other hand not too successful efforts to produce locally - caused people concerned with small hydropower development (SHD) to investigate how others cope with these problems.

China undoubtedly was found to have by far the largest experience of any country in this field. But, in order to understand why it was so successful, it is important to know enough about the background, the "climate" or situation, in which these developments took place. It is one of the most common mistakes I find in SHD that attention is focused primarily on one aspect of development like design, price, or even opportunities to manufacture equipment locally.

As one out of 12 specialists I attended a study tour on water-resources development in China in August 1980. There I learned that it is of prime importance to put SHD into the framework of general development of the country. This strategy is the reason it was possible in China to increase manufacturing capacity for SH-equipment from practically zero in 1949 to close to 1,000 MW per year in 1980 for plants smaller than 10 MW only.

Chapter 1. gives a summary from the report of the above-mentioned tour (1) to clarify the apparent prerequisites enabling China to build up indigenous manufacturing and installation capacity so successfully.

1.2 General Aspects of Water Resources Development in China

With the uneven distribution of monthly precipitation, both regionally and through the year, floods or droughts used to afflict at least one of the vast provinces of China almost every year. Big losses in the grain-producing provinces in the northeast and southeast of the country, where most of its aerable land is situated, and where the annual precipitations concentrate, occurred regularly.

In harnessing and developing the water resources, priority, therefore, was always given to flood control measures and irrigation. The building of water diversions, canals and dykes, as well as the reclamation of marginal and submarginal land through irrigation or drainage, are old Chinese practices which antedate the establishment of the People's Republic of China. However, the systematic development of water resources on a large scale only started after the liberation in 1949.

As early as 1948, Chairman Mao Dsedong gave high priority to the construction of hydraulic schemes: " we must .....make plans for the construction of hydraulic schemes whenever it proves possible." May 25, 1948). In 1955 the construction of hydraulic schemes became a declared policy and was included in the 2nd five year plan: "Parallel to the activities in river training, number of small hydraulic schemes have to be constructed, in order to practically eliminate floods and droughts of average amplitude within seven years." (Mao Dsedong: 7th point of Questions of opinion about the seventeen points concerning the agriculture," 21st December 1955). The main aim was to make continuous agricultural production possible, to increase the production through multiple harvests, and to reclaim arid and semi-arid areas through irrigation and the establishment of a regular water husbandry.

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Today 75% (20 million hectares) of the formerly flood prone areas are ameliorated and 48% (46 million hectares) of the arable land is under irrigation. As a result, the average annual yield in grain, increased 13-fold since 1949 (i.e. from about 700 kg/ha to about 9,000 kg/ha).

1.3 Policy in rural Electrification in China

In the early years of the young People's Republic of China, the overwhelming importance of a regular energy supply to rural areas was realized: "... with the progress of its new technologies and its modernization, the agricultural sector will require more and more machines, fertilizer, hydraulic schemes, electric energy and transportation facilities...," Mao Dsedong: "About the just solution of the contradictions among the people. XII The way of industrialization in China." (27th February 1957). As a result small, decentralized hydropower stations were integrated in the other hydraulic activities.

The total hydraulic potential in China is estimated to be in the range of 680,000 MW; 70% of this potential is situated in the provinces and autonomous region of the southwest. Out of this total potential, about 150,000 MW are estimated to be feasible for harnessing by hydropower stations (i.e. stations up to 10 MW according to the definition given by the Ministry of Water Conservancy). This small hydropower potential is mainly concentrated in 1,100 of the total 2,100 counties. In 70% of these counties, small hydropower stations are operating, and about 30% have their electric power supply mainly from small hydropower stations.

Production and distribution of electric energy in general, and the construction of small hydropower generation units in particular, have been strongly promoted since 1949. Before liberation only a few electric power stations (mainly coal operated) were running for the supply of urban centers. In 1949, thus, the total installed

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capacity was about 1,700 MW out of which about 200 MW was hydropower. In 1974 the total installed capacity amounted to about 32,000 MW. (Unfortunately, no figures about the total installed capacity in 1979 were available.)

The output of small hydropower stations in this balance increased steadily from 2 MW in 26 stations in 1949 to 6,300 MW in about 90,000 stations in 1979. The rate of increase in installed capacity from small hydropower stations has been fixed at about 1,000 MW per year until the economically justifiable potential is exploited (i.e. 40-60% of the total small hydropower potential.)

At the central government level, the Bureau of Farmland Water Conservancy of the Ministry of Water Conservancy is responsible for the planning and construction of the small hydro stations.

Its task is:

- to coordinate country wide the planning and integration of small hydropower stations;
- to guarantee optimal interconnection of isolated stations;
- to promote production of required equipment at province and county level.

The planning is based on the 5-year plans of the communes which are approved at county level for projects smaller than 500 kW and at province level for larger projects. A leading dictum of the Chinese economy is "to walk on two legs" (i.e. not only to develop large enterprises to expand the modern sector, but to develop small schemes in traditionally unexploited areas as well.) The construction of small hydropower stations is certainly one of the most significant applications of this policy.

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1.4 The Role of Small Hydropower Stations

"There are mainly two problems with small hydropower plants:

- they are not economical;
- the electricity produced by them is of bad quality (frequency, voltage)."

(Quotation from the introductory speech by Deng Bingli, Deputy Director of the Bureau of Farmland Water Conservancy, Beijing, 22nd August 1980.)

This quotation seems to be in contradiction with the large number of already constructed and planned small hydropower stations in China and with the efforts which are still made in this field.

a) The Economy

All development efforts in China during the past 30 years have mainly been aimed at satisfying basic needs of the population. All development activities had to conform to this main goal. Small hydropower stations, therefore, never were and are implemented as isolated, infrastructural projects, but are as a rule part of multi-purpose projects. Actually, the group did not see one single small hydropower station during the present tour, which was a reason "per se" for any hydraulic activity. All the hydraulic structures which were visited aimed at flood control through retention reservoirs with irrigation from these reservoirs and the reservoirs being used as ponds for fishbreeding etc. Electricity production through small hydropower stations, with only one exception, is last on the list of priorities. In one case even recreational activities such as boating, ranked above the generation of electricity (300 kW plant on the Tao Hua River in Guilin). It should, however, be noted that China faces an acute shortage of electric power and that, within this integrated approach, electricity production is an important goal. Additionally, this statement has to be viewed in light of the actual changes in the country the opening to industrialized countries and corresponding comparisons. China

has abundant oil and coal resources and that energy obviously cannot be challenged.

On the consumer side, the electricity is used to run irrigation pumps, for fertilizer production and for processing raw food (i.e. 65% of the energy produced in small hydropower plants is returned to the agricultural sector.) Other small industries consume 16% and only 19% of the electric energy is consumed for domestic purposes (i.e. for lighting since rural households use mainly wood, coal, or biogas for cooking.)

With this approach to planning and distribution, the small hydropower stations in China certainly are economically more viable than in other countries where an isolated approach to the implementation of small hydropower projects still is the rule and where the economic justification becomes more and more difficult. This fact certainly is reflected in the large number of small hydropower stations built in the recent past and still being implemented in China.

b) The Quality of Electricity

Besides the national distribution system, 160 counties have their own local grid which is fed by large power stations besides the small hydropower stations which helps to improve the quality of the power. This arrangement also has the advantage that many small hydro power plants can feed directly into this local grid without any governing. Thus it is felt, that the quality of the produced power cannot be that bad.

Besides the above-mentioned inputs for agriculture and industry, the small hydropower stations are structurally important as well. The decentralized production of electric energy and the integration of small hydropower stations in multi-purpose rural develoment projects have big advantages:

- the hydraulic structures can be built with labor-intensive methods by local population themselves;
- the production of the equipment for plants smaller than 500 kW can be decentralized (province level);

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- ecological consequences such as conservation of existing landscapes and creation of new ones, as well as places for recreation and excursion;
- improvement of the level of environmental consciousness of the rural masses.

These advantages definitely counter balance an approach to rural electrification which is not fully economical.

1.5 The Standardization of Equipment in China

1.5.1 The Role of Standardization

The following quotation[1] gives an idea of the background behind the thinking on SHD in China.

"Before liberation (1949) there was few capacity in the manufacture for small hydropower generation sets in China. Almost all the equipments were imported. In 1952, the first 800 kW water turbine generator sets were produced, and in 1954 we began to manufacture 10,000 kW hydro electric sets with a head of over 30 m.

Due to the abundant hydro resources and big differences in its hydrographical diversity, appropriate measures must be taken in order to meet various requirements, otherwise the result will be a great variety of different models and types which makes the mass production very difficult. Beginning from 1972, standardization of the hydropower generating equipment was made. Since then, unified design work was practiced on a national scale and strict quality requirements for the products have been defined."

1 Paper presented by Mao Wen Jing and Deng Bing Li on the occasion of the UNIDO Seminar-Workshop on the Exchange of Experiences and Technology Transfer on Mini-Hydroelectric Generation Units in Kathmandu in September, 1979.

This statement clearly expresses China's attempt to keep costs of small plants down, while maintaining high quality standards.

The thorough standardization of the equipment has made it possible for factories on the county level to go into mass production. The standard range of turbines, covering output power from 12 to 1,250 kW and heads from 0.8 to 45 om, has only 29 types. No special order outside this range seems possible.

With centralized R&D, capital expenditure and personnel are avoided, usually needed in every single turbine manufacturing company. Little emphasis is being placed on further development and sophistication of the machinery. The designs we saw were somewhat old fashioned, but will produce a limited number of varieties, resulting in lower costs, and guaranteed quality and reliability of the machines. These factors, in the Chinese context, outweigh by far the disadvantages of standardization.

The standardization of the designs of equipment and their quality standards seem to be a crucial factor in China's success in developing small sites. The designs used are proven from the manufacturing, as well as the operating, point of view. The success of a new project, therefore, depends largely on factors which can be influenced by the customer, the local people, such as time and cost involved in building the civil works. The result of all this is easily seen in the prices of Chinese factories. The Jinhua Small Turbine Manufacturing Plant quotes 100 Y (US$67) per kW for low hed and 20 Y (US$13) per kW for high head for the turbine only. By comparison, German manufacturer asks US$400 per kW for the turbine only.

1.5.2 Turbines

The standardized turbine designs used in China are principally the same used all over the world. They are Pelton for high, Francis for medium, and propeller for low head. The difference, however, lies in the simplicity of the design, always keeping in mind, the factors of mass production and reliability, and only third efficiency.

a) Head Range 0,8 to 25 m

Two types of turbines are used:

- Propeller turbine with open flume (fig. 1) or scroll casing with adjustable guidevanes and fixed runner blades. The runner is available with four different angular positions of the blades.

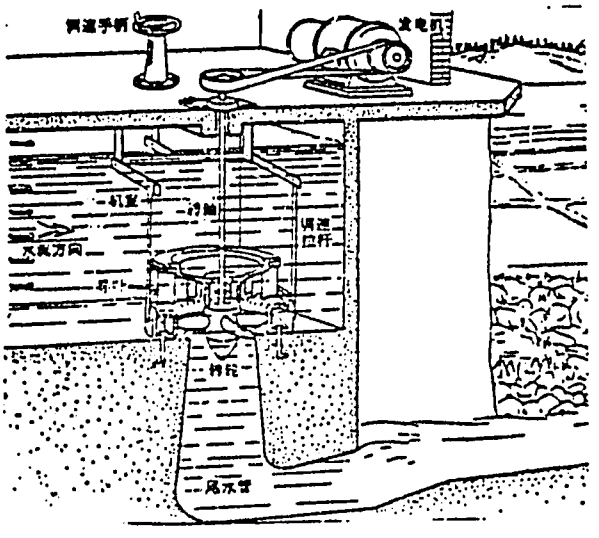
  Number of sizes: five

  Head: 2 to 18 m;

  Flow: 0,8 to 4,13 m^3

  Speed: 300 to 800 rpm

  Output: 14 to 440 kW



- Speed transmission to the generator is done with flat bells up to 24 kW and with CV-bells up to 145 kW output power. For higher outputs, turbine and generator are coupled directly.

Tubular - Turbine (similar to fig. 2)

Number of sizes: 5

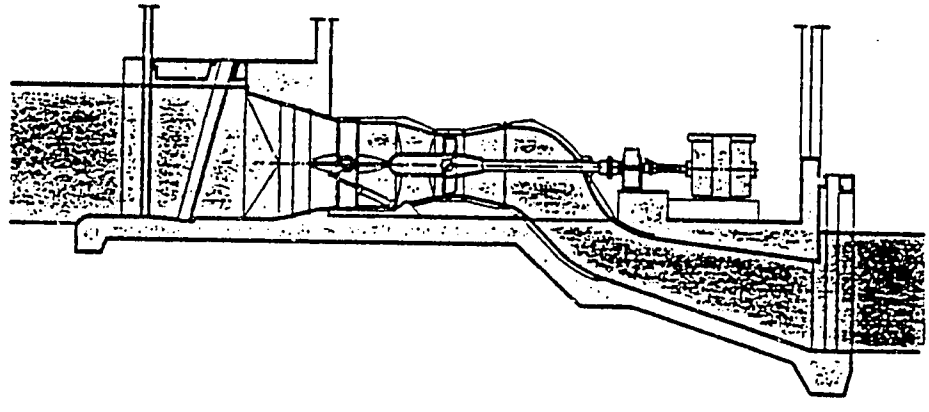
Head: 0,8 to 25 m

Flow: 0,9 to 28 m^3

Speed: 428 to 1,000 rpm

Output: 54 to 818 kW

For both turbines, the bearings running in water are waterlubricated plastic bearings.



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b) Head Range 15 to 120 m

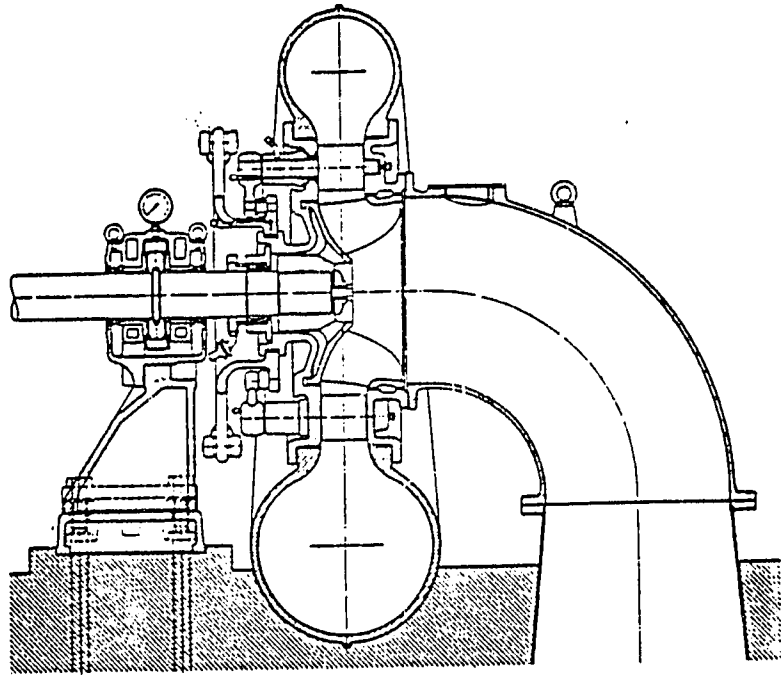
Francis Turbine (similar to fig. 3)

Number of sizes: 8

Flow: 0,7 to 1,96 m^3

Speed: 600 to 1000 rpm

Output: 148 to 1332 kW



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c) Head Range 100 to 450 m

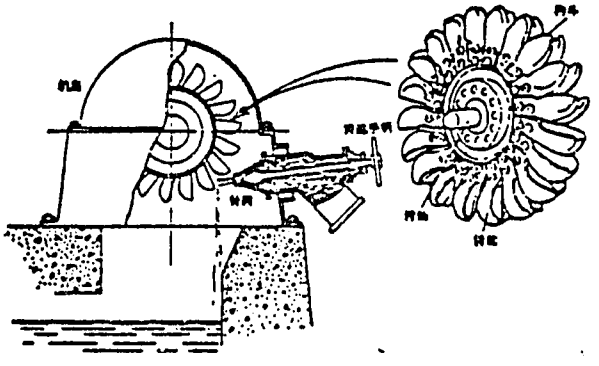
Pelton Turbine (fig. 4)

Number of sizes: 11

Flow: 0,067 to 0,4 m^3

Speed: 600 to 1,000 rpm

Output: 53 to 1,000 kW



1.5.3 Generators:

Generators seen in China were synchronous machines. The larger older machines were separately excited, while the smaller newer ones were self-excited slip-ring generators with static excitation units. All of them are produced indigenously though some material (e.g. laminations for stampings) were imported. There are 100 state manufacturers in China, grouped into provincial- and county-level plants.

Compared with current western designs, the machines seen in use or under construction were quite large and heavy, with old types of insulation being used (Class B was quoted in one factory). A 40 kW generator weighted 500 kg compared with 270 KGF

for a comparable machine from a U.K. manufacturer. This again lies in the line of putting the emphasis on mass-production of proven designs under the lowest possible cost. This results in high reliability and low cost of small plants, but also in "trucks" rather than "racing cars." However, one area it would seem that substantial savings could be made is in the application of induction generators. These are basically induction motors running at a slightly higher speed than synchroncus. They are mechanically strong and produced in big numbers. For excitation, these machines need a grid, to which most of the power stations seen were connected. This grid also provides the governing if it is stabilized by a comparatively large reserve of synchronous generators. The excitation can also be provided by capacitors in which case no grid is needed. Again, the standardization of the generators is interesting.

P = output power per generator in kW;

n = speed in rpm

for n = 1,000 P = 12, 18, 30, 40, 55, 75, 100, 125, 160, 200, 250, 320, 400, 500, 630, 800, 1,000, 1,250

for n = 750 P = 30, 40, 55,..... 500

for n = 600 P = 100, 125, 160,..... 630

for n = 428,6 P = 200, 250, 320,.....800

All generators are designed for overspeed of 2 - 4 times running speed and for a power factor of 0,8. To give an idea of the price level: 40 kW price (domestic) Y 500 (US$335)

1.5.4 Governing

A hydraulic mechanical governor which keeps the speed of the turbine constant is an expensive and complicated item and is omitted wherever possible. Governors are used in China, as a rule, only for turbines with runner diameters exceeding: Pelton - 450 mm; Francis - 500 mm; Propeller - 800 mm.

Smaller turbines are manually-controlled as they are in most cases connected to a grid and run continuously at full capacity. Operators are on continuous duty in case emergency shutdown is required.

Electronic load controllers, where an electronically switched ballast load is used to maintain a constant load on the generator, are also produced. These electronic devices are cheaper and simpler than hydraulic-mechanical governors for low-output units.

1.5.5 Turbine-Pump

Waterpower does not only mean electricity production. It is expensive to transform the mechanical power from the turbine into electrical energy and then back to mechanical, when only the latter is required. The development and dissemination of the turbine-pump is one example of Chinese ingenuity in developing small hydro in an appropriate way. Here an excerpt from "The High-Lift Turbine-Pump" (2):

> The turbine-pump is a water-lifting device that utilizes water as motive power and requires neither oil nor electricity. Besides pumping water it can also generate electricity or provide mechanical power for agricultural processing. It brings great impetus to the raising of agricultural productivity.
>
> The turbine-pump is a combination of a water turbine and a pump (Fig. 1). The turbine is the driving part while the pump is the working part. By extending the shaft upward, the turbine-pump can be made to drive a generator or agricultural process machinery which

adds greatly to its versatility. This is known as a dual-purpose turbine-pump.

The construction of a turbine-pump station is quite like a hydroelectric station, that is, by use of the concentrated head of a certain stretch of the river. There are three common types of construction:

1. Channel type. At locations where the terrain is inclined and the water flows rapidly, low dykes or only head works need to be built taking advantage of the greater slope of the river bed. A channel running alongside the hill will form the required head at the station, as shown in Fig. 3.

2. Dam type. At locations where both the topographical and geological conditions are favorable, a dam is built across the river to recreate a higher head, as in Fig. 4.

3. Combination type. This is a combination of the two types mentioned above, where the head is formed by a channel with a dam built additionally to provide a reservoir for regulation of flow, as in Fig. 5.

There are also other types of construction, such as locating the turbine-pump station at cascade of a

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channel, at the mouth of a spring, or utilizing tidal energy, etc.

Guizhou Province is situated on the Yun-Gui Plateau with the Miaoling Mountain traversing across the whole region. The terrain is high in the northwest and low in the southeast and is interspersed with very rapid rivers. Rainfall is bountiful here, the annual average being over 1000 mm. Development of turbine-pumps is quite favorable in view of the rich hydraulic resources. Since 1964, a total of 9014 units have been put into operation on various sites affording irrigation to 27,000 hectares of farmland.

In the mountainous areas where the fields are high and the rivers low, the life can easily be over 100 meters. The conventional turbine-pumps are only applicabler to 40-50 meters because of the limitation of mechanical design. To solve this problem, the hydraulic, mechanical and scientific research departments of the Province have joint forces in conducting investigations and worked out improvements in the design of turbine-pumps. From 1968 on many advncements have been achieved such as the introduction of the multi-stage turbine-pump, the use of ductile iron or cast steel in making the casing and impellers, the improvement of the shaft design and the replacement of metallic

bearings by plastic bearings. New prospects have been obtained for the turbine-pump by substantially increasing the net lift, the maximum reaching 263 meters. Generally, units in series with total life more than 100 meters are called high-lift turbine-pumps.

We now have two series of high-lift turbine-pumps with head ratios of 1:6 and 1:17 respectively. The head ratio is taken as the head suplied to the turbine versus the lift produced by the pump. The 1:6 series is a single-stage machine and consists of two sizes, the 40-6 and the 60-6 (Fig. 11), applicable to high lift and larger flow sites. The 1:17 series is a machine with a three-stage pump and consists of three sizes, the 30-18, 40-17 and 60-17 (Fig. 12), and is suited for high lift and low flow sites.

1.6 Conclusions

China undoubtedly has by far the most extensive experience of any country in the field of small hydropower. This experience of course is a specific Chinese one - trying to copy it would surely be not helpful to any country, but a number of lessons can be learned:

- there is effective government planning so that hydroelectric development is integrated into the other aspects of water resource management;

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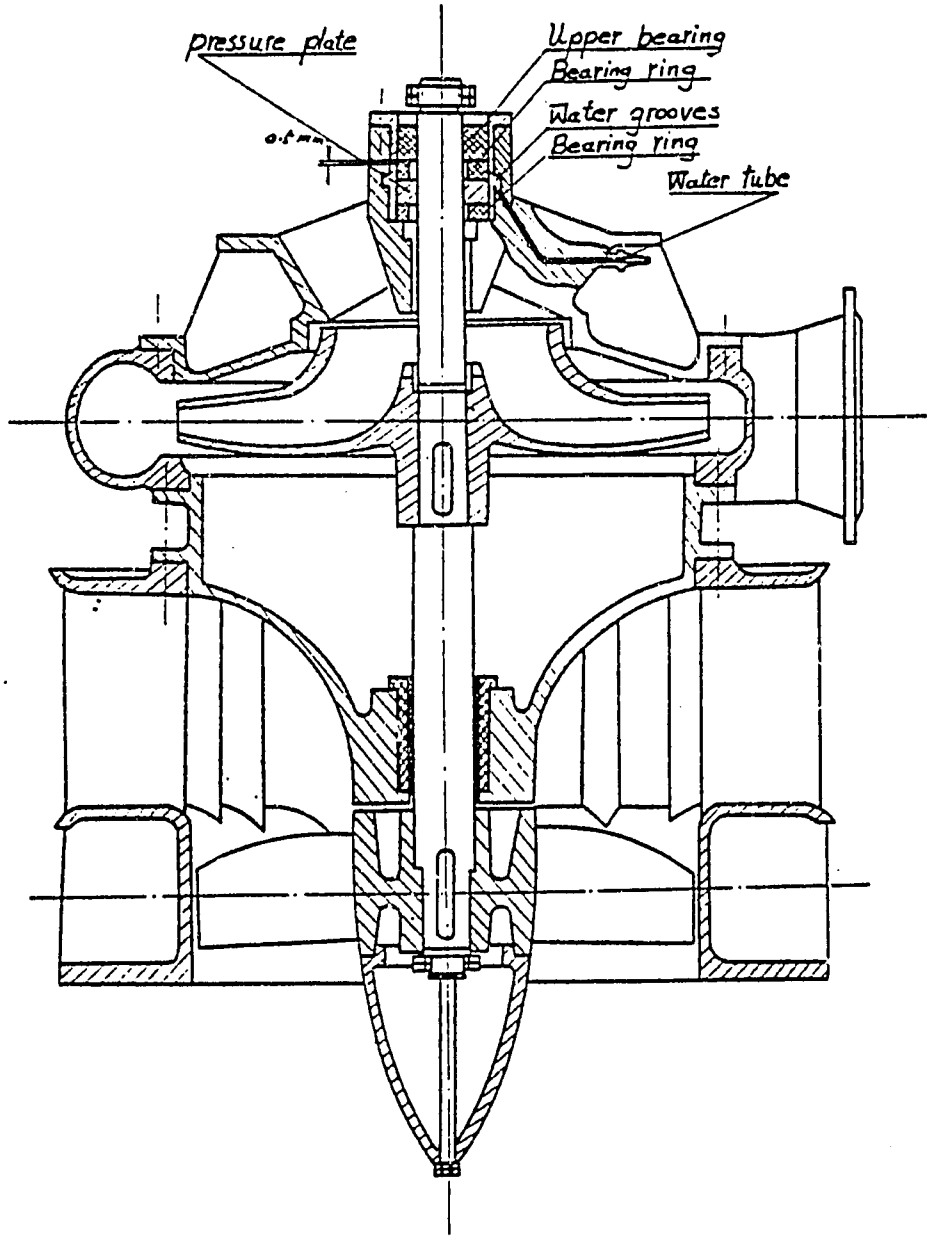

Fig 11 Single stage high lift turbine-pump

there is strong motivation on a common basis and hydro plants are built on local initiative;

- electricity is largely used in the industrial and agricultural sectors, and in the latter particularly for increasing the productivity of the land through drainage and irrigation;
- decentralized workshops for manufacture and repair of equipment are established in many counties;
- standardized designs of equipment enable it to be manufactured quickly and cheaply to a higher standard.

All this seems to suggest that it is most important to build up a "climate," an infrastructure, in which indigenous programs are able to grow. The best designs and programs will not take root if this prerequisite does not exist.

2. Efforts of Small Hydro Development (SHD) in Nepal

2.1 The Import-Oriented Approach

Nepal's hydro potential has been estimated by 90,000 MW out of which only 0,07% is developed. On the other hand, Nepal suffers from an immense energy shortage, especially in the remote areas. A fast-growing population needs increasing amounts of firewood. A study by the Tribhuvan University (3) has shown, that, if there is no change in the present rate of consumption, there will be no commercial forest left in the hills by 1985. Thus waterpower is the only form of energy Nepal has indigenously and abundantly. The Government recognizes the key role micro-hydro (under 100 MW) could play in the development of remote areas. These small power plants would make it possible to rely on Nepal's own resources and foster production of the necessary equiment in indigenous workshops. (4).

It was only natural that the Government started it's SHD program in a district centre, where it had officials from the different departments to rely on. The plan was to use the power of a river for a plant of about 300 kW. Since, for this size, no

experience existed in the country, foreign experts were called in for project planning. They went to the site, saw an existing irrigation channel, a drop of about 60 m and about 1 m^3/ sec. water in the river, about 1 km from the centre. Since no manufacturing know-how for the equipment of this size existed in the country, quotations of foreign companies were asked for. Prices differed very little (from US$1,052 to US$1,200 per kW) for turbine, generator, and governor 170 kW capacity.

The guaranteed output, however, varied for the same site between 208 kW and 162 kW (approximately 20%). The reason for this significant difference was the different way the companies had made their standardization.

In 1977, the Government decided to order the 162 kW equipment with the lowest price. During the design and construction period many problems developed. It was extremely difficult to get any information or drawings on the equipment from the company. The company, of course, is quite large and from their nature the project seemed to be so small that it was hardly worth their effort.

No road exists to the site and it can be reached only by a one day's trek or by helicopter; so transport weights and sizes are crucial. But, since this is usually not the main problem in countries where equipment is designed, this information was extremely hard to get. So construction continued in the meantime. The irrigation canal was widened, the penstock laid, and the powerhouse erected. However, the canal was continuously cut open by farmers who needed irrigation water and had no appreciation of a power project using their water to provide lighting to people in the center. Erecting the high tension line proved to be difficult. The same farmers (not belonging to the centre) refused, for the same reason, to permit putting the necessary poles into their fields. They had to be forced by officials. To erect the line in the center was equally difficult since nobody wanted the line crossing his premises. Since the entire project was ordered continued from above, the local people refused to cooperate, let alone to assist into this "strange" project. After a long period, the equipment appeared in 1979 at the

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border creating transport problems which had to be solved. The heaviest piece was the cast iron scroll casing of the Francis turbine which turned out to weigh 1,400 kg. The biggest helicopter in the country had a capacity of just that and no pilot could be found to take the risk (the price for the helicopter was US$1,100 per hour.) Discussions between the Government, the manufacturing company, and the airline continued. The monsoon broke and the equipment had to stand the rains for another reason. Finally, a military pilot mustered the courage to lift the equipment in 1980.

How it will run remains to be seen. There is no workshop close by and no experienced manpower to maintain the plant (the hydraulic-mechanical governor is a delicate piece of equipment.) Since the civil works were finished two years earlier before the equipment finally reached the site, a small 30 kW cross-flow turbine set was installed for testing. This set was produced locally and transported on a porter's back in three days to the site. It ran until the imported equipment arrived - altogether two years. In this time, the load was for lighting only (15 kW at night and zero during the day.) It will be difficult to justify bigger equipment at this low load. No significant increase in load is expected in the near future.

This painful experience should warn anybody working in the field of SHD. To learn from it, I made the following summary of mistakes:

1. Importing foreign consultants as the only source of know-how. Consultancy is important. But it should always be realized that it is difficult to come from outside and give opinions about plans for such a matter as complex as a community. Foreign plans have to be matched with local ideas and know-how.

2. Relying on imported equipment as the cure for all problems. In this project, it would have been better to start small and grow as the load grew. With this approach, local manufacturers could have been asked to produce the equipment. The 30 kW set installed in the meantime proves that production is possible - however, on a small scale. But with a second, somewhat bigger set, which still can be produced locally, sufficient output could have been reached for years, with a much lower capital investment.

3. Making price the decisive factor for choosing the equipment. If local manufacturing is not possible, greatest care has to be taken in choosing the equipment and the manufacturer. Equipment is designed for the situation in which it is usually sold. In the country of the above-mentioned manufacturer, for example, transport weights and sizes are not of prime importance. In Nepal, however, they are crucial factors.

The same applies to the level of technology - turbines can be controlled manually as in the case of the 30 kW plant. To import automatically-controlled equipment can result in not being able to repair it when it breaks down. Machinery tends to be more critical the more complex it gets.

Another problem area of importing equipment is the communication between the manufacturer and the project. For a big company, it is difficult to deal with small plants and sending personnel to put up the machinery is out of the question for the budget of small projects. This makes it difficult for both parties.

2.3 Building up Indigenous Know-How

2.3.1 The Project

The "Small Turbine and Mill Project and Rural Electrification Program" attempts a different approach for developing Nepal's hydropower resources. Listening to local people, it was found that the immediate need was for mechanical power for milling grain and pressing oil. Therefore, it was decided to develop a water turbine which could power milling machines. The market for this turbine is the area of the middle hills and heads tend to be around 5 to 20 m. Building irrigation channels to irrigate the terraces on the steep mountain slopes is an old tradition in Nepal. These are unlined earth channels and their maximum water carrying capacity is around 300 l/sec.

2.3.2 Choosing the Turbine Design

For this head and flow range, a Francis turbine is used usually. This type of turbine, however, has some marked disadvantages:

a) The water-flow through the runner turns from radial to axial direction. This means that a different flow head combination needs

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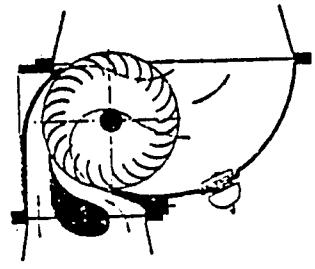
a different runner diameter, which also changes the entire design of the turbine. This necessitates a number of standard designs which is only economical if they are mass produced.

b) The part-load efficiency of this type of turbine is very low. Since, in small streams, the change in water-flow is quite significant, high efficiency, even with only a part of the nominal water flow, is a very important factor, especially in run-of-the-river plants, where the changes can not be counterbalanced by a reservoir.

c) The flow through the turbine is three dimensional which makes the whole design quite complicated. Therefore, this turbine is one of the most expensive designs to manufacture, especially in small series.

A turbine which does nt have these three drawbacks is the cross-flow turbine (fig. 12) also known as Banki- or Mitchell-Ossberger turbine. This design is relatively unknown and little development work had been done on it for years. In the general trend for big scale, this turbine had been almost forgotten, since it is a typical small-scale turbine (up to approximately 1 MW.) It has three major advantages:



1) Water-flow through the runner is radial only. This means, that the turbine is adapted to different a head flow combination only by varying the width of the runner, but not its diameter. Thus, the basic design always stays the same.

2) The part-load efficiency is quite high. It resembles nearly the curve of a Pelton turbine.

3) It is easy to build.

Because of these reasons, the cross-flow turbine was chosen. It took four years to reach a design which satisfied the five criteria which were considered crucial:

a. It must be simple enough to be built in a small engineering workshop.

b. Although a turbine of relatively advanced design is needed, it should, as far as possible, require no maintenance.

c. All the material used must be obtainable in Nepal without foreign currency.

d. It must be comparable in efficiency with, and notably cheaper than imported turbines.

e. Since every part has to be carried by porters, none of it should weigh more than 70 kg or be too bulky. The result of this work is published in (5).

2.3.3 The Application

In Nepal 68 turbines have been installed. One has been exported to Papua New Guinea. They power mills for milling grain and pressing oil; they drive sawmills and grain-dryers all by direct mechanical power by belt transmission. The mills are all owned privately, two of which are run by cooperatives.

In searching for further applications for the turbine, it was noticed that heat for processes in cottage industries is an area where small hydropower could substitute for scarce firewood. A machine, the heat generator (6) was developed and is able to convert mechanical energy directly into heat. Thus, the expensive electricity production can be avoided, where only heat is necessary. Two pilot generators are still running using the heat for ginger- and fruit-dryers. A project at the Technical University of Furtwangen/West Germany has been started to further develop the heat generator. The aim is to produce heat at a high enough level to be able to boil soap or dye wool. A mining company in Nepal has ordered new turbines (200 kW) to power air compressors.

This experience suggests that there is a distinct need for mechanical power in rural areas, where electricity is too expensive.

2.4 Conclusions

Of course, these projects are very small, but they have important effects:

- By developing and producing these small turbines together with the appropriate machinery local workshops and people can gain valuable experience essential to understanding and coping with problems encountered with bigger machinery.

- Local people, undertaking projects like mills, have the chance to gain understanding and a feeling for what is involved in hydro projects and what can be gained for the community. For both the people in the workshop and those in the village the change comes quite fast. It may be slow enough, if sufficiently small projects are started which can be understood and pursued by local people. In this way, an indigenous know-how in SHD can develop without that, the maintenance of bigger and imported equipment is impossible.

Secondly, load can develop gradually, which in a later stage may necessitate a bigger powerplant. By then enough know-how and demand has been built up to ensure that the new plant is maintained and needed.

Enough projects have shown that a powerplant put into a community will neither necessarily spur development of the load automatically once energy is available, nor that the plant will continue to run if the know-how is not developed. Imports of equipment, in the field of small hydro should have only the role of bridging the gap of not yet available manufacturing capability which can be slowly built up by undertaking small enough projects in big enough numbers. Resisting the temptation to go fast and big is, of course, difficult. Just to import know-how and equipment seems easy, but works in very few cases and makes a country dependent on other countries. I don't know of anybody, who has put this problem into words better than Hari Man Shrestra, Member of the Nepali Ministry of Water Resources (7):

> "Nowadays, 'more talking than real working' and 'easy money earning' type of attitude is being developed in Nepalese society. With this type of social atmosphere, it is but natural, the extent of import dependency on technology, consultancy, supplies, etc., will raise day

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by day. We talk much about standard design, standard equipment, standard technology, and import not only materials and equipment, but also hire unimaginably high-cost engineering and technical manpower from abroad, neglecting that the locally available manpower could also better accomplish the same job, if they are encourage to work by providing necessary incentives. We must try to realize now itself (not late) that development of skilled and engineering manpower, incentives and encouragement for the use of the locally-available skills, manpower, and materials are the major steps towards combatting the import dependency."

Bibliography

1. Report on a Study Tour on Water Resources Development in China, Sept. 1980, Swiss Association for Technical Assistance, P.O. Box 113, Kathmandu, Nepal.

2. The High Lift-Turbine-Pump, Zhao Shilong, Water Conservancy, Scientific Research Institute, Guizhou Province, China, 1979.

3. Nepal: The Energy Sector, Institute of Science, Tribhuvan University, Kathmandu, 1976.

4. Mini-Hydro Development Program in Nepal, B.P. Adikari HMG, 1979.

5. GATE Modul 1/13: Small Water Turbine Instruction Manual for Construction of a Crossflow turbine, Scheuer, Metzler, Yoder, GATE P.O. Box 5180, D-6236 Eschborn, Fed. Rep. of Germany.

6. The Heat Generator: A Report on R&D Done on a Device for Direct Conversion of Mechanical Energy into Heat, R. Metzler, Fachhochschule Furtwangen/West-Germany, 1981.

7. Proceedings of the Workshop Seminar on Renewable Energy Resources in Nepal, Kathmandu, April, 1981.

8. Local Experience with Micro-Hydro Technology, Vol. 1. U. Meier, SKAT, Varnbuelstrasse 14, CH 900 St. Gallen, Switzerland.

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Alphabetical Manufacturer's List for Small Hydro Equipment[1]

Allis-Chalmers
Hydro Turbine Division
Box 712
York, Pennsylvania 17405
U.S.A.

- Standardized tubular turbines for 50 kW to 50 MW; heads up to 15 m.

A B Bofors Nohab
S - 46101 Trollhatten
Sweden

- Propeller turbines from 100 to 2,000 kW

Balaju Yantra Shala Private Limited
P.O. Box 209
Kathmandu, Nepal

- General engineering firm specializing in the manufacture of Cross-flow turbines and related equipment; standardized turbine program within output capacity of max. 70 kW/unit.

Butwal Engineering Works Pvt.
Butwal, Nepal

- General engineering firm specializing in the manufacture of Cross-flow turbines and related equipment; standardized turbine program within output capacity of max. 100 kW/unit.

China National Machinery Imp. & Exp. Corporation
12 Fu Xing Men Wai Street
Beijing, China

- Exporters of small hydro turbines 12 to 12,000 kW of Francis, Pelton, Kaplan, and Turgo - type; also
  - alternators up to 12 MW capacity;
  - speed governors of various types and other accessories.

Disag Dieselmortoren AG
7320 Sargans
Switzerland

- Manufacturer of Cross-flow turbines and Pelton turbines in the small range; also produce a small governor.

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Drees GmbH
Postfach 43
4760 Werl
Federal Republic of German

- Manufacture a variety of Pelton and Francis turbines in the small range.

Elektro GmbH
St. Gallerstrasse 27
4760 Winterthur
Switzerland

- Manufacture small Pelton sets with output up to 25 kW besides non-related other equipment.

Gilbert Gilkes & Gordon Ltd.
Kendal, Cubria
England LA 9 7BZ

- Manufacturer of Francis, turgo, and Pelton-turbines with capacity up to 350 kW; also manufacture control equipment besides other non-related products.

Independent Power Developers Inc.
Box 1467
Noxon, Montana 59853
U.S.A.

- Manufacturer of 3 hp Pelton and 6 hp propeller sets.

James Leffel & Co.
426 East Street
Springfield, Ohio 45501
U.S.A.

- Manufacturer of a large range of Kaplan, Francis, and Pelton turbines from a few kW up to the MW range.

Jyoti Limited
R.C. Dutt Road
Baroda 390 003
India

- Manufacturer of a range of water turbines more or less according to the program of Gilkes, including alternators and associated equipment.

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Koessler GmgH
St. Georgener Hauptstrasse
3151 St. Polten
Austria

- Manufacture Pelton, Francis, and Kaplan turbines in the small range.

Leroy-Somer
Boulevard Marcellin Leroy
B.P. 119
16004 Agouleme Cedex
France

- Manufacturer of a large range of standard alternators from 4 kW to 1,200 kW; also produce a bulb turbine with built-in alternator for low-head installations up to 34 kW output.

Mitsubishi Electric Corporation
Nagasaki, Japan

- Manufacture a very small bulb turbine with 4 kW output for very low-head application.

Nikki Corporation, Engineering Company
2940 Shin Yoshidamachi
Koohoku Yokohama, Japan

- Have recently started manufacturing Cross-flow turbines up to 800 kW output.

Niagara Waterwheels Ltd.
706 East Main Street
Welland, Ont. L 3 B 3 Y 4
Canada

- 4 models of propeller turbines range 20 250 kW.

Northern Waterpower Inc.
P.O. Box 49
Harrisville, New Hampshire 03450
U.S.A.

- Tubular turbines range 20 to 250 kW; head range: 3 to 20 m

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Ossberger - Turbinenfabrik
Postfach 425
8833 Weissenburg, Bavaria
Federal Republic of Germany

- Longtime producer of Cross-flow turbines has delivered equipment up to 1,000 kW per unit.

Peltech Hydraulic Turbines
5141 Wickersham
Acme, Washington 98220
U.S.A.

- Manufacture small Pelton turbine-sets.

Sorumsand Verksted
N 1920 Sorumsand
Norway

- Standardized Pelton, Francis, and tubular turbines from 100 kW to 10 MW.

Sukaraja, C.V.
Jalan Kom. Ud.
Supadio 98
Bandung, Indonesia

- Manufacture Cross-flow turbines of local design

Tamar Designs Ptv. Ltd.
Deviot, Tasmania 7251
Australia

- Manufacture Francis, turgo, and Pelton turbines up to about 100 kW capacity.

Wasserkraft Volk
Gfaell 45
D 7809 Simonswald
Federal Republic of Germany

- Pelton turbines up to 500 kW, Cross-flow turbines up to 100 kW, and waterwheels for low-heads up to 300 kW (!).

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Woodward Governor Company
Engine and Turbine
Controls Division
Ft. Collins, Colorado
U.S.A.

- Manufacture a variety of speed governors of high quality.

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AN ELECTRONIC LOAD GOVERNOR AND RELATED DEVELOPMENTS

Professor Jack L. Woodward

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University of Auckland

Auckland

New Zealand

January 1982

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INTRODUCTION

The relative simplicity, absence of fuel costs, and low maintenance requirements make water-power attractive. Unfortunately the capital cost of conventional small hydro generating sets is very high. One study undertaken recently in New Zealand indicated that for small hydro to be competitive with supply from the rural distribution system, the total installed cost of the small hydro system must be less than $1400/kW. Even this cost would put small hydro beyond the means of rural Third World communities. That it would be impossible to meet the foregoing cost criterion using standard commercial equipment is demonstrated by the curves in Figure 1, which apply to the generating plant above. Construction and installation would more than double these cost figures. Efforts by manufacturers to reduce costs have aimed at standardization with some simplification in design, but commercial incentive is lacking in the smaller sizes, which will probably continue to be very expensive.

A typical small hydroelectric generating plant of conventional design comprises the following parts:

(i) a hydraulic turbine with flow control mechanism;

(ii) a speed governor;

(iii) a single- or three-phase alternator with a voltage regulator;

(iv) gearing or a belt drive to match the operating speeds of turbine and alternator;

(v) electrical control equipment;

The most important single step which can be taken to effect a cost reduction is to eliminate the speed governor. This can be done if the turbine is operated at constant flow and the total load on the generator maintained constant, avoiding unacceptable sudden fluctuations in speed, frequency, and voltage. The cost benefits arise in a number of ways: the speed governor is a very expensive item, and may account for more than 25% of the total cost of a small set; turbine design can be simplified since continuous

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automatic variation of flow is no longer required; finally, without the need to coordinate the dynamics of governor, rotating machines, and water column, matching of the turbine to the site is not critical.

Most small low-cost hydro schemes are "run-of-the-stream," and operation at constant flow imposes no great penalty. For other than a simple lighting load however, additional equipment is required to maintain a constant total load on the generator. This may be done by automatically varying the load taken by a ballast load unit as the consumer load changes. An electronic load governor can sense alternator voltage or frequency and maintain it substantially constant by controlled switching of triacs or thyristors in the ballast load circuit. This technique is probably most appropriate in the smallest sizes, single- or three-phase, but is readily applicable to 30-50 kW sets. Such a unit should produce minimum waveform distortion, be self-contained with few or no adjustments to match it to the plant, be robust, reliable, stable, and cheap. A load governor which matches this specification has been developed at the University of Auckland,[1] and will shortly be available commercially. Similar equipment has been developed elsewhere.[2]

Work on low-cost small hydro sets has been done in small engineering firms, aid-related agencies, appropriate-technology groups, and universities in both developed and Third World countries. The main emphasis has been on turbine designs involving fabrication methods suitable for small factories and workshops. Propeller turbines[3] have been favored for low heads, the cross-flow or Banki turbine[4,5] for medium heads, and the Pelton Wheel[6] for high heads.

The most remarkable achievement in cost reduction has been reported from Pakistan.[5] Costs per installed kW ranging from $250 - $400 have been attributed to:

(a) low administrative costs

(b) labor contributions by the villagers

(c) maximizing the use of local materials

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(d) local fabrication of some equipment

(e) no governor

(f) minimal use of costly technical expertise and supervision

The fitting of an electronic load governor to these installations would increase the total cost by 20-25%, but would permit virtually any type of electrical load to be supplied, and make possible the simple forms of energy management described below.

THE LOAD GOVERNOR

The resistance of the ballast load is varied automatically as the frequency deviates from its rated value. A zero voltage switching method was chosen, whereby separate resistors are switched across the supply, the switching instants corresponding always to voltage zeros. The method produces negligible harmonic distortion and radio frequency interference but is not a stepless control. The number of steps and their relative size can be varied, though increasing the number of steps generally increases cost and complexity. The operation of the single-phase governor may be explained by reference to Figure 2.

Observed frequency is used to control four loads arranged in the resistance ratios 1:2:4:8. By appropriate selection of various combinations the load can vary from zero to full rated load (1 per unit) in 1/15 per unit steps. In essence the electronic controller comprises: two edge-triggered monostables, a precise crystal reference at 26.0 kHz, counting and storing logic, and four triac switches connected to their respective load resistors. In operation of a four-bit counter, supplying gate signals to the load-switching triacs, stores counts in the range 0-15 corresponding to frequencies in the range 49.34 Hz - 50.67 Hz. An input frequency of 49.34 Hz or less corresponds to a count of zero and all triacs will be switched off. At exactly 50 Hz a load of 7/15 per unit will be switched on. If the frequency is too high all triacs will be switched on. The switched load is very nearly proportional to frequency over the active range.

Single-phase load governors rated at 10 kW have been built and thoroughly tested in the laboratory. To increase the rating it is only necessary to replace the triacs. One unit has been installed on a 7.5 kW Pelton Wheel village micro-hydro set in Papua New Guinea. Another unit has operated successfully with a 1.5 kW Banki turbine locally built for a remote forest research out-station in New Zealand. The oscillograms of Figure 3 show the typical behavior of the system in response to a sudden removal and application of consumer load. The delay in reaching a new steady state is the time required to bring the generating set to its new equilibrium speed.

Three identical single-phase load governors may be used with a three-phase ac generator, each comprising only three load resistors in the ratio 1:2:4, and having reference crystals with nominal frequencies 26.0 hHz, 26.0 kHz, and 26.0 + kHz, respectively. With appropriately-selected crystal frequencies, the 21 steps of shunt load are switched into the three phases in sequence while maintaining approximate phase balance, as frequency is increased through the active range of the governor. In tests at a small power station, a load governor with a three-phase rating of 30 kW has successfully controlled an auxiliary set consisting of a manually-regulated Pelton Wheel driving a three-phase 40 kVA inducation generator.

THE GOVERNOR LOADS

The energy dumped into the governor loads may be discharged to waste or used to provide hot water[7] or space heating. In many parts of the developing world the "energy crisis" is most apparent in an acute shortage of firewood, and the development of heat-storage cooking stoves could be worthwhile.[8] Other obvious uses include crop-drying and refrigeration, but looking further ahead useful electro-chemical processes might be developed.[9]

Because the load governor is sensitive to system frequency, it need not be located adjacent to the generator, but can be sited wherever the energy is to be utilized. Indeed

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a number of such governors of reduced rating could be distributed around the system, and if desired could be tuned to operate over different frequency bands by appropriate selection of crystal frequency. This would give a priority ordering of loads. The three units of a three-phase governor need not be physically adjacent. For negligible extra cost and complexity, the load governor includes a further feature which might not be used in a simple village scheme, but does allow an additionial level of energy management. Additional electronic switches control the flow of power to low-priority loads, which are supplied on a continuous basis provided that there is excess power after all high-priority consumer demands have been satisified. This is shown diagrammatically in Figure 4.

AVAILABILITY OF LOAD GOVERNOR UNITS

The design and proving of our load governor unit was completed over two years ago, and, since the appearance of a paper[1] describing it in the technical press, we have had a steady stream of inquiries from would-be purchasers from many countries. Since the majority of those interested did not have the facilities or skills to construct a governor to our instructions, and since we are not geared to produce such items on a continuing quantity basis, the inquiries have come to nothing. For such units to be applied usefully in the Third world, they must be cheap, reliable, and readily-available, and this highlights a situation where, although much has been said and written on load governors, would-be users have great difficulty in locating sources.

We decided therefore to try to interest a local manufacturer in producing the governor unit for sale both within New Zealand and overseas. Since the market may be a low-volume one and the final selling-price should be kept low, the manufacturer should have low overhead costs and be flexible in his approach. After a number of false starts, we have achieved success, and governor units are expected to be available commercially by mid-1982. We are aware that in general the objective should be to encourage local

manufacture in Third World countries in order to keep costs down and to upgrade local skills, but in this instance, there appears to be a good case for establishing a secure source of reliable load governor units as soon as possible.

A great advantage of this load governor unit is that it can be applied without difficulty to any small system, and that the matching of the various parts of the system is not critical. For example, application of a governor to the low-cost Pakistan systems[7] would greatly increase the versatility and security of the supply without a major increase in the total cost.

A NOTE ON OTHER RELEVANT RESEARCH IN PROGRESS

Replacement of the conventional synchronous generator by an induction machine in isolated micro-hydro schemes could have a number of advantages. Unlike small synchronous machines, squirrel-cage induction motors are mass-produced in a variety of frame sizes and pole numbers (and hence speeds), and are robust and cheap. Induction machines have a low transient impedance so that they should be good for motor starting and other switched-load applications, they produce good waveforms, and are tolerant of unbalanced loads.

Against these advantages there are a number of very real difficulties. Inducation machines will not naturally self-excite - they must be connected to a VAR source to provide the magnetizing current. They do not generate at a frequency exactly related to the shaft speed but at a lower frequency - determined by the rotor slip frequency.

Both the above problems are, however, overcome by a system which incorporates a frequency-sensitive load governor, and an automatically-controlled VAR source. We have an active research program aimed at achieving the lowest-cost system compatible with reliability and convenience.

Since the voltage of the induction machine inherently collapses on overload, we also anticipate the development of fuseless protection systems.

REFERENCES

1. "Electronic Load Governor for Small Hydro Plants," Woodward and Boys, Water Power and Dam Construction, July 1980, pp 37 - 39.

2. "Community Load Determination, Survey and System Planning," Holland, Armstrong-Evans, and Marshall, Proceedings of NRECA Workshop on Small Hydroelectric Plants, Quito, Peru, August 1980, pp 59 - 76.

3. "On Stream - Answer to Your Energy Crisis," Mackay, The Sunday Times, London, 1 June 1980, p 60.

4. "Mitchell Turbine Development Project," Dakers, Conference Paper, Ministry of Agriculture and Fisheries Agricultural Engineering Conference, Lincoln College, New Zealand, November 1978.

5. "Rural Power Schemes in Pakistan," Abdullah and Inversin, Water Power and Dam Construction, November 1981, pp 23 - 25.

6. "A Pelton Micro-Hydro Prototype Design," Inversin, Appropriate Technology Development Unit Report 1980, Papua New Guinea University of Technology, Lae, Papua New Guinea.

7. "Technical Notes on the Baindoang Micro-Hydro and Water Supply Scheme," Inversin, Appropriate Technology Development Unit Report 1980, Papua New Guinea University of Technology, Lae, Papua New Guinea.

8. Mini Hydro Report, World Water, July 1979, p 30.

9. "Fertilizer Production by Water Power," Treharne, McKibben and Moles, Proceedings of NRECA Workshop on Small Hydroelectric Plants, Quito, Peru, August 1980, pp 241-246.

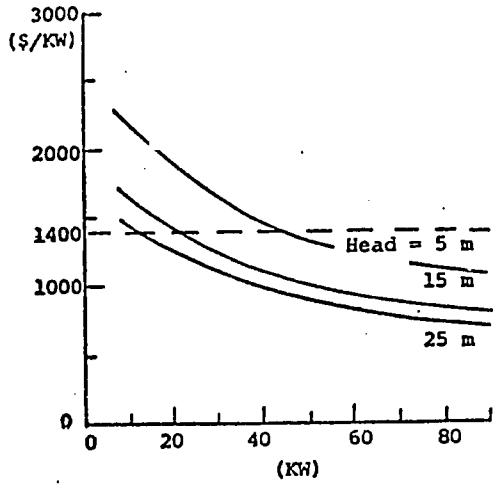


Figure 1: Approximate cost of commercial hydro plant, landed in New Zealand

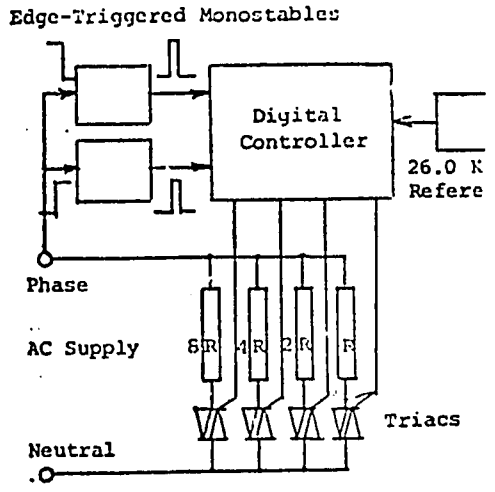
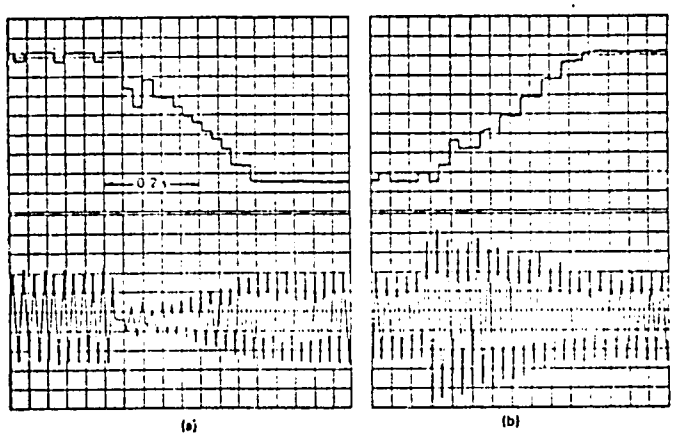


Figure 2: Single-phase electronic load governor

Figure 3: Response of single-phase load governor to sudden changes
(a) full load removal
(b) full load application
upper traces - step load switching
lower traces - total alternator current



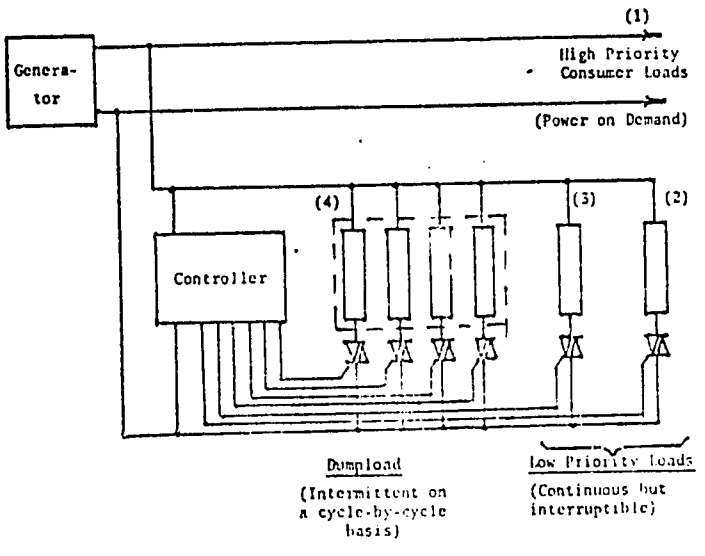


Figure 4: Priority ordering of system loads. Priorities (1)-(4).

ECONOMIC FEASIBILITY AND ECONOMIC RETURNS

SMALL HYDROPOWER DEVELOPMENT

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African Development Bank

Union of Producers, Conveyers, and Distributors
of Electrical Energy to African Nations

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Economic Feasibility and Economic Returns

Tobie E. Lanou

Abstract

A decade ago, the low cost of fossil fuel made construction of new hydropower facilities uncompetitive. With rising fuel prices, however, the economics of hydropower have changed. Small hydropower is much cheaper to operate than petroleum-based energy generators, and is an attractive energy alternative in spite of high initial costs. Still, small hydropower is not always a feasible choice. Economic feasibility studies are needed to help select among alternative energy projects. Repeated feasibility tests are also useful to improve or optimize good quality projects so the best project will emerge.

Biographical Sketch

Tobie E. Lanou has degrees from Harvard University and the University of North Carolina. He has more than fifteen years experience in consulting on urban and regional econom-nomic development problems. With the consulting engineering firm of CH2M HILL, Mr. Lanou specializes in evaluating the feasibility of public investment decisions for a wide variety of projects. Mr. Lanou recently completed a countrywide survey of small hydropower potentials in Togo.

ECONOMIC FEASIBILITY AND ECONOMIC RETURNS

A decade ago, the low cost of fossil fuel made construction of new hydropower facilities uncompetitive from an economic point of view. It was cheaper to build thermal plants, or particularly in third world countries, to construct small diesel-generated power stations to serve outlying areas. Diesel is cheap to set up, and used to be cheap to operate.

Now that situation is changed. Small hydropower is an attractive energy source today because once installed, even at a high initial cost, it is cheap to operate and maintain. Compared to diesel stations, it uses little or no fossil fuel, so it does not face the fuel cost escalations which drain foreign exchange reserves and slow down economic growth.

Still, small hydropower is not always a feasible choice. This paper presents a simple discussion of an economic feasibility study of a small hydropower project. The paper discusses these elements of the feasibility study:

- Economic Background Review

- Site Specific Demand and Supply Studies

- Key Types of Analysis of Economic Feasibility

- Three Common Techniques of Economic or Financial Analysis

First, however, a question is in order: What really makes any project feasible? The following answers may seem rudimentary, but they are worth restating.

One can say a project is feasible when there is real demand for it, not just an assumption of demand; when the project contributes a meaningful supply of power to the demand; and when cost and revenue factors are reasonable for the given output.

Other questions which control feasibility need to be asked as well:

- Is there any funding in sight for the project?

- Is the project popular or politically useful?

- Is the project in line with current trends or practices?

Feasibility is actually a complex subject, of which "economic analysis" is only one part. One cannot render a

definitive feasibility judgment on a project, using economic tools alone, without reference to other technical and political realities. Let us turn now to our discussion of the elements of an economic feasibility study.

Economic Background Review

Even for simple projects it is useful for an economic analyst to make a check of background factors which may have a direct bearing on a project's feasibility. Background factors include the country's economic growth outlook; trends in subarea economic development; and reviews of a country's financial structure and functioning, including its debt, its balance of payments, and its foreign exchange reserves. Other factors to understand are: international development bank lending policies in the country, status of other significant foreign aid projects, and similar items.

But certainly the main background matters to explore carefully are a country's energy consumption trends and projections. An understanding of these is directly related to any small hydropower development project, precisely because small hydropower projects are an alternative to petroleum product-based energy systems.

In a country like Togo, for instance, which we recently had occasion to study as part of an NRECA assignment, only about

seven percent of electric power needs are supplied by diesel generators. The rest is supplied by hydropower from a major dam, the Akosombo, in Ghana. The seven percent diesel part is costly, of course, and demand growth in areas served by the diesel generators--the provincial areas--is doubling every few years. Since these provincial areas fall outside the national power grid, and will continue to be isolated for many years to come, it is very important to try to find alternatives to expensive diesel to fuel these areas.

In order to offer uniform electrical rates throughout Togo, the energy produced by burning diesel fuel is subsidized down to a rate comparable with that produced by large-scale hydropower sold from neighboring Ghana. This is considered important to do for economic and political reasons.

Prevailing energy rates are the benchmark for evaluating the economic feasibility of alternate solutions. So along with a study of the geographical layout of the country's existing and proposed power grid, it is necessary to study the economics of energy rates, established by the national or regional power companies. How are these constructed? Where are the subsidies in them? Where is power obtained? What contracts govern energy purchases?

It is well to study all one can about other proposed energy projects, too. Naturally, studies about them are convenient

sources of data you may need, but more to the point, they help to provide an overview of future energy supply sources, what their feasibility characteristics are, how large or strategic they are, and how likely they are to get implemented and enter the energy supply picture.

Some of this information may seem to have a dubious or remote significance for a small-scale hydro project. But experience shows that the background economic review drops many clues which are useful and may even be crucial in understanding the feasibility of a specific project.

Site Specific Demand and Supply Studies

In studying a particular project or a group of possible projects, it is necessary to make a study of demand and supply factors at each site.

Sites for small hydropower development are not, unfortunately, always located where the demand for energy is greatest. Large scale hydroelectric projects, also typically located in remote areas, have production economics such that one can often afford to transmit power over long distances where it is needed. But not so with small hydro projects.

So, a first demand question to ask is whether a project is "isolated" or "integrated." An isolated project is one located away from the national power grid, one which may or may not have enough demand locally to support it. Even if a project has a promising source of demand, such as an integrated rural development project sponsored by UNDP or others, it can still be said to be isolated. A project that we looked at in Togo was situated about 20 km from Lama-Kara, an important provincial center. It had such a small potential output that, even though near an important urban demand source, it was considered "isolated."

An "integrated" or interconnected project would be considered one where the energy produced could be introduced into the mainstream of the national power grid. We found an example of an interconnected project in the town of Tomegbe in Togo, in a well-developed area. To be feasible, the energy from this Tomegbe project would have to be demonstrated to be as cheap as that from Togo's principal source of cheap power, the Akosombo Dam project in nearby Ghana, or as cheap as any other announced hydroelectric power source feeding Togo.

The line between "small hydro" and "large hydro" can blur as an analysis deepens. For instance, in the Tomegbe situation just described, the team started out assessing small hydro potentials to feed local demand only. When the feasibility

analysis was complete, we determined the project was in another league altogether. We had to place it in an economic and competitive context outside what is normally considered "small hydro," because its output potential was much greater than an early analysis on paper had led us to believe.

It is not always clear at the outset whether a project will be "isolated" or "integrated." One must start with an analysis of local demand. Sometimes such demand is apparent, somtimes it is hidden. One starts by taking population counts and estimating area household incomes, in order to estimate demand. Often, when one is dealing with extremely isolated or simple local economies, where no electrical demand is even remotely in evidence, then the demand measurement can be quite rudimentary.

Where an economy give signs of more complex activity, including modern as well as small cottage industries, then a demand profile needs to be conducted on a more specific basis. Consumption in electrical energy or in alternate energy types can be measured and forecast. Probabilities of converting existing non-electrical energy demand to electrical demand can be assessed based on initial estimates of business or personal income and ability to pay.

In a demand analysis for a small project in a country with rapidly developing energy consumption, the issue is not so much whether demand is sufficient, but rather how to provide cheap service. The hard part of the economic analysis often is not the adequacy of demand character, but the adequacy of supply.

In Togo, the urban coastal area is serviced by cheap hydroelectric power transmitted from Ghana. The outlying provincial centers are serviced by diesel-generated fuel. The plan is gradually to enlarge the national power grid. But for the foreseeable future, some of the outlying centers will be obliged to generate their own energy, using high-cost diesel fuel. Accordingly, any possible hydro project near a provinicial center now dependent on diesel will elicit much interest.

One of the most remarkable aspects of energy supply in Africa is its booming use even in the face of stiff prices. Price rises have recently levelled off. Energy consumption is expected to continue growing.

In a study, the local supply situation needs to be studied and measured. In a small provincial center, this requires visiting the local generating station or stations, gathering data on equipment sizing, condition and function; use and load patterns; and similar information. Often, the best

demand growth statistics available are those contained in the supply statistics of the generating stations.

Finally, the energy supply situation needs to be studied with reference to potential new projects in the service area, how they relate to demand, what their economics are expected to be, and how they complement or compete with the project under study.

Based on the foregoing market studies of demand and supply, we are in a position to evaluate a project more specifically with respect to its feasibility performance, the critical test.

Key Types of Analysis of Economic Feasibility

Economic analysis can be quite simple or complex. The greater potential investment in a project, the greater requirement for complexity and detail in the project economic analysis. Obviously, the more investement dollars riding on a decision, the more one has thoroughly to study the factors in the decision.

Static and Dynamic Analysis

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A simple economic analysis is done on a static basis, with all project revenues and costs stated together in a one-year

analysis. Often this kind of simple analysis is sufficient to get a preliminary feasibility reading. A "typical operating year" analysis is an example of a standard, one-time economic analysis.

A more complete picture is obtained by conducting a dynamic analysis, one which models a project as it would actually be carried out. Both revenue and costs are forecast over a period of years, which correspond to the project's financing life cycle or its useful life cycle.

A dynamic analysis can give a more definitive feasibility reading, more calibrated and reliable. For instance, it is entirely possible that a project may appear to have merit on the basis of a static analysis, whereas the feasibility evaporates in the process of a more complete dynamic analysis.

Economic and Financial Analysis

Economic analysis tools are quite flexible as to what they cover, and what data they contain. There are two principal points of view about data content:

- the Economic Analysis point of view

- the Financial Analysis point of view

Economic analysis, strictly speaking, excludes financial information, notably, the interest paid on borrowed money. Interest costs are considered to cloud the inherent economic utility of a project. Economic analysis has a wider, more inclusive concept of benefits, too. In economic analysis, one is not concerned only with revenue benefits in an accounting sense, but with larger latent benefits which a project can stimulate over the longer term. An example of an "economic benefit" would be flood control from a project primarily designed to generate power.

Financial analysis, on the other hand, specifically incorporates project financing information--the cost of money--and ties the project analysis results to money rates. For example, if a project has an investment return which is less than the cost of money, then in a financial analysis framework, you are clear that your money is better off invested in a bank than in your project.

When Does One Use One or the Other?

Whether to employ economic or financial analysis is partly a matter of ground rules. Certain government agencies or lenders want analyses done in a predetermined way. The U.S. Army Corps of Engineers, for instance, has an entire manual which sets forth specific mathematical formulae and ground rules for conducting both economic and financial analyses.

Furthermore, they tell you when one is appropriate and when the other. The World Bank, U.S.A.I.D., and other agencies often have fairly specific procedures for conducting economic analyses.

We can make some general observations about the choice of economic or financial analyses. Economic analysis is more theoretical, more "macro-economic" than financial analysis. Economic analysis is useful when:

- (a), a proposed project is being considered for an area without sufficient past economic experience or economic yardsticks for projects of the same type, when in other words it is hard to relate the merit of your project to conventional competing projects.

- or (b), when you do not want extraneous variables, such as money costs, to cloud the study of the project.

A well-known example of a huge public investment in the U.S.A. which was justified by economic analysis was the Tennessee Valley Authority (T.V.A.). These large scale hydroelectric projects were able to be justified, when the government took a very long term view of benefits vs. costs. The Tennessee Valley was an underdeveloped area where the

economy was backward and where there was too little apparent energy demand to warrant the huge public investment that finally was made.

Financial analysis is more practical, in a way, more "micro-economic." Financial analysis is necessary:

- (a) to actually administer a project and is

- (b) clearly indicated when a project has definite ties to a competitive market situation. Aside from project merit, which an economic analysis measures, a public investor, like a private investor, needs to know what a project is going to cost, whether the investment is prudent, and how it is to be carried on the books.

In practice, economic and financial analyses are not always divided neatly into clear categories. Most complete studies will contain elements of both, because often both are needed to justify a project, or to properly conceptualize its real merit, or to administer it.

Three Common Techniques of Economic or Financial Analysis

We have seen that feasibility analysis can be either static or dynamic; and that it can be either economic or financial

in character. Now I would like to describe three interrelated analytic techniques commonly in use nowadays: net present worth analysis; benefit/cost analysis; and rate of return analysis.

Ideally, each of these evaluation techniques produce a number or an index, which can be compared to other projects judged under similar conditions, and so constitutes a standard of value. For instance, a benefit/cost index consists of the value of benefits divided by the value of costs. In principle, a project grows more attractive as its benefit/cost ratio exceeds one. Or, to take another example, the index expressed in rate of return is the percentage relationship of the project net revenue to the project carrying charges or costs.

Not all the techniques are always appropriate. But usually, two or more techniques are used jointly to provide different points of understanding about one project.

Net Present Worth

Net present worth is really a point of view about investment. It is always a dynamic concept, rather than a static one. The net present worth theory, developed earlier in this century, is a key concept in most economic and financial analyses.

A simple example from banking and investment makes present worth clear. Present worth is the value today of a stream of money invested (or received) in the future. The present worth of one million CFA francs paid to you in 5 annual installments of 200,000 CFA francs would be, at a 10 percent discount rate, only 744,526 CFA francs, indicating the time value of money.

The present worth concept is useful in a real project because neither project costs nor project revenues are expended all at once, but rather over time in a sequence. The present worth analysis brings this array of future costs and revenues back to a single numerical concept, which simplifies analysis and comparison among projects.

A project's net present worth is equal to the present worth of the future net benefits, that is, the future benefits minus the future costs. If project costs exceed project benefits over time, then obviously the present worth does not exist. If, as is desired, project benefits exceed project costs over time, then the measure of worth for a given set of alternative projects, is: which project has the greatest present worth?

For those who like to see things expressed mathematically, here is the present worth equation:

$$P_n = \sum_{j=0}^{n} \left[(B_j - C_j) \frac{1}{(1+i)^j} \right]$$

Let P_n = Net present worth
n = Period of analysis in years
j = The incremental year
B_j = Benefits in year j
C_j = Costs in year j
i = Discount rate

Notice that for present worth to be useful as an analytic tool, a number of alternatives need to be considered simultaneously. Since the present worth analysis and calculation results in a money amount, not an index like the benefit/cost ratio or the rate of return, it is clear that it has to be compared to some other project present worth, one which aims at similar goals or similar benefits. This procedure is useful as a screening technique to evaluate a number of projects on a priority basis.

Benefit/Cost Analysis

This technique is perhaps the most widely used investment yardstick for projects in the public sector. It was really

formulated originally for public investment projects. Private market projects do not make use of it, as a rule.

The benefit/cost technique compares project benefits and costs on a ratio basis. Projects with a ratio of less than one are generally discarded as infeasible. But an index above one is not a guarantee of feasibility by itself. In certain situations where competition for funds is great, it takes a benefit/cost ratio of 1.5 or greater to attract any interest.

What are "benefits" and "costs"? The concept is flexible and covers both tangible and/or intangible benefits and costs. An example of intangible benefits might be such social benefits as flood control or recreation, useful to have but not necessarily measurable in extra revenues. Tangible benefits would be such clearcut items as revenue from the sale of hydroelectricity. Intangible benefits could be included in an economic analysis, but not in a financial analysis. You can appreciate why economic feasibility does not always jibe with financial feasibility.

By the same token, a financial benefit/cost analysis may exclude intangible cost factors, such as pollution or other environmental costs, which really make an otherwise attractive project unsound from an overall social viewpoint.

The benefit/cost analysis may be done on a static or a time-discounted basis. In a dynamic or time-discounted model, the benefit/cost ratio is the present worth of project benefits divided by the present worth of costs. Present worth is determined by discounting future benfit and cost streams over the life of the project (or financial life of the project) back to the present at an agreed-on discount rate, as already explained. Such a rate might be equivalent to the cost of money to finance a project like the one being studied (in financial analysis) or equivalent to the so-called opportunity cost of capital (in an economic analysis).

Mathematically, the Benefit/Cost Ratio would look like this:

$$\text{B/C RATIO} = \frac{P_b}{P_c} = \frac{\sum_{j=0}^{n} \frac{B_j}{(1+i)^j}}{\sum_{j=0}^{n} \frac{C_j}{(1+i)^j}}$$

Let P_b = Present worth of the benefits
P_c = Present worth of the costs
n = Period of analysis in years
j = The incremental year
B_j = Benefits in the incremental year
C_j = Costs in the incremental year
i = Discount rate

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Rate of Return

The rate of return is a standard concept from banking and mortgage lending. Rate of return analyses can also be conducted on both a static basis and on a dynamic basis.

Quite simply, the rate of return is defined as the percentage that results from dividing project revenues (or net benefits) by project investment (or costs). Rate of return is a concept close to rate of interest. If a project capital cost is one million CFA francs, and the annual net revenue on the project is 100,000 CFA francs, the nominal static rate of return is 10 percent. Similarly, one million CFA francs invested at 10 percent yields a 10 percent rate of interest.

You can see that a rate of return is tied, practically speaking, to the cost of borrowing money or to the interest available on money investments. Obviously, the rate of return on a project shouldn't fall below the cost of money for the same project. Rather, it should ideally be well above interest rates, in order to compensate the investor for his risk, and for his time and trouble.

In the public sector, rates of return are likely to be judged on a much more complicated basis than this. What constitutes a suitable return rate will depend on the social

or economic utility of the project. But always the rate of return has to be tied back to the cost of borrowing money for the same or similar projects, because that is the universal yardstick for judging how and where to invest money.

There is no single number that represents a suitable rate of return. What is "suitable" will depend on:

- project risk
- project quality
- what other competing projects offer
- cost of money and types of financing available
- sources and types of grant funding
- economic conditions

Rate of return analyses become more sophisticated when they are conducted on a time-discounted basis, according to an ingenious principle called the internal rate of return (I.R.R.). The internal rate of return, also a percentage figure, is defined as the rate at which the stream of all future project costs and benefits is reduced to zero. Another way to say this is "the discount rate at which all the negative flows (costs) are equated with the positive flows (benefits)."

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An internal rate of return calculation conducted by the computer for the Tomegbe project in Togo is shown on the following page. Note that the computer also calculates the net present value and the benefit cost ratio.

The internal rate of return is an iterative process. I remember before computers when such an analysis was a trial-and-error mathematical process which could take several hours or more, depending on project complexity. Now machines prepare the calculations in a few seconds.

Internal rate of return (I.R.R.) is often used as a ranking or screening tool, like benefit/cost ratios. It is used more often in private sector investments, unlike benefit/cost, but has gained currency in public projects as well. Normally an internal rate of return screening serves to reject projects which show an I.R.R. less than the cost of money. It is a useful analysis for reviewing either a large number of projects simultaneously, or for choosing among different variants of the same project--for instance, where the timing of capital investments is speeded up or is slowed down. In this way, too, I.R.R. is very useful in project optimization. It helps shape the best timing and sequencing of project investment.

TOMEGBE - DISCOUNTED CASH FLOW ANALYSIS

DISCOUNT RATE:
10.000 PERCENT

PERIOD	FACTOR	PROJECT REVENUES		PROJECT COST		PROJECT CASH FLOW	
		CASH FLOW	DISCOUNT CASH FLOW	CASH FLOW	DISCOUNT CASH FLOW	CASH FLOW	DISCOUNT CASH FLOW
1	1.000000	0	0	-3333330	-3333330	-3333330	-3333330
2	0.909091	0	0	-3333330	-3030300	-3333330	-3030300
3	0.826446	0	0	-3333330	-2754818	-3333330	-2754818
4	0.751315	3870000	2907588	-1693000	-1271976	2177000	1635612
5	0.683013	3870000	2643262	-1693000	-1156342	2177000	1486920
6	0.620921	3870000	2402966	-1693000	-1051220	2177000	1351746
7	0.564474	3870000	2184514	-1693000	-955654	2177000	1228860
8	0.513158	3870000	1985922	-1693000	-868777	2177000	1117145
9	0.466507	3870000	1805384	-1693000	-789797	2177000	1015587
10	0.424098	3870000	1641258	-1693000	-717997	2177000	923261
11	0.385543	3870000	1492053	-1693000	-652725	2177000	839328
12	0.350494	3870000	1356417	-1693000	-593386	2177000	763025
13	0.318631	3870000	1233103	-1693000	-539442	2177000	693659
14	0.289664	3870000	1121001	-1693000	-490402	2177000	630599
15	0.263331	3870000	1019092	-1693000	-445820	2177000	573272
16	0.239392	3870000	926447	-1693000	-405291	2177000	521137
17	0.217629	3870000	842225	-1693000	-368446	2177000	473779
18	0.197845	3870000	765659	-1693000	-334951	2177000	430708
19	0.179859	3870000	696054	-1693000	-304501	2177000	391553
20	0.163508	3870000	632776	-1693000	-276819	2177000	355957
21	0.148644	3870000	575251	-1693000	-251654	2177000	323597
22	0.135131	3870000	522955	-1693000	-228776	2177000	294179
23	0.122846	3870000	475414	-1693000	-207978	2177000	267436
SUB-TOTALS			27229335		-21030402		6198933
RESIDUAL VALUE		0	0	0	0	0	0
TOTALS			27229335		-21030402		6198933

NET PRESENT VALUE AT 10.000 % IS: $ 6198933
BENEFIT/COST RATIO AT 10.000 % IS: 1.29
BREAKEVEN AT 10.000 % OCCURS AT PERIOD: 11
THE INTERNAL RATE OF RETURN IS: 17.633 PERCENT

Conclusion

As a closing remark, let me say that economic feasibility work can serve its most creative function when it is used not just to screen out bad projects, but when a skillful analyst working with project design engineers can tailor a good project more carefully. This is done by a process of iteration which identifies strong and weak points in the project design and the project delivery and seeks to perfect these so the best project will emerge. This optimization process is the most challenging and creative role of financial feasibility analysis.

REFERENCES

1. "Economic and Financial Feasibility Methodologies," Mark Henwood, in Small Hydroelectric Powerplants, a seminar held in Quito, Ecuador, August 19-21, 1980.

2. James, L.D. and Lee, R.R., Economics of Water Resources Planning, McGraw-Hill, 1971.

3. "A Methodology for Prefeasibility Studies of Candidate Mini-hydro Sites," National Rural Electric Cooperative Association.

4. Togo Small Decentralized Hydropower Study, NRECA sponsored by U.S. Agency for International Development, July 1981.

5. "Economic Tests of Project Acceptability," World Bank Monograph, March 1971.

6. Hydropower Investigation Guidelines, CH2M HILL, November 1980.

7. Feasibility Studies for Small Scale Hydropower Additions, U.S. Army Corps of Engineers, July 1979.

8. Rural Electrification, A World Bank Paper, World Bank, October 1975.

END USE OF MINI-HYDROPOWER

BY

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Abstract

This paper discusses the potential role of mini-hydropower in rural development. Demand for energy in rural areas is related to the output characteristics of small-scale hydropower. The importance of productive uses of energy in rural areas is explored as well as the constraints to their proliferation and suggestions for overcoming those constraints. In addition, some individual applications of small-scale hydro systems which have special significance are described in more detail.

Biographical Sketch

Daniel Boyle is a mechanical engineer on the staff of NRECA's Small Decentralized Hydropower Program. His major areas of responsibilities are the development of programs to encourage productive use of energy in rural areas and the conduct of reconnaissance studies for small hydropower sites.

Before joining NRECA, Mr. Boyle was a U.S. Peace Corps Volunteer in Colombia, South America where he worked on appropriate technology devices for small farmers and in small business development. Prior to Peace Corps Service, he was a field Engineer for the Square D Company. He has a Bachelor's degree in Mechanical Engineering Administration from the University of Delaware.

END USE OF MINI-HYDROPOWER

Introduction

High energy costs are leading many economists and development theorists to conclude that energy should be considered along with land, labour and capital as a major input to production. With the cost of commercial energy increasing, and the ability of the oil importing developing countries to meet their foreign debt requirements decreasing, there is a clamor to develop renewable energy resources. A frenzied approach to renewable energy development runs two major risks: 1) irresponsible development of energy resources which do not necessarily represent least cost solutions and; 2) a tendency to forget the primary objective of investments in the energy sector; namely economic development. The first of these problems can be avoided by careful analysis of the financial, social and economic factors surrounding the various supply alternatives including a sensitivity analysis to determine how the results vary under differing assumptions of cost, load growth, discount rates and selling price. The second problem can be avoided by recognizing that the least cost establishment of reliable power facilities is merely a supply side perspective. The contribution which energy investments make to economic and social progress clearly depends on how the energy is used.

The relationship between per capita energy consumption and per capita GNP has been a widely discussed topic. Since the oil crisis of 1973, however, the dogma which claims the two to be inextricably related and further implies that developing countries should follow the same path to development as the industralized countries has been exposed as untenable.[1] "State of the Art" development theory encourages instead,

[1] A recent incisive paper on this topic, entitled "Energy Options for the Third World," by A.K.N. Reddy states, "For instance, on the basis of U.S. energy consumption figures, India alone would require about three times the total energy now consumed by the U.S.A. - a requirement which is 150 times the present production of commercial energy in India."

"decentralized" production centers, presumably requiring less energy for transportation and distribution of goods and services. Through the decentralization of the various productive components of a nation's economy, it is hoped that higher living standards can be achieved without the high per capita energy consumption levels characteristic of the developed countries. The development of remote small scale energy systems such as mini-hydropower offers a unique opportunity for pursuit of a decentralized approach to economic development.

Despite the simplistic sound of these theories, when one leaves the cerebral world of academia and places himself in a rural (i.e., decentralized) context, he encounters several practical problems with this approach. The micro world of rural subsistence farming and village lifestyles, as opposed to the macro world of economic sector analysis and GNP composition, better reveals the nature of energy demand, productive opportunities in rural areas, and the appropriate role of an energy supply option such as mini-hydropower. But, experience with the complexity of rural development, has shown that abstract energy supply and demand considerations, either at the macro or micro level, form an inadequate analysis. "Different frameworks of preferences - social, cultural, and religious - clearly affect how energy is used and the demands which a new energy source must meet."[2] These demands also affect (and, in turn are affected by) technological design choices, existing income distribution and ownership patterns, environmental considerations and institutional arrangements.[3] This paper does not attempt to address these issues in an international setting as related to small hydropower development. The present focus, instead, is a general discussion of energy needs and fuel consumption patterns in rural areas, the nature

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[2] Cecelski, et al. Household Energy Use and the Poor in the Third World. Resources for the Future, Washington, D. C., 1979. p.5.

[3] Ibid. p.5. See also: John Ashworth and Jean Neuendorffer, "Matching Renewable Systems to Village - Level Energy Needs." Solar Energy Research Institute, Boulder, Colorado. June 1980.

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of the energy output of small hydro facilities; and how that output can be used most productively.

In all aspects of small hydro technology, from hardware to management, there is a distinction between village implemented and operated schemes and those developed as part of a national energy plan by public power authorities. The contrasts between the two approaches relate back to the development goals of the project. Nationwide small hydro programs are usually designed to reduce oil imports, either through grid interconnection or by replacing existing diesels. In some cases, these programs are connected with ongoing or planned rural electrification programs. Local, villager implemented or private mini-hydro schemes, on the other hand, are to provide electric service to areas for the first time or for a captive hydro application, often strictly for mechanical power generation. End use thus depends on end objective.

The term "productive use" is quickly becoming an overworked phrase in economic development. In the broadest sense productive uses of energy are those uses which increase or enhance production in agricultural, industrial, commercial and residential activities; although the definition seems to vary with the context.[4] It is generally felt that these uses should receive emphasis in programs to provide commercial energy to rural areas of developing countries, such as rural electrification programs. Productive uses are income earning for the end user and financially attractive for the energy supplier as well since they usually boost load factors. These uses are also considered to be the most important linkage between energy supply investments and

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[4] See, for example, AMARU IV Cooperative Guide to Evaluation for Small Hydro Units in the Field and Lessons from the Literature. Draft document prepared under AMARU IV/NRECA contract. Here, the contrast between direct and indirect productive uses and the narrow implications of defining productive uses strictly as those which generate cash are explored.

rural development. Whether or not productive uses represent the most appropriate application of small scale hydro power depends on the overall development objectives of the project and the area. However, the benefits of these uses will often be essential to a scheme's viability. Thus, the potential for productive application of the energy should be evaluated at the pre-feasibility stage of project development. In addition, programs and policies to enable and encourage productive uses in rural areas are important energy planning considerations.

In the end, hydropower is just an energy source. Even if tapping this energy source was free, but required major changes in the user's lifestyle, it is very likely that any use of the energy would be slow in developing. The fact is that water power is not free, but merely an attractive alternative to diesel and other thermal means of power generation. Depending on site characteristics and design, it is an attractive alternative for several reasons: cost, maintenance, operation, fuel supply, foreign exchange requirements, etc... The underlying question of linkages between energy supply and development still needs to be addressed. Here, experience gained with rural electrification is particularly relevant. The specter of low load factors on costly systems compels us to seriously consider these investments and exactly how they are related to economic development. This will require an analysis of the complementary programs needed to encourage productive energy use. These complementary programs will have to be aimed at overcoming the constraints to significant use. The constraints are many and varied, ranging from lack of capital to problems with market access for increased production.[5] Small hydro also represents a large capital

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[5] There are several additional constraints such as lack of technical know, unavailability of equipment and supplies, etc. They are site specific. A very recent study (authored by Janice Brodman) of factors affecting levels of productive use will soon be published. The study covered a single project area in Indonesia's rural electrification program and found lack of capital and market access to be the major constraints to increased business production and use of electricity. Another important factor which appears time and again is lack of information and knowledge.

investment and cannot be viewed alone but must be contemplated as part of a more comprehensive development program.

I. Energy Demand in Rural Areas

Demand for energy is a derived demand, linked to the activities which require energy for their execution. Some useful categories for classifying these activities in rural areas are: agricultural production, agricultural processing, small and medium scale industry, commercial, and residential. Simply stated, energy is used in three form: heat, work and light; all three forms being utilized in each category of activity.

The quality of the energy source required for the execution of these activities is an important consideration. Heat is considered an inferior form of energy when compared to mechanical work. The quality of heat energy is related to temperature - lower temperatures correspond to lower energy intensities and thus are of lesser quality. Typically, one classifies heat energy requirements as low temperature (drying foods), medium temperature (cooking) and high temperature (electricity generation). Mechanical work (shaft power) and electricity correspond to infinite temperatures and are the highest quality forms of energy.[6] The use of electricity for lighting is without comparison. On the other hand, alternatives to the use of conventional electrical devices for low and medium temperature heating applications in depressed rural settings should be investigated whenever possible; because the cost of the conventional devices and the overall inefficiency of such operations make their use for meeting these lower level energy requirements inadvisable. Other, less costly,

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[6] Ueli, Mier, Local Experience with Micro-Hydro Technology. SKAT publication No. 11, Vol. 1. St. Gall, 1981.

fuels and means can usually be found. This is especially true for thermal based steam generation since the maximum theoretical efficiency for electricity production is limited by the Law of Carnot and in practical terms, rarely exceeds 35-40%. For diesel cycles, whose efficiencies run at roughly 50-60%, these same arguments apply.[7] In summary, the use of expensive fossil fuels to generate electricity for low and medium temperature heating applications represents major losses of energy. Where possible, alternative means should be studied.

Although the fuel consumption patterns of traditional rural societies are highly variable between countries,[8] and despite the fact that data on quantities consumed and for what purpose is non-existent for most areas; one can state matter of factly that biomass fuels, especially wood, are the major source of energy for rural households. Furthermore, it is clear that the predominant energy need is for cooking, with firewood often supplying over 80% of rural cooking requirements. Lighting requirements are met by kerosene, candles, and electricity. Motive power (either stationary or moving) is often from animal traction, diesel or gasoline engines and/or electricity. By practically all measurements, energy consumption per capita in rural areas is considered to be at or below subsistence levels. One report "states that the consumption levels for most of the developing world including productive uses need to triple in order to secure an adequate life with some opportunity for improved health and well being."[9]

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[7] Modern power systems operate under complex versions of the Rankine Cycle whose basic efficiency is lower than for the Carnot. For a complete discussion refer to a text on thermodynamics, such as Fundamentals of Classical Thermodynamics, by Van Wylen and Sonntag. John Wyley & Sons, Inc. 1976.

[8] Cecelski, et al. op. cit., p.12.

[9] Ibid, p.33.

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Discussions of the productive use of energy, and specifically electricity, have become commonplace in the literature on rural energy development and rural electrification.[10] One study in Indonesia defines "Productive use.... very narrowly to include only that use which altered business hours or production techniques."[11] Another study[12] classifies productive uses as direct (machines or processes involved in production) and indirect (uses which extend business hours or improve operations). As mentioned in the introduction, the broadest meaning of the term "productive use" would be any use of energy to enhance or increase production in economic activities. For a modern form of energy (such as electricity) to contribute to rural development, it is generally felt that the energy must be put to productive use. This assertion has many underlying assumptions such as demand for increased production, market access, energy cost, and others which are beyond the scope of this paper to explore. Nonetheless, intuitively, one can sense that investment in costly, capital intensive, energy supply schemes in rural areas would represent a misallocation of scarce resources if used solely for domestic lighting.

The productive utilization of electricity can contribute to the user's income, thereby improving his ability to pay. Productive uses often improve system capacity factors which in turn lowers unit costs and if these savings are passed on to consumers, the power becomes more affordable for everyone. In the final analysis, the potential and importance of productive uses of energy need to be analyzed on a project by project basis; but, their financial and economic significance for small hydro and rural electrification cannot be overlooked.

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10 See, for example: Tendler, Judith, "Rural Electrification: Linkages and Justification" AID Program Evaluation Discussion Paper No. 3. April, 1979; Cecelski, et al. op. cit.; Cecelski, Elizabeth, "The Role of Rural Electrification in Development." Working Paper for Discussion, Resources for the Future. Washington, D. C. July, 1979.

11 Brodman, Janice, "Levels of Electricity Use." Draft document, 1982.

12 Amaru IV Cooperative, op. cit.

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An attempt to quantify the additional commercial energy[13] requirements for productive uses in rural areas of developing countries would be an honerous and academic task. Still one can hardly imagine a modern economy without a mechanical agricultural base, including the availability of electricity and motive power in rural areas. The following tables are provided as examples of the power requirements for various agricultural and industrial tasks.

Table 1 provides an overview of electrical power use in three regions of India (Madras, U.P., W. Bengal) as of 1963. It was extracted from a report to USAID prepared by the General Electric Co. and the Massachusetts Institute of Technology.[14] Although it refers to the specific areas where the study was performed, the load characteristics and consumption figures should approximate those in other parts of the world for similar equipment.

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[13] The World Bank defines "commercial energy" as "any energy form sold in the course of commerce or provided by a public utility...", excluding wood and other traditional fuels despite the fact that they are also traded on the market. For complete definitions of the various fuel classifications see The World Bank. "Energy in the Developing Countries." August, 1980.

[14] General Electric Co.. "Analysis of Demand for Electric Power in Rural Communities." USAID contract AID PEPAS-1. March. 1963.

Table 1

Technical Characteristics of Agricultural Processing Machinery

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

Ranges of typical power requirements for several rural industries in Colombia can be seen in Table 2.[15]

[15] C.CH.LG. Ltd. Viabilidad de Las Micro Centrales en Colombia. Fundacion Mariano Ospina Perez. p.24. Bogota, 1979.

Table 2

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

Displacement of fossil fuel consumption is often a major objective of a small hydro program. Since the 1930's, rural areas of the world have been dotted with isolated diesel and gasoline engines for shaft power and engine generator sets for electrical power. In many areas, kerosene is used for lighting and refrigeration. Provision of power to these activities from a small hydro plant can represent savings to the economy as well as improve the quality of service. These systems often represent the major potential for productive application of hydroenergy and should receive special importance in reconnaissance evaluations and benefit calculations. In Malaysia, for example, conversion of scattered diesel installations to small hydropower is the major focus of their small hydro program.

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II. Role of Small Scale Hydro Systems in Meeting Rural Energy Needs

Relationship to Overall Development Objectives

The appropriate role of small scale hydropower in a country's development plan is a function of the development objectives of the projects and regions where hydro potential exists. At the national level, policies for energy planning and for selection of energy related projects for funding need to be established. The task of determining the appropriate energy supply option to meet an area's energy requirements is, of course, site specific. The number of potentially viable sites is finite and the expected power and energy output as well as the proximity to the grid and/or demand center will largely determine the most logical approach to site development and consequently the end use. In this light, hydro projects in the 0-1000 kW range will fall into four categories:

1) Low power output projects to meet Basic Human Needs[16] (e.g. Colombia, Papua New Guinea);
2) Projects by private developers for a specific application (examples can be found worldwide);
3) Decentralized electrification and/or replacement of existing diesels (e.g. Malaysia); and,
4) Grid interconnection (e.g. Philippines).

Specific end uses for the power can be assessed only after the basic determination of the purpose for site development is made.

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[16] A useful analytical framework for selecting technologies at this level is developed in: Ashworth and Neuendorffer, "Matching Renewable Energy Systems to Village-Level Energy Needs." Solar Energy Research Institute; Boulder, Colorado. June 1980.

Small Hydro Output Characteristics

Except where small hydro plants are designed at the 90% exceedence level,[17] or where large storage is used, output is usually highly seasonal; depending on the availability of water. Aside from economic implications, this is rarely a major concern on grid connected sites. In the isolated case, however, seasonal and daily fluctuations in power availability need to be closely matched to energy needs.

The quality of the energy output of a small scale hydro plant really depends on the level of sophistication required. Water power at the point of entry to the turbine is kinetic and/or pressure energy. That energy is used to rotate a shaft which in turn drives either a generator to produce electricity or is directly coupled to some machine.[18] Thus, shaft power can be used mechanically or electrically. Some systems in Nepal, Colombia and Pakistan are hybrid, producing both mechanical and electrical power.

Mechanical power must be used at the site. History provides many examples of this use of water power, often to spur industrialization. Contemporary examples of mechanical use of water power can be seen in several areas also. In Nepal, crossflow turbines are used for rice hulling, milling and polishing.[19]

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17 90% exceedence means that the optimum turbine design flow is available at least 90% of the time, based on the flow duration curve.

18 Boyle, Daniel. "Productive End Use of Mini-Hydro Power for Rural Development." Proceedings of NRECA/AIT Conference, "Small Hydropower for Asian Rural Development. June 1981.

19 Meier, op. cit. See also, Yoder, et. al., "The United Mission to Nepal's Involvement in Small Scale Water Power Development for Milling." Draft. Cornell University. 1980.

The Appropriate Technology Development Organization in Pakistan has designed and installed some 20 sites, in the 0-15 kW range, either for direct mechanical use, electrical use, or for hybrid applications.[20]

Either directly coupled, or through a speed increaser, an electric generator greatly enhances the versatility of water power. Generators can be direct current (DC) or alternating current (AC). DC schemes are simpler and less costly because speed regulation is not a requirement, but, practical application of DC power is usually restricted to low power requirements, near the site. Two advantages of DC are the potential use of vehicle generators (car, truck, airplane) and the option of storing energy in batteries without intermediate transformation. DC appliances, motors and lighting fixtures, on the other hand, are not as commonplace as comparable AC devices. AC electric energy is the most versatile and efficient form of energy we know. The potential applications of electric energy in agriculture, industry, commerce and in the home are vast. Alternating current allows for the simplistic transformation, transmission and distribution of this energy. Both alternating and direct current can be used for lighting.

Production of heat from water power can be done either mechanically or electrically. Mechanical systems involve heat transfer through viscous dissipation in fluids. Of course, air and water would be the most practical fluids. A prototype mechanical "Heatgenerator" has been developed in Nepal in conjunction with work performed by the United Nations.[21] This system heats air to 110C and is designed for direct coup-

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[20] Inversin, Allen R. "A Case Study: Micro-Hydropower Schemes in Pakistan." NRECA. December, 1981.

[21] Metzler, Reinhold. "The Heatgenerator." Butwal Engineering Works Pvt. Ltd., United Mission to Nepal. January 1981.

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ling of water turbines. A commercially available unit for heating water is manufactured by the All American Engineering Company of Wilmington, Delaware, U.S.A. under the trademark "Water Twister."[22]

Analagous to frictional losses in mechanical systems, resistance losses in an electrical circuit result in heat generation. This is the well known I^2R term (current squared times circuit resistance). Virtually all medium and low temperature electrical heating devices work on this principle. Electronic load controllers, used to control the voltage and frequency of the electrical power output from small hydro schemes, divert excess power generated above load requirements to an electric resistive ballast. In this way excess energy is dissipated as heat. To date, very little attention has been given to the possibility of productive utilization of that heat (e.g. for drying foods).

To summarize this discussion on small hydro output characteristics, we can see that the small plant can produce a full range of output possibilities; from mechanical power for either heat or motive force to electrical power for either motive force, heat or light. They can operate in isolation or can be grid connected. However, the availability of power and energy is determined by the available head, quantity and duration of flow, and the overall efficiency of the scheme.

Scale of System Vs. Array of Uses

Up to now this discussion has focused on the quality of the output of small hydro plants. Theoretically, the output can be in whatever form required. Without relating

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22 Detailed information on the design, operation and characteristics of these mechanical systems can be found in the publication by Schroeder and Tu. "An Assessment of SWECS/Mechanical Heating Systems." Prepared by Rocky Flats Plant Wind Systems Program under contract with the U.S. Dept. of Energy. July 1981.

end use to the quantity of power needed, these possibilities are nonsense. Direct mechanical power has to be used at the hydro site and for practical reasons is really only appropriate for the lower end of the power range (below 50 kW). Hybrid mechanical/electrical schemes add much versatility to the output but are again only appropriate for the smaller projects. Direct current, while simplifying speed control, cannot be economically transmitted over very long distances without sophisticated technologies. Furthermore, DC machinery is far less common than its AC counterpart. Alternating current generators can cover the entire range of power outputs, but, voltage regulation and stability problems tend to limit the scope for productive uses on smaller systems. Motor loads can have starting requirements up to seven times running current and the system must be of sufficient capacity to meet this instantaneous demand. Also, severe instability can result if a single motor has a rating with respect to other loads of 1/3 or more of the system capacity.[23] Since reliability of power is crucial to productive end use, these factors can be seen to be of special importance. Table 3 summarizes the points of this discussion.

Special Applications

Despite the versatility of hydroenergy, finding good uses for the output is often a severe limitation. The best sites are frequently located in poor remote areas where economic activity is low. Thus, even though costs for site development in these areas might seem attractive, demand for such a quality energy source can sometimes be so low as to nullify investment benefits.[24] How to overcome this problem

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[23] General Electric Company, "Small Scale Power Supplies for Rural Communities in Developing Countries". USAID Report No. TA/OST-AN-63-3-1. March 1963.

[24] Correspondence between ITDG and NRECA supports this assertion. In the words of Ray Holland, "...the essential point as far as decentralized schemes are concerned, ...must be that an industrial, income earning end use must be found for the power so that reasonable load factors can be built up." (Letter to A. Inversin, NRECA, 10 November, 1981).

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Table 3

Type of End Use at Various Ranges of Power Output

	Mechanical	Mech/Elec. hybrid	DC electricity	AC electricity	
0 - 50 KW	Two or three directly connected machines (e.g. rice huller & polisher)	Daytime repair shop and mill. Nightime village electrification for lighting	Central Battery charging. Local electrification of immediate vicinity for lighting and small appliances.	Small array of uses including local electrification.	VILLAGE SCHEMES
50 - 100 KW	Several large machines. Entire factory.	Rare	Electrification in vicinity, conceivably for small industry.	Local electrification including small industrial & agr. use. Possibly supply grid with excess energy/ capacity.	
100 - 500 KW	Rare	Rare	Rare	Electrification of major population center (s). Scale for larger users. Usually supplies grid energy.	NATIONAL SCHEMES
Above 500 KW	Non-existant to author's knowledge.	Non-existant to author's knowledge.	Rare	Grid supply.	

strikes at the heart of rural development itself. Policy considerations aside, there are a handful of potential applications of hydroenergy which, under certain circumstances, could save otherwise good sites from the problem of finding appropriate uses. These applications deserve special consideration.

In many areas of the world, deforestation has become an acute problem. Demand for wood stems from demand for fuel, building materials, and need for additional farming and grazing areas. Population increases exacerbate this problem. In mountainous areas especially, deforestation has resulted in wholesale erosion of topsoil, flooding and landslides. Some land has been rendered worthless. Fuelwood for cooking and other heating requirements is only part of the problem, but perhaps a manageable part.

As mentioned earlier, the most significant energy requirement to meet basic human needs in rural areas is for cooking. Firewood is the major fuel used. A more modest amount of firewood is used in some areas for drying, space heating, water heating and other low-medium temperature applications. The possibility of substituting conventional electrical resistance heating elements for firewood in these activities is hampered by two major obstacles: 1) the cost of electric stoves and heaters and, 2) the cost of electricity. Additionally, for isolated hydroelectric schemes, the peak demand requirements of conventional devices would result in excess capacity and/or expensive storage.[25] Since firewood rarely represents a cash outlay to the rural subsistence farmer, the task of convincing him to replace firewood with a commercial fuel has limited prospects for success.

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[25] Yoder, Robert." Thesis in partial fulfillment of requirements for Master of Science degree."Cornell University. January 1981.

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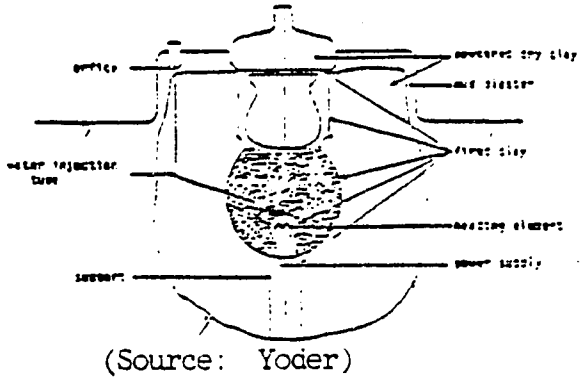
An alternative approach to using conventional electric heating devices would be the use of sensible heat systems. These systems store energy as it is produced, thus levelling load requirements and improving load factors. Several designs for cooking stoves which utilize this method were in use in conjunction with decentralized hydro schemes in several countries before the days of cheap energy.

In Norway, where these cookers were commonplace at one time, marketing discontinued in the early 1950's.[26] Present circumstances demand that we re-think the suitability of sensible heat storage cookers, especially in areas with deforestation problems.[27] These cookers can be seen to have additional importance where tariffs are based on installed capacity (controlled by current limiters) and not kWh consumption.

Exposed Rock Bed Energy Storage Cooker



(Source: Yoder)

The heating element of the cooker produces a constant output, provided power is available Traditionally, the heat was stored in material with high heat capacities, such as cast iron. However, the use of indigenous materials such as clay for heat storage have also been used successfully. For example, with an energy input of 250 w, the exposed rock bed energy storage cooker shown here produced heat required to cook the daily meal of an average Nepali family. This was accomplished at considerably higher efficiencies than those found with conventional wood and gas stoves (21% vs. 3-6 %). The disadvantage of not being able to observe the food while cooking would have to be field tested.[28]

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26 Ibid. p.45

27 Additional information on these devices can also be found in Whitby, Garry. "Heat Storage Cookers. The Norwegian Experience and Indications for Implementation in Developing Countries." Draft. ITIS. Rugby, U.K. September 1981.

28 Yoder op. cit. Conclusions

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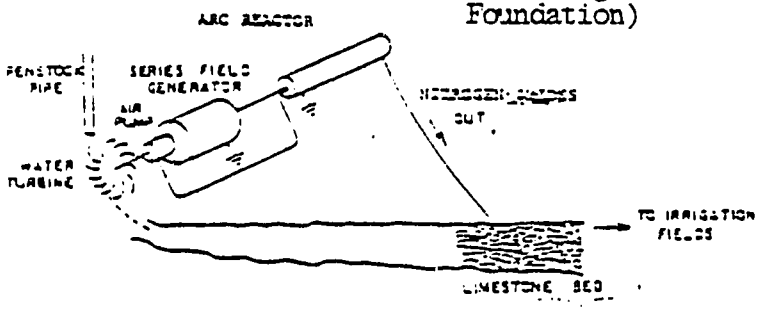
The use of chemical fertilizers can drastically improve agricultural yields. On a large scale, the most economical way of producing high quality fertilizers is with the Haber-Bosch process. This process uses natural gas or liquid hydrocarbons for the production of ammonia, and is highly energy intensive. Furthermore, the centralized nature of fertilizer production leads to high transportation costs in reaching remote consumers. Another method of producing nitrogen fertilizer is the electric arc discharge method. Under normal circumstances, and for large scale operations, the Haber-Bosch method is the least costly of the two. In fact, the electric arc method was all but abandoned during the early part of this century.

In the context of our discussion of the special applications of hydroenergy in remote rural areas, the electric arc discharge method of nitrogen fertilizer production takes on renewed significance. The basic principle of the process is simple. Air is injected into an electric arc reactor, producing nitrogen oxides. The nitrogen oxides are then passed through an absorption column of either limestone or rock phosphates and mixed with water. The end result is high quality calcium nitrate fertilizer.

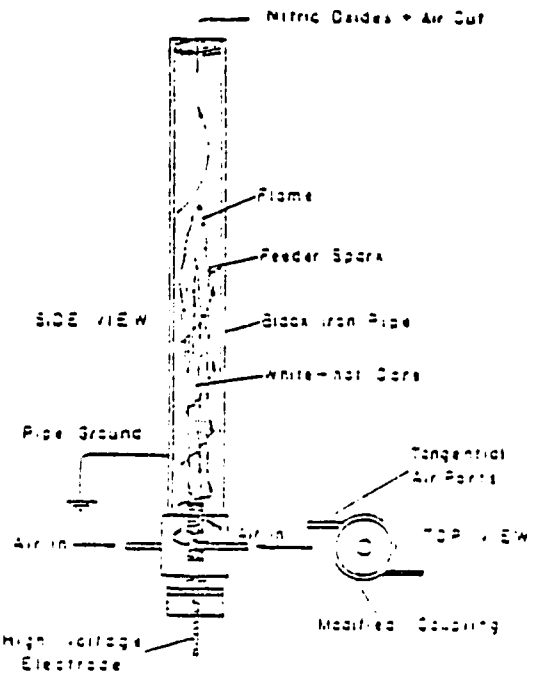
WATER POWERED SYSTEM FOR PRODUCING NITRATE FERTILIZER

(Source: Kettering Foundation)



Kettering Electric Arc Reactor

(Source: Kettering Foundation)



An experimental 3 kW unit requiring only readily available components and low level technology has been operating successfully in the U.S. The output is sufficient to fertilize 5-20 hectares. This system can be used effectively as a base load and load levelling technique.[29]

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[29] Charles F. Kettering Research Laboratory. "A Nitrogen Fertilizer Production System for Farm Use. Kettering Foundation. Dayton, Ohio. See also Treharne. et al. "Fertilizer Production by Water Power." Univ. of Nevada Field Day Program. 1980.

Firewood is not only used for cooking; it is used to produce heat for other agricultural processing activities as well. The mechanical "Heatgenerator"[30] was developed for isolated villages with deforestation problems. Air is heated to 110° C with accompanied forced convection by recirculating fresh air several times through a series of baffles. The warm air can be used for numerous purposes such as drying, producing concentrate, processing fruits, distillation, etc... A prototype developed in Nepal with a 25 kW drive cost $800 in January, 1981.

Several miscellaneous applications of the energy from small-scale hydro schemes should be contemplated where appropriate. Examples include battery charging and directly coupled compressors for communal refrigeration facilities.

III. ENCOURAGING PRODUCTIVE USES OF ELECTRICITY IN RURAL AREAS

The introduction of electricity to depressed rural areas is expensive. Nonetheless, electricity is an important part of rural development. Productive uses of electric energy which serve as a tool for integrated rural development are constrained by numerous factors. Electricity is often considered a social good and government responsibility and electrification programs in rural areas often place emphasis on household and public uses of electricity. Electric suppliers and users face severe shortages of capital and are understandably unwilling to take risks. Power supplies are often expensive and unreliable. It is difficult to convince consumers who have purchased diesel machinery that electric energy is superior. This is due to supply problems, the user's sunk investment and his lack of familiarity with electricity. Ancillary electric machinery is rarely readily available. Last but not least is the widespread lack of understanding of electricity and its proper and productive application.

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30 Metzler, Reinhold. "The Heatgenerator." Butwal Engineering Works Pvt. Ltd. Kathmandu, Nepal 1981.

In the United States, overcoming these constraints to productive use of electricity in rural areas did not happen overnight. It was the result of a concerted, dedicated effort on the part of several diverse groups, including rural electric cooperatives, banking institutions, agricultural extension services, electrical equipment manufacturers and their distributors, and major universities. The rural electric cooperatives took lead in this activity. Through Member Service Departments, they conducted sign up, promotional and educational drives, provided financing for equipment purchasing and performed several other services to enable proper and productive use of electricity in rural areas. The lesson to be learned from the U.S. experience is that properly conceived and implemented promotional/educational programs, integrated into other developmental efforts, are vital to the success of major electrification programs.[31] While not providing a panacea, the importance of these programs cannot be overlooked.

IV. CONCLUSIONS

1) Hydropower at any scale is a very versatile source of energy whose proper end use is a function of the development objectives of the particular hydro projects and the region(s) where hydro potential exists.
2) The identification and establishment of income earning end uses of hydropower, often crucial to project viability, are of special importance.
3) Special applications of hydroenergy such as those mentioned in the text for areas with unique problems should be considered wherever relevant.
4) For larger scale electrification efforts, it is vitally important that the introduction of electric energy in rural areas be integrated into other development efforts with complementary and well conceived promotional/educational programs designed to overcome the major constraints to significant productive use.

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[31] Evaluations of rural electrification programs in the Philippines, Bolivia and Costa Rica support this assertion.

REFERENCES

Agency for International Development. "Bolivia: Rural Electrification." AID Project Impact Evaluation Report No. 16. Washington, D.C. December, 1980.

Agency for International Development. "The Philippines: Rural Electrification." AID Project Impact Evaluation Report No. 15. Washington, D.C. December, 1980.

Amaru IV Cooperative. Guide to Evaluation for Small Hydro Units in the Field and Lessons from the Literature. Draft document developed under contract with NRECA. 1981.

Ashworth, John and Neuendorffer, Jean. "Matching Renewable Systems to Village - Level Energy Needs." Solar Energy Research Institute. Boulder, Colorado. June, 1980.

Boyle, Daniel. "Productive End Use of Mini-Hydropower for Rural Development." Proceedings of NRECA/AIT Conference, "Small Hydropower for Asian Rural Development." June, 1981.

Brodman, Janice. "Levels of Electricity Use." Draft document, 1982.

C. CH. LG. Ltd. Viabilidad de Las Micro Centrales en Colombia. Fundacion Mariano Ospina Perez. p. 24. Bogota, 1979.

Cecelski, Elizabeth. "The Role of Rural Electrification in Development." Working Paper for Discussion, Resources for the Future. Washington, D.C. July, 1979.

Cecelski, et al. Household Energy Use and the Poor in the Third World. Resources for the Future. Washington, D.C. 1979.

General Electric Co. "Analysis of Demand for Electric Power in Rural Communities." USAID contract AID REPAS-1. March 1963.

General Electric Company. "Small Scale Power Supplies for Rural Communities in Developing Countries." USAID Report No. TA/OST - AN-63-3-1. March, 1963.

Inversin, Allen R. "A Case Study: Micro-Hydropower Schemes in Pakistan." NRECA, December, 1981.

Kettering Research Laboratory. "A Nitrogen Fertilizer Production System for Farm Use." Charles F. Kettering Foundation. Dayton, Ohio.

Metzler, Reinhold. "The Heatgenerator." Butwal Engineering Works Pvt. Ltd., United Mission to Nepal. January, 1981.

Mier, Ueli. Local Experience with Micro-Hydro Technology. SKAT publication No. 11, Vol. 1. St. Gall, 1981.

Reddy, A.K.N. "Energy Options for the Third World." Draft. U. of Calif. 1978.

Schroeder and Tu. "An Assessment of SWECS/Mechanical Heating Systems." Prepared by Rocky Flats Plant Wind Systems Program under contract with the U.S. Dept. of Energy. July, 1981.

Sonntag & Van Wylen. Fundamentals of Classical Thermodynamics. John Wyley & Sons, Inc. 1976.

Tendler, Judith. "Rural Electrification: Linkages and Justification." AID Program Evaluation Discussion Paper No. 3. April, 1979.

Trenarne, et.al. "Fertilizer Production by Water Power." University of Nevada Field Day Program (1980).

Whitby, Garry. "Heat Storage Cookers. The Norwegian Experience and Indications for Implementation in Developing Countries." Draft. ITIS. Rugby, U.K. September, 1981.

The World Bank. "Energy in the Developing Countries." August, 1980.

Yoder, et. al. "The United Mission to Nepal's Involvement in Small-Scale Water Power Development for Milling." Draft. Cornell University. 1980.

Yoder, Robert. "Thesis in Partial Fulfillment of Requirements for Master of Science Degree." Cornell University. January, 1981.

COST IMPLICATIONS OF SMALL HYDROPOWER SYSTEMS

by

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Abstract

Of all renewable energy technologies presently available to developing countries in search of indigenous energy development opportunities, small-scale hydropower may be the most economic option due to its reliability, accessibility, and low cost. Costs of small hydropower systems vary widely and are dependent on site characteristics, size, the development approach, and the end-uses of the energy, in terms of the delivered cost. The ultimate cost of a project is chiefly a function of whether the design is suitable to the need for the plant, the resources available to implement it, and the means of managing it.

Conventional small hydro cost data indicate that predictable economies of scale prevail whereby the unit cost increases as the size of the installation decreases. Recent experience with this technology at the lower end of the capacity range in a number of developing countries, however, tends to contradict conventional thinking with respect to economies of scale. This experience suggests that, due to the scarcity of equipment, materials, and technical and manufacturing expertise in most developing countries, per-unit costs tend to be greater with larger-sized small hydro plants. These plants typically require more complicated engineering, and larger and more sophisticated equipment than plants at the lower end of the scale which afford greater opportunity for non-conventional approaches using local materials, equipment and technology.

Biographical Information

Mr. Clark has acted as Training and Information Specialist for NRECA's Small Decentralized Hydropower Program since February, 1981. He previously served with the U.S. Senate Budget Committee for four years, where he advised Committee members on fiscal and monetary affairs pertaining to national economic policy. He was also Legislative Assistant to U.S. Senator Gary Hart of Colorado for economic, energy and foreign affairs from 1975 to 1977. Mr. Clark has an MA in International Studies focusing on economic development from the American University in Washington, D.C. and a BA in Political Science from the Colorado College.

1. INTRODUCTION

Why Hydropower?

Unlike thermal-based power generation, hydropower systems are not subject to continuous cost escalation--indeed, they are essentially inflation-proof, once built. They carry no energy (fuel) cost, and since their useful lives can be more than twice as long as thermal plants, this is significant. Moreover, they usually incur none of the environmental costs associated with thermal systems. The advantage of this technological choice are enhanced when one considers that, apart from these cost advantages, hydropower can provide secondary benefits that are not possible with other energy technologies, such as irrigation, public water supply, and flood control.

Why Small Hydropower?

Another advantage of hydropower technology, when considered for small-scale applications, is that it is accessible to most parts of the world where technical and financial capabilities may foreclose the option of utilizing more expensive and complicated technological solutions, including large-scale hydropower development.[1] Apart from the enormous complexity of building large storage hydro facilities, it should also be borne in mind that the long lead-time that must be allowed for its planning and construction, including longer procurement schedules, can reach 10-15 years, which bears with it a considerable cost to the project. Smaller scale hydropower development is also more adaptable to incremental, or staged, development, allowing for earlier pay-back on the investment.[2]

Other reasons may be offered which favor the development of small hydro systems as an alternative to large central power stations, particularly for purpose of providing energy to dispersed rural regions, which consume roughly one-tenth as much energy as urban areas.[3] The cost of building transmission facilities over long distances, particularly in mountainous regions, can be very high, ranging from $15,000 to $25,000 per km in the U.S., and maintenance costs may be considerable. Yet rural energy demand is typically very low,

particularly during daytime hours. Thus, large centralized powerplants generally cannot compete successfully with small plants where loads are small and widely scattered. Moreover, it should not be overlooked that grid extensions do not eliminate the need to generate new power to meet rural loads. This is especially significant where the grid power is based on thermal generation. Finally, environmental costs, both with regard to human and natural environments, are more likely to come into play. Grid extensions may nevertheless be more economical if distances are not excessive, the terrain is compatible, and the energy demand warrants them. The choice between isolated development or interconnection with the central grid to serve rural needs depends on these, and a number of other criteria which are discussed below, that must be viewed on a site-by-site and country-by-country basis in terms of identifying the least-cost option.

Point-of-Departure

A great deal of literature is available on the costs of small hydro development within the industrial nations of North America and Europe which goes back for a century or more. Economic and cost analysis of more recent experience with this technology in a number of developing countries, however, is almost non-existent. Information on direct costs of installation are available to some degree, but data relating to reliability, efficiency, and durability of these systems, as well as specfic information relating to intangible costs, is difficult to attain. Yet it is this experience that may be more relevant here, and more revealing as to the true costs of small hydro technology in remote rural regions of Africa.

For a number of reasons, some of which have already been alluded to, this paper does not attempt to provide a specific costing methodology for small hydropower development. While cost tables and cost curves are abundant in this field, it is generally inadvisable to suggest that any of these indices can be applied generally--indeed, an important conclusion of this paper is that they should not. General cost parameters can be offered, and a number of examples are presented to give the reader some idea of the actual costs that

are associated with small hydropower plants. Costing of small hydro plants is dependent on a large number of variables that are site-specific; there are virtually as many cost indices for small hydro plants as there are sites. Rather, the purpose of this paper is to present some views on factors that tend to influence costs. Further efforts are needed in developing a comprehensive costing methodology that takes into account some of the cost-influencing factors presented here, and which is adjustable to reflect the relevant technological conditions pertaining to small hydropower development that exist in different parts of the world. This paper is offered as a brief introduction to some of the key issues involved and a preliminary assessment of what the existing experience reveals.

For purposes of this paper, the term "small hydropower" refers to any size of plant with the range of 1 kW to 1,000 kW unless specifically indicated otherwise. Further, it will generally avoid the question of whether rural energy development--be it in the form of mechanical or electrical power--is worth the cost of investment. In a discussion of costs, one can quickly become embroiled in a debate on the merits of rural electrification. While this question is well worth debating, in light of the high costs of electrification, the relative merits of energy versus other investments is not considered.

2. GENERAL COST HISTORY

It would be misleading to suggest that a general statement on the costs of small hydropower installations can be made. Costs will vary from case to case since labor, equipment, terrain, and technical experience, to name but a few of the criteria, are highly variable. Moreover, it is hazardous to attempt to directly apply the data and experience developed in certain countries to other regions of the world where the same conditions and assumptions may not apply. Indeed, much of the published data (see tables given in Appendix A) are based on cost indices that are drawn from large hydrosystem development which has been scaled down to smaller sizes, leading to distortions that tend

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to make small hydropower appear overly costly. Costing achieved by this method cannot only prejudice the decision-maker against the small hydro option, but more importantly may influence the choice of development approach which may be inappropriate--and needlessly costly.

It is therefore perhaps more valuable to take a quick look at some cost data that have been drawn from actual experience in a number of developing countries where small hydro development has taken place in recent years (see Fig. A). Again, caution is advised in accepting these figures into the record. The numbers shown here have been taken from published and unpublished sources without any critical evaluation, and therefore may not reflect the true costs of the cases given. Moreover--and this can be said of virtually any source--these costs typically reflect

Country	Capacity	Head	Cost/kW[1]	Equipment as % of Cost	Comments
Thailand	800 kW	40 m	$2850(80)	15%	concr. construction for civil works
Ecuador	400 kW	40 m	$2200(79)	36%	lined canal; imported equipment
Ecuador	400 kW	19 m	$2700(79)	30%	lined canal; direct intake; import. equip
Nepal*	200 kW	58 m	$ 900(80)	36%	part. lined canal; loose-packed rock dam
Nepal	120 kW	14 m	$ 900(80)	21%	masonry-lined headrace
Indonesia	120 kW	15 m	$1300(77)	58%	no headrace; local turbine
Thailand	100 kW	79 m	$ 950(80)	21%	concr. construction for civil works
Philippines*	100 kW	27 m	$ 750(80)	39%	local construction materials and turbine
Indonesia	90 kW	19 m	$1050(78)	54%	concr.-lined headrace
Nepal	80 kW	16 m	$1650(80)	23%	local materials and turbines (2)
Nepal	80 kW	34 m	$1050(80)	31%	local materials and turbines (2)
Nepal	25 kW	22 m	$ 650(80)	28%	existing irrigation works
Indonesia*	15 kW	22 m	$ 600(80)	33%	no headrace or governor, used alternator
Thailand	15 kW	10 m	$2350(80)	41%	earth dam and headrace
Thailand	10 kW	6 m	$1500(80)	27%	lined canal; local turbine
Pakistan*	10 kW	**	$ 270(78)	61%	local materials and equipment
Nepal	9.5 kW	9 m	$ 600(80)	46%	local materials and equip. except penstock
Pakistan*	7.5 kW	**	$ 320(78)	60%	local materials and equipment

[1]not including transmission and distribution costs; figures correspond to dates given in parentheses

*projects implemented and managed locally

**precise heads unknown, but generally between 5-10 m.

Fig. A. Installation Costs for Small Hydro Plants in Developing Countries.

Sources: Thailand (NEA); Philippines (NEA); Indonesia (PLN); Nepal (BYS); Pakistan (ATDO); Ecuador (INECEL).

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only direct costs associated with the construction of small hydro plants, and do not take into account indirect or "intangible" costs that inevitably occur in the development process, which may take the form of subsidies, "experience-building" costs that occur over many years of a program, or socio-cultural costs that may occur at the site, which are certainly real costs, but are difficult to quantify and are therefore overlooked.

In terms of identifying an acceptable cost-range for small hydro plants, notwithstanding the World Bank's target of $2,000-$3,000/kW installed,[4] it is similarly inadvisable to toss out numbers that do not take into account important considerations such as the energy demand characteristics (both in quantity and quality terms) of the region served, the fuel transportation costs to the area, the distance from the existing grid, and the physical characteristics of the site itself, among others. Clearly, what determines the acceptable cost-range for a small hydro plant will depend on the relative costs of alternative energy options. To provide the reader with a very general rule-of-thumb, the graphs in Fig. B. give an idea of the range of cost of a small hydro plant which makes it a relatively attractive investment compared to a similarly-sized diesel plant. Note that as the load factor increases, the cost of the hydro can be higher and still remain competitive. This is due to the longer life-span and the lower operation and maintenance cost of the hydro as compared to the diesel.

3. UNDERLYING ISSUES

Matching Technology to Need

As mentioned earlier, costs taken out of context can be misleading, since the data are frequently incomplete or not quantifiable, and since market values are quite different from country to country or even between regions of the same country. Moreover, analyses that are based on cost alone, or even the partial cost of an installation, such as the equipment and civil works, cannot give an accurate picture of the value of a project since there are so many variables that determine the economy of a project. The economic attractiveness of a project is a function of both the cost and the end-use of the energy

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produced. While it is certainly appropriate to consider factors that can reduce the input variables (i.e. costs), perhaps even more significant will be efforts to maximize the use of the energy. It is generally easier to reduce the delivered cost of energy by means of load enhancement, the economist's function, rather than by means of reducing input costs, the function of the

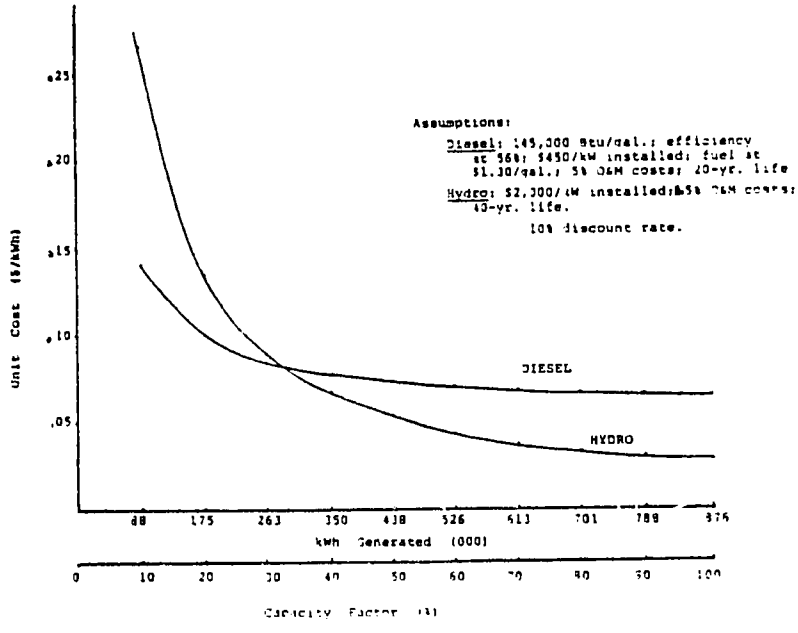

Fig. B(1). Annual [illegible] for 100kW Diesel and Hydropower Installations.

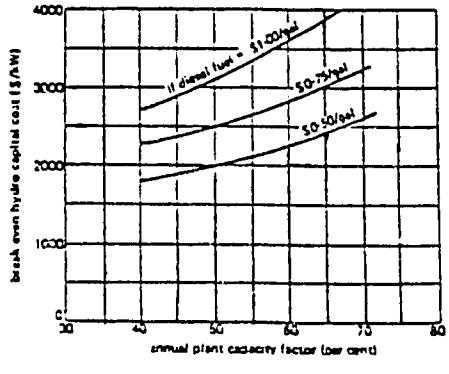

Fig. B(2). Break-even Costs for 170kW Hydro Plant Compared to Diesel Assuming Benefit/Cost Ratio even for both.

source: King (1979)

Fig. B. Comparison of Diesel and Small Hydropower.

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engineer. For this reason load planning is critical to the ultimate cost of the energy produced. This will be a function of how well the technology is matched to the consumer's energy needs in terms of both efficiency and capacity of the plant, and the tariff policy.

First, the energy form must be appropriate. Complex energy solutions for simple needs, in the rural context, implies higher costs to the consumer. A table is offered in Appendix B which can be helpful in matching energy technologies to the appropriate energy requirements. Please note that cost is an important criteria in the matching process. A corollary to this question of appropriateness is the matter of timing. Since small-scale hydro systems typically operate intermittently due to flow variations, the time-factor of energy supply can be critical. For example, if the energy demand does not coincide with the seasonal flow characteristics of a site, it should be borne in mind that storage requirements that may be necessary can add enormously to the costs of building the plant.

Second, capacity considerations are important. It is generally thought that plant factors should reach at least 20-30% in order for hydro to compete successfully with alternative energy technologies.[5] Domestic loads are typically very low in most of these regions, so it is important to emphasize day-time industrial uses, or "productive" end-uses, especially where existing demand is currently served by more expensive thermal generation, or where new industrial demand can be served which otherwise cannot be achieved economically by traditional energy means. Once an industrial load is established, domestic service can be provided at more feasible rates, as studies show that once modern power sources are introduced to an area and take hold (i.e. industrial uses), power demand from the general sector increases rapidly.[6] The tables shown in Fig. C. demonstrate the relationship between the load factor and the costs of producing the energy. Note that the cost of the delivered energy is reduced as the load factor increases. Fig. C(1). indicates that higher load factors allow a larger margin for capital costs at a standard tariff rate.

A key element here is that initial development of a new, isolated energy source must be scaled to the rate of demand in order to keep unit costs

sufficiently low to the consumer to permit the demand growth process to begin. This can be achieved both by designing the system to permit staged development, and by means of tariff policies which induce consumption.

Load Factor (%)	Capital Cost/kW ($)
10	212
20	675
30	1,150
40	1,613
50	2,075
60	2,537
70	3,000
80	3,475
90	3,938
100	4,400

Fig. C(1). Comparison of Load Factor to Capital Cost for Typical 50kW plant in Uttar Pradesh State, India.

(assumes standard U.P.S. tariff rate and full capital recovery)

Project	Average Load Factors (%)	Average kWh Cost (¢)
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

Fig. C(2). Comparison of Load Factors to Generating Cost for five 200kW projects in Uttar Pradesh State, India.

(assumes full depreciation over 6 years)

Fig. C. Relationship of Load Factor to Capital and Generating Costs

Source: ITIS (1980)

Costs and Benefits

In general, costs and benefits are judged in terms of what costs one is avoiding by either doing nothing (e.g. loss of forest cover, cost of diesel fuel), or investing in some alternative project (e.g. transmission costs), as

compared to the costs of electing the small hydro project, whose components are summarized in Appendix C.

In order to do an economic and financial analysis of a project, ideally the full range of costs and benefits associated with the investment must be quantified in some form, usually in monetary terms. This is true for virtually any analytical tool, whether one is seeking to find the internal rate of return, or the ratio of benefits to costs over the project's useful life, or if monetary calculations are not possible, by some means of imputed mass analysis. Although benefits calculations are an important part of assessing a project's worth, particularly in comparing different sector investment options, public infrastructure projects such as usually is the case with power generation are commonly analyzed by first setting a target in terms of a rate of return or a stream of benefits to establish the minimum desired result, and applying a least-cost analytical methodology which is often called the life-cycle costing method. What one is attempting to do by this method is to quantify all costs involved over the life of a project and to discount their values to present worth using an interest rate that reflects the opportunity cost of the investment. This is discussed in a previous paper but it worth noting that, as the discount rate used in the calculations increases, the value of the project declines. Moreover, an artificially low discount rate tends to favor capital-intensive approaches, which may not be appropriate for rural development projects.

4. MAJOR COST-INFLUENCING FACTORS

Small hydropower costs can be affected by numerous factors pertaining to the site, the scale of development, the technological approach, and the purpose of the project. For this reason it is difficult to present a uniform set of costs that can be applied simply and universally. The costs of individual components of a system are more easily defined, but even these depend largely on these same factors. The following is a brief discussion of each of the four major categories of cost-influencing factors.

A. Site Characteristics

Selecting the site is critically important to the ultimate cost that will result. The chief aspects of site selection which will affect cost are:

(1) its relation to the load center;

(2) the availability of head and flow, particularly the former;

(3) the river slope and hence the distance over which the head must be concentrated; and

(4) the degree of access to the site.

Relation to Load--Interconnected or Isolated. First, the plant must be located in a place where the energy can be used. Unless it is a site that can be grid-connected, all-important capacity factors may be very low if the site does not have a sufficient load center nearby. The energy must not only be appropriate, but it must be affordable. Sites that can be interconnected are certainly best, depending on the power capacity available, since load factors would theorectically be 100% of the convertable energy and since the need for expensive asynchronous frequency control equipment could be avoided by using induction generators. This cost-savings would be mitigated somewhat, of course, by the additional cost of voltage step-up equipment and transmission lines. Again, this depends on the capacity that is available at the site, and the distance from the grid.

Hydraulic Characteristics. Site selection is important also in terms of the type of scheme to be developed--whether low-head or high-head, and whether run-of-river type or storage (impoundment) type, which depends on the availability of natural head and flow.

Given the choice between run-of-river schemes and those requiring the construction of new dams, it is generally wise to avoid sites requiring the latter due to the high cost of dam construction and maintenance, particularly for low-capacity plants (see Appendix A-4 for dam construction costs). Moreover, the can:

(1) entail considerable environmental and health problems;

(2) cause enormous damage in the case of failure during peak flows;

(3) add considerably to the construction period;

(4) result in relocation of buildings or entire communities up-river;

(5) interfere with the use of the river for navigation and fish migration.

Dams are also susceptible to silting problems, which can complicate the design and up-keep of the intake structure, and can eventually render the dam worthless if used for impounding water.

An alternative approach for sites with higher natural heads is to build a low diversion weir to direct a partial flow of the river into the intake, as have been described in detail elsewhere. They are easier to construct and maintain in remote rural settings, and need not be of permanent construction, but could be formed by placing rocks and boulders across the stream that can be easily replaced following each peak-flow season. This would be the most simple design for a weir for a very small scheme, but permanent structures for larger sites can also be built at substantially lower costs than for an impoundment structure. Care should be take in selecting the placement of the diversion structure to avoid silting and erosion, which can add considerably to the cost of keeping the intake servicable.

Generally speaking, the degree of head available to a small hydro site is the single most important determinant of cost, since the amount of water needed to create a given amount of energy is reduced with higher heads, yielding cost-savings in both the turbo-generating equipment and potentially the civil works as well, depending on the slope of the river and the terrain. However since most siting opportunities will occur on rivers and streams with gradual gradients, the distances along which the water must be conducted to achieve significant heads may be considerable, perhaps several kilometers. Thus, the civil works costs for higher head schemes may often be the highest cost component. In short, for the greatest cost-effectiveness, sites should be selected to allow the highest head possible covering the shortest distance from the intake to the turbine

Low-head sites tend to be more expensive due to the large size of the machinery--which can account for up to 65% of the total cost[7]--and since dam structures are often required. Total costs for low-head plants (20m or under)

can be as much as two to three times as great as schemes with higher heads.[8] A final note--for very small micro schemes requiring less flow, heads need not be above what is generally presented as the low-head range in order to achieve the most cost-effective scheme. This is one reason why micro plants using local labor and materials appear to offer the best economies

Finally, flow considerations are also important in terms of the annual cost of energy supplied by the small hydro plant where flows are intermittent and varied, as found in many countries of the West and Central African region. If flow needed to operate the plant is available for only a few months of the year, per kWh costs may make the plant uneconomical. For this reason the quality of hydrologic calculations can be critical to the ultimate cost of the plant, particularly if the capital costs are high.

Access Considerations. Finally, the degree of access to the site may be important, particularly for larger schemes where equipment and materials may be large or heavy, requiring roads. Frequently the best high-head sites are found in areas where the terrain is inhospitable or the forest-cover dense. It therefore may be best to reserve these sites for very small schemes where equipment and materials do not require motorized transport, since the cost of building roads can be extremely high, about $50,000 per km in the U.S.,[9] and since population densities are likely to be low.

B. Economy of Scale Factors

Size of the Plant. The record is not clear on the question of economies of scale with respect to small hydropower. Conventional wisdom is that as the size of the plant decreases, the per-unit cost goes up. Certain costs which are relatively fixed such as the feasibility analysis, the engineering design costs, training, and the "experience-building" costs mentioned earlier, do tend to make lower capacity plants less competitive with larger plants; moreover, for low-head schemes requiring larger, more sophisticated equipment and impoundment structures, the economies of scale rule applies more readily.

Where design and construction techniques for small projects follow from modern technology that has been developed for conventional large hydropower, this rule generally holds true. However, if a different, non-conventional

approach is taken, based on smaller-sized plants emphasizing simpler designs and local expertise and materials, good economies can be achieved. More will be said on this later, but it is evident that reverse economies occur with this approach, where unit costs increase with the size of the plant above a certain level.

Programmatic Considerations. Economies of scale are also evident in the size of the program, whereby multiple development--especially when performed in the same river basin--can reduce the impact of fixed costs mentioned above by spreading the costs out amoung several projects. Overall costs can be reduced by as much as 10% in this manner.[10] Moreover, it may be particularly advantageous to consider establishing regional grids under such an approach to improve load factors, and to limit the number of plants that must be built. If multiple development is possible, thought should be given to standardizing the techniques used, the general design, and the equipment, although over-standardization can reduce cost-effectiveness. Since conditions from site to site are likely to be different, the civil works design should be flexible enough to allow innovation that is appropriate to each site. The greatest cost-effectiveness can be achieved by selecting sites with similar characteristics (i.e. head and flow) and standardizing equipment packages, particularly in the case of low-head sites, to operate within that range of conditions. Standardization of the turbo-generating equipment in this fashion will not only reduce the design and fabrication costs, but would shorten delivery time and minimize the need for spare parts inventory, which can be shared among various sites. Project costs can be reduced by 10-15% where standardization of equipment is possible.[11] It should be noted that over-standardization of equipment can reduce operational efficiencies of plants, so care should be given to the use of turbines that can operate under wide head and flow conditions, such as are possible with cross-flow types and converted centrifugal pumps used in multiple-unit configurations.

Timing of Development. Finally, economies of scale can be improved by approaching site development of an isolated plant on an incremental basis rather than developing the full energy potential of the site at the outset, in order to save on the ocst of the equipment or civil works. Again,

this is a function of the load factor, which is typically low during the initial stages of operation. With incremental development in mind, the headworks and penstock should be initially designed to capture the full amount of head feasible and so that larger flows could be accomodated for future capacity growth, assuming there is adequate water supply. The penstock should be sized to withstand larger volume and pressure than are initially required, or may be fitted with a bifurcation tee at some point along its length, if multiple units are feasible. Additional turbines may then be added as load growth warrants. Allowances should be made in the excavation depth and floor space of the powerhouse for these future additions. The principal reason for this approach is to avoid retarding the demand growth process by making the power cost to consumers excessively high initially. Staged development also in a programmatic sense permits "experience-building" to occur at a relatively low cost risk and can allow for experimentation with design innovations without laying too much money on the line. The decision of plant sizing and the timing of additional development should, of course, be predicated on the socio-economic feasibility study. However, since load growth is often difficult to predict in isolated regions of developing countries, the incremental design approach may be especially appropriate.

C. Use Criteria

Multiple Uses. With low-head sites, priority should be given to projects where power generation can be one component of a multi-purpose project. For example, installing a plant on existing irrigation works or an existing dam used for flood control, fish-breeding, or recreational purposes can vastly improve the cost-effectiveness of a project. Similarly, new multi-purpose water projects which include power generation as one component can yield better economies than a project where the only benefit is energy. Although costs would be greater for multi-purpose projects in absolute terms, since they can be shared among the various purposes, including municipal water supply, irrigation, flood control,fish-breeding, navigation and recreational uses, the unit energy costs would be significantly lower. Cases where the water supply can be attributed to irrigation and power generation, which is

frequently the case in China and Indonesia, offer the best configuration for multi-purpose projects since the irrigation works can reduce the cost of the power, while the power can be used to reduce the cost of distributing the water. Please note, however, that timing and design circumstances can lead to competitive uses of the water, indirectly raising the cost of the other water use (e.g. power generation when the water is diverted to irrigation.).

Project Purpose. Use criteria can also be viewed in terms of whether the purpose of the project is for fuel-substitution or for rural development (i.e. rural energy supply). This is not to suggest that these two criteria are mutually exclusive. Even for small isolated plants, where fuel substitution is minimal in the national scale of things, cash-savings achieved by reducing the need for kerosene and diesel fuel can be the most important benefit, aside from the rural development considerations of such a project. In this sense, small hydro technology may only be economical where the cost of fuel is particularly high due to transportation costs over long distances. However when the primary objective of the project or program is to effect reductions in the trade deficit, issues of plant capacity and the size of the program, hence the technological approach, become critical. It has been seen in Fig. A. that the greatest economies are achieved under conditions which permit the development of very small plants based on non-conventional technology. Yet import-substitution from a national perspective is limited due to the low aggregate capacity of even a large number of such sites.* It is only with much larger sites, where cost-effectiveness may not be as great, that this objective is better served. The point here is that, as an import-substitution technology from a national perspective, cost-effectiveness may at present only be achieved in a size-range above 1 MW, where the economies of scale rule applies more readily.

Tariff Policy Considerations. Lastly, tariff policies can be an important

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* Taking the Ivory Coast as an example, we see that over 1 million MWh of thermally powered electricity is now produced each year. If fifty 25 kW plants were installed throughout the countryside, assuming a relatively high capacity factor of 50%, the annual yield of fuel substitution that could be achieved would amount to only 5,500 MWh, or only 0.5% of the total currently produced.

determinant of the per-kWh cost of an isolated plant. Since there is no fuel cost associated with hydropower generation, unlike thermal stations, high capacity utilization reduces unit costs, whereas it tends to have the opposite effect with fuel-based generation. Hence, the objective should be to: (1) match the installed capacity to the peak-load factor on an incremental basis (design function), and (2) maintain a high load factor (tariff function). In other words, tariff policies should be set to encourage energy consumption and demand growth. Therefore the key element with small-hydro plants is to keep installation costs low, since operation and maintenance costs are minimal, in order to allow low unit costs to the consumer, which in turn improve load factors. Even with low installation costs, moreover, it may be necessary to provide power below cost for a period sufficient to induce demand growth during the critical period following the introduction of power, and to increase the capacity factor of the plant. This is particularly true for remote rural regions of developing countries, where, as one has put it, "it is not easy to get the consumer to pay for a service he is not used to having and that is foreign to his social behavioral patterns,"[12] and where, of course, people are usually too poor to pay much for such a service.

Experience has shown that it is best to rely on non-domestic uses in order to achieve economic success with isolated small hydro projects. Power stations where power is generated for industrial uses (often mechanical drive, not electrical applications solely) have shown plant factors to be twice as high as those where electricity is used for domestic and public lighting.[13] On this point it might be also be suggested that domestic consumers be charged on the basis of a flat-rate tariff (e.g. x amount per light bulb per month), as has been done in Nepal and Pakistan, to encourage consumption growth and to avoid costly metered connections for unit-pricing.

D. Development Approach

The foregoing discussion of cost-influencing factors with respect to site characteristics, economies of scale, and end-uses raises a number of fundamental issues that reflect two general approaches to small hydropower, particularly in terms of the technological approach that is used. On one

side of this dichotomy, the approach can be said to be conventional; that is, employing standards established in the construction and management of large hydroelectric powerplants and scaling the designs down to smaller sizes. In developing countries, this approach is more often associated with programs initiated and managed by central agencies, frequently using imported equipment, and predominantly permanent materials such as cement and reinforced steel for the civil structures. On the other hand, the approach may be of a non-conventional form, usually initiated and managed locally, where the designs are simpler, using locally-supplied equipment and civil engineering based on techniques already familiar to villagers for irrigation and primitive hydraulic energy. A key difference between these two approaches which reflects a fundamental trade-off in terms of cost and performance, is that conventional development tends to emphasize resource maximization, meaning the use of permanent structures and more sophisticated machinery based on designs that attempt to extract the most energy possible from a given site. Unconventional designs, on the other hand, are based on minimal needs, implying less effort in the feasibility analysis, but less efficient and less durable construction. Yet, contrary to conventional thinking, it may not be cost-effective to attempt to squeeze out every ounce of efficiency from a plant, since the greater costs implied with this approach may not be worth the additional energy conversion that is achieved, particularly for smaller isolated plants. Fig. D. presents a general description of the elements typical to each of these two approaches.

The more non-conventional approach, while being constrained in size by the limited capability of local resources to produce the larger and more complicated machinery and structures needed for systems over 100 kW, offers cost savings since:

(1) the technology is simpler, and can be easily grasped by villagers;
(2) greater innovation in design is possible;
(3) maintenance is simplified since the materials are provided locally; and
(4) community participation, upon which this approach is based, will reduce labor, engineering and management costs, and will provide greater assurance of long-term success.

	Type A.	Type B.
Scale	Over 100 kW.	Under 100 kW.
Type of System	All types, but more frequent incidence of impoundment and low-head with large flows.	Run-of-river, both high and low head, using low flows.
Technological Approach	Conventional hydro; emphasis on efficient imported equipment for resource maximization.	Non-conventional, innovative engineering; emphasis on local technique and materials, volunteer labor, based on "as good as needed" approach.
Use of Energy	Electricity for large rural centers or grid-connection.	Mechanical and/or electrical power for small towns and villages.
Project Purpose	Imported fuel-substitution, rural electrification.	Basic energy needs, rural development.
Management	Central agencies, national utilities.	Local villages, cooperatives, entrepreneurs.
Tariff Policy	Conventional unit-pricing based on marginal cost.	Flexible rate setting; flat-rate structure for consumption enhancement.

Fig. D. Two Types of Small Hydro Development in Developing Countries.

The importance of the last point cannot be over-stressed. Apart from the cost-savings gained by eliminating the need for constant supervision by a remote central agency, self-generated local involvement improves the chances from the outset that the project will be better designed to serve the local population's needs, since it will participate in its design and construction, and that the powerplant will be something that the people are both able and willing to pay for, and keep running.

5. COST TRENDS

Taking into account the major cost-influencing factors, particularly those relating to size and the development approach, the historical cost

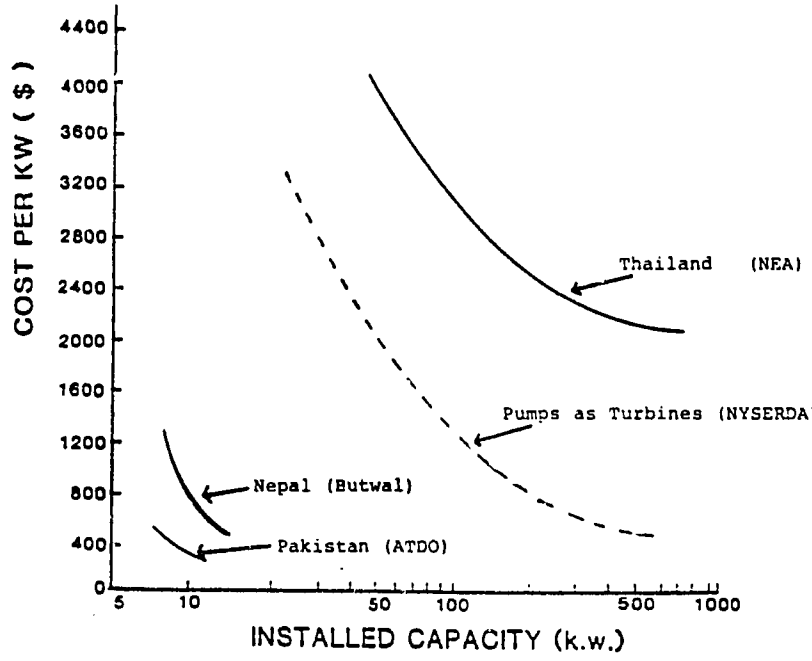

Fig. E(1). Comparison of Different Approaches to Development

source: Pakistan (ATDO); Nepal (Butwal); Thailand (NEA); New York State Energy Research and Development Authority

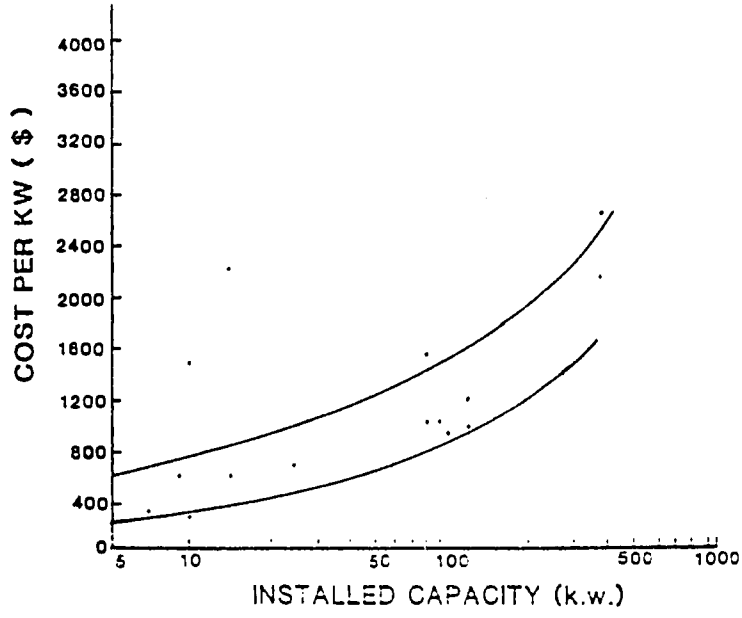

Fig. E(2). Cost Trend for Small Hydropower Plants in Developing Countries.

source: Curve plotted from figures shown in Fig. [illegible]

Fig. E. Cost Trends for Small Hydropower Plants.

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data available to date suggest some interesting trends. Fig. E(1). gives a series of cost curves covering a range of sizes and approaches to development. At the lower end of the capacity scale, costs are considerably lower for schemes emphasizing local approaches to development, such as are found in Pakistan (Appropriate Technology Development Organization) and Nepal (Butwal), as compared to the costs of similarly sized plants under the more conventional approach, such as in the case of Thailand (National Energy Administration). Falling between the two general categories is a curve showing the costs of plant designs where civil structures are generally of a conventional nature but the turbo-generating equipment is not conventional using centrifugal pumps run in reverse and standard, off-the-shelf generators. Note that each curve shows economies of scale where the unit capital costs decline as the size increases. But taken together, the curves show that as the capacity increases, so do the unit installed costs, or that reverse economies of scale occur.

Fig. E(2). plots the unit capital costs of the plants given in Fig. A. The resulting curve, or "envelope," since that data present only a general trend, from this sampling of actual costs tends to confirm the reverse economies theory. It should be acknowledged, however, that the local approach shown here only applies to very small capcity plants, due to the limited manufacturing capabilties of small workshops and the difficulties of using traditional village civil engineering techniques to accomodate larger water flows generally required for larger schemes.

The general conclusion one might derive from Fig. E. is that where hydraulic conditions permit the development of only very low capacity plants, of 100 kW or under, conventional development approaches are not as cost-effective as non-conventional approaches. As you move toward larger capacity schemes, above 500 kW, economies are not as great but nonetheless, may certainly be worth undertaking, depending on the cost of alternative solutions, and particularly if the plants can be interconnected with an existing national or regional grid. What is left is the least economical range, between 100 kW and 500 kW, where local technologies are presently difficult to apply, but economies of scale with more conventional approaches tend to auger against the small hydro option. For this range of plant, it may be best to consider

adapting certain aspects of civil works used in local schemes that avoid the use of extensive materials such as concrete and steel, and substituting standardized pumps and generators for custom-made turbo-generating equipment as proposed by the New York State Energy Research and Development Authority.

6. CONCLUSION

In summary, the costs of small hydropower plants are widely variable, and are subject to a host of interrelated technical, economic, and institutional factors. Least-cost solutions are more likely when all are considered as a whole. A technically ideal project may result in a misuse of resources if socio-economic factors have not been sufficiently taken into account. Is the energy appropriate to the need, and will it be available when it is needed? Is it affordable, and if so, are the people willing to take responsibility for making it economically viable? Can it be maintained? Local community participation that exists in the project right from the start--in the design, the collection of technical information, the construction, and the management and maintenance of the system--can lead to cost-effectiveness of a small hydropower project both in terms of the capital cost and in terms of extending its useful life.

Small hydropower technology, as with rural electrification in general, should not be viewed as an objective, but as a means; nor should it be "pushed" at any cost. In some cases, particularly where the goal is import-substitution, it may not be warranted as the most cost-effective option. The capacities of these plants may not be great, and therefore may not be worth the cost of capital-intensive development using a conventional power management approach aimed at maximizing the power potential of a site.

As an alternative to the conventional approach, the record to date suggests that small, micro-sized (below 100 kW) hydropower systems, based on:

-- maximum use of local expertise and materials;

-- acceptance of a lower, but acceptable, standard of reliability; and

-- simple, and easily maintained machinery,

may offer be the best hydro solution for very remote rural areas where energy demand is initially low. The reason is that conventional development, which relies on imported equipment and foreign engineering standards, and substantial use of expensive materials for civil works such as steel and cement, do not allow as much opportunity for flexibility in design and construction. This is not to say that larger mini-hydro systems, where conditions are right (e.g. retrofitting existing dam structures; easy interconnection with the grid; opportunities for standardized "fits"), cannot be a cost-effective means of expanding a national power system. However, the cost-competitiveness of this approach in the medium size-range has generally not been proved, not only in developing countries, but in the United States as well. However, when significant economies of scale can be achieved at high load factors--in a range generally above 500-1,000 kW--the technology fares bettter economically. Again, it should be stressed that there is a fundamental trade-off between cost, on one hand, and operational reliability and efficiency on the other hand, in selecting the development approach. However, plants that are constructed simply are also relatively easy to operate, maintain, and replace. The same cannot be said for plants based on more complicated technology in parts of the world where technological infrastructure is not yet fully developed.

FOOTNOTES

1. Conferees at the United Nations Conference on New and Renewable Sources of Energy in Nairobi last summer ranked hydropower first among all other technologies on the basis of its economy and technological accessibility.

2. In a recent study examining the net energy ratios (output/costs) of small vs. large, conventional hydropower plants, small schemes showed a mean ratio more than twice as high as large plants, even without the additional cost of transmission included. Oak Ridge National Laboratory (U.S. Dept. of Energy), Net Energy of Seven Small-Scale Hydroelectric Power Plants (July, 1981).

3. Goldenberg, Jose, "Energy Consumption and Decentralized Solutions", Energy and the Developing Nations, Electric Power Research Institute (March, 1980).

4. Energy in the Developing Countries, World Bank (1980)

5. Small Hydroelectric Powerplants, NRECA (1981), and Small Hydropower for Asian Rural Development, NRECA (1982)

6. Dickinson, H. and Whittington, H.W., Rural Electricity Supplies, University of Edinburgh School of Engineering Science (June, 1978).

7. Standardization of Hydroelectric Generating Units for Low-Head Hydro, Allis-Chalmers (1979).

8. Meier, Ueli, Local Experience with Micro-Hydro Technology, Swiss Center for Appropriate Technology (1981).

9. Simplified Methodology for Economic Screening of Potential Low-Head Small Capacity Hydroelectric Sites, Electric Power Research Institute (1981).

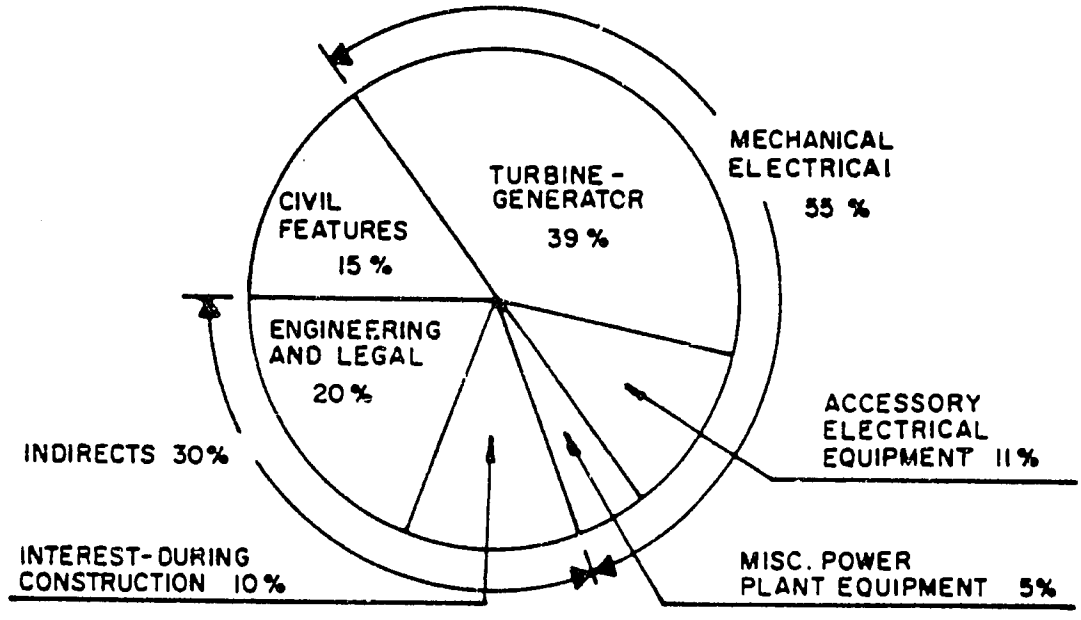
10. Allis-Chalmers, op. cit.

11. Ibid.

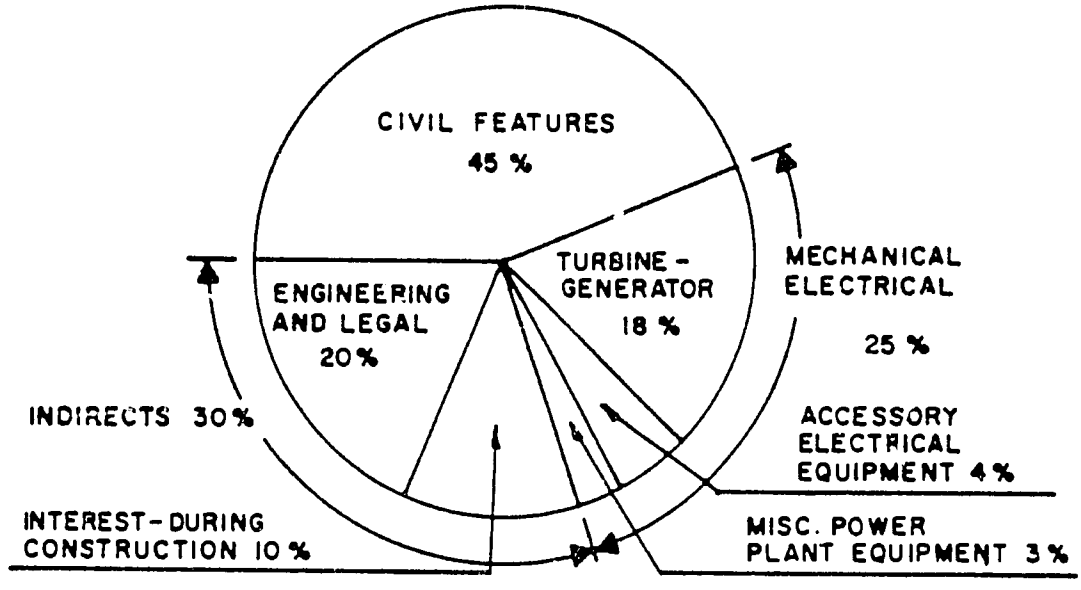
12. Small Hydroelectric Powerplants, op. cit.

13. Mohammed Abdullah (ATDO), in a conversation with author regarding experience in Pakistan (NWFP) with micro-hydro projects (1982).

Appendix A-1. Approximate Proportion of Project Capital Costs for Conventional Development



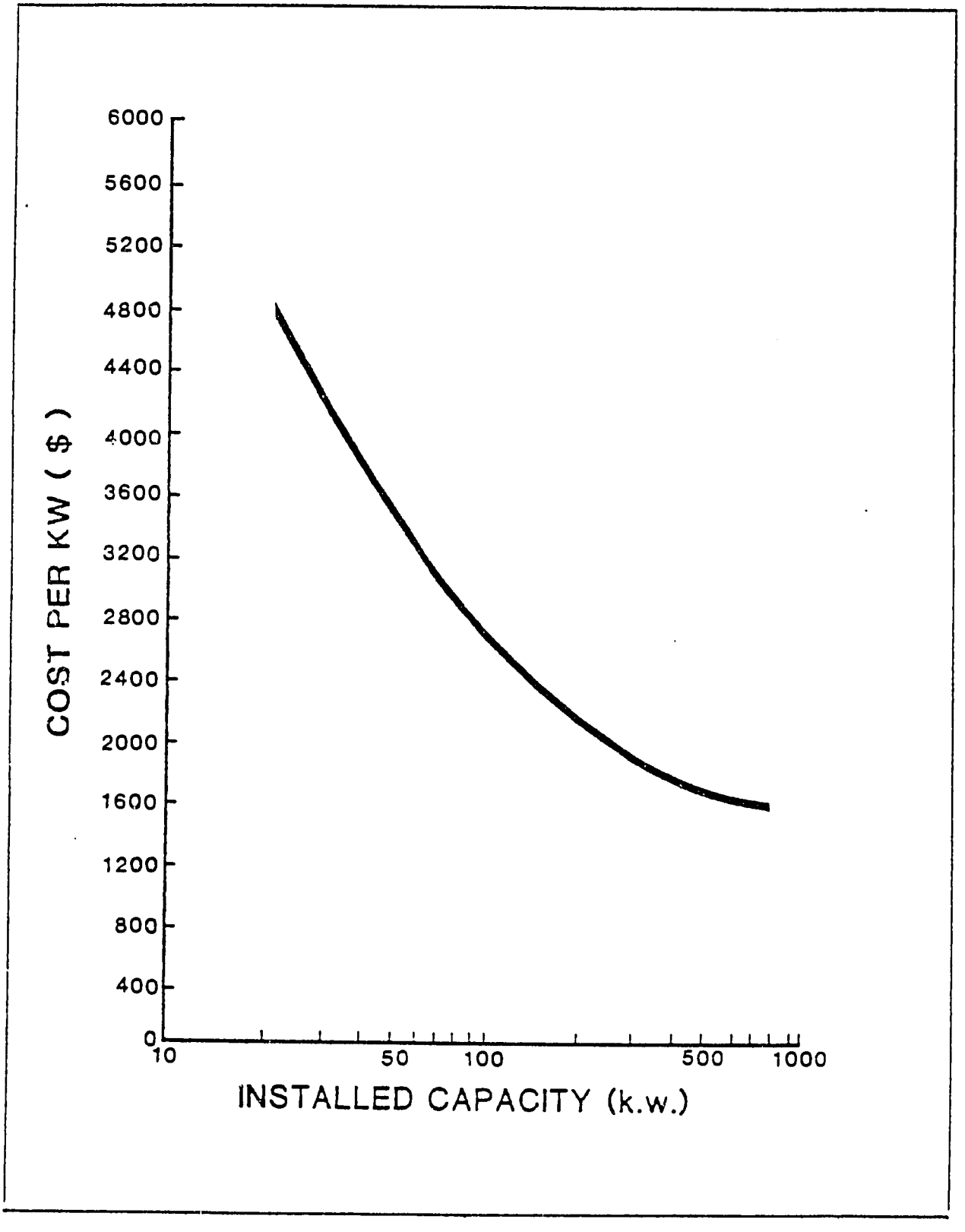
MINIMUM CIVIL FEATURES COSTS



MAXIMUM CIVIL FEATURES COSTS

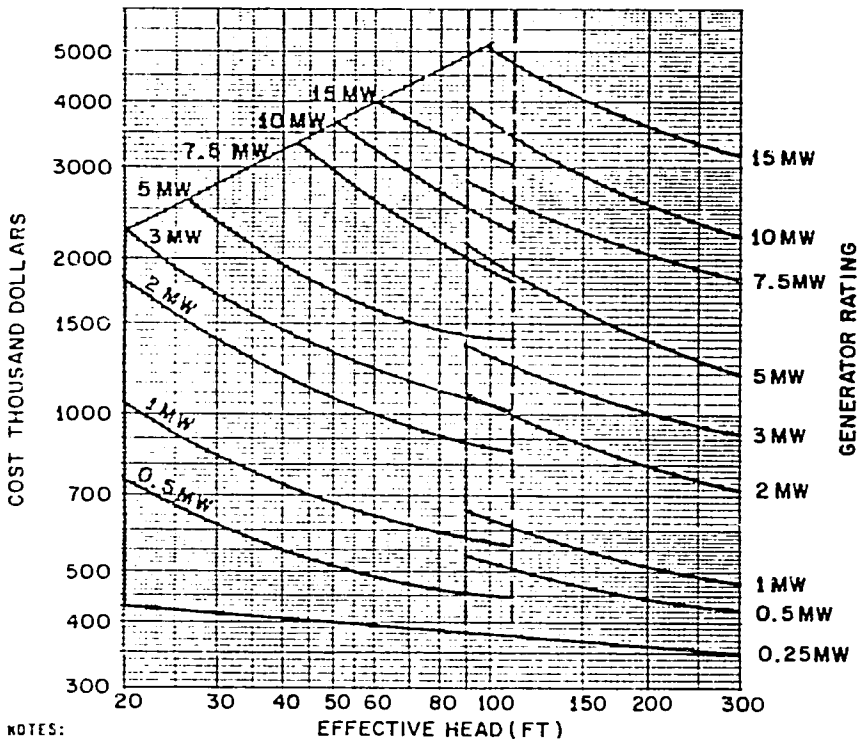
source: U.S. Army Corps of Engineers (1979)

Appendix A-2. Base-line Cost Curve for Conventional Small Hydro Plants



source: New York State Energy Research and Development Authority (1981)

Appendix A-3. Cost Guide for Conventional Small Hydro Plants.



NOTES:

1. Estimated costs are based upon a typical or standardized turbine coupled to a generator either directly or through a speed increaser, depending on the type turbine used.
2. Costs include turbine/generator and appurtenant equipment, station electric equipment, miscellaneous powerplant equipment, powerhouse, powerhouse excavation, switchyard civil works, an upstream slide gate, and construction and installation.
3. Costs not included are transmission line, penstock, tailrace construction and switchyard equipment.
4. Cost base July 1978.
5. The transition zone occurs as unit types change due to increased head.
6. For a Multiple Unit powerhouse, additional station equipment costs are $20,000 + $56,000x(n-1) where n is the total number of units.

source: U.S. Army Corps of Engineers (1979)

TABLE 4-2
MISCELLANEOUS RECONNAISSANCE ESTIMATE COSTS*
(Cost Base July 1978)

PENSTOCK COST

Effective Head (Ft)	10	20	50	100	200	[illegible]
Cost Index (CI)	1,500	745	295	145	70	[illegible]

Installed cost = CI x Penstock Length (ft) x Installed Capacity (MW)
Minimum Penstock Cost is $50 per linear foot

TAILRACE COST
Construction Cost = $15,000 fixed plus $200 per linear foot

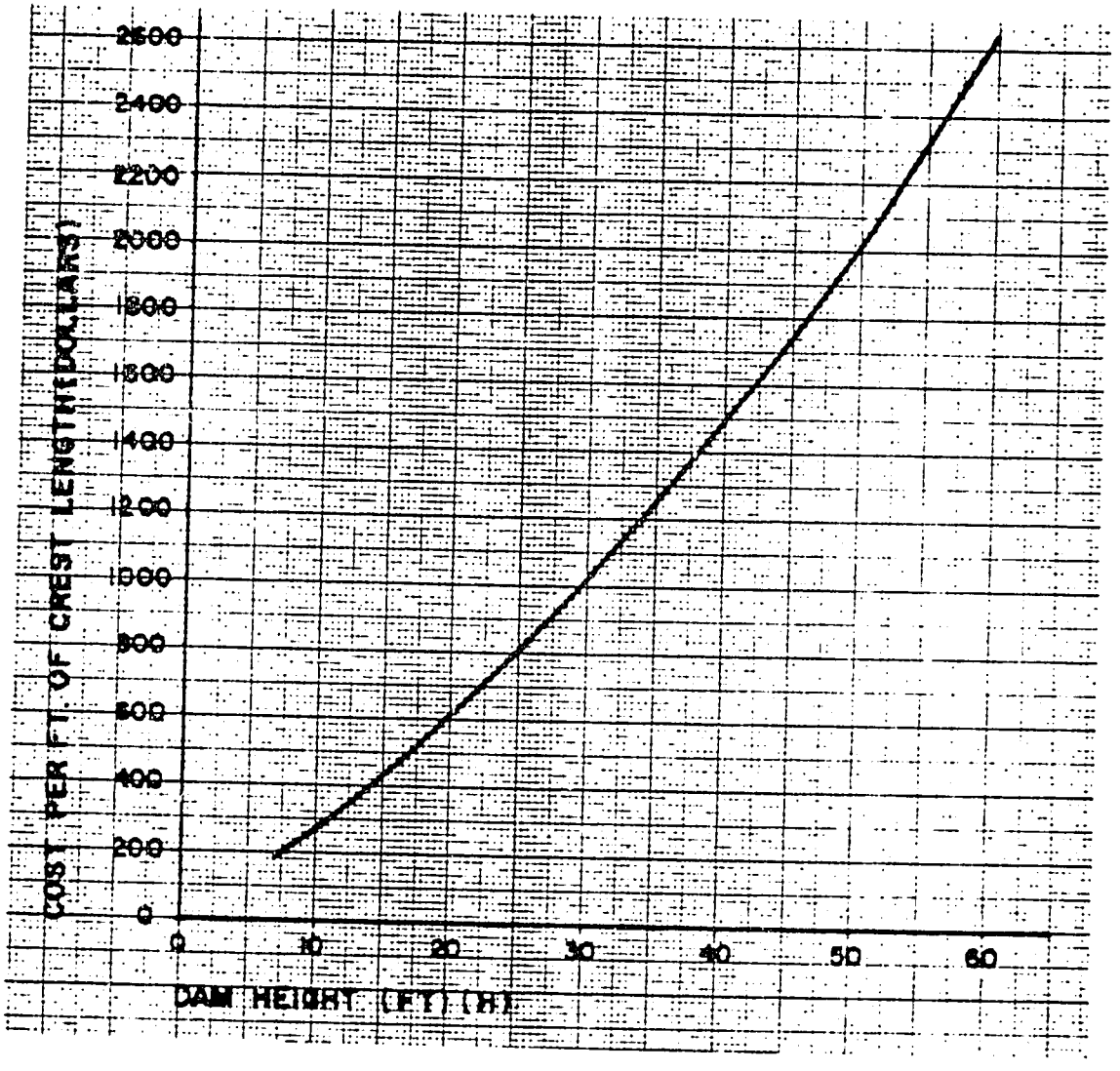
SWITCHYARD EQUIPMENT COST
(Thousand Dollars)

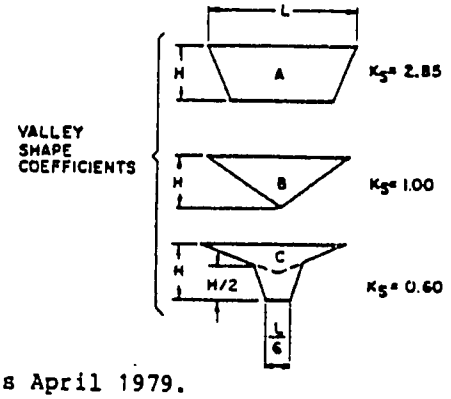
Plant Capacity	Transmission Voltage 13.8	34.5	69	115
1 MW	50	60	110	160
3 MW	85	100	120	175
5 MW	110	125	150	210
10 MW	150	170	210	280
15 MW	185	220	250	320

TRANSMISSION LINE COST
(Thousand Dollars)

Plant Capacity	Miles of transmission line 1	2	5	10	15
0.5 MW	30	60	150	—	—
5 MW	45	80	160	320	500
10 MW	50	100	180	380	600
15 MW	80	140	230	460	700

Appendix A-4. Embankment Dam Costs



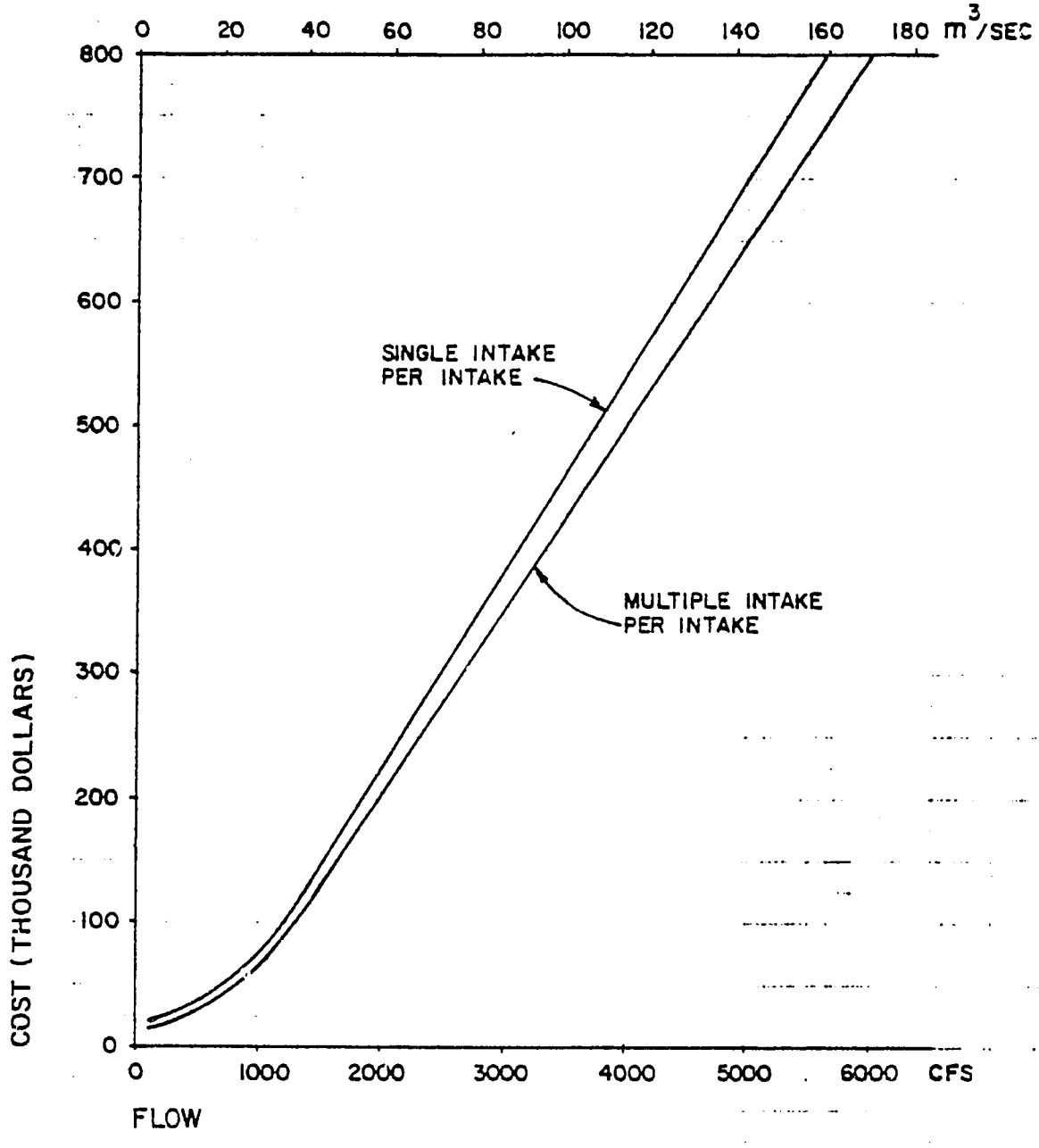


NOTES:

1. Date of costs is April 1979.
2. Total costs obtained by multiplying the cost per foot by the dam crest length.
3. The cost must be multiplied by the valley shape coefficients shown. See also Figure A-2.
4. The cost is based on a unit price of $10 per cubic yard for embankment fill.
5. Costs include 20 percent for excavation, foundation treatment, drainage and other minor items.

source: Electric Power Research Institute (1991)

Appendix A-5. Intake Costs

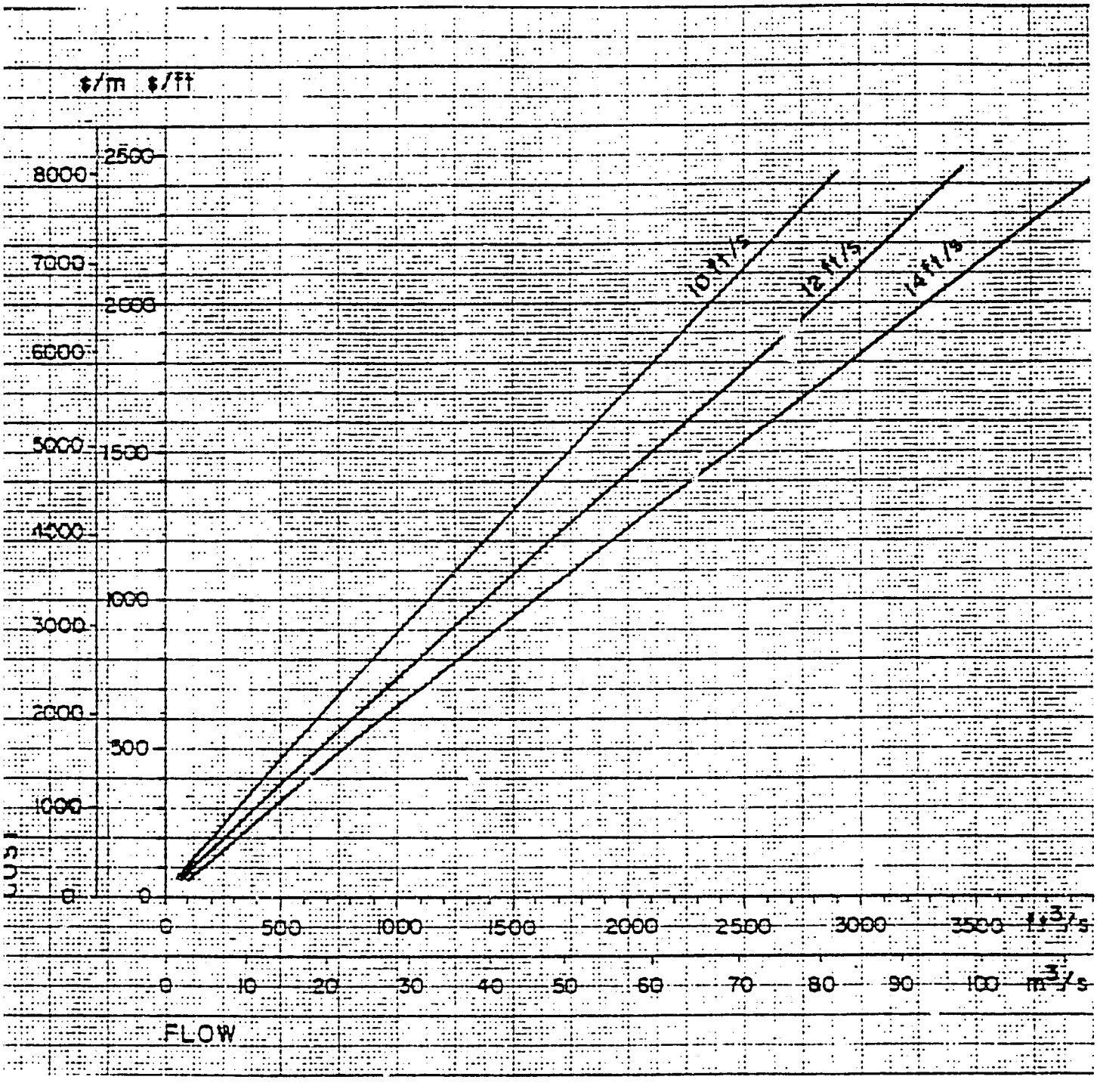


NOTES:

1. Date of costs is April 1979.
2. The estimated cost includes excavation, concrete, reinforcing steel, backfill, trash rack, miscellaneous metal and embedded metal.
3. No cost is included for an intake gate. The gate cost can be obtained from Figure 4-6.

source: Electric Power Research Institute (1981)

Appendix A-6. Steel Penstock Costs for Conventional Low-Head Plants

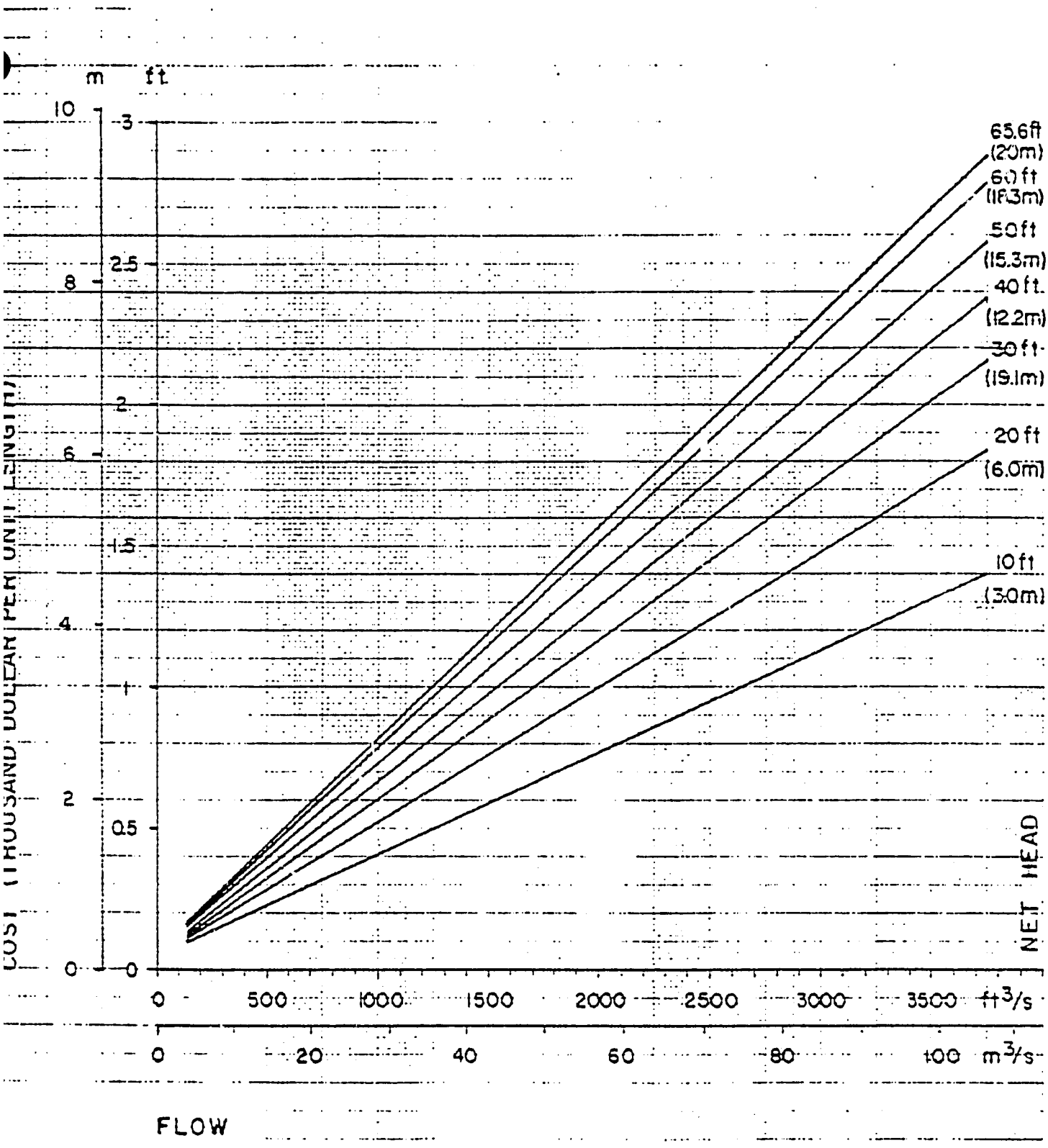


NOTES:

1. Costs based upon minimum handling thickness and a maximum net head of 65.6 ft (20m).
2. If the penstock gradient is greater than 15°, add 1% of total cost for each degree greater than 15°.
3. Costs include a steel penstock, supports, site clearing and excavation.
4. The cost of valves and bifurcations and anchor blocks are not included.
5. Cost base is July 1978.

source: U.S. Department of Interior (1980)

Appendix A-7. Concrete Penstock Costs for Conventional Low-Head Plants

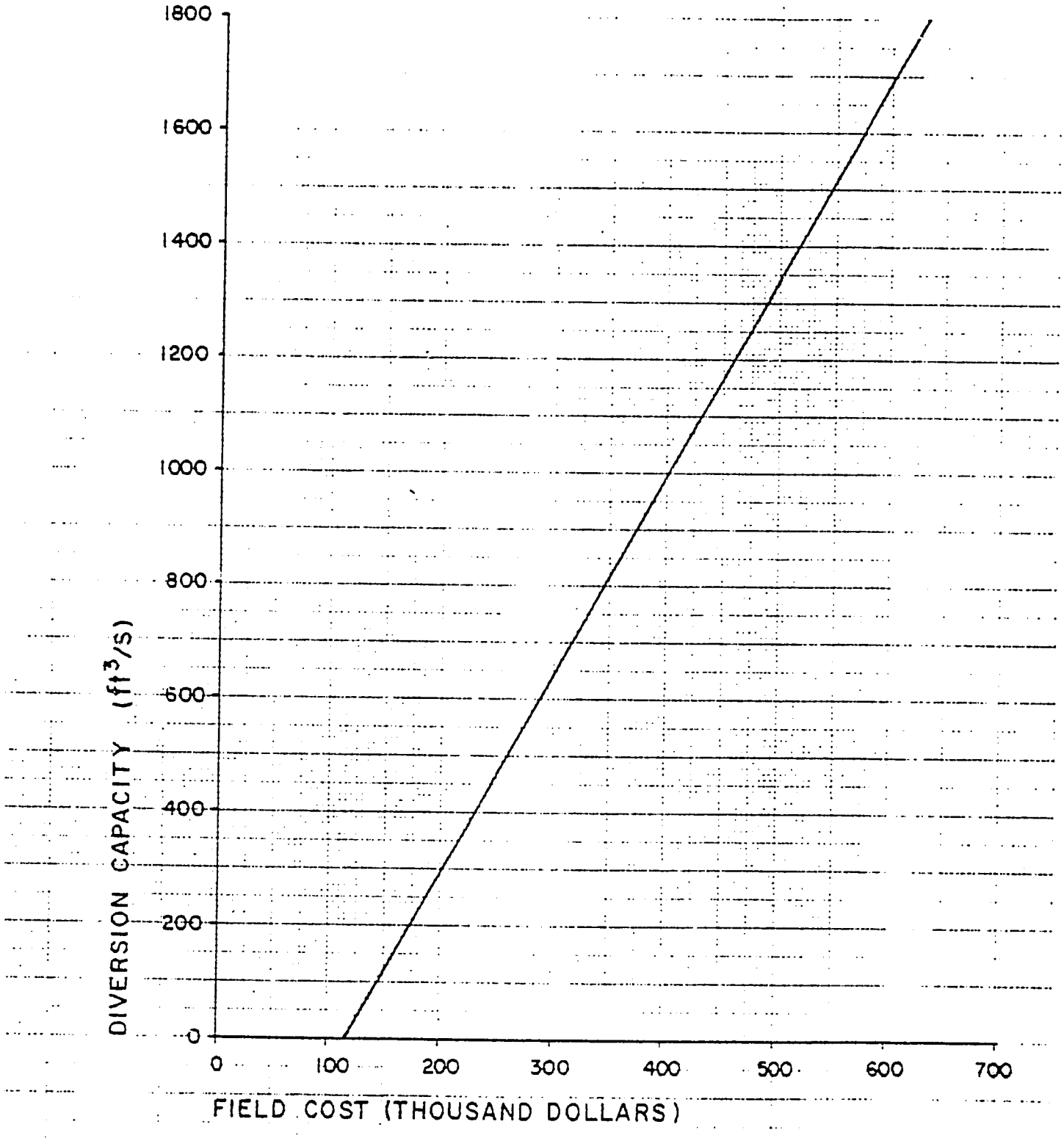


NOTES:

1. The curves give the cost per unit length of a reinforced concrete box section culvert at net heads in the range 10 to 65.6 ft. (3 to 20m).
2. Cost includes concrete, reinforcing steel, excavation 50% rock, 50% common), compacted backfill, foundation preparation, drains and filters.
3. Costs are for a penstock flow velocity of 10 ft/s.
4. Cost base is July 1978.

source: U.S. Department of Interior (1980)

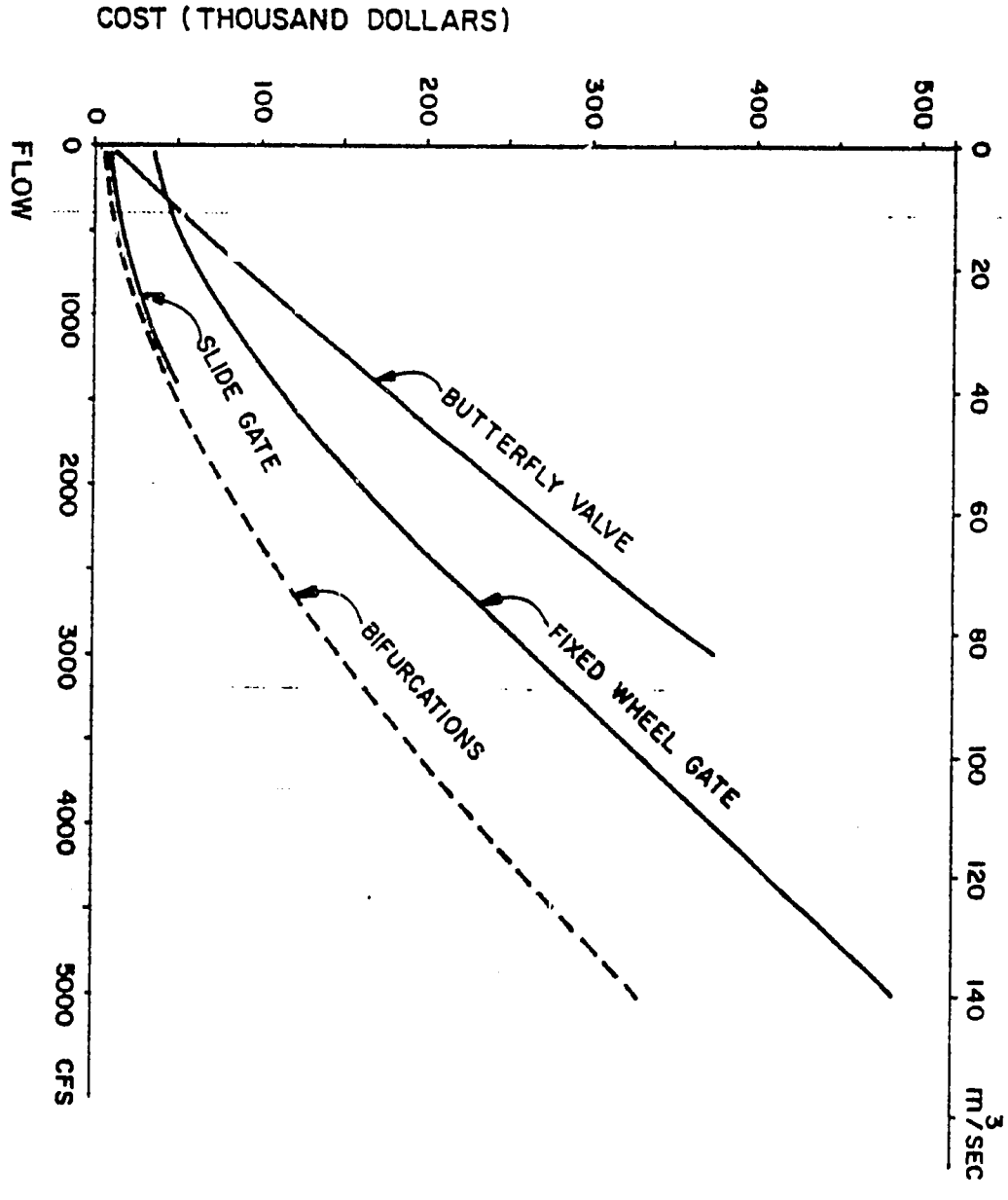
Appendix A-8. Diversion Dam--Field Cost of Canal Headworks, Discharging into Open Canal



NOTE: Cost base is July 1978.

source: Department of Interior (1980)

Appendix A-9. Valve, Bifurcation and Gate Costs

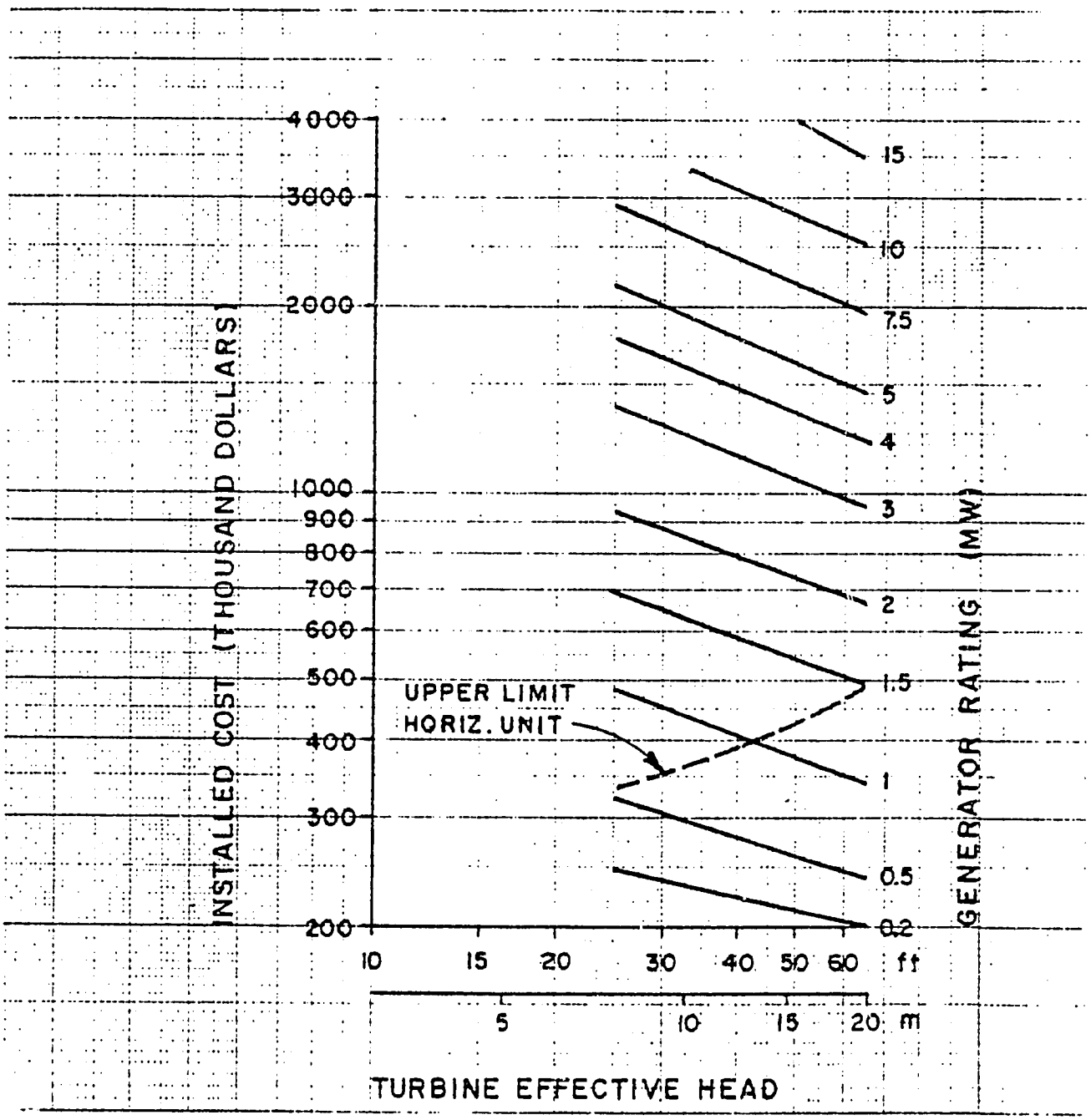


NOTES:

1. Date of costs is April 1979.
2. The estimated cost of the fixed wheel gate includes a hoist, gate frame, guides and installation.
3. The estimated cost of the slide gate includes an operator, gate frame, guides and installation.
4. The estimated cost of the butterfly valve includes a hydraulic operator and installation.
5. The bifurcation cost must be added to the cost of the equivalent length of steel penstock.

source: Electric Power Research Institute (1981)

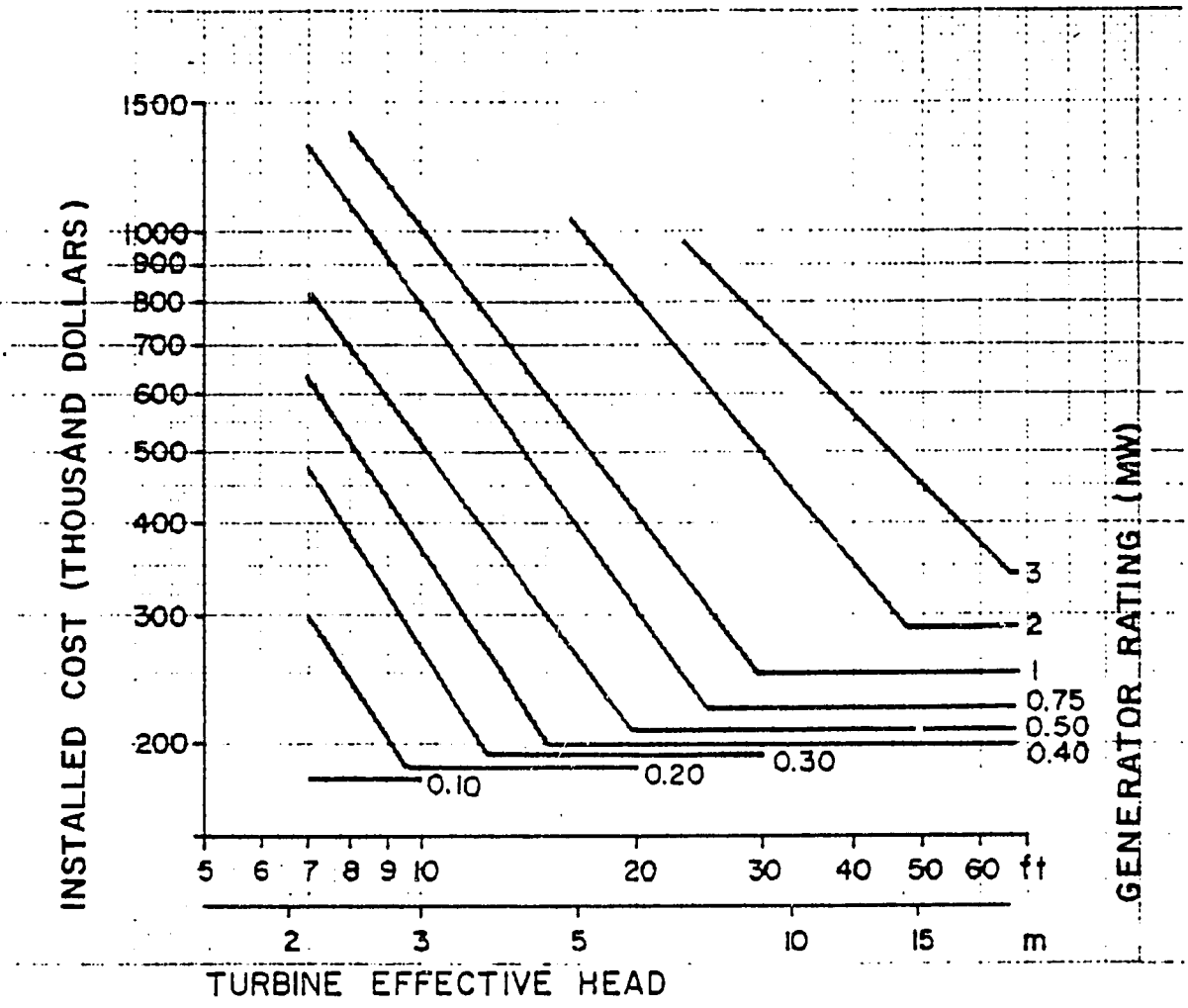
Appendix A-10. Francis Turbine Costs



NOTES:
1. Estimated costs are based upon a typical vertical Francis turbine direct coupled to the generator.
2. Costs include a turbine, synchronous generator, inlet valve, non speed regulating governor and installation.
3. Installation costs are estimated at 15% of the total equipment cost.
4. Add $60,000 for speed regulating governor.
5. For horizontal mounting, deduct 7% of cost.
6. Cost base is July 1978.

source: Department of Interior (1980)

Appendix A-11. Closed Flume Turbine Costs

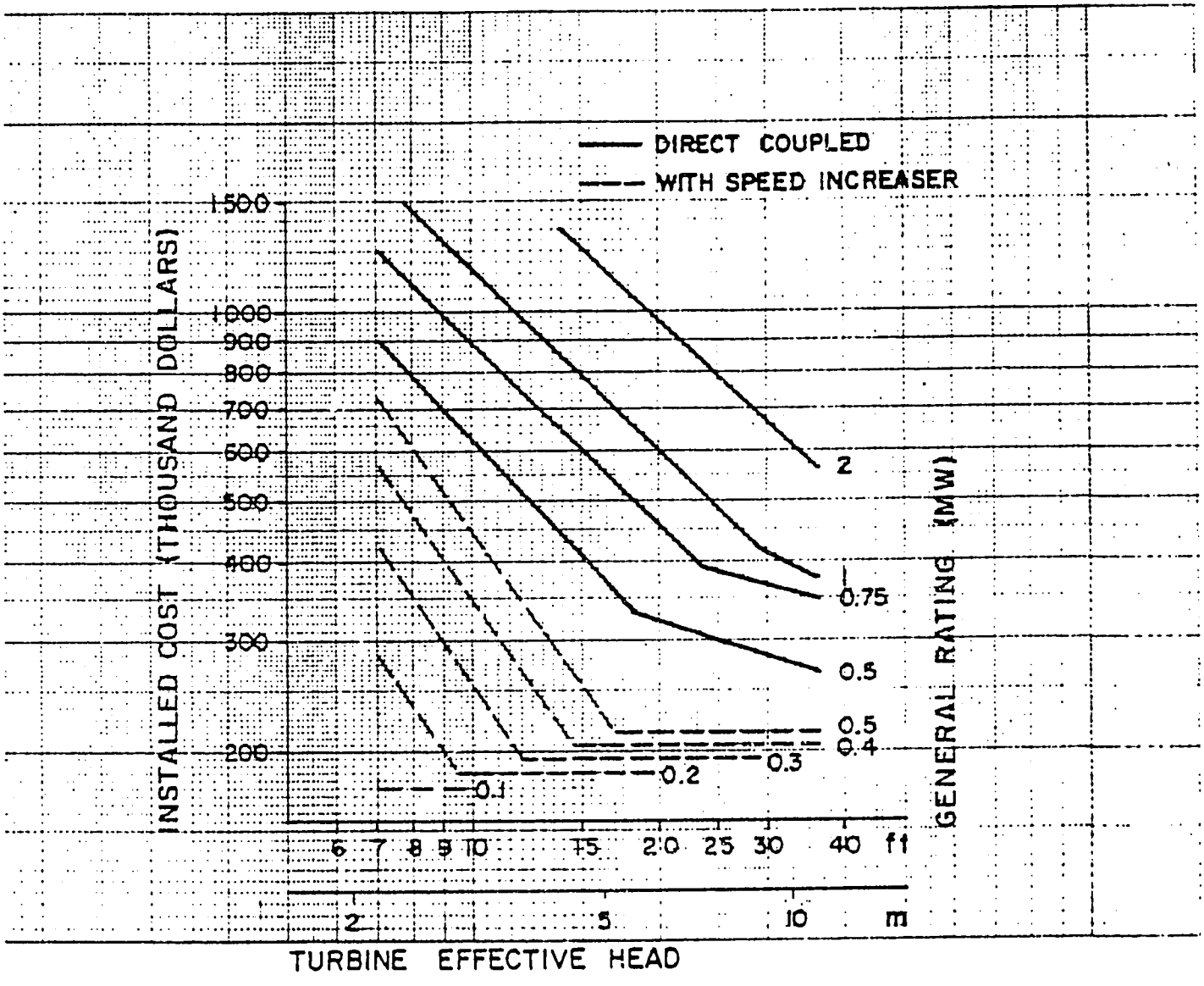


NOTES:

1. The estimated costs are based upon a typical horizontal turbine of either the propeller type coupled to the generator through a speed increaser.
2. Costs include a turbine with fixed blade runner and wicket gates, synchronous generator, speed regulating governor, speed increaser, steel spiral case and installation.
3. Installation costs are estimated at 15% of the total equipment cost or $40,000 minimum.
4. For vertical units, add 7% of cost.
5. Cost base is July 1978.

source: Department of Interior (1980)

Appendix A-12. Open Flume Turbine Costs

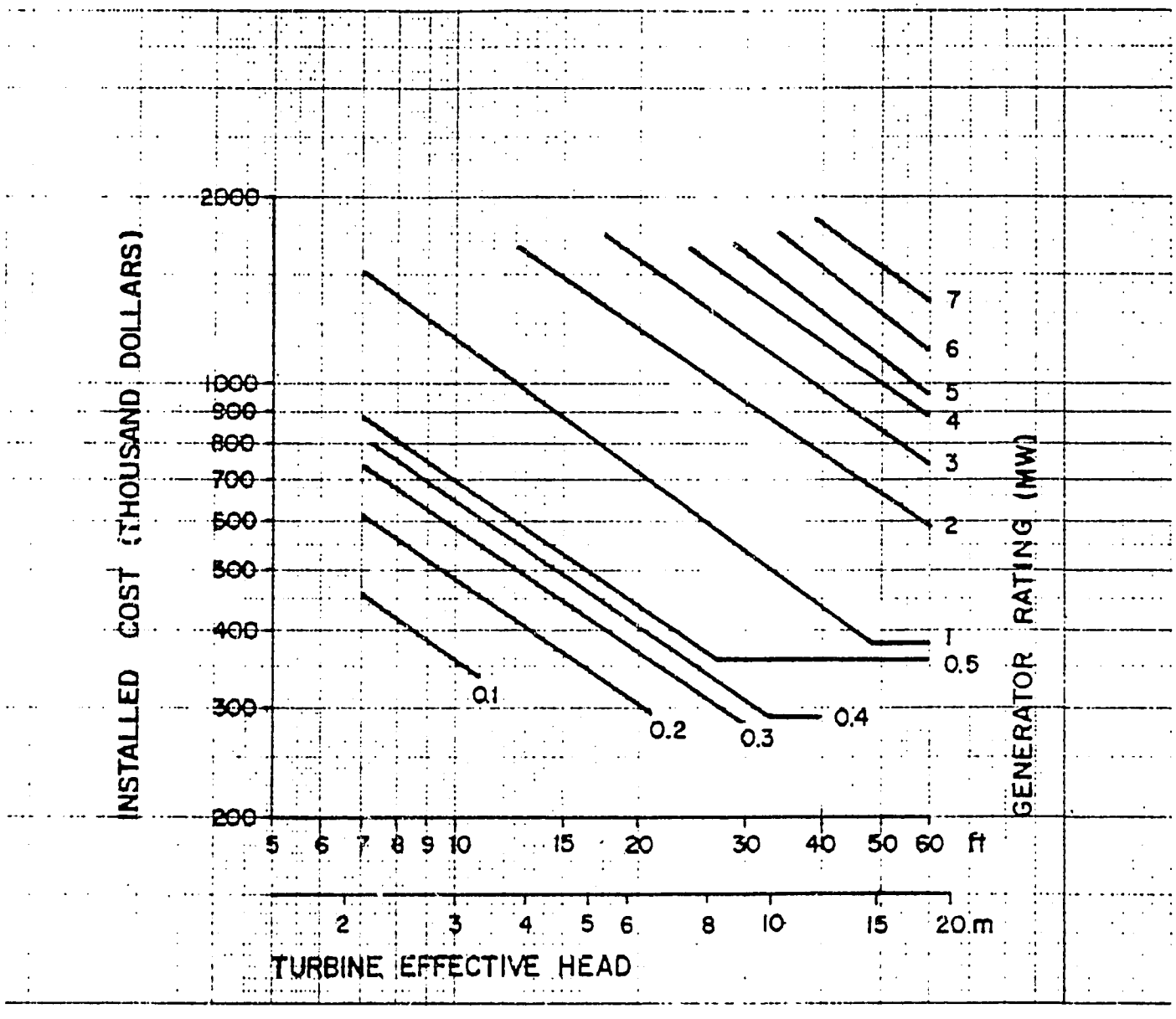


NOTES:

1. The estimated costs are based upon a typical vertical propeller turbine, coupled to the generator through a speed increaser.
2. Costs include a turbine with fixed blade runner and wicket gates, synchronous generator, speed regulating governor, speed increaser and installation.
3. Cost base is July 1978.

source: Department of Interior (1980)

Appendix A-13. Standard Tubular Turbine Costs

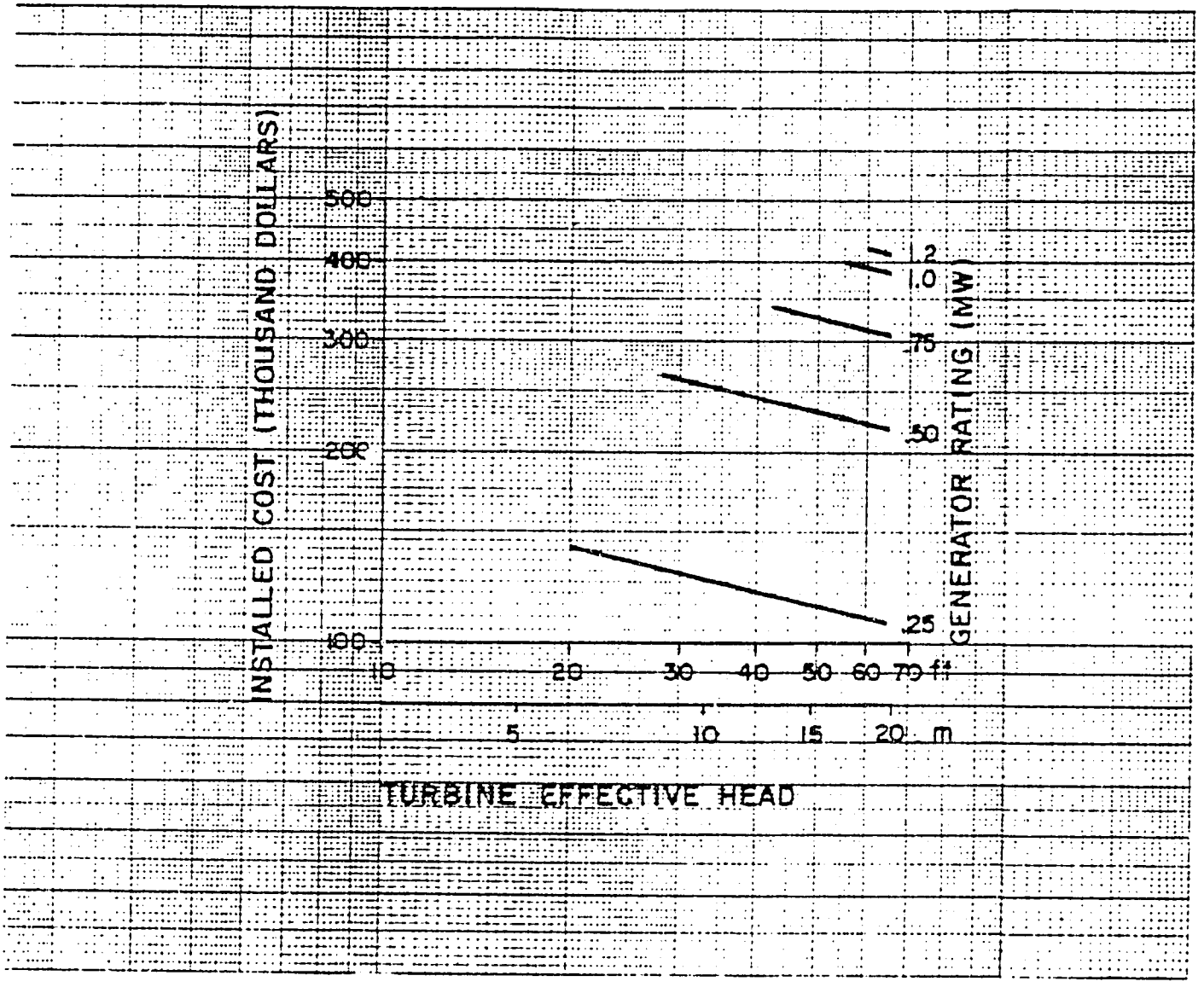


NOTES:

1. The estimated costs are based upon a standardized tubular turbine, coupled to the generator through a speed increaser.
2. Costs include a turbine with adjustable runner blades and fixed guide vanes, inlet butterfly valve, speed increaser, synchronous generator, speed regulating governor and installation.
3. Installation costs are estimated at 15% of the total equipment costs.
4. For fixed blade units, deduct $27,000.
5. Cost base is July 1978.

source: Department of Interior (1980)

Appendix A-14. Crossflow Turbine Costs for Conventional Plants

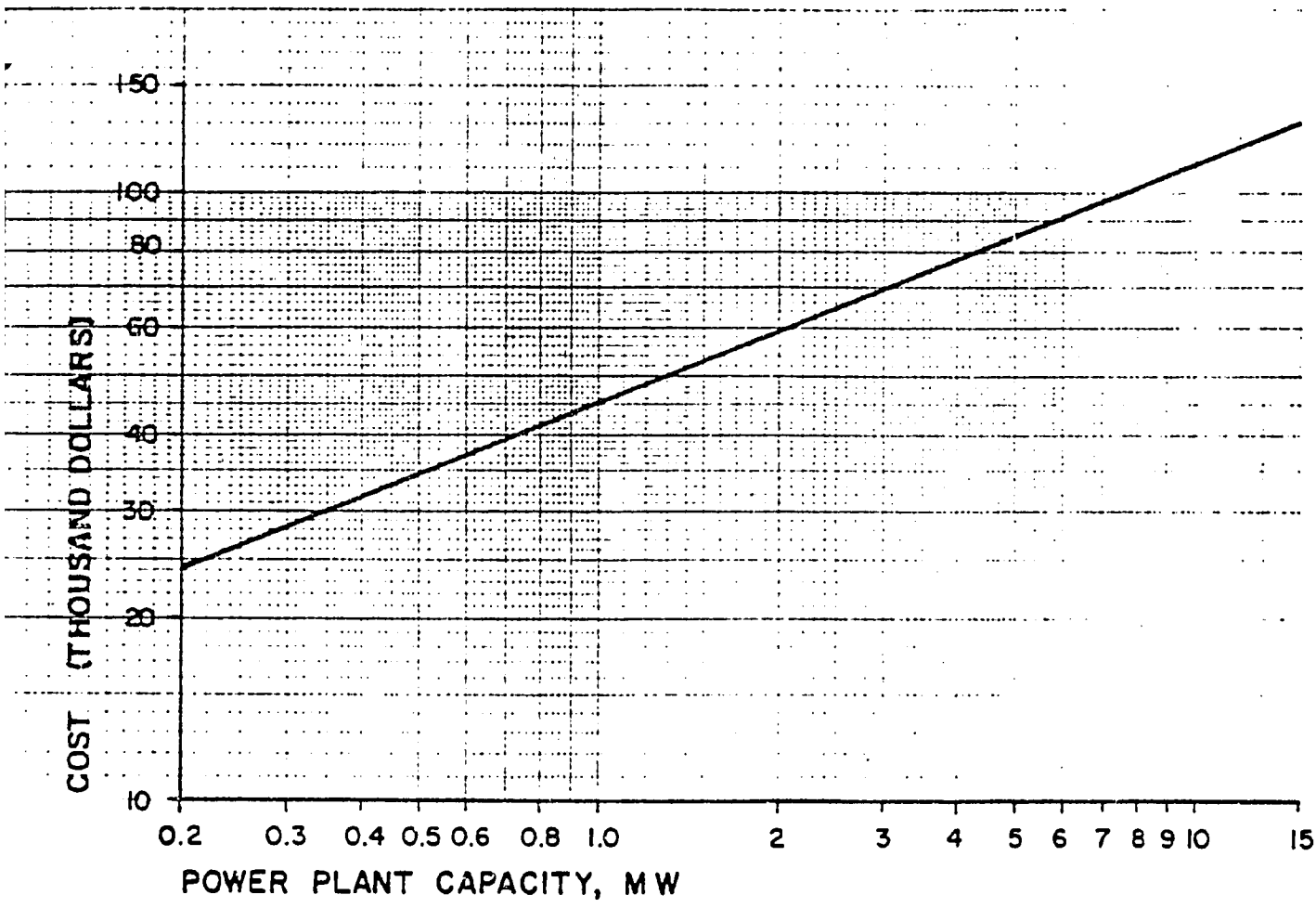


NOTES:

1. The estimated costs are based upon a typical crossflow turbine coupled to the generator through a speed increaser.
2. Costs include a turbine, synchronous generator, speed increaser, inlet valve, non speed regulating governor and installation.
3. For speed regulating governor, add $60,000.
4. Cost base is July 1978.

source: Department of Interior (1980)

Appendix A-15. Miscellaneous Power Plant Equipment Costs



NOTES:

1. The major miscellaneous power plant equipment is listed below:
   a. Ventilation equipment
   b. Fire protection equipment
   c. Communication equipment
   d. Turbine/generator bearing cooling water equipment
2. Communication equipment includes supervisory and radio facilities for unattended remote control of unit; further cost figures should be obtained for very remote locations or integration with complex communication networks.
3. All figures shown include 15 percent for freight and installation.
4. Cost base is July, 1978.

source: Department of Interior (1980)

Appendix A-16. Station Electrical Equipment Costs

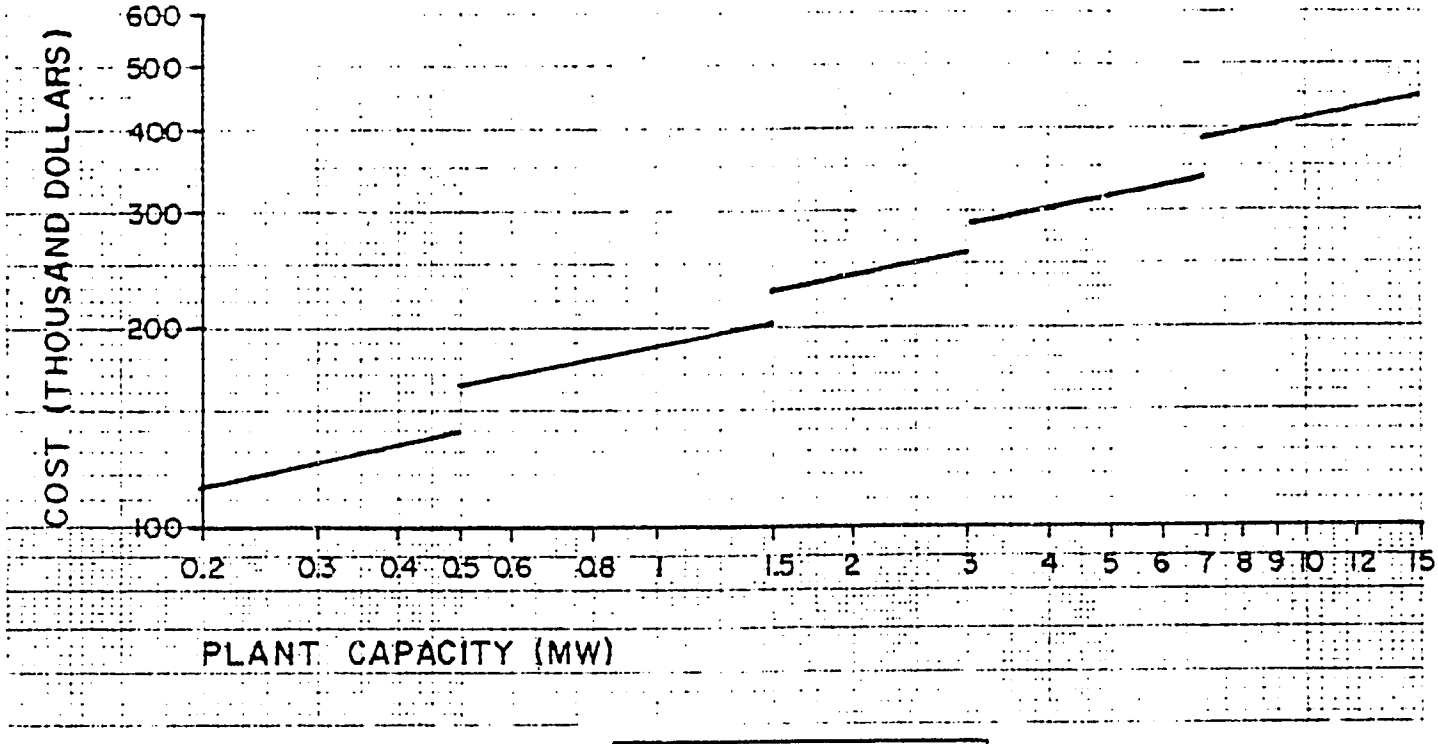


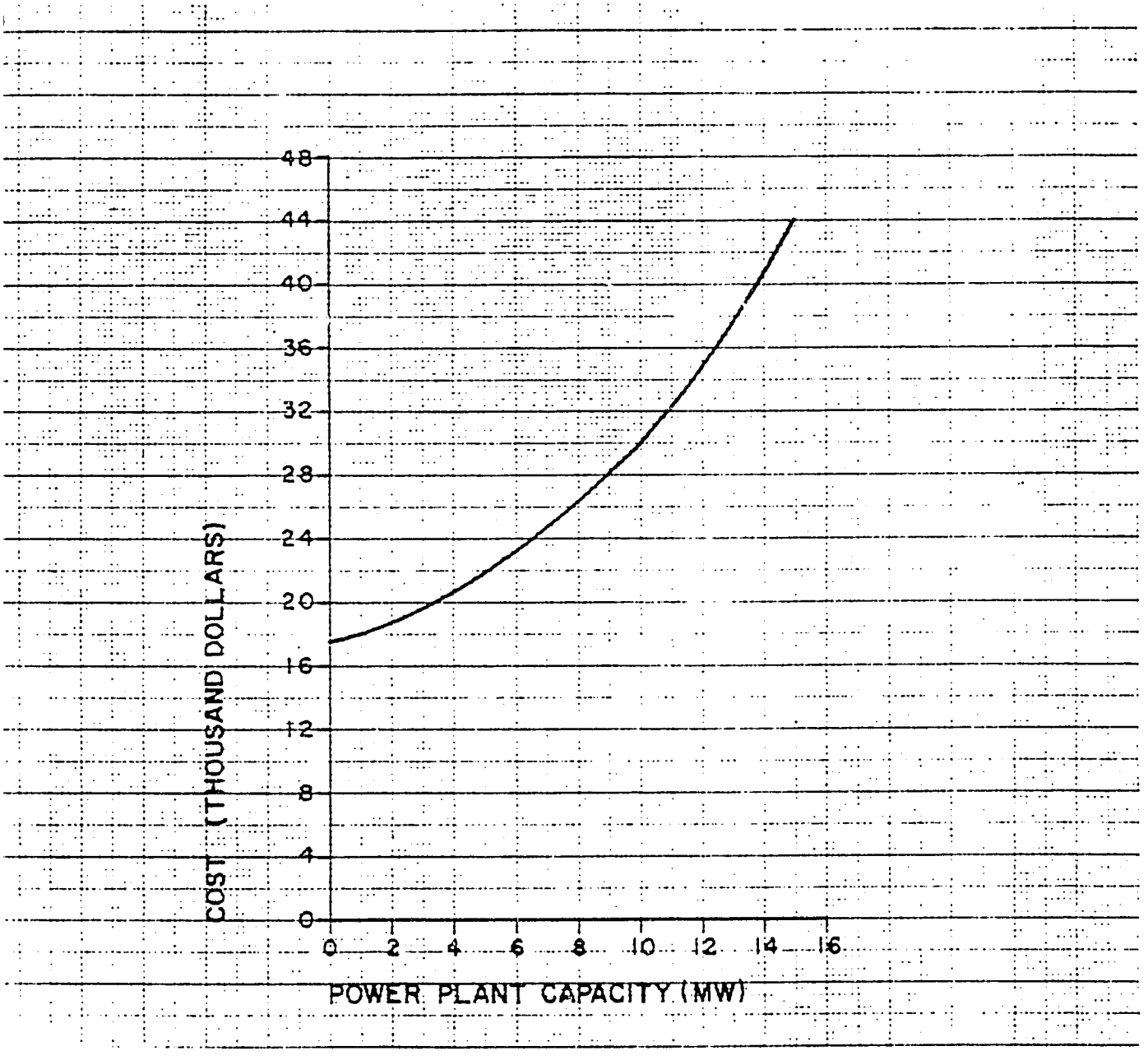
TABLE A	
MW	COST
0.2 - 0.5	25,000
0.5 - 1.5	35,000
1.5 - 3.0	45,000
3.0 - 7.0	60,000
7.0 - 15.0	95,000

NOTES:

1. The equipment and systems for which costs are included are:
   a. D-C switchgear and batteries.
   b. Station service transformer and switchgear.
   c. Main control switchboard.
   d. Wire and cable system.
   e. Conduit system.
   f. Grounding system.
   g. Lighting system.
2. Costs include freight and installation.
3. Costs are shown for a single unit plant.
4. To determine costs for a plant with multiple units:
   a. Determine cost from curve for plant capacity.
   b. Subtract cost from Table A for plant capacity.
   c. Add cost from Table A for unit capacity times number of units.
5. Cost base is July 1978.

source: Department of Interior (1980)

Appendix A-17. Switchyard Civil Costs



NOTE: Cost base is July 1978.

source: Department of Interior (1980)

Appendix C. Cost Summary for Small Hydro Projects in Developing Countries

A. Project Planning and Feasibility Assessment

1. Project Site Selection.
   a. hydrologic investigations.
   b. geologic and topographical investigations.
   c. environmental assessment.
   d. socio-economic and financial studies.
   e. socio-cultural and institutional studies.

2. Project Design.
   a. overall project design.
   b. technical design of power station.

3. Administration and Management.
   a. administration.
   b. management structure.
   c. training.

B. Project Implementation and Construction

1. Direct Costs.
   a. civil works.
   b. turbo-generating equipment.
   c. control equipment.
   d. station electrical equipment.
   e. transmission and distribution.
   f. unskilled labor.
   g. construction management and technical assistance.
   i. transportation of material, equipment and workforce.

2. Other Direct Costs.
   a. access system.
   b. construction equipment and tools.
   c. construction period interest.
   d. land, land and water rights.
   e. contingencies.

3. Indirect Costs.
   a. relocations.
   b. subsidies.
   c. foreign currency
   d. environmental costs.
   e. end-use requirements (forward linkages).
   f. indigenous resource development requirements (backward linkages).

C. Recurring Costs

1. Operation, Maintenance, and Replacement.

2. Financing Charges.

Author's note: A number of these items are relevant only in terms of the economic analysis of a project, and may not appear in the financial analysis; they might even appear as benefits (e.g. subsidies) in terms of the financial analysis. It is also recognized that some of these costs might not be considered as adding to the costs of a project, but would be costs that may be incurred whether the project is undertaken or not (e.g. hydrologic investigations, administrative costs). By the same token, this list may not be fully comprehensive, depending on the circumstances of a given situation. Further, it should be pointed out that some items, such as end-use requirements, may only apply for isolated projects undertaken for a specific purpose.

Appendix B. Characterization Criteria for Matching Renewable Engery Technologies to Village-Level Needs

Criteria	Basic Needs	Renewable Energy Technologies	Unit of Measure
		I. Discrimination Criteria	
Type of output	Form of energy that can satisfy demand	Form of energy produced	Not applicable
Temperature of output	Level of heat to perform required work	Range of temperature of energy system output	°C
Spatial dispersion	The number of locations per village needed for the performance of the basic need task	Capability to distribute the energy output produced by the technology	Number of sites per village required
		II. Site-Specific Temporal & Climatic Criteria	
Seasonality	Time of year when the energy demand occurs	Time of year when the resource produces useful energy output	Growing season, non-growing season, or all year long
Time of day	Time of day when energy is required to perform the basic need task	Time of day when the useful energy is produced	Morning, daytime, night, or 24-hour day
Duration	Duration of time per day required to perform the basic need task	Duration of time the technology provides useful energy during the day	Number of hours per day
Sensitivity to interruption	Length of time the performance of the task can be halted	Variability of output of the energy source	Can be interrupted or cannot be interrupted / Variable or not variable
		III. Site-Specific Social/Cultural/Environmental Criteria	
Usage by type of person	Persons participating in the basic need task affected by changing the energy source	Persons likely to be involved in operating the renewable energy technologies and their various skills	By sex, age, and class
Historical, social, & religious influences	Historical, social, and religious requirements/ customs that affect how basic needs are met	Traditional patterns that could create resistance to the use of the energy technology and energy use	Description of the historical, social, & religious customs that affect basic needs
Traditional energy sources used	Sources of energy used to satisfy village requirements	Traditional use of renewable energy sources Traditional technologies used to protect renewable energy sources	Units consumed per capita or per task (kilograms of firewood, charcoal, dungs, etc.)
Environmental and ecological factors	Climatic and resource conditions that limit local ability to satisfy needs or that alter relative importance of basic human needs	Factors that influence energy system performance, durability, maintenance requirements, etc.; also factors that are affected by the installation of an energy system or the reallocation of resources	Qualitative descriptions
		IV. Cost Considerations	
Cost	The cost limits for new energy technologies (given the monetary, labor, and social costs of traditional and conventional energy used for basic need requirements and the financial resources available to the village)	Costs of the technology's local application	Costs given in dollars (and/or person days) per unit of work or per unit of output; social cost qualitatively described

source: SERI, U.S. Department of Energy (1980)

FINANCING SMALL DECENTRALIZED HYDROPOWER (SDH)

PREPARED BY DOUGLAS GARDNER

UNITED NATIONS CAPITAL DEVELOPMENT FUND

The views in this document are those of the author and should not be attributed to the United Nations, to its affiliated organizations, or to any individual acting in their behalf.

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BIO SKETCH

Douglas Gardner is the Regional Coordinator for Upper Volta, Mali, and Niger for the United Nations Capital Development Fund. Previously, Gardner was a vice president of Chase Manhattan Bank, N.A., responsible for bank lending in Africa. A former Peace Corps volunteer, Gardner received his B.A. in economics in 1974 from Denison University and a M.B.A. in 1976 from the American Graduate School of International Management.

ABSTRACT

Various lending sources are available for small hydro projects. However, the nature of hydro development eliminates or makes more difficult lending by certain types of financial institutions. Proper packaging of the project and the right approach to various lending organizations are emphasized as key to raising funds successfully.

In this paper the key lending criteria and considerations of various financial organizations in the private and public sector including multilateral, bilateral and national sources are discussed. Various forms of financing are presented in terms of their desirability for hydro development.

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INTRODUCTION

Money for financing development projects has traditionally been a scarce resource. The availability of funds for development projects, including small decentralized hydropower, has become even tighter due to the recent world economic downturn. Therefore, the borrowers for projects such as small hydro dams must be aware of any and all available resources, to finance their capital and technical needs.

This paper will provide potential aid recipients with a spectrum of donor sources. It will outline their decision making criteria which are used in selecting various projects. If one knows the criteria used by various aid sources in their choice of projects, one becomes a more efficient borrower by submitting an appropriate plan and by addressing those sources where the probability of obtaining funds is the greatest. A hierarchical ranking of donors by degree of desirability (rates, tenor, etc.) will then be developped.

Finally, the paper will offer suggestions to aid seekers on how to best approach donors. The request and the packaging of the project must be properly formulated since in many cases it is the quality of the presentation, manifesting sound judgement behind the concept, which is the key to success in raising funds.

The need for expertise in the field of financing small hydro dams is particularly acute due to the nature of this kind of project which makes funds difficult to obtain i.e. the high cost per capita, the uncertainty of consumer response in rural areas, etc. The paper will hopefully serve as a working tool in this task of raising funds as well as provide a basis for discussion at the seminar. It is the provision of financial resources that will be a crucial element in the maximal realization of this important source of renewable energy.

AID SOURCES

I. Public Sector

Within the public sector the borrower will find multilateral, bilateral and national sources of funds for financing small hydro dams. Within each of these categories will be found organizations with distinct objectives and lending criteria.

Before looking at these individual organizations, there are certain key criteria which are common to all donors in the public sector. As a borrower or grant recipient, one should be aware of the following considerations which are typical of public sector donors:

- Donors will only finance projects which are considered priority projects in the country. Donors will request clearly defined development plans that indicate that the envisaged project is indeed a priority. In the context of small hydro dams, donors will examine the country's energy plan and water development scheme. If such plans are not fully developed and well thought-out, donors will be hesitant to fund SDH's since such an action could be viewed as patchwork assistance if there is not an overall scheme. Therefore, prior to specific project requests the government of the borrowing entity should formulate an overall, macro development plan.

- With the SDH project viewed in the context of the borrower's development plan and energy scheme, public sector donors will then carefully analyze the socio-economics of the project.

Donors will not view SDH project requests in a vacuum. The economic returns and social benefits of the SDH will be compared to the same returns from using the money in alternative development projects. There is an

opportunity cost of available capital for donors. Even if SDH's were the governments top priority, donors would be hesitant to lend to such projects if they were considered too costly for the desired goals and/or if the donors felt that there were more appropriate uses for the desired funds.

Therefore borrowers should focus a portion of their SDH request on the socio-economics of the project. The macro economics of the project such as the impact on the region's income, employment levels and secondary industry should be stressed. Donors do not consider the provision of electricity alone as development but rather see the productive uses of this energy as true development. The micro economics of the project such as the cost estimates, rates of return, cash flow, energy production, source of equipment, local input, time to completion, etc. are also integral elements in an aid request.

A. Multilateral Sources

Multilateral sources include a wide variety of organizations a few of which include: the spectrum of United Nations agencies and the World Bank; Regional aid organizations such as the European Common Market's Economic Development Fund: Non-Governmental Organizations (NGO's) such as Oxfam and Catholic Relief Services; and regional development banks such as the African Development Bank.

Multilateral sources can be tapped for both technical assistance and capital assistance. Both forms of assistance are key in the realisation of SDH. The technical assistance could include the financing of feasibility studies, training, and technical experts, while capital assistance could finance equipment purchases and construction costs.

Some Multilateral Organizations specialize in funding either technical or capital assistance. Other institutions are capable of financing both types of assistance. A prime example of this technical assistance/capital assistance

division exists within the United Nations system. In a hypothetical SDH project, the United Nations Development Program (UNDP) would finance a feasibility study and if the results were positive, UNDP could finance training programs of the technicians as well as the provision of technical advisors. Complimenting this technical assistance, another U.N. agency, specializing in capital assistance, the Capital Development Fund (CDF) could provide funds for the purchase of necessary equipment and for the construction of the project.

Individuals seeking donor funds should be aware of the fact that the institutions providing money have clearly defined mandates on what kind of assistance can be provided for various projects. Knowing the domains of assistance of the potential donors, the borrower has better direction and greater probability of success in raising funds.

Multilateral sources fund development projects through either grants or long term loans with low interest rates. Such concessionary financing is ideally suited for SDH's which in general have a low rate of return and cash flows which can ill afford to pay back a non-concessionary loan. Only when an SDH has a specific end-user that could rapidly reimburse a non-concessionary loan should other sources be considered. Even in this latter case with a specific end-user to reimburse the borrowings of the project, non-cessionary sources should only be used as a last-resort.

Having stated the nature of the multilateral source financing (i.e. grants/loans, capital assistance/technical assistance) the paper will focus on certain groupings within the multilaterals.

The United Nations and the World Bank have specialized divisions and sources of funds for rural projects such as SDH's. They should be approached in the formulation stages of an SDH. They represent tremendous sources of expertise in the energy/hydroelectric field as well as excellent sources of financing with desirable concessionary terms.

The United Nations has a respresentative office in almost every developing country in the world. The Resident Coordinator in this office should be approached by the appropriate authorities when an SDH is being considered. The Resident Coordinator can direct the inquiry to one or several agencies within the United Nations Organization who would be concerned with this type of project. Since SDH's can have a multitude of end uses, this type of project would fall into the domain of several U.N. agencies who could provide the capital and/or technical assistance that would be required.

The World Bank's Representative located in most developing countries plays a role similar to the U.N.'s Resident Coordinator. This individual can direct appropriate requests and inquiries to the proper experts within his organization. Within the World Bank, the three sources of funds, the IDA, IBRD, and IFC can provide different degrees of concessionary loans.

Regional Aid Organizations such as the Common Market's, Economic Development Fund also possess a wealth of technical expertise and financial resources. Regional aid organizations have humanitarian development objectives and usually provide their concessionary assistance with few strings attached.

Various organizations formed by the oil producing Arab States represent a tremendous source of funds for a country's SDH development. Their participation in projects is generally on a large scale. Therefore they should be approached with an SDH program rather than individual rural SDH projects. The arab world has been particularly cash rich in the past decade due to petrolum receipts.

Within Regional aid organizations should be included Non-Governmental rganizations (NGO's). Such organizations are not affiliated with any government and are usually funded by private, charitable donations. In most cases these organizations are created to embody religious or humanitarian goals. NGO's have a much smaller monetary base than other multilateral or bilateral organizations though they are certainly a viable

source of funds for rural SDH projects. Since their funds are limited, NGO's usually focus on micro projects in a given region rather than on large ambitious macro projects such as the overall energy development of the country. Therefore, NGO's should in general be approached for individual SDH's rather than a comprehensive program of SDH's for the country.

Regional Development Banks also represent possible sources of funds for the financing of SDH programs. Examples of such organizations include the ADB, BOAD and the BDEAC. The long payback terms (10 - 15 yrs) and reasonable interest rates that are usually fixed (under 10%) are attractive for such projects. However since the form of intervention is a loan, the project will have to show sufficient cash flow to reimburse the loan. Such development banks will tend to be more lenient on this latter point of payback than commercial banks.

Since these development banks are regional in nature, they often prefer projects that will benefit several states. This is a factor working against the financing of SDH projects by regional development banks since the electricity output only covers a small area. These banks are still viable sources to be approached.

In summary on multilateral sources, the above mentioned donors can provide attractive concessionary financing as well as technical expertise. Since they are multilateral in nature there are rarely nationalistic or political criteria attached to the financial assistance.

B. Bilateral Sources

Individual governments of countries in the developed world represent excellent sources of funds and expertise in realizing SDH projects. The general criteria that the project must be a governmental priority and socially and economically justified, are also key considerations with bilateral sources. However, due to the nature of bilateral aid, i.e. one state directly assisting another, political and strategic concerns play a role in the donor's assistance.

Bilateral donors have dual objectives in their development assistance. On one hand, the bilateral donor has the humanitarian goal of assisting in the development of a country, though on the other hand. bilateral donors have certain nationalistic goals in their assistance, i.e. they are interested in supporting only certain developing countries with which they have common interests, which have a strategic location, critical natural resources, or good markets for donor goods. Bilateral assistance often requires that the goods used in the SDH project originate in the donor country. Furthermore expatriate technical assistance, if needed in the project, must favor individuals of the donor's nationality. As with the afore-mentioned multilateral agencies, bilateral assistance can be grants or concessionary loans.

The writer does not in any way make a qualitative judgement on the nationalistic elements of bilateral assistance but simply brings these elements to the reader's attention. Again, when the borrower knows the donor's aid criteria, he becomes more adept in raising funds.

Supplier credits from governments whose country manufactures equipment, can sometimes be obtained for SDH's. However these loans have stricter credit standards and more severe terms than concessionary grants or loans. The tenor for supplier credits is generally under 10 years with fixed interest rates varying around 10%. Supplier credits are provided primarily to stimulate the manufacturing country's exports rather than for development objectives.

C. National Sources (Public)

Within the public sector, national sources represent an excellent source of funds to finance local inputs. As a general rule for SDH's, the maximization of local inputs is desirable to assure delivery, facilitate repairs, and avoid the outflow of precious foreign exchange. National sources will also be concerned with the key criteria of the priority of the project and the socio-economic justifications. Political considerations such as the regions being served, politics of these regions etc. also will play a role in the national decision making process.

The government budget is a possible source of funds that can be used to pay for local materials, equipment and labor. However, since governmental revenues often fall short of desired expenditures, this source of funds is very limited in many African states.

National Development Banks are another potential source for financing local needs. These banks know the local conditions very well and will generally follow the governments priorities. Sufficient cash flow will need to be generated from the end-users to reimburse the medium term, fixed rate loans of these banks.

The individual communities using the SDH may not be able to provide cash for the project but they can provide valuable labor, local materials, and transport. In maximizing these inputs, the funds needed from multilateral, bilateral, and other national sources can be minimized. Local community input generally indicates that the local populace fully supports the project.

In conclusion on the public sector, no set formula can be used to determine what source of funds is available or how to obtain these funds. The variables of the politics and economics of the country involved and the economics of each SDH project, make such formulas impossible. However, in being aware of the organizations that are interested in SDH's and their major financing criteria, the borrower improves the chances of successfully raising funds.

The borrower must identify his needs in terms of grant vs loan, technical assistance vs capital assistance, multilateral vs bilateral, and then approach in a prudent, scientific manner the appropriate institutions.

II. Private Sector Funds

The private sector can finance a project in two classical methods: via capital injection as a shareholder or through loans with set payback

periods and interest rates. Unfortunately the high cost, low return, infrastructural nature of SDH's effectively minimizes private sector participation in such projects. However, this sector should not be ignored.

Private shareholders in a project can be either individuals or corporations. Since the return on investment of money placed in an SDH program is marginal at best, the only individuals or corporations that would be conceivably interested in investing would be the end users of the electricity from the SDH unit. For example, the owners of the forest land surrounding the SDH unit may be willing to invest in the SDH which would provide power to their envisaged saw mill. Thus, private investment in SDH would only be seen when the investor has an interest in the end use of the generated electricity.

The key criterion of private lenders to a project, be they national or international banks, is the ability of the project to generate sufficient cash to service their debt. Included in the payments to the lenders is a profit margin that induces the lender to take the risk of lending to the project.

Commercial lenders will in most cases not be interested in SDH's since the cash flows are usually not strong enough to service a medium term loan. Only in the case where a specific end-user is able to assure an adequate cash flow, might commercial lenders be interested in assuming the risk of lending to an SDH. The national banks of the country may be willing to assume this risk since they have an intimate knowledge of the local environment and the creditworthiness of the end-user. International banks, who are usually unfamiliar with the end-users, could conceivably make a loan to an SDH program with specific end-users, but only with a full guarantee of the government.

In any case, the non-concessionary nature of commercial lending (medium term, higher interest rates) makes this source of funds the least desirable of all of those mentioned in this paper.

Several African states are able to borrow under their government's name and in turn downstream these funds to certain projects such as SDH programs. International commercial banks, who would not lend directly to infrastructural projects such as SDH, may be willing to lend to the government of the country who would use the funds for a basket of projects. Such commercial loans have a maximum tenor of ten to twelve years and are on a floating rate basis.

In general, international commercial banks, when lending to governments, have additional financing criteria not previously mentioned. These banks analyze the economic strength of the country and its ability to service debt. There are a multitude of economic measures used in their analysis including the country's G.N.P., existing debt levels, balance of trade, balance of payments, percentage of export receipts needed to service debt, etc. Banks will also consider the policies of the government and its attitude toward foreign debt. The government's historic track record in servicing other debt will be closely scrutinized. Since these banks are not as interested in the details of the SDH project in that their borrower is the government, their lending decisions are based on more macro-considerations.

The fundamental goal of such an alytical exercise is to determine if the conditions in the country will permit the government to make final payments over the life of the loan. This is a difficult analysis since, as previously mentioned, the life of the loan can extend for 10 to 12 years.

Borrowers should approach international commercial banks only as a last resort since the base rate of interest for these floating rate loans (LIBOR) has surpassed 20% in recent years! A profit margin of from ½% to 2½% is added to this base rate. Finally, borrowers should be aware that international commercial lenders are relatively inflexible on rescheduling loans if conditions arise that temporarily impede repayments.

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In conclusion on Private Sector Funds for the financing of SDH projects, the end-user of the electricity is the key in attracting private capital or local commercial loans. The low return of SDH systems minimizes the interest of most investors and commercial lenders (unless the end-user changes this perspective). If no concessionary sources can be found to finance an SDH project, a worthy government can borrow on the international commercial market and downstream these funds to SDH programs.

Resume of Public and Private Sources

Donor organization funds can be ranked by the desirability of the financial conditions (repayment term and interest rates). This ranking of desirability (from the recipients point of view) will be the same regardless of the end-user. If the end use of the SDH is destined for simple public utility functions, the sources of funds will be limited to public sector grants and long term loans. However, if the end-user can assure a strong cash flow to the SDH unit, additional sources from the private sector may become available. This however does not change the order of desirability of funds.

The following ranking assumes equal dollar sums will be received from each source:

1) Grants and/or capital investments (no required reimbursement)

2) Multilateral and/or bilateral concessionary loans (long term, low interest)

3) Development bank loans (medium to long term, moderate interest)

4) Supplier credits (medium term, moderate interest)

5) Commercial credits (short-medium term, high interest)

N.B. (Short term 0-2 years; medium term 2-10 years, long term beyond 10 years).

This ranking views only the financial terms of the grant or loan. Other variables such as the amount of the assistance, availability of funds, and the possible conditions that may be attached have to be weighed on a case by case basis by the borrower. In general, this ranking suggests that SDH projects require the longest term and lowest rate possible.

Packaging the request

The decision-making process of donors on projects is naturally effected by their experience on previous projects. General problems that have arisen on earlier projects will be viewed as potential roadblocks in the long term realization of a successful SDH program. It the borrower can mitigate these concerns of the donor, the probability of obtaining funds will be improved.

Three common nemeses which have often plagued development projects include problems with maintenance, management, and cost overruns. In the planning of an SDH project and in the request for funds, the borrower should clarify how these issues will be dealt with during the life of the project.

The maintenance issue concerns the proper handling of the equipment and the ability to cover recurring costs. The SDH plan should include the use of local technology and material whenever possible to facilitate repairs and provision of spare parts. Financing sources also prefer to see a large degree of standardization in the equipment. The availability of proper technicians and the training of mechanics to maintain the equipment will also be considered by donors.

The planners of the project should analyze the performance of proposed equipment in the desired terrain and climatic conditions. Experiences of surrounding regions and neighboring countries with SDH equipment should be reviewed. Donors want to see that the equipment which they are financing is appropriate for the environment.

Finally, the importance of a sound cash flow is highlighted on the subject of maintenance since the project must be able to generate sufficient revenues to purchase spare parts and pay techniciens. Donors are extremely apprehensive about seeing well intentioned projects fall into disrepair as a result of a lack of operating funds.

The proposed management of the project will be carefully analysed by the donors since this factor plays such a key role in the success of SDH programs. In particular, donors will focus on the supervision of construction, the administration of finances, the training of local technicians, etc. The success of a water authority's management on earlier energy projects will be closely scrutinized. Therefore, when formulating any SDH programs or aid requests, heavy emphasis should be placed on the capabilities of the project's management. If managerial capabilities are weak, the borrower should not hesitate in seeking training and/or experts in the aid request.

Donors frequently receive requests for additional funds when the initial assistance proves to be insufficient. These cost overruns occur frequently as a result of improper estimates, poor planning, weak management or delays in completion which boost the overall price tag. Cost overruns can be avoided by proper pricing of envisaged needs and building in adequate margins for unforeseen contingencies and inflation. Following the initial grant or loan from an aid source, the same organization should not be counted upon to provide additional funds to cover cost overruns.

SDH projects can avoid these three problems of maintenance, management, and cost overruns through prudent planning and research at the start of the project. These issues are raised so that individuals, electical cooperatives, water authorities and/or governments who are seeking funds will understand the concerns of potential donors.

The final presentation to the proper donor should manifest the detailed research and planning that has brough an SDH program to the formal request stage. The presentation should ideally include a clear statement on the short and long terms objectives of the project. The major

technical and financial specifications should be provided to the donor in the request. By also including a well planned implementation/execution scheme, the SDH request conceptually moves from the domain of the theoretical to that of a fully realizable project. Such an implementation/execution scheme should include precise timetables with clear delineations of the responsibilities of all parties involved in the construction and ongoing management of the project.

The financial and technical justifications of the presentation to the donor must show that hydro-power is the most appropriate energy sources. The traditional alternative to hydro-power has been oil-based thermo power. Thus, a comparison of hydro-power to this more traditional source is recommended. Such a comparison should focus on the technical viability of the two sources plus detailed financial comparisons on the cost of investment, the cost of production, and the cost to the consumer.

The final elements of the presentation which could be annexed and which are so indispensible in making a prudent investment decision are the market studies, hydrology studies, cost/benefit analyses, etc. Concepts from such studies will certainly be included in the presentation, but the full documents should also be available to the donor. As a rule of thumb on this subject, one can never provide too much project information the proper donor.

CONCLUSIONS

The financing of small decentralized hydropower projects, be they individual dams or a regional program of hydropower units, is a complex task. A tremendous amount of work and creativity is required to raise funds necessary to realize this renewable source of energy.

Prior to the formulation of such projects the government of the country will have to prepare comprehensive development plans with ancilliary energy/hydro schemes. When the government has delineated its energy priorities in such plans, specific programs such as SDH can be presented.

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Donors are particularly sympathetic to the need of African countries, who are dependent on expensive oil imports, to develop sources of locally generated energy. Therefore, the concept of SDH programmes to meet the energy needs of rural populations falls nicely within the movement of aid organisation to finance the development of alternative energy sources.

The multitude of public and private sector sources of funds which this paper has highlighted should be reviewed for their appropriateness relative to the borrower's needs. In addition to providing funds, many donors can provide invaluable expertise resulting from their past experience on SDH programmes.

Donors should be viewed as active partners in the realization of such programs. Public sector donors share the same objective of providing electricity for viable development purposes. Donors do not apply certain restrictions on their funds for the sake of being stern lenders. Instead, they do this to maximize the utility of their scarce resources. Again, when a donor finances a project, it becomes a partner with the originators with an equal interest in seeing its successful implementation.

A sketch of the lending criterion of various aid organizations has been presented by the writer of this paper. Through the knowledge of what donors require, potential aid recipients can tailor their planning and requests for funds according to certain guidelines. The ideas put forth on the various aid sources and their primary concerns will hopefully start the seminar's discussion and in the long term serve as a working tool in successfully raising funds so that this renewable source of energy can reach its full potential.

BRIEF COMMENTS ON THE COST ASPECTS OF MINI-HYDROPOWER SYSTEMS

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Introduction

The two principal impediments hindering the rapid development of mini-hydropower projects are initial high capital cost (two to threefold compared to thermal plants) and a lack of financial resources earmarked for small dispersed energy sources. These combine to keep mini-hydropower programs at the discussion and project documentation stage. Ways of reducing costs must be sought. Possibilities under consideration include streamlining the project development cycle, using labor intensive construction techniques, locally manufactured equipment and improving the system's load factor. This brief paper will examine these cost issues and present a methodological approach to the economic analysis of a micro-hydro project.

Cost of the Technology

Small water wheels and turbines have a long history in providing both mechanical and electrical power. Traditionally mini-hydro units were more expensive than diesel-powered generators, although this situation is changing due to technical breakthroughs such as electronic load controllers. Estimates of total installed costs (1978) for micro/mini-hydro units in Asia range from $400/kW to approximately $2000/kW, depending on size, origin of equipment, complexity of civil works, and cost of labor. In Papua New Guinea, calculations show the installed capital costs of 5 kW micro-hydro unit to be $438/kW compared to $580/kW for a diesel generator of the same size.[1] The economics of mini-hydro systems can be enhanced if the system can be coupled with irrigation, fish-breeding or flood control projects. For example, an Indian survey estimates that around 10,000 MW of mini-hydro capacity could be installed on their irrigation canal systems.[2]

Operating costs, of course, depend heavily on the load factor. The low demand for electricity in most remote rural villages, e.g., in Nepal, is an obstacle to the cost-effective use of mini-hydro units. Yet, the operating costs for petroleum-fueled engines, often dependent on shipments of diesel or gasoline fuels by airplane or over difficult terrain or poor roads, are also very high. To the extent that mini-hydro units can replace the fuels used in diesel generators, kerosene lamps, and other petroleum-consuming devices, they can serve to marginally reduce the foreign exchange costs of imported petroleum. This is especially true for more expensive (than crude oil) middle distillate products which are frequently imported due to the inability of local refineries to meet the heavy demand for these products.

Since the technology is proven and if the economics are increasingly attractive for remote sites off the main grid, it is also true that mini-hydro technology is attractive for social and political reasons. Government leaders in developing countries view with increasing urgency the problem of expanding rural productivity and employment. Political instability is often associated with the failure to bring modernization to rural areas and with the increasing migration of unemployed and underemployed rural people to overcrowded urban centers. Micro/mini-hydro systems offer a way for rural villages to begin electrification with a modest capital outlay, as well as to increase the efficiency of traditional tasks, e.g., grain grinding, and to stimulate the development of new rural industries, e.g., machine shops making agricultural implements. The importance of electricity is summed up by a Chinese expert on mini-hydro, "Without electricity, it is impossible for a county or a people's commune to make any long-term planning and development."[3]

Although politicians in many developing countries, e.g., Bangladesh, have elevated the provision of electricity to rural villages to a national commitment, the costs of constructing and maintaining conventional transmission

and distribution networks are very high, particularly given the characteristically low load factors in rural areas. A Government of India report concludes:

> "The need to draw transmission and distribution lines over long distances from the central electric supply systems makes the cost of supplying electricity to villages very high. This cost is further aggravated because the characteristics of the load in rural areas is such that the losses in transmission and distribution are also high...The present tariff rates involve a very large subsidy to electricity uses in rural areas."[4]

Mini-hydro technology represents a possible approach in some countries to maintaining this political commitment, while at the same time reducing costs and providing service to remote areas at an earlier time than would have been possible through the expansion of the centralized grid. The problem of high transmission losses may exist, however, for mini-hydro-based systems as well. Losses in rural Chinese systems are running as high as 25 percent, a factor encouraging the building of larger stations that are integrated into local or regional networks.

Type and Origin of Equipment

A policy issue that is the subject of intense debate in some countries is whether mini-hydro technology should be imported. The 1979 UNIDO/ESCAP Workshop on Mini-Hydro concluded: "It was agreed that the development of technology in the field of mini-hydro plants should take place within the developing countries themselves."[5] While this is certainly occurring in Thailand, India, Nepal, Papua New Guinea, Indonesia, Columbia, Peru and the Philippines, mini-hydro systems from Norway, Sweden, Japan, Canada, the United Kingdom, Germany, China and the United States are being purchased by developing countries, generally on concessional terms as part of foreign assistance or expert promotion programs. In Asia, China has provided credits to the Philippines for a large number of mini-hydro units.

The issue of imported versus locally-made equipment often revolves around the question of reliability and efficiency. The national utilities prefer

systems that will have minimal problems, especially at sites that are remote from centers of technical expertise. The cost differential is considerable, however, between a locally-made unit and the more efficient imported foreign technology. The Chinese mini-hydro units are among the cheapest foreign units available. Yet at approximately $1000/kW for a 5 kW unit, they are over twice as expensive as the locally-made unit in Papua New Guinea, even before installation. The Chinese have succeeded in standardizing units of various sizes. China had around 90,000 units in operation at the start of 1980, with an average power rating of 70 kW. Generally, it is not cost-effective to use imported equipment in order to gain a few percentage points of efficiency.

Pricing and Credit Policies

While mini-hydro technology may offer a cheaper alternative than diesel in off-grid locations, the issue of pricing of the electricity and its affordability by the local community remains a fundamental issue. The cost of wiring a house may itself be beyond the reach of most families without credit and the expense of electric appliances may prevent the use of the electricity for anything except lighting. Yet, with mini-hydro technology there is a built-in incentive to increase load factors, since there is no fuel cost. Unlike diesel units requiring an additional cost for each kWh supplied, pricing strategies with mini-hydro can be designed to encourage, up to a limit, the consumption of electricity. Higher load factors in turn lower the cost per kWh. In Papua New Guinea, the 6 kW mini-hydro unit near the village of Baindoang supplies a 3.6 kW heater element at a community wash house. This base load approach eliminates the need for an expensive governor. The villagers also pay a fixed charge for the lighting of their houses.

Although most governments have established mechanisms to provide low-interest loans to local communities and cooperatives for energy production

projects, programs to support the increase in the productive uses of electricity have been inadequate. Until recently, rural electrification programs have emphasized lighting of households and have not been closely coordinated with agricultural development projects.

Economic Analysis of a Typical Micro-Hydro Project

Life-cycle costing can be used as a yardstick for comparing the economics of alternative energy systems. The rationale for adopting this approach over traditional methods is due to rising prices of conventional fuels as well as the need to consider the full costs--operating and capital together--over the entire project lifetime.

The life-cycle cost of an energy system can be defined as the present value sum of all expenditures related to capital, operation and maintenance over its useful life. There is nothing particularly new about life-cycle costing--often referred to as discounted cash flow analysis. Life-cycle cost of a system equals capital cost plus operating and maintenance costs over the entire lifetime of the system, minus residual or scrap value at the end of the life-cycle, all terms expressed in dollars of a base year. By reducing all expenditures to a single figure, it is possible to make cost comparisons of alternative energy systems having very different capital and operating cost profiles. There is recent interest in this method partly as a result of:

(i) The need for economic yardsticks for comparing energy systems with very different cost profiles, e.g., comparing systems with relatively high front end capital costs with those characterized by high operating costs;

(ii) The belief that costs of energy systems over a long period (i.e., over the entire life-cycle of a system and possibly even costs to the next generation) should be considered when making economic decisions; and

(iii) The prospect that high initial costs associated with certain energy systems, mini-hydro, for example, may be justifiable in the face of higher operating costs of conventional systems due to real price increases of conventional fuels.

The entire process of life-cycle costing is linked by a common method of treating capital expenditures, unit operating and maintenance costs, residual values, project life, future energy prices and discount rates.

Case Study: Swaziland Mini-Hydro Project[6]

Life-cycle costs for diesel-pump are compared with a mini-hydro electric pump combination. Within the UNEP/UNICEF/WHO Integrated Water Supply and Sanitation Demonstration Project, located in the Shiselweni district of Swaziland, seven diesel pumps are to be installed to supply potable water to approximately 1000 homesteads. Located in the vicinity of one of the boreholes is a small stream, the Matimatima, where a mini-hydro plant could be installed to provide electricity for an electric pump to replace one of the proposed diesels.

Life-cycle cost analysis is used to compare the two alternatives. The basic economic assumptions are given in Table 1. Project life for small diesels is usually 8 to 10 years and for micro-hydro plants 15 to 20 years. For simplicity, a figure of 10 years is used for both. Discount rates of 10, 20 and 30 percent are applied since the higher rates are likely to occur. Of course, for very high discount rates, choosing a long-time horizon may be irrelevant since expenditures after a certain period would be inconsequential. (For example, 90 percent of the total present value of a constant stream of revenues are captured within 13 years at a discount rate of 20 percent.) Residual or scrap value is difficult to determine; however, a 10 percent figure for mechanical equipment is not uncommon. Diesel fuel prices will continue to rise. Swaziland diesel fuel prices were in the neighborhood of $1.50 per gallon during August 1979. Considerable uncertainty exists in future long-term diesel fuel prices. It is convenient to present a wide band of increases and then conduct a full sensitivity analysis. Three reference scenarios are shown in Table 1: high, intermediate and low. Since the intermediate projection is no more likely to occur than the high or low ones,

it is important to use all three projections to determine the sensitivity of the results to different levels of fuel prices.

Table 2 outlines Diesel-Pump capital and O & M costs. Capital costs are $2000 and operation/maintenance costs are $200 exclusive of diesel fuel expenses. Table 3 outlines the Mini-Hydro Electric Pump capital and O & M costs. As expected, capital costs are higher but operating costs will be less due to the absence of fuel. It should be noted that the civil cost at $3000 is approximate since some rather detailed engineering is necessary to make an exact determination.

Results

Computations were carried out to determine the sensitivity of costs to:

(a) Three reference diesel fuel annual real price increases, 5, 10, 20 percent.

(b) Three discount rates, 10, 20, 30 percent.

Figure 1 illustrates the constant chronological dollar cash flows for the two projects. We can note the effect of diesel fuel price increases. On the basis of constant dollar cash flows, the diesel-pump is cheaper for the first five years. However, the high capital cost of the mini-hydro installation is overshadowed after five years by the escalating fuel price increases, despite the application of various discount rates. Since hydropower is so capital intensive, life-cycle costs are particularly sensitive to discount rates.

Figure 2 shows life-cycle costs or present worth of all future expenditures as a function of discount rate. We see the rather interesting result that with "severe" discount rates, the diesel-pump becomes competitive with the hydro. However, it is somewhat doubtful that the dual effect of a real fuel price increase of only five or ten percent will occur simultaneously with discount rates going above 20 percent. It is assumed that the discount rate is informally pegged to energy price increases. A discount rate of 15 percent

and an annual real fuel price increase of 15 percent appear more likely. Under these circumstances the mini-hydro scheme is favorable.

An additional factor not considered is that generally the project life for the micro-hydro exceeds ten years, whereas for the diesel pump, it is often less than ten years. A replacement cost was not considered. If it were, micro-hydro would appear even more attractive.

The Appendix defines the expressions which were used to develop the present worth of all future expenditures for the two schemes. The PW of life-cycle costs of the mini-hydro are limited to current capital cost and O & M costs subject to the discount rates. The PW of the diesel-pump system costs include capital costs, O & M costs subject to the discount rate and fuel costs subject to annual real increases as well as the discount rate.

It would appear from the above analysis that the micro-hydro is cost competitive based on broad assumptions. If we use only constant dollar cash flow, then the micro-hydro is competitive after 5-years' service. If we chose life-cycle costs, then the discount rate should govern our decision. However, since we acknowledge that diesel fuel prices will climb severely and the discount rate is anyone's guess, it certainly appears prudent to spend more of today's dollars to avoid uncertain expenses further along.

Conclusion

From the foregoing discussion and analysis, it is clear that costs must be closely examined in planning a mini-hydro project. In the economic analysis, the choice of assumptions may determine project feasibility. It is therefore important to determine what costs will be by obtaining accurate prices from manufacturers and engineering contractors. Often, these prices will vary widely and additional questions must be posed regarding quality and reliability. Unfortunately, costs are so site specific that only through extensive experience can reasonable estimates be made.

TABLE 1

Life-Cycle Costing Basic Assumptions

Economic:

Project Life	10 Years
Discount Rate	10, 20, 30%
Residual Value	10% of capital cost
Diesel Fuel Price Increase (1) (2) (Base price, $1.50/gallon, 1979)	5, 10, 20%

NOTES:

1. Diesel fuel price for any year can be computed by $P=P_b \ (1 + f)^t$, where P is price year t, P_b is base price, i.e.: $1.50, f is annual increase, i.e.: 10%, and t is years, i.e.: 5.
2. The diesel fuel price increase does not include inflation since a constant-dollar analysis is used.

TABLE 2

Diesel-Pump Costs (Dec. 1979)

Capital Costs:

Listor Diesel, 10 kW (1)	$ 1000
A-C Pump, 500-foot head	600
Frame, Controls, Miscellaneous Equipment	400
	$ 2000

Annual Operation and Maintenance Costs:

Diesel Fuel, 0.50 l/kWh @$1.50/gallon, pumping for 4 hours per day yields $16.48 per day or	$ 2370
Maintenance, 10% of capital cost	200
	$ 2570

NOTES:

1. Total head is 163 m at Matimatima which includes a well 42.6 m deep. No pressure drop is assumed due to friction since pipe size has not been determined and the pump will not be drawing from the bottom of the well, but from the drawdown located above the bottom.

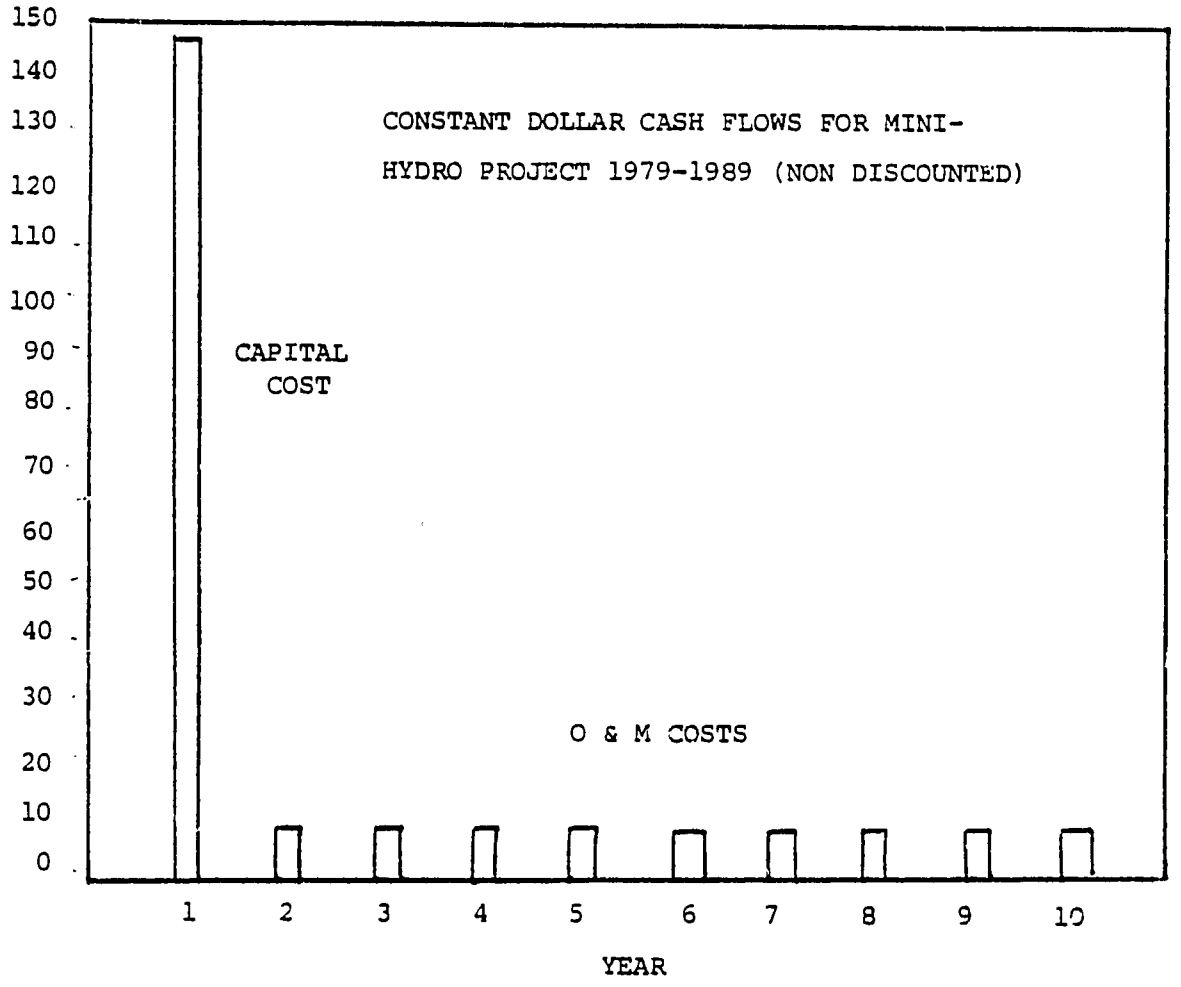
   To pump 3 l/s (approximately 50 gpm) over a 163 m head requires 4.7 kW or with a 50% efficient engine/pump will require a 10 kW machine.

TABLE 3

Hydro-Electric Pump Costs (Dec. 1979)

Capital Costs:	
Electro-Mechanical Equipment	
10 kW turbine-generation set, GSA estimate	$ 6000
Extension line, 900 volts	
1 km	4000
Civil Works impoundment, penstock, power house	3000
A-C Electric Motor Pump	
500 foot head, 50 gpm	1000
	$ 14,000
Annual Operation and Maintenance Costs:	
6% of capital costs	$ 840

FIGURE 1


CONSTANT DOLLAR CASH FLOWS FOR MINI-
HYDRO PROJECT 1979-1989 (NON DISCOUNTED)
CAPITAL
COST
O & M COSTS
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
YEAR

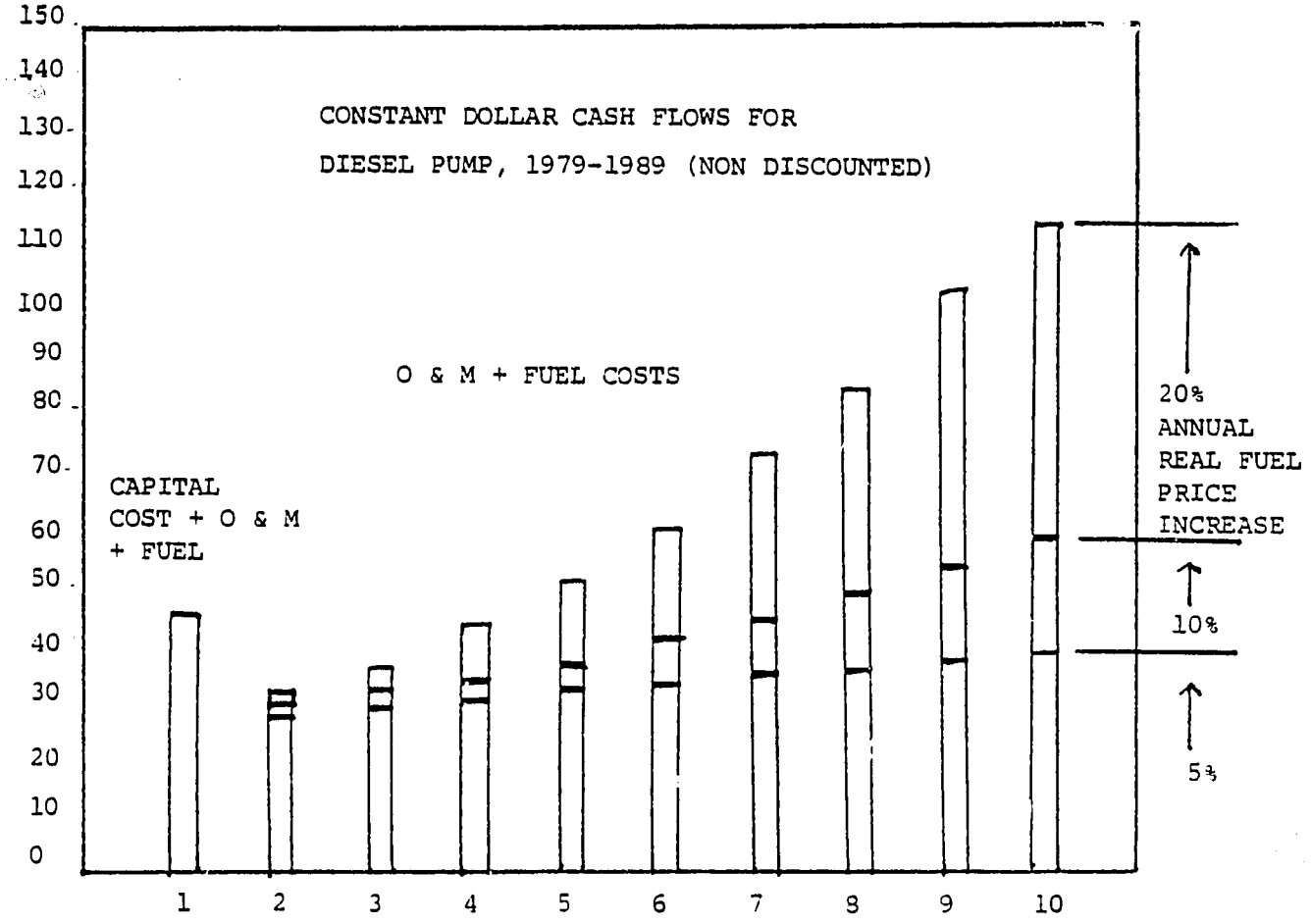
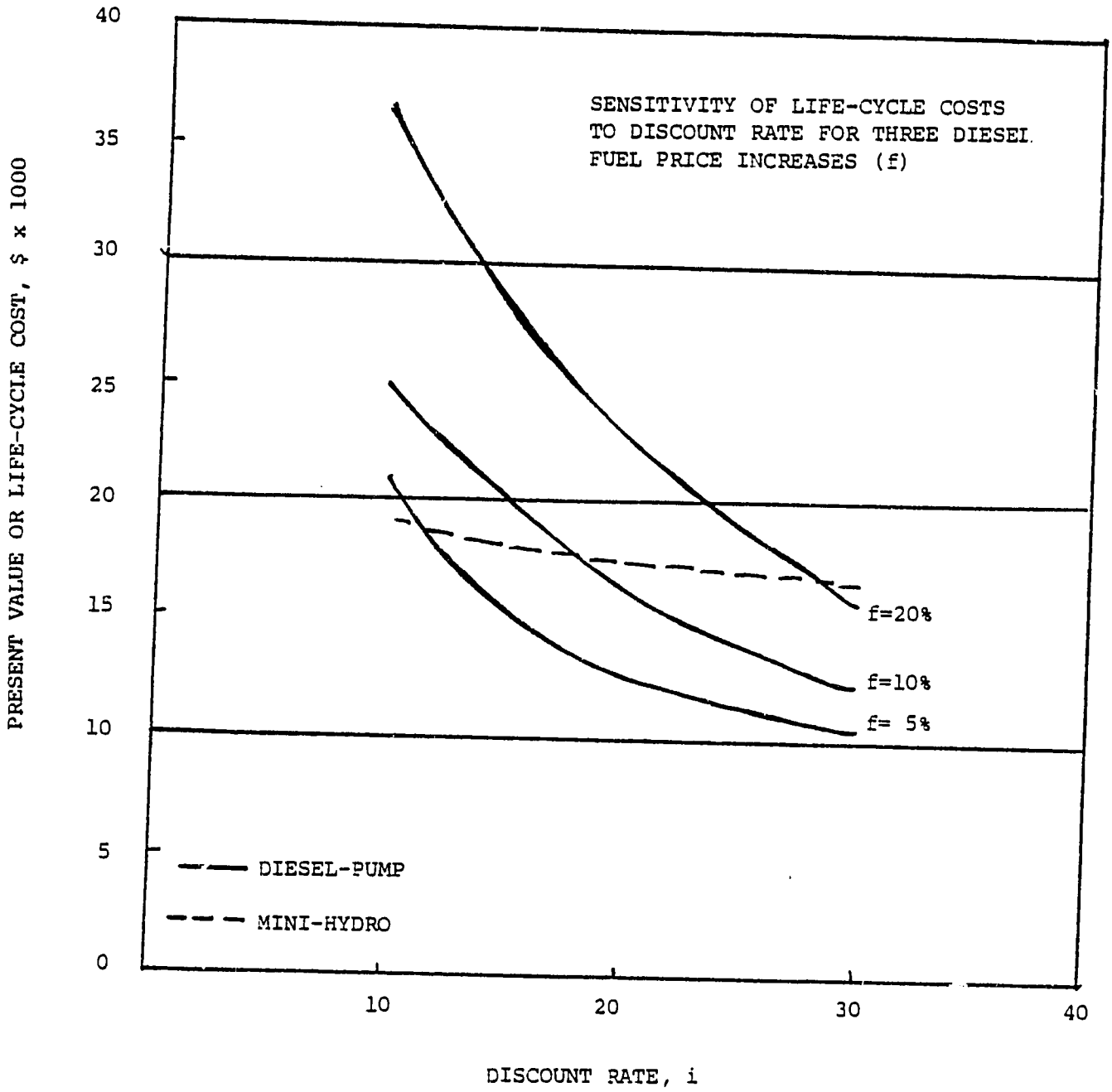

CONSTANT DOLLAR CASH FLOWS FOR
DIESEL PUMP, 1979-1989 (NON DISCOUNTED)
O & M + FUEL COSTS
CAPITAL
COST + O & M
+ FUEL
20%
ANNUAL
REAL FUEL
PRICE
INCREASE
10%
5%
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10

FIGURE 2


SENSITIVITY OF LIFE-CYCLE COSTS
TO DISCOUNT RATE FOR THREE DIESEL
FUEL PRICE INCREASES (f)
PRESENT VALUE OR LIFE-CYCLE COST, $ x 1000
40
35
30
25
20
15
10
5
0
10
20
30
40
DISCOUNT RATE, i
f=20%
f=10%
f= 5%
DIESEL-PUMP
MINI-HYDRO

REFERENCES

[1] Allen Inversin, "A Pelton Micro-Hydro Prototype Design," (Lae, Papua New Guinea: Appropriate Technology Development Unit, 1980).

[2] Government of India, Planning Commission, Report of the Working Group on Energy Policy, New Delhi, 1979.

[3] Mao Wen Vin and Deng Bing Li, "An Introduction to the Development of Small Hydropower Generation in China," paper presented at UNIDO/ESCAP/RCTT Seminar on the Exchange of Experiences and Technology Transfer on Micro-Hydro Electric Generator Units, September 1979.

[4] Government of India, op.cit., p. 91.

[5] UNIDO, op.cit., p. 26.

[6] Fritz and T. Graham, "Swaziland Renewable Energy Project," AID Project Paper, AID, Washington, D. C., 1979.

APPENDIX

PW=present worth

f=annual diesel fuel price increase, exclusion of inflation

i=discount rate

<u>micro-hydro</u>

$$PW = 14{,}000 + 800 \sum_{j=1}^{10} \frac{1}{(1+i)^j}$$

<u>diesel pump</u>

$$PW = 2000 + 200 \sum_{j=1}^{10} \frac{1}{(1+i)^j} + 2370 \left[\frac{1}{1+i} \right]$$

$$+ \ldots\ldots\ldots\ldots\ldots + 2370 \left[1 + f \right]^{10} \left[\frac{1}{(1+i)^{10}} \right]$$

ELECTRICITY TARIFFS FOR RURAL COMMUNITIES

By

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ELECTRICITY TARIFFS FOR RURAL COMMUNITIES

INTRODUCTION

One of the common problems facing electric utilities in the developing countries is the application of an appropriate tariff structure for the rural communities, which are often isolated from the rest of the country. Different countries have adopted different approaches to solve these problems depending on their respective socio-economic and political conditions. This paper suggests one such approach based on marginal cost pricing but modified to suit the electricity sector and the social and economic environment in the rural areas.

EXISTING TARIFF STRUCTURES

During the energy crisis 1973-1974, many developing countries, and in particular those which are not endowed with petroleum reserves, were suddenly faced with price-hikes of 400% in oil price within a short span of less than two years. For the electric utilities, the impact of oil price escalation was more serious as the existing tariffs did not incorporate any fuel price and lengthy procedures were required for tariff adjustment. Moreover the tariffs being based on traditional historical costs were no longer adequate to generate resources to finance new investment to meet the additonal demand of existing or new consumers. To overcome this problem, many electric utilities carried out tariff studies based on marginal cost pricing and started applying them with appropriate modification based on their respective socio-economic conditions.

CONCEPT OF MARGINAL COST PRICING

The concept of marginal cost pricing has been widely discussed during the last decade. In its application to electricity tariffs, incremental costs of generating, transmitting and distributing electricity at different places (or voltages) are obtained from the investment programme prepared to meet the demand according to a load forecast for a period of usually ten years. A tariff is then devised to reflect these costs as well as the operating costs.

One of the objectives of the marginal cost pricing is to achieve efficient allocation of resources by charging the consumers the economic cost of meeting their new or additional demand. In practice, the tariffs derived on this basis are modified to meet other objectives such as social and financial objectives.

After deriving the costs of supply, it is a question of policy whether to charge consumers according to their costs of supply or to allow for cross-subsidy from one group to another in consideration of low- and high-income consumer groups.

As a rule, tariffs on average should give adequate revenues to meet the objective of marginal cost pricing. This departure from the original concept is necessary to achieve social objectives, equity and fairness among consumers as well as to simplify metering.

In particular, special attention is needed to such tariffs before applying them to rural communities because the latter are,

in general, living in areas of poverty and low productivity and may not be in a position to pay for their consumption.

RURAL ELECTRIFICATION

In Africa, many countries are putting increased resources into rural electrification with a view to raising standards of living, to set up industries in order to create regional balance, to prevent rural drift, and to create more jobs in rural areas. Generally, electricity is introduced into rural areas in the following ways:

i) Extension of grid - This is generally done in countries which already have an existing network.

ii) Installing diesel generators - This is a very common case and it was the cheapest way of supplying consumers until the energy crisis.

iii) Micro-hydro power stations - After the oil crisis in 1973-74 many micro-hydro power stations have been set up supplying electricity to rural areas.

iv) New and renewable sources of energy - Many rural localities have been supplied with electricity more or less on an experimental basis by new sources of energy such as biomass, wind, energy, and solar energy.

The costs of supplying electricity by the above ways vary considerably and consequently tariffs based on these costs would differ.

COST ANALYSIS

A short analysis is given below to illustrate the tariff implication of the various systems.

i) Extension of Grid - This is generally the most expensive way of supplying rural consumers but it has several long term benefits such as high reliability, optimum use of available plant capacity and rapid development of the rural areas. The costs of supply could be 4000 to 40000 dollars per km of line, depending on system voltage. In this particular case, it is recommended that tariffs should be based as far as possible on marginal costs of supply for the system as a whole and the same tariffs should be applied irrespective of the location of the consumer. If the rural consumers were to be charged on the basis of the costs of extension of the grid, tariffs would be prohibitive.

ii) Diesel Generators - The present cost of providing electricity supply for medium sized diesel units is about 1000 - 1200 dollars per kW. Allowing for investments in distribution, the cost per kW would be about 1500 - 2000 dollars per kW for a small rural community. The fuel cost would be around 15 cents per kWh assuming the price of fuel to be 2.40 dollars per gallon. The monthly cost per kW would be 25 dollars assuming 14% discount rate.

$$\text{Cost per kWh} = 15 + \frac{2500 \times 100}{24 \times 30}$$ (assuming 30% load factor for domestic consumers)

$$= 15 + 11.6 = 26.6 \text{ cents}$$

If an allowance is made for distribution losses, billing costs and maintance, the cost per kWh would be around 30 cents.

iii) Micro-Hydro Power Stations - The costs of micro-hydro power stations could be broadly classified in three categories and these costs are given below:

Small installation	3 - 15kW	300$ - 500 $/kW
Medium installation	15 - 200kW	500$ - 1000 $/kW
Large installation	200 - 1000kW	1000$ - 5000 $/kW

Taking the highest cost in each category, and assuming 14% discount rate with an average life of 30 years and 30% load factor for the plant, the monthly cost/kW and kWh are:

Small range	6$/kW/month	- 2.6 cents/kWh
Medium range	12$/kW/month	- 5.2 cents/kWh
Large range	60$/kW/month	- 26 cents/kWh

If we allow for maintenance, and billing expenditure, the cost per kWh would be:

Small range	7.6 cents/kWh
Medium range	10.2 cents/kWh
Large range	31 cents/kWh

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iv) New and Renewable Sources of Energy

In recent years, special efforts have been made to re-examine the possibility of using new and renewable sources of energy such as solar, wind, sea, wood, agricultural residues and cow dung for electricity production. However the application of these new sources of energy is still on experimental basis and therefore costs are quite high. The use of solar energy in photo-voltaic cells is likely to be developed on an industrial basis and the costs of photo-voltaic cells would be competitive with other conventional sources of energy in the coming decade. For the time being, their costs are prohibitive for electrifying rural consumers.

TARIFF POLICY

From above analysis, it is clear that with escalating prices of fuel oil, micro-hydro power stations are very economical and competitive in small and medium ranges. For the large range if we compare them with diesel alternative and assume 10% increase in fuel oil price, micro-hydro power stations would still be the least cost solution.

After deciding the costs of supplying a rural community, a common dilemma is to decide the basis of pricing policy which meets the dual

objectives of marginal cost pricing and the "willingness to pay criterion." A compromise can be reached by setting up high tariffs for lighting so that they recover fixed cost as well as running cost. Whereas for other off-peak loads, tariffs could be based on marginal costs of supply. This would be an incentive for increased consumption and thereby it would also improve the load factor.

From experience gained in many countries it has been found that in rural areas, electricity is generally used for lighting, radio, pumping and to a limited extent for small industries. As regards to lighting, it has been found that consumers generally can afford to pay the cost of diesel alternatives as the consumption for lighting is usually small. Whereas pumping is generally done during off-peak hours, a low tariff based on marginal cost pricing could be appropriate and this would help to improve the load factor of the system.

As rural electrification schemes are ultimately to be connected to the national grid, it is necessary that as far as possible electric utilities should adopt the same tariffs for all consumers irrespective of their location provided that national tariffs are based on marginal costs of supply with appropriate modifications to suit local conditions.

Another important aspect of tariff policy is that consumers should not be encouraged to waste electrical energy and should be motivated (usually by tariff policy) to use the energy in a form which is the most economical. For example, in rural communities supplied by diesel

generators, electricity tariffs should be prohibitive so as not to encourage heating or cooking for which gas and wood are generally better alternatives. However, for micro-hydro power stations, this limitation may not apply. This gives micro-hydro schemes an enhanced advantage over the other alternatives.

For extremely poor areas, it is recommended that electricity supply should form part of a broad integrated rural development programme so that with the gradual implementation of the programme, incomes of the rural community would increase to the extent that consumers could be in a position to pay the costs of the infrastructure, in particular electricity.

Institutional Development for Managing Small Decentralized Hydropower Systems

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Abstract

There are two major approaches to hydroelectrification, the centralized program with a national grid and the decentralized program of widely dispersed small hydro units. Each approach represents a specific strategy of economic development and nation building. The centralized grid program is capital intensive, requires sophisticated technology and stresses tight control of hardware. Small decentralized hydropower (SDH) tends to be labor intensive, requires only simple technology and stresses process-oriented, open-ended management. In this paper the distinguishing features of each approach, including technology and management, and the advantages and disadvantages of each are discussed. The appropriateness of each strategy will depend on the demographic and geographic conditions, technological possibilities and the program goals of the nation. However, small decentralized hydropower can play a crucial role in a national electrification plan, and, as an integral part of a broader national development strategy, will strengthen ties between the central government and the rural community.

Biographical Sketch

Richard Harvey Brown was trained in the social sciences at Columbia University and the University of California. He has traveled, engaged in field research, or directed action programs in many parts of the world, including Africa. Dr. Brown was a Director of the Community Development Foundation, an international consulting firm involved in development projects; he did policy studies on intercultural relations at the Hudson Institute; and as Assistant Commissioner to New York City's anti-poverty program, he had extensive experience with social economic development efforts within the United States.

In addition to his work as a manager and a consultant, Richard Brown also is a teacher and a scholar. He is a theorist of note on intercultural and international problems, as well as issues relating to the economic development and

political autonomy of Third World nations. In addition to two scholarly works published by Cambridge University Press, he has just completed a book on Indian civilization. Dr. Brown has published numerous essays on the management of economic and social change, and has written on Japan and China, India, and Latin America, in addition to his studies of African culture and history.

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Institutional Development for Managing Small Decentralized Hydropower Systems

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There are two major approaches to hydroelectrification. The first -- a centralized program with a national grid -- is the best known and the most often used, particularly in West Africa. This approach certainly has proven its effectiveness in many countries and situations. But there is a second approach, as well, one that is much less well known and much less widely used. This is a decentralized approach, using small scale free-standing hydrogeneration units in great numbers throughout the rural areas. In my remarks today I will call these two approaches centralized and decentralized, or grid and SDH. I want to discuss the basic features that distinguish them, and what are the major advantages and limitations of each. And I particularly want to suggest how a decentralized approach might be used to extend and complement a centralized approach with a national grid. Finally, I will conclude with some general comments on SDH as part of a total strategy of national development.

The most embracing distinction between the centralized and decentralized approaches to electrification is that they represent respectively the "trickle down" and the "bubble up" strategies of economic development and nation building. The term trickle-down implies that decisions are made in the upper levels of the national

hierarchy and their results, designed to stimulate the major industries, are expected to eventually reach or trickle down to the common citizen. Advocates of the trickle down strategy of development speak the language of technical economics and capital intensive industrialization. They favor programs that start with relatively few major projects that are sophisticated, large, and costly per unit. By contrast, in the bubble up strategy, the actions are initiated at the local level and their ramifications pass up through the national hierarchy. Advocates of this approach speak the language of national autonomy, resist dependency on foreign capital and technology, and favor numerous widely dispersed projects that are scaled to the capital, technical, and organizational resources of the masses of rural people. Each of these positions constitutes a comprehensive theory and practice of social change.

Several other distinctions between the two strategies should be made also. One distinction has to do with technology as such. Here centralists tend to favor sophisticated, capital intensive hardware, while decentralists favor simple, labor intensive technology. Another distinction refers to the basic focus and style of management in an electrification program. Centralists stress the end product or hardware of the system, whereas decentralists focus more on the human and social processes. Moreover, the centralists usually prefer deterministic planning and tight managerial control, whereas the decentralists incline toward open-ended coordination and an integration of planning and implementation.

The different aspects of the centralized approach have logical compatibilities with each other. This is also true of the decentralized approach. For example, the trickle down theory supports a monetary

industrial strategy for development, thereby leading to highly capitalized, technologically sophisticated projects in a relatively few centers of development. Given such a strategy, it becomes necessary to focus on setting up and running the expensive hardware, since this is seen as the engine of development. Similarly, given such sophisticated technical systems, comprehensive advance planning and tight managerial control become necessary.

By contrast, the bubble up theory argues that economic development is inseparable from political autonomy, in that poverty is seen as a product not of "backwardness" within the poor nation, but of its relations of dependency with wealthier nations. To eliminate this crippling dependency, say decentralists, it is necessary to mobilize the indigenous resources of the country itself -- the simple skills, local materials, and labor of the masses of people who reside mainly in the rural areas. It follows logically, then, that electrification should proceed using simple technology, elementary management systems, low levels of capitalization, and as much labor as possible. And given an approach it further follows that the main focus of management will be on stimulating this broad participation. Emphasis, therefore, will be on generating a mass social process, rather than on constructing massive physical hardware. Finally, since such a process is more of a social movement than a formal organization, the appropriate style of management becomes one of open-ended coordination rather than deterministic planning and control, since such control would either be impossible or would preempt the local initiative upon which the program's success depends.

To summarize, then, there are two major distinctions between centralized grid and decentralized SDH approaches to national electrification programs. These are:

Centralized Grid	Decentralized Grid
1. Capital intensive, sophisticated technology	1. Labor intensive, simple technology
2. Hardware orientation, deterministic control	2. People orientation, open-ended coordination

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I would now like to speak of the distinction between the capital intensive, sophisticated technology typical of centralized grid systems, and the labor intensive, simple technology usual in decentralized SDH programs. I will also point out some of the relative advantages and disadvantages of each. My hope is that this discussion will suggest ways in which an SDH approach may be used to complement a national grid program.

Major factors to be considered in assessing the technology appropriate for an electrification program include the geographic characteristics of the area to be served, the number of consumers that will eventually hook up to the system, and the methods available for generating power. In a nation such as Egypt, for example, whose population is concentrated along a single massive river, larger technical facilities are highly feasible and appropriate. The Aswan High Dam on the Nile, for instance, is a one billion dollar structure with a capacity of 2100 megawatts of electricity. Although start-up costs were very high, the Aswan High Dam represents an economical investment in electrical power given the relevant economic considerations, especially when considering the other social benefits associated with it. By contrast, such sophisticated technologies would not serve people well in a nation such as Nepal, whose far-flung villages are all served by small, steeply dropping mountain streams. In this

case, micro technology is highly feasible and cost effective.

In contrast to the sophisticated technology of the centralized grid programs, a decentralized, SDH approach favors simple, low cost technology. Simple technology, however, is not directly equivalent to small scale either of projects or of kilowatt output. What is critical for the decentralized approach is that the simple technology be geared as closely as possible to the capital, technical, and managerial resources of the owners, builders, and users of the system -- that is, of the ordinary local people themselves. In most Third World countries, the greatest such resource is the unused labor power and simple skills of rural villagers. Thus a technology that stressed relatively large labor investments and was relatively simple to manage would fall into this category, even if it was relatively large in size or kilowatt output.

To illustrate the above, imagine a rural municipality located near a large natural basin, one that could be easily made into a lake by blocking one end with an earthenwork barrage, much in the manner of the Aswan Dam, but on a greatly reduced scale. Given such a large storage capacity, almost all of which could be created through simple construction by local labor, a relatively cheap generator might still provide more than enough power to meet demand. In addition, such a facility also would be well within the technical and managerial capacities of the townspeople themselves.

Simple technology, then, is intended to fit more smoothly in the unsophisticated rural environment of most LDCs where massive labor resources reside but where capital is scarce. The hydro equipment therefore is kept fairly elementary so that it can be built, used, maintained, and repaired on the spot without great

dependence on trained engineers, mechanics, and imported parts. Construction of hydro power sites also is undertaken with materials of far less purity or exact specifications, and the marketing of power, which generally is primarily for the local community itself, is far less vulnerable to fluctuations due to regional blackouts, transmission breakdowns, and other outside factors uncontrollable by users. People are more easily trained, supervision, control and organization are simpler, and the operation in general is calibrated to the capacities of those whom it seeks to make more productive.

In most underdeveloped areas, the gap between the "$1,000,000 technology" of the sophisticated generators and the "$10 technology" of the kerosene lanterns is so gigantic that a quick, massive, and direct transition from one to the other may be impossible. Moreover, even if it were successful, such a shift might kill off the traditional workplaces and displace much of the populace. For a decentralized approach, then, what are needed are simple technologies in the $1,000 to $100,000 range, ones that are immensely more fruitful than indigenous methods of lighting or power, but that also are immensely cheaper than the highly capitalized technology of most modern hydrogeneration. At such a level of capitalization, many SDH sites and, hence, large numbers of workplaces in remote rural communities, could be created.

Simple technology is technology designed to use the scarcest resources the least, and the abundant resources the most. By keeping the requirements for outside capital and technology to a minimum, appropriate technology permits many small sites to be started, each of which is accomplished mainly through local effort and investment.

This allows the ratio of local investment to be high in relation to outside investment, which in turn enables many local projects to be initiated. With such investment ratios, the success of a national decentralized program depends on the initiation of hundreds of local projects at relatively low cost per unit to the national government. It is therefore critical that each project have a "demonstration effect" built into it. The demonstration effect of simple technology is powerful because similar opportunities are perceived as being within reach of the more progressive and enterprising individuals and communities within the rural district.

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Permit me now to turn to a comparison of the managerial approaches that characterize these two basic types of technology that I discussed above. The centralized grid typically is managed with an emphasis on the hardware or physical aspects of the program, using administrative techniques that help central managers control and determine things in advance. By contrast, decentralized SDH programs tend to be oriented more toward the social processes involved in electrification, adopting an administrative approach that favors open-ended coordination and collaboration rather than strict planning and control.

In the design and implementation of a national electrification program, the orientation of management can heavily influence the nature and structure of the overall program. In the centralized approach the focus of management's attention usually is on tight control of the hardware and the products of the program, whereas the

decentralized approach tends to focus on open-ended coordination of the social processes that the program engenders. Neither emphasis entirely excludes the other. Product-oriented managers assume that if the hardware is created, the social-political processes will also be improved in the long run. Conversely, the process-oriented managers feel that, in the long run, if the community development aspects are working well the technology will easily fall into place.

A hardware-oriented, deterministic approach proceeds as if project factors are susceptible to advanced prediction by experts. These experts, in turn, operate under the control of a centralized executive. Most of our familiar physical and social structures result from this deterministic model of design. Such products as industrial plants, large hydroelectric dams, and even systems of administration are usually built according to pre-determined forms and procedures. The assumption is that the desired outcome requires little reconceptualization by the planners, flexibility by the managers, or participation by the users. A deterministic approach to electrification therefore is appropriate where the environment is predictable, where the context is static, where agreement is well-established, or where the central authority controls all the resources needed to accomplish its objectives. Such an environment can readily and efficiently be subject to centralized managerial and technical control.

The product-oriented, deterministic approach, then, is excellent for projects where the hardware aspect is crucial -- that is, for large scale, capital intensive sites that employ sophisticated technology. Certainty concerning hardware, however, may sometimes be achieved at the expense of local initiative, openness to opportunities, and respect for tradition. The development of rural communities --

which is one goal of electrification programs -- may be experienced as frustrating by the managers and brutalizing by the local people if attempted with the same managerial approach that is appropriate to developing highways, bridges, or large scale hydroelectric dams.

In many settings, when difficulties are encountered in the implementation of the project, they are viewed as impediments to creating the final electrification system, rather than as a source of insights about the hypotheses upon which the system itself is based. This is not surprising, in that with the deterministic approach if the basic assumptions are challenged there is little recourse except to start again from scratch. Thus the only solution often appears to be to "overcome" the "problems" -- usually with more expenditures and sometimes by authoritarian methods. Thus implementation of master plans for rural electrification almost invariably overruns the initially projected project costs. Moreover, having strictly separated planning and implementation, the entire process has little flexibility in responding creatively to unforeseen difficulties that inevitably arise.

In most centrally directed electrification projects, a study is prepared to determine the practicality of a particular undertaking. Its outcome is either, "Yes, go ahead," or "No, the project is not feasible." Where a project appears impractical, alternatives usually are recommended. These alternatives are then shown to be feasible in varying degrees. In any case, the essential nature of such studies is to start with a fixed premise and to work out a scheme that somehow shows it will work. This is usually accomplished either by increasing the scope of the project to produce more revenues, or by reducing the project so that it requires less capital. In both

instances, the analysis is based on norms and average profit ratios that are adequate for assessing conventional electrification schemes but may be less reliable in assessing the unique development opportunities available to a decentralized SDH program. In the SDH approach, the initial start-up capital required for a national program is relatively low, because the projects are smaller and much of their cost is borne by local communities. To stimulate such local initiative, however, the program must be prepared to respond rapidly and flexibly to local opportunities and constraints. Such responsiveness is characteristic of an open-ended, collaborative style of management.

One key point in the open-ended, process-oriented approach is that "things", such as hydrogenerators or irrigation canals, help create and express the "meaning" of a given community, region, or nation. If such physical entities are simply transferred without transformation to the project sites, they can become meaningless appendages, anomalous presences that are unresponsive to the needs that are eminent in that particular setting. For example, a hydro facility may be perceived by local people as something alien, "the government's project," rather than as "our project," something that belongs to "us." If it is defined as something alien, the facility will be underused; it may even generate fear and suspicion. Maintenance of feeder canals or power lines, for example, may not be seen as a civic responsibility, and payment of rates may be resented or even avoided entirely.

The stress on process, then, is not soft-headed sentimentalism and it may not even involve a principled commitment to fostering self-government. More usually, it is based on the practical awareness

that it is easier to develop technically sound plans in the capital city than it is to stimulate support for them in the rural villages. In the process orientation, then, management is seen not merely as a technical undertaking; it also is understood to be a process of building a constituency for the program that is to be managed. Hydro development is viewed as one aspect of a larger process of community and national development which, if properly guided, will lead to additional projects and products.

A process- or people-oriented approach also suggests that many projects can be undertaken simultaneously in collaboration with many local communities, including communities that may come into the program at a later date. Projects are started in those communities that have the most enthusiasm and the greatest willingness to contribute to their own development, with only secondary consideration given to where such community projects may fit into an ultimate national grid. A process of self-selection, rather than pre-selection, is thereby built into the program from the beginning. In terms of purely technical considerations, this may not be the most efficient approach. But the method does stimulate participation from groups that otherwise might have been left out entirely. Moreover, by this method passive recipients and potential critics can be transformed into active agents of improvement who appreciate what they themselves have helped to shape.

Such a growth in local capacities for self-improvement is likely to spill into additional areas as well. For example, the entrepreneurial or cooperative energies than have been mobilized might be directed later toward building an irrigation system or a fisheries industry. Also, because local people are the major partners in the

program, there is a real demonstration effect for other rural communities. Costs are kept down even while addressing situations that are defined as important by residents and that therefore can serve as motivators.

In the decentralized approach, then, rural electrification is an orchestration of processes that begins with the arrival of the first survey team and continues beyond the completion of the hardware facilities. Instead of positing an ultimate product and working back from that, the ongoing process of electrification is stressed at all stages of development. The system has to function in a way that is appropriate and adequate for each particular stage and locale. There is thus maintained a perception of continuing progress, and of the availability of opportunity to contribute to that process. This means, in effect, that the SDH system is never done. It is always being improved.

Since every silver lining has its cloud, we should note that the process orientation often can be insensitive to the technical requirements of all but the simplest electrification projects. Once the stakes go up in terms of levels of capitalization, the technical requirements of the project tend to assume an overwhelming urgency, an urgency to which process-oriented managers often find it difficult to respond. There is built into the process orientation, then, a difficulty in moving from the micro to the macro technical levels. Larger scale projects tend to be beyond the capital, managerial and technical resources of local communities that might be involved in a collaborative process. And, given their dependency on outside help for these resources (and the relatively low importance of labor in such projects), the role of local participation is significantly

reduced, rendering the process orientation comparatively less relevant.

Another difficulty with the process-oriented approach is that it requires a flexible and egalitarian style of management. That is, to institute a process of local initiative and self-help, the program officer must avoid encouraging habits of dependency on the outsiders. Yet in the eyes of villagers, the officer himself is the outsider. To engender a decentralized process of SDH development, therefore. it is necessary to create a cadre of field officers possessed of very unusual skills. Such persons must be specially trained in the hardware as well as the people aspects of electrification. Moreover, such field staff would have to be highly mobile in order to offer the services of the program to many communities on a self-selection basis, and in order to service those entrepreneurs and groups that do opt into the program. Such an extensive style of field work might itself engender still other problems for a process-oriented approach. First, the field officers will need transportation. They should have a jeep or, in some areas, access to light airplanes or motor launches. Since field officers of government programs are usually considered close to the bottom of the bureacratic "totem pole", and since such transportation is often considered a privilege and symbol of high status, it may be difficult to provide field officers with the mobility that is necessary for their success.

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In my concluding remarks I will consider SDH programs in the context of the overall development process that includes not only SDH, but also national grid power systems, as well as many activities other than power such as industrial development, creation of employment,

development of political institutions, and so on.

In this larger context, it is important to note that SDH programs provide a technology appropriate to a rurally-oriented, town and village level strategy of national development. First, one central goal of SDH programs is rural development. The sites of SDH projects are in dispersed and often remote towns and villages. Second, the range of SDH technologies, from 1 to 1,000 kilowatts in capacity, is appropriate only to low levels of use, despite whether they are centrally or locally managed.

In addition, the organizational infrastructure provided by a national SDH program can facilitate centralized grid programs in a number of ways. Suppose, for example, it is decided in the capitol to built a large hydroelectric dam so that new industries can be started and new land brought under cultivation. At the same time arrangements are made for all the ancillary activities that will ensure that the greatest benefit is derived from the very high initial investment. Dykes and secondary dams are to be built upstream to prevent siltation and erosion; settlements are to be established in the new farmland and provided with schools, dispensaries, and other services; roads are to be built linking the villages with each other and with the market town; agricultural and veterinary services are to be set up; cooperatives are to be stimulated; and village industries are to be encouraged. In all, funds may be allocated to ten or twelve different Ministries or bureaus.

But a Central Planning Board cannot work out details such as where best to place a school in relation to a branch road or clinic. It can only inform the other Ministries that the building of the dam places upon them obligations to the tune of so many thousands of

dollars and that the money will be made available upon approval of the Ministries' plans. Even so, it is normally quite beyond the scope of such a Board to examine and collate all the schemes submitted to it. At worst, some Ministries may use their allocations for purposes related only in name to the original proposal.

Such fruitless efforts of centralized planning and control can be even more harmful to projects emanating from the bottom upward. For example, a municipality may propose a hydrogeneration scheme for which the Ministry of Public Works may have the major responsibility. If the project is to work, however, it is crucial that the technical and material services of many other Ministries be brought into play. The Ministry of Lands may have to be consulted on public domain and riparian rights; Agriculture will be concerned with extending cultivation; Economic Development might be involved in helping power-related industries.

Both these examples illustrate the need for an intermediate coordinating mechanism in order to integrate governmental services and ensure that they are calibrated to local peoples' needs and capacity to absorb them. A national SDH program can help create such structures, because it is decentralized in the location of its sites, its usual level of technology, its administrative structure, and the locus of its impacts in the rural areas. In the context of total national development, SDH programs can provide a bridge between the immense concentrations of capital and technology used for the national grid, and the small scale, decentralized projects at the local level.

In sum, I have argued that decentralized, small scale hydrogeneration can play a crucial role in national electrification

strategies. If a nation wishes to avoid the extremes of client-type dependence, on the one hand, and economic isolation, on the other, it must specialize in products relevant to the world market, yet on its own terms as much as possible. In order to carry this out, labor intensive but sufficiently specialized appropriate technology and industry is necessary. SDH is a prime example of such a technology, as well as a potential source of energy for many other such industries.

By making use of SDH as part of the broader strategy of national electrification, a country may also help to strengthen ties between its central government and its local communities. Since its focus is local but its scope is nationwide, an SDH program in effect offers a model of "intermediate management" as well. An SDH program, therefore, can have a significant impact upon the struggle of African nations for political autonomy and economic growth.

APPENDIX

It should be obvious, of course, that neither centralized nor decentralized approaches to national electrification programs are correct or superior in and of themselves. Instead, each has its advantages and disadvantages, and each will be more or less appropriate depending on geographic and demographic conditions, technological possibilities, and program goals. Because my remarks have focused on the decentralized approach as a supplement to a national grid, in this appendix are summarized the major advantages and disadvantages of the decentralized approach as part of a national electrification program.

Advantages	Disadvantages
Lower start-up costs due to the use of cheaper equipment.	Does not fully utilize the potential of the site.
More easily installed by using local labor and materials.	Might not provide sufficient amounts of electricity after some period of growth of the local community.
Better prospect for actual implementation and viability since it can be administered locally thus circumventing bureaucratic delays. People are more easily trained and repairs can be made more quickly.	Could be subject to more frequent breakdowns and malfunctions.
Can provide a positive demonstration effect to other local communities.	
Expands commitment and constituency, thereby facilitating implementation, use, operations and maintenance.	Uses endless amounts of time in talking and discussing. Risks involving the "wrong people". (For example, vociferous, low status persons may see the program as their main chance, but in trying to dominate it they actually stigmatize it.)

Develops a system of relationships that may be used for other products. (For example, community or entrepreneurial organizations developed to build a dam that can be used to initiate a fisheries industry or a mosquito eradication program.)	Diffuses effort of SDH team. Requires them to be skilled in community development, which is unusual for persons trained as field technicians or engineers.
Focuses discussion in local communities on positive local choices rather than on polemics or personalities.	Disrupts traditional habits of mind and may raise expectations beyond what can be fulfilled.
Engenders habits of entrepreneurship and local community initiative.	May make local communities more powerful and demanding of government.
Enhances input into process of planning and implementing projects, thereby insuring better fit between technical requirements as seen by experts and community needs as seen by users.	Creates excessively loud voice for incompetent persons. Disrupts hierarchic, authoritarian style of host country managers.
Uses the national SDH Entity as a catalyst stimulator, and transmission belt that links the needs and contributions of local groups with the resources of broader public and private institutions.	Reduces the role and power of the national SDH Entity to that of a consultant and broker without a large capital budget.
Reaches many communities through its extensive outreach activities.	Requires specially trained and dedicated field officers and special transportation.
Allows greater space for feedback from experience gained in the process of planning and implementation itself.	Allows less space for advance planning and therefore invites more unforeseen obstacles and difficulties.
Maintains flexibility in responding to unforeseen contingencies, thus avoiding threats or exploiting opportunities.	May become unrelated to overall national priorities or even its own program priorities through over-response to local initiatives.
Is susceptible to interruption until additional funds become available, rather than being simply terminated if resources run dry.	Lacks sufficient advance planning and study to ensure international lending agencies that their investments will be well spent.

Puts host country agency in greater actual control over workflow by depending less on outside consultants and making them more accountable and pragmatically oriented to the needs of the local situation.	Forces host country into greater dependence on its own scarce resources, thereby making national elites more dependent on their own populations.
Tends to enhance the participation and capacities of individuals and groups who might otherwise be left out of, and therefore hostile to, the development process.	Tends to increase levels of expectation and autonomy of local communities, or at least of local elites, thereby creating centers of power that compete with the national government and national elite.
Able to respond to a wide range of community initiatives with a variety of technical and organizational modes.	May become too diffuse, may even disintegrate, by seeking to be all things to all persons.
Capitalizes on local resources in remote areas at low opportunity cost.	Overlooks opportunities at national and international levels because of "worm's eye," instead of "bird's eye" perspective.

THE PROCESS OF INTRODUCING HYDROPOWER TO RURAL PEOPLE

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THE PROCESS OF INTRODUCING HYDROPOWER TO RURAL PEOPLE

When discussing decentralized small hydropower, the condition and perception of the rural people cannot be omitted. In reality, introducing small hydropower to rural people involves more than installing a turbine or other technical apparatus. Numerous social aspects should be taken into consideration. Thus, technicians who work in this field, especially in rural areas, need to be aware of any social problems which may arise during a project.

As technical, economical and financial planning, etc. have been discussed thoroughly already, this paper will concentrate on the social approach necessary for introducing decentralized small hydropower to rural people.

Project Implementation

Several methods are possible for implementing small hydro in rural areas, each with its own advantages and disadvantages, namely:

a. Small hydrooower is implemented by either governmental or non-governmental organizations, and the local people purchase power from them.
   - Since the local people take no part at all in the project and purchase power from others, they usually have a passive attitude towards the project.
   - The project will not dynamize the local people, nor help to develop self-confidence because the idea and the implementation of the project do not originate from them but from other people (government or other companies). These two aspects are very important for rural development in general.

- In this type of project, commonly the main emphasis will be on technical aspects and management only.

b. Small hydropower is implemented by local people cooperatively or by similar bodies.

- As the idea comes from the local people themselves, they will gain a sense of achievement, self-confidence and self-reliance that they can do something themselves, instead of always depending on help from others. From our experience, this will be a strong and valuable basis, especially for the utilization of the electricity for any productive efforts in the future.
- Much time and patience is required from technicians (who usually are not patient enough) to achieve the type of success described above.
- Engineers/technicians should have a working knowledge or at least should be aware of the social condition and perception of the local community. In developing countries such engineers/technicians are still rate.

Does electricity always mean diesel?

As a result of the effective and continuous brain washing of several diesel products, most rural people simply identify electricity with the diesel engine. Moreover they sometimes identify electricity with one of the engine brands, such as Honda, Kubota, M.W.M., etc.

Thus, to change these perception about electricity, especially within a country which consist of thousands of islands like Indonesia, a continuous campaign strategy is necessary. From our experience with various campaign techniques, film seems to be the most effective. The following strategy is being implemented on a trial basis:

Our experience shows that the use of standard management techniques will face many obstacles and therefore will be difficult to use.

If these two aspects have been carefully examined and if change is possible within the community, Achievement Motivation Training can be held for the leaders. From our experience this A.M.T. greatly influences the way of thinking and in the future should influence rural people's management methods. At this point electricity utilization for productive activities are possible.

Professional film maker	Government Institution	to be shown
Various types of films	N.G.O.s	in the potential
	Formal & non-formal	localities
	Education	

Note: In the film, it should be emphasized that electricity does not mean lamps.

Operational Cost

Although the concepts of operational cost, depreciation etc. of small hydro are obvious to us, they are not understood fully by rural people. To rural people water is something that comes from nature. So, when there is a project concerning water, rural people only consider the cost for the first implementation because water is regarded as something that will last forever. This manner of thinking may pose an obstacle for management of the project in the future. Moreover, in many developing countries, often rural projects are just given the rural community, which may reinforce their short-term perception of small hydro costs.

Changing wrong perceptions may appear to be a simple aspect of implementing small hydro schemes, but it is a long process. Thus studies should examine several factors which may reflect the readiness of the society for small hydro.

a. Local groups/organizations.

- social groups: death, art, etc.
- economy : credit, cooperative shop, or pre-cooperative, etc.

b. Traditional management

Rural people's ways of managing credit, finance, sharing, etc. more or less may reflect their complex methods of management and we should examine carefully which ones are possible to develop in relation to small hydropower.

BRIEF COMMENTS ON SOME INSTITUTIONAL ASPECTS OF MINI-HYDROPOWER PROGRAMS

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Energy and Rural Development: A New Policy Arena

Mini-hydropower for developing countries is currently being discussed as a facet of a new policy arena, that of energy and rural development. Until recently the problem of providing energy to rural areas meant merely extending urban grids and petroleum distribution. In many developing countries, these two functions are in different hands--government-operated centralized electricity systems and foreign oil companies who with private entrepreneurs own and operate a network of oil refineries, oil product transportation facilities (i.e., pipelines, trucks, railroad tank cars) and distribution depots and retail outlets.

During the decade of the 1970's, the international oil cost/supply crisis and its convergence with the fuelwood/traditional energy crisis in certain countries focused attention on the need to develop indigenous energy resources.

One of the most promising options for meeting rural energy needs is mini-hydropower, particularly in the tropical and highland areas of Latin America, Africa and Asia. In these regions, technical, economic, social, and political factors are combining to stimulate interest in this technology.

Demand for Electricity and the Role of Mini-Hydropower Technology

Most rural areas of developing countries do not have electricity. Energy consumption is primarily in the form of traditional energy sources predominantly for cooking. Given this pattern of consumption, a growing number of studies

suggest that demand for electricity for productive uses will not develop unless there are a range of other inputs available. Roger Revelle notes some of these factors:

1. The actual or potential existence of adequate transportation facilities to and from markets and sources of raw materials;
2. Availability of an adequate supply of other forms of energy needed for a particular industry or industrial complex;
3. Sufficient investment capital, either in the form of credit or savings;
4. The presence of trained technicians and of managers familiar with problems of marketing, cost accounting, personnel management, and business operation;
5. The existence of a market town or small city in which a complex of mutually-supporting industries can be established;
6. The availability of skills, disciplines, and comparative costs of labor in the rural areas vs. the labor force in large cities.[1]

Where the provision of electricity is deemed appropriate, the issue of centralized or decentralized generation may be important. Competition may develop between the national organization responsible for large-scale power generation and the entity or entities at the national or local level involved in providing energy to rural users. International donors may back one or both groups, further complicating the problem of determining an optimum electric power investment plan for the country.

The emphasis on developing decentralized options such as mini-hydropower may be viewed as a threat by the centralized national power organization over generation and the development of an integrated national grid. In some countries, however, the unreliability of power from the national grid provides an incentive for businesses and local communities to have their own captive source of power, whether diesel or small hydro. Thus, economics may not be the dominant concern in government or local community considerations of the mini-hydro option.

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Organization and Management

The configuration of institutions involved in rural electrification and mini-hydro projects varies from country to country. Four basic approaches can be characterized:

(a) Single utility

In countries with a socialist tradition, a single national utility may be involved in generation, transmission, and distribution of electricity to both rural and urban areas. This situation is present, for example, in Indonesia, Peru and Sri Lanka, where the Indonesian National Electric Company (PLN), Electroperu and the Ceylon Electricity Board monopolize government electricity activities. In Indonesia, though, considerable autogeneration capacity exists outside the PLN network. PLN is taking an increased interest in mini-hydro and has a full-scale testing laboratory for mini-hydro systems in Bogor.

(b) Separate central and rural electrification authorities

Many developing countries have separated the national power corporation from the organization that distributes power to rural areas. This bifurcation, in part, reflects the large subsidies that are sunk into rural electrification programs. These rural electrification boards (Bangladesh), corporations (India) or administrations (Thailand, Ecuador, Bolivia) may or may not own and manage the distribution system. In Bangladesh, India, Bolivia and the Philippines, cooperatives have been established for this purpose, with technical, managerial, and financial support from the government authority. Some of these rural systems have mini-grids into which power is fed from diesel units. The high operating costs of these units are forcing rural electric authorities and cooperatives to turn to mini-hydro if an adequate hydro resource exists near these grids.

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(c) Autonomous mini-hydro authority

While institutional responsibility for mini-hydro generation usually resides in the national power organization or the rural electricity corporation, there are instances, e.g., in Nepal and Peru where a separate mini-hydro board has been established. This board is involved in the construction of mini-hydro stations in the remote mountainous regions and is separate from the Rural Electrification Divsion of the Department of Electricity, which also works with villages in the construction of small hydro plants. In Peru, an ad-hoc commission serves to coordinate the planning and execution of mini-hydro projects.

(d) Local community approach

In a growing number of cases, micro-hydro units are being installed by local communities, sometimes with the assistance of faculty and students from a nearby technical university. In Papua New Guinea, the Appropriate Technology Development Unit of the University of Technology at Lae has adapted a Pelton runner design to high-head sites near Lae. The Butwal Institute of Technology in Nepal has for many years assisted in local hydro development. Church groups have installed units to pump water and provide electricity to schools and hospitals in Nepal and India. The people's communes in China have installed thousands of hydro units, generally less than 20 kW in capacity with commune members being trained at college and vocational institutes in all aspects of hydraulic machines. The Peace Corps in Liberia has also been active in the promotion of micro-hydro with installation of a 30 kW unit in a remote village.

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Comparative Case Experiences

This section examines the development of mini-hydro programs in two Asian and two Latin American countries from a comparative institutional perspective.

Philippines and Thailand

The Philippines and Thailand are among the top ten oil-importing developing countries. Both have approximately the same per capita income levels and have fairly advanced rural electrification programs. These programs involve the extensive use of small diesel generators. In Thailand, there are approximately 400 diesels ranging in size from 50 to 6,000 kW. Both countries are desperately trying to reduce their dependence on imported oil and want to substitute mini-hydro units where possible.

Each country has a central rural electrification authority--the National Electrification Administration (NEA) in the Philippines and the Provincial Electricity Authority in Thailand (PEA). A fundamental difference in approach, however, is found in the development of rural electric cooperatives in the Philippines. As of February 1980, 101 cooperatives had been electrified under the NEA program, representing 27 percent of the barrios and 20 percent of the households. The national objective is to electrify all barrios by 1985. In general, the cooperatives in the Philippines are dominated by the wealthier members of the rural communities--government employees, businessmen, sugar planters, and professionals. On the other hand, in Thailand, cooperatives have not fared well and the government has resisted this approach in its rural electrification program.

Thailand and the Philippines both have substantial potential for mini-hydro development. In Thailand, several hundred sites have been identified, especially in the north, and one source estimates a potential capacity of approximately 800 MW of firm, dry-season, unregulated power.

Responsibility for mini-hydro development is dispersed in Thailand, while a Presidential Directive in the Philippines in 1979 gave NEA sole jurisdiction in this area. This directive was related to an overall policy decision to promote energy self-sufficiency in all rural cooperatives. Under this policy, NEA has begun working with rural cooperatives in planning for the introduction of either mini-hydro systems or "dendro-thermal" units (wood-burning steam or gas-fired power plants). NEA has signed agreements with China and France providing credits for hydro units and gas-turbine power plants. NEA will provide loans and technical assistance to cooperatives in the adoption of these technologies. In Thailand, both the National Energy Administration and the Provincial Electrification Administration are currently installing mini-hydro units in rural areas. The Royal Forestry Department and the Royal Irrigation Department also operate small, locally-made units. While PEA, which reports to the Ministry of Interior, is the agency of the government responsible for distributing electricity to rural consumers, NEA, which is under the Ministry of Science, Technology and Energy, has a broad mandate in the energy planning and supply field and views itself as playing a catalytic role in the development and demonstration of alternative energy technologies for rural areas. NEA and PEA officials hold quite different philosophies toward the development of mini-hydro in Thailand. NEA is concerned with developing an indigenous, low-cost system that is appropriate in rural villages, particularly those that are remote from the main grid or from district centers. NEA officials also believe the local cooperatives can effectively build and manage micro-hydro systems at significantly lower costs than with imported units. NEA has obtained assistance from the UNDP, USAID, and Japan for micro-hydro projects. PEA, on the other hand, is seeking to provide reliable power for rural district grids and to replace high-cost diesel generators as quickly as possible. PEA looks to proven, imported

equipment and is receiving assistance from Norway, as part of the World Bank's second rural electrification loan, and from Finland in mini-hydro projects involving units with a power rating of about 500 kW.

The main entity responsible for economic planning in Thailand is the National Economic and Social Development Board (NESDB). The NESDB is currently considering the program and structure of the mini-hydro sector in Thailand. An overall Energy Master Plan is also in preparation with assistance from the Asian Development Bank. This plan will assess the potential from mini-hydro and other alternative technologies in meeting future energy needs. Some rationalization of this sector may therefore occur in the future.

The pace of development in mini-hydro in both the Philippines and Thailand is clearly accelerating. The growth of decentralized generating capacity is necessitating increased investment coordination in the power sector. The World Bank has expressed to the Philippines government the importance of coordination between NEA and the NPC, which is embarking on a major program to build large generating plants based on geothermal and domestic and imported coal. Similarly in Thailand, the Electricity Generating Authority of Thailand is planning new capacity based on lignite and imported coal. At this point, neither country has a firm understanding of the optimal future mix of centralized and decentralized capacity. However, it will be interesting to compare the relative costs/benefits of the two approaches, in particular to see whether the Philippine policy of rural energy self-sufficiency stands the economic test of time.

Peru and Ecuador

Peru and Ecuador are currently oil exporting countries whose petroleum resources will be severely diminished by 1990 due to high domestic consumption resulting from government subsidies. However, policymakers in both countries

realize that future electricity generation in rural areas must be through mini-hydro plants with aggressive programs.

The theoretical hydroelectric potential for Peru as calculated by the Ministry of Energy and Mines (MEM) in 1979 was approximately 200,000 MW. Approximately 30 percent is exploitable or some 60,000 MW of which only 3 percent has been so far developed. The electricity sector is operated by ELECTROPERU, the public sector enterprise charged with system operation and project execution. ELECTROPERU is composed of five operating regions; however, 87 percent of the electricity demand is concentrated in the region around Lima.

As of 1979, approximately 73 percent of Peru's electricity generation or 5,470 GWh from 1397 MW of capacity, come from hydropower, primarily large plants. Within ELECTROPERU, small or mini-hydro plants are within the purview of the Office of Applied Technology (OPTA) under its Programma de Pequenas Centrales Hidroelectricas. MEM began its program of mini-hydro development in 1978 initially carrying out studies of power system of 50 to 1000 kW capacity to meet the electricity needs of rural people. The 1980 budget was $1.85 million with several plants under construction. Plans call for 50 plants to be built between 1980 and 1985, many financed through foreign assistance programs.

ELECTROPERU is aggressively carrying out its plans to dot the countryside with mini-hydro plants. The program is centrally managed from Lima; however, local participation by the municipality is usually sought, particularly during the construction phase. Operation of the system is carried out by the local authorities with training provided through ELECTROPERU. This approach has proved successful in bringing about cooperation between rural people and Lima decisionmakers.

Ecuador, on the other hand, has only begun to exploit its hydroelectric potential which is estimated to be 22,000 MW. Installed capacity in 1977 was 612 MW, thermal and hydro, which was developed on a large scale only during the seventies. Roughly 60 percent of Ecuador's population remains without electric power.

Aside from a small number of regional power companies, the Institute Ecuatoriano de Electrification (INECEL), is under the jurisdiction of the Ministry of National Resources and Energy (MNRE). The development of energy resources in Ecuador had not been coordinated until the creation of the Instituto Nacional de Energia (INE) in 1978 to coordinate energy policy and recommend courses of action. Ecuador's oil reserves are rapidly being depleted with importation expected to begin during the late eighties. Therefore, early planning efforts followed by conservation and exploitation of the vast hydropower base is expected to go forward during the early eighties.

Development of hydroelectric power is one of the cornerstones of the national development plan. The contribution to electric generation from hydro plants is expected to be increased to 80 percent by 1985 in contrast to 32 percent in 1978. INECEL will execute and manage the grid and the large electric generating projects; whereas, regional and municipal power will be managed locally. It is expected that this program will provide power to 60 percent of the rural inhabitants. The program is principally a grid extension effort suited for the larger communities, principally those with more than 500 inhabitants, near major roads and with high agricultural productivity. Since this program was found to be restrictive bypassing many isolated villages, a Mini-Micro Hydroelectric Plan was formulated.

Prior to construction of a national grid, INECEL had constructed some 50 mini-micro hydropower systems, some of which were subsequently abandoned. Under the new plan, retired plants will be either brought into operation or the equipment moved to more attractive load centers. By mid-1980, several feasibility studies of new or existing sites were underway.

The management of new mini-micro hydro systems is expected to include the formation of cooperatives, local power companies or municipal structures. The organizational structure will depend upon the characteristics of existing local organizations. Management expertise and training will be provided by INECEL. This type of organization structure is similar to that found in Peru with a central decisionmaker determining how energy technology will be applied in rural areas. Often, this type of situation can lead to misperceived needs or concentration solely on the urban centers. A balanced program meeting the needs of both urban and rural peoples is necessary.

Conclusions

The issue of the role of mini-hydro in developing countries is caught up in current policy debate over the merits of rural electrification. In most developing countries, the balance of power continues to rest with the proponents of total national electrification. These dominant elites view the provision of electricity to rural areas as much in political as in social or economic terms. Electrification is a tool of political integration and provides tangible proof of the commitment of the government to improving the quality of rural life.

Nevertheless, planners should be extremely sensitive to the overall problem of village "energization" (as contrasted with village electrification) and to the social impact of various energy supply and delivery systems. Only in this way can appropriate policies, programs, and institutions be designed to meet both the basic energy needs of the poor for cooking and heating and the requirements of rural agriculture, industry, and transportation for mechanical, electrical, and thermal energy.

REFERENCE

[1] Roger Revelle, "Future Energy Resources and Use in Asia: The Needs for Research and Development," in Proceeds of USAID Asia Bureau Conference on Energy, Forestry, and Environment, Manila, November 12-16, 1979, p. 46.

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THE CONTRIBUTION OF LEGISLATIVE INITIATIVES SUCH AS PURPA TOWARDS INVOLVING THE PRIVATE SECTOR IN THE DEVELOPMENT OF SMALL HYDROELECTRIC POWER PLANTS IN DEVELOPING COUNTRIES

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1.0 INTRODUCTION

The involvement of the private sector in managing small hydroelectric power projects in developing countries brings with it the possibility of a quick and efficacious development of a nation's hydroelectric resources. By their nature, small hydro projects are attractive propositions for the entrepreneur:

- Geographical dispersion of sites minimizes the stress on a nation's infrastructure.
- Project scale permits its development by a small group of professionals in a relatively short space of time.

The development of small hydropower power plants (SHPP) by the private sector is helped when a market is guaranteed for the plant generated energy at an attractive price. The developer can then negotiate a capital loan from a bank to finance the SHPP construction and operation. In this context, the promulgation by the U.S. Congress in 1978 of the Public Utilities Regulatory Policies Act (PURPA) is a very promising development. Of particlar relevance are Sections 201 and 210 of the act. These sections mandate electricity utilities to purchase electricity from any small producer (of capacity of up to 80 MW and which uses renewable resources as its primary energy source) at the price that reflects the incremental cost to the electric utility of alternative electrical energy. On the other hand, PURPA mandates that sales of supplementary and backup power by the utility to the small producer shall not be discriminatory and that they reflect the utility's average cost of electricity generation.

This paper then considers the contribution of legislative initiatives such as PURPA towards fomenting the involvement of the private sector in the development of small hydro electric power plants in developing countries. Elements of the U.S. approach that are appropriate for developing country application are emphasized. Other in-country factors that would be indispensable for transferring the PURPA model are explored. The paper is divided in the following sections:

- A major U.S. Initiative: The Promulgation of PURPA
- Applicability of PURPA to Developing Countries.
- Draft Policy.
- Example of a PURPA Situation.

2.0 A MAJOR U.S. INITIATIVE: THE PROMULGATION OF THE PUBLIC UTILITIES REGULATORY POLICIES ACT (PURPA)

The promulgation in 1978 of the Public Utilities Regulatory Policies Act (PURPA) has played a major role in renewing interest in the development of Small Hydroelectric Power Plants (SHPP) in the U.S. Extracts from Section 2 of the Conference Report point to the interest of the U.S. Congress in this issue:

"The Congress finds that the protection of the public health, safety and welfare, (and) the preservation of national security ... require

(1) A program providing for increased efficiency in the use of facilities and resources by electrical facilities (and)

(2) A program to provide the expeditious development of hydroelectric potential at existing small scale dams to provide electric power.

Title II of PURPA contains provisions that are without precedent world-wide (Taubman and Weingart, 1981), namely the use of legislative fiat to govern the purchase of power from two types of electric power generators-small power producers (including SHPPs) and cogenerators. Specifically, Section 210 of PURPA was designed to circumvent three obstacles faced by small power producers that desired to interconnect with an electric utility (Silverstone, November 1980):

- First, heretofore, electricity utilities were not required to purchase electricity generated either on an "as available" or firm contract basis even if the electricity were offered at a favorable rate.

- Second, backup power sales to small power producers, who usually met all or most of their own needs was often priced at a discriminatory high rate.

- Third, even if a small power producer were permitted to supply energy to a utility, it ran the risk of being deemed a utility and thereby being subject to a plethora of federal and state regulations. Compliance with such regulations could often be much more costly than any economic benefits that could accrue from the sale of electricity.

Section 201 in conjunction with Section 210, addresses each one of these impediments and to varying degrees eliminates or substantially reduces them.

2.1 Discussion of Relevant Parts of Sections of 201 and 210 of PURPA

Important provisions of Title II of the Public Utilities Regulatory Policies Act (PURPA) are listed in Appendix I. In essence, they provide the framework that determines the purchase of electricity by electric utilities from qualifying small power production facilities (QF) at a rate consonant with the incremental cost to the utility of alternative electrical energy. A QF is defined to include facilities of capacity no greater than 80 megawatts that produce electric energy primarily by the use of a renewable resource (including hydroelectric) and of which no more than fifty percent of the equity interests is owned by an electric utility.

PURPA also requires that the rates for the sale of electricity by an utility to a QF shall not be discriminatory and that QFs be exempted from federal and state laws and regulations that pertain to electrical utilities. A further mandate of PURPA calls for "rulemaking provisions respecting (a) minimum reliability of qualifying ... facilities (including reliability of such facilities during emergencies)" and (b) "reliability of electric service to be available to such facilities from electric utiities during emergencies."

Additionally, Congress had directed the Federal Energy Regulatory Commission to promulgate rules to guide the implementation of Sections 201 and 210 of PURPA after "appropriate consultation with representatives of Federal and State regulatory authorities having ratemaking authority for electric utilities" and the general public. Finally, Section 210(f) defines the role which states are required to perform in the PURPA regulatory structure by requiring that each state regulatory authority shall after appropriate consultation with the general public," implement such [FERC] rule (or revised rule) for each electric utility for which it has ratemaking authority".

2.2 Federal and State Implementation of Selected Provisions of TIRE II of PURPA

2.2.1 FERC Promulgation of Rules

On February 25, 1980, FERC issued its final set of rules under Section 201 and 210 of PURPA (to be codified as 18 CFR §292). Broadly, the regulations cover the following issues: (1) electric utility reporting requirements; (2) purchase rates; (3) sales rates; (4) interconnection costs; (5) required characteristics of qualifying facilities such as a) ownership; b) operating and efficiency standards; and c) certification and d) exemptions from federal and state law. In general, the rules are designed to make it exceedingly worthwhile for QF's to sell electricity to any (inter)connected utility at an agreed purchase rate.

The purchase rate of electricity from a new QF (i.e., built after 11/9/78) by an electric utility will depend upon the avoided costs (which are the FERC defined proxies for incremental costs as mentioned in PURPA) plus the characteristics of the QF system itself. Avoided costs are "... the incremental costs to an electric utility of electric energy or capacity or both which, but for the purchase, from the qualifying facility or qualifying facilities, such utility would generate itself or purchase from another source" (Section 292.101 (b)(6))[45 FR 12214 (2/25/80)]. The data reporting requirements of the utilities have been designed to assist the competent state regulatory agencies in determining the avoided costs. These include: 1) the estimated avoided energy costs (¢/kWh) for various levels of purchases from QFs. Data must include costs of daily and seasonal peak and off-peak periods for the current year and each of the next five years; (2) the utility's plan for additions to or retirements from capacity (by type and amount) and any purchases of firm energy and capacity for the next ten years; and (3) estimated capacity costs in dollars per kilowatt and associated energy costs per kilowatt for each planned capacity addition or planned firm purchases [Section 45 FR 12214 (2/25/80)].

Data provided by the QFs which may also be considered in calculating the avoided costs include (1) availability of capacity or energy during

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daily and seasonal peak periods (including dispatchability, expected or demonstrated reliability); (2) contract terms with the utility (including duration of purchase obligations; termination notice requirements and sanctions for non compliance); (3) coordination of scheduled outages; (4) usefulness of QF capacity and energy during emergencies, including ability to separate its load from its generation; (5) the individual and aggregate value of energy and capacity to the electric system. Also, the relationship of the availability of energy or capacity and the ability of the utility to avoid costs (including the deferral of capacity additions and the reduction of fossil fuel use plus the costs or savings resulting from line losses) may be taken into account (Section §292.304(E)]

Each state regulatory authority has the option of weighing the above mentioned factors as it sees fit, of utilizing and promulgating standard purchase rates throughout its service area for each type of QF (such as wind energy conversion systems (WECS) or SHPPs) or of examining the factors on a case by case basis (for facilities of capacity greater than 100 KW only).

FERC rules for sales rates by utilities to QFs are couched in terms of average costs of electric energy generation and provisions of generating capacity. Rates shall not discriminate against any QF in comparison to other customers of the same class who do not generate electricity for supplementary, backup, maintenance, and interruptible power. Also rates for backup and maintenance power must reflect the extent of coordination between scheduled outages of the QFs and the utility's facilities.

The above discussion has touched lightly on the rules that have been issued by the FERC to facilitate implementation of Section 201 and 210 of PURPA. More detailed analyses of the rules have been made by Silverstone (1980, 1981), Golden (1981), and the Energy Law Institute (1980). The work of Fox (1981) is particularly useful in developing a methodology for calculating avoided cost. Finally, it bears noting that small projects, such as SHPPs will only gain substantial allowances for avoided capacity costs if considered in the aggregate for both size and reliability criteria.

2.2.2 Implementation of FERC Rules by State Regulatory Authorities

PURPA and the FERC regulations promulgated thereto do not specify a specific implementation plan for the states. Each state is given broad

procedural and substantive latitude in formulating its response to federal directives which thereby permits it to implement PURPA with greater sensitivity to local conditions and with innovative methodologies. A well conceived state implementation plan will reflect state policy objectives and regulatory principles and have a rulemaking procedure that minimizes demands on state fiscal and administrative resources and that addresses directly the issues and concepts relating to rate structure and design on a technology option basis. Then, regulations would be established that would be applicable statewide to all utilities and QFs.

The state utility commissions were required to promulgate implementation plans for carrying out the mandate of Sections 201 and 210 of PURPA by March 20, 1981. As of early June 1981, only 15 states had implemented FERC rules regarding PURPA small producer rules (Hydrowire, July 1981). As expected, the standard purchase rates are heavily influenced by the fuel (such as nuclear, coal, or fuel oil) that the purchased power would replace. Sample purchase rates are shown below (Pope, 1981).

State	Intermittent Power (¢/kWh)	Constant Power (¢/kWh)	Displaced Fuel
New Hampshire	7.7	8.2	Fuel oil
North Carolina	3.0	5.0	Nuclear
Vermont	6.6	9.0	Fuel oil

2.3 Impact of Private Sector Involvement on Small Hydro Development

In April, 1980, the Federal Energy Regulatory Commission (FERC) in an Environmental Impact Assessment estimated that PURPA would stimulate the building by non-utility controlled entities of 12,000 MW of capacity by 1995 (for all renewable resource technologies plus cogeneration).

However, already it seems that the FERC's estimate is unduly conservative. In 1981, the FERC expects to receive 1,800 applications to study hydro- generation at existing dams and in developement sites - a hundred fold increase from just 18 in 1977 (Norman 1981). Most of the applications deal with sites that meet PURPA requirements, albeit approximately half of them compete for the chance to develop existing dams. As of April 1, 1981, private entreprenueurs had filed applications representing 5,674 MW with the FERC (Gallant, 1981).

The proposed projects are scattered throughout the country and involve installing SHPPs in places such as impoundments of abandoned textile mills (in New England and the Southeast), irrigation dams (in the Northwest) and at locks in major rivers such as the Mississippi, the Missouri, the Arkansas, and the Alabama.

A noticeable feature of private sector involvement in small hydro development is that a new kind of company is entering the field. Typically, this kind of company aims to develop small hydro on a large scale and specializes in putting together "package deals" that include (1) the management of a project through all its regulatory, technical, and financial aspects, (2) developing a contract to sell the SHPP output, and (3) formulating a scheme to attract investors.

A typical contract between a QF and a facility would require that:

- The QF be responsible for constructing, owning and maintaining the hydroelectric plant;
- The utility would be responsible for constructing, owning, operating and maintaining all the distribution and substation connection facilities required to connect the QF and the utility,
- The QF would reimburse the utility for all the initial distribution and substation facility connection costs and pay an annual fee to the utility for O&M of the facilities (Barkovich, 1981).

2.4 Technical Issues

The incorporation of qualified facilities in the generator/load mix of a given utility will occasion a review of the utility planning and operating practices. As a minimum the following technical concerns will need to be addressed:

- safety to personnel and equipment
- quality of service
- operational accommodations
- metering
- sizing procedures and interconnection limits
- installation data needs.

None of these concerns are insurmountable. Prichett (1981) has delineated possible procedures for dealing with them. However, clear guidelines need to be established on who is going to pay for any special equipment and/or labor consuming procedures that will be involved.

3.0 APPLICABILITY OF PURPA TO DEVELOPING COUNTRIES

The circumstances that induced the U.S. Congress to promulgate the Public Utilities Regulatory Policies Act (PURPA) in 1978 apply even more in developing countries whose economics have been devastated by the oil price increase since 1973. The massive payments for oil imports have soaked up a growing share of the export earnings of these countries, strained their ability to pay for essential imports and slowed down their economic development. Thus the development of all viable renewable sources of energy (including small hydro) is imperative (from both national security and economic well being viewpoints) for developing countries.

For many countries, the optimal development of its indigenous hydroelectric resources will need a partnership arrangement between the public and private sectors. The existence of legislation, such as PURPA, that guarantees an attractive market price for electricity generated by qualified facilities is a necessary but not sufficient step for involving the private sector in the development of Small Hydroelectric Power Plants (SHPP's) in developing countries. This section first delineates other factors that influence SHPP development by the private sector and then reviews those elements of the U.S. PURPA that may be applied in developing countries.

3.1 Factors that Influence SHPP Development in Developing Countries

Some factors that need to be considered in judging whether SHPP development by the private sector is viable are:

- *A national awareness of the importance of fomenting small-scale energy projects* by the public and private economic sectors and the general public is vitally necessary to get rapid action. This is especially important in countries where the production potential of small energy resources is so large that it may make a significant contribution to the energy supplies country-wide.

  In practise, this awareness translates into a positive attitude on the part of all public and private entities that may influence the success of small hydroelectric projects.

- *Sensitivity to overcoming institutional problems.* For example legally in India, SHPP projects cannot be developed by the private sector (Barnea 1981). In most countries in Latin America, water use for food production has the first priority such that hydroelectric projects are always subordinated to the use of water for irrigation. Thus it is important that clear rules define the involvement of the different entities interested in water resources development (Indacochea 1980).

- *Eenergy organizations charged with planning the development of the nations energy resources* can highlight the importance of developing hydroelectric and other renewable resources. Such organizations can also influence electric utilties in developing tariff structures that reflect the true cost of fossil fuels and encourage the incorporation of hydroelectric and other renewables into their energy supply mix.

  Since many SHPP service areas will be in rural areas, such an energy planning organization could also be used in catalyzing the coordination of the activities of energy development entities with those of agriculture and rural development agencies.

- *Existence of a public utility commission*, with the responsibility to regulate the orderly development of the electricity sector and especially to regulate electricity tariffs.

- *Availability of capital for construction* is a major concern to private developers. Clasgens and Rothchild (1981) have listed many mechanisms for financing SHPP projects including tax-exempt bonds and debt-services guarantees. The State of California for example has created the California Alternative Energy Source Financing authority to issue tax-exempt bonds to make low-cost funds available for solar, wind, biomass, geothermal and SHPP projects.

- *Government debt service guarantees* reduce project risk and thereby stimulate private sector interest in SHPP development, at little or no cost in tax revenues. If rigorous screening of projects takes place to minimize the possibilities of default, the program can operate at virtually no cost. A standardized technical and financial project appraisal procedure is also necessary in minimizing program costs (Marsden, 1981).

- *The availability of drought insurance* especially for the early SHPP operating years is also important.

- *Flexibility in the possible contracting arrangements between* the utility and the SHPP developer is another important issue. The possibility of the utility giving a contract that would allow the SHPP to pay back all loans in the first 5 years after the plant is operating would make many projects very attractive. (Merrill 1981).

- *Availability of programs for training possible project managers technologists and technicians* for planning, design, construction and operation of the SHPP's is vitally important. Wherever the prospects for obtaining trained personnel are poor, investments become risky, and credit will not be available.

- *A high level of local community interest and participation in small energy projects and similar (water sanitation projects)* is an important factor. The involvement of the local community helps SHPP projects in lowering project costs (especially civil engineering costs) and improving reliability of operation through maintenance of the watershed upstream from the headrace entry point and concern for proper plant operation.

3.2 Elements of the U.S. PURPA That May be Applied to Developing Countries

In the context of this paper, the most important objective of PURPA is to incentivate the rapid development of a nation's renewable (including hydroelectric) resources through a partnership of the public and private sectors. A measure of the efficacy of PURPA will be the rate that new renewable systems (including SHPP's) are integrated into the national grid and the subsequent reliability of the new systems.

For developing countries, any PURPA style initiative will have to be promoted within the context of each nations legal/socio-economic milieu. What is important is to bear in mind the five principal assumptions of sections 201 and 210 of PURPA:

- Only qualifying facilities can sell electricity to the utility. The QF will be defined in terms of its ownership structure, its size and the resources it uses for generating electricity.
- The utility will purchase electricity at a rate consonant with the incremental cost to the utility of generating electricity.
- The utility will not discrimate in its sale tariffs against QF's.
- The QF's will be exempt from the legal and regulatory requirements governing the organization and financial reporting of electrical utilities.
- The QF's and the utilities will be expected to meet minimum specified reliability requirements in furtherance of the objective of PURPA.

The actions taken by the Federal Energy Regulatory Commission (FERC) and the Public Utility Commission (PUC's) shoudl be judged strictly on their applicability to the reality that exist in each country. The concept of "avoided cost"that takes into account both the capacity and the amount of electricity provided by the QF to the electric utility seems a useful one. Likewise the criteria that may be used in determining the reliability of service provided by the QF to the utility are helpful.

As time progresses, a rich lode of experience is being generated on the efficacy of PURPA in the U.S. It may be interesting monitor the situation in a state such as California, where already a number of utility-private sector SHPP contracts have been signed (Barkovich 1981) with the objective to finding out what kinds of arrangements are proving to be the most satisfactory.

There is one element that must be accounted for in many developing countries in a PURPA type initiative that is not contemplated in the U.S. law. This is the active participation of the local community in the construction and operation of the SHPP to help ensure its reliability of peformance. Experience in many countries has shown that SHPP's are often out of service because of poor maintenance of the watershed upstream of the diversion dam. This adverse situation can be avoided when the local community knows that the continuation of their electricity service depends uniquely on how well they conserve "their" watershed.

4.0 DRAFT POLICY

For many countries, the optimal development of its indigenous resources will need a partnership arrangement between the public and private sectors. Clearly, a PURPA type initiative is a necessary step for stimulating the involvement of the private section in mid or higher level developing countries. In such cases, the vitality of the private sector's contribution to small hydro development would be enhanced if public policy followed the lines mentioned below.

- The national legal infrastructure (including the pertinent electricity sector and water resources law) would permit participation of the private sector in the development of small hydro sites and guarantee the subsequenct sale of electricity to the electrical utilities (using a wide range of possible contract mechanisms).

- An energy planning organization be put in place with the mandate to plan for the rational development of the nation's energy resources and to coordinate all energy development activities.

- Availability of capital for SHPP construction (using mechanisms such as tax-exempt bonds and debt service guarantees) would be assured.

- Clear rules delineating the role and responsibilities of foreign resources (capital, technical) would be promulgated including guidelines for the establishment of joint ventures with host country firms.

- Drought insurance would be made available where appropriate.

- Training programs for SHPP project managers, technologists and technicians would be put in place.

- The role of local communities in the development and operation of SHPP's would be highlighted through the provision of educational outreach programs in rural communities on the benefits of electricity and on the important role these same communities will play in guaranteeing reliability of its supply. The local communities will benefit from their involvements in the development of small hdyro systems through electrification on favorable terms.

Figure 1 shows the interrelationship of the public and private sectors in the development of SHPP's when a PURPA style initiative is used.

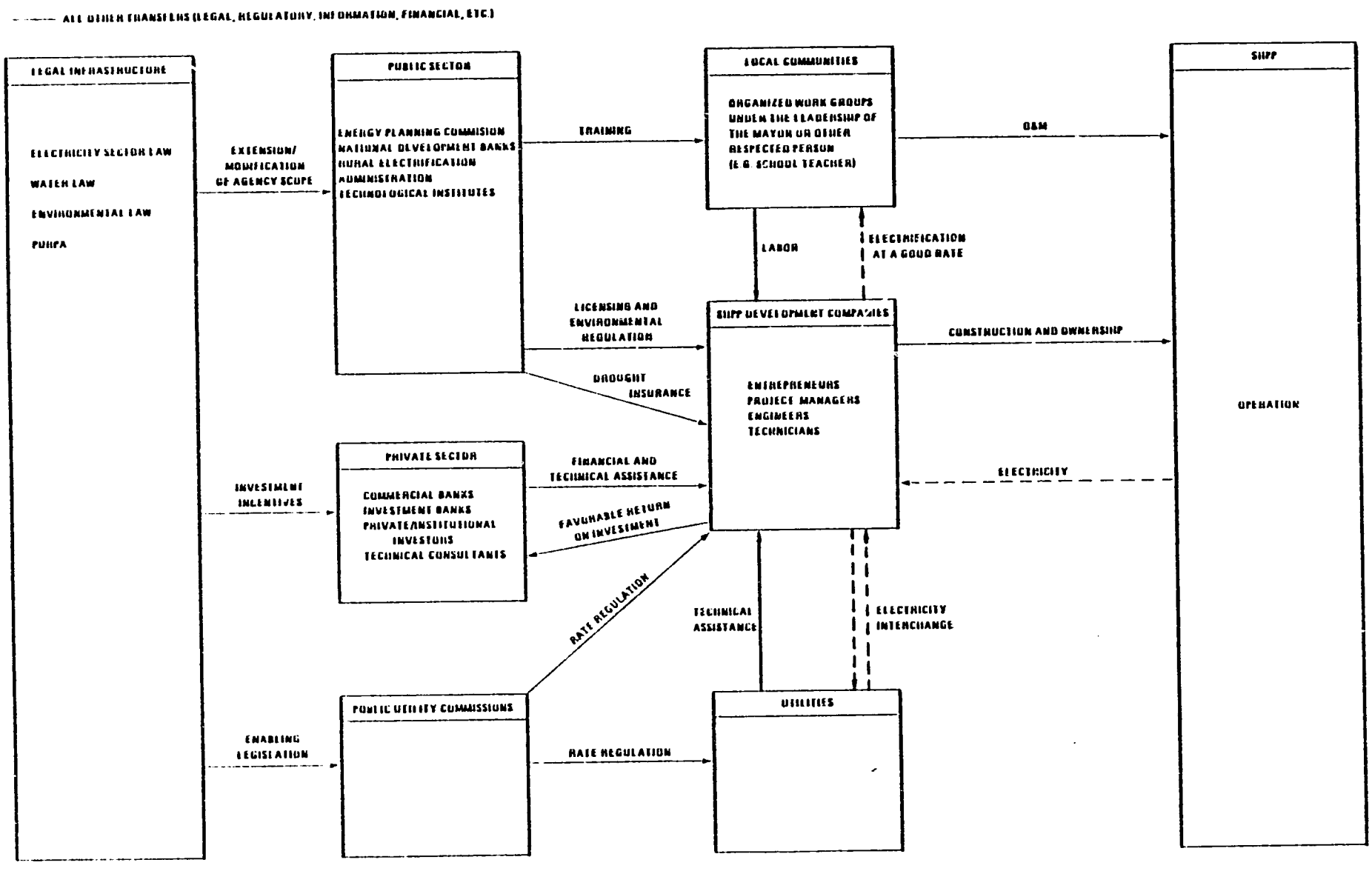

FIGURE 1 INTERRELATIONSHIP OF THE PUBLIC AND PRIVATE SECTORS IN THE DEVELOPMENT OF SHPPs

5.0 EXAMPLE OF A PURPA SITUATION

In this section, a real example from the Dominican Republic has been chosen to demonstrate how the application of a key provision of Section 210 of PURPA (i.e., the purchase price of electricity by a utility from a small producer should reflect the utility's avoided cost) could make the development of a SHPP very attractive for the private sector. The situation as described below is a summary of a detailed study (NRECA, July 1981) that was conducted using a customized site selection methodology (NRECA, June 1981). This methodology reflected current standard engineering practice in the United States and the Dominican Republic. The discussion is divided into 2 parts: (1) engineering review of the project; and (2) financial review of the project.

5.1 Engineering Project Review

The engineering review of the project begins by looking at the site characteristics in terms of location, hydrology, and topography and then develops a design that optimizes the site electricity generation capabilities.

Site Characteristics: The site is located in Azua Province with the proposed location of the powerhouse about 1 km distance from a 12.5 KW distribution line. The drainage area of the watershed associated with the intake to the power canal was 200 km^2 in surface area. Five years of pertinent stream flow data were available.

Design Considerations: Using information provided by a flow duration curve and following the procedures laid down in the site selection methodology, a design flow (Q_d) of 1.5 m^3/sec was determined. A number of project configurations were considered that depended upon project layout and single vs. multiple turbine arrangements. The optimal configuration chosen was a cross-flow turbine of 726 kW capacity based on a design head of 61.75 meters and potential annual generation of 2.41 GWh. Further engineering details of the project are shown in Table 3.

The project also included the following features:

- A diversion rock and concrete dam 36 meters long and 3 meters high;
- A 2.3 KM trapezontal rock and mortar tailrace with a gradient of 0.01 and a flow capacity of 1.7 m^3/sec;
- A 36" diameter steel penstock of 8mm thickness, 100 meters length and 1.5 m^3/sec capacity;
- A synchronous 726 KW generator with a voltage rating of 4160 volts at 60 Hz and a speed of 1200 rpm (through a stepped speed increaser);
- 7 km of 12.5 kV transmission line.

5.2 Financial Project Review

The financial review of the project first estimates the project costs, then estimates the project benefits and finally evaluates the project in terms of internal rate of return, benefit-cost ratio, and net benefits.

Project Costs

The following assumptions prevailed in determining the costs:

1. The equipment and material costs reflect the price as delivered to the site.
2. All costs are expressed in terms of 1981 RDS. All equipment that would be procured abroad was costed at the official exchange rate of 1 RDS = 1 U.S. $.
3. The cost of labor in construction and installation is assigned a value that is a weighted average of local labor costs and semi-skilled labor cost.

Table 1 presents a summary of the project costs as prepared by a team of professionals from the Dominican Republic while following the above-mentioned site selection methodology.

Project Benefits

The project's benefits are calculated as the revenues from the sale of the annual report of electricity generated at the assumed grid purchase rate of 11¢/KWh. This is the average cost of generation of electricity

TABLE 1
ESTIMATED PROJECT COSTS

		RDS
1.	New Dam and Spillway	105,000
2.	Power Canal	198,700
3.	Power Intake	24,000
4.	Penstock	56,000
5.	Power Plant and Electrical Equipment	405,800
6.	Transmission Line, Transformer and Protection Equipment	102,000
7.	Land Clearing and Access	14,000
		950,000
Admin. and General Expenses (10%)		95,100
Contingencies (15%)		142,600
		1,188,200

for the National Electrical Utility (CDE, 1980). It is calculated as follows:

	Cost per kWh
Operation	9.15
Maintenance	0.42
	9.67

At an annual inflation rate of 15% for 1981, this comes to 11.12 ¢/kWh. The following additional assumptions are made:

1. All capital costs will be incurred prior to the first year of operation (C_0).
2. Recurring costs for year i (R_i) include 1.28% for operation and maintenance (O&M) and 0.01% for administration and general expenses (A&G), as percentages of capital cost.
3. The discount factor represents the opportunity cost of capital, officially set at 12%.

The procedure for calculating the present value of the project benefits, costs and net benefits is shown in Table 2 plus the pertinent calculations for this example. The results may be summarized as follows (1981 dollars):

The total present value of the project benefits (PVB_{30}) = RD $3,415,720
The total present value of the project costs (PVC_{30}) = RD $1,311,665
The total present value of the net project benefits ($NPVB_{30}$)= $2,104,055

The benefit cost ratio = 2.60

The project internal rate of return is 34%.

5.3 Institutional Considerations

The previous two subsections have shown the feasibility (both financially and technically) of developing a real site in the Dominican Republic. Financially the project is very attractive. In fact the project benefits have been underestimated because the analysis assumed:

Table 2

CALCULATION OF THE PRESENT VALUE OF THE PROJECT BENEFITS AND COSTS

For a planning horizon of 30 years the total present value of the benefits (PVB_{30}) is:

$$PVB_{30} = \sum_{i=1}^{30} B_i \frac{1}{(1+r)^i} \quad ....(1)$$

In this case B_i is constant (B) for each year of the planning horizon and

$$B = 0.11 \text{ \$/kWh} \times 3.855\times10^6 \text{ kWh} = \text{RD \$424,050}$$

and remembering that the present value factor PVF_T is defined as

$$PVF_T = \sum_{i=1}^{T} \frac{1}{(1+r)^i} = \frac{1-(1+r)^{-T}}{r}$$

where,

T is the length of the planning horizon (Maass, 1962).

In this case,

$$PVF_{30} = 8.055.$$

Thus equation (1) may be re-written

$$PVB_{30} = PVF_T . B$$

$$= 8.055 \times \text{RD \$424,050} = \text{RD \$3,415,720.}$$

The total present value of the project costs (PVC_{30}) is:

$$PVC_{30} = C_o + \sum_{i=1}^{30} C_i \frac{1}{(1+r)} = \quad ..... (3)$$

In this case,

$$C_i = (0.0129)C_o, \; i = 1, 2... 30$$

Thus equation 3 may be re-formulated as:

$$PVC_{30} = C_o + 0.0129 \; PVF_{30} \; C_o$$

$$= C_o \; (1 + 0.0129 \times 8.055) = \text{RDS } (1,188,200 \times 1.104)$$

$$= \text{RDS } 1,311,665$$

The net project benefits ($NPVB_{30}$) are calculated as follows:

$$NPVB_{30} = PVB_{30} - PVC_{30} = \text{RDS}2,104,055$$

1. The utility's average rather than marginal cost of electricity generation;

2. No real increases in imported petroleum costs over the planning horizon;

The prima facie evidence shows that this project is extremely attractive for the private sector. An analysis was made of the factors listed in Section 3.1 that could affect the feasibility of this project being brought to fruition by the private sector. The results of the analysis are shown in Table 3. Essentially, the prognosis for private sector development of SHPP sites in the Dominican Republic is good, but not at this time.

The current impediments to SHPP development in the Dominican Republic by the private sector are primarily institutional. What is needed are the following:

1. The promulgation of a rational Electrical Sector Law (ESL) that clearly defines institutional responsibilities for the generation, transmission, distribution and sale of electricity. The law will carefully delineate institutional responsibilities for hydroelectric resources development;

2. The ESL will also mandate the establishment of a public utility commission (PUC) that will oversee the rational development of the electricity sector;

3. The promulgation of a PURPA style law to optimize the contribution of both the public and private sectors in SHPP (and other renewables) development. The general characteristics of the law are outlined in Section 3.2.

TABLE 3 ANALYSIS OF THE EXISTING SITUATION IN THE DOMINICAN REPUBLIC CONCERNING SHPP DEVEOPMENT BY THE PRIVATE SECTOR

FACTOR	SITUATION
A National Awareness of the Importance of Fomenting SHPP	Feasibility SHPP studies have been conducted under the aegis of many foreign governments and agencies (including USAID, KfW, Canada, France, Norway and Spain) in conjunction with Dominican Republic Government Agencies. Two SHPP's are in operation; 1 is under construction. Construction will begin on 3 more in the near future. USAID is contemplating financing at least 3 more SHPP projects.
Existence of an Energy Organization Charged with Planning the Development of National Resources.	A permanent National Energy Policy Commission (CNPE) was established in 1979 to help coordinate the energy-related activities of different agencies, analyze the national energy situation and identify and promote appropriate energy policies and programs. CNPE has established a hydroelectric unit that has the responsibility for the preparation of short, medium and long-term plans and policies for hydroelecric generation. The National Electrical Utility (CDE) tariff structure is designed to put the utility on a solid financial basis.
Sensitivity to Overcoming Institutional Problems	Currently, only CDE can sell electricity. CDE has a barter arrangement with some large autogenerators of electricity to transfer energy back and forth at appropriate times. Legal situation on the development of hydroelectric resources is very unclear and has lead to turf battles between CDE and INDRHI (National Hydraulics Development Institute). A comprehensive study of the legal structure of the electricity sector is planned to get under way shortly that will eventually lead to the drafting and promulgation of a modern and efficient electricity sector law. The law may mandate the operation of an electrical utility regulatory commission.
Availability of Capital for Construction by the Private Sector	At present this is a moot point, since only CDE may sell electricity. The country has an active commercial banking system and more than 15 development lending institutions with ties to the central bank. One development institution (FIDE) has a policy, of nearly two years standing, of special treatment of loans designed for energy conservation in industry or agriculture or production of alternative energy devices.
Availability of Drought Insurance	No
Flexibility in Contracting Arrangements Between the Utility and the SHPP Developer	N/A
Availability of Programs for Training Possible Project Managers, Technologists and Technicians	The Dominican Republic has a cadre of well-trained professionals who are familiar with all aspects of SHPP development. CDE has in place a training program in O&M for SHPP operators.
Community Interest and Participation in Small Energy and Similar (Water Supply) Projects	Field trips by NRECA personnel and discussions at all levels of society attest to a widespread community interest in small energy projects and an active record of participation in previous water supply projects.

6.0 BIBLIOGRAPHY

Barkovich, Barbara R., 1981. Creating a Market for Small Power, presented at the UNITAR Conference on Small Energy Resources, Los Angeles. California, September 9-18.

Barnea, Joseph, 1981. The Future of Small Energy Resources, presented at the UNITAR Conference on Small Energy Resources, Los Angeles, California, September 9-18.

Corporacion Dominicana de Electricidad (CDE), November 1980. General Balance and Supplementary Accounts.

Clasgens, Joseph H. III and A. Frank Rothschild, 1981. Some Mechanisms for Financing the Development of Small Energy Resources, presented at the UNITAR Conference on Small Energy Resources, Los Angeles, California, September 9-18.

Energy Law Institute, University of New Hampshire, Concord, N.H. June 12, 1980. PURPA Section 210: Final Regulations-Section-by-Section Analysis, prepared for the U.S. Department of Energy, Region I.

Fox, John, March 23, 1981. Pre-file Testimony submitted on behalf of the Parallel Generation Association of Kansas Before the State Corporation Commission of the State of Kansas, Docket No. 115,379-U.

Gallant, Frank, K. June 1981. Small Hydro's Second Coming, Rural Electrification, pps. 25-31.

Golden, William Brownell, April 1981, State Implementation of Section 210 PURPA Regulations: A Federal Experiment in Decentralized Policymaking and Implementation. Kennedy School of Government, Harvard University, Cambridge, Massachusetts.

Hydrowire, available from Hydro Consultants Inc., P.O. Box 2321, Boston, Massachusetts, 02107.

Indacochea, Enrique, 1980. Requirements and Methodologies for the Massive Implementation of Small Hydroelectric Power Plants in Latin America (in Spanish) published by the Latin American Energy Organization (OLADE). Quito, Ecuador.

Maass A., 1962. Design of Water Resources Systems, Harvard University Press. Cambridge, Mass., p. 105.

Marsden, Keith, September 1981. Creating the Right Environment for Small Firms. Finance and Development, pp. 13-16.

Merrill, Philip, President of Maine Waterpower, October 7, 1981. Communication with author.

Norman, Colin. 26 June 1981. Renewable Power Sparks Financial Interest Science, (212). pps. 1479-1481.

NRECA, June 1981. Site Selection Methodology for Small Hydroelectric Plants, prepared for the USAID Mission in Santo Domingo.

NRECA, July 1981. The Viability of an AID Financed Small Hydro Program in the Dominican Republic, prepared for the USAID Mission in Santo Domingo.

Pope, Chris, July 1981. U.S. Entrepreneurs Fall for "Patriotic" Power Source, Canadian Renewable Energy News, 4, (5), p. 34.

The Power Line, published by Environmental Action, 724 Dupont Circle Building, Washington, D.C., 20036.

Prichett, Wilson, 1981. Concerns of Rural Electric Systems with Interconnection to Small Power Producers and Cogenerators, paper presented at the National Rural Electric Cooperative Association, Engineering and Operations Conference, Kansas City, Missouri, November 2-5.

Public Law 95-617 [H.R. 4028]; November 9, 1978. Public Utility Regulatory Policies Act of 1978; Title II - Certain Federal Energy Regulatory Commission and Department of Energy Authorities.

Silverstone, David, November, 1980. PURPA Provisions on Cogeneration and Small Power Production, published by the Environmental Action Foundation, 724 Dupont Circle Building, Washington, D.C. 20036 under DOE Contract Number DOE-FG01-79IR10802.

Silverstone, David, July 1981. PURPA: Promise, Performance and Prologue. published by the Environmental Action Foundation, 724 Dupont Circle Building, Washington, D.C., 20036 under DOE Contract Number DE-FG01-79IR10802.

Taubman, Elliot and Jerome Weingart, April 1981. Renewable Energy Technologies and Developing Countries: The Potential Relevance of Recent U.S. Regulatory, Legal and Financial Experience. Report #RM-003-AID-81 prepared for the 1981 U.N. Conference on New and Renewable Sources of Energy, held at Nairobi, Kenya.

U.S. Congress, 1978. House Report (HR) 4028 on Public Law (PL) 95-617: Public Utilities Regulatory Policies Act (PURPA).

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RADICAL APPROACH TO RURAL ELECTRIFICATION FOR DEVELOPING COUNTRIES

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AIT, Bangkok, Thailand

Summary: A technique of rural distribution with rural electrification being redefined is discussed in the light of rural development relating to small power sources.
The system, employing a current limiter, battery charger and a battery limits the demand of the consumer from the point of view of the source. The consumer's supply of electricity is taken in terms of energy rather than electrical power. The advantages of the system is tabled and its significance on rural electrification programme in relation to micro hydro stations, small diesel stations and excessive long lines extended from the grid is elaborated.

RADICAL APPROACH TO RURAL ELECTRIFICATION FOR DEVELOPING COUNTRIES

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Rosli Alias Bsc. Eng.

Introduction

In developing countries, utilities would definitely face problems in the implementation of rural electrification programmes especially to very remote areas. Even then there are areas not far from the local grids which do not receive supply. This is because the technical standards and philosophy of rural supply adhered to by utilities become the stumbling block to the potential rural consumer. In order that electricity can be introduced to the rural areas in a more dynamic and economical method, a radical approach to rural electrification is presented here. The approach requires a re-definition of rural electrification in its basic aspects. The acceptance of this then depends greatly on attitudes of implementors, social scientists and politicians to a new concept. In this area one has also to define limits of electrical energy that can be supplied to the rural consumer rather than the limits of electrical power that could be made available to him. Growth in the use of electricity may be limited but the socio-economic impact that will prevail has got to be taken into account.

Present Concepts

One of the present methods of rural electrification as seen in many countries are just mere extentions of lines from local grids. Systems of transmission may vary, depending upon the ingenuity of the implementor. Technical constraints to the supply utilities are high due to system losses, voltage variations, loading condition, cable capacitances etc. In cases where the area is isolated supply may be given through diesel, small thermo-dendro or mini hydro stations, but these are again limited in capacity due to standards that have been adhered to. Innovative methods are thus abandoned and supply cannot be given unless total rehabilitation of the distribution systems takes place. This results in very expensive rural electrification programme.

There is little advantage in terms of time and money in the existing methods of supply. The following are true when seen in proper perspective:

(i) In terms of cost benefit rural electrification programme is usually a loss programme;

(ii) In terms of operation, the small load does not justify the revenue collection procedures service, and maintenance of systems;

(iii) It is normal that the rate of growth in energy consumption in rural areas is higher than expected for the initial period of supply. This will increase system rehabilitation cost unless controlled growth is allowed for.

The normal technique of supplying the consumer also creates problems in areas where diesel stations, mini hydro and small thermo-dendro stations are the sources of supply. Uncertainty arise in sizing the capacity rural of power stations and more so when it is known that load factors are low. The time spent by these stations operating at low utilisation factors are expensive.

Redefinition

In an approach to supply rural consumers one has to look into the requirements and the needs of the consumers in terms of consumption of electrical energy. In many instances, the consumption of electrical energy is rather low and it is normal that the maximum demand per consumer in rural electricity supply systems in developing countries to be in the order of 200 watts or less. The growth of the system in the rural area is perhaps 10% per annum in the first few years, after which, the whole system growth stagnates. Further growth of the system takes a longer period because of constraints on the financial ability of the rural consumer. This being the case, the philosophy to be adopted, whereby, limiting the demand of electricity as well as a new form of system of supply has got to be put into practice. It is then necessary to redefine rural electrification. The definition one ought to give is as follows:-

> Rural electrification in developing countries is a means of supply of electricity whereby the rural consumer is supplied in terms of quantities of electrical energy rather than electrical power.

With this definition, limitations arise but the supply utility concerned will reap definite advantages and the growth of rural electrification in countries adopting such a definition, and also adopting a new system of supply, will definitely increase.

Birth of a System

In this system of rural supply called the 'limited charger system' the following is provided for each household consumer.

(a) A current limiter of approximately 60 to 100 watts;

(b) A battery charger capable of maintaining RMS voltage for a variation of 50% input* This battery charger, charges a battery+ The consumer can demand as much as 200 Watts for a 60-Watt limiter connected in the system+;

* Refer to Appendix 'C'

\+ Refer to Appendix 'A'

(c) DC wiring for an equivalent of 8 x 20 Watt load. The voltage of the system is 12 Volts;

(d) Lighting is by means of flourescent lamps with individual invertors (lamps will have a long life span as heater elements are not used);

(e) TV and other accessories for household requirements are to be of direct current types;

(f) Batteries of the system are normally automobil batteries each of 105 A-hour or greater. The battery size depends upon household requirements.

The circuit diagram of the supply system to the rural consumer is as shown below:-

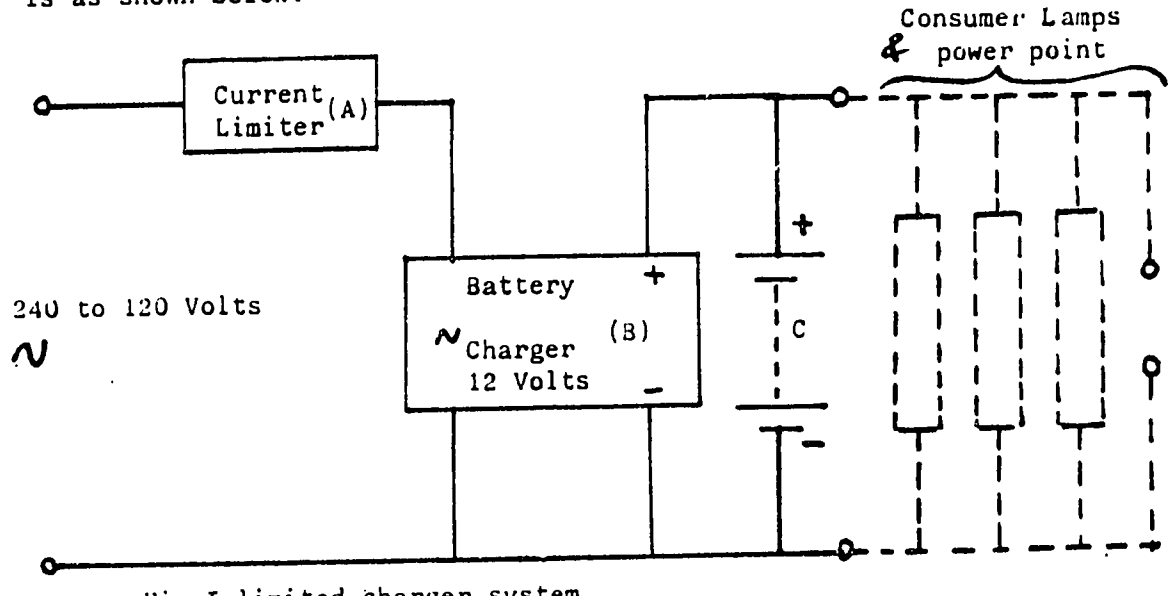

Fig I limited charger system

The system to be employed is analogous to the concept of the present system of water supply where the water tank provides excess demand requirements for the day. Thus, the 'limited charger system' consists of a current limiter (A) after which is connected a battery charger (B) of 60-100 Watts. The 12V charger charges a battery (C) which becomes the reservoir for electrical energy. The development of this idea was to meet the need to store electrical energy in mini hydro schemes, to minimise its costs and to reduce plant capacity. The system can also be used for consumers in:-

(a) rural diesel stations;

(b) wind energy systems and

(c) solar energy systems.

After further analysis it was found that this limited charger system would be considerably useful for rural areas supplied from local grids.

Application to rural systems extended from local grids

When a 'limited charger system' is provided to the rural consumer (where the main supply comes from a local grid) the following can be seen:-

(a) The household is fed constantly (say) at 60Watts. This is the maximum value and it is governed by the current limiter. Available energy on demand is 200 Volts.

(b) It can be seen that the battery is charged at most times during the 24 hour period the grid supplies the consumer. During operation of the system where the consumer requires larger output, the energy is available from both the battery and the charger.

(c) The current limiter has the function of preventing over-loading of the mains. The system load factor is almost unity.

The concept of use of this system is as shown in the diagram below:-

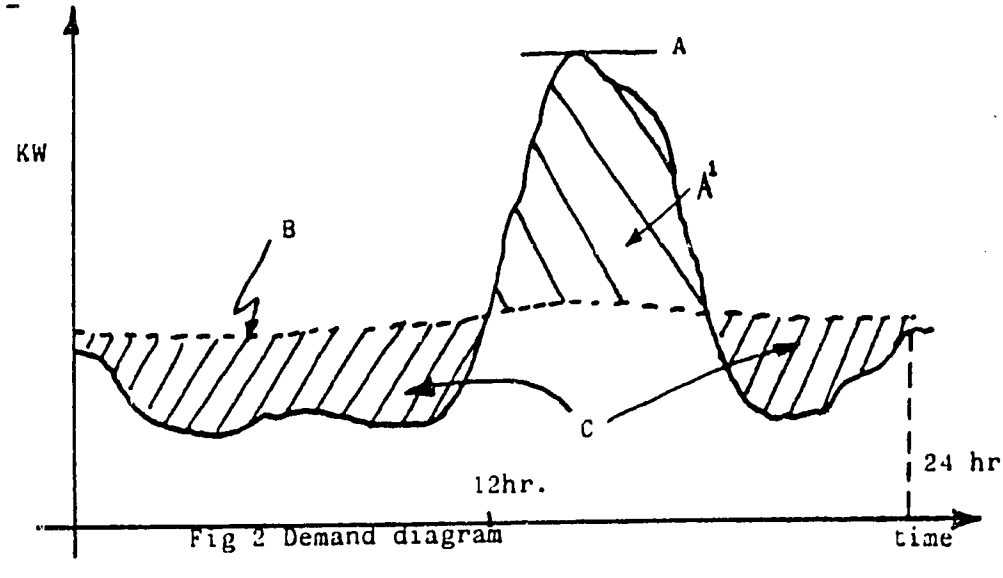

Fig 2 Demand diagram

In a normal system, the maximum demand is as indicated at level A. In the case of the 'limited charger system' where the battery compensates for the extra requirements of electrical energy, the new demand for the system would be at level B. The area shaded A^1, the extra energy required, is actually retrieved from areas C where energy storage has taken place. The capacity of the battery determines the level of demand of the new system.

Advantages of a 'Limited Charger System' (See Appendix B for table)

As the charger converts alternating current to direct current it is obvious that this system is independent of frequency. With each household taking approximately 60 Watts through the limiter, the number of consumers for such a system can be rather large. As an example, a 100 kW source of supply can cater for approximately 500 consumers in the conventional manner but in this new system the number of consumers that can benefit from the system ranges from 1,000 to 1,800 consumers. It should be noted that the charger is specific in its duty that it can be made to maintain RMS voltage for a variation of 50% input. The extension of long low voltage distribution lines becomes possible i.e. many times the present length at full load. This also means that the high voltage system (say 11 kV) can be extended to an isolated village where the secondary winding of the low voltage transformer registers a new operational minimum of 50% of (say) 240 V i.e. 120 V.

Single phase and long distribution lines in the system become possible since load balancing is easier and is no more a problem. In the 'limited charger system' the sizing of wires can be more economical as voltage drops of 50% can be allowed for. One can see that although the current limited is used the energy capacity per consumer is increased with the number of batteries. Any over-loading on the supply system will cut off the battery-charger from the mains.

From the operational point of view, the feeding end from grid sees the load factor of the rural scheme as towards unity. The 'limited charger system' is independent of frequency. The diversity of the system is minimised and the power factor will be greatly improved. The voltage fluctuations which is a major problem in normal and off-line rural system will be limited. In other words, the voltage difference between day and night due to any Ferranti effect will be controlled by the system. All this means that from the point of view of operation, the energy fed to the consumer is under control. This also means that there can be optimum usage of energy and better stability of supply. The stability of supply can be seen from the fact that faults occuring on the feeder lines will not prevent the use of the batteries as standby supply units.

From the implementors point of view, the 'limited charger system' of distribution can be cheap and there will be a reduction in the wastage of electrical energy. House wiring is at low voltage and therefore a safety aspect.

The 'limited charger system' can be changed to a normal system when there is adequate demand. The 'limited charger system' can be retained even after voltage level have been raised to normal. This system then becomes a standard system which supplies lighting, TV, radio etc. whilst the direct 240 V ac system provides for larger machinery, refrigerators, irons and other high energy-consuming electrical appliances.

An added advantage of such a system is that optimum use can be made of diesel stations and other generating stations of limited capacities. In the case of diesel stations which run for 12 hours only, the introduction of this system can extend the time electricity is available to the consumer to 24 hours although the battery is charged within the 12 hour period.

The limited charger system plays a major role when use with micro hydro stations where the energy output of the micro hydro stations can be stored in batteries at the consumer end. This cuts down the need for water storage demands and also the need for extensive governing of turbine speeds. The consumers form a constant load to the generating system thereby cutting excessive speed variations. A properly balanced system may even eliminate the use of governors in micro hydro schemes. It should be noted that the system is independent of frequency and voltage.

Economics of the system

In the evaluation of the system one finds that the cost of the system is relatively low. The single phase long distance wiring can be economical and the operational cost can be minimal. The spending of money at a later date to improve the system will show better cost benefit. The evaluation of the 'limited charger system' together with that of a normal system is as shown in Appendix A.

The economics of the system does not merely concern the cost but also the social benefits offered. The consideration given to the system is to provide electrical ammenities to the community which otherwise would be without any, due to technical and development constraints to the area.

In most cases of rural electrification, the load demand consist mainly of domestic and lighting load thereby economically, any rural electrification project can be proved to be financially uneconomic. Seeing it from point of system development, the capital cost incurred to supply this rural demand is not feasible, especially when the load factor of the requirements is low.

The normal alternative is to supply the demand through a 12 hour diesel electric generating system. Even this system is limited in its distribution distance capability.

The aim of the 'limited charge system' is to provide the minimum electrical ammenities such as lighting, television and radio as well as to control the load in the area served. The normal grid system will be extended once the system has established a better load demand.

Distribution design

The system proposed will extend the distribution distance considerably. Aptly the consumer end would not be subjected to low voltage since the 'limited charge system' will ensure a good voltage level. Thus a single phase line will extend much further than the normal system. This is more appropriate for rural electrification since consumer distribution is scattered. The cost incurred in developing the distribution system will serve as a basis for rehabilitation to the normal system in the future. Hence it will help to reduce the capital cost in future system improvement.

The extension of distribution system also reduce the number of distribution substation since voltage regulation is not rigid. The likelihood of using more low voltage line boosters is great. Their location will later be an appropriate location of substations for future system improvement.

Single phase 11 kV system can also be applied as means of transmission in this system. Hence cost wise it will be much lower than a three phase system. Of course limitation of distribution is governed by the ingenuity of the design engineer.

Consumer connection

The individual consumer has to bear the responsibility of taking care of the batteries. This responsibility will give them a better understanding of electrical supply facilities. They have to maintain the battery for good supply. Instructions for keeping a good battery condition have to be provided.

Metering is not done and practically no man hour will be spent by the supply authority in reading meters for billing purposes. Billing will be done on a fixed rate basis.

Conclusion

The advantages of the 'limited charger system' is obvious. The main criteria whereby this system can be used in the context of rural electrification has got to be in line with the appropriate definition of rural electrification. The attitude of the implementors, social scientists and politicians to the system is of great importance. The impact of such a rural electrification system will be tremendous if the limitation is acceptable to the rural consumer and to the electricity supply authority. With such a system being implemented one finds that a greater number of rural consumer can have the benefit of electrical energy and this means a faster development programme for rural electrification. It is also obvious that the programme of system improvement can be controlled. Operations wise the advantages seen far out-weigh existing systems. In the context of rural electrification for developing countries

one can see that this system would bring benefit to the rural people. The system in no way limits the use of electrical energy at the same time it restraints the rural consumer from wastage and unnecessary burden on his financial standing. To a utility, the system is financially viable as the cost of distribution, the stability of supply, the control of the system and the revenue collection procedures are greatly reduced as this system encourages a fixed monthly payment on use of the electrical energy.

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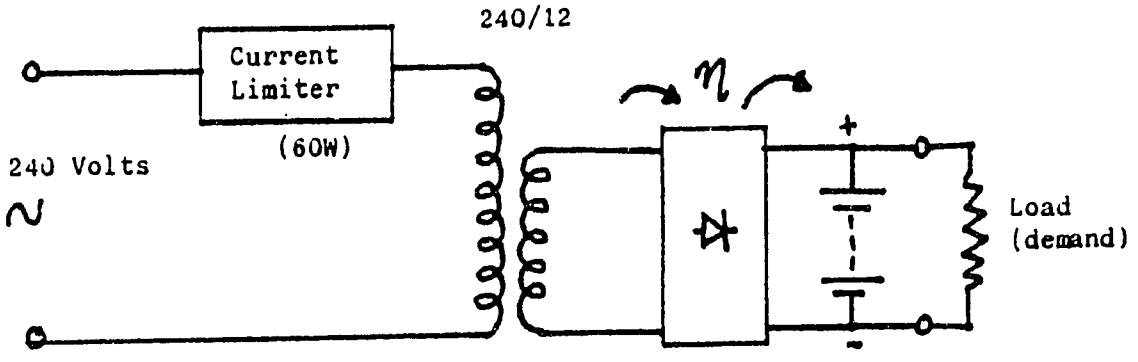
Evaluation of Limited Charger System

In calculating the individual consumer's consumption the utilisation time is important. Utilisation time is the duration the consumer uses the load. This load referred to as connected load demand. The relationship between the connected load demand with utilisation time can be shown as:

$$\text{Connected load demand} = \frac{\text{energy available per day}}{\text{Utilisation time}}$$

Consider the proposed system is as shown below:-



$$\text{Energy available/annum} = \frac{\text{rated size of current limiter} \times 24 \times 365 \times \eta}{100}$$

$$\text{Connected load demand/day} = \frac{\text{rated size current limiter} \times 24 \times \eta}{\text{utilisation time} \times 100}$$

$$= \frac{24 \times \text{rated current limiter} \times \eta}{\text{utilisation time} \times 100}$$

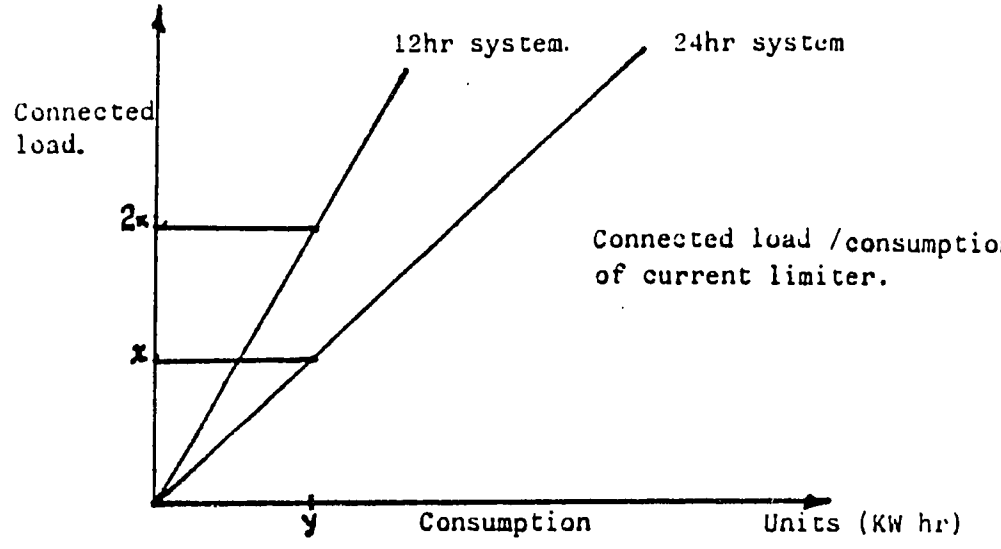
The range of utilisation time is between 0 - 24 hr.
In general the maximum demand of the consumer never reaches utilisation of more than 6 hr. per day.

$$\text{Hence connected load demand} = \frac{24 \times \text{rated size of current limiter} \times \eta}{6 \qquad 100}$$

$$= \frac{4 \times \text{rated size of current limiter} \times \eta}{100}$$

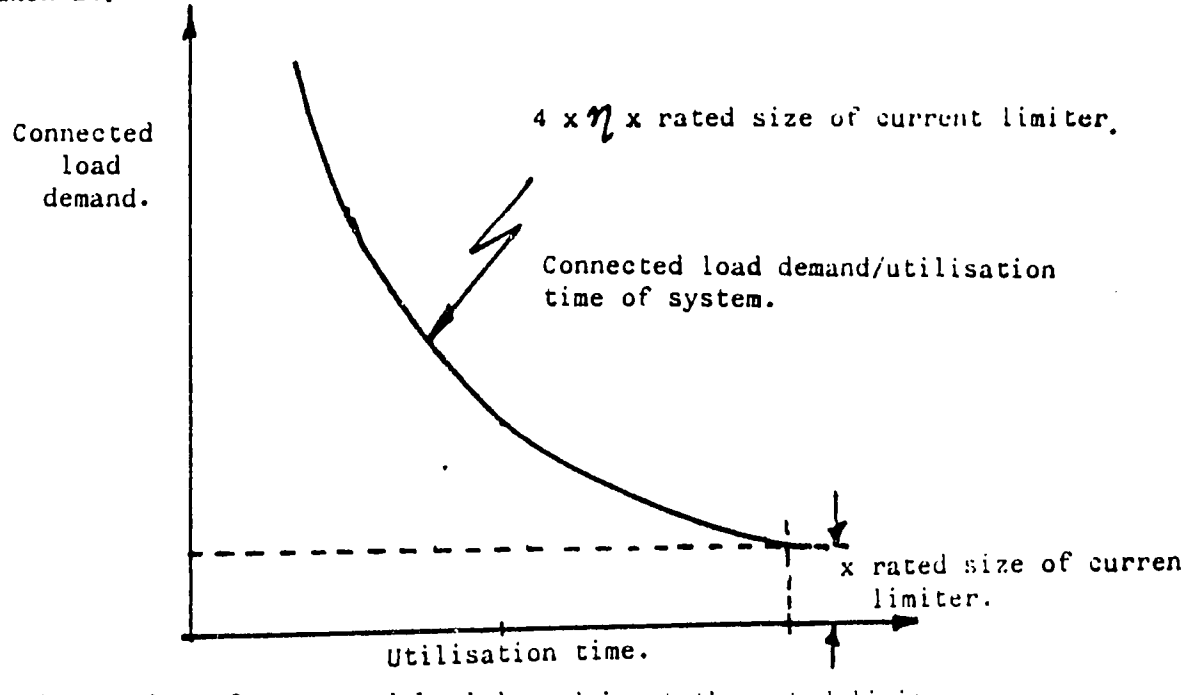
* Assuming that the battery is able only to absorb η % of the electrical energy input due to inefficiencies etc.

The current limiter connected load relationship with consumption can be drawn graphically as below:-



for y units the size of the consumption current limiter for a 24 hr. system is half that of 12 hr. system.

Also relationship of connected load demand against utilisation time can be taken as:-



The minimum value of connected load demand is at the rated limiter current value.

The definition of utilisation time as against load factor is taken because the system in consideration limits the consumer consumption to a fixed amount of energy per month.

Similarly we can visualise the connected load demand as the maximum demand of the consumer connected for any particular utilisation time. However, in the context of maximum demand, as seen from the source of supply for this system, it is limited to the rated value of the current limiter. Hence, for a consumption of 30 kWhr/month, limiter rating is about 41 W or a current equivalent of 0.167 A for a 24 hr. system.

Electrical energy consumption per month = 30 units

Consumption per day = 1 unit i.e. 100 watt-hr.

∴ for a 240 V, 24 hr. supply system, the current limiter is rated as:

$$\text{Size of limiter} = \frac{\text{watt-hour}}{24 \text{ hrs.}}$$

$$\text{say} = \frac{1000}{24}$$

$$= 41.7 \text{ watts (say 50 watts due to efficiency of charging)}$$

Hence the supply authority sees the consumers consumption as 50 watts only.

The rated voltage is at 240 Volts. However, the system supply voltage can be very much lower as earlier described.

Examples of economic evaluation

The following are the assumptions taken in the economic comparisons between the limit charger system and the normal supply system for power distribution in rural electrification:-

(a) Assumptions

For the limited charger system:

(1)	Diversity factor	=	1
(2)	Load factor	=	0.8
(3)	Individual consumption	=	30 units per month
(4)	Capital cost per consumer	=	300 M Ringgit
(5)	The distribution cost per consumer	=	1,500 M Ringgit
(6)	Fixed rate tariff per consumer	=	7.50 M Ringgit
(7)	Cost of battery (12V, 105AH)	=	150 M Ringgit
(8)	Incremental cost of battery	=	5%

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(b) Assumptions

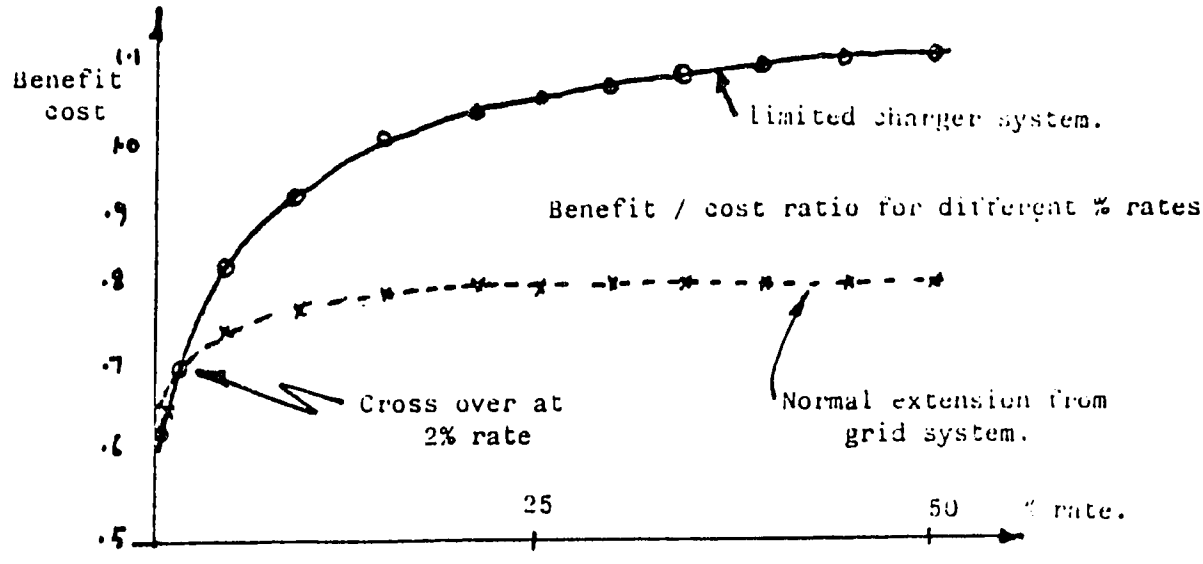
The normal grid system:

(1)	The diversity factor	=	0.6
(2)	Load factor	=	0.15
(3)	Tariff rate	=	0.25 per unit
(4)	Capital cost including contribution per consumer.	=	$1,800 M Ringgit

(c) Common data

(1)	Capacity of the source	=	25 kW per firm output
(2)	Life span of output	=	15 years
(3)	Reliability factor	=	0.9

The rate of interest is varied from 1% to 51% and the benefit to cost ratio comparing the ability of the source to supply different number of consumers is as shown in the diagram below:-

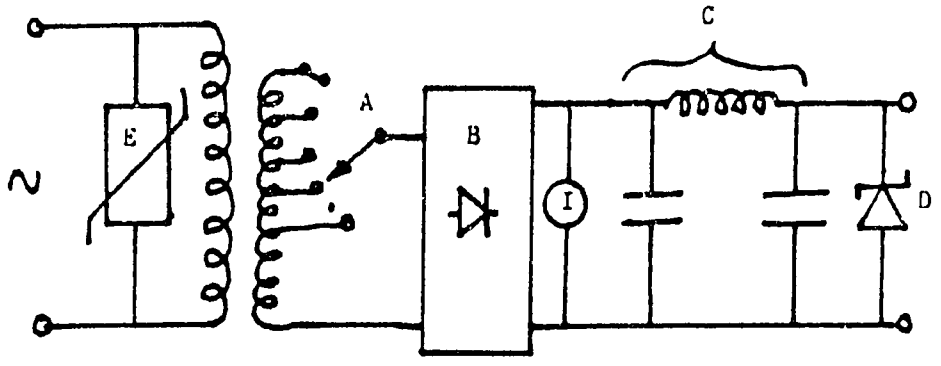


From the above graph, an imaginery system indicates that a small source (25 kW firm) is able to supply a large number of consumers who would be able to benefit more than the normal system of supply. The benefit to cost ratio of the system intersect at as low as 2% but for real cases the merits and de-merits of both the system can only be seen from the social benefit that arises in reality. This social benefit cannot be quantified. If the benefits are quantified the advantages of the limited charger system in rural electrification will over-shadow the normal system of supply.

APPENDIX 'C'

Battery Charger Types

Two types of battery chargers can be designed for the 'limited charger system'. Each type of design is dependent upon requirement, the type of source of supply, the reliability needed etc. The simplest of the two designs consist of a circuit as shown below:-

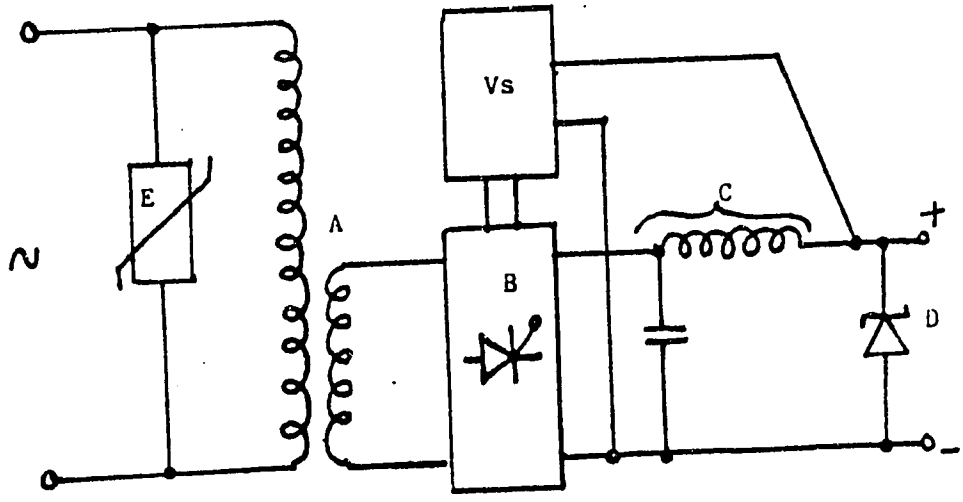


The above is a simple system where a transformer with tapped secondary winding A is connected to a rectifying unit B followed by an RC filter C. D is a zener diode for surge protection at the output of the charger. E at the primary winding of the transformer is a metal oxide varistor for lightning surge protection. I is a voltage indicator made up of light emitting diodes and zener diodes combinations which will indicate voltage levels for proper operation of the charger. A simple charger can be made by ommitting C and I.

The above charger is connected up the mains in series with the current limiter and its output is connected to the battery. In its charging operation, the switch at A is moved to a suitable tap position where indicator I indicates the most suitable tap position. Slight adjustments may be made by the consumer for his system requirements depending upon the voltage level of the mains. Once this has been set, there is no necessity for frequent future adjustment.

In the second type of design the battery charger is capable of automatic voltage regulation by maintaining an RMS output for a 50% mains voltage variations. This system is more complicated and utilises thyristor controlled circuitry for its operation. The basic

circuit of the system is as shown below:-



As in the first type, the circuit consist of the normal charger system but thyristors are incorporated in the bridge rectifier unit. Vs is a circuit which ensures the charging voltag of the charger and maintain this output for a 50% variation in the mains input voltage.

SMALL HYDRO POWER IN AFRICA
REGIONAL WORKSHOP
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A VIEWPOINT ABOUT SMALL WATER POWER DEVELOPMENTS

by Jaime Lobo Guerrero *

I. INTRODUCTION

The present paper expresses views and recommendations related to small water power based on the author's experience in Colombia and the Caribbean area during the past 8 years.The intention of the paper is to promote discussion about the subject by presenting some alternatives and untried ideas.

It should be realized that in small w ater power one is talking about hydroelectric plants starting at 0.2 KW installed capacity for single rural homes and up to say 500 KW supplying villages and or local industrial activities.Plants within the previous range,although similar in principle to the minihydro range (order of 10 MW) and the large 100 MW plants,demand a different approach in their design,development and operation. The main reason for this difference in approach stems from their small scale and in consequence comparatively small investment per plant leaving no room for costly engineering studies and skilled technical expertise for operation and maintenance.

Engineers and planners in hydropower are normally trained and geared to think big,that is huge plants;in this case thought is around many widespread tiny plants,all different and subject to the particular whims of nature.The problem is therefore larger and complicated.In large power projects one tends to ignore the end user who appears in reports as a nameless statistic.With medium and small plants you will probably meet

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the end users,talk to them and most surely they will be involved in the project right from the start.In the very smallest plants the power package has to be sold as piece of agricultural equipment leaving the end user to instal on a do it yourself basis.

II. WHAT KIND OF PROJECTS ARE THERE ?

The variety of projects is great and any attempt to classify microhydro projects is extremely difficult.One can always adopt technical criteria like high head,medium and low head type projects but perhaps it is more important to look at what is needed and what is available.In general there are two broad types of projects:those to suit scarce water resources with scarce money and those to suit abundant water resources and scarce money.Microhydro for developing countries will lie in between these cases and technology offers various alternatives for each case.Considering only the domestic type of power demand in the first type of project there is no choice but to store energy and in the second kind a run of the river type project might be appropriate but storage of energy should also be considered. Energy can be stored in va rious ways but in practical terms only reservoirs and storage batteries are attractive possibilities.

Before discussing various alternatives it is worth noting that in the past two decades there have been important technical developments that have opened the way for very small water power plants.New developments in materials,solid state electronics, home appliances and lighting have now pushed up the efficient use of electricity and reduced the power demand.Thus old criteria ruling out small developments of water power have changed and more important still is the scope to enlarge the number of people served per installed KW capacity in a hydroelectric plant.

Comparing home appliances of the 50's with the equivalent of today the efficiencies for the same service has doubled,in the case of electronics the factor is tenfold and in the case of lighting very recent developments promise a sixfold bettering. Although electric storage batteries have not changed much in 20 years efforts are now being made for something lighter,

more reliable and with more capacity per volume.

Unfortunately the nature of domestic type of power demand poses an important difficulty in small water power plants.Its non uniform and peaky character means that control is required and that one must either waste or store energy and install in equipment a sufficient capacity to cope with peaks.Under these circumstances most of the investment in a plant will remain idle and unproductive.

Various ideas have been tried to avoid this difficulty and it is felt that with very scarce resources some electricity for all is better than ample provision for a few.It often happens that through lack of knowledge electricity is missused and lies beyond the capabilities of poor communities.A case related to this problem is the idea that standards for electrical equipment and for distribution should be enforced by law when perhaps freeing the standards will probably generate ideas that can reduce the overall costs of electricity.There is no point in adopting,by enforcement,standards that do not correspond to local conditions;it is like trying to live with U.S. standards in my country where the yearly income of mar families is around one thousand dollars,there must be an appropriate standard for each situation.

The end user of electricity will rapidly learn about its efficient use if the price on energy is right.While a lot can be done with the education of the end user,the design can also incorporate ways inwhich efficient use is promoted.Take for instance the typical public utility system for towns with a high voltage grid for distribution,transformers and homewiring according to whoever's standard has been adopted.Add a meter and the innefficient incandescent bulbs and we have a system appropriate for some people who have to buy everything for their home taking into account the voltage and frequeny compatibility.On the other hand consider the same public utility delivering say every three days or so a storage battery to be hooked on to your home wiring to supply efficient D.C. lighting and appliances.Each alternative has its advantages and disadvantages but it is possible to discern which is the

most appropriate.There must be other sound possibilities which will probably be explored in the future according to technological developments.The previous discussion shows that when small water power developments are to be planned non conventional solutions should be examined all the way from the water resource to the end user.

III. SOME OPTIONS

In the included table some options for projects are shown depending on the amount of power to be eploited.These are just a few of the possible combinations for small water power projects. Of these only option 6 has not been tried to my knowledge. Purposefully the cases adopted exclude productive end use because more often these activities are a result of entrepreneurs and local effort in free dynamic societies.In other societies with a communal organization due consideration to the productive side of the plant is indispensable during the design stage.I believe that initially the domestic load should be given priority because generally speaking the industrial load will promote itself once knowhow is available.

Referring to the first option, the development of such installed power can only be done by the interested end user in order to keep costs down. A cheap reliable and flexible hydrogenerating unit that anybody can install is the main problem here, only recently have some efforts been made to put such devices on the market. The initial approach is to use standard automotive alternators and locally made turbines. Voltage regulation in order to charge the batteries without ruining them has been done with reliable electronic regulators. In short the approach is to make available on the market a simple agricultural implement that can be bought and used by farmers to provide lighting, communications and a few appliances for their homes. Electronic inverters at reasonable costs allow for transmission of power to the end user, however losses and reduced capacity limit somewhat the possibilities here.

The second, third and fourth options develop the same resource but differ widely in the number of people attended and the costs

involved. The load factors on the plants of options three and four show that they will be more expensive per potentiall user. Option four can only be a good solution when funds are scarce if something productive is done with the energy in order to increase the load factor. Option 3 is an atempt to adapt large waterpower technology to small waterpower developments and although the real plant load factor might be high the extra investments will remain idle part of the time because the design is focused on attending peak power demands. Option 2 is focused on energy demand and is economic but relies on some form of convenient transport for the batteries and the control of their charging.

Options 5 and 6 are presented to show the advantages of trying non conventional approaches to provide electricity to small villages.The greatest benefit of option 6 is the increased number of people that can be attended for a given dependable resource.As in option 2 there will be some difficulties with battery handling.

All the previous cases can not afford costly engineering studies.Different ways in which the developments can take place through self aid,using local knowhow,local technologies etc. should be promoted.

Option 7 is a typical microhydro plant for conditions of ample water power resources.The only difference between this plant and an equivalent turn of the century plant is the type of control.The recent electronic load control developed specifically for microhydro receives the power from the generator and switches the power either to suit demand or to a ballast load in order to make the turbine feel a continuous full load The costs are less than the conventional electromechanical controls and the reliability is much higher.The most interesting advantage of the electronic load control is that the reliability of the plant improves dramatically and some cost savings are attained: no moving parts except turbine and generator,flow required is constant,no control valves or gates are required,no surge protection is needed and only overspeed safety devices can be put in case of an accident.The turbines can therefore have fixed geometry with incorporated flexibility to cope with a range of

heads and flows.The generators can also be simplified somewhat in the sense that automatic regulating features within the machine are not required.

I hope that the ideas expressed in this paper will trigger questions and new ideas.I expect that conditions in Africa will be different to those in Latin America and therefore African thought will have to come with its own approach for such a large continent.

IV. ACKNOWLEDGEMENTS

I wish to thank N.R.E.C.A. from Washington for the opportunity of participating in this workshop.I am indebted to Dr. John Burton for reviewing the English paper and to Engineer Antonio Suarez for translating the paper to French of which I know a little but write very poorly.

Examples of Microhydro Projects for Domestic Loads

Alternative	Dependable Water Resource Capacity (KW)	Shaft Power (kw)	Typical Turbine efficiency	Typical Gen. efficiency	Regulation or Control	Type of energy or Power Transmission	Number of Homes Attended	Productive Energy per day (Kw-hr/DAY)	Peak Capacity (KW)	Overall efficiency & LOAD FACTOR
1	0.5 run-of-the river	.35	.7	.7	Electronic Voltage regulator	(BATT) 50 m 12 V DC. 20% Losses; BATT. Inv. 500 m 120 VAC 30% Losses	1-2	5.0 4.0	2.0 1.0	0.4 0.35 High.
2	5 run-of-the river	3.5	.7	.75	120 V AC ↓ 12 V DC Voltage Control	Batteries are transported & Distributed 20% Loss	10-20	50	20	0.4 High
3	5 storage reservoir	25	.7	.8	Mechanical Flow Control (Woodward)	Low voltage AC. 500 m	12-24	60 or more if flow permits.	20	0.5 Low
4	5 run-of-the river	3.5	.7	.8	No Control	Low voltage. A.C. 500 m	2	60	2.5	0.5 Low
5	2-20KW run of the R.	1.5 to 15	.7	.8	Electronic LOAD Control + Ballast	Low voltage A.C. 500 m	1-15	25-250	10	.55 Low
6	2-20 KW run of the R.	1.5 to 15	.7	.8	Electronic LOAD Control + BALLAST	500 m Low V. AC. Battery charger + Batteries to Distribute	4-40	20-200	2-100	0.4 HIGH
7	20-500 run-of-the R.		.8	.9	Electronic LOAD CONTROL + BALLAST	25 Km HIGH VOLTAGE T T	1 to 1.8 Kw-hrs/home-day	300-7500	12-350	0.64 LOW

W O R K S H O P O N

SMALL HYDROPOWER IN AFRICA

MARCH 1-5, 1982

Abidjan, Ivory Coast

An Overview

Zulu Hydro - Karawa, Zaire

By

Robert S. Thornbloom
CEUM Karawa, Zaire

1. INTRODUCTION:

The rapidly increasing cost of generating our own electrical power by engine driven generators and the increasing demand and need to up-grade our service has caused us to seek other sources of electrical supply.

We are presently developing a small hydro-electric potential located in the northwestern Equatorial province of Zaire. This project is sponsored by the Eglise du Christ au Zaire/CEUM, a PVO in collaboration with the G.O.Z. and funded mostly by US/AID. There is very little rural electrification in this area. Some of the larger cities are serviced with diesel generators but it was felt that it would be necessary to develop our own power source so as to provide 24 hour service to the hospital and educational facilities. Because cost and availability of fuel is a constant problem, an active effort was launched to invest in this hydro plant.

Although the initial installation cost is rather high, the low cost of operation and maintenance is very attractive. It is regretable that this was not installed several years ago, as all costs have gone up drastically in the past five years since the oil crisis. Now, it is questionable whether we could ever obtain sufficient quantities of fuel to operate diesel plants on a full 24 hour basis even if we could afford to purchase it. At present, it is rationed as is L.P. gas and gasoline.

2. SELECTION OF SITE:

The main factors in selecting a suitable site are flow, head, pondage and the cost of development.

We are fortunate to have two rivers and three possible sites near Karawa, each with its own pros and cons, which eventually led us to settle on Zulu. The Bagbau River is located 2 km. east of Karawa with a good flow (6 to 8 m^3/sec), but no natural falls. The valley narrows somewhat between two large hills but it would require a dam 600 meters long and 7 meters high to develop about 300 kw of power. The earth-fill, spillway and flood control problems are where the expense would be.

The Libala, 2.5 km. south of Karawa is a larger river with an even greater potential, but involving a greater cost in preparation of an earth filled dam requiring enormous quantities of fill with similar spillway and flood control problems. Both of these sites have the advantage of being close to the population and load centers.

Zulu, with an average flow of 5 m^3/sec., is located 11.2 km. west of Karawa in a heavily forested area. Although farther away, its advantage is in the natural falls and rapids totaling 7 meters head. Our problems are the rather long dam (350 m long by 3.5 m. high), and the length of power line to load center. Also the 11.5 km. distance involved in trucking back and forth during construction is a disadvantage in time and fuel.

3. ECONOMIC FEASIBILITY AND END-USE:

It is very important to get a clear idea of the relative cost as

soon as possible. These will be estimates at best, with inflation and short supply causing some very high spiking at times. Major areas of expense should be isolated with emphasis on quantities (cubic meters, tons, barrels of fuel, man hours, etc.) to facilitate computing actual dollar cost as price and conditions change.

In our case, for example, cement was Z2,89 when we originally wrote the project in 1977. We budgeted Z6,00 to allow for inflation. By 1979, when we purchased our first sack, cement was Z16,00. It then proceeded to jump in price to Z24,00 and Z32,00 and Z60,00 during 1980 and 1981. Now, in 1982, we are purchasing cement for Z75,00 with our next 1000 sacks slated for Z100,00 each. Handling and transportation costs are increasing right along with the purchase costs.

There are costs of supportive activities which also must be realized. Building access roads to reach the aggregate and fill areas, possibly an airstrip to receive supplies, and sometimes the main roads and bridges need repairs. Should these become a part of your hydro project or will they be developed by other sources? Will they be useful to the area during and after the project? Will you be able to consider them as a long-range benefit to the area?

Equally important is a listing of end-use and benefits. There are many changes that affect a community when a source of power is developed. It is important to estimate and give a dollar value where possible to the various benefits to and from your project directly and the ripple effect to the area. Fortunately in many cases, the

value of the output also increases as the cost of development increases. Therefore, your end products remain competitive, particularly as you project these values over a long life and when you consider the increasing fuel costs.

The benefits list is most noticeably led by the decreased dependance on fossel fuels. Availability and cost have been a big problem to most of us. A more dependable source of power helps all departments know better how to plan, and will greatly reduce operating cost which is passed on to those we serve as a P.V.O.

In the Medical Service, we are planning on better lighting in wards and work areas, lab equipment that need a constant source of power such as incubators and refrigerators, air conditioning (offering a cleaner and increased sterile work situation in the operating rooms as well as more comfort in the hot climate), as well as cold storage for film and pharmaceuticals. Auto-claving requires a significant load on the power source (7 to 10 kw each) and is a very necessary and often used piece of equipment. Laundry and water heating are also essential expenditures of energy if the hospital is to be efficient and proper.

The Educational department will have better lighting for studying and power for lab equipment and audio-visual equipment. Staff dwellings will need power for lighting and house-hold needs.

Technical Services will have a greater flexability to use power tools, and lights in their task of keeping the community functioning. A hammermill will produce corn and manioc flour for the community and village near-by.

Hopefully, these time-saving benefits will result in some of the many secondary benefits as the ripple effect moves out to touch more people. If this stimulates more food production, better nutrition and health care and improved education opportunities at a reduced unit cost, then our goal will be achieved. We would like to think that more leisure time would mean more time with the family, more time for self-improvement, and hopefully advancement from the subsistance level to a more rewarding life style.

4. SCHEDULE OF ACTION:

It is important to plan movements, supply lines, labor pools, as well as construction steps to the fullest. One needs to consider the weather conditions, dry season durations, river levels for coffer dams and river transport. When delays occur, you must be ready with alternate solutions which may often tax your ingenuity.

Because machinery is not readily available, we depend on manual labor to carry out much of the civil works. Delays may occur due to shortage of manpower during prime dry season time as work in the garden keeps people home. Due to lack of semi-skilled help, it may be necessary to do "on the job" training which takes time and personnel capable of training.

When possible, plan so as to complete a given portion of the project which when ready will yield a benefit to the area or facilitate the completion of the construction.

In our case, we hope to operate the smaller turbine at 1/3 capacity mainly on the flow of the river while completing the dam

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to full height. It will not necessarily cut construction cost, but it will feed three times the power to our community that we presently have with diesel generator sets.

5. SOURCES OF EQUIPMENT:

There are many suppliers of small hydro equipment on the World Market. In our case, we are using Leffel and Ossberger Turbine units. Both have many years of experience and have been very helpful in planning and working out needed information. Their units are complete and are supplied with plans to bolt into place.

We have also used the US/AID/E.P.D. as a source of very good equipment including dump trucks, compressors and fuel and water tanks.

Almost all commodities in our project have come from out of the country with the exception of a Penstock that was fabricated in Kinshasa, the capital city of Zaire. We have been able to adapt used equipment in some cases to keep things going. Our Technical Services has had many years experience in trying to keep equipment in service. We deal mainly with small trucks, pumps, and generator sets in the 2 to 15 kw. range.

6. IMPLEMENTATION:

Briefly, these are some of our problems and observations as to the effect of the Zulu hydro-electric project.

Funds:

Delays in permissions for transfer.
Delays in the Bank up to 7 months.
Short supply of currency during exchange of new Zaire bills.
Short supply of currency during coffee season.

Technical Assistance: Secure good consultants in several areas of expertise.

Procurement:
Need more time to find supplies than expected.
Need to keep more stock on hand than anticipated
Need good communication system between site and home base.
Need alternate transportation facilities.

Equipment:
Need two of any key unit on hand, or the ability to rent a similar unit.
Example: Our loader was down for 11 months waiting for parts and repair.

Labor:
Skilled and semi-skilled work force is not always available. You may need to train local people in even the basic skills.
Professional training delays of 1½ years, when technical courses offered in schools were cancelled.
Unskilled Labor Pool - how large a pool is available during the crucial times of the project as well as during the duration of the project. (We needed our pool during the local garden cutting time when many wanted to be excused from work.)
Need good supervision from within local culture.

Compensation:
If the payscale is too low to attract labor, try Bonus Systems for attendance and good performance.
Incentives: food rations on the job, PX sale of common goods at favorable prices to work force (machettes, shoes, soap, salt, meat, lumber, etc.).
Provision of uniforms and caps.
Medical care in the form of first-aid on the job site as well as near-by hospital care.
Insurance for accidents.

Public Relations:
Invite local government officials to visit and take tours of project site.
Credit and recognize all who have had a part in the project including those responsible for land permissions, project permissions, funding and donors, technical assistance, and contribution in kind of supplies and labor.

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Energie Hydroélectrique à Petite Echelle en Afrique

Abidjan, Côte d'Ivoire
1-5 mars 1982

Programme de la Conférence

sous le parrainage conjoint de:

la Banque Africaine de Développement (BAD)

l'Union des Producteurs, Transporteurs et Distributeurs d'Energie Electrique des Pays Africains (UPDEA)

la National Rural Electric Cooperative Association des Etats-Unis (NRECA)

l'Agence des Etats-Unis pour le Développement International (AID)

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Energie Hydroélectrique à Petite Echelle en Afrique

Lundi 1er mars

PREMIÈRE SESSION GÉNÉRALE:
Discours de Bienvenue et d'Introduction

8 h **Inscription**

8 h 30 **Appel à l'Ordre**

Président de Conférence:

G. Dossou
Directeur de la Division Infrastructure et Industrie
Banque Africaine de Développement

8 h 40 **Discours de Bienvenue**

Sera annoncé ultérieurement
Banque Africaine de Développement

Kana Mutombo
Secrétaire Général
de l'Union des Producteurs, Transporteurs et Distributeurs de l'Energie Electrique des Pays Africains

Gordon W. Evans
Directeur du Bureau Régional des Services du Développement Economique pour l'Afrique Occidentale
USAID

David Zoellner
Directeur du Programme des Petites Centrales Hydrauliques Décentralisées (SDH)
NRECA

9 h 30 **Exposé Principal**

Konan Lambert
Directeur Général de l'Energie Electrique de la Côte d'Ivoire

10 h **Pause-Café**

10 h 30 **Présentation de Diapositives**

10 h 45 **Exposé: Introduction à la Technologie et au Développement des Petites Centrales Hydroélectriques**

Maurice Albertson
Professeur au Département du Génie Civil
Université de l'Etat du Colorado

11 h 30 **Déjeuner**

DEUXIÈME SESSION GÉNÉRALE:
Etude de Certaines Petites Centrales Hydroélectriques

14h **Afrique: Côte-d'Ivoire**

Small-Scale Hydropower in Africa

Monday, March 1

FIRST GENERAL SESSION:
Welcome and Introduction

8:00 a.m. **Registration**

8:30 a.m. **Call to Order**

Workshop Moderator:

G. Dossou
Director, Infrastructure and Industry Division
African Development Bank

8:40 a.m. **Welcome Speeches**

To Be Announced
African Development Bank

Kana Mutombo
Secretary General
Union of Producers, Conveyors, and Distributors of Electrical Energy to African Nations

Gordon W. Evans
Director, Regional Economic Development Services Office/West Africa
USAID

David Zoellner
Program Manager
Small Decentralized Hydropower Program
NRECA

9:30 a.m. **Keynote Address**

Konan Lambert
Director General
Energie Electrique de la Côte d'Ivoire

10:00 a.m. **Coffee Break**

10:30 a.m. **End-Use Slide Presentation**

10:45 a.m. **Paper: Introduction to Small Hydro Technology and Development**

Maurice Albertson
Professor, Civil Engineering Department
Colorado State University

11:30 a.m. **Lunch**

SECOND GENERAL SESSION:
Small Hydropower Case Studies

2:00 p.m. **Africa: Ivory Coast**

Energie Hydroélectrique à Petite Echelle en Afrique

Diby Kroko
Directeur des Etudes et de la Recherche Technologique
Energie Electrique de la Côte-d'Ivoire

14 h 30 **Amérique Latine: Equateur**

Eduardo Moran
Conseiller
Institut Equatorien de l'Energie

15 h **Asie: Pakistan**

Mohammad Abdullah
Professeur et Chef du Département d'Electrotechnique
Université NWFP d'Engineering et de Technologie

15 h 30 **Afrique: Zaïre**

Mulamba Wa Kabasele
Département d'Engineering
Université du Zaïre

16 h **Pause-Café**

16 h 30 **Discussions: Systèmes de Petites Centrales Hydro-électriques Rurales**

Président:

Clarence Kooi
Conseiller en matière d'Energie
Bureau Régional des Services du Développement Economique pour l'Afrique Occidentale USAID

18 h **Levée de Session**

18 10 **Réception: Présentation des Participants**

Mardi 2 mars

TROISIÈME SESSION GÉNÉRALE:
Sélection du Site

8 h 30 **Appel à l'Ordre**

8 h 30 **Présentation de Diapositives: Projets de Petites Centrales Hydroélectriques**

Allen Inversin
Ingénieur en Micro-Centrales Hydrauliques
Programme des Petites Centrales
Hydroélectriques Décentralisées
NRECA

9 h 15 **Exposé: Méthodologies Concernant l'Estimation Hydrologique**

Paul Kirshen
Expert-Conseil en Ressources Hydrauliques

Small-Scale Hydropower in Africa

Diby Kroko
Director of Studies and Technological Research
Energie Electrique de la Côte d'Ivoire

2:30 p.m. **Latin America: Ecuador**

Eduardo Moran
Advisor
Ecuadorian Energy Institute

3:00 p.m. **Asia: Pakistan**

Mohammad Abdullah
Professor and Head, Electrical Engineering Department
NWFP University of Engineering and Technology

3:30 p.m. **Africa: Zaire**

Mulamba Wa Kabasele
Department of Engineering
University of Zaire

4:00 p.m. **Coffee Break**

4:30 p.m. **Panel: Rural Small Hydro Systems**

Moderator:

Clarence Kooi
Energy Advisor, Regional Economic Development Services Office/West Africa
USAID

6:00 p.m. **Adjournment**

6:10 p.m. **Get-Acquainted Reception**

Tuesday, March 2

THIRD GENERAL SESSION:
Site Selection

8:30 a.m. **Call to Order**

8:30 a.m. **Slide Presentation: Small Hydropower Schemes**

Allen Inversin
Micro-Hydro Engineer
Small Decentralized Hydropower Program
NRECA

9:15 a.m. **Paper: Hydrologic Assessment Methodologies**

Paul Kirshen
Water Resources Consultant

Energie Hydroélectrique à Petite Echelle en Afrique

10 h Pause-Café

10 h 30 Discussions en Commissions: Evaluation des Ressources et Sélection du Site

12 h Déjeuner

QUATRIÈME SESSION GÉNÉRALE:
Développement du Site et Sources D'Equipement

14 h 30 Exposé: Développement du Site et Emplacement de la Turbine

Sera announcé ultérieurement

15 h 15 Exposé: Conception de l'Equipement et Possibilités de Fabrication Locale

Reinhold Metzler
Assistant de Recherches et Ingénieur-Conseil
Université Technique de Furtwangen

16 h Pause-Café

16 h 30 Discussions en Commissions: Développement du Site et Sources d'Equipement

18 h Levée de Session

Mercredi 3 mars

8 h Départ pour une Sortie d'Etude sur le Terrain (Aboisso)

19 h Réception

19 h 45 Banquet

Orateur d'Honneur:

Gordon W. Evans
Directeur du Bureau Régional des Services du Développement Economique pour l'Afrique Occidentale
USAID

Small-Scale Hydropower in Africa

10:00 a.m. Coffee Break

10:30 a.m. Workshop Discussion Groups: Resource Assessment and Site Selection

12:00 p.m. Lunch

FOURTH GENERAL SESSION:
Site Development and Sources of Equipment

2:30 p.m. Paper: Site Development and Turbine Setting

To Be Announced

3:15 p.m. Paper: Equipment Design and Local Manufacturing Opportunities

Reinhold Metzler
Research Assistant and Consulting Engineer
Technical University of Furtwangen

4:00 p.m. Coffee Break

4:30 p.m. Workshop Discussion Groups: Site Development and Sources of Equipment

6:00 p.m. Adjournment

Wednesday, March 3

8:00 a.m. Departure for Field Trip (Aboisso)

7:00 p.m. Reception

7:45 p.m. Banquet

Guest Speaker:

Gordon W. Evans
Director, Regional Economic Development Services Office/West Africa
USAID

Energie Hydroélectrique à Petite Echelle en Afrique

Jeudi 4 mars

CINQUIÈME SESSION GÉNÉRALE:
Faisabilité Economique et Applications

8 h 30 **Appel à l'Ordre**

8 h 30 **Exposé: Faisabilité Economique et Rendement Economique**

Tobie Lanou
CH_2M Hill

9 h 15 **Exposé: Planification des Applications**

Daniel Boyle
Spécialiste des Mini-Centrales Hydroélectriques
Programme des Petites Centrales Hydrauliques Décentralisées
NRECA

10 h **Pause-Café**

10 h 30 **Discussions en Commissions: Faisabilité Economique et Applications**

12 h **Déjeuner**

SIXIÈME SESSION GÉNÉRALE:
Coûts et Financement

14 h 30 **Exposé: Coûts Relatifs Aux Petites Centrales Hydroélectriques**

Paul Clark
Spécialiste de la Formation et de l'Information
Programme des Petites Centrales Hydrauliques Décentralisées
NRECA

15 h 15 **Exposé: Stratégies et Planification du Financement**

Douglas Gardner
Directeur de l'Application sur le Terrain pour la Haute-Volta, le Niger et le Mali
Fonds des Nations Unies Pour le Développement des Capitaux

16 h **Pause-Café**

16 h 30 **Discussions en Commissions: Coûts et Financement**

18 h **Levée de Session**

Small-Scale Hydropower in Africa

Thursday, March 4

FIFTH GENERAL SESSION:
Economic Feasibility and End-Uses

8:30 a.m. **Call to Order**

8:30 a.m. **Paper: Economic Feasibility and Economic Returns**

Tobie Lanou
CH_2M Hill

9:15 a.m. **Paper: End-Use Planning**

Daniel Boyle
Mini-Hydro Development Specialist
Small Decentralized Hydropower Program
NRECA

10:00 a.m. **Coffee Break**

10:30 a.m. **Workshop Discussion Groups: Economic Feasibility and End-Uses**

12:00 p.m. **Lunch**

SIXTH GENERAL SESSION:
Costs and Financing

2:30 p.m. **Paper: Cost Implications of Small Hydropower Systems**

Paul Clark
Training and Information Specialist
Small Decentralized Hydropower Program
NRECA

3:15 p.m. **Paper: Financial Strategies and Planning**

Douglas Gardner
Field Implementation Manager for Upper Volta, Niger, and Mali
U.N. Capital Development Fund

4:00 p.m. **Coffee Break**

4:30 p.m. **Workshop Discussion Groups: Costs and Financing**

6:00 p.m. **Adjournment**

Energie Hydroélectrique à Petite Echelle en Afrique

Vendredi 5 mars

SEPTIÈME SESSION GÉNÉRALE:
Questions Relatives à la Gestion

8 h 30 **Appel à l'Ordre**

8 h 30 **Exposé: Développement Institutionnel pour la Gestion de Petites Centrales Hydroélectriques**

Richard Brown
Président
Institut de Recherches Sociales de Washington

9 h 15 **Exposé: Formation, Fonctionnement et Entretien dans la Gestion des Petites Centrales Hydroelectriques**

Sera annoncé ultérieurement

10 h **Pause-Café**

10 h 30 **Discussion: Gestion—Approches Locales Contre Approches Centralisées**

Président:

David Zoellner
Directeur de Programme
Programme des Petites Centrales Hydroélectriques Décentralisées
NRECA

12 h **Déjeuner**

HUITIÈME SESSION GÉNÉRALE:
Clôture de la Conférence

14 h 30 **Sera annoncé ultérieurement**

15 h 15 **Discussions en Commissions: Gestion et Etude des Impacts**

16 h 45 **Pause-Café**

17 h 15 **Résumé et Clôture de la Conférence**

David Zoellner
Directeur de Programme
Programme des Petites Centrales Hydroélectriques Décentralisees
NRECA

18 h **Levée de Session**

Small-Scale Hydropower in Africa

Friday, March 5

SEVENTH GENERAL SESSION:
Management Issues

8:30 a.m. **Call to Order**

8:30 a.m. **Paper: Institutional Development for Managing Small Decentralized Hydropower Systems**

Richard Brown
President
Washington Institute for Social Research

9:15 a.m. **Paper: Training, Operation, and Maintenance in the Management of Small Hydropower Systems**

To Be Announced

10:00 a.m. **Coffee Break**

10:30 a.m. **Panel: Local vs. Centralized Management Approaches**

Moderator:

David Zoellner
Program Manager
Small Decentralized Hydropower Program
NRECA

12:00 p.m. **Lunch**

EIGHTH GENERAL SESSION:
Workshop Conclusion

2:30 p.m. **To Be Announced**

3:15 p.m. **Workshop Discussion Groups: Management and Impact Evaluation**

4:45 p.m. **Coffee Break**

5:15 p.m. **Summary and Conclusion**

David Zoellner
Program Manager
Small Decentralized Hydropower Program
NRECA

6:00 p.m. **Adjournment**