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Small-Scale Hydropower in Africa

Workshop Proceedings

March 1-5, 1982
Abidjan, Ivory Coast

Cosponsored by:

African Development Bank
Union of Producers, Conveyors, and Distributors of Electrical Energy in Africa
National Rural Electric Cooperative Association
U.S. Agency for International Development

SMALL DECENTRALIZED HYDROPOWER PROGRAM

This publication is one of a series that fosters the effective use of small decentralized hydropower systems. This series is published by the Small Decentralized Hydropower (SDH) Program, International Programs Division, National Rural Electric Cooperative Association (NRECA). NRECA manages the SDH Program under the terms of Cooperative Agreement AID/DSAN-CA-0226 with the Office of Energy, Science and Technology Bureau, U.S. Agency for International Development.

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- Creating specialized products such as productive-use plans for energy from small decentralized hydropower.

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1

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In memoriam . . .

William L. Eilers
1924-1983

2

TABLE OF CONTENTS

ACKNOWLEDGEMENTS iii

OVERVIEW 1

Introduction 3
David Zoellner

Hydropower Development in the Sub-Saharan African Countries 5
Lambert Konan

Introduction to Small Hydropower Technology and Development 9
Maurice L. Albertson

CASE STUDIES 17

The Future of Small Hydropower in the Ivory Coast 19
Diby Marcel Kroko

The Micro-Hydroelectric Generation Program of Ecuador 23
Eduardo Morân

Micro-Hydroelectric Schemes in Pakistan 27
Mohammad Abdullah

Small Hydroelectric Power Development in Zaire 31
Mulamba wa Kabasele

An Overview: The Zulu Hydropower Project 37
Robert S. Thornbloom

TECHNICAL CONSIDERATIONS 41

Small Hydropower Schemes (A Slide Presentation) 43
Allen R. Inversin

Hydrologic, Environmental, and Geologic Factors in Mini-Hydropower Site Selection 47
Paul H. Kirshen

Hydrologic Data Requirements for Developing Small Hydropower Sites 63
Walter D. Lawrence

Equipment Design and Local Manufacturing Opportunities 67
Reinhold Metzler

An Electronic Load Governor and Related Developments 75
Jack L. Woodward

A Viewpoint about Small Waterpower Developments 79
Jaime Lobo Guerrero

A Radical Approach to Rural Electrification for Developing Countries 83
Hoesni Nasaruddin

ECONOMIC CONSIDERATIONS 89

Economic Feasibility Analysis of Small Hydropower Projects 91
Tobie E. Lanou

End Use of Mini-Hydropower 97
Daniel J. Boyle

Cost Implications of Small Hydropower Systems 105
Paul J. Clark

Financing Small Decentralized Hydropower 115
Douglas Gardner
with comments by Gaston Dossou

Cost Aspects of Mini-Hydropower Systems 121
Jack J. Fritz

Electricity Tariffs for Rural Communities 127
Shashi C. Desai

INSTITUTIONAL CONSIDERATIONS 129

Management Approaches to Small Hydropower Systems 131
Richard H. Brown

Management, Training, Operation, and Maintenance of Small Hydropower Plants 137
Rupert Armstrong Evans

Institutional Aspects of Mini-Hydropower Programs 141
Jack J. Fritz

Management Considerations for Small Hydroelectric Powerplants 145
Hédi Messolli

Staffing and Record-Keeping for Mini-Hydropower Plants 147
Aboki Semanou

The Process of Introducing Hydropower to Rural People 151
Anton Soedjarwo

Legislative Contributions to Private-Sector Development of Small Hydropower Plants 153
Donal T. O'Leary

CONCLUSION 163

Summary of the Aboisso Small Hydropower Working Group Exercise 165
Paul H. Kirshen

Closing Remarks 171
Gaston Dossou

LIST OF PARTICIPANTS 173

4

OVERVIEW

Introduction
David Zoellner

Hydropower Development in the Sub-Saharan African Countries
Lambert Konan

Introduction to Small Hydropower Technology and Development
Maurice L. Albertson

Introduction

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Of the world's estimated 2.2 million MW of exploitable hydropower resources, some 360,000 MW or 16% of that total is found in Africa. Yet less than 5% of Africa's power potential has been developed, leaving untouched nearly 340,000 MW, or more than twenty times the existing total electric power capacity in all of Africa (1).*

The significance of these figures grows in light of the region's economies, which, according to the World Bank, are expanding at twice the rate of the world's industrial countries, and which are severely limited by the need for indigenous energy supplies. Donatien Bihuté, Vice President of the African Development Bank, underscored this dilemma in his opening remarks to the first plenary session of this workshop, "Small-Scale Hydropower in Africa." The per capita commercial energy consumption rate in Sub-Saharan Africa is one-fourth that of the developing countries as a whole, and roughly one-twentieth the world-wide energy consumption rate. Most of the energy consumed is supplied by thermal sources which rely on imported petroleum, adding to the economic burdens borne by the region's countries. The current-account trade deficit of the oil-importing developing countries, which characterizes all but six of the 52 African developing countries, was $80 billion in 1981. An economic drain of this magnitude makes the task of investing in new energy sources all the more difficult and dictates that spending choices among competing options undergo rigorous examination to capture the highest possible return.

Against this background, then, the purpose of this workshop is to better enable the developing countries of Africa to identify the ways and means of making practical, economic use of small decentralized hydropower resources.

Kana Mutombo, Secretary General of the Union of Producers, Conveyors, and Distributors of Electrical Energy in Africa, noted in his welcoming speech that successful development of small hydropower is achieved only when the cost of providing the energy to consumers is compatible with their means to pay for it. The objective of the week's deliberations, therefore, is not to understand how small hydropower plants are constructed, but rather how they may be developed in the context of the particular needs and constraints of the African nations.

Thus, this workshop does not just focus on the technical aspects of small hydropower development. Indeed, the design and construction of small hydropower plants are quite straightforward, once the technical approach to their development has been established. The issue of selecting the proper technical approach is itself subject to a wide range of institutional and socio-economic factors; but apart from these, other, more challenging issues, such as system management, end-use planning, and financing small hydropower plants are also reviewed. The technical approach, on the one hand, determines the initial capital cost; but the integration of the constructed unit into the overall development program—including the institutional framework—determines, on the other hand, the ultimate life-cycle cost of the project and its overall value as an instrument for development. Together, both aspects may determine whether financing will be available to undertake the project.

As pointed out by Gordon Evans, Director of USAID's Regional Economic Development Services Office for West Africa, it is essential to recognize that small-scale hydropower is different from large-scale hydropower development. At the larger end of the power range, from 500 kW to 5 MW and beyond, small hydro can displace thermal generation supplying the national power grid on a considerable scale. At the lower end of the power range—under 50 kW—it may only provide enough energy to satisfy the needs of a handful of homes in a city; but it can and has provided sufficient energy to serve entire villages and small rural towns, where energy requirements are more modest.

Since the capacity range possible with small hydropower development is wide—from a few kilowatts to several megawatts—different styles of development are also possible. The argument is often made that economies of scale increase costs of smaller plants. This argument has proven true where plants are built while adhering to conventional approaches, but it overlooks the fact that as plant size is reduced below a certain point—roughly 100 kW—the degree of complexity required can also be reduced, permitting cost-cutting techniques which are not possible with conventional approaches.

This workshop examines both styles of development—conventional and unconventional—in search of the most cost-effective means to design and construct plants.

* Excluding the Republic of South Africa.

Furthermore, implementation means more than the design and construction of small hydropower plants. If the plant is not connected to the national power grid, what will be the uses of the power? Whose needs will be served? What steps are to be taken to ensure growth in demand, and what planning is needed to meet demand growth? What management system is appropriate, and are the direct beneficiaries of the energy to be involved in the design or maintenance of the plant? What are the possible sources of financing, and what are the criteria by which funding decisions will be made? How can the various national and local agencies coordinate their activities to ensure a viable small hydro program?

Each of these questions may be answered differently, depending on the size, purpose, and nature of the project. The overall design, equipment standards, end uses, management structure, and financial approach for 1 MW and 10 kW schemes are likely to be—and should be—quite different. Problems occur when the same solutions are applied to both. That is the essential lesson to be learned from the experience of developing countries in small hydropower development.

Above all, the workshop has been designed to expose representatives from African developing countries to this experience, to allow them an opportunity to learn from the successes and failures of others. This workshop has assembled experts from Pakistan, Ecuador, Malaysia, Great Britain, Indonesia, Colombia, Germany, New Zealand, Zaire, Ivory Coast, Morocco, Liberia, Upper Volta, and the United States, all with experience in differing approaches to small hydropower development, for this purpose. Through a series of lectures, workshop discussions, case study presentations, panel discussions, and a working group exercise, solutions to problems and issues common to developing countries in small hydropower development are discussed in detail.

The benefits of this workshop will be reflected only in what happens beyond the meeting rooms of the African Development Bank, the site of the workshop. The discussions during the workshop in Abidjan must lead to further discussions, among the participants themselves in their various countries, about the potential which exists and how to develop it. The workshop exercises must lead to the development of practical methodologies to assess the small hydropower resources and to select projects with appropriate designs, end uses, management systems, and financing approaches. The field exercise in Aboisso and the case studies of the Ivory Coast, Ecuador, Pakistan, and Zaire will be useful only to the extent that they establish an understanding that different design approaches may be feasible in developing actual project sites.

This workshop has served as a forum for a range of ideas. The participants are now left with the crucial tasks of exploring the appropriateness of any of a number of approaches to developing small hydropower resources in their respective countries and of then developing this potential.

REFERENCE

1. NRECA. Proceedings of NRECA workshop on Small Hydroelectric Powerplants, Quito, Ecuador, August 1980. Washington, DC: National Rural Electric Cooperative Association, 1981.

Hydropower Development in the Sub-Saharan African Countries

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INTRODUCTION

Third World countries are constantly beset by enormous and varied difficulties that frustrate the plans of their political and technical authorities. In the past decade, a world-wide energy crisis, the deterioration of the exchange policy, the scarcity of equipment funding, and inflation have conspired to make the problem of energy supply particularly difficult.

The African countries are not exempt from these difficulties. On the contrary, as countries which only recently won their independence, they seem more vulnerable to the energy crisis than other countries.

This workshop, and other initiatives like it, are sorely needed to allow African authorities an opportunity to become better informed about the potential of indigenous resources such as small hydropower.

The sponsoring organizations of the workshop are eminently capable of assisting in this important effort, based on their considerable familiarity with the problems of rural development. About 1,000 rural electric cooperatives, members of the National Rural Electric Cooperative Association, have been working jointly in the field of rural electrification for about 40 years; the African Development Bank, for about 20 years; and about 20 electrical societies, members of the Union of Producers, Conveyors, and Distributors of Electrical Energy in Africa (UPDEA), for more than 10 years.

It is in this essential field of energy supply that African countries are encountering serious difficulties. The reasons for these difficulties are many, among them:

- Lack of adequate industrial infrastructure,
- Lack of local skilled manpower,
- Inadequate financial resources,
- Deterioration of the international exchange system.

Above all, the efforts of these countries to resolve their difficulties have been further handicapped by the unwillingness of the industrialized nations, which are motivated by self-interest, to view these problems from the African point of reference.

LACK OF KNOWLEDGE OF ENERGY RESOURCE POTENTIAL

The Sub-Saharan African nations know very little about their actual resource potential, although experts agree that it is immense, equaling that of the rest of the continent. This lack of knowledge is largely due to the lack of adequate exploration. Most of the countries that today boast of programs to research petroleum resources had to wait until very recently for foreign companies to become interested in the search for oil in Sub-Saharan Africa.

However recent this prospecting has been for oil, it remains almost nonexistent for uranium or coal, and slow for hydropower potential. Even though numerous important hydroelectric projects exist, the resource assessment usually has been undertaken on individual sites, and not in a comprehensive national, or regional, manner. Therefore, it is not surprising that, in the energy resource field, most of the costs for Africa, and for much of the Third World, are only estimates.

The first long-term assessment of the energy perspectives in the developing countries was not published until September 1980, on the occasion of the 10th World-Wide Energy Conference held in Munich, Federal Republic of Germany (1). This study had been requested in 1978 by the Ad Hoc Committee on Energy Problems of the Developing Countries, created during the meeting of the International Executive Council of the CME in Banff, Canada. The "regionalist" approach adopted during this meeting allowed data on the energy realities of Third World countries to be understood. These data show that Africa possesses immense resources with 25%-30% of the world-wide hydropower potential; yet, only a very small portion of it presently used.

Another explanation for the lack of knowledge about Africa's indigenous energy resources is that the Africans do not participate in the resource assessment, the analysis of data, or the interpretation of the results of this analysis. Because they do not participate, they ignore most of the discoveries in their respective countries.

* Excluding the Republic of South Africa.

8

LACK OF INDUSTRIAL INFRASTRUCTURE

The same is true for the resource development stage as for the resource assessment stage, since African countries lack the industrial infrastructure required to develop their energy resources. Even in the hydroelectric field, well-known for its capacity to generate an important additional benefit, all of the electromechanical equipment must be imported, and foreign consulting firms still undertake the engineering. Consequently, the Africans have no control over the costs of the energy equipment projects; a third party determines the price of the energy necessary to the development of their countries.

Therefore, training assumes economic importance in this particular field, because it is more essential than ever to build "an original, creative, and interdependent economy where the infrastructure of goods must not exclude the training of men." The experience of the oil-producing Arab countries demonstrates that such an economic policy fosters, at the very least, the acquisition of bargaining power. Felix Houphouet-Boigny, President of the Ivory Coast, recently said:

> The day we stop selling our raw materials as we have been doing until now, and the day we have the capability to develop, independently, our nation's agricultural resources and minerals, will be the day we speak another language, the language of respect of the interests concerned.

Protecting their respective interests is the real stake in negotiations between the developed and the developing countries. The Africans want fair payment for their raw materials to be able to reimburse their debts. Unfortunately, the poor countries are obliged to incur further debt to the industrialized countries in order to speed up their own industrialization, which should allow them to produce about 25% of the world's energy supply by the year 2000.

LACK OF DECENTRALIZATION

The absence of decentralization also aggravates the energy supply problems of the African countries. The centralized nature of many of their energy-generating operations generally requires the energy produced by a given site to be transported over long distances to the development center, which is almost invariably the capital city and its immediate surroundings.

Other difficulties are unique to the hydroelectric energy field. This energy, abundant in wooded areas, becomes increasingly scarce north of the the Equator and disappears completely in most of the Sahelian countries. Even in forest areas, the local topography does not always allow the construction of cost-effective dams, because the necessary equipment requires flow of up to several million cubic meters for even a small-scale hydropower site.

Such difficulties frequently have led to the neglect of small hydropower plants in favor of isolated diesel plants fueled by expensive distillate diesel oil. Because oil costs have risen repeatedly since 1973, however, the oil-importing countries have attempted to diversify their energy sources in order to obtain a measure of energy independence.

In the Ivory Coast, the consequences of these cost increases were immediate. So was the reaction of the authorities responsible for the energy sector.

Before the first oil embargo in 1973, the Energie Electrique de la Côte d'Ivoire (EECI) was able to maintain its financial equilibrium without increasing rates, although the electrical energy is produced mostly by thermal powerplants. These rates remained unchanged from 1964 to 1973. As soon as the price of oil rose, it became necessary to increase the rates. This policy of passing on cost increases through rate increases could not continue through the numerous price hikes without risk of serious consequences. Therefore, the Ivory Coast could no longer rely on thermal powerplants alone to produce its elecricity. Diversification became mandatory. The EECI recommendation to emphasize hydropower, adopted in 1975, addresses two goals: the search for energy independence in the Ivory Coast, and the control of the electricity costs by the Ivorian consumers. The results have been particularly encouraging, and have justified the choice of hydropower.

Before any government makes a policy decision to develop hydropower, it must have a thorough knowledge of the country's hydroelectric resources. For this reason, the EECI decided in 1976 to complete the inventories conducted in 1962 and 1972. This new inventory required 2 years of systematic resource assessment to determine the actual potential of the Ivory Coast, which was found to be 13,500 GWh, including the output of micro-hydroelectric plants. That figure might appear small compared to the potential of other countries, but it represents enough energy to serve the total requirements of the Ivory Coast until the year 2010. Only 20% of this potential is presently utilized.

This inventory is not limited to the big hydroelectric sites. On the contrary, the inventory included smaller sites capable of operating micro-hydro plants. Despite the fact that large sites are already being developed, the Ivory Coast remains interested in small hydropower for several reasons:

- The search for a true energy independence requires that all the available national resources be taken into account, small-scale hydropower included. In the Ivory Coast, small-scale hydropower accounts for about 10% of the total hydroelectric potential.

- The development of small hydropower furthers the goal of technical independence by permitting Ivorian engineers to gain experience, since the technology is comparatively simple. "Hands-on" training, of course, is essential. Talking about technology

9

transfer is worthless if it is not undertaken on a practical level.

- Small hydropower plants can also permit the optimization of national water resources; for example, irrigation dams generally can be equipped to produce electricity. For this reason, the EECI extended its 1976 inventory of sites to include irrigation dams. Moreover, installing small hydro plants upstream of existing hydro stations can help reduce water loss through evaporation, thereby increasing the energy output of the downstream hydroelectric sites.

The decision to give priority to the development of hydroelectric resources in the Ivory Coast yielded positive results, and prompted what is now usually called the "hydro turning point" of the Ivory Coast. The control of electricity costs is one of the direct consequences of this decision. Another is the improvement of the technical authorities' awareness of the need to equip sites in the best possible way. This desire to equip the sites as effectively as possible led to the renewal of the study of the Soubré hydroelectric project. The result was that the water level in the storage area was raised 6.50 m, bringing the installed capacity from 288 MW to 328 MW and increasing the average annual productivity by 9%.

Through the development of the Taabo site in 1979 and the Buyo site in 1980, the "hydro turning point" was made possible. The contribution of these two projects laid the foundation for a complete change in the use of the country's hydraulic resources. Today, more than 90% of the electricity output of the Ivory Coast is provided by hydroelectric powerplants; they produced just 15% of this energy only 4 years ago. The substantial savings from hydroelectricity will increase when other sites become operational, especially the Soubré site, which should be at full capacity in 1985.

The EECI's present rate policy, supported by the savings from hydroelectricity, is economically advantageous to consumers. For the present, a rate increase of only 9% was necessary. If more than 70% of the production system had been supplied by thermal energy, as was the case in the past, this increase would have been at least 25%. The economic advantage is obvious, for the standard of living of the country's population, and for the competitiveness of its enterprises as well.

Hydraulic resources, including micro-powerplants, contribute to social peace and national harmony, because they contribute to the control of electricity prices, and because they are capable of serving multiple purposes. Decreasing dependence on oil is just one of the benefits.

OTHER ENERGY SOURCES

Unfortunately, hydropower resources do not exist everywhere in Africa to the same degree; in fact, the Sahelian countries of the continent lack them entirely. Almost everywhere, including the rural areas, the dispersed and minor nature of the electricity demand obliges the Africans to resort to other resources that are more available. Therefore, economic subregional organizations give particular importance to new energy sources, particularly solar energy and biomass, but also wind energy. The energy potential of Africa's solar, biomass, and wind resources is among the highest in the world.

Within the member countries of the Economic Community of Western Africa and of the Inter-States Committee for the Struggle against Aridity in the Sahel, for instance, the periods of sunshine—although variable according to the seasons and the locations—range from 1,800 hours per year in Abidjan, to 3,600 hours in Agadès. The overall radiation at the earth's surface is sufficient throughout the year to supply 5-8 kWh per m^2 per day.

Although reliable figures on biomass are not available, the variety of agricultural, forest, and animal wastes in Africa allows one to say that the continent possesses a very important source of energy in its biomass.

The wind potential, which is extremely variable from country to country, reaches values sufficient to allow some application for electricity generation and for water pumping as well.

These resources can satisfy the modest demand of many dispersed rural locations. Therefore, it is not surprising that many countries and subregional organizations have high expectations for these energy sources. They are expected not only to satisfy the energy needs of the population, but also address other problems, such as the alarming phenomenon of depopulation.

Micro-hydropower plants, which do not compete with other energy sources, have a role to play in the satisfaction of these needs. However, it is essential to know the exact potential of hydropower, and to know how to use it in its environment. The local, as well as national, socio-economic impact of micro-hydropower can be significant; therefore, it is important not to neglect the development of this important energy resource.

REFERENCE

1. Frish JR. "Perspectives Energétiques des Pays en Voie de Développement: Horizon 2010." Proceedings of the 10th World-Wide Energy Conference, Munich, Federal Republic of Germany, September 1980.

Introduction to Small Hydropower Technology and Development

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BACKGROUND

Small hydropower has been used around the world for thousands of years. Waterwheels provided mechanical power for grinding grain and raising water to a higher elevation for water supply and irrigation 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, featuring gears that permitted speed variations to provide 28 tons of flour per day.

Over the centuries design improvements increased the capability of waterwheels, which were used to grind grain, saw lumber, operate spinning wheels and looms, cut stone, and raise water. By the 14th century, thousands of waterwheels were providing mechanical power in Europe. Five centuries later, the development of turbines made hydropower a source of electrical power as well. This evolution, culminating in the development of alternating current in 1901, set the stage for more recent developments in hydropower.

Although the hydropower potential of the world is enormous (greater than 2.2 million MW), only 13.6% of it has been developed (see Table 1). 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—and half of that developed hydropower is at three major dam sites—Aswan on the Nile, Kariba in East Africa, and Akosombo in Ghana (3). In other words, the hydropower potential of Africa has barely been tapped. With proper planning, hydropower probably can provide most of Africa's power requirements as its nations develop and move into the 21st century.

Hydropower has been defined as large, small, mini-, and micro-hydro. These terms are somewhat ambiguous, but a survey of the literature shows the range of each term as follows:

Micro-hydro:	less than 100 kW
Mini-hydro:	100-500 kW
Small hydro:	500 kW to 50 MW
Large hydro:	more than 50 MW.

It is usually more economical to plan water resource development to serve multiple purposes simultaneously, including:

- Hydropower,
- Navigation,
- Irrigation,
- Sediment control,
- Flood control,
- Recreation,
- Municipal and industrial water supply, and
- Fisheries.

Water resource systems engineering can determine how much emphasis to place on each of these purposes in the planning and design of a single project (5). With the aid of the electronic digital computer, this process of simulation, optimization, and maximization has become an indispensable tool to hydropower technology.

TECHNOLOGY OF HYDROPOWER

In a typical large hydropower installation (see Fig. 1), electricity is created by a generator which is driven by a turbine. 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. The head on the turbine is the difference in elevation between the surfaces of the headwater and the tailwater.

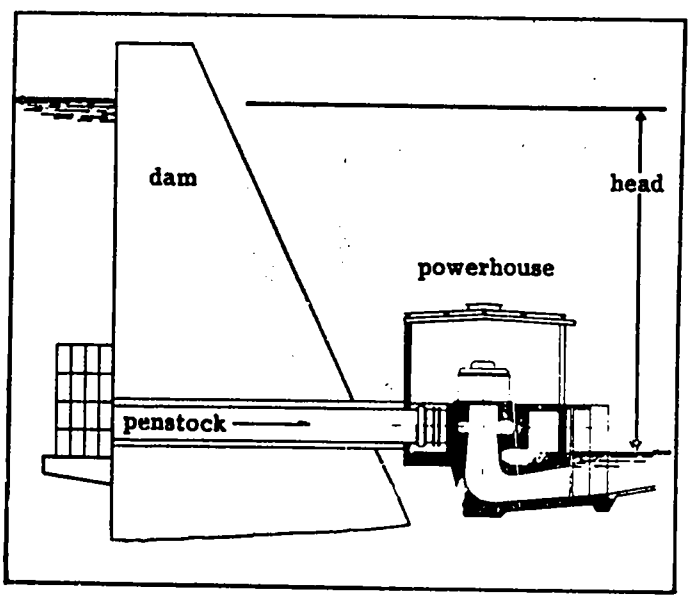

Fig. 1. Typical large hydropower installation (9).

TABLE 1. World Hydroelectric Power Capacity and Production Capabilities, 1974

Continent or area	Total capacity (MW)	Total world capacity (%)	Developed capacity (MW)	Capacity developed (%)	Average annual production capability (GWh)	Total world production capability (%)	Developed average annual production capacity (GWh)	Production capability developed (%)
Africa	437,104	19.3	8,154	1.9	2,019,934	20.6	30,168	1.5
Asia (minus USSR)	684,337	30.3	47,118	6.9	2,638,169	26.9	198,433	7.5
Europe (minus 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	100.0	9,802,420	100.0	1,307,564	100.0

Source: World Energy Conference, Survey of Energy Resources, New York, 1974; Energy Perspectives 2, U.S. Department of the Interior, June 1976.

The simplest form of small hydropower station (see Fig. 2) is the run-of-the-river plant, which has no storage dam. This arrangement diverts water from the river into a turbine located downstream and back into the river. The water may be delivered to the turbine in two ways, depending on the terrain:

- Where the river flows down a very steep gradient through a narrow gorge, often the water is diverted directly into the penstock.
- Where the river gradient is more gradual, water must be conveyed a longer distance to obtain the same head. In this case, it is often more cost-effective to divert the water into an open channel or a low-pressure pipe, which is run at a very gradual slope above the river to a point directly above the turbine. At this point, the water is fed into the turbine.

In both methods, the objective is to concentrate the head over the shortest possible distance to reduce the length—and, thus, the cost—of the penstock.

With run-of-the-river schemes, an expensive diversion dam is unnecessary. A diversion dam is needed only to stabilize and control the water entering the intake upstream. When the riverflow is high, the intake must be protected against being washed away; where it is very low, most of the water may have to be diverted to the intake to obtain the discharge needed for power generation.

A run-of-the-river plant has another benefit if there are competing uses for the water that is used to generate hydropower. A run-of-the-river plant diverts the waterstream from its natural course for only a short distance; it is never held for any period of time to prevent use downstream. Consequently, a run-of-the-river hydropower plant rarely causes conflict with the environment or other uses of the water supply. If water is stored to provide peaking capability or carryover water to generate electricity during dry periods, the hydropower requirements are more likely to compete with other uses, such as irrigation and flood control. On the other hand, creating storage capacity as part of the hydropower project can contribute to these other needs.

A hydropower plant may also have a forebay and draft tube, each of which improves the performance of the powerplant. The forebay allows for minor fluctuations in the flow of water entering it and short-term fluctuations in the flow of water through the turbine. It can also provide for temporary water storage, which the fluctuations of demand through the turbine make necessary. The draft tube helps to convert the kinetic energy remaining in the water after it leaves the

12

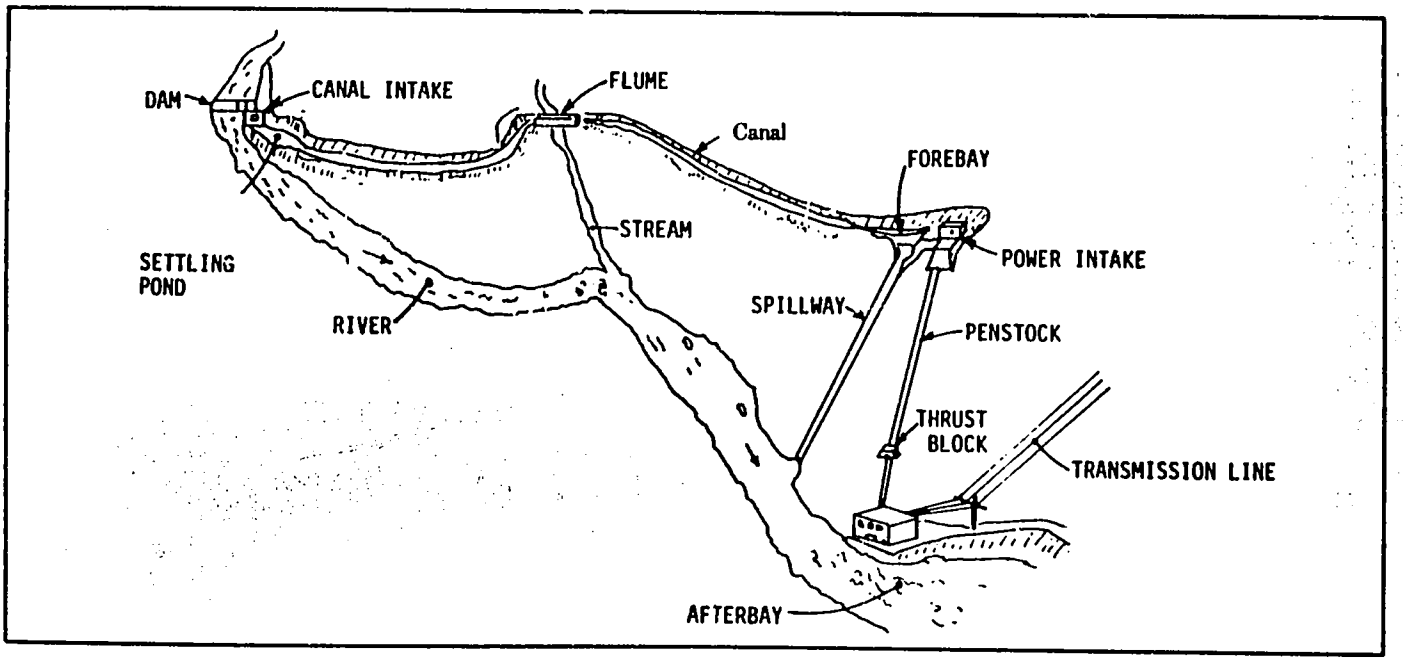

Fig. 2. A typical run-of-the-river small hydropower scheme (6).

turbine into potential energy. This reduces the pressure on the downstream side of the turbine runner.

While the forebay and draft tube increase efficiency, they also increase costs and are not absolutely essential to powerplant operation. Similarly, the quantity of water and the head involved largely determine whether a penstock is essential. For very low-head plants, the penstock can be eliminated and the water in the forebay can run directly into the turbine (see Fig. 3).

Governors commonly are used in hydropower plants to control the frequency of the electricity produced. For micro-hydro units, however, this expense may not be necessary. An electronic load controlling approach can be used instead.

The hydropower installations described above often have efficiencies of 60%-70%, depending on the design. Although this figure seems low, with adequate water supply and head, it is possible to increase output simply by passing larger volumes of water through a larger turbine. Communities in Pakistan and China recently have built thousands of low-efficiency hydropower units which provide electricity that otherwise would not be available.

A hydrologic analysis is necessary to determine whether the water supply is adequate for hydropower, and if it is, to determine the desirable size of generating units. The hydrologic analysis is a study of streamflow, groundwater, and precipitation records. The data from this analysis, plus topographic information, are necessary to determine the maximum turbine and generator size. Because the demands of the community may not require the maximum size, it is necessary also to evaluate the potential demand for hydropower.

Various types of generators and electrical equipment can be used for small hydropower. Since these are standard components of most electricity generating systems, there is no need for these to be described any further. It should be noted that a small hydropower plant can also be operated either grid-connected or in isolation.

Waterwheels and turbines

The various types of waterwheels and turbines are illustrated in Figs. 4 and 5, respectively. Fig. 6 shows typical operating ranges for various turbines. The vertical waterwheel has a horizontal shaft. It is slow-moving and best adapted to grinding and milling processes; to operating tools such as drill presses, lathes, and saws; and to operating pumps and electrical generators that have gearing mechanisms to increase the shaft speed. Although it has a much lower efficiency than a turbine, it is simpler and less

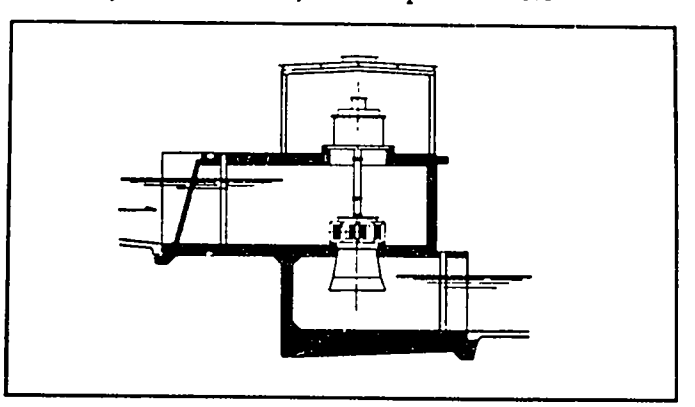

Fig. 3. A turbine arrangement for a low-head small hydro site without a penstock (1).

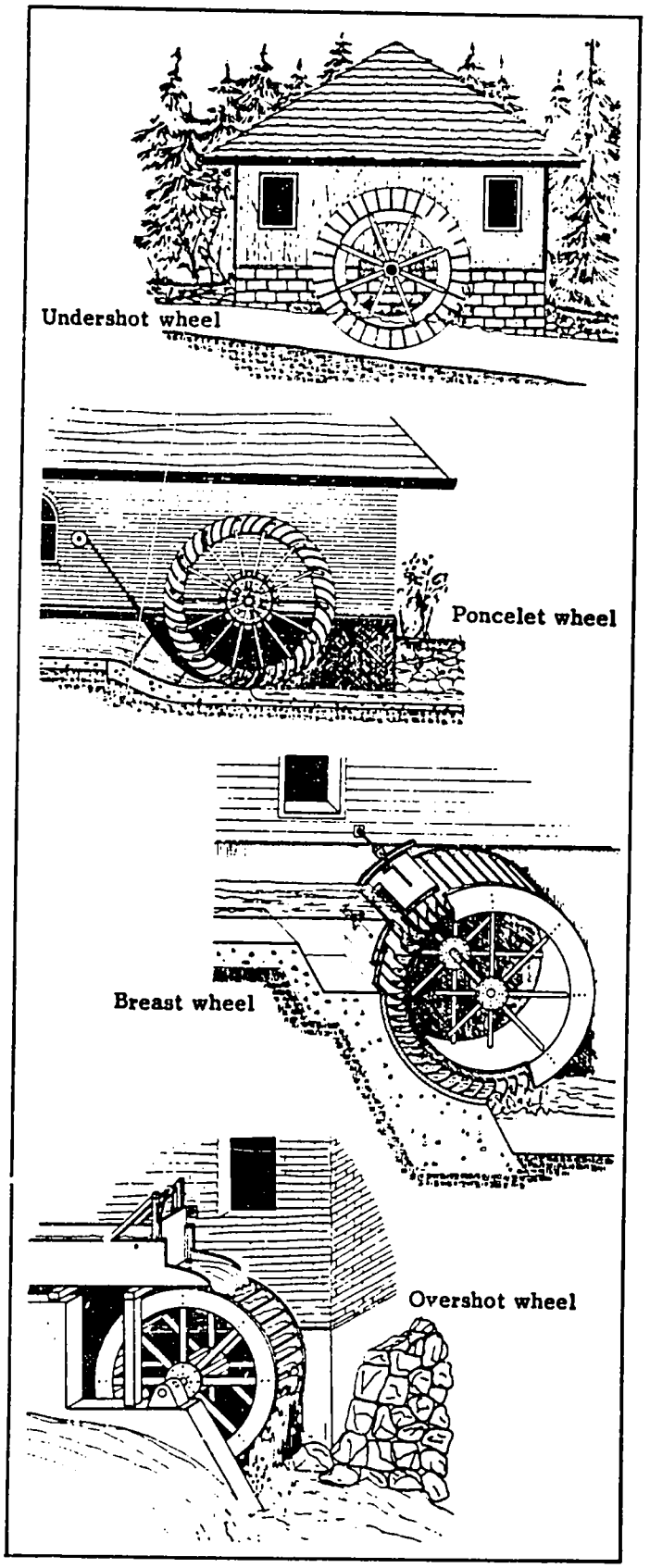

Fig. 4. Waterwheels (undershot, Poncelet, breast, and overshot) (1).

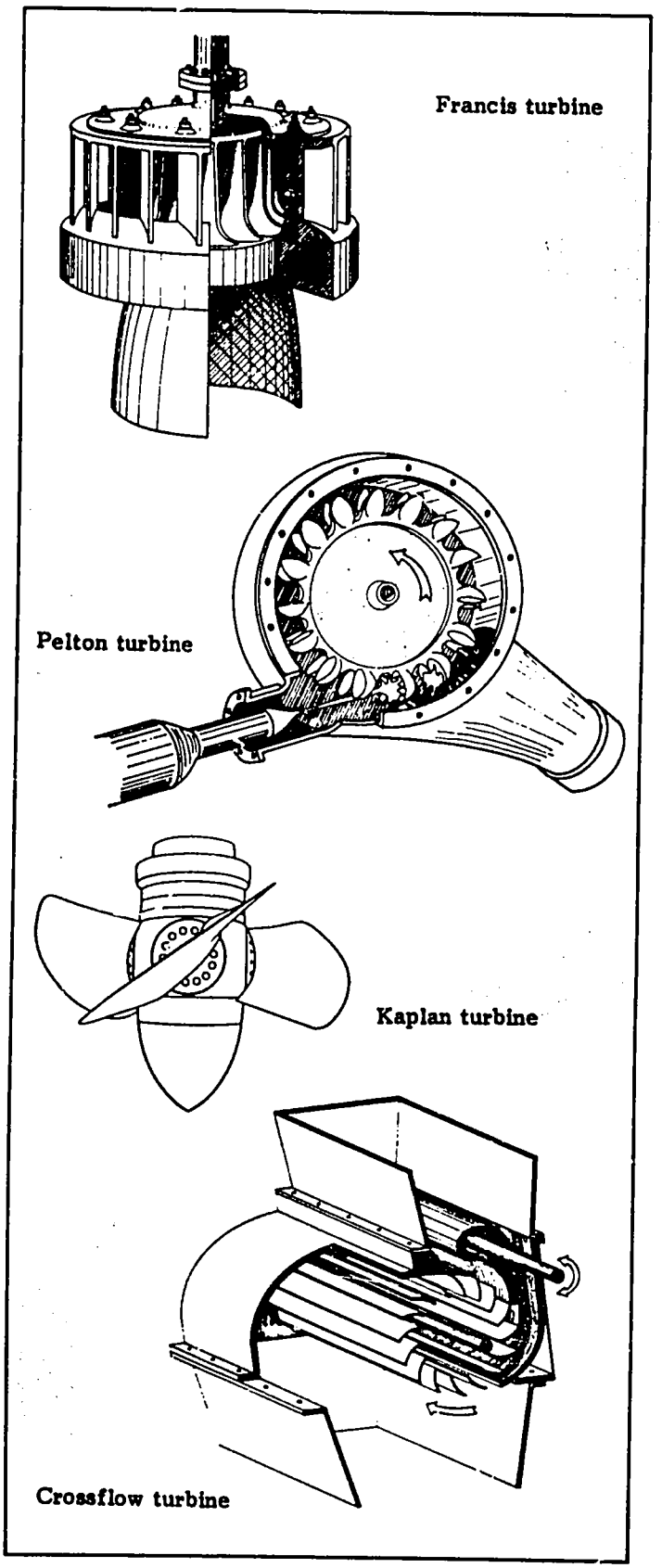

Fig. 5. Turbines (Francis, Pelton, Kaplan, and crossflow) (1).

14

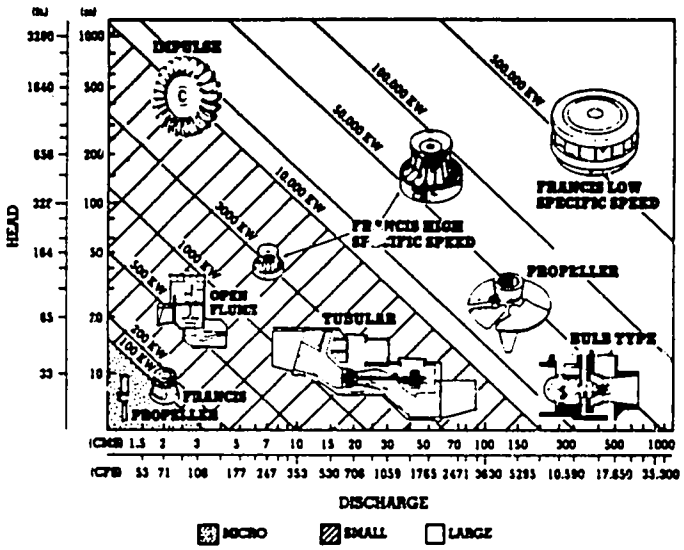

Fig. 6. Typical operating ranges for various turbines (2).

expensive. (See Table 2 for efficiency ranges.) It can be built, serviced, and maintained by local semiskilled personnel. Water is introduced to the undershot wheel and the poncelet wheel at the bottom of the wheel; and the water is introduced to the breast wheel and the overshot wheel at the top of the wheel.

The undershot wheel is the most elementary waterwheel. It can operate with as little as 30 cm of head, but the optimum head is 2-5 m. A common diameter is 5 m. This wheel has a very low efficiency.

The Poncelet wheel is a modification of the undershot wheel with curved blades. 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. This wheel has a greater efficiency than the undershot wheel and requires much closer tolerances; therefore, the floor and walls around the Poncelet wheel are made of wood, masonry, or concrete.

The water enters the breast wheel near the top and is held in the buckets all the way to the bottom. Breast wheels usually operate at heads of less than 3 m; their diameters are usually two to three times that of the head. The maximum efficiency is usually about 65%.

Water is fed to the overshot wheel through a flume. A sluice gate controls the discharge of the water. The head is the same as the wheel diameter, usually a maximum of about 10 m. The efficiency is relatively high.

A turbine uses the kinetic and potential energy in water to force itself to rotate and create mechanical energy. It can be connected directly to mechanical equipment or to a generator to produce either AC or DC electricity.

The power produced by a turbine is directly proportional to the product of the head and the discharge—that is, P is proportional to 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; they are open to atmospheric pressure and generally operate best with high heads. A good example of an impulse turbine is the Pelton turbine.
- Reaction turbines are generally selected to serve lower head sites and thus require a large volume of water to operate. Reaction turbines operate on the principle of pressure rather than velocity, and turn from the force of water flowing through the blades rather than from water striking the blades. A good example of a reaction turbine is the Francis turbine.

The Pelton turbine is a disc wheel that has cup-shaped bucket blades around the outside edge of the disc. A high-velocity jet of water strikes the buckets, which deflect the water. The change in the momentum of the water results in a force against the bucket; this force drives the wheel. The Pelton is used for relatively high heads and low discharges and can have an efficiency as high as 90%.

Another example of an impulse turbine is the crossflow turbine. It has curved blades and is shaped like a squirrel-cage air blower (which acts as an air pump). The water enters the crossflow turbine near the top, as in the breast wheel, but its blades are shaped so that as the water enters one side of the turbine, it imparts an initial thrust to the turbine. The water then is directed across the inside of the turbine to strike the blades on the other side, where it imparts a second thrust before

TABLE 2. Typical Efficiency Ranges for Small Waterwheels and Turbines (1)

Type	Efficiency (%)
Waterwheels	
Undershot	25-45
Breast	35-65
Poncelet	40-60
Overshot	60-75
Turbines	
Reaction	80
Impulse	80-85
Crossflow	60-80

it leaves the turbine. This turbine can operate under heads as low as 1 m. Its efficiency is usually about 60%-70%, with a maximum of 80%.

The Francis turbine is a reaction turbine which confines the flow completely inside. The water flows against and along the blades, and the force caused by a combination of the ambient pressure and the change in momentum drives the blades to rotate the runner. The water flows into the runner from either an open chamber or a scroll case. It may first flow through governor-operated wicket gates that control the amount of water that enters the turbine. This is an intermediate-head turbine that is most efficient when operating between extremely high and extremely low heads.

In a propeller turbine, the propeller and blades are confined. The Kaplan turbine is a special type of propeller turbine that has adjustable blades. It is used for low head and high discharge and is efficient over a wider range of heads and discharges than other propeller turbines.

The bulb turbine is a recently developed propeller unit that encases the generator and turbine within the flow. The water flows around the unit and through the propeller blades to generate electricity. The tubular turbine and the Straflo turbine have similar characteristics (see Fig. 7).

In recent years, several turbine manufacturers have standardized their various sizes of turbines so that mass production can reduce costs. This has been the case in pump manufacture for years. By reversing the direction of waterflow, it is possible to use pumps as turbines. Such units have lower efficiency but offer the advantages of simplicity, ease of servicing, lower initial cost, and pumped storage for peaking power.

ECONOMICS

A hydrologic analysis determines whether a hydropower plant is physically feasible. An economic analysis determines the benefit/cost (B/C) ratio. The decision to build a hydropower plant should be preceded by an economic analysis to prevent (or reduce) surprises ahead as the project is designed, built, operated, and maintained. The kind of analysis being made and the nature and wishes of the sponsoring organization will dictate the items that will be included as benefits and costs (9).

The benefits portion of the ratio is the present value of future benefits resulting from the hydropower project. They may include one or more of the following, depending on the type and extent of the analysis:

- Revenues from the sale of power,
- The saving of fuel and capacity costs of existing or alternative thermal generating plants which the hydropower project replaces, and
- Economic or social benefits resulting from the use of power.

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

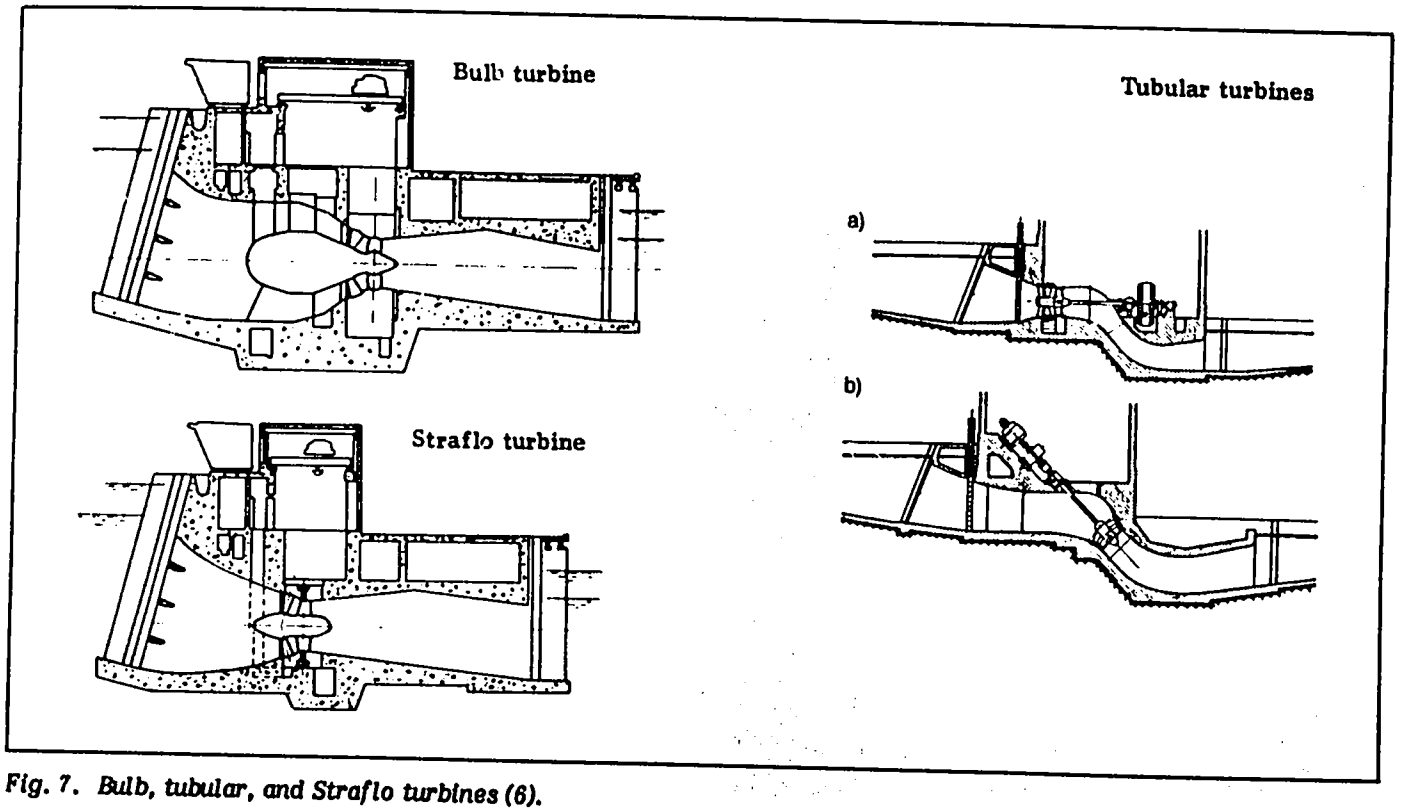

Fig. 7. Bulb, tubular, and Straflo turbines (6).

16

- Initial costs of planning and design,
- Capital costs,
- Operation costs,
- Maintenance and replacement costs,
- Financing costs, and
- Indirect costs, such as environmental impact costs or the costs of resettling displaced residents and businesses if a reservoir is required.

Numerous reference materials detail these benefit/cost items and calculations (9-11).

In addition to these economic considerations, it is necessary to evaluate such factors as competing uses of water and the social, cultural, political, and institutional effects of hydropower projects, which may affect the true costs or benefits of a project.

CONSTRAINTS, PROBLEMS, AND MOTIVATIONS

When considering a hydropower project, engineers and planners frequently give little or no attention to the socio-cultural effect that the project will have on the local community and the region. Electricity can free people from an enormous amount of time-consuming hand labor, making them available to perform other tasks to help improve conditions in the community. However, both favorable and unfavorable side-effects can result if the project involves a large dam and reservoir or irrigation, flood control, or navigation (3). Small-scale hydro may have fewer negative effects, but it is very important to anticipate and evaluate these effects in advance, rather than be, surprised by them after the hydro plant is in operation. The project's effects in the following areas should be studied in advance:

- Agriculture,
- Fisheries,
- Forestry,
- Mining,
- Health,
- Employment,
- Income distribution,
- Political factors,
- Standard of living,
- Ecology and environment,
- Self-reliance of local people, and
- Erosion and sedimentation.

Although a government may be tempted to borrow money (from the World Bank, for example) for construction of small hydropower plants in rural areas, this is not always in the best interests of the people themselves. China demonstrated clearly that tens of thousands of small hydropower plants could be built by local initiative alone, with no funding from the central government. Stimulated by leadership to be self-reliant, local populations developed various types of turbines and generating equipment throughout China.

Recent developments in Pakistan have also shown that local initiative can fabricate the necessary equipment, facilities, and funding required for hydroelectric power. This approach has several advantages:

- 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.
- As local people build the required equipment and facilities, they also gain the skills necessary to service and maintain the equipment.
- An enormous sensee of pride and satisfaction results from solving local problems with local resources.
- Such an accomplishment leads local people to believe that they are able to solve other problems through local initiative and local financing.

REFERENCES

1. Alward R, Eisenbart S, and Volkman J. Micro-Hydropower: Reviewing an Old Concept. Butte, MT: National Center for Appropriate Technology, 1979.

2. Boese GW, and Kelly JA. Developing Hydropower in Washington State. Olympia, WA: Office of Water Programs, Department of Ecology, State of Washington, 1981.

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

4. Goodman LJ, Hawkins JN, and Love RN. Small Hydroelectric Projects for Rural Development. New York: Pergammon Press, 1981.

5. Hall WA, and Dracup J. Water Resources System Engineering. New York: McGraw-Hill Book Co., 1979.

6. NRECA. Proceedings of NRECA workshop on Small Hydroelectric Powerplants, Quito, Ecuador, August 1980. Washington, DC: National Rural Electric Cooperative Association, 1981.

7. NRECA. Proceedings of NRECA workshop on Small Hydropower for Asian Rural Development, Bangkok, Thailand, June 1981. Washington, DC: National Rural Electric Cooperative Association, 1983.

8. Rouse, Hunter, and Simon, Inc. History of Hydraulics. Iowa City, IA: Iowa Institute of Hydraulic Research, 1957.

9. Tudor Engineering Co. Reconnaissance Evaluation of Small, Low-Head Hydroelectric Installations. Report prepared for the U.S. Bureau of Reclamation, July 1980.

10. Tudor Engineering Co. Simplified Methodology for Economic Screening of Potential Low-Head, Small-Capacity Hydroelectric Sites. Report prepared for the Electric Power Research Institute. Palo Alto, CA: Electric Power Research Institute, January 1981.

11. U. S. Army Corps of Engineers. "Feasibility Studies for Small Scale Hydropower Additions." U.S. Corps of Engineers Guide Manual. Davis, CA: U.S. Army Corps of Engineers, July 1979.

12. U. S. Army Corps of Engineers. 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, DC, October 1979.

13. U. S. Army Corps of Engineers. Waterpower '81: An International Conference on Hydropower. Proceedings in two volumes of a conference sponsored by the U.S. Army Corps of Engineers, Washington, DC, June 1981.

14. U.S. Bureau of Reclamation. Selecting Hydraulic Reaction Turbines. Engineering Monograph No. 20, Water Resources Technical Publication. Denver, CO: U.S. Bureau of Reclamation, 1976.

CASE STUDIES

The Future of Small Hydropower in the Ivory Coast
Diby Marcel Kroko

The Micro-Hydroelectric Generation Program of Ecuador
Eduardo Morán

Micro-Hydroelectric Schemes in Pakistan
Mohammad Abdullah

Small Hydroelectric Power Development in Zaire
Mulamba wa Kabasele

An Overview: The Zulu Hydropower Project
Robert S. Thornbloom

The Future of Small Hydropower in the Ivory Coast

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INTRODUCTION

Although hydropower development techniques were mastered long ago, many think of small hydropower as a "new" source of energy. Authorities thoughout the developed, as well as the developing, countries have focused their attention on developing large hydropower resources to supply industrial power needs. As a result, until recently with the advent of the oil crisis, small hydropower resources have been largely overlooked.

Before it achieved independence in 1960, the Ivory Coast had already developed the Ayame-I hydropower plant (1957), with a capacity of 20 MW. It was followed by the 30 MW Ayame-II installation in 1965. Since 1960, however, the Ivory Coast has experienced rapid economic growth. Because this economic growth has created a demand for large amounts of electric power, the Ivory Coast has developed several hydroelectric plants of capacities greater than 100 MW: Kossou, 175 MW (1972); Taabo, 210 MW (1976); and Buyo, 165 MW (1980). By 1985, the Soubré project will be in operation, with an installed capacity of 328 MW.

The 1973-74 world energy crisis prompted a more complete assessment of national hydroelectric potential. In 1975, public authorities reached the "hydro turning point" of the Ivory Coast, making decisions to use hydropower as the country's major source of electricity. The Energie Electrique de la Côte d'Ivoire (EECI) inventoried potential sites for hydro installations. This inventory revealed a large hydropower potential in the Ivory Coast. EECI gave special attention to small hydropower sites, and initiated a small hydropower program designed to develop these sites gradually.

HISTORICAL OVERVIEW

Ivorian rural populations typically have an agricultural base. Their demand for electricity is usually low, and the demand centers are dispersed.

Rural electrification in the Ivory Coast has been based primarily 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 in which they were installed. Their numbers increased very rapidly after 1960. These power stations use distillate diesel oil. After the 1973 oil crisis, the proliferation of such units became economically unattractive.

The EECI has always endeavored to adapt its services to the rural environment through its rural electrification methods in general, and its production and distribution techniques in particular, always considering the geographic, economic, and social impact of hydro development. It began experiments with local networks in the late 1960s. As fuel prices soared, these networks became more attractive to EECI planning managers. They established networks throughout the countryside to serve not only new districts but also electrified villages. These networks made it possible to discard existing equipment and to reduce considerably the number of new diesel units procured. This reduction in the maintenance and purchase budget has reduced the overall budget necessary for the rural electrification program. In addition, the network approach also guarantees continuity of service by enabling several power stations to supply a single center.

These "spider web" centers are the latest development in the EECI's rural electrification program. Designed to serve remote geographical areas, they rely mainly on an important diesel generating station of a few megawatts or an HV/MV station of appropriate capacity. This spider web approach eliminates more power stations than local networks do. Unfortunately, the load capacity per kilometer per line is often about 1 kVA in the spider web program. The low development level, the low demand, and the dispersion of consumption centers contribute to the reduced load of the MV network of the spider web program.

The EECI has scheduled experiments with new techniques to address this problem. The goal of these experiments is to reduce investment costs by using simple but proven methods in appropriate areas. One of the most attr[illegible]ple techniques is the Single Wire Earth Return (SWER) system, which will be used in the rural electrification program of the relocated villages in the Kossou Lake area. It is important to note that simple techniques do not imply a reduction in reliability; it is necessary to maintain quality service and to guarantee safety. With the SWER system, the EECI gives special attention to the quality of grounding.

The ideal rural electrification program not only should adapt itself to the conditions and needs of rural areas

but also should enable the country's electricity company to achieve a certain autonomy, especially in light of soaring oil fuel prices.

Can small hydropower fulfill these requirements? This answer will depend mainly on the attractiveness of small hydropower plants in comparison to other energy sources, especially agricultural and forest wastes, biomass, and solar energy.

OTHER ENERGY SOURCES

The Ivory Coast has large quantities of agricultural and forest waste which, if processed adequately, could supply a significant amount of electric power. Large amounts of coffee wastes, molasses, sawdust, and barren hevea trees constitute hundreds of tons of energy wastes that are simply discarded every year at the processing plants. From this waste, appropriate digesters can produce methanol, which can be used to generate electricity.

The experience of other countries and the successful tests conducted in the Ivory Coast by local research institutes make it possible to assess the energy value and attractiveness of such wastes. Tests carried out elsewhere indicate that the vaporization of vegetal and animal wastes is a safe means to produce electricity in the rural environment. However, these wastes are profitable only when used locally; the transportation cost will increase the real cost of each kilowatt-hour produced.

The universal availability of solar radiation free of charge makes it more suitable for the dispersed demand of rural areas than all other conventional or new energy sources. Also, current technology is likely to develop the capacities of solar energy to a level that could satisfy the requirements of rural consumers. The EECI is experimenting with new energy sources, including solar energy. Its Solar Experimental Rural Electrification Program (ERES) should make it possible to determine, by 1986, the extent to which solar energy (particularly photovoltaics) can provide an appropriate solution to energy supply for low-consumption rural areas.

The availability, cost, and technical aspects of small hydro operation will ultimately determine whether small hydropower is used instead of other energy sources.

CONSIDERATIONS IN SMALL HYDRO DEVELOPMENT

Small hydro vs. large hydro

Most of the large hydro potential in the Ivory Coast is in the south of the country. For this reason, the EECI is equipping the south with hydroelectric schemes, whereas the north retains its isolated diesel plants. In fact, the Missouli site on the Marahoué River is the only significant hydropower site in the north.

There are 50 potential small hydropower sites fairly evenly distributed throughout the country. In the north, 28 sites would provide 706 GWh per year and in the south, 22 sites would provide 449 GWh per year.

Small hydropower plants generally have a higher investment cost than large hydropower plants. The cost of the various sites identified in the EECI inventory ranges from about 1 million to 2.75 million CFA francs per kW installed (approximately US$ 4,000-11,000). For the same sites, the price per kilowatt-hour ranges from 100-550 CFA francs (US$ 0.40-2.20).

A comparison of Tables 1 and 2 shows that the development of small-capacity sites costs four times more than that of larger sites. This ratio applies to the price per kilowatt-hour and the price per kilowatt installed.

TABLE 1. Cost of Energy Produced by the Main Small Hydropower Sites, Ivory Coast

Site	CFA francs per kW (in thousands)	CFA francs per kWh
San Pédro	350	87.6[a]
Aboisso	360[a]	78[a]
Koundisso	1,264	215
Sambadougou	2,500	549
Missouli	940	235
Ile-aux-Palmiers	2,750	314
Tahibli	590	113
Ghadio	2,000	467
Average[b]	1,674	315.50

[a] Approximate.

[b] Outside Aboisso and San Pédro.

TABLE 2. Cost of Energy Produced from Large Hydro Basins, Ivory Coast

Basin	CFA francs per kW (in thousands)	CFA francs per kWh
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

Small hydro operation and maintenance

Operation problems of small hydropower plants result mainly from connecting the hydro plants to the MV network, because their production capacity generally is higher than the local demand, particularly in the Ivory Coast. Such problems are not insoluble; however, it is important to recognize that they exist. Special measures are necessary to maintain quality of service, limit constraints, and guarantee safety.

It is unacceptable to let the quality of service deteriorate as a result of connecting a small hydropower plant at any point in the system. The maintenance of quality service requires the protection of the MV network against any fault likely to affect the small hydropower plants connected to the system. Special provisions must be made to this end.

It is also necessary to take steps to maintain reasonable ranges of voltage and frequency where a small hydropower plant is isolated from the grid. Undue tripping and false relaying are constraints that are likely to affect the efficiency of a normal operation.

The necessity of guaranteeing safety is obvious. It is particularly important in energizing operations, or when a fault occurs while the small hydropower plant is isolated.

Small hydro vs. other energy sources

Solar generators or generating sets fed by animal or vegetal gas can avoid most of the previously mentioned problems because these installations can be sized to suit the local requirements and need not be connected to the system.

It is difficult to compare costs of small hydro and other energy sources. A comparison of costs between small hydropower and other sources of energy can be based only on quality. However, cost calculations are often influenced by publicity biased in favor of other energy sources.

The Ivory Coast's potential for small hydropower development is relatively high (1,000 GWh per year). Because the 50 potential small hydro sites, unlike the large hydro sites, are well distributed throughout the country, small hydropower plants rank fairly high among the available new energy sources, despite the large investment required and the operational problems.

The new energy sources mentioned should not be viewed as competing entities. Each one can be adapted to a specific use compatible with its nature, availability, and technical requirements. The role that small hydropower plants will play in the Ivory Coast will depend less on the availability of other power sources than on the new power resources distribution policy the EECI and the public authorities eventually adopt.

SMALL HYDRO SITES

The general inventory of hydroelectric resources of the Ivory Coast, carried out between October 1976 and July 1979, identified 50 small hydro sites. The annual production of most of these these sites is less than or equal to 100 GWh. Some six sites have a capacity that exceeds 10 MW; all the other sites have a capacity that ranges from 1.5-5 MW. The lowest capacity is about 500 kW (see Tables 3 and 4).

TABLE 3. Main Characteristics of Five Small Hydropower Sites

Name of site	Head (m)	Rated flow (m^3/s)	Installed capacity (MW)
Ferke	11	100	8.0
Agboville	4	16	0.5
Daloa	4	25	0.8
Palee	—	16	2.5
Zegberi	24	30	11.0

TABLE 4. Distance Between Small Hydropower Sites and Existing MV Network

Name of site	Distance from site to MV newtork (km)
Palee	15
Drou	3
Aboisso	2
Daloa	1
Agboville	2
Ferke	16
Zegberi	45

Construction of the Grah Rapids site has already begun. The dam and the units have been completed, and the electromechanical equipment will be installed by the end of March 1983. This plant's installed capacity is 5 MW, supplied by two turbines with a unit capacity of 2.5 MW, which operate under a head ranging from 8.9-11 m. The flow is 60 m^3/s. This facility will generate 20 GWh annually on the 33 kV system, and the dam will provide a catchment basin to serve the needs of San Pédro and various nearby industrial and agricultural consumers (2 m^3/s). The catchment will supply water to a paper plant, which will be built near the dam, at an initial rate of about 2.7 m^3/s, increasing to 4.5 m^3/s during full operation.

The Bia River has a natural drop at the Aboisso site of 4.5 m, which will be raised to 5 m by a concrete sill. The flow of 125 m^3/s will make an installed capacity of 5 MW possible.

The capacities of most small hydropower sites identified considerably exceed local needs; therefore, their connection to the MV distribution network is a preliminary condition for their development. (Many of these sites are less than 15 km from the existing network.)

In addition to the attitude of the Ivorian authorities, the future of small hydropower in the Ivory Coast will depend on the small hydro potential, the performance of small hydro installations, and the quantity of energy that the plants can supply to the power system.

The Government's decision to exploit its hydroelectric sites and to delay the installation of additional thermal plants has enabled the Ivory Coast to save large amounts of foreign currency since 1975. Hydropower produced 76% of the country's electricity in 1979-80 and 82% in 1980-81. This contribution is expected to rise to 90% by 1988-89 if the hydro option is maintained.

Current political opinion favors the development of small hydro sites; their development is part of a policy to save foreign currency and achieve some autonomy in the field of energy. The small hydro potential exists; obstacles to its incorporation into the national power system can be surmounted. Small hydropower development not only conforms to national energy policy but offers advantages such as electric power production, water supply, flood protection, development of rural areas, and an increase in the hectares available for agricultural production as a result of stream regulation.

It is a national duty to exploit indigenous hydropower resources, for the present and future benefit of Ivorians. Doing so can offer one additional benefit: the development of technical skills. Small hydropower plants provide a special opportunity to develop such skills; they become operational within a short period, and they are easy to operate.

In view of the many benefits of small hydropower plants, it is reasonable to expect that the Ivory Coast will retain a national energy policy that supports small hydro development.

23

The Micro-Hydroelectric Generation Program of Ecuador

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INTRODUCTION

Like all mountainous countries in tropical areas, Ecuador is rich in hydraulic resources. Hydroelectricity has been the primary source of energy for many cities and towns since the beginning of the century. Small hydroelectric (up to 5,000 kW) and micro-hydroelectric (up to 500 kW) plants were spread around the country, creating a decentralized system still partially in operation. The national hydropower potential is estimated at 22,000 MW, of which less than 1.5% has been developed. In fact, 76% of the energy presently produced is generated by thermoelectric equipment. This development of thermoelectricty has been due to accelerated economic growth and the availability of cheap oil. It has also been a consequence of the lack of rational energy planning and the need to satisfy energy requirements as they appeared, especially in the urban areas.

Ecuador created a National Electrification Authority (INECEL) in the late 1960s and with it, a National Electrification Master Plan. As the first national energy planning body, INECEL initiated an era of grand hydro schemes, big thermoelectric plants, and the National Interconnected System (NIS), which became a reality in 1979. By law, only INECEL or one of its regional enterprises was able to produce, distribute, and sell electricity. One of the objectives of the National Electrification Master Plan is to provide electricity to 700,000 inhabitants of rural areas by 1984. The Master Plan contains a rural electrification program consisting of installations of small powerplants, substations, and transmission and distribution lines, most of them branching out of the NIS. However, the geographic distribution of 40% of the national population prohibits their integration into the NIS. For these areas, a more suitable solution than traditional electrification had to be found.

THE ROLE OF THE NATIONAL ENERGY INSTITUTE (INE)

In 1979, the year the NIS was established, the National Energy Institute (INE) was created to coordinate national energy planning. For the first time, energy was treated as one factor in social and economic development intimately related to other factors such as technology and social organization. INE recognized that the geographic dispersion of Ecuador's population and its socio-economic characteristics posed problems in electrifying rural areas. INE responded by creating specialized technical groups to study and develop alternative sources of energy for rural areas, making micro-hydropower a priority among these. In addition, as a coordinating body, INE ensured that every institution that would be involved in the eventual development process participated in the planning and design of each alternative energy program.

At the same time, INECEL mobilized its rural electrification and planning divisions to join in the process, creating a national program for micro-hydropower development.

It is important to note that the intervention of INE made possible the creation of planning systems where most of the important related, nonenergy factors were considered. Discussing plans with INECEL and other prospective executors of the energy policies enabled the planners and executors to identify their separate and mutual objectives. As this experience demonstrates, achieving a coordinated planning system requires that more than one institution participate in each phase.

NATIONAL MICRO-HYDROELECTRICITY

According to a study of the power sector, following the establishment of the NIS, numerous micro-hydro plants that had been serving small towns within the NIS were disconnected or, in certain cases, abandoned. A preliminary inventory showed 68 such plants. The principal task of the INECEL micro-hydro group was to conduct an indepth study and inventory of this equipment. This evaluation of the out-of-service equipment and installations served as a valuable preliminary step in the creation of a national micro-hydroelectricity program. INECEL is handling the reallocation of this equipment, which requires considerable work. This group is also identifying population centers that will not be tied to the NIS but will be able to use the surplus hydro equipment.

While INECEL was conducting its study, INE began to standardize evaluation procedures for site selection, equipment selection, and local manufacturing capability. INE studied the "state of the art" in developed and developing countries, making contacts with people and institutions capable of carrying out plans for national production of partial, or even complete, micro-hydro plants. During the first stages of the program in August 1980, INE invited all the people and organizations that would participate in the project to a workshop. This workshop, incidentally, was

organized and cosponsored by the NRECA in cooperation with the USAID. This contact with foreign researchers, field workers, company representatives, and other specialists permitted INE to weigh the real possibilities of its plans. Later, the United Nations hired some of these technicians and consultants to help INE accomplish its goals.

DEVELOPMENT OF A NATIONAL TECHNOLOGICAL CAPACITY

Rather than enlarging the technical bureaucracy to develop and manage its energy programs, INE has worked cooperatively with specialized institutions, providing funds, personnel, and clearly defined objectives for each jointly run program.

INE's agreement with the National Polytechnic School (NPS) contemplates the construction of micro-turbines of the Michell-Banki and Pelton types and all technical work necessary to transform pumps into turbines. Its agreement with the Electrical Engineering Department of NPS and a local manufacturer of electronic panels includes the development and construction of electronic load controllers and adaptation of the generators to the turbines. A contract with the United Nations enabled INE to bring in a consultant highly experienced in the construction, operation, and installation of micro-hydro equipment. This consultant worked with INE and the NPS in turbine construction and all other aspects of the programs. The importance of international expertise should be noted. Only by working with and learning from experienced personnel can a group of inexperienced but capable national technicians acquire this expertise.

What has been the cost of the INE-NPS program to develop the three turbine types and construct the electronic load controllers? The disbursement has been close to US$ 15,000, excluding the technical manpower. If this project had not existed, the time and effort of the NPS research team would have been employed in projects or thesis work generally not applicable to national needs. In the case of the electronic load controllers, a cost was assigned to manpower by the local manufacturer that worked with the NPS to develop the designs and equipment. The total manpower cost of a typical control unit for a 50 kW turbine was approximately US$ 2,000.

Several alternatives are under consideration for the construction of different elements of the civil works, with special attention given to the possibility of using local labor and materials. In certain cases, the use of plastic pipe for the penstock is possible and appears to reduce costs substantially. A suitable manufacturer of this pipe has been found.

PROJECT OF THE CENTER FOR RESEARCH, DEVELOPMENT, AND TRAINING IN MICRO-HYDRO TECHNOLOGIES

One might ask why, in a country where more than 100 micro-hydro plants have been constructed, including the equipment, is there a lack of technical micro-hydropower expertise?

The reasons are that:

- The projects have been spread out geographically and chronologically, preventing in-country development of experience in this field;
- Ecuador has depended totally on foreign companies and expertise for the evaluation, design, and installation of the hydro plants;
- No group of national engineers or companies has worked in the field in a continuous fashion; and
- Ecuador has lacked institutions where technical capability could be developed.

INE believes that the creation of a center for technological development, where practical training will complement applied research, will address the problems listed above. In December 1981, Electric Enterprise Quito signed a contract for construction of the center.

INE believes that the center will function as a hub for a wide variety of coordinated activities, involving many different groups and institutions. A group of INE engineers (mechanical, civil, and hydraulic) will constitute the permanent staff of the center. The local electric company will provide the physical plant, services, and water for the center; it will also have an engineer in the work group. The other research institutions and universities could assign personnel to work in the center, permanently or temporarily. The electric companies, in the same manner as the universities, will assign personnel to the center. The costs of material, personnel, and economic support for the operation will be borne almost completely by INE, which will also direct, operate, and maintain the center.

The center will permit the testing of equipment up to 200 kW; it will have all the facilities necessary to test different types of turbines, controllers, and electrical systems. A mechanical shop with basic tools will permit the assembly, disassembly, 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 will also be built.

The projected center will have the principal types of micro-hydropower equipment sold on the international market. It will also have locally manufactured turbines, controllers, generators, electric panels, and repair equipment.

The following types of research and training activities are envisaged for the center:

- Applied research in operation of the systems, testing and reproduction of parts and pieces, and testing of equipment produced locally;

- Training in installation and operation of micro-hydropower equipment for groups of engineers belonging to public or private entities that will be in charge of design, construction, and operation of this type of equipment;

- Training in operation and control of equipment for personnel from electric companies, communes, or private entities engaged in these tasks; and

- Training in repair and installation of equipment for personnel of the electric companies.

The prefeasibility study of the center calculated an approximate cost of US$ 560,000; more detailed studies are still in process. However, a provisional facility already has been finished adjacent to the future facilities. This permits the INE-NPS group to test turbines of a capacity up to 70 kW, which is especially useful for testing the pump-turbine and the Michell-Banki units already finished. The cost of this provisional facility is about US$ 15,000. The Municipal Water Company provided pipes, valves, and the experience from similar mechanical works.

SUMMARY

Only an understanding of the importance of micro-hydropower by the highest authorities can make a national plan successful. Since the Ecuadorian Government realized the importance of micro-hydropower for the development of rural areas, the program started by INE and INECEL has received the necessary support. An appropriate planning system is in operation at the highest levels of energy planning. The assignment of personnel to programs of INE, INECEL, NPS, and two regional electric companies shows increasing interest; 12 full-time engineers are working in this field. The programs are well-financed, and resources are already allocated for the development of the different programs.

The Ecuadorian micro-hydropower program, especially the installation of pilot facilities, has generated international interest. USAID will work with INE-INECEL in a project to provide electricity to two rural villages. In these projects, the methodologies developed by INE for planning, execution, and operation will be applied. Foreign governments and international organizations have also shown interest in financing programs for micro-hydropower, but experience shows that a country must develop its own technical expertise before technical and technological advancement is possible.

Ecuador's program, which started 2 1/2 years ago, has achieved its present success as a result of favorable conditions within the country. It is hoped that further progress will be made to enable micro-hydropower to contribute to better economic and social development of a vast sector of the Ecuadorian rural population.

Micro-Hydroelectric Schemes in Pakistan

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INTRODUCTION

Pakistan is primarily a rural country; two-thirds of the total population lives in villages. Most of the energy needs of people in rural areas are met from locally available noncommercial sources. To date, only 10,000 out of a total of 43,000 villages have been electrified. The consumer saturation within the electrified villages is nearly 14%; this 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, and forest wood and kerosene as a source of light. The cost of kerosene is higher in mountainous areas than it is in towns. Typically, a 4-gallon can of kerosene will cost about Rs 40* (nearly $4) in a hilly area. A household generally uses Rs 20 worth of kerosene per month for lighting purposes. In areas close to forests, a rural family annually uses forest wood worth Rs 10,000 to meet its heating and cooking energy needs.

OPTIONS OF RURAL ELECTRIFICATION

In Pakistan, electricity supply is the responsibility of the Federal Government. The generation system is a thermal-hydro mixture; the installed capacity is 3,350 MW (1980 figure). Rural areas are electrified by extending the national grid, giving preference to areas that are close to an existing transmission line. Because resources are limited, 1,000 villages per year have been electrified in the recent past. Typically, electrifying a village costs Rs 500,000 ($50,000).

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

The Government initiated a scheme of mini-hydroelectric plants to fulfill local electricity needs. Turbo-generating plants (50-100 kW) were manufactured, in collaboration with foreign manufacturers, in Pakistan. The project was planned and implemented along conventional lines, which resulted in a cost of about Rs 50,000-60,000 per kW. This high cost prohibited implementation of the schemes on a large scale.

The existing systems of rural electrification are unsuitable because they are capital-intensive and have high operating costs and low financial returns. Nearly 95% of the electricity is used for domestic purposes. Consumer saturation also is low; this adds to social inequity.

MICRO-HYDROPOWER PLANTS OF THE APPROPRIATE TECHNOLOGY DEVELOPMENT ORGANIZATION (ATDO)

Hydroelectric plants, regardless of their capacities, have several features in common. Each plant has a water storage and diversion system, a turbo-generating 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-$5,000 per kW. Only a detailed analysis of the approach to implementing such schemes and of the cost implications of these can explain this wide range of costs.

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, cost does not matter and electricity could be generated by harnessing the potential in the conventional manner. For Pakistan and for several developing countries, however, constraints of resources—financial and technical—control hydropower projects. Electricity in rural areas is mainly used for domestic purposes. For this end use, is it worth supplying electricity at a cost of perhaps $2,000 per kW? If mini- and micro-hydroelectric projects are to be feasible in such places, a new approach is necessary.

The approach adopted by the Appropriate Technology Development Organization (ATDO) of the Government of Pakistan relies on local resources—people, material, finance, and technology. In addition to meeting the desired objective at a reduced cost, this approach enhances the overall development of the community. Local people participate in all phases of the scheme. Thus far 25 plants of capacities in the range of 5-15 kW have been installed at a cost in the range of US$ 250-400 per kW (see Table 1).

* US$ 1.00 = Rs 10.

TABLE 1. Data on Selected Micro-Hydroelectric Powerplants

Location	Discharge (cusec)	Head (ft)	Installed capacity (kW)	Houses electrified	Street lights	Industrial activity
Lilloni	10	18	12	60	7	Flour mill, rice huller, oil expeller, cotton gin, band saw, wooden lathe, tool grinder
Alpuri	15	20	12	190	31	
Shang	6	40	10	44	15	Flour mill, band saw, cotton gin
Melvegai	3	80	10	43	20	Flour mill, rice huller, cotton gin, wooden lathe, tool grinder
Barkalay	3	30	5	35	8	
Barkana	10	20	10	40	8	Cotton gin, wheat thresher
Paras	8	105	20	Under construction		

Objective

The main objective of the ATDO schemes is the development of a suitable technology and system—simple and inexpensive—for meeting the electricity needs of the rural people. To meet this objective, suitable technologies have been developed and appropriate implementation and management procedures have been adopted.

Approach

In the mid-1970s, Pakistan recognized the possibilities of running electric generators on sites where local people already were running grinding mills by diverting a small quantity of water. On visits to several existing grinding mills, it was estimated that the mills were operating on a waterflow of a couple of cusecs and a head of 5-10 feet. Water drops down an open wooden channel and drives a wooden wheel constructed of radial blades. A grinder is placed on the vertical shafts of the wheel. Some of these sites have been in operation for 20-25 years without any major failures; only the blades of the wheel ever needed replacement. The waterways, wheels, and grinders are all built by the local people without outside assistance.

The first pilot plant was built 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 permitted construction of the experimental plant at his site; local people received electricity in return for local labor. The promising results encouraged application of the technology to a remote village that had no electricity. That plant generated 6 kW of power and electrified about 60 houses.

The successful implementation of the first scheme interested several neighboring villages. People visited the plant and showed interest in having a plant in their village. The demonstration approach proved contagious, and groups of persons from numerous villages 100-200 miles away requested installation of their own powerplant.

When a request is received, the ATDO technical staff visits the village. Usually 20-30 people meet with staff members, who explain the technical, financial, and managerial aspects of the scheme to them. They learn how various aspects of the scheme are implemented and how the expenses are shared between the Government and the local community. The staff stays in the village for a day or so to explain to the people the likely benefits of the power and the likely expenditures for operation and maintenance of the plant. This information helps them decide on an appropriate tariff. During this stay, the staff assesses the local power potential.

Technology

The power output is estimated by measuring the discharge and the head available at the site. The flow is estimated by using a "float," which has been found to be the only appropriate method and gives fairly good results. The fall is determined by measuring the difference of elevation between the proposed penstock entrance and the turbine inlet. Reference tables giving the power available for different combinations of flow

28

and head have been prepared; the rural people can use these tables to estimate the available power potential.

The location of the powerhouse is determined by evaluating 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 through which the channel will pass, and ownership of the land on which the powerhouse is to be constructed. All these issues are considered when a decision is being made about the location of the civil works and hydraulic structures.

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

For heads up to 20 feet, unconventional but readily available materials such as wood and oil drums are used. For higher heads of 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 400-500 miles from the project site. Transportation of materials 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. Where mechanical power is used to drive processing units, the room may be 15' x 40'. The powerhouse is constructed of rubble masonry 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 locally available materials. ATDO staff members occasionally visit the site and give instructions when required.

Site conditions, simplicity of operation and fabrication, and cost dictate the selection of the prime mover. The crossflow Banki turbine has been found suitable 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 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 designated dimensions is fabricated; the rotor has a through shaft. The nozzle is made from sheet steel and is fixed at the lower end of the penstock; it is independent of the turbine. The rotor is supported by three ball bearings secured on concrete pads. The power input is controlled with a gate or valve; the design does not include an automatic governor. The rotor shaft supports a V-type pulley that couples the turbine to the generator.

Single- and three-phase 50 Hz, 1,500 rpm, 220/380 V electric generators made in the People's Republic of China are purchased locally. Because the generators are expensive in relation to the cost of other items, the ATDO has initiated a program of local design and fabrication. A panel board containing voltmeters, ammeters, switch-fuse units, and overcurrent protective devices accompanies each generator unit. An overvoltage relay also is fitted to avoid overvoltages in case of very low loads or an accidental open circuit of the generator load.

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:

Civil works	US$	800
Turbine		200
Generator		1,500
Technical services		400
Total:	US$	2,900

The cost of the distribution system depends on the size of the service area. A 10 kW plant typically costs about $800-$1,000. For heads in the range of 40-100 feet, the cost of long lengths of iron pipe penstock may increase the cost of the civil works to about $1,500. The unusually low cost of $250-$400 per installed kW in the ATDO projects results from several factors: low administrative cost, labor contributed by villagers, use of local materials, local fabrication wherever possible, and appropriate system design. The cost is about 25 mills (1 mill = US$ 0.001) per kWh generated.

Financing

In the initial stages of the project, 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. Now the schemes are implemented on a cost-sharing basis. ATDO and local governments share the cost of the turbine and generator; the community or local entrepreneurs share the cost of the civil works, including the penstock and distribution system. The ATDO provides technical services. The entrepreneur's investment is recovered by running cottage-level industrial units (band saw, flour mill, rice huller, cotton gin, etc.). A number of banks have introduced loans to farmers for agro-based industries; loans probably could

be arranged for multipurpose 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 schemes are designed. Local people are associated with the ATDO projects from the identification of the site to the installation of the plant. During construction of the waterway and powerhouse, ATDO technical staff make only occasional visits to the site to ensure progress and the quality of the work. The ATDO staff and local technicians install the machinery jointly. The ATDO staff then operate the plant for a few days. During this period, a local technician learns the techniques of the plant's operation. Thereafter, the local community operates, maintains, and manages the plant.

Usually the community assigns to one or two of its members the duties of plant operation and maintenance. The community makes decisions regarding the provision of electricity to the residents, giving first preference to those people who have contributed to the project. Then people living close to an existing distribution line are connected. Public facilities—religious places, schools, dispensaries, street lights, and shops—are also connected to the line.

The community determines the charges to be collected from the consumers to meet the running expenses. The charge is usually a fixed rate of 30-40 cents per light point per month. The Government collects no taxes on the schemes; its contribution is aid to the people.

The local people are managing the system well. Necessary spare parts (belt, bearings, and fuse wires) are kept in stock so that the villagers need not come to the town when replacements are needed. They also attend to the social problems resulting from the supply of electricity and approach the ATDO only when major problems arise. There is a close link between the local community and the ATDO staff, who monitor the projects frequently.

End Uses

The micro-hydroelectric power programs are primarily planned and implemented to meet the basic needs of electricity for household purposes. Most of the electrical load is lighting, with three or four incandescent bulbs of 40-60 W in most homes. Fluorescent tubes are used by those who can afford them. Some well-to-do villagers have also installed television receivers at their homes. The community shares the maximum power available in such a way that all benefit fairly equally. The level of consumer saturation in the electrified villages is about 80%-90%.

The industrial application of the power depends on the agricultural products of the area and the existing methods of processing. Usually, the agricultural products are processed at the traditional grinding mill or are taken to a town. Both these systems are inconvenient and time-consuming; the latter can also be expensive. People are advised and encouraged to use the power for cottage industries.

Micro-hydropower plants at a number of places are supplying power to cottage industries and agricultural processing units. Generally, the mechanical power of the turbine drives various devices by means of a suitable pulley-belt system. These devices include band saws, flour mills, rice hullers, cotton gins, corn shellers, wooden lathes, and grinders.

At one installation, an electrically driven combination wheat thresher and corn sheller operates 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, lifting water to an elevation of 60 feet is under consideration.

These industrial activities are a great help to the local people. They make it easy and convenient for people from nearby villages to have their agricultural products processed. The plants are sources of income to their owners, and they provide employment to a few people.

CONCLUSION

Conventional methods of rural electrification are 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. Through the use of local resources, these power schemes can be implemented at a low cost. The ATDO schemes in Pakistan have brought socio-cultural reform. They have led to:

- A sense of accomplishment and pride through local participation in development schemes;
- A greater awareness of a need for development;
- An increase in the number of hours available for study and work;
- A healthier environment through smokeless lighting;
- A reduction in tree cutting;
- The introduction of small-scale industrial activity; and
- The creation of jobs and an increase in income.

Small Hydroelectric Power Development in Zaire

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INTRODUCTION

Electrical energy is at the heart of world economic development. Any of a number of sources of electrical energy are used to drive various types of generators that transform mechanical energy into electrical energy. This mechanical energy enters generators and is converted to electrical energy. Each process used 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 the available head. Hydroelectric powerplants fall into two general groups (7): large scale and small scale. Large hydro plants generally have a minimum capacity of 3,000-5,000 kW; usually they serve large urban areas. Small hydro plants usually fulfill the needs of rural areas and farms; they have capacities ranging from 0-3,000 kW.

HISTORICAL BACKGROUND

The Republic of Zaire is a largely landlocked country centrally located in equatorial Africa. It is the third largest country in Africa and is roughly equal in size to the United States east of the Mississippi. Zaire's 1979 population has been estimated at 27,048,000 (5). The annual population growth rate has increased from an average of 2% between 1950 and 1955 to about 2.9% today.

Zaire's potential hydropower is about 13% of the total world hydropower potential (4) and is estimated at more than 1 million MW. The number of feasible sites probably exceeds 1,000.

Large hydropower plant development

Large hydroelectric power production is one of the main uses of water resources in Zaire. Several large dams exist; others are in the planning or construction stage.

The largest existing site is located on the lower part of the Zaire River on the Inga plateau about 40 km upstream from the port of Matadi in Bas-Zaire Region. (See Fig. 1 for a map of Zaire.) The Inga I plant, which was begun in 1968 and went into operation in 1972, has a reliable generating capacity of 300 MW. Work is underway on Inga II, which will furnish 1,272 MW. An 1,800 km, high-voltage, direct-current transmission line links the plant to the 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, southwest 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 because of 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; in Kivu, a 12.6 MW station on the Ruzizi River supplies power to Bukavu.

Shaba Region has the largest amount of installed hydroelectric power capacity—nearly 530 MW. 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 the country's total hydroelectric production; the western part of the country, including Kinshasa, Bas-Zaire, and parts of Bandundu Regions, consume about 23%. The remainder is accounted for by the rest of Zaire. The mining and metallurgic industries use about 68% of the total output; other industrial sectors use about 18%. Home consumption and street and other public lighting account for about 11% of the total output.

Diesel powerplants

Some cities, missionary stations, and private establishments use diesel powerplants. Most of these plants operate only several hours a day because diesel oil is expensive and supplies are unreliable; others are not running at all because fuel is unavailable.

Small hydropower plant development

The Government of Zaire has installed only one small hydropower plant, a 2 MW plant near Matadi. Until recently, the Government was not very interested in small hydropower installations. However, as the cost of petroleum continued to rise, the Government revised its

Fig. 1. General map of Zaire.

national energy policy to give priority to the exploitation of Zaire's small hydropower potential.

EXISTING SMALL HYDROPOWER PLANTS

A number of private firms and religious groups have installed small hydropower plants in Zaire. Currently there are 10 of these either operating or planned (see Table 1). They are scattered around the country and have a range of about 10-100 kW. These small hydropower plants are not interconnected and are not connected to the national electrical system. They are installed in remote areas, often widely separated and serving different load centers.

Construction materials and equipment

Structures necessary for small hydropower facilities include dams, powerhouses, canals, and penstock supports. Construction of these structures requires

32

TABLE 1. Small Hydropower Plants in Zaire

Plant	Location	Description
Katale	Northern Kivu	Rated power: 50 kVA
Ruangura	Rutshura, Ivu	Rated power: 200 kVA
Bibanga	Katana zone, Kasai Oriental	Rated power: 14 kVA
Idzim	Idiofa, Bandundu	Power: 108.9 kW Head: 28.55 m Flow: 470 l/s
Osso	Bas-Zaire	Power: 190 hp (141.7 kW) Head: 8.6 m Flow: 2,000 l/s
Nioka	Bunia, Haut-Zaire	Power: 26.6 hp (19.8 kW) Head: 5 m Flow: 500 l/s
Pères Trapistes	Kikwit, Bandundu	Power: 76 hp (56.7 kW) Head: 64 m Flow: 450 l/s
Raedeck	Bukavu, Kivu	Power: 23.9 hp (17.8 kW) Head: 64 m Flow: 35 l/s
Franz	Bukavu, Kivu	Power: 64 hp (47.7 kW) Head: 10 m Flow: 600 l/s
Robert	Bukavu, Kivu	Power: 19.7 hp (14.7 kW) Head: 14.2 m Flow: 130 l/s

materials such as reinforced concrete, rock masonry, and reinforcing bars, which are available locally in Zaire and can be purchased with local currency. Their average cost is estimated at about one-half the total cost of the equipment (see Table 2).

Equipment for small hydropower plants includes penstocks, turbines, generators, high-voltage towers, conductors, insulators, transformers, and meters. Zaire, and probably most countries in Africa, must import this equipment because there are no local manufacturers. The cost of these items generally must be borne in foreign exchange (dollars).

End uses of power generated

Missionary-owned hydropower facilities in Zaire supply power to hospitals and maternity facilities, dispensaries, machine shops, schools, home appliances, and lighting systems. Hydropower facilities owned by individuals and small businesses supply power to commercial equipment, machinery, mills, and appliances, and for domestic needs such as home lighting and appliances.

PRELIMINARY NEW SITE ASSESSMENTS

The Government of Zaire and various donors, especially the USAID, have conducted preliminary assessments of suitable hydropower sites for rural areas.

The Government's energy policy working group, steered by the Service Présidentiel d'Etudes (SPE), has made a partial inventory of small hydropower sites to be considered in the future development of Zaire's rural electrification program (see Table 3). The Government defines a mini-hydroelectric plant as having an installed capacity of 2,000-10,000 kW. Plants with a capacity of less than 2,000 kW are considered micro-hydropower plants.

USAID/Zaire has investigated other small hydropower sites in response to requests from various parties interested in financial and technical assistance in developing rural hydroelectric power potential (see Table 4).

USAID classifies small hydropower plants as either micro-, mini-, or small hydropower plants. Under USAID definitions, micro-hydro plants have capacities of less than 100 kW; mini-hydro plants have capacities of 100-1,000 kW; and small hydro plants have capacities of 1-15 MW.

Criteria for site selection (4)

The criteria considered in site selection are:

- Social and economic impact. This is measured in terms of population, schools, medical facilities,

TABLE 2. Koda Hydroelectric Project, Summary Cost Estimate, February 1982[a]

Item	Total Cost	
	Z	$
Materials	1,017,500	—
Equipment	248,900	361,000
Training and supervision	14,800	45,000
Contingency	380,000	40,000
Total	1,661,200	446,000

[a] 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.

TABLE 3. 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	160.00
	Miao	Kazumba	Tshibuayi	4.26	66.50	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
Kivu	Lutulu	Lubero	Butembo	174.00	3.10	6,000.00
	Butahu	Beni	Ruwenzori I	180.00	3.10	6,000.00
	Lusilube	Beni	Ruwenzori II	180.00	2.50	6,000.00
	Kiliba	Uvira	Kiliba	545.00	2.00	15,000.00
	Lubero	Lubero	Lubero	45.00	2.50	1,700.00
	Talya South		Muhuma	280.00	8.10	25,000.00

commercial enterprises, and agro-industrial facilities in the area. It includes an assessment of the community's capacity to generate revenues sufficient to amortize installation and operating costs.

- Existing availability of electric power. The site evaluation considers 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 planned) would be considered appropriate sites only if existing lines cannot be tapped (as when step-down transformers would be too costly or incompatible with the major system).

- Potential power. The electrical potential at a site is considered in terms of capacity (kW) and energy (kWh). Sites where water resources exist but the electrical potential is too low or too unreliable because of seasonal flow fluctuations are not suitable.

- 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. Generally, it is impractical to develop a site where the available head is less than 3 m.

- Compatibility with regional development plans. Each site is checked for compatibility with the development program of the Government of Zaire. The Government gives certain agricultural production centers a higher priority for development.

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

- Distance to load centers. The distance from the generating plant to load centers determines the extent of transmission lines needed. Very long lines serving a small load are not practical.

- Geologic conditions. An initial assessment of geologic conditions at the site should be favorable.

- Availability of skills. The availability 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.

It is also necessary to evaluate the environmental effects, the distance between powerplant and load center, the geologic conditions at the site, and the local availability of requisite construction skills.

PLANS FOR FUTURE DEVELOPMENT

Following a national energy colloquium in 1980, SPE was designated to head a Government working group charged with developing a national energy policy. The first drafts of that policy have given priority to the development of small rural hydropower. SPE now is proceeding with regional surveys to establish a national rural hydroelectric development plan. Initial plans envision a series of pilot projects to develop a base of information on technical, managerial, and financial requirements at both the national and local levels.

The Government has requested USAID assistance in conducting operational studies for rural hydroelectric development. The Government and USAID/Zaire are planning to undertake operational feasibility studies through demonstration projects. In 1981, USAID requested the assistance of NRECA in conducting a preliminary survey for this project. The NRECA report (4) endorsed the concept and outlined a range of options for initial planning. The cost of a national pilot program is estimated to be US$ 15 million.

The project's concept focuses on institution building and technology transfer to establish a foundation for the long-term development of Zaire's rural hydroelectric potential. Current plans anticipate that the national electricity company, Société Nationale d'Electricité (SNEL), will have operational responsibility. Under the project, SNEL would establish a Rural Mini-Hydro Division staffed with engineering, economic, administrative, and logistics specialists. A technical assistance team of experienced professionals representing these disciplines would train and support the Division over the life of the project. Key managerial and technical personnel would be trained both in Zaire and abroad.

The project would include installing a number of mini-hydro facilities to test feasibility in different

TABLE 4. Site Assessment Summary II (USAID/Zaire)

Region name	Zone name	River name	Fall name	Head (m)	Flow (m^3/s)	Power (kW)
Equateur	Gemena	Libala River Tributary	Zulu-Karawa Karawa	7.00	5.00	200.00
Haut-Zaire	D'jungu	Koda	Koda	94.00	0.28	254.59
Shaba	Kamina	Lulelwe	Songa	11.20	24.00	2,104.76
Bas-Zaire	Luozi	Ngudi	Sundi-Lutete	16.50	24.00	3,106.00
	Mbanza-Ngungu	Lunionzo	Sona-Pangu	—	—	20.00
Kivu	Rutshuru	Rutchurce	Rwanguba	—	—	125.80
Bas-Zaire	Mbanza-Ngungu	—	Gombe-Matadi	—	—	140.00
	Mbanza-Ngungu	Notake	Nkamba	30.00	0.07	15.00
	Madimba	—	Sona-Bata	—	—	40.00
Haut-Zaire	Irumu	Notake	Tshabi	17.00	0.30	50.00
	Irumu	Ababiba	Tshabi	30.00	0.12	40.00
Kivu	Shabunda	—	Katchungu	—	—	12.00
	Fizi	—	Nundu	—	—	100.00
	Pangi	—	Kama	—	—	—
Kasai Occidental	Dibaya	Lubi-Mpata	Lubi-Mpata	—	—	180.00
	Dibaya	Lukula	Tshidimba	8.13	2.39	154.46

geographic regions and under various socio-economic conditions. Development of these facilities would provide practical experience to SNEL personnel and would help refine the criteria for site identification within a long-term national energy development program. Through the project, SNEL would develop the institutional capacity to provide the essential technical, managerial, and logistical support for future mini-hydro electrification in rural areas. Specific support capacities would include:

- Civil engineers to design and construct water control structures, conduct hydrologic analysis (water supply and flood estimation), select and install appropriate turbines, conduct environmental impact and geologic assessments;

- Electromechanical engineers to design and construct electrical systems and install generation, control, and transmission equipment for small hydroelectric systems;

- Economic and social analysts to assess and assist with community organization, planning for power distribution and use, financing for installation and operation, and amortization of costs; and

- Administrative and logistical support to facilitate planning and to reduce constraints to implementing plans effectively and efficiently.

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.

SUMMARY AND CONCLUSION

Because the GNP of a developing country bears a close relationship to the quantity of energy consumed (2), continued efforts to develop hydroelectric potential whenever it is feasible can play a vital role in the economic and social development of any country.

Small 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 (3).

Ever-increasing oil costs are directing more attention toward the design of hydroelectric equipment packages for cost-efficient 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 small hydro projects.

With the availability of new material—bearings, small generators, and electronic controls—it has become possible to develop small hydropower systems with installed costs of $2,000 or less per kW and operation and maintenance requirements of less than 5% of invested capital per year. 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 to reduce costs and complexities from start to finish should be the goal if the potential for rural hydroelectrification is to be exploited fully and rapidly.

REFERENCES

1. 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. Washington, DC: National Academy Press, 1981, p. 48.

2. Gladwell JS, and Warnick CC. Low-Head Hydro, An Examination of an Alternative Energy Source. Moscow, ID: Idaho Water Resources Research Institute, June 1979.

3. NRECA. Small Hydroelectric Powerplants, An Information Exchange on Problems, Methodologies, and Development. Washington, DC: National Rural Electric Cooperative Association, 1981, p. 6.

4. NRECA. Small Hydropower and Rural Electrification Project for Zaire. Washington, DC: National Rural Electric Cooperative Association, July 1981.

5. Science and Technology Division, Library of Congress. Phase I Environmental Profile of the Republic of Zaire. AID Contract No. SA/TOA 1-77 with the United Nations Secretariat on Man and the Biosphere. Washington, DC: Department of State, June 1980.

6. Service Présidentiel d'Etudes (SPE). Colloque National sur l'Energie—Potentialités Energétiques. Nsele, 25-28 février 1980, p. 22.

7. Zerban A, and Nye EP. Power Plants. Second Edition. Scranton, PA: International Textbook Company, 1967, p. 41.

An Overview: The Zulu Hydropower Project

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INTRODUCTION

The rapidly increasing cost of electrical power from engine-driven generators, the increasing demand for electrical power, and the need to upgrade services has caused many in Zaire to seek other sources of electrical supply.

The Eglise du Christ au Zaire/Communauté Evangélique en Ubangi-Mongala, a private voluntary organization (PVO), in collaboration with the Government of Zaire, is developing a small hydroelectric site in the northwestern province of Equateur. USAID is providing the major funding. There is very little rural electrification in this area. It was deemed necessary to develop a power source here in order to provide 24-hour service to the hospital and educational facilities. There was an active effort to develop this hydro plant, because the cost and availability of fuel are constant problems. Even if fuel were affordable, it is questionable whether adequate supplies would be available to operate diesel plants on a 24-hour basis. Like L.P. gas and gasoline, this fuel is currently rationed.

The initial installation cost of the Zulu hydro project is rather high, but the low cost of operation and maintenance is very attractive. It is regrettable that this technology was not installed several years ago, because all costs have risen drastically since the oil crisis of 1973.

SITE SELECTION

The main factors in selecting a suitable hydropower site are flow, head, pondage, and development cost. Three possible small hydro sites near Karawa were identified originally.

Although they are close to the population center, two sites were eliminated because of earthfill requirements and spillway and flood control problems. One site is located on the Bagbau River, which is 2 km east of Karawa with a flow of 6-8 m^3/s. However, there are no natural falls, and the site would require a dam 600 m long and 7 m high to develop about 300 kW of power. The earthfill, spillway, and flood control problems made developing the site prohibitively expensive. A second site is on the Libala River, which is a larger river located 2.5 km south of Karawa with an even greater potential. However, developing the site would require an enormous earthfill dam and would have spillway and flood control problems similar to those found at the Bagbau River site above.

The remaining site, Zulu, is 11.2 km west of Karawa in a heavily forested area, but offers the advantage of natural falls. The site has a head of 7 m and a flow rate of 5 m^3/s. Disadvantages of the Zulu site are its distance from the load center and the necessity of constructing a 350 m x 3.5 m earthfill dam.

ECONOMIC FEASIBILITY AND END USES

Cost projections are very important. They should isolate major areas of expense to facilitate computation of actual dollar costs as prices and conditions change. In the case of the Zulu project, for example, the price of cement increased more than 3,000% between 1977 and 1982. Handling and transportation costs also increased dramatically during this period.

Costs of supportive activities and structures also must be realized. These can include access roads, airstrips, and repairs to existing facilities. It is necessary to ask questions such as:

- Should these become a part of the hydro project, or will they be developed by other sources?
- Will they be useful to the area during and after the project?
- Can they be considered a long-range benefit to the area?

Equally important is an evaluation of end uses and benefits. Development of a power source brings many changes that affect the community. Where possible, it is important to give a dollar value to the benefits, both direct and indirect, to and from the project. Fortunately, the value of the output often increases proportionally with the cost of development. In such cases, the end products remain competitive, particularly in light of a long service life and increasing fuel costs.

The major benefit of a small hydro project is decreased dependence on fossil fuels. A dependable source of power enhances planning and reduces operating costs. These savings can be passed on to the users in Karawa.

In Karawa, the small hydropower plant will greatly benefit the Mission by providing electricity for:

- The Medical Service, through improved lighting, incubators, refrigerators for pharmaceutical and film storage, air conditioning for operating rooms, and hot water for bathing and laundry;
- The Educational Department, for laboratory and audio-visual equipment; and
- The Technical Services Department, for power tools and for a hammermill, which will grind corn and manioc to produce flour for the surrounding community.

The developers of the Zulu site hope that these time-saving benefits will have a ripple effect throughout the community through increased food production, better nutrition and health care, and improved, lower-cost educational opportunities. These benefits can help the surrounding rural areas to advance from a subsistence level to a more rewarding lifestyle.

SCHEDULE OF ACTION

It is important to plan movements, supply lines, labor pools, and construction procedures. Weather is of paramount importance to all planning activities. Often it is necessary to improvise as weather-related and other unforeseen difficulties arise.

Because machinery is not readily available, manual labor is used to construct much of the civil works. For this reason, shortages of labor during harvest seasons may delay the project. A lack of semiskilled help may necessitate on-the-job training, which requires time and instructors. When possible in implementing a scheme, it should be planned so that each component as it is completed can provide a service to the area or facilitate the construction work.

In the case of the Zulu project, while the dam is being built to its full height, a smaller turbine will operate at 1/3 capacity on the flow of the river. Although this will not necessarily reduce construction costs, it will provide three times the power that the diesel generator sets presently provide the community.

SOURCES OF EQUIPMENT

There are many suppliers of small hydro equipment on the world market. The Zulu site uses Leffel and Ossberger prepackaged turbo-generating equipment which is ready for installation. Both manufacturers have many years of experience and have been very helpful in planning and in providing needed information. USAID also has provided the project with equipment including dump trucks, compressors, and fuel and water tanks.

Almost all commodities in the project are imported. One exception is a penstock, which was fabricated in Kinshasa. In some cases, used equipment has been adapted to keep the project going. The Zulu project mainly utilizes small trucks, pumps, and generator sets in the 2-15 kW range which the Technical Services Department keeps in good working condition.

IMPLEMENTATION

Several problems have arisen in the development of the Zulu hydroelectric project. These problems, and some suggestions for avoiding them on similar projects, are outlined below.

Funds

There have been delays in permission to transfer funds, and delays at the bank of up to 7 months. In addition, currency was in short supply while the new Zaire bills were exchanged and during the coffee season.

Technical assistance

It is important to secure knowledgeable consultants in several areas of expertise at crucial points of project implementation, particularly for site selection, design, and commissioning of the plant.

Procurement

More time has been needed to find supplies than was originally expected, and it has been necessary to keep more stock on hand than anticipated. The project also needs alternate transportation facilities and a good communication system between the site and home base.

Equipment

It has been necessary to keep two of any critical unit on hand, or to be able to rent a similar unit. For example, the loader was broken down for 11 months awaiting parts and repair.

Labor

A skilled and semiskilled workforce is not always available. In some cases, it may be necessary to train local people even in basic skills. At the Zulu project, there were professional training delays of 1 1/2 years when technical courses offered in schools were cancelled.

It is important to determine how much unskilled labor will be required and when. Unskilled labor may not be available during crucial times of project development. For example, the Zulu project needed a pool of unskilled labor during the local garden cutting time, when many laborers wanted to be excused from work.

It is important that the workforce receive good supervision from a member of the local community.

Compensation

If the pay scale is too low to attract labor, bonus systems for attendance and good performance may help

offset the problem. Several other incentives can help attract a workforce, such as food rations on the job and the sale of much-needed goods, such as machetes, shoes, soap, salt, lumber, at favorable prices. Workers also should be provided with:

- Uniforms and caps,
- Medical care in the form of first aid on the job site, as well as care at a nearby hospital, and
- Insurance for accidents.

Public relations

The public relations benefits that derive from inviting local government officials to tour the project site can be considerable. It is equally valuable to credit and recognize all who have had a part in the project, including those responsible for rights-of-way, project approval, funding, technical assistance, and contributions-in-kind of supplies and labor.

TECHNICAL CONSIDERATIONS

Small Hydropower Schemes (A Slide Presentation)
Allen R. Inversin

Hydrologic, Environmental, and Geologic Factors in Mini-Hydropower Site Selection
Paul H. Kirshen

Hydrologic Data Requirements for Developing Small Hydropower Sites
Walter D. Lawrence

Equipment Design and Local Manufacturing Opportunities
Reinhold Metzler

An Electronic Load Governor and Related Developments
Jack L. Woodward

A Viewpoint about Small Waterpower Developments
Jaime Lobo Guerrero

A Radical Approach to Rural Electrification for Developing Countries
Hoesni Nasaruddin

Small Hydropower Schemes (A Slide Presentation)

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INTRODUCTION

Most people are more familiar with large hydroelectric projects generating hundreds of megawatts and beyond than with small hydropower projects. 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 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. They can introduce adverse environmental impacts, including the spread of disease carriers, the flooding of agricultural land, and social dislocation. Generally, they rely heavily on costly outside expertise for their design, construction, and maintenance and on costly imported equipment and materials.

Smaller hydroelectric schemes allow for greater local contributions and therefore greater financial returns and benefits to a nation. A 3 MW plant near Fang in northwestern Thailand, for example, was designed by Thais and constructed by local companies; only the turbo-generating equipment and associated hardware were imported (see Fig. 1).

The increasing cost of oil has increased 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.

Near the bottom of the power range are even smaller hydropower plants. Although these do not contribute significantly to the total power available to a country, they do meet specific needs and perform a valuable service. For example, a 90 kW plant provides power to a hospital and staff housing in the central highlands of Papua New Guinea; a 12 kW plant furnishes power to a forestry station and tribal village in northwestern Thailand (see Fig. 2); and a 1 kW plant supplies lighting to a very remote mountain village in Papua New Guinea (see Fig. 3). These smaller plants permit even greater local involvement, including local fabrication of a portion of the turbo-generating hardware and community participation in the installation and management of the schemes. They can make a direct contribution to rural development.

PRINCIPAL FEATURES

Although they come in a wide range of sizes and designs, all hydropower plants perform the same function—by means of a turbine, they harness the energy water loses as it drops in elevation. A variety of turbines are available to cover the entire range of heads; conditions at the proposed site determine designs for hydropower schemes. However, all hydropower schemes include some or all of the following components (see Fig. 4):

- Dams. 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 a 1 MW locally

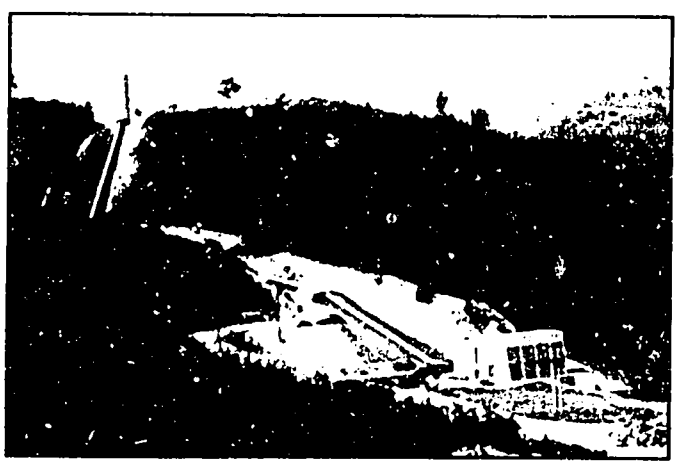

Fig. 1. A 3 MW plant near Fang, Thailand.

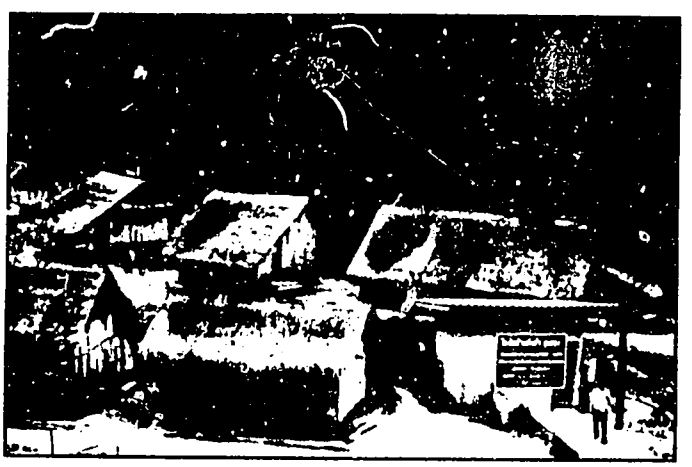

Fig. 2. A 12 kW plant at Khun Khong, Thailand.

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Fig. 3. A 1 kW plant at Gemaheng, Papua New Guinea.

constructed project in Nepal. Dams are generally associated with large hydroelectric plants because they allow excess water to be stored. However, dams are avoided in designing small schemes because the heavy rainfalls in the tropics, often coupled with hillside slopes made bare for agriculture, contribute to heavy silting and large flow variations and create the potential for problems. Also, dams often require a costly series of engineering studies of the site as well as the structure.

- Weirs. Small schemes are generally run-of-the-river designs, which use water as it flows downstream without storing any for later use. In this case weirs or other diversion structures are placed across the stream to deflect water into the intake.

- Intake. The intake from the stream is generally equipped with a metal grill or trashrack to prevent large debris from entering. A gate to control the flow toward the powerhouse is often included.

- Settling basin. A settling basin, located near the intake, may be incorporated to permit any water-borne sand and gravel to be deposited there. Otherwise, this debris would be deposited in the canal on the way to the powerhouse, where it would gradually hinder the flow of water, or be carried through the turbine, where it would cause rapid deterioration.

- Power canal. Although it is sometimes advisable to convey the water directly from the intake or settling basin to the turbine by means of a pipe, this approach often leads to excessive costs. To reduce these costs, an alternative is to bring the water as close to above the powerhouse as possible by means of a canal that follows the contour of the land. This power canal can be constructed of a variety of materials, including concrete, wood, and earth.

- Forebay. The power canal carries water to the forebay, a basin located just before the intake to the pressure pipe to the turbine. It provides space where any suspended matter in the water can settle out and stores small volumes of water to accommodate initial changes in flow through the turbine.

- Penstock. The water then flows through the penstock, a pipe that conveys the water, under pressure, to the turbine in the powerhouse.

- Powerhouse. In the powerhouse, the turbine harnesses the waterpower and the spent water is returned, usually to the original stream.

These components are integrated into an overall hydropower scheme on the island of Bali in Indonesia. Like many hydropower schemes in Indonesia, this scheme is integrated into an irrigation system. Water therefore is used for irrigation or power generation or both. Because 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 to store water. The intake takes water in at right angles to the river and leads into a settling area. 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

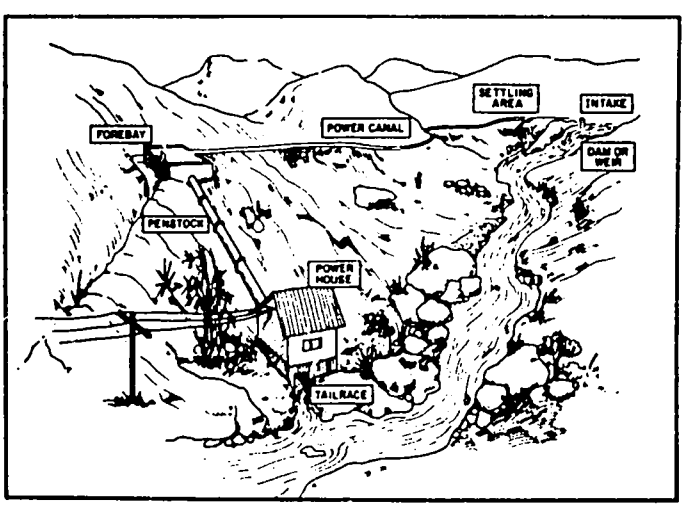

Fig. 4. Typical features of a mini-hydropower plant.

42

irrigation, and another portion is carried off to the forebay and then down the penstock to the powerhouse, where a drop of 11 m generates about 80 kW.

Although all serve the same purpose, hydropower plants have different layouts and require different turbines depending on the site. The choice of turbine depends primarily on the operating head, which may range from 1-2 m to 1,000 or more. An approximate relationship between the power (P, in kW) generated by a hydroelectric plant and the head (H, in meters) and flow (Q, in m^3/s) available at the site is: $P = 6QH$. This relationship assumes an overall efficiency of 60%.

A low-head site is at Wonodadi on the island of Java in Indonesia (see Fig. 5). It is similar to other schemes in the country that are integrated in the existing irrigation network. The scheme on the island of Bali uses excess water from an irrigation canal, whereas this one uses a drop along a major irrigation canal. When the plant is operating, water is diverted by a short canal just upstream from the 3-4 m drop through the turbine, which generates 230 kW. Because the head is low, a large flow must pass through the turbine.

Fig. 5. A 210 kW plant harnessing the power otherwise lost at an irrigation drop on the island of Java.

A higher head site is a new site at Nam Dang in northern Thailand. Under a head of 79 m, this scheme requires less water, and consequently a much smaller turbine, to produce 50 kW (see Fig. 6). In this case the turbine was fabricated in a local workshop.

UNIQUENESS OF SMALL HYDROPOWER

Until recently, only large hydroelectric schemes attracted the attention of developing countries. Now they are directing increasing interest toward small decentralized hydropower schemes. There are several reasons for this change:

- Large projects rely heavily on imported materials, equipment, and expertise; small projects permit greater use of locally available materials and labor. In Pakistan, for example, penstocks are fabricated not only of steel when necessary, but also of discarded oil drums and even timber from the local forests. Smaller schemes also increase the possibility of local manufacture of at least some of the turbo-generating equipment.

Fig. 6. One of two 50 kW turbo-generating units at Nam Dang, Thailand.

- Large schemes generate electrical power in addition to electricity generation exclusively; small hydropower schemes permit direct mechanical drive for workshop equipment, small industries, and agro-processing equipment (see Fig. 7). All these can be run directly 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 the technical skills necessary to maintain electrical equipment are not highly developed.

- Large schemes generate a large quantity of power, but the high cost of transmission prevents most of this power from reaching the rural areas. Compounding this problem is the fact that the load in rural areas is not developed, being used only for lighting, and there is no economic base to pay for the electricity from the grid. On the other hand,

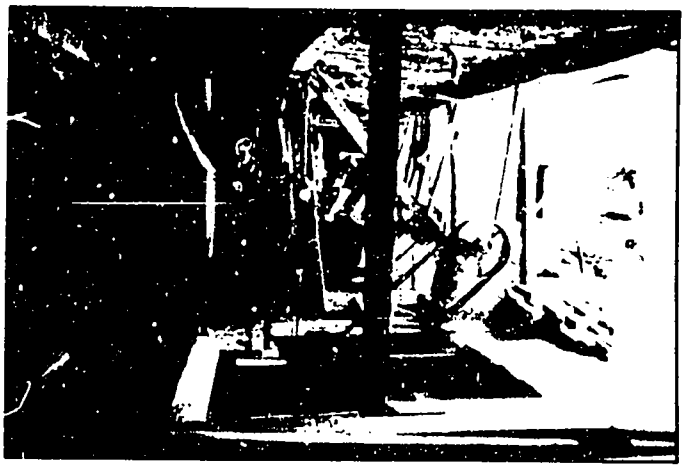

Fig. 7. At this 10 kW site in Pakistan, electricity is generated in the evening for 80 homes in the village and direct mechanical power drives a variety of equipment during the day.

small decentralized hydropower plants permit power to be generated near the rural customers and thus avoid the enormous costs of transmission.

- Small plants, in conjunction with end use programs, can encourage the development of economic growth in rural areas. If the local needs eventually exceed the capacity of a small plant, the higher load factor that will have developed will reduce the cost of power transmitted from large centralized schemes when the grid is extended in the future. Also, the customers will be in a better position to meet these costs because of the income-generating activities that will have developed as a result of the power supplied by the small hydropower plant.

MICRO-HYDROPOWER IN NEPAL

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 must begin their program more modestly. Nepal's program is an example of such an approach.

In Nepal, the hulling of rice, milling of grain, and expelling of oil required manual assistance. Centuries ago a rudimentary water-powered mill mechanized the grinding of grain. Recently, mills have been replaced by diesel engines that power the hulling, milling, and oil-expelling equipment. During the past 2 years, one company in Butwal, Nepal, has fabricated and installed turbines to replace the costly diesel processing at more than 50 remote sites throughout the country (see Fig. 8). These installations are virtually unsubsidized; costs are kept down by using local manufacture as much as possible, conducting as few preinstallation studies as possible, and using local labor and appropriate designs.

After receiving an inquiry from an entrepreneur or group in a village, one or more staff members from this company investigate the proposed site. They discuss with the villagers the details of how work at the site would proceed, the obligations the villagers would assume in implementing the project, and the financial costs that would be involved. If the decision is then made to undertake the project, the villagers make a down payment for the turbine and equipment, and the company begins fabrication work in its workshop. At the same time, the villagers conduct excavation for the canal, powerhouse, and forebay, and collect stones, sand, and other necessary materials that are locally available. When the villagers have completed their work, they make arrangements for the machinery and other materials to be transported to the site. After the villagers have assembled all the materials, the company sends a two-person team to help them install the equipment. The team is paid by the day, which

Fig. 8. A 10 kW mill at Argali, typical of the numerous micro-hydro mills found in remote areas of Nepal.

encourages the villagers to use the team's expertise efficiently. The penstock, turbine, and draft tube are assembled first and then are moved into place and secured as a unit. The huller, grinder, and oil expeller are installed next. In 3-4 weeks, the plant is completed and operational. Although these plants were installed primarily to drive agro-processing equipment, there is growing interest in using the power in the evening to generate electricity.

This company's hydropower activities began slowly; however, work is now proceeding more rapidly as villagers become aware of the potential of water-driven equipment. A large workshop in Kathmandu, Nepal, has undertaken similar work and also has installed about 50 plants. This approach is appealing because it is replicable. Others in the country can copy it, creating a widespread impact in the countryside. Several small workshops in Nepal, seeing the potential for hydropower in the mountains from the examples set by these two larger companies, have begun local fabrication of turbines on their own.

This discussion presents one approach to the implementation of small hydropower schemes. There are many others. It is hoped that this workshop will increase the participants' awareness of the options open to each country, the problems that must be addressed, and the contributions to development that small decentralized hydropower can make.

Hydrologic, Environmental, and Geologic Factors in Mini-Hydropower Site Selection

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INTRODUCTION

When a mini-hydro project comes on line, it represents the successful completion of the planning process shown in Fig. 1. A broad-scale assessment identifies areas where mini-hydro best meets the needs of a country. Prefeasibility studies then reduce the large number of potential sites in the region or country by coarse-grained analysis to a much smaller number of candidate sites. The last step in site selection is the feasibility study which evaluates the candidate sites in greater detail and selects the final sites. These sites then go through the site approval, planning, design, and construction steps.

Hydrologic, environmental, geologic, economic, financial, social, and energy policy factors must be considered at each step in the process. Ideally, all factors should be considered simultaneously at each step, but usually hydrologic factors initially dominate. It is important to remember that all methods and analyses must be adjusted for local factors and data availability.

HYDROLOGIC ANALYSIS

The major purpose of hydrologic studies is to estimate the power and energy available at a site through discharge and head studies (see Table 1). Related studies evaluate:

- The change in tailwater elevation, to determine the net head fluctuation,
- The magnitude of the flood discharge, to design the spillway, and
- The evaporation and transpiration rates to account for storage losses and head changes.

This paper generally assumes that sufficient and high quality data are available; methods of studying data-poor sites are discussed in Appendix A.

Power and energy potential

The well-known formula for power at a site is:

$$P = 9.81\, QH_n e$$

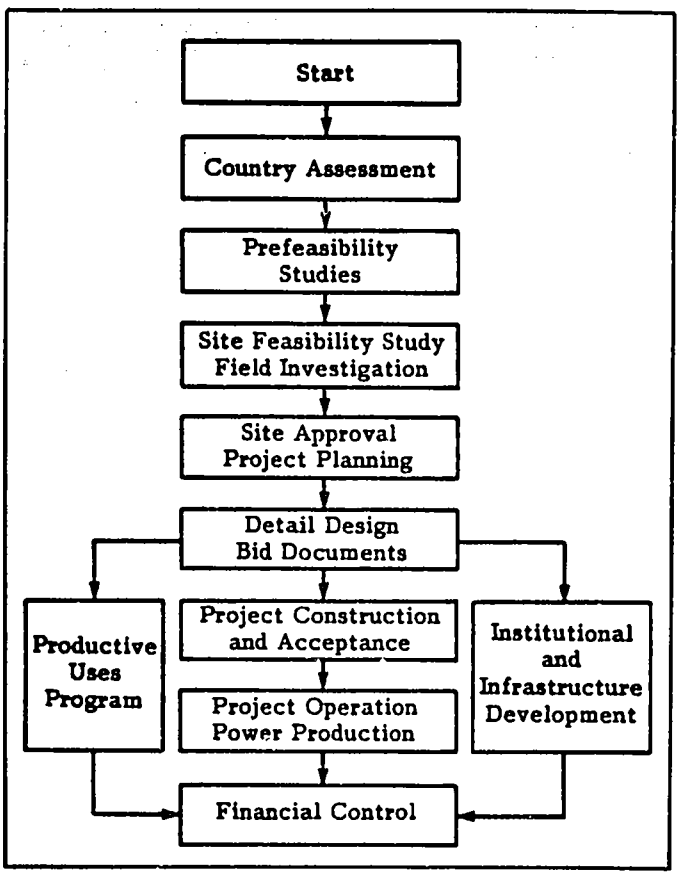

Fig. 1. Stages of project development (10).

where P = power (kW), Q = discharge (m^3/s); H_n = net head (m); and e = efficiency of turbine and generator.

In English units, the formula is:

$$P = \frac{eQH_n}{11.81}$$

where Q = discharge (ft^3/s), H_n = net head (ft), and other variables are the same. Energy is determined by multiplying the power by the time of operation. To estimate the power and energy potential at a site, both discharge and head must be known.

45

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. Use rules of thumb 2. Use sequential simulation of typical year 3. Calculate annual flow duration curve
Net head	1. Use topographic map 2. Visit site (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 prefeasibility studies)
Flood discharge	1. Need only to consider that spillway may be needed
Evaporation and transpiration losses	1. Need only 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. Calculate annual flow duration curve 2. Calculate monthly flow duration curves 3. Use sequential simulation of historic or synthetic flows
Net head	1. Must consider type of turbine, tailwater elevation, and evaporation and transpiration losses
Tailwater effects	1. Determine monthly elevations using equation of Gradually Varied Flow
Flood discharge	1. Plot annual peak flow data on semilog graph paper and extrapolate 2. Fit extreme value distribution to data 3. Use rainfall intensity-frequency-duration curves and runoff analysis 4. Compare to similar types of watersheds 5. Visit site
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

Prefeasibility study

To compare average annual energy value to average annual costs, it is necessary to estimate the average energy production resulting from the installation of one or several turbine-generator units.

The simplest method of selecting a turbine for a site is to assume that the net head and efficiency are constant and storage effects 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% capacity factor usually produced economical designs. (Capacity factor is defined as actual annual energy production divided by theoretical energy production if the plant is operated all year at design discharge.) Therefore, this method was used to estimate power and energy production in prefeasibility studies. In another part of the world, it was found that capacity and energy production could be

46

estimated by sizing the tubines at 50% of the mean flow and assuming the plant operated at full capacity for 5 months of the year and produced an additional energy output of 10% during the remaining 7 months. Other rules of thumb are based on precipitation values and drainage areas. It is important to review how the rule was derived.

Such rules of thumb may not exist. To develop them, the results of prefeasibility or feasibility studies of mini-hydro in hydrologically similar areas can be reviewed (see Appendix A). An alternative is 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 several actual years whose annual discharge approximates the average annual discharge at the site. Then choose the one most representative of a typical year and estimate the annual energy production that would result from a turbine of a particular size (see Fig. 2). Estimates of energy production derived from these methods are very approximate, but they are satisfactory for prefeasibility studies.

The most accurate but time-consuming method of estimating annual average energy production for a prefeasibility study is to construct a monthly or daily annual flow duration curve (6,13). Fig. 3 shows how to use the curve to estimate energy production for a possible turbine size.

As mentioned, net head is usually assumed to be constant in mini-hydro prefeasibility studies. For a reaction turbine, net head is the elevation difference between the forebay water surface and the tailwater surface minus friction losses in trashracks, intakes, penstocks, etc. Depending on the configuration, these

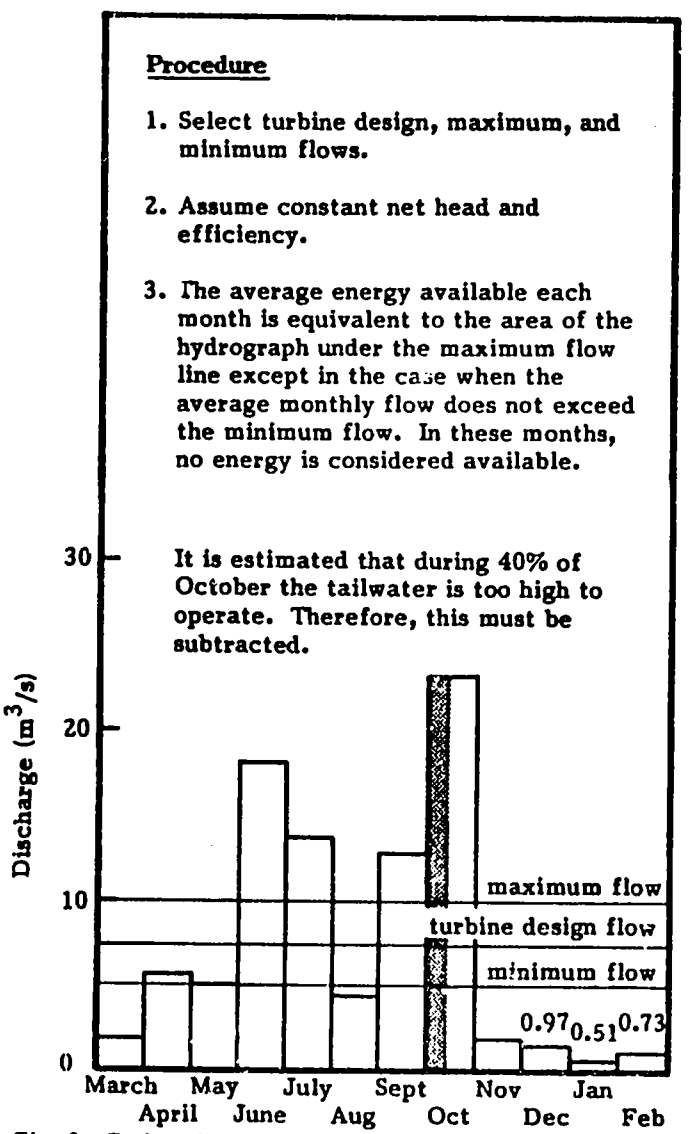

Fig. 2. Estimating mean annual energy production using mean flow sequence (7).

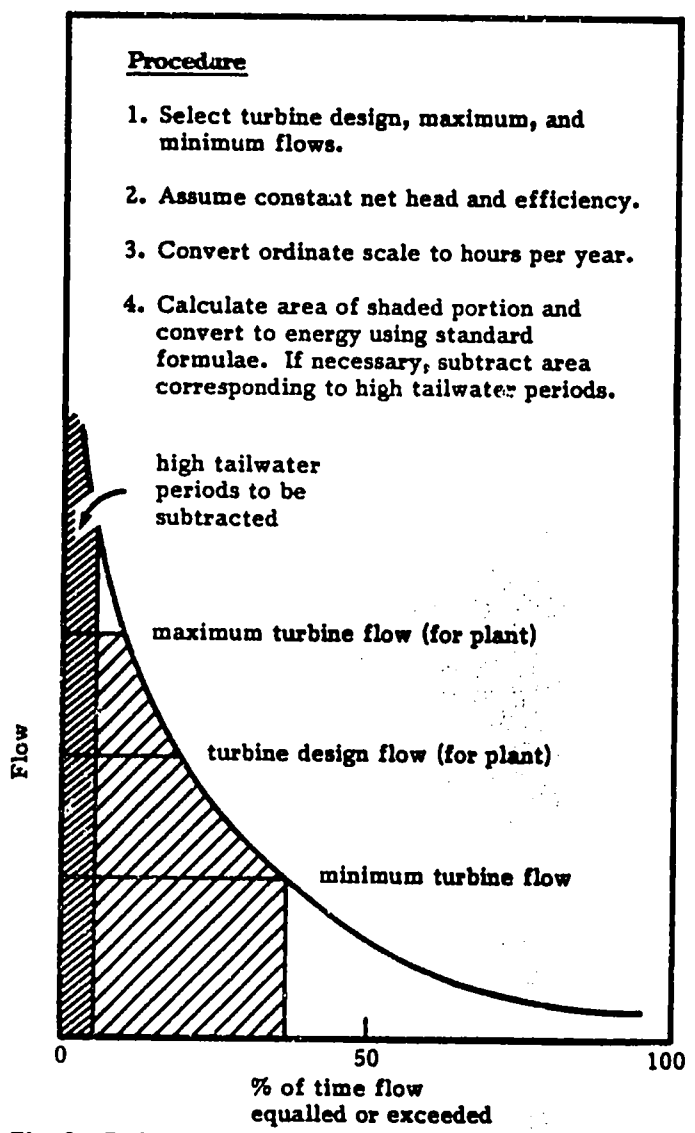

Fig. 3. Estimating mean annual energy production using a flow duration curve (10).

losses may range from negligible to 10%. For an impulse turbine, the discharge velocity head must be deducted also. This is the elevation difference between the nozzle center line and the tailwater surface.

There are many ways to develop head or elevation drop at a site. 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;
- Using penstocks to connect across a steep river bend or to divert water from one river to another.

In conducting a prefeasibility study, it is best to view a potential site on a topographic map to determine different possible configurations and then measure the head during a site visit using one of the survey methods described in Appendix B.

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

Feasibility study

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

At this level of analysis, 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 or evaporation and transpiration losses, it may be necessary also to assume a monthly distribution of net heads and efficiencies.

Sequential simulation of the operation of the plant provides the most accurate method of determining a site's average annual energy production and temporal distribution of energy. This is usually necessary at sites with significant storage. In this method, a computer model of the reservoir, turbine, and generator is used to simulate the operation of the system with 10-100 years of historic or synthetic data in increments of a few hours to a month. Indicators of system performance, such as average annual energy production, temporal distribution of energy with specified reliability, and average volume of spills, are measured. In the most complex cases, the reservoir volume-area-elevation, turbine head-discharge-efficiency, and downstream flow-tailwater elevation curves are used (11).

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

Tailwater elevation

Prefeasibility Study

It is rarely 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 usually can be obtained by speaking to local residents or applying the equation of Gradually Varied Flow to average monthly flow conditions (3).

Feasibility study

Because feasibility studies must produce reasonably accurate cost estimates and design criteria, tailwater effects must be evaluated in detail. The studies identify how these effects vary throughout the year. They also must identify the lowest level that will ever occur under turbine operation to prevent cavitation damage to a reaction turbine.

Monthly variation in tailwater level can be estimated by assuming a downstream flow condition, a reservoir or spillway release, and then applying the equation of Gradually Varied Flow. A similar method can be used to estimate the lowest probable tailwater level during turbine operation. This figure probably will not be the minimum recorded flow at the site, because the turbine probably will not operate with this minimum flow.

Flood discharge

Prefeasibility study

For this study, it usually is not necessary to estimate the magnitude of the spillway design flood; it is necessary only to estimate the type of dam and spillway needed.

48

Feasibility study

In a feasibility study, however, it is necessary to estimate the magnitude of the spillway design flood. The method of analysis used and level of safety sought both depend on the consequences of exceeding the spillway's capacity. For example, if an earth dam is to be used and below the dam is an operation that cannot 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 as a spillway also, and there is little important activity below the dam, a lesser degree of safety and accuracy is needed. Because dams and reservoirs for mini-hydro are small, a design recurrence interval that does not exceed 50-100 years generally should be used.

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

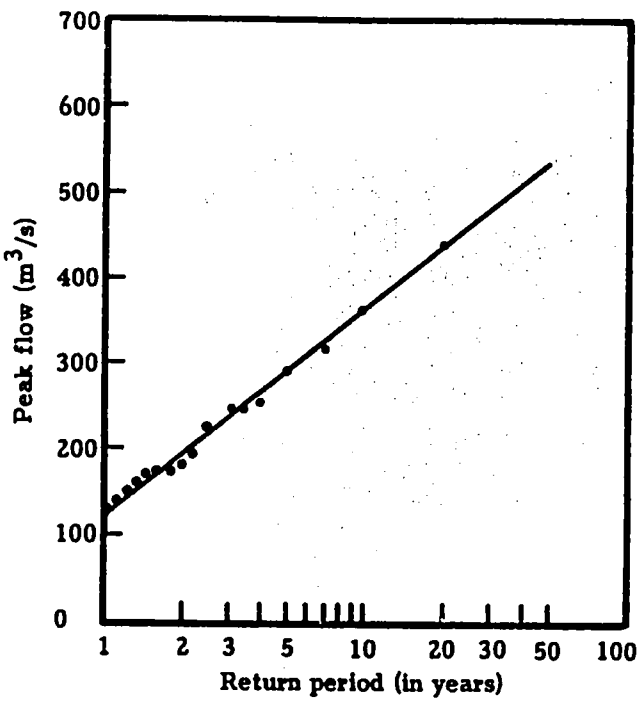

Fig. 4. Flood frequency—peak flow vs. return period (4).

A slightly more complex method is to 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 (9).

If such streamflow data are not available but data on rainfall intensity, frequency, and duration are, a variation of the rational method can be used to estimate the peak flow (4).

When streamflow or precipitation data are insufficient, there are several alternatives. One is to find a hydrologically similar watershed (see Appendix A) with sufficient data and find the peak flow per unit area or unit annual rainfall, then apply this information 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 (4). The drawback to this method is that it cannot estimate the recurrence interval of the peak flow. In most cases, this drawback is not a major problem—if the depth estimate is indeed an extreme value—because there is no great difference between the recurrence intervals of peak flow values at the higher recurrence intervals (more than 30-40 years.) For example, as shown in Fig. 4, the peak flow increases by 100% between the 1- and 10-year recurrence intervals. Between the 40- and 50-year recurrence intervals, the flow increases by only 5%. Therefore, whether the actual depth measured corresponds to a 40-50 year period does not make a significant difference.

Evaporation and transpiration losses

Reservoirs can go dry during extended dry periods if surface evaporation and transpiration losses from phreatophytes bordering the reservoir are large.

Prefeasibility Study

At the prefeasibility study level, it is necessary to know only if there are significant losses during extended dry periods. If there are, most shallow reservoirs will go dry and over-season storage will not be possible.

Feasibility Study

Where there are significant annual losses (more than 50% 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 with methods such as the energy balance approach and the Penman method (9). Transpiration losses from bordering phreatophytes can best be estimated from local agricultural transpiration data.

Energy potential at sites where hydropower is a secondary purpose

Hydropower facilities can be located at dams and other structures designed for primary purposes such as water supply and irrigation. In such cases, the stream discharges do not occur naturally; therefore, the pattern of dam releases (the "operating policy") must be discovered from reviewing project documents and interviewing dam operators and owners. Once this pattern of flow is known, previously discussed methods can be applied. For particularly complex operating policies, sequential simulation may be the only method of estimating energy output for feasibility studies.

ENVIRONMENTAL ANALYSIS

Technological, social, economic, financial, hydrologic, and environmental effects are several of the factors that must be considered in the design of a mini-hydro project. A decision to implement a project must be based on the trade-offs among these factors. Environmental effects include only changes to the natural or physical environment, not to the social or human condition, that result from a project. Because environmental impacts are site-specific, not all the environmental impacts discussed in this section may be significant or occur at a particular site.

Positive impacts of mini-hydro

Zoellner (14) describes the positive aspects of small hydro:

> 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 also may be 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.

Prefeasibility study

The objective of a prefeasibility study is to reduce a large number of potential sites to a smaller number for more detailed analysis. At this level of analysis, there are four basic issues of concern (2):

- The impact of the development induced by the project upon the resource base. If a project is to be built in an undeveloped area or is likely to change land use or occupations in a developed area, it must be determined how the changes will affect the resource base. For example, the construction of a mini-hydro project may lead to 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.

- The availability of water of adequate quantity and quality. Obviously, there must be sufficient water-flow for power production; however, the question of possible competition among various water uses must be addressed. To avoid potential conflicts, these other uses must be identified. If there are too many conflicts, it may be necessary to remove the site from consideration. It is also necessary to consider the present quality of the water at the site. If the quality is poor or the site is in an area that has water-related disease, development of a project may further deteriorate the water quality or increase the incidence of disease.

- 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 legally protected areas such as national parks. If a potential site will affect rare or endangered species, it should be noted in a prefeasibility study.

- Level of interest and support from the local community. The project must benefit the local residents and, they, in turn, must support the project. This support is necessary, because residents may have to make lifestyle changes to accommodate the project. For example, they may no longer be able to swim in certain parts of the river, they may have to adopt public health measures, or some of their land may be flooded.

Feasibility study

An environmental assessment must be conducted for each potential site to identify the project's potential effects on the environment, identify alternatives to the project, and propose mitigating measures for some of the negative effects. The environmental assessment should be conducted as concurrently as possible with other studies to identify particularly adverse environmental impacts early in the planning process, when it may be possible to mitigate them by design or operational changes. Such a change might be the elimination of sluice gates below a certain elevation to prevent water with a low dissolved oxygen content from flowing downstream or to prevent flooding of a wildlife habitat.

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

Mini-hydro can have diverse environmental impacts; therefore, it is valuable to present the information to decision-makers by category (aquatic organisms, diseases, etc.) and to describe impacts as short- or long-term, reversible or irreversible, and construction- or operation-related. Mitigating measures also should be discussed.

Cada and Zadroga (2) note that the single most important factor in assessing the impact of a mini-hydro project is whether or not the project has a water impoundment. Significant impoundment of water, results in more physical, chemical, and biological changes in the stream than no impoundment. The relative size of the plant in part determines the magnitude of these changes (2). A large plant will generally have more serious effects than a small one, and a small plant on a small river may have more serious effects than a plant of moderate size on a large river.

Flow disruption. These impacts include channel degradation, downstream sedimentation, and, if water is diverted from one basin to another, a net loss of water in 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 disturbance of saltwater and freshwater balances in estuaries. If pond elevation fluctuates greatly because of peaking power production, shoreline erosion and habitat destruction may occur. The least disruptive operation is "run-of-the-river," which has no water storage and returns water to the same stream at a lower elevation (2).

Sedimentation. Sedimentation results from both project construction and operation. The impacts of sedimentation are many. It can cause turbine damage, bury fish spawning areas and bottom-dwelling organisms, and shift the composition, abundance, and distribution of aquatic biota. Additionally, the retention of sediment by reservoirs can result in premature siltation of the reservoir. It also can trap nutrients in the reservoir and upset the nutrient balance, because these nutrients otherwise would have traveled to downstream wetlands and estuaries. The increase in the reservoir's nutrients 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 (2). Water quality may be affected, 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 if there is an impoundment. The impoundment can affect water quality if the water undergoes thermal stratification, causing a temperature differential, a decrease in bottom dissolved oxygen, an increase of hydrosulfide, and a reduction of ionic forms of iron and manganese (2). 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. Oils, greases, and chemicals entering the stream from the construction site also can affect water quality.

Aquatic organisms. There are many possible effects on aquatic organisms. 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 low temperature water; changes in the composition and abundance of species due to change from flow to reservoir habitat (particularly important to economically important fisheries); and gas bubble disease to fish caused by supersaturation of water by atmospheric gas as water is released from the spillway.

Water-borne diseases and parasites. Water impoundments provide breeding grounds for mosquitoes, which carry such diseases as malaria, yellow fever, dengue, and snails which are part of the chain of schistosomiasis and other diseases. Impoundments also decrease the natural purifying elements of running water—turbulence, sunlight penetration, and aeration. On the other hand, impoundments also decrease flow in certain sections of a stream and lead to a possible localized reduction in onchocerciasis (river blindness).

Land use and development. The direct impact of a mini-hydro project on land use is the loss of land for access roads, canals, turbine-generator buildings, transmission lines, and reservoir pools. A more significant impact may occur, however, as a result of development created by the project. For example, colonization in the headwaters region of a project may lead to increased erosion and subsequent siltation of the reservoir.

Terrestrial impacts. Terrestrial 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 landforms and vegetation and hinder wildlife migrations.

Environmental checklist. Cada and Zadroga (2) present a checklist designed to help the analyst organize the data and identify and assess the relative significance of environmental impacts (see Table 2).

TABLE 2. Environmental Checklist for Feasibility Studies (2)

1. Obtain topographic maps (1:25,000 if possible) that 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 streamflow data for a number of years in order to ensure both the maintenance of minimum flows in the stream and reliability 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 by construction and operation of the mini-hydro plant (for example, drained or filled with sediment).

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 (ecologic) 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 there are in each water year.

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

13. Obtain maps of land use capability or land use potential 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.

15. Determine what important soil, geologic, historical, cultural, or archaeological resources will be lost by site construction, access road construction, transmission 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 streamwaters near the site are used as 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 water-borne diseases or parasites that are endemic to the area and determine the probability that mini-hydro development will spread or accentuate disease problems.

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

23. Identify any pre-existing (natural or human-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 and the bedload of the stream.

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

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

27. Consider any unique plant design features (impoundment, transbasin diversion) that would necessitate special consideration in assessing and mitigating environmental impacts.

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

HUMAN ENVIRONMENT ANALYSIS

Because a mini-hydro project provides electricity to a region, it will have direct impacts on the human environment. Examples include population growth, increase in light industry, changes in land use patterns, and increase in educational opportunities due to electric lights and radio. In addition, the environmental impacts of the project will indirectly affect the human environment. For example, fish losses due to sedimentation may result in economic losses to commercial fisherman. Zoellner (14) presents a framework for analysis of these 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 habitat.

4. Derive the impact—for example, more hunting opportunities.

This is a simplified example because a changed condition may be the result of several causes, and effects may result from several changed conditions.

GEOLOGIC ANALYSIS

Three major geologic factors must be considered in the siting of mini-hydro projects:

- Sediment loads in streams,
- Conditions of valley sidewalls and foundations at dam sites, and
- Earthquake conditions (which will not be discussed here but 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 environmental damage due to sediment releases from reservoirs. They can be estimated by using specially designed sampling devices, empirically derived sediment rating curves, or comparisons to similar watersheds.

Sediment accumulates in reservoirs because flow velocities decrease 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 (see Fig. 5). 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 in several ways: Employing land use control to prevent sedimentation, providing for sediment storage, discharging sediment-laden water through sluice gates, and dredging.

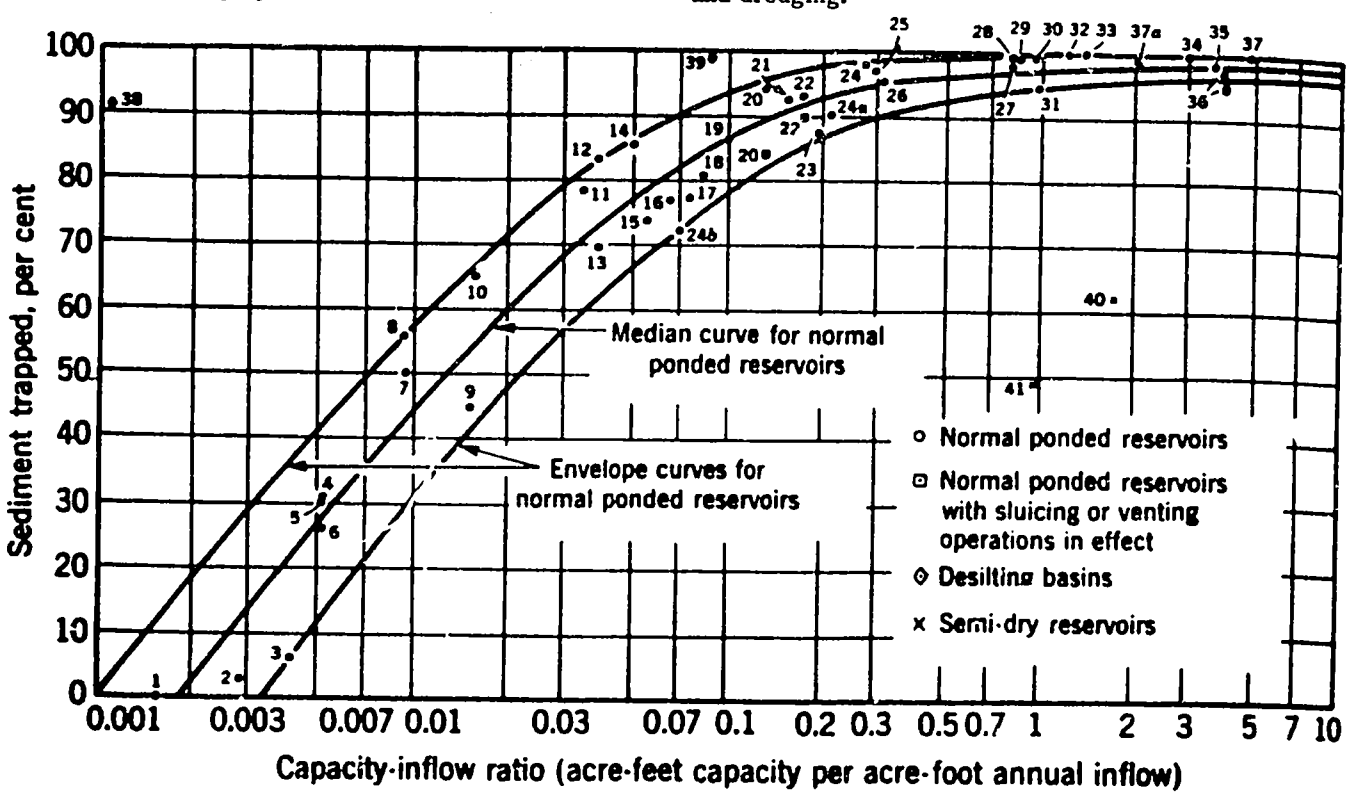

Fig. 5. Reservoir-trap efficiency as a function of the capacity-inflow ratio.

Prefeasibility study

It is necessary only to note from visual observation whether sedimentation effects are likely to be severe.

Feasibility study

It is usually necessary to estimate the sediment load in the stream by using one of the measurement methods previously described. This estimate enables the reservoir siltation, turbine damage, and environmental effects to be studied.

Conditions of valley sidewalls and foundations at dam sites

In addition to the cost of materials and labor, the type of sidewalls and the foundation composition at a potential dam site are 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, because 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.

Prefeasibility study

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

Feasibility study

Because one result of a feasibility study is the selection of the type and approximate size of the dam, detailed investigation of sidewall and foundation conditions must be undertaken. Borings may be necessary if a large dam is planned.

APPENDIX A

Quality and augmentation of streamflow data

Introduction

Two problems frequently arise in the analysis of water resources projects:

- The need to examine the quality of available streamflow data (do they really represent what is likely to happen at the site over the project's expected lifetime?), and
- The absence or inadequacy of data.

It is possible to study the quality of streamflow data and to augment or extend such data from other sources, (4-6,12,13).

Quality of data

Data quality can be measured by the homogeneity of the data 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." (12) A record is long enough if it contains the expected variations and extreme values of the streamflow, or if these can be inferred from it with sufficient accuracy for the scale of the project. Having "high" quality data enables the project to be designed for all conditions that are likely to affect it over its lifetime.

Streamflow data lack homogeneity when data are collected from an area that has changing characteristics and when there are trends and cycles in the data. Usually human activities, such as diversions and deforestation, are the major cause of change. Such inconsistencies can be noted by plotting the cumulative values of one affected variable (streamflow) versus the cumulative value of a related variable (streamflow in an unaffected watershed or precipitation) (12). After an inconsistency has been determined, it can be "corrected" by interpolating and extrapolating from the cumulative plot or by adjusting the past records with the known quantities of change inducing activities (diversions, etc.). Trends and cycles in data can be determined by 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 the study will analyze only a short segment of the data or use records of different lengths.

The study's purpose and the region's hydrologic characteristics determine the length of record needed. The regional hydrologic characteristics are probably the most important variables. If the precipitation and streamflow vary little from year to year, a record of 10-15 years is probably suitable for all levels of analysis. If these values vary considerably, a record of 30-60 years is needed to capture the variability accurately. For example, 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 m^3. Over two different 10-year periods, the calculated means are 17 and 50 billion. Obviously, designs for these three "mean" values will have different implications.

In conducting a comparison study between sites, it is desirable to use records that cover the same periods to

be able to make consistent comparisons between the sites. If records of different periods or lengths are used, some records should be either extended or filled in.

Augmentation of data

Streamflow data can be augmented (or synthesized) by extending or filling in records at gauged sites, or by developing flow estimates and parameters at ungauged sites. Such synthesized data must be used carefully. The following warning for fill-in data also applies to estimates at ungauged 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 produce only estimates of the means of missing values. In such cases, the natural variations about the mean will be eliminated and the overall variance, thus, diminished (6).

Record extension and fill-in. The simplest method of extending or filling in streamflow data is to correlate the flows at a data-poor site and a data-rich site. The two sites must be located reasonably close to each other and have similar hydrologic characteristics. In many cases, it is only necessary to use the ratio of mean flows in the regression equation, as shown in the following equation:

$$\text{Daily flow at i} = \frac{\text{mean flow at i}}{\text{mean flow at j}} \times \text{daily flow at j.}$$

More sophisticated regressions may contain parameters such as basin slope, precipitation, or temporarily lagged parameters. If it is important to maintain the random variations between the flow at the sites, it is necessary to add a random number component to the regression (5). Another simple method of data extension or fill-in is to use double-mass curve analysis. However, this method has the serious disadvantage of eliminating some of the natural variation in streamflow because the plotted line represents only mean conditions.

Streamflow estimates for ungauged streams. One of the rules of thumb in hydrology is that if watersheds are located near each other, are at approximately the same elevation, and have similar land use, area, topography, geology, and precipitation patterns, the flows (daily in some cases) are related by the ratios of drainage area, precipitation, and slope (in some cases). Two such watersheds can be considered to be "hydrologically similar." If the flows are unknown at one site but known at a similar site, this procedure permits estimates of flow at the ungauged site to be determined by multiplying the flow at the gauged site by the ratio of the drainage areas or of the precipitation. It may be necessary to include slope ratios if peak discharge information is needed. If it is important to maintain the natural variation in flows between the gauged and ungauged sites, a random component might be added to the simple regression.

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

It is possible to estimate flows at ungauged sites where there are no hydrologically similar gauged sites (4). These methods are based upon physical observations and simple rainfall and streamflow routing procedures.

APPENDIX B

Measurements of streamflow, head, and power

During field investigations, it is necessary to measure the streamflow and the head at a site to determine the power available.*

Streamflow measurement

There are three major methods of measuring streamflow, two of which depend upon the size of the stream (1).

Dam method. For small mountain streams or for springs, the dam method can be used. 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 s to fill a 55-gallon barrel, the flow rate is 1.375 gal/s, or 82.5 gal/min, or 11 cfm.

Float method. For larger streams, the float method can be used. If done carefully and repeated several times, it can give sufficiently accurate results for most calculations. For this method, the cross-sectional area of the stream and the stream velocity must be known.

- The cross-sectional area. This 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. Then, using a stick, measure the depth (d) at equal intervals across the width of the stream (see Fig. A). Record the depth at each interval and calculate the average depth.

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

  $d_1 = 1.0$ ft

  $d_2 = 1.3$ ft

  $d_3 = 1.2$ ft

*Material on flow and head measurement is reprinted with permission from the National Center for Appropriate Technology (1).

d_4 = 1.8 ft

d_5 = 1.0 ft

d_6 = 0.8 ft

d_7 = 1.1 ft

d_8 = 1.8 ft

d_9 = 1.3 ft

d_{10} = 0.7 ft

Total = 12 ft

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

Next, multiply the width (w) by the average depth (d) to get the cross-sectional area (A) of the stream. For example, in the above stream, if the width at the point where the depth measurements were made was 8 ft, the cross-sectional area (A) is:

$$\begin{aligned} A &= w \times d \\ &= 8 \text{ ft} \times 1.2 \text{ ft} \\ &= 9.6 \text{ ft}^2. \end{aligned}$$

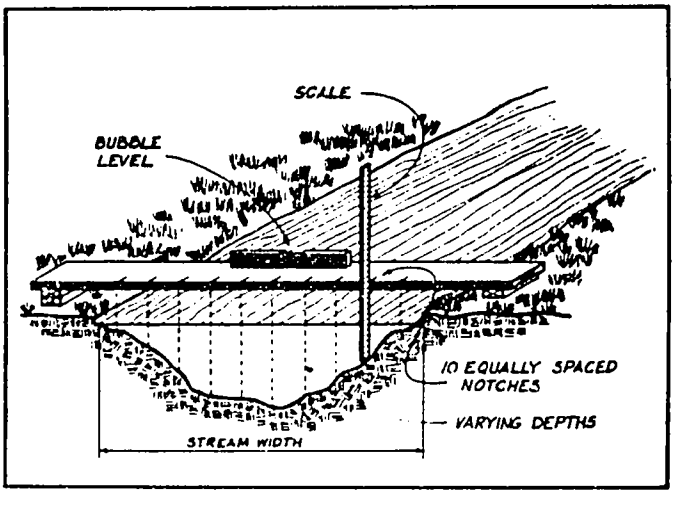

Fig. A. Measuring cross-sectional area to determine discharge using float method (1).

- The stream velocity. This can be determined by choosing a straight stretch of water at least 30 ft long with sides approximately parallel and bed unobstructed by rocks, branches, or other obstacles. Mark off two points, perhaps 30 ft 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 makes 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 ft apart is 15 s. The velocity of the float is thus:

$$\frac{30 \text{ ft}}{5 \text{ s}} = 2 \text{ ft/s.}$$

This float velocity does not, however, represent the velocity of all the water in the stream. At the sides and bottom of the stream, water flows less quickly than at the center or near the top because of streambed friction and channel roughness. A correction factor, depending on the roughness or smoothness of the streambed, is usually included 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:

$$V = 2 \text{ ft/s} \times 0.65 = 1.3 \text{ ft/s}$$

or

$$V = 78 \text{ ft/min.}$$

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:

$$\begin{aligned} \text{Flow} &= A \times V \\ &= 9.6 \text{ ft}^2 \times 78 \text{ ft/min} \\ &= 748.8 \text{ cfm.} \end{aligned}$$

The usable flow can now be determined. Simply multiply the streamflow rate just calculated by the portion of the flow that will be used.

For example, if only 25% of the minimum streamflow will be used, and the streamflow determined above is 748.8 cfm, then the usable flow is:

$$\begin{aligned} \text{Usable flow} &= 748.8 \text{ cfm} \times 0.25 \\ &= 187.2 \text{ cfm.} \end{aligned}$$

Weir method. There is a third method for determining streamflow, 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.

A temporary dam structure (weir) is built across the stream perpendicular to the flow, with a rectangular notch or spillway of controlled proportions located in the center section. Because this notch has to be large enough to take the maximum flow of the stream during the period of measurement, it is important to make

some rough estimate of the streamflow before building the weir. The notch width (W) should be at least three times its 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 built out of timber, with all edges and the bottom sealed with clay, earth, and sandbags to prevent any leakage (see Fig. B).

A simple depth gauge must be set up to measure the flow of water over the weir. This is done by driving a stake in the stream bed at least 5 ft upstream from the weir, until a preset mark in the stake is precisely level with the bottom edge of the notch. The depth of water at this stake, above the preset mark, will indicate the flow rate of water over the weir. Refer to a weir table to determine this flow rate (see Table A).

TABLE A. Weir Table (1)[a]

Depth of stake in inches	cfm per inch of notch width
1	0.40
2	1.14
3	2.09
4	3.22
5	4.50
6	5.90
7	7.44
8	9.10
9	10.86
10	12.71
11	14.67
12	16.73
13	18.87
14	21.09
15	23.38
16	25.76
17	28.20
18	30.70
19	33.29
20	35.94
21	38.65
22	41.43
23	44.28
24	47.18

[a]1 in = 2.54 cm; 1 cfm = 28.32 l/min.

To use this weir table, determine the depth of water in inches over the preset 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 the weir notch to obtain the streamflow rate in cubic feet per minute.

For example, a particular stream has a weir with a notch width of 30 in. The depth of the water on the stake above the preset marking is 6 in. On the weir table, read opposite 6 in to the flow rate of 5.90 cfm per inch of notch width. The flow rate of the total stream is then:

5.90 cfm/in x 30 in = 177 cfm.

When the weir is in place, readings can be taken easily. If the weir will be used for an extended period of time, it is important check the watertightness of the sides and bottom frequently.

Head measurement

The greater the vertical distance that water falls, the more potentially useful power is available in the water. There are several methods of measuring head.

Topographic maps. For high head systems, detailed topographic maps of the 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 be used only for very preliminary estimates.

Photographic surveying. For those who are acquainted with photographic surveying techniques, this method can give fairly accurate results. Pictures taken in the field

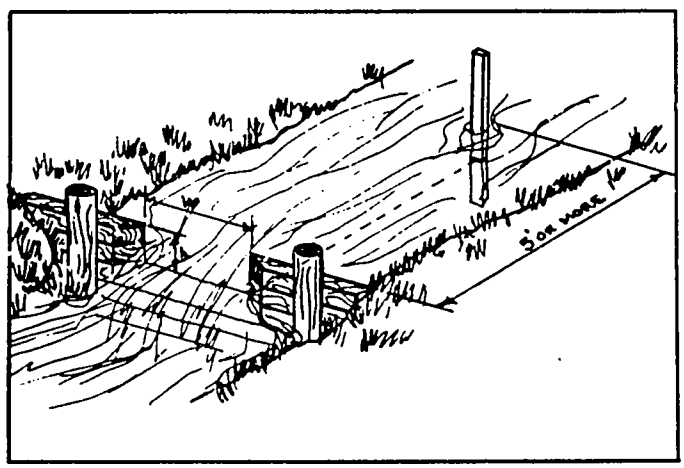

Fig. B. Drawing of a weir used to determine discharge (1).

can be developed and the elevations scaled on the photographs. However, this method is not for amateurs. Photographic surveying requires skill and training.

Portable altimeters. Pocket altimeters can give preliminary estimates of the elevation difference between intake and tailwater locations on proposed high-head systems. However, the accuracy of measurement is not suitable for serious calculations.

Some larger portable altimeters that are available can permit elevation measurements within an accuracy of a couple of feet. These instruments are suitable for engineering calculations; however, they do not give

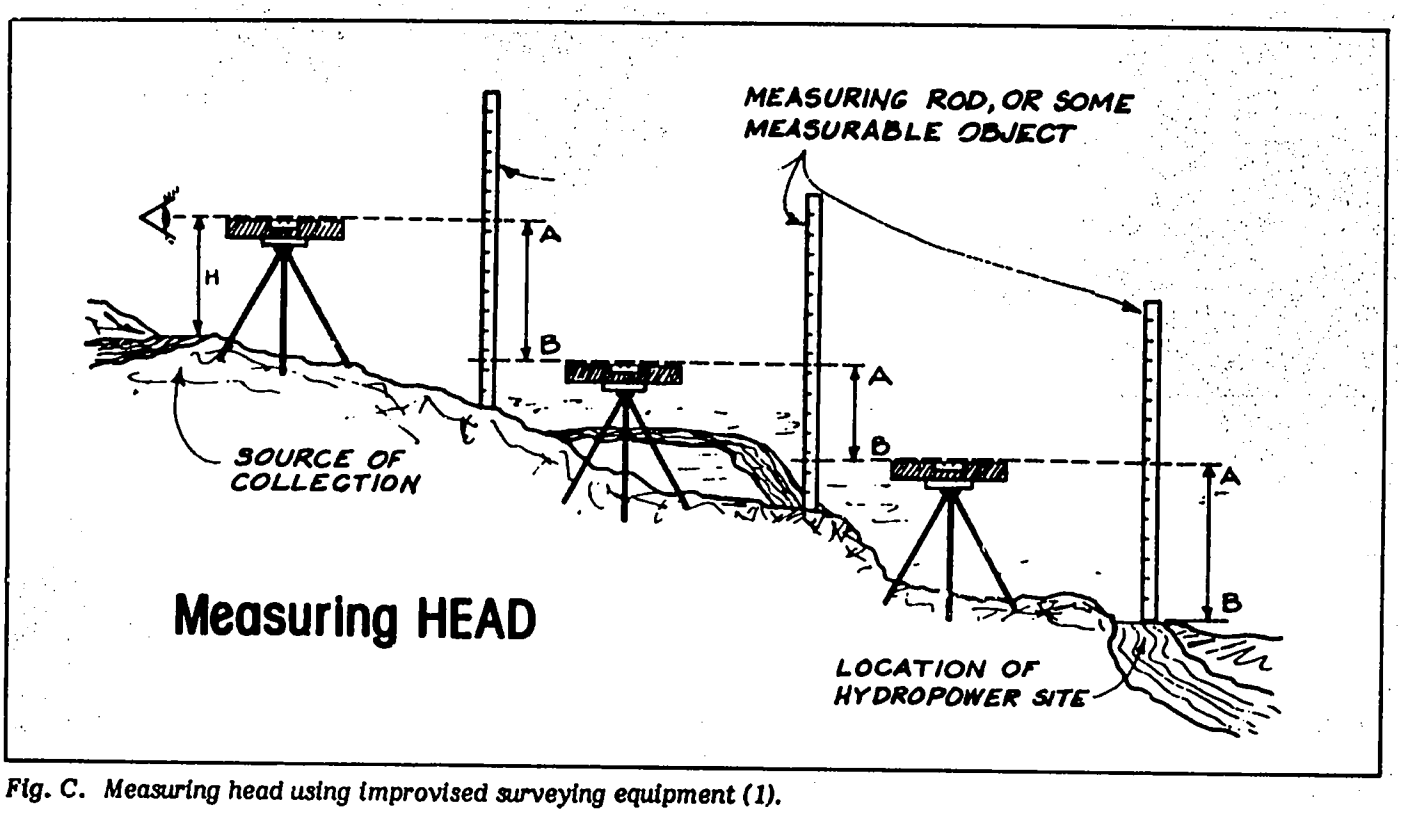

Fig. C. Measuring head using improvised surveying equipment (1).

measurements as precise as do the following three methods, and they tend to be very expensive.

Professional surveyor. A good surveyor can be hired to determine the head. Ask the surveyor to find the vertical distance between the water source (or proposed intake location) and the proposed location of the powerplant. Hiring a surveyor will be expensive. If this is the only appropriate method, it is important to be reasonably sure that the project will be undertaken. A surveyor may be advisable if the head is less than 25 feet, because very precise measurements are necessary in such cases.

Professional surveying equipment. Those who know how to use standard surveying equipment, for example, a transit or a surveyor's level and leveling rod, can borrow or rent the appropriate equipment and have friends help make the necessary measurements.

Improvised surveying equipment. Another technique involves a do-it-yourself approach. The equipment required is a carpenter's level, a stand to raise the level a few feet off the ground, and a tape measure. Assistance may or may not be necessary (see Fig. C).

- 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.

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

- Note this precise spot on the object and mark it (Point A).

- Move the level and stand down the hill slope and set them up again. This time the upper edge of the level is at some Point B below Point A on the first object, as in the diagram. 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 farther down the hill.

- Repeat this procedure until the same elevation as the proposed powerplant site is reached.

- If more than one set-up was required, add all the vertical distances A-B. If the 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 to determine the total head.

In undertaking the above measurements, several things should be remembered:

- It is not necessary to be concerned with horizontal distances for head determination.

- Every time the level is reset, its upper edge should be at precisely the same level as Point B (sight back to check).

- It is not necessary to travel in a straight line.

When the total, or gross, head has been determined, various losses must be considered before any theoretical power calculations can be made. The net head is required for these calculations:

Net head = gross head - losses.

Losses occur for several reasons. Whenever water flows through a pipe, there are friction losses. These friction losses are greater for increased flow rates and for smaller pipe diameters. Elbows and bends in the pipe also increase friction losses. PVC pipe offers low friction loss, rarely exceeding 8% of the gross head. Good steel pipe has twice the friction loss as PVC. Iron, asbestos, and concrete pipe all cause higher losses. Typical PVC pipe losses are indicated in the nomograph in Fig. D. Any reputable pipe manufacturer or supplier will be able to supply the pipe size and friction loss information for particular flow conditions.

Other losses that might occur in a hydraulic system depend on the type of turbine or wheel that will be used. In an impulse turbine, a slight head loss results from the vertical distance between the n[illegible] and the tailwater, because the wheel has to run free of, and therefore slightly above, the tailwater. On the other hand crossflow, Francis, and propeller turbines with draft tubes have almost no inherent head losses.

Power calculation

When the usable flow rate and the net head have been determined, the expected amount of power can be calculated. First, calculate the theoretically available power, assuming that 100% of the power available in the water can be converted usefully. The theoretical power available (P_{th}) is found by the following equation:

$$P_{th} = 62.4\ Q \times h$$

where Q = usable flow in cfm; h = net head, in ft; 62.4 = density of water, in lbs/ft^3. This equation gives P_{th} in ft-lb/min.

REFERENCES

1. Alward A, Eisenhart 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. Butte, MT: National Center for Appropriate Technology, January 1979.

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

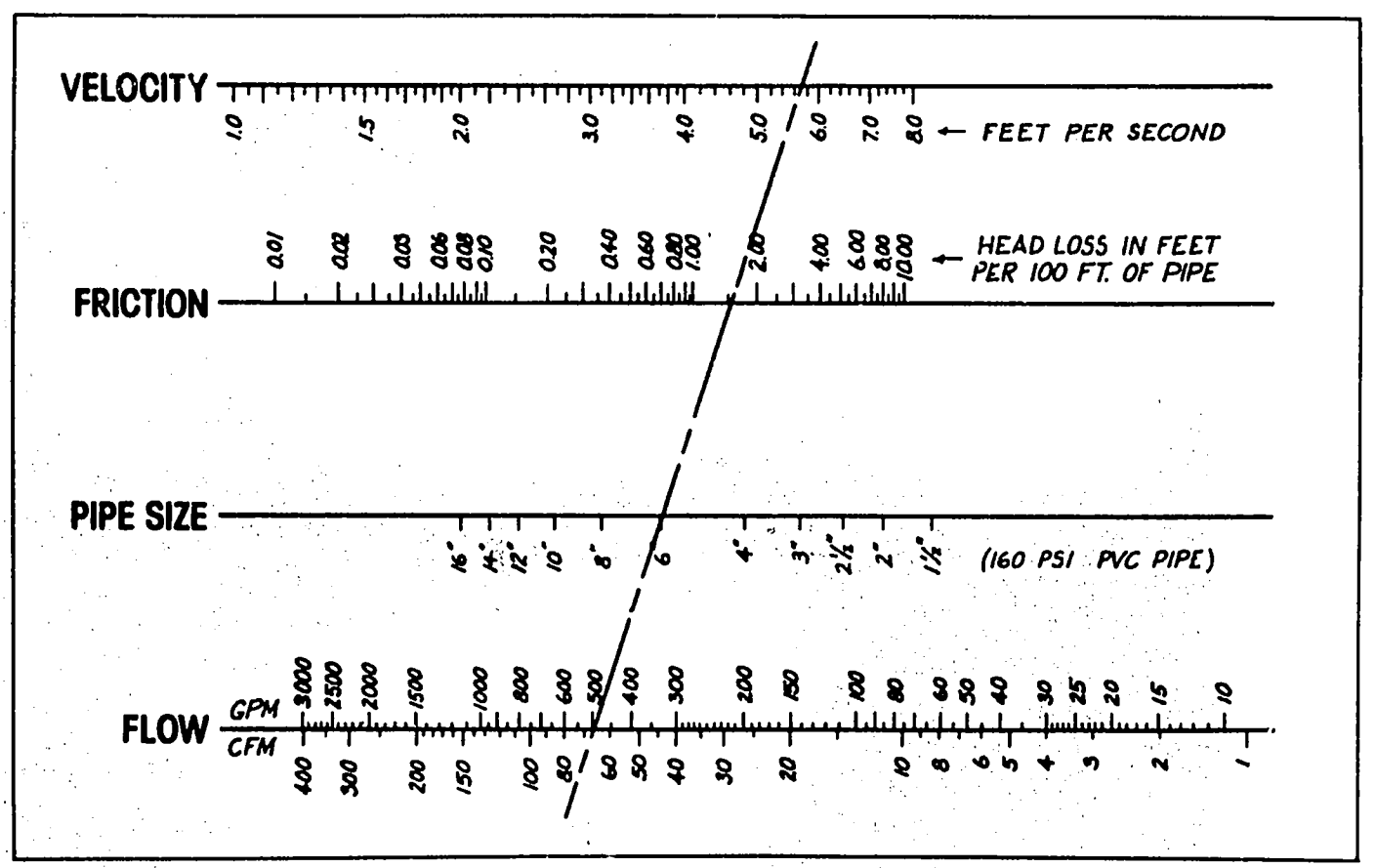

Fig. D. Nomograph to determine losses due to friction in PVC pipe (1).

3. Chow VT. Open-Channel Hydraulics. New York: McGraw Hill Book Co. 1959.

4. Crawford NH, and Thurin SM. Hydrologic Estimates for Small Hydroelectric Projects. Washington, DC: National Rural Electric Cooperative Association, 1981.

5. Fiering M, and Jackson B. Streamflow Synthesis. Washington, DC: American Geophysical Union, 1971.

6. Gladwell JS. "Hydrologic Studies for Hydropower Assessment." Proceedings of NRECA Workshop on Small Hydroelectric Plants, Quito, Ecuador, August 1980. Washington, DC: National Rural Electric Cooperative Association, 1981.

7. Lawrence WD, Kirshen PH, and Lanou TE. Togo Small Decentralized Hydropower Study. Washington, DC: National Rural Electric Cooperative Association, 1981.

8. Linsley RK, and Franzini JB. Water-Resources Engineering, 3rd Edition. New York: McGraw Hill Book Co., 1979.

9. Linsley RK, Kohler MA, and Paulhus JL. Hydrology for Engineers, 2nd Edition. New York: McGraw-Hill Book Co., 1975.

10. NRECA. A Methodology for Prefeasibility Studies of Candidate Mini-Hydro Sites. Washington, DC: National Rural Electric Cooperative Association, undated.

11. U.S. Army Corps of Engineers. Feasibility Studies for Small Scale Hydropower Additions. Hydrologic Engineering Center, Davis, CA 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: U.S. Bureau of Reclamation, July 1980.

13. Viessman W, Knapp JW, and Lewis GL. Introduction to Hydrology, 2nd Edition. New York: Harper and Row, 1977.

14. Zoellner D. "Environmental Assessment of Small Scale Hydropower." Proceedings of NRECA Workshop on Small Hydroelectric Plants, Quito, Ecuador, August 1980. Washington, DC: National Rural Electric Cooperative Association, 1981.

Hydrologic Data Requirements for Developing Small Hydropower Sites

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Developing countries often lack topographic, geologic, and hydrologic data from which to determine the physical and electrical features of the power subsystem. In conducting prefeasibility studies of small hydro sites, it is necessary to interpolate and extrapolate from very rough data to determine whether a site is worthy of more detailed analysis and, if so, what the focus of such analysis should be.

ACQUIRING HYDROLOGIC DATA

Hydrologic (precipitation and streamflow) data frequently are limited in coverage of time and area; sometimes they are unreliable or unavailable. A paper by Norman H. Crawford, presented at a workshop entitled "Small Hydropower for Asian Rural Development," offers methods of calculating streamflows from available rainfall, evaporation, and other data without establishing rainfall/streamflow correlations that require gauging of streamflows (1).

The paper considers two results of precipitation:

- The flow during and immediately after precipitation is short-term in nature; if the precipitation is great enough, flood flows result.
- Water absorbed by the soil moves as subsurface flow; a portion of this flow emerges later as streamflow. This subsurface flow usually is an important component of the total streamflow, because there is a significant interval between the time that the precipitation soaks into the ground and the time it emerges as a return flow in the lower areas of the basin. The resultant streamflow is much more uniform in the lower parts of the basin because of the effective ground storage and diversity of the subsurface channel lengths and flow capacities there.

Crawford's paper considers the basic water balance equation:

Precipitation - actual evapotranspiration + storage change = runoff.

Storage includes soil moisture and groundwater aquifers. Crawford goes on to consider watershed characteristics, coefficients of soil moisture storage capacity, the fraction of runoff that enters subsurface water courses, and the amount 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 it is dry) also are considered.

Crawford covers flood flow predictions in terms of the somewhat inverse relationship of rainfall intensity to rainfall duration, catchment area, channel length and gradient, and watershed loss rate as affected by the soil characteristics. A table that shows six soil types and related loss rates helps the reconnaissance personnel make soil classifications. It is even more useful because it includes the predominant types of vegetation found on each type of soil.

Rain gauges

Crawford's procedures require topographic, geologic, and soil information, which usually are available in some form, and rainfall data, which are not always available for the relevant catchment areas. The longer the period of record, the more reliable are the significant flow figures. However, even 1 or 2 years of daily rainfall data are better than none, and they can be obtained while much of the other reconnaissance work proceeds. For that purpose, responsible villagers can read and record data from a simple funnel-type rain gauge.

If the upper catchment areas are relatively uninhabited or are inaccessible, as is often the case, recording gauges might be considered. Such gauges will operate over periods of months. Radio-reporting gauges are portable, easy 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. A simple weight-driven, clock-operated, tipping-bucket rain gauge which records rainfall distribution on a strip chart over a period of time can also be used. 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 to a project in the reconnaissance stage.

Staff gauges

Stream stage information can be obtained from staff gauges located at a stable cross-section in the stream that can be calibrated. Staff gauge locations are also determined by whether or not tributary flows are to be included and whether or not correlations are to be

established between catchment area rainfall and streamflow.

Staff gauges for river stage measurements are simple to install and to read. The challenge is to get people sufficiently intelligent, interested, responsible, and well paid to read the gauge at the prescribed times and to follow times of abnormal precipitation. River stage recording equipment is also available. Its cost can be justified for very inaccessible or important locations or for locations where the data must be as reliable as possible.

This procedure requires some rainfall data, but there may be no such data from which streamflows can be predicted. There are many methods of estimating streamflows in addition to the few mentioned here. It is possible to develop the ability to look at a flow of water and estimate streamflows within about 15%. Such an ability can be developed by observing flows at a weir and in channels below the weir.

Instead of a bridge over a stream, many rural roads use a masonry or concrete structure built through the stream at bed level with sloping approaches. In a stream that always has some flow, these structures offer a smooth cross-section and smooth waterflow where the water velocity is easy to measure and the flow quantity is easy to calculate.

Minimum monthly flow values

Minimum flow values are the most significant elements of hydropower studies because they establish the base power capability of the system. A flow duration can be derived from flow or rainfall data if they are available by months for a number of years. Another form of graphic presentation that can be useful is a year-by-months (calendar or hydrologic year) bar graph that puts all the flows onto one graph (see Fig. 1).

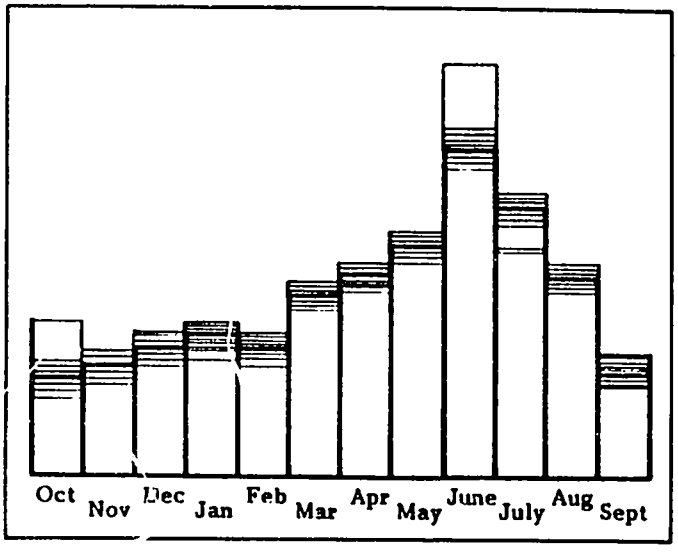

Fig. 1. Streamflows by months.

This graph shows a frequency of occurrence pattern from which preliminary hydrologic information can be obtained. Suppose data from a hypothetical water year are needed to determine the power capability of a potential project. The monthly flows can be averaged, but the values from some months may differ so greatly from the others that they distort the average. In Fig. 1, the fine lines are the plots of monthly flows over the period of record and the heavy line represents the flow values that are mostly likely to occur. The heavy line is drawn in by inspection. It usually is possible to find an actual year's flow record that closely matches that of the derived year. Call this the "typical year" and use the data to determine the monthly water supply (see Fig. 2).

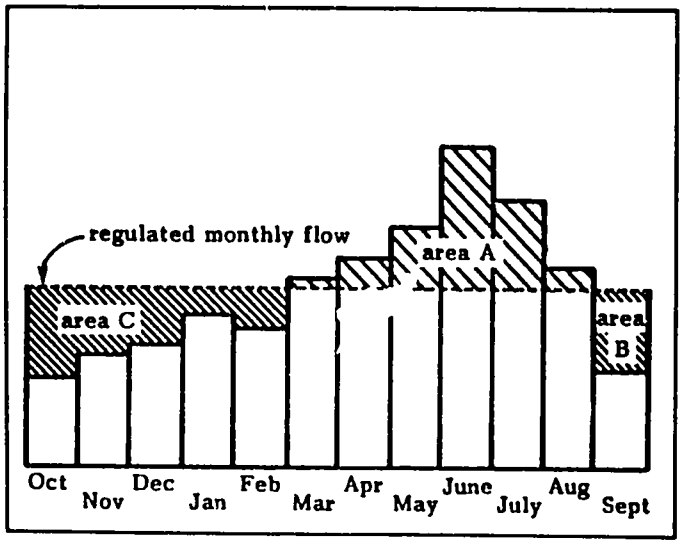

Fig. 2. Streamflows by months in a typical year.

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 powerplant capacity. This figure will not necessarily be from the minimum month. In fact, it would be prudent to set the value at a somewhat higher monthly figure to enable the powerplant to use more than the minimum quantity of water when it is available; excess power usually finds a load to use it.

Daily flow values

Thus far, runoff data have been considered in terms of quantities, because hydrologic records are typically in that form and presume a constant flow throughout the month. However, there could be daily or random variations in the flow. During months when the available water exceeds the power requirements or the powerplant's capacity, daily flow variations are not of concern; however, they can be important during low-flow months. Several days of observations can determine whether such variations occur. A river system (one that combines a number of tributaries) probably would not show much daily variation because of its different surface and return flow sources above

62

the point of diversion for power. However, a small stream with little catchment area above it could show considerable flow variations, with rapid and sharp responses to precipitation in the catchment area.

POWER REQUIREMENTS VS. LOAD REQUIREMENTS

The initial load of the typical small hydro system tends to be low during day hours and higher during night lighting hours. Around-the-clock loads (refrigerators, domestic and commercial) and other commercial or small industry loads (food processing, grinding, etc.) are developed as rapidly as possible to make full use of the hydro potential. The typical 24-hour load curve is lowest in the first quarter (midnight to 0600 hours), rises from 0600-1200 hours in the second quarter, is more or less steady from 1200-1800 hours during the third quarter, and peaks from 1800-2400 hours during the fourth quarter. Power generation, therefore, must conform to the changing load pattern. There are several possible ways to do this.

For example, if the water source (as determined by the typical year's monthly run-of-the-river flow) is sufficient to develop the power required through some future year, say the 10th year, the plant could use a "water wasting" type of turbine-generator control. With this type of control, the turbine-generator runs at rated speed and constant (rated) output at the generator terminals. An electronic switching device diverts the difference between the rated output and the variable load requirements to passive resistor loads.* Several types of electronic load controllers are in production for single-phase machines up to 60 kW and three-phase machines up to 180 kW capacity. One version uses an induction generator that 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. When these controllers are produced in quantity, they should be built of modules to permit spares for the electronic components to be kept in stock as replacements for defective units. The passive load resistors are simple and should be reliable.

Storage options

If power (kW) and energy (kWh) requirements and daily waterflow require the use of all the available water, storage for daily regulation or for monthly holdover or both may be necessary. If possible, a small hydropower plant should then have a forebay pondage capable of storing at least 1-2 days of the typical daily flow. A conventional governor is necessary for such installations, because 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 it enables to go to active loads.

Holdover storage to supplement low monthly flows with the excess from high monthly flows generally is more justifiable for larger hydro projects, those in the megawatt range. However, if holdover storage can be found for a small hydro project, a rough estimate of storage volume requirements can be made by using Fig. 2; a horizontal line can be constructed by eye to make the areas A + B = 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.

Flood flows

There are several methods for estimating peak or flood flows, but with them, the flow has to be routed through the stream channel and water stage levels calculated. Actually, the flood flow rate (ft^3/s or m^3/s) is not as significant as 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, and marks on rocks or trees. Area residents can be a good source of flood stage data.

It is necessary to consider flood stages during various hydro project phases from feasibility studies through operation. Preliminary designs and cost estimates for diversion dams should include abutment protection well above such high flood stage indicators. Turbine settings must take into account flood stages at the powerhouse location. Although the reaction turbine with a submerged runner is affected only by a reduction in net head by high tailwater during floods, the impulse wheel must always be above tailwater level.

REFERENCE

1. Crawford NH. "Hydrological Methodology Without Streamflow Data." Proceedings of NRECA Workshop on Small Hydropower for Asian Rural Development, Bangkok, Thailand, June 1981. Bangkok, Thailand: National Rural Electric Cooperative Association, 1983.

* The literature I have seen has not explained how the electronic load controllers are adapted to automatic start-up or shut-down.

Equipment Design and Local Manufacturing Opportunities

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INTRODUCTION

The People's Republic of China and Nepal both have enormous hydropower potential, but each country has had quite different experiences with this valuable resource. China has done much to develop its water resources since 1949 and now has approximately 100,000 small hydropower stations. Nepal currently is attempting to develop its water resources but has not yet fully defined its policy toward small hydropower. Nepal is representative of those countries that have hydro potential which they are only beginning to develop.

SMALL HYDROPOWER DEVELOPMENT IN CHINA: THE INDIGENOUS MANUFACTURE APPROACH

The integration of small hydro development with the general development plan of the country is of great importance to the success of small hydro development. China has adopted this strategy and has increased its manufacturing capacity for small hydro equipment from practically zero in 1949 to almost 1,000 MW per year in 1980.

Background

At one time, China's uneven distribution of precipitation caused annual flooding or drought in at least one of its vast provinces each year. For this reason, the priorities of water resource development were flood control and irrigation. Although these were not new concepts, their use as part of a systematic, large-scale water resources plan began only after 1949. The construction of "hydraulic schemes" became a declared policy in 1955 as part of the five-year plan. The policy's goals were:

- To make continuous agricultural production possible,
- To increase production through multiple harvests, and
- To reclaim arid and semi-arid areas through irrigation.

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

Rural electrification in China

The People's Republic of China, realizing the importance of a regular rural energy supply, integrated small decentralized power stations into its other hydraulic (and hydropower) systems. The total hydraulic potential in China is estimated at about 680,000 MW; 70% of this potential is in the provinces and the autonomous region of the southwest. Of this total potential, it is feasible to harness about 150,000 MW with small hydropower stations (stations up to 10 MW, according to the definition of the Ministry of Water Conservancy). Most of this small hydropower potential is in 1,100 of China's 2,100 counties. Small hydropower stations are operating in 70% of these counties and are the main source of electric power supply in about 30%.

Production and distribution of electric energy, and construction of small hydropower generating units in particular, have been strongly promoted since 1949. Before then, only a few electric power stations (mainly coal-operated) were operating, and they supplied only urban centers. The total installed capacity in 1949 was about 1,700 MW, of which about 200 MW was hydropower; in 1974, the total installed capacity was about 32,000 MW.

The output of small hydropower stations 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 small hydropower capacity has been fixed at about 1,000 MW per year until the economically justifiable potential (40%-60% of the total small hydropower potential) has been exploited.

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 the planning and integration of small hydropower stations countrywide;
- To guarantee optimal interconnection of isolated stations; and
- To promote production of required equipment at the province and county levels.

The planning is based on the five-year plans of the communes. These are approved at the county level for

projects smaller than 500 kW and at the province level for larger projects. A leading dictum of the Chinese economy is "to walk on two legs"—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.

The economy

The goals of all development efforts in China since 1949 have been to satisfy the basic needs of the population. For this reason, small hydropower stations have never been implemented as single-purpose projects but as a part of multipurpose projects.*

The generation of electricity by small hydropower stations is almost always of lowest priority. Despite this low priority, the generation of electricity is an important, if ancillary, function of hydraulic structures because China has an acute shortage of electric power. Consumers use 65% of the electricity in agricultural applications such as pumping irrigation water, producing fertilizer, and processing raw foods. Small industries and domestic users consume 16% and 19%, respectively. Domestic use is largely for lighting.

China's multipurpose approach to planning and distribution makes small hydropower stations economically more viable than those in countries where an isolated approach to planning, distribution, and implementation is the rule. This is certainly reflected in the large number of small hydropower stations built in the recent past and still being implemented in China.

The quality of electricity

There are 160 counties with their own local grids. These grids are fed by large power stations as well as small hydropower stations to help improve the quality of the power. This arrangement also allows many small hydropower plants to feed directly into the local grid without a governor.

In addition to their agricultural and industrial value, the small hydropower stations have structural importance as well. The decentralized production of electric energy and the integration of small hydropower stations in multipurpose rural development projects offer several advantages:

- The hydraulic structures can be built with labor-intensive methods by the local populations themselves;
- The production of the equipment for plants smaller than 500 kW can be decentralized (province level);
- There are ecological benefits such as conservation of existing landscapes, creation of new landscapes, and creation of places for recreation and excursion;
- The environmental consciousness of the rural population is heightened.

These advantages counterbalance an approach to rural electrification that is economically justified but still costly on a national scale.

Standardization of equipment in China

China's ability to manufacture high-quality, low-cost small hydropower equipment has been a major factor in the success of its small hydro development. This capability was almost nonexistent in 1949; it expanded gradually until 1972. At that time, China standardized its hydropower generating equipment. Centralized research and development avoids the high capital expenditure and personnel requirements that an individual turbine manufacturing company usually has. Little emphasis is placed on developing machinery of greater sophistication. The designs are somewhat old-fashioned, but allow a limited number of variations. These designs offer lower costs and machines of guaranteed quality and reliability. In the Chinese context, these factors easily compensate for the disadvantges of standardization.

The standardization of equipment and its quality seem to be crucial to China's success in developing small hydro 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 not on the design but on factors that the customers, the local people, can influence, such as the time and cost involved in building the civil works. The result of standardization is seen in the prices of Chinese equipment. The Jinhua Small Turbine Manufacturing Plant quotes 100 Y (US$ 67) per kW for a low-head and 20 Y (US$ 13) per kW for a high-head turbine; a German manufacturer asks US$ 400 per kW for the turbine.

Turbines

The standardized turbine designs used in China are basically the same as those used all over the world: the Pelton turbine for high head, the Francis turbine for medium head, and the propeller turbine for low head (see Albertson, Introduction to Small Hydropower Technology and Development). They differ from other turbines mainly in the simplicity of their design. The two major design factors are mass-producibility and reliability; efficiency is of tertiary importance.

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*While on a study tour in China in August 1981 (7), I did not see one hydraulic structure whose main function was the generation of electricity. Flood control was the primary purpose of the installations visited. All of these had retention reservoirs and used the impounded waters for irrigation and as fish breeding ponds.

65

Head range: 0.8-25 m. Two types of turbines are used for this head range:

- Propeller turbine

  Number of sizes: five
  Head: 2-18 m
  Flow: 0.8-4.13 m^3/s
  Speed: 300-800 rpm
  Output: 14-440 kW

- Tubular turbine

  Number of sizes: five
  Head: 0.8-25 m
  Flow: 0.9-28 m^3/s
  Speed: 428-1,000 rpm
  Output: 54-818 kW.

The propeller turbine has an open flume or scroll casing with adjustable guidevanes and fixed runner blades. The runner is available with four different angular positions of the blades. Speed transmission to the generator is handled by flat belts for output power up to 24 kW and by V-belts for output power up to 145 kW. For higher outputs, the turbine and generator are coupled directly. For both the propeller and the tubular turbines, the bearings running in water are water-lubricated plastic bearings.

Head range: 15-120 m. The Francis turbine is used for this head range:

- Francis turbine

  Number of sizes: eight
  Flow: 0.7-1.96 m^3/s
  Speed: 600-1,000 rpm
  Output: 148-1,332 kW.

Head range: 100-450 m. The Pelton turbine is used for this head range:

- Pelton turbine

  Number of sizes: 11
  Flow: 0.067-0.4 m^3/s
  Speed: 600-1,000 rpm
  Output: 53-1,000 kW.

Generators

The larger, older synchronous generators in China are separately excited, whereas the smaller newer ones are self-excited slip-ring generators with static excitation units. All generators are produced indigenously, although some materials, such as laminations for stampings, are imported. There are 100 state manufacturers in China, grouped into provincial- and county-level plants.

Compared with current Western designs, the machines in use or under construction were quite large and heavy and used old types of insulation (Class B was quoted in one factory). A 40 kW generator weighed 500 kg, compared to 270 kg for a comparable machine from a U.K. manufacturer. This reflects China's emphasis on low-cost, mass-production of proven designs, which results in high reliability and low cost of small plants, but also in "trucks" rather than "racing cars." However, the application of induction generators could produce substantial savings. These are induction motors that run at a speed slightly higher than synchronous, are mechanically strong, and are produced in quantity. For excitation, these machines generally should be grid-connected, which was the case with most of the powerplants visited. The grid also handles the governing if it is stabilized by a comparatively large reserve of synchronous generators. Where there is no local grid, the excitation can also be provided by capacitors.

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 two to four times the running speed and for a power factor of 0.8. The price for a 40 kW generator (domestic) is 500 Y (US$ 335).

Governors

A hydraulic mechanical governor that maintains constant turbine speed is an expensive and complicated item. The Chinese omit them wherever possible, using them only for turbines with runner diameters that exceed 450 mm for Pelton turbines, 500 mm for Francis turbines, and 800 mm for propeller turbines. Smaller turbines are manually controlled; they generally are connected to a grid and run continuously at full capacity. Operators are on continuous duty in case emergency shutdown is required.

China also manufactures electronic load controllers, which use an electronically switched ballast load to maintain a constant load on the generator. For low-output units, these electronic devices are cheaper and simpler than hydraulic-mechanical governors.

Turbine-pumps

Waterpower does not mean only electricity production. It is expensive to transform the mechanical power from the turbine into electrical energy and then back to mechanical energy 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.

There are three major types of site construction for a turbine-pump (8):

- Channel type. Where the terrain slopes and the water flows rapidly, only low dikes or 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.

- Dam type. Where both the topographic and geologic conditions are favorable, a dam is built across the river to create a higher head.

- Combination type. This is a combination of the channel and dam types, where the head is formed by a channel and a dam is built to provide a reservoir for regulation of flow.

The turbine-pump station also can use tidal energy or be located at the cascade of a channel or at the mouth of a spring.

Circumstances appear quite favorable for development of turbine-pumps in the Guizhou Province, which is situated on the Yun-Gui Plateau and has rich hydraulic resources. The Miaoling Mountains traverse the whole region. The terrain is high in the northwest and low in the southwest and contains very rapid rivers. Rainfall is bountiful, with an annual average of more than 1,000 mm. Since 1964, a total of 9,014 turbine-pump units have been put into operation in this region, irrigating 27,000 hectares of farmland (8).

In the mountainous areas of Guizhou Province, where the fields are high and the rivers low, the lift can be more than 100 m; however, limitations of mechanical design make the conventional turbine-pumps applicable only for lifts of 40-50 m. To solve this problem, the hydraulic, mechanical, and scientific research departments of the Province joined forces to improve the design of turbine-pumps. Since 1968, they have made numerous improvements, such as:

- The introduction of the multistage turbine-pump;

- The use of ductile iron or cast steel in the casing and impellers;

- The improvement of the shaft design; and

- The replacement of metallic bearings with plastic bearings.

Furthermore, a substantial increase in the lift capacity, (maximum 263 m) has created new prospects for the application of turbine-pumps. China now has two series of high-lift turbine-pumps (total lift more than 100 m) with head ratios of 1:6 and 1:17, respectively. The head ratio is the head supplied to the turbine vs. the lift produced by the pump. The 1:6 series is a single-stage machine that comes in two sizes, the 40-6 and the 60-6; it is applicable to high-lift and larger flow sites. The 1:17 series is a three-stage pump that comes in three sizes, the 30-18, 40-17, and 60-17; it is suited for high-lift and low-flow sites (8).

Conclusions

China's success in the field of small hydropower developments is exceptional. Certain elements of China's program can be incorporated in small hydropower development programs for other countries. The following factors have contributed to the success of the Chinese small hydro program:

- Effective government planning ensures that hydroelectric development is an integral part of water resource management;

- Motivation is strong, and hydro plants are built on local initiative;

- Electricity is used largely in the industrial and agricultural sectors, and in the latter, particularly to increase the productivity of the land through drainage and irrigation;

- Decentralized workshops for manufacture and repair of equipment are established in many counties; and

- Standardized designs enable equipment to be manufactured to a high standard both quickly and cheaply.

It is important to create a "climate," an infrastructure in which indigenous programs can grow. Without such an infrastructure, even the best designs and programs will not take root.

SMALL HYDROPOWER DEVELOPMENT IN NEPAL: THE IMPORT-ORIENTED APPROACH

Background

Nepal's estimated hydro potential is 90,000 MW, of which only 0.07% is developed. Yet 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 (2) has shown that, if there is no change in the present rate of consumption, no commercial forest will be left in the hills by 1985. Thus, waterpower is the only form of abundant energy in Nepal.

The Government recognizes the key role micro-hydro (less than 100 kW) could play in the development of remote areas. These small powerplants would make it possible for Nepal to rely on its own resources and foster production of the necessary equipment in indigenous workshops (1).

The Government began its small hydropower program in a district center, where it could rely on officials from the different departments. The plan was to use the power of a river for a plant of about 300 kW. The site had a flow of about 1 m^3/s and a drop of about 60 m in an existing irrigation channel about 1 km from the

67

center. Because the country did not possess the capability to plan a project of this size, the Government consulted foreign experts. Because Nepal lacked manufacturing know-how for equipment of this size, the Government requested bids from foreign companies. Prices differed very little (US$ 1,000-1,200 per kW) for turbine, generator, and governor of 170 kW capacity. The guaranteed output, however, varied approximately 20% (162-208 kW) due to the various methods the individual companies used to make their standardizations.

In 1977, the Government decided to order the 162 kW equipment with the lowest price. Many problems developed during the design and construction period. The manufacturer is quite large and, from its perspective, the project seemed very small.

There was no road to the site, which could be reached only after a day's trek or by helicopter. It was therefore important to know the weight and size of the equipment to be transported. However, because transportation is not a critical problem in countries where equipment is designed, information on weight and size was extremely hard to obtain.

Construction continued in the meantime. The irrigation canal was widened, the penstock laid, and the powerhouse erected. However, the canal was cut open continuously by farmers who needed irrigation water and did not appreciate a power project that used their water to provide lighting to people in the district center. Erecting the high-tension line proved to be difficult as well. The same farmers, for the same reason, refused to permit the installation of the poles in their fields and had to be forced to do so by officials. Running the line to the center was equally difficult, because no one wanted the line to cross his property. The Government ordered the entire project to proceed, but the local people refused even to cooperate, much less assist in this "strange" project.

After a long period, the equipment appeared at the border in 1979. This created transport problems. The heaviest piece was the cast-iron scroll casing of the Francis turbine; it weighed 1,400 kg. The biggest helicopter in the country had a lift capacity of just that, and no pilot was willing to take the risk (the price for the helicopter was US$ 1,100 per hour). Discussions among the Government, the manufacturing company, and the airline continued. Then the monsoon season came and the equipment had to weather the rains for another season. Finally in 1980, a military pilot was found to lift the equipment.

How it will run remains to be seen. There is no workshop close by and no experienced manpower to maintain the plant, and the hydraulic-mechanical governor is a delicate piece of equipment. Because the civil works were finished 2 years before the equipment finally reached the site, a small 30 kW crossflow turbine was installed for testing. This set was produced locally and transported to the site on a porter's back in 3 days. It ran 2 years until the imported equipment arrived. During 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 with such a low load. No significant increase in load is expected in the near future.

This painful experience should be a lesson to anyone working in the field of small hydropower development and points out several mistakes to avoid:

- Importing foreign consultants as the only source of know-how. Consulting is important, but it is more difficult for individuals who come from outside than for local individuals to address questions dealing with local realities. Foreign plans must be matched with local ideas and know-how.

- 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 produced the equipment. The 30 kW set installed in the interim proves that production is possible, although on a small scale. If the second, somewhat bigger set had been produced locally, a much lower capital investment could have ensured sufficient output for years.

- Making price the decisive factor in selecting equipment. If local manufacture is not possible, great care must be taken in choosing the equipment and the manufacturer. Equipment usually is designed for the conditions of the country in which it is sold. In this case, transport weights and sizes were not of prime importance in the manufacturer's country; however, they were crucial factors in Nepal. The same applies to the level of technology. Turbines can be controlled manually, as in the case of the 30 kW plant. Importing automatically controlled equipment can result in problems if it breaks down and no one is able to repair it. Machinery tends to be more critical as it becomes more complex.

- Inadequate communication between the manufacturer and the project. A big company often finds it difficult to deal with small plants, and sending personnel to install the machinery is out of the question for the budget of small projects. Thus, problems arise for both parties.

Building indigenous know-how

The "Small Turbine and Mill Project and Rural Electrification Program" attempts a different approach to developing Nepal's hydropower resources. Local people expressed an immediate need for mechanical power for milling grain and pressing oil. Efforts to develop a water turbine that could power milling machines ensued.

Choosing the turbine design

The market for this turbine is the area of the middle hills of Nepal, where heads are around 5-20 m. Building irrigation channels to irrigate the terraces on the steep mountain slopes is a tradition in Nepal. These are unlined earth channels, and their maximum water carrying capacity is around 0.3 m^3/s.

For this head and flow range, a Francis turbine usually is used. However, this type of turbine has several disadvantages:

- The flow through the runner changes from the radial to the axial direction. This means that a different flow-head combination needs a different runner diameter. This changes the entire design of the turbine and necessitates a number of standard designs, which are economical only when mass-produced.

- The part-load efficiency of this type of turbine is very low. In small streams, the change in flow is quite significant. For this reason, high efficiency—even at only a part of the nominal waterflow—is very important, especially in run-of-the-river plants, where streamflow changes cannot be counterbalanced by a reservoir.

- The flow through the turbine is three-dimensional, which makes the design quite complicated. This turbine is one of the most expensive designs to manufacture, especially in small series.

The crossflow turbine, also known as the Banki or Michell-Ossberger turbine, does not have these drawbacks. This design was relatively unknown and little development work had been done on it for years. In the general trend toward large scale, this turbine had been almost forgotten, because it is typically a small-scale turbine (up to approximately 1 MW). It has three major advantages:

- The flow through the runner is radial only. Therefore, the turbine adapts to a different head-flow combination by varying the width of its runner and not the diameter. Thus, the basic design always stays the same.

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

- It is easy to build.

For these reasons, the crossflow turbine was chosen. It took 4 years to achieve a design that satisfied the following five criteria, which were considered crucial (6):

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

- Although a turbine of relatively advanced design was needed, insofar as possible, it should require no maintenance.

- All the material used had to be obtainable in Nepal without foreign currency.

- It had to be comparable in efficiency to, and notably cheaper than, imported turbines.

- Because every part had to be carried by porters, none of it should weigh more than 70 kg or be too bulky.

The application

Sixty-eight turbines have been installed in Nepal and one has been exported to Papua New Guinea. These turbines 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 are run by cooperatives.

In searching for further applications for the turbine, it became apparent that small hydropower could substitute for scarce firewood to provide heat for cottage industry processes. A heat generator was developed to convert mechanical energy directly into heat, thus avoiding expensive electricity production where only heat is necessary. Two pilot generators are still running; they use the heat for ginger and fruit dryers. A project at the Technical University of Furtwangen, Federal Republic of Germany, has been started to develop the heat generator further (4). The goal is to produce heat at a level high enough 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.

Conclusions

These projects are very small, but they have important effects:

- The development and production of turbines and ancillary machinery in local workshops affords valuable experience to local craftsmen. This experience is essential to understanding and coping with problems encountered with bigger machinery.

- When local people undertake projects such as mills, they have a chance to learn what is involved in hydro projects and what such projects can mean for the community. For the people in the workshop and those in the village, the change can come fast, in some cases, too fast. It may be slow enough if projects are sufficiently small to permit indigenous know-how in small hydropower to develop. Without that foundation, local people cannot maintain bigger and imported equipment.

- When load can develop gradually, by the time a bigger powerplant is needed, enough know-how and demand have been built up to ensure that the new plant is maintained and needed. Experience has shown that putting a powerplant into a community will not necessarily spur development of the load automatically, and that the plant will not continue to run if the know-how has not been developed.

Imports of small hydro equipment should only bridge the gap until domestic manufacturing capability exists. This capability can be developed gradually by undertaking small projects in large numbers. It is sometimes difficult to resist the temptation to develop hydropower quickly and on a large scale. Importing expertise and equipment may seem easy, but works in very few cases. Although hydropower development programs often are designed to achieve energy independence, a policy of importing know-how and equipment ultimately leads to technology dependence.

APPENDIX A

List of small hydro equipment manufacturers (7)

Allis-Chalmers
Hydro Turbine Division
Box 712
York, PA 17405
USA

Manufacturers of standardized tubular turbines for 50 kW-50 MW capacity heads, up to 15 m.

A B Bofors Nohab
S - 46101 Trollhattan
Sweden

Manufacturers of propeller turbines 100-2,000 kW capacity.

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

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

Butwal Engineering Works Pvt.
P.O. Box 1
Butwal, Lumbini Zone
Nepal

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

China National Machinery Import & Export Corporation
12 Fu Xing Men Wai Street
Beijing, China

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

Disag Dieselmotoren AG
7320 Sargans
Switzerland

Manufacturer of crossflow turbines and Pelton turbines in the small range; also produces a small governor.

Drees GmbH
Postfach 43
4760 Werl
Federal Republic of Germany

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

Elektro GmbH
St. Gallerstrasse 27
4760 Winterthur
Switzerland

Manufacturer of small Pelton sets with output up to 25 kW, and other unrelated equipment.

Gilbert Gilkes & Gordon Ltd.
Kendal, Cumbria
England LA9 7BZ

Manufacturer of Francis, Turgo, and Pelton turbines with capacity up to 350 kW; also manufactures control equipment and other unrelated products.

Independent Power Developers Inc.
Route 3
Box 174H
Sandpoint, Idaho 83864
USA

Manufacturer of 3 hp Pelton and 6 hp propeller sets.

The James Leffel & Co.
426 East Street
Springfield, OH 45501
USA

Manufacturer of a large range of Pelton, Francis, and Kaplan turbines with capacity 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.

Koessler GmbH
St. Georgener Hauptstrasse
3151 St. Polten
Austria

Manufacturer of Pelton, Francis, and Kaplan turbines in the small range.

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

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

Mitsubishi Electric Corporation
Nagasaki, Japan

Manufacturer of a very small bulb turbine with 4 kW output for very low-head applications.

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

Recently started manufacturing crossflow turbines up to 800 kW output.

Niagara Waterwheels Ltd.
706 East Main Street
Welland, Ontario L3B 3Y4
Canada

Manufacturer of four models of propeller turbines with a range of 20-250 kW.

Northern Waterpower Inc.
P.O. Box 49
Harrisville, NH 03450
USA

Manufacturer of four tubular turbines with a range 20-250 kW; head range: 3-20 m.

Ossberger - Turbinenfabrik
Postfach 425
8933 Weissenburg, Bavaria
Federal Republic of Germany

Longtime producer of crossflow turbines, has delivered equipment with capacity up to 1,000 kW per unit.

Small Hydroelectric Systems and Equipment
5141 Wickersham
Acme, WA 98220
USA

Manufacturer of Pelton turbine sets.

Sorumsand Verksted
N 1920 Sorumsand
Norway

Manufacturer of standardized Pelton, Francis, and tubular turbines with capacity from 100 kW-10 MW.

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

Manufacturer of crossflow turbines of local design.

Tamar Designs Pvt. Ltd.
Deviot, Tasmania 7251
Australia

Manufacturer of Pelton, Francis, and Turgo turbines with capacities up to about 100 kW.

Wasserkraft Volk
Gfaell 45
D 7809 Simonswald
Federal Republic of Germany

Manufacturer of Pelton turbines up to 500 kW capacity, crossflow turbines up to 100 kW capacity, and waterwheels for low heads up to 300 kW.

Woodward Governor Company
Engine and Turbine Controls Division
Ft. Collins, CO 80521
USA

Manufacturer of a variety of speed governors of high quality.

REFERENCES

1. B.P. Adikari HMB. Mini-Hydro Development Program in Nepal. 1979.

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

3. Meier U. Local Experience with Micro-Hydro Technology. SKAT publication Vol. 1, No. 11. St. Gall, Switzerland: Swiss Center for Appropriate Technology, 1981.

4. Metzler R. The Heat Generator: A Report on R&D Done on a Device for Direct Conversion of Mechanical Energy into Heat. Furtwangen, Federal Republic of Germany: Fachhochschule, 1981.

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

6. Scheuer H, Metzler R, and Yoder R. GATE Module 1/13: Small Water Turbine Instruction Manual for Construction of a Crossflow Turbine. Eschborn, Federal Republic of Germany, 1979.

7. Swiss Association for Technical Assistance. Report on a Study Tour on Water Resources Development in China. Kathmandu, Nepal: Swiss Association for Technical Assistance, September 1980.

8. Zhao S. The High Lift-Turbine-Pump. Guizhau Province, China: Scientific Research Institute, 1979.

71

An Electronic Load Governor and Related Developments

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INTRODUCTION

The relative simplicity, absence of fuel costs, and low maintenance requirements of waterpower make it attractive. Unfortunately, the capital cost of conventional small hydropower 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 $1,400 per kW. Even this cost would put small hydro beyond the means of rural communities in the developing world.

It would be impossible to meet this cost criterion using standard commercial equipment (see Fig. 1); construction and installation would more than double these cost figures. Manufacturers have tried to reduce costs through standardization with some simplification in design, but commercial incentive is lacking in the smaller sizes of equipment, which will probably continue to be very expensive.

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

- A hydraulic turbine with flow control mechanism,
- A speed governor,
- A single- or three-phase alternator with a voltage regulator,
- Gearing or a belt drive to match the operating speeds of turbine and alternator, and
- Electrical control equipment.

The single most important step to reduce cost 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 is constant, avoiding unacceptable sudden fluctuations in speed, frequency, and voltage. The cost benefits from this step result from the following facts:

- The speed governor is a very expensive item and may account for more than 25% of the total cost of a small unit.

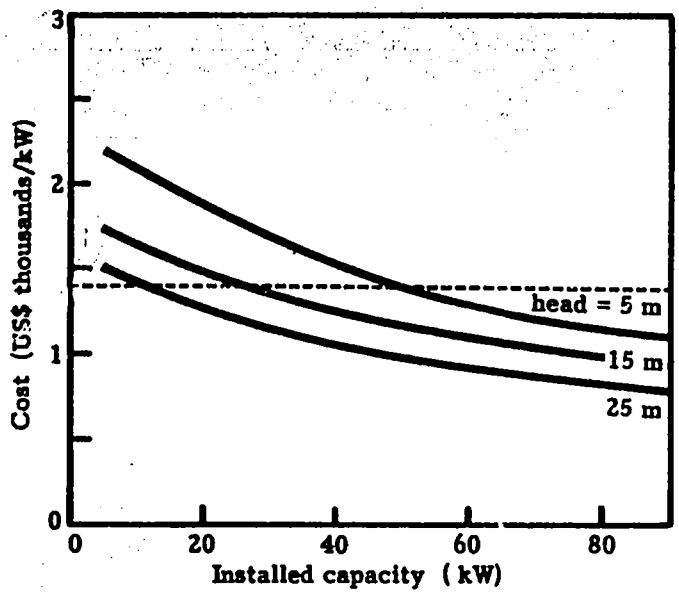

Fig. 1. Approximate cost of commercial hydro plant in New Zealand.

- Turbine design can be simplified because continuous automatic variation of flow is no longer required.
- Without the need to coordinate the dynamics of governor, rotating machines, and water column, matching the turbine to the site is not critical.

Most small, low-cost hydro schemes are "run-of-the-river"; 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 automatically by varying the load taken by a ballast load unit as the consumer load changes. An electronic load governor (also commonly referred to as load controller) 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 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; and be robust, reliable, stable, and cheap. A load governor which matches these specifications has been developed

at the University of Auckland (9) and will be available commercially soon. Similar equipment has been developed elsewhere (5).

Work on low-cost, small hydro sets has been undertaken by small engineering firms, aid-related agencies, appropriate technology groups, and universities in both developed and developing countries. The main emphasis has been on turbine designs involving fabrication methods suitable for small factories and workshops. Propeller turbines have been favored for low heads (6), the crossflow or Banki turbine for medium heads (1,2), and the Pelton turbine for high heads (3).

The most remarkable achievement in cost reduction has been reported from Pakistan (1) (see Abdullah, Micro-Hydroelectric Schemes in Pakistan). Costs per installed kilowatt ranging from $250-$400 have been attributed to:

- Low administrative costs,
- Labor contributions by villagers,
- Maximizing use of local materials,
- Local fabrication of some equipment,
- No governor, and
- Minimal use of costly technical expertise and supervision.

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

THE LOAD GOVERNOR

The resistance of the ballast load varies automatically as the frequency deviates from its rated value. A zero-voltage switching method was chosen in which separate resistors are switched across the supply. The switching instants always correspond to voltage zeros. This 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, although increasing the number of steps generally increases cost and complexity. Fig. 2 explains the operation of the single-phase governor.

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 consists of:

- 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.

A four-bit counter supplies gate signals to the load-switching triacs and stores counts in the range 0-15, corresponding to frequencies in the range 49.34-50.67 Hz. An input frequency of 49.34 Hz or less corresponds to a count of zero, causing all triacs to 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 necessary only to replace the triacs. One unit has been installed on a 7.5 kW Pelton 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 outstation in New Zealand. The oscillograms in Fig. 3 show the typical behavior of the system in response to sudden removal and application of consumer load. The delay in

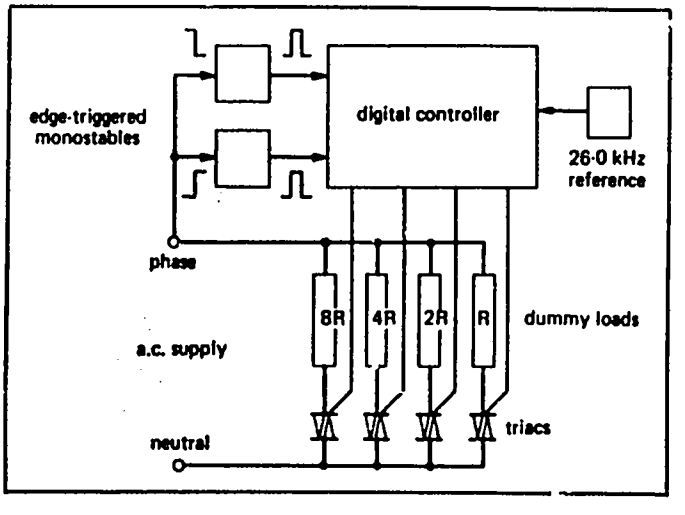

Fig. 2. Single-phase electronic load governor.

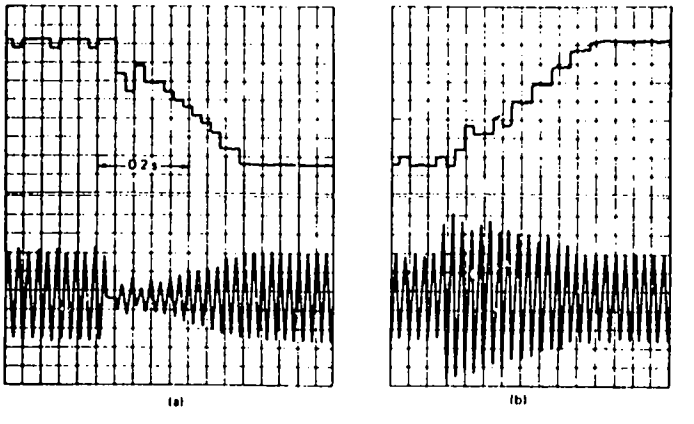

Fig. 3. Response of single-phase load governor to sudden changes: (a) full load removal; (b) full load application. (Upper traces—step load switching; lower traces—total alternator current.)

13

reaching a new steady state is the time required to bring the generating unit 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 kHz, 26.0 - Δ kHz, and 26.0 + Δ kHz, respectively. With appropriately selected crystal frequencies, the 21 steps of shunt load are switched into the three phases in sequence while approximate phase balance is maintained and 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 unit that drives a three-phase, 40 kVA induction generator.

The governor loads

The energy dumped into the governor loads may be discharged as waste or used to provide hot water (4) or space heating. In many parts of the developing world, the energy crisis is apparent in an acute shortage of firewood; therefore, the development of heat-storage cooking stoves could be worthwhile (7). Other obvious uses include crop drying and refrigeration, but, looking ahead, useful electrochemical processes might be developed as well (8).

Because the load governor is sensitive to system frequency, it need not be located adjacent to the generator, but can be placed wherever the energy is to be used. Indeed, 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 allow a priority ordering of loads. The three units of a three-phase governor need not be physically adjacent either. For negligible extra cost and complexity, the load governor includes a feature that might not be appropriate in a simple village scheme, but does allow an additional level of energy management. Additional electronic switches control the flow of power to low-priority loads, which are supplied continuously—provided that there is excess power after all high-priority consumer demands have been satisfied (see Fig. 4).

Availability of load governor units

The design and testing of this load governor unit was completed more than 2 years ago. Since a paper described it in the technical press (9), a steady stream of inquiries has come from potential purchasers in many countries. These inquiries have come to nothing because most of those interested lacked the facilities or skills to construct the governor and because the current producer is not geared to production on a quantity basis.

For such units to be applied usefully in the developing world, they must be cheap, reliable, and readily available. Such units are difficult to locate. For this reason the research group attempted to interest a local manufacturer in producing the governor unit for sale within New Zealand and overseas. Because 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 approach. This attempt eventually succeeded. Governor units are expected to be available commercially by mid-1982. In general, the objective should be to encourage local manufacture in developing countries to keep costs down and to upgrade local skills. However, 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 easily to any small system and that matching various parts of the system is not critical. For example, applying a governor to the low-cost Pakistani systems (1) would greatly increase the versatility and security of the supply without a major increase in total cost.

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 speeds. They are strong and cheap. Induction machines have a low transient impedance, making them appropriate for motor-starting and other switched-load applications. They produce good waveforms and are tolerant of unbalanced loads.

Despite these advantages, there are a number of difficulties. Induction machines will not naturally self-

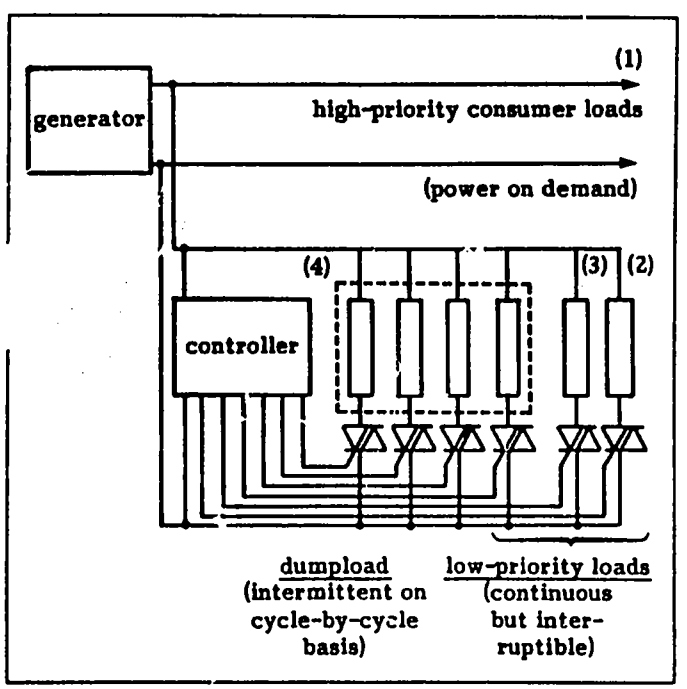

Fig. 4. Priority ordering of system loads.

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 that is determined by the rotor slip frequency.

Both of these problems are overcome by a system that incorporates a frequency-sensitive load governor and an automatically controlled VAR source. The University of Auckland has an active research program aimed at achieving the lowest-cost system compatible with reliability and convenience. Because the voltage of the induction machine inherently collapses on overload, the University also anticipates the development of fuseless protection systems.

REFERENCES

1. Abdullah M, and Inversin A. "Rural Power Schemes in Pakistan," International Water Power and Dam Construction, November 1981, pp. 23-25.

2. Dakers. "Michell Turbine Development Project." Conference Paper, Ministry of Agriculture and Fisheries Agricultural Engineering Conference, Lincoln College, New Zealand, November 1978.

3. Inversin A. "A Pelton Micro-Hydro Prototype Design." Lae, Papua New Guinea: Appropriate Technology Development Unit Report. PNG University of Technology, 1980.

4. Inversin A. "Technical Notes on the Baindoang Micro-Hydro and Water Supply Scheme." Lae, Paupa New Guinea: Appropriate Technology Development Unit, PNG University of Technology, 1980.

5. Holland R, Armstrong-Evans R, and Marshall K. "Community Load Determination, Survey and System Planning." Proceedings of NRECA Workshop on Small Hydroelectric Plants, Quito, Ecuador, August 1980. Washington, DC: National Rural Electric Cooperative Association, 1981, pp. 59-76.

6. Mackay. "On Stream-Answer to Your Energy Crisis," The Sunday Times, London, June 1, 1980, p. 60.

7. Mini-Hydro Report, World Water, July 1979, p. 30.

8. Treharne RW, McKibben CK, and Moles DR. "Fertilizer Production by Water Power." Proceedings of NRECA Workshop on Small Hydroelectric Plants, Quito, Ecuador, August 1980. Washington, DC: National Rural Electric Cooperative Association, 1981, pp. 241-46.

9. Woodward JL, and Boys JT. "Electronic Load Governor for Small Hydro Plants," International Water Power and Dam Construction, July 1980, pp. 37-39.

15

A Viewpoint about Small Waterpower Developments

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INTRODUCTION

The term "small waterpower" refers to hydroelectric plants with an installed capacity of 0.2 kW (supplying individual rural homes) to 500 kW (supplying villages or local industrial activities, or both). Plants within this range, although similar in principle to mini-hydro (10 MW) plants and large hydro (100 MW) plants, demand a different approach in their design, development, and operation. Their small scale and comparatively small capital investment per plant precludes costly engineering studies and skilled technical expertise for operation and maintenance.

Engineers and planners in hydropower normally are trained to think in terms of huge plants. In small hydro, however, the object is many widespread tiny plants, all different and subject to varying site-specific conditions. The problems, therefore, are more complicated. In large power projects one tends to ignore the end users, who appear in reports as nameless statistics. Those involved with medium-sized and small plants, however, will probably meet and talk with the end users who, it is very likely, will be involved in the project from the start. In fact, for the very smallest plants, the power package may be sold as a piece of agricultural equipment for the end user to install on a do-it-yourself basis.

KINDS OF MICRO-HYDRO PROJECTS

Because of their variety, micro-hydro projects are extremely difficult to classify. It is possible to use technical classifications, such as high-head, medium-head, and low-head. It is also possible to define projects as those which are suitable for scarce water resources and scarce money and those which are suitable for abundant water resources and scarce money. Micro-hydro for developing countries will lie in between, and technology offers a variety of alternatives for each case. Where domestic power demand is low and water resources are scarce, there is no choice but to store energy; where water resources are abundant, a run-of-the-river project might be appropriate, but storage of energy also should be considered. Energy can be stored in various ways, but in practical terms, only reservoirs and storage batteries are attractive options.

Technical developments in the last two decades have opened the way for very small hydropower plants. New developments in materials, solid-state electronics, home appliances, and lighting have increased the efficient use of electricity and have reduced the power demand. Even more important, more people are now served per installed kilowatt capacity of a hydroelectric plant.

A comparison of home appliances of the 1950s with today's equivalent shows that the efficiencies for the same service have doubled; in the field of electronics, there has been a ten-fold improvement; and in the case of lighting, very recent developments promise a sixfold increase. Electric storage batteries have not changed much in 20 years, but research is now attempting to create batteries that are lighter, more reliable, and of greater capacity per unit volume.

Unfortunately, the nature of domestic power demand poses a major difficulty in small waterpower plants. Its nonuniform and peaking character necessitates the use of control devices that either waste or store energy. Nonuniform demand also requires that the installed equipment have sufficient capacity to cope with peak demand. Under these circumstances, most of the investment in a small plant will remain idle and unproductive.

There have been various attempts to maximize the usefulness of a small hydropower plant. This can be achieved by improving its load factor by spreading the load over a larger population. Where resources are very scarce, some electricity for all may be better than an ample supply for a few. Lack of knowledge often results in a misuse of electricity that places it beyond the reach of poor communities. A case in point is the belief that standards for electrical equipment and for the distribution of electricity should be enforced by law. Perhaps relaxing the standards would generate ideas that could reduce the overall costs of electricity. There is no point in adopting and enforcing standards that do not correspond to local conditions; it is like trying to live with U.S. standards in Colombia where the yearly income of many families is around US$ 1,000. There must be an appropriate standard for each situation.

The end user of electricity can be educated to use energy efficiently if the price of energy is right. While educating the end user will help, the design can incorporate methods to promote efficient use. Take, for example, the typical public utility system for towns, with a high voltage grid for distribution, transformers, and homewiring according to whichever standard has

been adopted. With the addition of a meter and inefficient incandescent bulbs, the result is a system appropriate for some people who have to buy everything for their home. On the other hand, the same public utility could deliver, possibly every three days or so, a storage battery to be hooked on to the wiring in each home to supply efficient DC power for lighting and appliances. Each alternative has advantages and disadvantages, but one will be more appropriate.

Technological developments of the future will probably present other sound alternatives. For now, however, it is clear that in the planning of small waterpower developments, unconventional solutions should be examined at every stage.

SEVERAL OPTIONS FOR MICRO-HYDRO PROJECTS

Some options for micro-hydro projects depend on the amount of power to be exploited. Table 1 shows just a few of the possible combinations for small waterpower projects. These examples intentionally exclude productive end uses, because such activities often result from entrepreneurial and community efforts in free societies. In societies with communal organizations, due consideration to the productive side of the plant is indispensable during the design stage. Initially, the domestic load should be given priority in such cases, because the industrial load generally will promote itself once the technological know-how is available.

With Option 1, cost can be minimized only if the interested end users develop the installed power. Finding a cheap, reliable, and flexible hydro generating unit that anybody can install is the main problem with this option; only recently have some efforts been made to market such devices. The initial approach is to use standard automotive alternators and locally made turbines. Reliable electronic regulators have been used to regulate voltage to charge the batteries without ruining them.

In short, the approach in Option 1 requires the availability of a hydropower generating unit purchased as one would a piece of agricultural equipment and used to provide power for lighting, communications, and a few appliances for homes. Electronic inverters at a reasonable cost would allow power to be transmitted to the end user at a higher voltage; however, losses and reduced capacity somewhat limit the suitability of these very small hydropower units.

Options 2, 3, and 4 develop the same resource but differ widely in the number of people served and the costs

TABLE 1. Examples of Micro-Hydro Projects for Domestic Loads

Option	Dependable water resource capacity (kW)	Shaft power (kW)	Typical turbine efficiency	Typical generator efficiency	Regulation or control	Type of energy or power transmission	Number of homes attended	Productive energy per day (kWh/day)	Peak capacity (kW)	Overall efficiency and load factor
1	0.5 run-of-the-river	.35	.7	.7	electronic voltage regulator	batt — 50 m — 12 VDC, 20% losses	1-2	5.0	2.0	0.4
						batt — Inv. — 500 m — 120 VAC, 30% losses		4.0	1.0	0.35 high
2	5 run-of-the-river	3.5	.7	.75	120 VAC 12 VDC voltage control	batteries are transported and distributed, 20% loss	10-20	50	20	0.4 high
3	5 storage reservoir	25	.7	.8	mechanical flow control (Woodward)	500 m low voltage AC	12-24	60 or more if flow permits	20	0.5 low
4	5 run-of-the-river	3.5	.7	.8	no control	500 m low voltage AC	2	60	2.5	0.5 low
5	2-20 run-of-the river	1.5 to 15	.7	.8	electronic load control and ballast	500 m low voltage AC	1-15	25-250	10	.55 low
6	2-20 run-of-the-river	1.5 to 15	.7	.8	electronic load control and ballast	battery charger and batteries to distribute 500 m low voltage AC	4-40	20-200	2-100	0.4 high
7	20-500 run-of-the river		.8	.9	electronic load control and ballast	high voltage 25 km	30-5,000	300-7500	12-350	0.64 low

involved. Option 2 focuses on energy demand and is economical but relies on some form of convenient transport for the batteries and the control of their charging. The load factors on the plants of Options 3 and 4 show that they will be more expensive per potential user. Option 3 attempts to adapt large waterpower technology to small waterpower developments. With this option, the real plant load factor, at times, might be high, but the extra investments will remain idle part of the time because the design focuses on meeting peak power demands. When funds are scarce, Option 4 can be a good solution only if some productive use is found for the energy so that the load factor is increased.

Options 5 and 6 show the advantages of trying unconventional approaches to provide electricity to small villages. The greatest benefit of Option 6 is the larger number of people that can be served from a given dependable resource. Like Option 2, Option 6 involves the use of batteries which may present handling difficulties.

None of these options can afford costly engineering studies. These options require the use of community self-help, local know-how, and local technologies.

Option 7 is a typical micro-hydro plant for conditions of ample waterpower resources. The only difference between this plant and an equivalent turn-of-the-century plant is the type of controls. The recent electronic load controller developed specifically for micro-hydro receives the power from the generator and switches that power not used by the consumer to a ballast load to ensure that a constant load is placed on the turbine. The costs are less than those of the conventional electromechanical controls, and the reliability is much higher. In fact, the electronic load controller improves the reliability of the plant dramatically and attains some cost savings as well. The only moving parts are the turbine and generator; control valves or gates are not required because the flow is constant; and surge protection is not needed. Overspeed safety devices can be installed in case the load on the turbo-generator is accidentally lost; therefore, the turbines can have fixed geometry that incorporates the flexibility to cope with a range of heads and flows. The generators can also be simplified somewhat to make automatic regulating features within the machine unnecessary.

A Radical Approach to Rural Electrification for Developing Countries

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National Electricity Board
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INTRODUCTION

In developing countries, utilities face problems in the implementation of rural electrification programs, especially in very remote areas. The technical standards and philosophies of rural supply adhered to by utilities are a stumbling block to the potential rural consumer. To overcome these, a radical approach to rural electrification is necessary, one that requires a redefinition of rural electrification. The acceptance of this approach depends on the attitudes of developers, social scientists, and politicians. It defines limits of electrical energy available to the rural consumer rather than limits of electrical power. Growth in the use of electricity may be limited, but the socio-economic benefits of rural electrification will be substantial.

CURRENT APPROACHES

One method of rural electrification is grid extension. This is impractical for isolated areas; any electric power that these areas receive usually is produced locally by diesel, small dendro-thermal, or mini-hydro stations. The local approach is less costly than grid extension, but still results in a very expensive rural electrification program. Existing methods of supply offer few advantages in terms of time and money. In general, the following is true of rural electrification:

- The cost/benefit ratio is unfavorable;
- The system operates at low loads that do not justify revenue collection procedures, service, and maintenance;
- The rate of growth in energy consumption is higher than expected for the initial period of supply, which increases system rehabilitation costs; and
- Low load factors make it difficult to design the capacity of generating facilities properly.

Rural power consumption is usually low. In developing countries, the maximum per capita demand is less than 200 W. The growth of a rural system is approximately 10% per year for the first few years of the system's life; later, the growth rate stagnates as a result of financial constraints on the consumers. It is possible to surmount these obstacles by limiting the demand for electricity and installing a new form of supply system. It is then necessary to redefine rural electrification as follows:

Rural electrification in developing countries supplies the rural consumer with quantities of <u>electrical energy</u> rather than <u>electrical power</u>.

This definition has limitations, but offers definite advantages to electric utilities. It will enhance rural electrification.

THE LIMITED CHARGER SYSTEM

One system of energy supply is called the "limited charger system." It provides the following to each consumer (household):

- A current limiter equivalent to approximately 60-100 W;
- A battery-charger capable of maintaining RMS voltage for a variation of 50% input (see Appendix A). With the battery, a consumer can use as much as 200 W with a 60 W limiter connected to the system (see Appendix B); and
- DC wiring for an equivalent of 8 x 20 W loads. The voltage of the system is 12 V.

With this system:

- Lighting is provided by fluorescent lamps with individual inverters (lamps will have a long lifespan because heater elements are not used);
- Television and other accessories for household requirements are DC types; and
- Batteries usually are automobile batteries rated 105 Ah or greater. The battery size is determined by household requirements.

The circuit diagram of the supply system to the rural consumer is shown in Fig. 1. The system is analogous to water supply where a water tank provides excess demand requirements for the day. The limited charger system consists of a current limiter (A), beyond which is a battery-charger (B) of 60-100 W. The 12 V charger charges a battery (C), which becomes the reservoir for electrical energy. The goal of this process is to store electrical energy in mini-hydro schemes, to minimize its costs, and to reduce plant capacity. This system can also be used for consumers in rural diesel stations, wind energy systems, and solar energy systems. Further

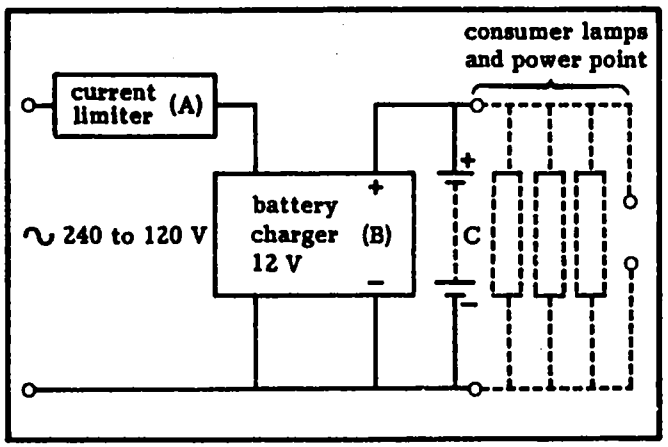

Fig. 1. Circuit diagram of the supply system to the rural consumer.

analysis shows that this limited charger system would be 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 whose main supply comes from a local grid, the following occurs:

- The household receives a constant flow of perhaps 60 W. This is the maximum value; it is governed by the current limiter. Available energy on demand is 200 V.
- The battery is charged at most times during a 24-hour period. When the consumer requires larger output, the energy is available from both the battery and the charger.
- The current limiter prevents overloading of the mains. The system load factor is almost unity.

Fig. 2 compares typical daily load imposed by conventional end uses vs. that imposed by a limited charger system. In a conventional system, the

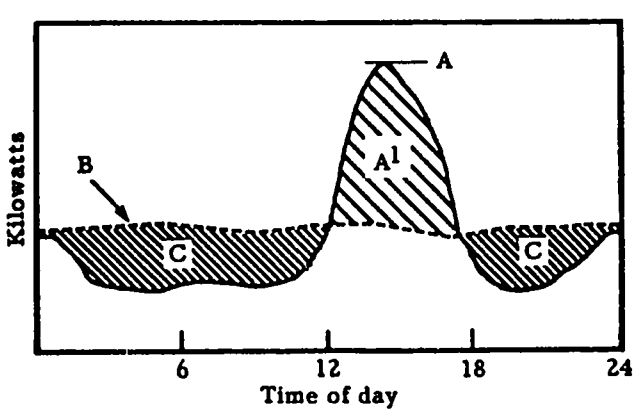

Fig. 2. Comparison of a typical daily load imposed by conventional end uses vs. that imposed by a limited charger system.

maximum demand is as indicated at level (A). With the limited charger system, the battery compensates for the extra requirements of electrical energy, and the new demand for the system would be at level (B). The area shaded (A^1)—the extra energy required—is actually retrieved from area (C), where energy has been stored. The capacity of the battery determines the level of demand of the new system.

ADVANTAGES OF A LIMITED CHARGER SYSTEM

There are numerous advantages of a limited charger system (see Appendix C). The charger converts AC to DC regardless of frequency. With each household receiving approximately 60 W through the limiter, the number of consumers for such a system can be rather large. For example, a 100 kW source can supply approximately 500 consumers in the conventional manner; in the new system, the 100 kW source can supply from 1,000-1,800 consumers. The charger is able to maintain RMS voltage for a 50% input variation. It becomes possible to extend low-voltage distribution lines many times their present length at full load. This also means that the high-voltage system, perhaps 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 perhaps 240 V, that is, 120 V.

Single-phase and long distribution lines become possible because load balancing is no longer a problem. In the limited charger system, wire sizing can be more economical, because the wires allow for voltage drops of 50%. Although the limited current is used, the energy capacity per consumer increases with the number of batteries. Any overloading on the supply system will cut the battery-charger off from the main.

From the operational point of view, the load factor of the rural scheme tends toward unity. The limited charger system is independent of frequency, which minimizes its diversity and improves the power factor. Voltage fluctuations, a major problem in normal and off-line rural systems, are limited, because the system will control the voltage difference between day and night caused by any Ferranti effect. This means that the energy fed to the consumer is under control. The system thus permits the optimum use of energy and improves the stability of supply, because faults on the feeder lines will not prevent the use of the batteries as standby units.

From the implementational point of view, the limited charger system is inexpensive; it also reduces waste. House wiring is at a safe, low voltage.

The limited charger system can be converted to a standard system when there is adequate demand, or can be retained even after demand levels have risen. This system then becomes a standard system which supplies lighting, television, radio, etc. 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 it makes optimum use of diesel stations and other generating stations of limited capacities. With diesel stations, which run for only 12 hours, the limited charger system can extend the time that electricity is available to the consumer to 24 hours, because the battery is charged within the 12-hour period.

The limited charger system allows the energy from micro-hydro stations to be stored in batteries, thus reducing water storage requirements. It also reduces the need for extensive governing of turbine speeds, because the constant load reduces excessive speed variations. A properly balanced system may even eliminate the use of governors in micro-hydro schemes altogether.

ECONOMICS OF THE SYSTEM

The cost of the system is relatively low. The single-phase long-distance wiring can be economical, and the operational cost can be minimal. Money spent to improve the system at a later date will show better cost/benefit ratios. (See Appendix B for evaluation of the limited charger system and a standard system.)

Any rural electrification project can be shown to be financially uneconomical. In most rural communities, electric power fulfills domestic and lighting needs, and the capital cost of supplying this rural demand is not feasible—especially when the load factor is low. The standard alternative is to supply the demand through a 12-hour diesel electric generating system, but even this system is limited by its distribution distance. The economics of the limited charger system encompasses not only its cost, but also its social benefits.

The aim of the limited charger system is to provide the minimum electrical amenities, such as lighting, television, and radio, while controlling the load in the area served. When the system has established a better load demand, the standard grid system can be extended.

DISTRIBUTION DESIGN

The limited charger system will extend the distribution distance considerably, because it can use single-phase 11 kV lines as the means of transmission. Single-phase lines can extend much farther than standard systems and are thus more appropriate for rural electrification, where consumer distribution is scattered. Single-phase lines have another benefit: They cost much less than three-phase lines.

The extension of the distribution system not only brings service to more consumers, it reduces the number of distribution substations, because voltage regulation is not rigid. With this system, it is possible to use more low-voltage line boosters, which will be appropriate locations for future system substations.

The costs of developing the initial distribution system can serve long-term needs. By providing a basis for upgrading to a standard system in the future, they help to reduce the capital cost of future system improvement.

CONSUMER CONNECTION

The consumers are responsible for maintaining their owr batteries and will be given instructions for keeping a battery in good operating condition. Because they will have to maintain the battery to receive a good supply, they will acquire a better understanding of electrical supply facilities.

The consumers are billed on a fixed-rate basis; there is no metering.

CONCLUSION

The limited charger system has obvious advantages if rural electrification is viewed as a means of providing electrical energy rather than electrical power. Operationally, its advantages far outweigh those of existing systems, especially in developing countries. It makes electrical energy available, yet discourages waste and unnecessary costs. By bringing electricity to rural areas, it can enhance the development of rural communities and rural electrification programs.

The attitudes of all those involved—planners, consumers, and vendors—are of critical importance to the success of the system, because limited service must be acceptable to both consumers and the utility. If it is, the effect of the limited charger system will be tremendous.

APPENDIX A

Battery-charger types

Two types of battery-chargers can be designed for the limited charger system. The type of design selected depends on power requirements, the energy source, the reliability needed, etc. The simpler of the two circuit designs is shown in Fig. A.

In this system, 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

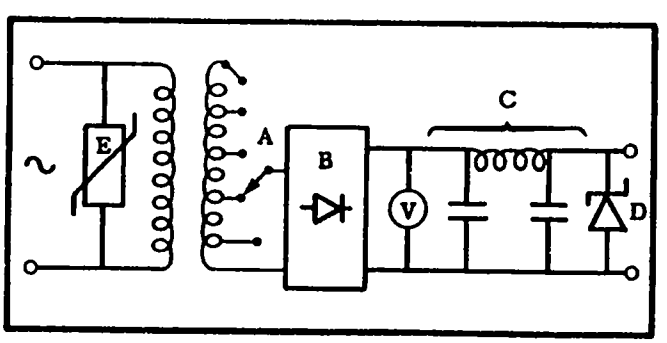

Fig. A. A simple battery charger design.

varistor for lightning surge protection. (I) is a voltage indicator composed of light-emitting diode and zener diode combinations that will indicate voltage levels for proper operation of the charger. A simple charger can be made by omitting (C) and (I).

The charger is connected to the mains in series with the current limiter; its output is connected to the battery. In the charging operation, the switch at (A) is moved to a suitable tap position, indicated by (I). Consumers can make slight adjustments to suit their system requirements, depending upon the voltage level of the mains. Once the tap position has been set, however, frequent adjustments are not necessary.

In the second type of design (see Fig. B), the battery-charger is capable of automatic voltage regulation by maintaining an RMS output for a 50% variation in the mains voltage. This system is more complicated and uses thyristor-controlled circuitry for its operation.

As in the first type, the circuit consists of the standard charger system, but thyristors are incorporated into the bridge rectifier unit. (Vs) is a circuit that ensures the charging voltage of the charger and maintains this output for a 50% variation from the main input voltage.

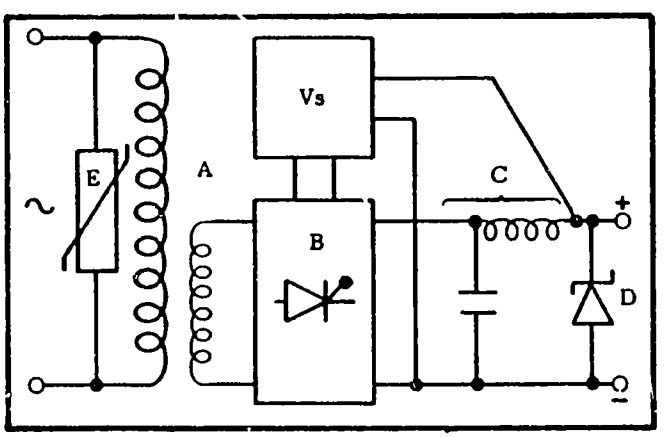

Fig. B. A battery charger design incorporating thyristor control.

APPENDIX B

Evaluation of the limited charger system

The utilization time is important in calculating the individual consumer's consumption. Utilization time is the time duration over which the consumer uses the load. This load is referred to as "connected load demand." The relationship between the connected load demand and utilization time can be shown as:

$$\text{Connected load demand} = \frac{\text{energy available per day}}{\text{utilization time}}$$

Consider the proposed system shown in Fig. C. Then:

$$\text{Energy available per annum} = P \times 24 \times 365 \times \eta$$

$$\text{Connected load demand} = \frac{24 \times P \times \eta}{\text{utilization time}}$$

where P = rated capacity of the limiter

η = efficiency of the charger system (battery and charger).

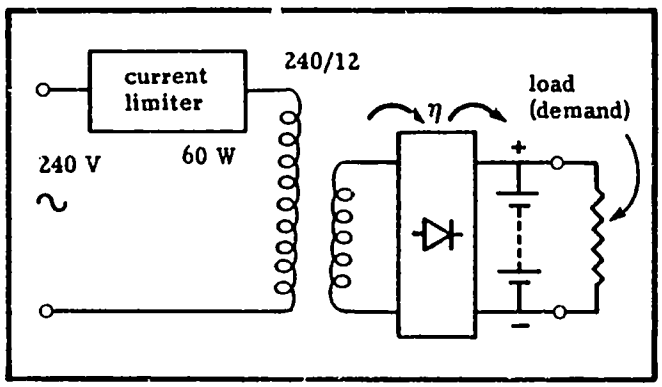

Fig. C. The limited charger system.

The relationship of connected load demand to utilization time is shown in Fig. D. Connected load demand is plotted against utilization time, because the system limits consumer consumption to a fixed amount of energy per month.

The connected load demand is the maximum demand of the consumer during any particular utilization time; this maximum demand is limited to the rated value of the current limiter.

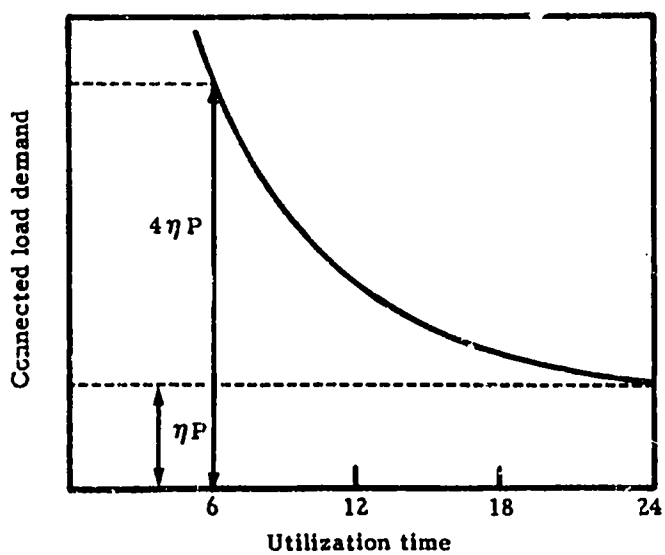

Fig. D. Connected load demand vs. utilization time.

82

For example, for a 240 V, 24-hour supply system and a consumption of 30 kWh per month, the limiter rating is found as follows:

$$\text{Size of limiter} = \frac{\text{daily energy consumption}}{\text{24 hours}}$$

$$= \frac{1{,}000 \text{ Wh}}{24 \text{ h}}$$

$$= 42 \text{ W.}$$

In this case, if limited charger system inefficiencies are included, the consumer's consumption would be about 50 W. This is equivalent to a current drain of about 0.2 A for a 24-hour system.

Electricity is available 24 hours per day. In general, the consumer's maximum demand is never more than 6 hours per day. Therefore:

$$\text{Connected load demand} = \frac{24 \times P \times \eta}{6}$$

$$= 4 \times P \times \eta.$$

The relationship of the current limiter's connected load to consumption is shown graphically in Fig. E. For example, for a given energy consumption (y), the size of the consumption current limiter for a 24-hour system is half that for a 12-hour system.

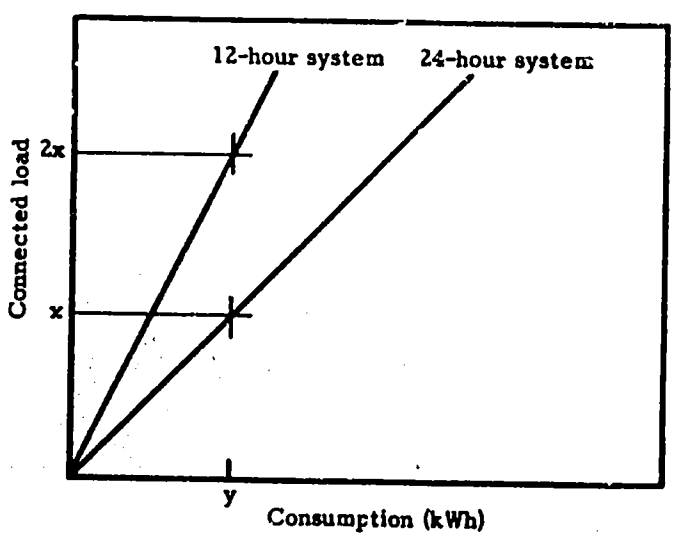

Fig E. Connected load demand vs. consumption of current limited.

Examples of economic evaluation

The following are assumptions used in economic comparisons between the limited charger system and the standard grid supply system for power distribution in rural electrification.

The limited charger system:

- Diversity factor = 1
- Load factor = 0.8
- Individual consumption = 30 kWh per month
- Capital cost per consumer = 300 M Ringgit*
- Distribution cost per consumer = 1,500 M Ringgit
- Fixed rate tariff per consumer = 7.50 M Ringgit per month
- Cost of battery (12 V, 105 Ah) = 150 M Ringgit
- Incremental cost of battery = 5%

The standard grid system:

- Diversity factor = 0.6
- Load factor = 0.15
- Tariff rate = 0.25 M Ringgit per unit
- Capital cost including contribution per consumer = 1,800 M Ringgit

Common data:

- Capacity of the source = 25 kW per firm output
- Lifespan of output = 15 years
- Reliability factor = 0.9.

The rate of interest varies from 1%-51%. Fig. F illustrates the relationship between the benefit/cost

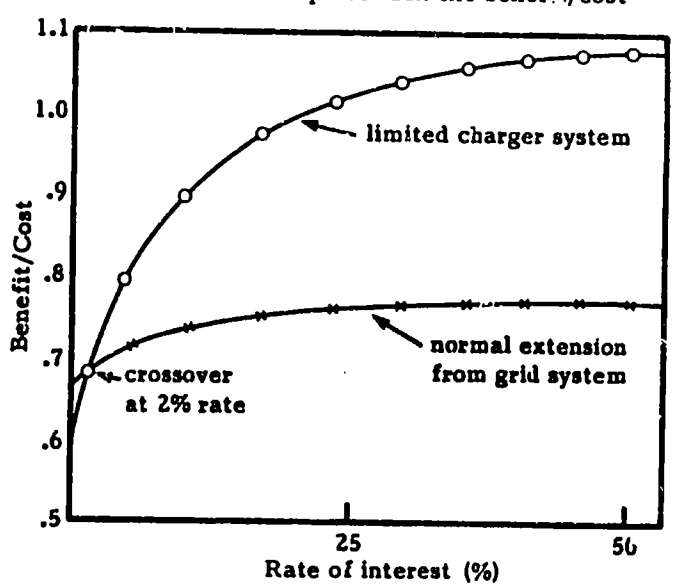

Fig. F. Comparison of benefit/cost ratios of limited charger and normal grid extension systems for varying interest rates.

* US$ = 2.28 M Ringgit

ratio and the interest rate. A small source (25 kW firm) is able to supply a large number of consumers. These consumers benefit more from the limited charger system than from the standard grid system of supply. The benefit/cost ratios of the two systems intersect at as low as 2%. For real cases, the advantages and disadvantages of both systems can be seen only from the social benefits achieved, and these benefits cannot be quantified. If the social benefits were quantified, however, the advantages of the limited charger system in rural electrification would overshadow those of the standard system of supply.

APPENDIX C

Advantages of a limited charger system

There are many advantages to a limited charger system:

- It is independent of source frequency.
- It can supply a large number of consumers.
- It eliminates consumer problems associated with voltage drops.
- It permits smaller size distribution wire to be used.
- It can use single-phase distribution lines.
- It makes sufficient power available to consumers.
- Its load factor is almost unity.
- Its voltage fluctuation, as seen from the source, is small.
- It permits control of energy use and growth of system.
- It provides the consumer with a stable supply.
- It automatically incorporates a standby power supply for the consumer during possible short-term shutdown of the generator.
- Inexpensive house wiring is possible.
- It is a low-voltage system (12 V), which is safe and inexpensive.
- It can be retained after the system is upgraded.
- It is applicable to micro-hydro, diesel, or grid systems.
- It permits maximum use of limited capacity.
- It precludes the need for meter reading since fixed tariffs are used.
- It is a good means of introducing electricity to the rural consumers and creates an energy-saving attitude.

ECONOMIC CONSIDERATIONS

Economic Feasibility Analysis of Small Hydropower Projects
Tobie E. Lanou

End Use of Mini-Hydropower
Daniel J. Boyle

Cost Implications of Small Hydropower Systems
Paul J. Clark

Financing Small Decentralized Hydropower
Douglas Gardner
with comments by Gaston Dossou

Cost Aspects of Mini-Hydropower Systems
Jack J. Fritz

Electricity Tariffs for Rural Communities
Shashi C. Desai

Economic Feasibility Analysis of Small Hydropower Projects

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Economist
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INTRODUCTION

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 the developing countries, to construct small diesel-generated power stations to serve outlying areas. Diesel is cheap to install and used to be cheap to operate.

Now that situation has changed. Small hydropower is an attractive energy source today because, once installed, even at a high initial cost, it is cheaper to operate and maintain. Compared to diesel stations, it uses little or no fossil fuel, so it does not face the fuel cost escalations that drain foreign exchange reserves and slow economic growth.

Still, small hydropower is not always a feasible choice. What really makes projects feasible? The following answers may seem obvious, but they are worth stating. A project is feasible when:

- There is real demand for it, not just an assumption of demand;
- It contributes a useful supply of power to the demand; and
- Cost and revenue are reasonable for the given output.

Other questions that affect feasibility also must be asked:

- Is any funding available 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.

ECONOMIC BACKGROUND REVIEW

Even for simple projects, it is useful for an economic analyst to check background factors that may have a direct bearing on a project's feasibility. Background factors include:

- The country's economic growth outlook;
- Trends in subarea economic development;
- Reviews of the country's financial structure and functioning, including its debt, its balance of payments, and its foreign exchange reserves;
- International development bank lending policies in the country; and
- Status of other significant foreign aid projects.

The main background matters to explore carefully are the country's energy consumption trends and projections. An understanding of these directly affects the feasibility of any small hydropower development project, because small hydropower projects are an alternative to petroleum product-based energy systems.

In Togo, for instance, only about 7% of electric power needs are supplied by diesel generators. The rest is supplied by hydropower from a major dam, the Akosombo, in Ghana. The 7% diesel-generated electricity is costly, and demand growth in areas served by the diesel generators—the provincial areas—is doubling every few years. Because these provincial areas fall outside the national power grid and will remain isolated for many years, it is important to try to find alternatives to expensive diesel for them.

To offer uniform electricity rates throughout Togo, the energy produced by burning diesel fuel is subsidized down to a rate comparable to that produced by large-scale hydropower sold from neighboring Ghana. This is considered important for economic and political reasons.

Prevailing energy rates are the benchmark for evaluating the economic feasibility of alternative solutions. Therefore, in addition to studying the geographic 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? What are the subsidies in them? Where is power obtained? What contracts govern energy purchases?

It is valuable to study other proposed energy projects, too. Studies about them are convenient sources of relevant data, but more to the point, they help to provide an overview of future energy supply sources, how feasible they are, how large or strategic they are, and how likely they are to be implemented and enter the energy supply picture.

Although some of this information may seem irrelevant to a small hydro project, experience shows that the background economic review yields many clues that are useful, and may even be crucial, in understanding the feasibility of a specific project.

SITE-SPECIFIC DEMAND AND SUPPLY STUDIES

It is necessary to make a study of demand and supply factors at each potential site. The production economics of large hydroelectric projects, typically located in remote areas, often make the cost of transmitting power over long distances, to remote locations where it is needed, unaffordable. Opportunities to develop small hydropower plants, on the other hand, are more numerous, and are often found in remote rural areas. However, the best sites for small hydropower development also may not be located where the demand for energy is greatest.

To determine demand, a first question to ask is whether a project is "isolated" or whether it can be connected to the grid easily. 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. To be feasible, it must have an adequate demand nearby.

An "integrated" or interconnected project is one where the energy produced could be introduced into the mainstream of the national power grid. An example of an interconnected project is in the town of Tomegbe in Togo, in a well-developed area. To be feasible, the energy from this project would have to be demonstrated to be as cheap as that from any other power source feeding Togo's grid system.

The line between "small hydro" and "large hydro" can blur as an analysis deepens. For instance, in Tomegbe, the team began by assessing small hydro potential to feed local demand only. When the feasibility analysis was complete, however, the project was found to be in another league altogether. It belonged in an economic and competitive context outside what is normally considered "small hydro," because its output potential was much greater than an early analysis had indicated.

It is not always clear at the outset whether a project will be isolated or integrated. One must start with an estimate of local demand by taking population counts and estimating area household incomes. Sometimes such demand is apparent; sometimes it is hidden. When one is dealing with extremely isolated or simple local economies, where electricity demand is not even remotely in evidence, the demand measurement often can be rudimentary.

Where an economy gives signs of more complex activity, including modern and small cottage industries, a demand profile must be conducted on a more specific basis. Consumption in electrical energy or in alternative energy types can be measured and forecast. Often, the best demand growth indicators are contained in the supply statistics of generating stations. This requires visiting the local generating station to gather data on equipment sizing, condition, and function; use and load patterns; and similar information. If electrical energy supply does not exist, initial estimates of business or personal income and ability to pay can be used to assess the potential for converting existing nonelectric energy demand to electricity demand.

In Togo, cheap hydroelectric power transmitted from Ghana serves the urban coastal area; the outlying provincial centers are served by diesel-generated power. 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 provincial center that is now dependent on diesel will elicit much interest.

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 what is the least-cost method of supplying power to serve the demand?

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 leveled off; energy consumption is expected to continue to grow. For this reason, the energy supply situation must 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.

These market studies of demand and supply make it possible to evaluate the feasibility of a project, the critical test.

KEY TYPES OF ANALYSIS OF ECONOMIC FEASIBILITY

Economic analysis can be quite simple or complex. The greater the potential investment in a project, the greater the requirement for complexity and detail in the project's economic analysis. Obviously, the more investment dollars riding on a decision, the more thoroughly one has to study the factors involved in the decision.

Static and dynamic analysis

A simple economic analysis is done on a static basis, stating all project revenues and costs together in a single-year analysis. Often this kind of simple "static analysis" is sufficient for 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 that models a project as it would actually be carried out. It forecasts both revenue and costs 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, better calibrated and more reliable. For instance, a project may appear to have merit on the basis of a static analysis; however, the feasibility may evaporate in the process of a more complete dynamic analysis.

Economic and financial analysis

Economic analysis is quite flexible in what it covers and what data it contains. There are two principal points of view about data content: the economic analysis point of view and the financial analysis point of view.

Economic analysis, strictly speaking, excludes certain financial considerations, notably the interest paid on borrowed money. Interest costs are thought 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 concerned not only with revenue benefits in a monetary sense, but with the larger latent benefits that a project can stimulate over the longer term. An example of an economic benefit would be flood control from a project designed primarily 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, in the framework of a financial analysis, if a project's investment return is less than the cost of money, it is clear that the money is better invested in a bank than in the project.

When to use economic or financial analysis

Whether to employ economic or financial analysis is partly a matter of ground rules. Certain government agencies or lenders want analyses performed in a predetermined way. The U.S. Army Corps of Engineers, for instance, has an entire manual that sets forth specific mathematical formulae and procedures for conducting both economic and financial analyses. Furthermore, this agency determines which analysis is appropriate. The World Bank, USAID, and other agencies often provide specific procedures for conducting economic analyses.

Some generalizations can be made about the choice of economic or financial analysis. Economic analysis is more theoretical, more "macro-economic" than financial analysis. Economic analysis is useful when:

- A project is proposed for an area that lacks past economic experience or data for projects of the same type, or
- When it is not desirable for variables such as interest costs to cloud the evaluation of the project.

In the United States, the Tennessee Valley Authority (TVA) provides a well-known example of a huge public investment that was justified by economic analysis. Earlier in this century, the Tennessee Valley was an underdeveloped area with a backward economy and too little apparent energy demand to warrant the huge public investment that finally was made. However, when the Government took a long-term view of benefits vs. costs, the TVA's large hydroelectric projects appeared to be justified.

Financial analysis is more precise, more "micro-economic" in a way. Financial analysis is necessary for:

- Assessing the project's competitive market situation. In addition to the project's overall merits, which an economic analysis measures, a public investor—like a private investor—needs to know the project's monetary rate of return, when it will begin to turn a profit, and whether the investment is prudent or not;
- Securing the necessary financing; and
- Actual administration of the project.

In practice, economic and financial analyses are not always entirely separable. Most complete studies will contain elements of both, because often both are needed to justify a project, to determine its real merit, or to administer it.

THREE COMMON TECHNIQUES OF ECONOMIC OR FINANCIAL ANALYSIS

Feasibility analysis, either economic or financial, commonly employs three interrelated analytic techniques: net present worth analysis; benefit/cost analysis; and rate of return analysis. Ideally, each of these evaluation techniques produces a number or an index which can be measured against comparable projects and thus constitutes a standard of value. Not all techniques are always appropriate. Usually, however, two or more techniques are used jointly to provide different perspectives on one project.

Net present worth

Net present worth is always a dynamic concept rather than a static one. The net present worth theory, developed earlier in this century, presents the concept of the opportunity cost of capital. It represents the present value of future benefits and costs, and is found by "discounting" future monetary values to take into account the time value of money. The discount rate used should ideally equal the rate of return that would be earned if the money were put in best possible market alternative; usually this is the prevailing bank borrowing rate.

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 1 million CFA francs paid in five annual installments of 200,000 CFA francs would be, at a 10% 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; they are expended 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 total net benefits, which is the future benefits minus the future costs. If project costs exceed project benefits over time, then the present worth does not exist. If project benefits exceed project costs over time for several alternative projects, the question becomes: Which project has the greatest present worth?

The net present worth equation is:

$$P_n = \sum_{j=0}^{n} \left[(B_j - C_j) \frac{1}{(1+i)^j} \right]$$

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

For present worth to be useful as an analytic tool, a number of alternatives need to be considered simultaneously. Because the net present worth analysis and calculation results in a monetary amount, not an index like the benefit/cost ratio or the rate of return, it must be compared to the present worth of another project, one that has similar goals or similar benefits. This procedure is a useful screening technique to evaluate a number of projects on a priority basis.

Benefit/cost

This technique is perhaps the most widely used investment yardstick for projects in the public sector. It was formulated originally for public investment projects; private market projects generally do not use it.

A benefit/cost index consists of the value of benefits divided by the value of costs. In principle, a project is worth undertaking if its benefit-to-cost ratio is 1, and grows more attractive as the ratio exceeds 1. Projects with a ratio of less than 1 are generally discarded as infeasible, but an index above 1 is not a guarantee of positive return on an investment. Where competition for funds is great, it often takes a benefit/cost ratio of 1.5 or greater to attract interest.

What are "benefits" and "costs"? The concepts are flexible and cover both tangible and intangible benefits and costs. Intangible benefits would be such social benefits as a sense of security which comes with electric outdoor lighting, 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.

By the same token, a financial benefit/cost analysis may exclude intangible cost factors, such as pollution or other environmental costs, which 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 benefit 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. Such a rate might be equivalent to the cost of money needed to finance a project like the one proposed (in financial analysis), or to the opportunity cost of capital (in economic analysis).

The benefit/cost ratio is:

$$\text{B/C RATIO} = \frac{P_b}{P_c} = \frac{\sum_{j=0}^{n} \frac{B_j}{(1+i)^j}}{\sum_{j=0}^{n} \frac{C_j}{(1+i)^j}}$$

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

Rate of return

The rate of return is a standard concept in banking and mortgage lending. Rate of return analyses can be both

static and dynamic. The rate of return is defined as the percentage that results from dividing project revenues (or net benefits) by project investment (or costs). The concept of rate of return is close to that of rate of interest. If a project's capital cost is 1 million CFA francs and the annual net revenue on the project is 100,000 CFA francs, the nominal static rate of return is 10%. Put differently, 1 million CFA francs invested at 10% yield a 10% rate of return.

The rate of return is compared to the cost of borrowing money or to the interest available on money investments to assess the comparative value of investing in the project. Obviously, the rate of return on a project should not fall below the cost of money for the same project. Ideally, it should be well above interest rates in order to compensate the investor for risk, time, and trouble.

In the public sector, rates of return are likely to be judged on a much more complicated basis. What constitutes a suitable return rate will depend on the social or economic utility of the project. But the rate of return always must be tied 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.

No single number can represent a universally suitable rate of return. "Suitability" will depend on:

- The project's risk;
- The project's quality;
- What competing projects offer;
- The cost of money and types of financing available;
- Sources and types of grant funding; and
- Prevailing economic conditions.

Rate of return analyses become more sophisticated when they are conducted on a time-discounted basis, according to a principle called the "internal rate of return." 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)."

CONCLUSION

Economic feasibility work can serve its most creative function when it is used not just to screen out bad projects, but to help a skillful analyst, working with project design engineers, to tailor a good project more carefully. Feasibility analysis can accomplish this by identifying strong and weak points in the project design and delivery and making maximum use of the strengths and correcting or compensating for the weaknesses. This process of "optimization" is the most challenging and creative role of financial feasibility analysis.

REFERENCES

1. CH2M Hill. Hydropower Investigation Guidelines. Reston, VA: CH2M Hill, November 1980.

2. Henwood M. "Economic and Financial Feasibility Methodologies." Proceedings of NRECA Workshop on Small Hydroelectric Plants, Quito, Ecuador, August 1980. Washington, DC: National Rural Electric Cooperative Association, 1981.

3. James LD, and Lee RR. Economics of Water Resources Planning. New York: McGraw-Hill Book Co., 1971.

4. Lawrence WD, and Kirshen PH. Togo Small Decentralized Hydropower Study. Prepared for NRECA. Washington, DC: National Rural Electric Cooperative Association, 1981.

5. NRECA. "A Methodology for Prefeasibility Studies of Candidate Mini-hydro Sites." Washington, DC: National Rural Electric Cooperative Association, 1980.

6. U.S. Army Corps of Engineers. "Feasibility Studies for Small Scale Hydropower Additions." Hydrologic Engineering Center, Davis, CA, and Institute for Water Resources, Ft. Belvoir, VA, July 1979.

7. World Bank. "Economic Tests of Project Acceptability." Washington, DC: World Bank, March 1971.

8. World Bank. Rural Electrification, A World Bank Paper. Washington, DC: World Bank, October 1975.

End Use of Mini-Hydropower

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INTRODUCTION

High energy costs are leading many economists and development theorists to conclude that energy, like land, labor, and capital, should be considered a major input to production. As the cost of commercial energy increases and the ability of the oil-importing developing countries to meet their foreign debt requirements decreases, a clamor to develop renewable energy resources arises. A frenzied approach to renewable energy development runs two major risks:

- Irresponsible development of energy resources that do not necessarily represent least-cost solutions, and
- A tendency to forget the primary objective of investments in the energy sector: economic development.

The first problem can be avoided by careful analysis of the financial, social, and economic factors surrounding the various supply alternatives. This includes 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 that energy investments make to economic and social progress depends on how the energy is used.

The relationship between per capita energy consumption and per capita GNP has been widely discussed. Since the 1973 oil crisis, however, the claims that the two are inextricably related and that developing countries should follow the industralized countries' path to development have been exposed as untenable. A recent paper on this topic states that "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." (16)

State-of-the-art development theory encourages a different path: decentralized production centers that presumably require less energy for transportation and distribution of goods and services. It is hoped that the decentralization of the productive components of a nation's economy can achieve higher living standards without the high per capita energy consumption levels characteristic of developed countries. The development of remote small-scale energy systems such as mini-hydropower permits an energy supply strategy favorable to a decentralized approach to economic development.

Several practical problems accompany the decentralized approach. The world of rural subsistence farming and village lifestyles reveals the nature of energy demand, productive opportunities in rural areas, and the appropriate role of mini-hydropower. However, experience has shown that abstract energy supply and demand considerations 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." (9) These demands also affect—and are affected by—techological design choices, income distribution and ownership patterns, environmental considerations, and institutional arrangements (4,9).

In all aspects of small hydro technology, from hardware to management, there is a distinction between village-implemented and -operated schemes and those developed by public power authorities as part of a national energy plan. The contrasts between the two approaches derive from the development goals of the project. Nationwide small hydro programs usually are designed to reduce oil imports, either through grid interconnection or replacement of existing diesels. In some cases, these programs are connected with ongoing or planned rural electrification programs. Local village-implemented or private mini-hydro schemes, on the other hand, are designed to provide electric service to previously unelectrified areas, or to provide a captive hydro application, often strictly for mechanical power generation. End use thus depends on end objective.

In the broadest sense, productive uses of energy increase or enhance production in agricultural, industrial, commercial, and residential activities, although the definition seems to vary with the context. One publication explores the contrast between direct and indirect productive uses and the narrow implications of defining productive uses strictly as those that generate cash (3). It is generally felt that these uses should be emphasized in programs to provide commercial energy to rural areas of developing countries, such as rural electrification programs. Productive uses are both income-earning for the end user and financially attractive for the energy supplier, because they usually boost load factors. These uses are also considered to be the most important linkage between energy supply investments and rural development.

Whether or not productive uses represent the most appropriate application of small hydropower depends on the overall development objectives of the project and the area. Because the potential for productive application of the energy often determines a scheme's viability, it should be evaluated at the prefeasibility stage of project development. Programs and policies that enable and encourage productive uses in rural areas also are important energy planning considerations.

In the final analysis, hydropower may simply be 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, including cost, maintenance, operation, reliability, supply, and foreign exchange requirements. But these advantages rely on the ability of the end user to use the plant to its fullest potential.

The underlying question of linkages between energy supply and development must still be addressed. Here, experience gained with rural electrification is particularly relevant. The specter of low-load factors on costly systems compels serious consideration of these investments and exactly how they relate to economic development. This, in turn, requires an analysis of the complementary programs needed to encourage productive use of energy. These complementary programs must 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. Several additional constraints, such as lack of technical knowledge and unavailability of equipment and supplies, are site-specific. A new study (6) of factors affecting levels of productive use 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.

Small hydro represents a large capital investment. It cannot be viewed alone, but must be contemplated as part of a comprehensive development program.

ENERGY DEMAND IN RURAL AREAS

Demand for energy is linked to activities that require energy. In rural areas, these activities can be classified as agricultural production, agricultural processing, small- and medium-scale industry, commercial, and residential. Three forms of energy are used in each category of activity: heat, work, and light.

The quality of the energy 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 lower 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 (14).

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, because the cost of the conventional devices and their overall inefficiency make it inadvisable to use them to meet these lower-level energy requirements. Other, less costly, fuels and means can usually be found. This is especially true for thermal-based steam generation, because the maximum theoretical efficiency for electricity production is limited by the Law of Carnot and in practical terms rarely exceeds 35%-40%. These same arguments apply to diesel cycles, whose efficiencies run at roughly 50%-60%. (Modern power systems operate under complex versions of the Rankine Cycle, whose basic efficiency is lower than for the Carnot.) (18)

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.

The fuel consumption patterns of traditional rural societies vary highly by country (9), and data on quantities consumed and for what purpose are nonexistent for most areas. Nonetheless, one can state with certainty that biomass fuels, especially wood, are the major source of energy for rural households. Furthermore, it is clear that energy is needed predominantly for cooking, and that firewood often supplies more than 80% of energy requirements for rural cooking. Lighting requirements are met by kerosene, candles, and electricity. Motive power (stationary or moving) is often supplied from animal traction, diesel or gasoline engines, and electricity. By most measurements, energy consumption per capita in rural areas is at or below subsistence levels. One report (9) 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."

Productive use

Discussions of the productive use of energy, specifically electricity, have become commonplace in the literature on rural energy development and rural electrification (8,9,19). One study in Indonesia (6) defines "Productive use. . . very narrowly to include only that use which altered business hours or production techniques." Another study (3) classifies productive uses as "direct" (machines or processes involved in production) and "indirect" (uses that extend business hours or improve operations). The broadest definition of "productive use" would be any use of energy to enhance or increase production in economic activities.

It is generally felt that for a modern form of energy (such as electricity) to contribute to rural development, it must be put to productive use. This belief has many underlying assumptions, such as demand for increased production, market access, and energy cost, which are beyond the scope of this paper. Nonetheless, investment in costly, capital-intensive energy supply

92

TABLE 1. Technical Characteristics of Agricultural Processing Machinery in India[a] as of 1963 (10)

Process or operation	Equipment	Motor rating (hp)	Output (lbs/hr)	Power consumption (kWh/100 lbs)[b]
Oil pressing and 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		0.25-1.0
Sugar cane processing	Crusher refining pan	3-15		0.50-3.0

[a] Madras, Uttar Pradesh, and West Bengal.

[b] See Table 2 for ranges of typical power requirements for several rural industries in Colombia.

schemes in rural areas, meant to be used solely for domestic lighting, would represent a misallocation of scarce resources.

Productive use of electricity can contribute to the user's income, thereby improving the user's ability to pay. Productive uses often help improve system capacity, which in turn lowers unit costs; if these savings are passed on to consumers, the power becomes more affordable for everyone.

Ultimately, the potential productive uses of energy and their importance must be analyzed on a project-by-project basis, but their financial and economic significance for small hydro and rural electrification cannot be overlooked.

Quantifying commercial energy requirements for productive uses in rural areas of developing countries would be a difficult task. 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 these also are traded on the market (22). Still, one can hardly imagine a modern economy without a mechanical agricultural base, including the availability of electricity and motive power in rural areas (see Tables 1 and 2). Although Table 1 is site-specific, the load characteristics and consumption figures should approximate those for similar equipment in other parts of the world.

TABLE 2. Typical Power Requirements for Rural Industries in Colombia (14)

Type of agro-industry	Range of power requirements (kW)
Sawmill	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

Replacement of fossil fuel consumption is often a major objective of a small hydro program. Since the 1930s, 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. Providing power to these activities from a small hydro plant can bring savings to the economy as well as improve the quality of service. These energy systems often represent the major potential for productive application of hydropower. For example, conversion of scattered diesel installations to small hydropower is the major focus of Malaysia's small hydro program.

ROLE OF SMALL-SCALE HYDRO SYSTEMS IN MEETING RURAL ENERGY NEEDS

Relationship to overall development objectives

The appropriate role of small 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, it is necessary to set policies for energy planning and for selection of energy-related projects to be funded.

The number of potential hydropower sites is finite, and the expected power and energy output, as well as the proximity to the grid and demand center, largely determine the appropriate approach to site development (and, consequently, the end use). The purposes of hydro projects in the 0-1,000 kW range fall into four categories:

- Low power output designed to meet basic human needs (Pakistan, Papua New Guinea) (4),
- Private development for a specific application (examples can be found worldwide),
- Decentralized electrification, including replacement of existing diesels (Malaysia), and
- Grid interconnection (the Philippines).

The purpose for site development must be determined first; then specific end uses for the power can be assessed.

Small hydro output characteristics

Output usually is highly seasonal, depending on the availability of water—except where large storage is used, or where small hydro plants are designed at the 90% exceedence level. The term "90% exceedence" means that the optimum turbine design flow is available at least 90% of the time, based on the flow duration curve. Economic implications aside, this is rarely a major concern on grid-connected sites. Occasionally, however, seasonal and daily fluctuations in power availability must be closely matched to energy needs.

The quality of the energy output of a small-scale hydro plant depends on the level of sophistication required. Waterpower at the point of entry to the turbine is kinetic or pressure energy. That energy rotates a shaft, which in turn either drives a generator to produce electricity or is directly coupled to some machine (5). 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 waterpower, often to spur industrialization. In Nepal, crossflow turbines are used for rice hulling, milling, and polishing (15,24). The Appropriate Technology Development Organization in Pakistan has designed and installed some 20 sites with capacities up to 15 kW for either direct mechanical or electrical use or for hybrid applications (12).

Coupled directly or through a speed increaser, an electric generator greatly enhances the versatility of waterpower. Generators can be direct current (DC) or alternating current (AC). DC schemes are simpler and less costly because they do not require speed regulation, but practical application of DC power is usually restricted to low power requirements near the site. DC has two advantages: 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, however, are not as commonplace as comparable AC devices. AC electric energy is the most versatile and efficient form of energy known. The potential applications of electric energy in agriculture, industry, commerce, and the home are vast; AC permits the easy transformation, transmission, and distribution of this energy. Both alternating and direct current can be used for lighting.

Heat can be produced from waterpower mechanically or electrically. Mechanical systems involve heat transfer through viscous dissipation in fluids (air and water are the most practical fluids). A prototype mechanical "heatgenerator" has been developed in Nepal in conjunction with work performed by the United Nations (15). This system heats air to 110 °C and is designed for direct coupling of water turbines. The All American Engineering Co. (Wilmington, Delaware) manufactures a commercially available unit for heating water under the trademark "Water Twister" (17).

Like frictional losses in mechanical systems, resistance losses in an electrical circuit generate heat. This is the well-known I^2R formula (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 power generated in excess of load requirements to an electric resistance ballast. This process dissipates excess energy as heat. To date, little attention has been paid to the possibility of using that heat productively, for example, to dry foods.

Small hydro plants can produce a full range of output possibilities from mechanical power for motive force or heat to electrical power for motive force, heat, or light. They can operate in isolation, or can be grid-connected. The available head, quantity and duration of flow, and overall efficiency of the scheme determine the availability of power and energy.

Scale of system vs. array of uses

Direct mechanical power must be used at the hydro site, and for practical reasons is appropriate only for the lower end of the power range (less than 50 kW). Hybrid mechanical/electrical schemes add versatility to the output, but again are appropriate only for smaller projects. Although direct current simplifies speed control, it cannot be transmitted economically over long distances without sophisticated technologies. Furthermore, DC machinery is far less common than its AC counterparts. Although AC generators can cover the entire range of power outputs, 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's capacity must be sufficient to meet this instantaneous demand. Also, severe instability can result if a single motor has a rating with respect to other loads of one-third or more of the system's capacity (11). Because reliability of power is crucial to productive end use, these considerations assume special importance (see Table 3).

Special applications

The difficulty of finding good uses for the output often severely limits the inherent versatility of hydropower. The best sites are frequently in poor and remote areas where economic activity is low. Thus, even though costs for site development in these areas might seem attractive, demand for such a high-quality energy source might be so low that it nullifies investment benefits. Overcoming this problem strikes at the heart of rural development itself. Under certain circumstances, a handful of potential applications of hydropower could solve the problem of finding appropriate uses at otherwise good sites. 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 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. Firewood for cooking and other heating requirements is only part of the problem, but perhaps a manageable part.

Firewood is the major fuel used in rural areas for cooking. A more modest amount of firewood is used in some areas for drying, space heating, water heating, and other low- and medium-temperature applications. Two major obstacles hamper the substitution of conventional electrical resistance heating elements for firewood in these activities: the cost of electric stoves and heaters,

TABLE 3. Type of End Use at Various Ranges of Power Output

Range	Mechanical	Mech/Elec hybrid	DC electricity	AC electricity
0-50 kW	Two or three directly connected machines (rice huller and polisher)	Daytime repair shop and mill Nighttime village electrification for lighting	Central battery charging Local electrification of immediate vicinity for lighting and small appliances	Small array of uses, including local electrification
50-100 kW	Several large machines Entire factory	Rare	Electrification in vicinity, conceivably for small industry	Local electrification including small industrial and agricultural use Possibly supplies 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
More than 500 kW	Nonexistent to author's knowledge	Nonexistent to author's knowledge	Rare	Supplies grid

and the cost of electricity. Additionally, for isolated hydroelectric schemes, the peak demand requirements of conventional devices would result in excess capacity and perhaps expensive storage (23). Because the rural subsistence farmer rarely pays for firewood, the task of convincing him to replace firewood with a commercial fuel has limited prospects for success.

An alternative to a conventional electric heating device is a heat storage system. These systems store energy as it is produced, thus leveling load requirements and improving load factors. Before the days of cheap energy, cooking stoves that use this method were in use in conjunction with decentralized hydro schemes in several countries.

In Norway, these cookers were commonplace at one time, but marketing was discontinued in the early 1950s (23). Present circumstances demand consideration of the suitability of sensible heat storage cookers, especially in areas with deforestation problems (21). These cookers have additional benefits where tariffs are based on installed capacity (controlled by current limiters) rather than kWh consumption.

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, indigenous materials such as clay have also been used successfully for heat storage. With an energy input of 250 W the storage cooker shown in Fig. 1 produces heat required to cook the daily meal of an average Nepalese family. This was accomplished at considerably higher efficiencies than those found with conventional wood and gas stoves (21% vs. 3%-6%). A field test can determine the possible disadvantage of not being able to observe the food while it cooks (23).

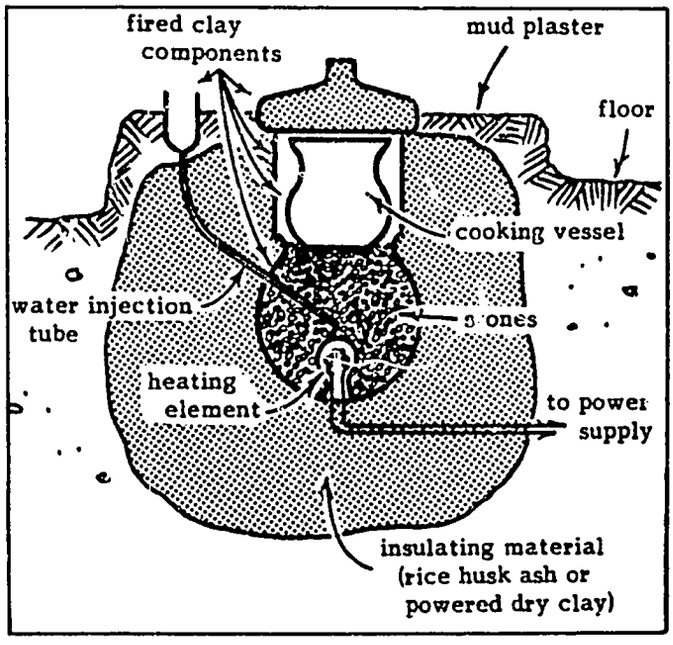

Fig. 1. Schematic of the heat storage cooker based on research undertaken at Cornell University.

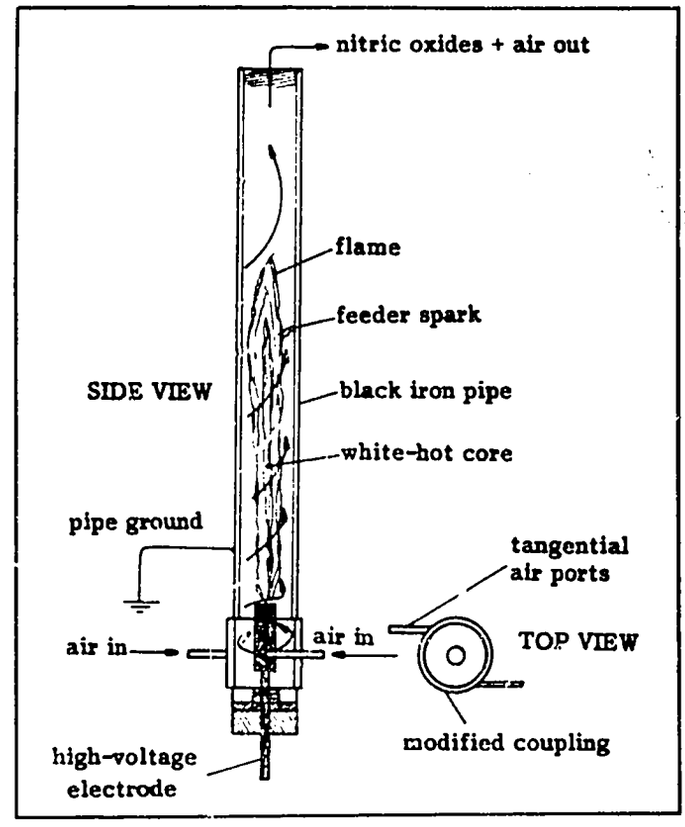

Fig. 2. Schematic of a reaction cell of a nitrogen fertilizer generator (13).

Chemical fertilizers can drastically improve agricultural yields; however, the centralized nature of fertilizer production leads to high transportation costs in reaching remote consumers. The Haber-Bosch process is the most economical way of producing high-quality fertilizers on a large scale. This process is highly energy-intensive, using natural gas or liquid hydrocarbons to produce ammonia. 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 less costly. In fact, the electric arc method was virtually abandoned during the early part of this century.

In a discussion of the special applications of hydropower in remote rural areas, the electric arc discharge method of producing nitrogen fertilizer 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.

An experimental 3 kW unit requiring only readily available components and low-level technology has been successfully tested in the United States (see Fig. 2). The output is sufficient to fertilize 5-20 hectares. This system can be used effectively as a base load and load leveling technique (13,20). Firewood is used not only for cooking, but for other agricultural processing activities

96

as well. The mechanical "heatgenerator" was developed for isolated villages with deforestation problems (15). It heats air to 100 °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. A prototype developed in Nepal with a 25 kW drive cost $800 in January 1981.

Miscellaneous applications of the energy from small-scale hydro schemes can be appropriate. Examples include battery charging and directly coupled compressors for communal refrigeration facilities.

ENCOURAGING PRODUCTIVE USES OF ELECTRICITY IN RURAL AREAS

Introducing electricity to depressed rural areas is expensive. Nonetheless, electricity is an important part of rural development. Numerous factors constrain the productive use of electric energy as a tool for integrated rural development:

- Electricity is often considered a social good, and government electrification programs in rural areas often emphasize 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, because they face supply problems, have already made an investment, and are not familiar with electricity. Also, ancillary electric machinery rarely is readily available.
- Lack of understanding of electricity and its proper and productive application is widespread.

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 by 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 the 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 power 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 and educational programs, integrated into other development efforts, are vital to the success of major electrification programs. Evaluations of rural electrification programs in the Philippines, Bolivia, and Costa Rica support this assertion. Although these programs do not provide a panacea, their importance cannot be discounted.

REFERENCES

1. Agency for International Development. "Bolivia Rural Electrification." AID Project Impact Evaluation Report No. 16. Washington, DC, December 1980.
2. Agency for International Development. "The Philippines: Rural Electrification." AID Project Impact Evaluation Report No. 15. Washington, DC, December 1980.
3. Amaru IV Cooperative. Guide to Evaluation for Small Hydro Units in the Field and Lessons from the Literature. Washington, DC: National Rural Electric Cooperative Association, 1981.
4. Ashworth JH, and Neuendorffer J. Matching Renewable Systems to Village-Level Energy Needs. Prepared for the U.S. Department of Energy under Contract No. E6-77-C-01-4042. Golden, CO: Solar Energy Research Institute, 1980.
5. Boyle D. "Productive End Use of Mini-Hydropower for Rural Development." Proceedings of NRECA Workshop on Small Hydropower for Asian Rural Development, Bangkok, Thailand, June 1981. Bangkok, Thailand: National Rural Electric Cooperative Association, 1983.
6. Brodman J. "Levels of Electricity Use." Draft. 1982.
7. C. CH. LG. Ltd. Viabilidad de Las Micro Centrales en Colombia. Bogotá: Fundación Mariano Ospina Perex, 1979, p. 24.
8. Cecelski E. "The Role of Rural Electrification in Development." Working Paper for Discussion. Washington, DC: Resources for the Future, July 1979.
9. Cecelski E, et al. Household Energy Use and the Poor in the Third World. Washington, DC: Resources for the Future, 1979.
10. General Electric Co. "Analysis of Demand for Electric Power in Rural Communities." Prepared for USAID under Contract AID REPAS-1, March 1963.
11. General Electric Co. "Small-Scale Power Supplies for Rural Communities in Developing Countries." USAID Report No. TA/OST-AN-63-3-1. March 1983.
12. Inversin A. "A Case Study: Micro-Hydropower Schemes in Pakistan." Washington, DC: National Rural Electric Cooperative Association, 1981.

13. Kettering Research Laboratory. "A Nitrogen Fertilizer Production System for Farm Use." Dayton, OH: Charles F. Kettering Foundation, 1978.

14. Meier U. Local Experience with Micro-Hydro Technology. SKAT publication Vol. 1, No. 11. St. Gall, Switzerland: Swiss Center for Appropriate Technology, 1981.

15. Metzler R. "The Heatgenerator." Butwal, Nepal: Butwal Engineering Works Pvt. Ltd., United Mission to Nepal, January 1981.

16. Reddy AKN. "Energy Options for the Third World." Draft. University of California, 1978.

17. Schroeder MP, and Tu PCK. "An Assessment of SWECS/Mechancial Heating Systems." Prepared by Rocky Flats Plant Wind Systems Program under contract with the U.S. Department of Energy, July 1981.

18. Sonntag and Van Wylen. Fundamentals of Classical Thermodynamics. John Wiley & Sons, Inc., 1976.

19. Tendler J. "Rural Electrification: Linkages and Justification." AID Program Evaluation Discussion Paper No. 3. April 1979.

20. Treharne W., et al. "Fertilizer Production by Water Power." University of Nevada Field Day Program, 1980.

21. Whitby G. "Heat Storage Cookers. The Norwegian Experience and Indications for Implementations in Developing Countries." Draft. Rugby, England: September 1981.

22. World Bank. "Energy in the Developing Countries." Washington, DC: World Bank, August 1980.

23. Yoder R. "Thesis in Partial Fulfillment of Requirements for Master of Science Degree." Ithaca, NY: Cornell University, January 1981.

24. Yoder R, et al. "The United Mission to Nepal's Involvement in Small-Scale Water Power Development for Milling." Draft. Ithaca, NY: Cornell University, 1980.

Cost Implications of Small Hydropower Systems

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INTRODUCTION

Unlike thermal-based power generation, hydropower systems are essentially inflation-proof, once built, because they carry no energy (fuel) cost. Moreover, they usually incur none of the environmental costs associated with thermal systems. The advantages of this technological choice are enhanced because, apart from these cost advantages, hydropower can provide secondary benefits, such as irrigation, public water supply, and flood control, that are not possible with other energy technologies.

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 using more expensive and complicated technological solutions, including large-scale hydropower development. Building large storage hydro facilities is enormously complex. Also, the long lead time required for planning and construction, including longer procurement schedules, can reach 10-15 years, bearing with it a considerable cost to the project. Small-scale hydropower development is also more adaptable to incremental, or staged, development, allowing for earlier payback on the investment.

Other factors favor the development of small hydro systems as an alternative to large central power stations, particularly to provide energy to dispersed rural regions, which consume roughly one-tenth as much energy as urban areas (4). The cost of building transmission facilities over long distances, particularly in mountainous regions, can be very high, ranging from $15,000-$25,000 per km in the United States, and maintenance costs may be considerable. Yet rural energy demand typically is 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, grid extensions do not eliminate the need to generate new power to meet rural loads. Finally, with grid extensions, costs to both human and natural environments are more likely to be significant.

Grid extensions may nevertheless be more economical than small hydro plants 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 must be viewed on a site-by-site and country-by-country basis to identify the least-cost option.

GENERAL COST HISTORY

A general statement on the costs of small hydropower installations cannot be made accurately. Costs will vary from case to case, because labor, equipment, terrain, technical experience, and other criteria are highly variable. It is equally hazardous to attempt to apply the data and experience developed in certain countries directly to other regions of the world where the same conditions and assumptions may not apply. Indeed, many of the published data are based on cost indices that are drawn from large hydrosystem development which has been scaled down to smaller sizes. This practice leads to distortions that can make small hydropower appear overly costly. Costing achieved by this method can prejudice the decision-maker against the small hydro option, and, more important, indicate a development approach that may be inappropriate—and needlessly costly.

It is therefore valuable to review some cost data that have been drawn from experience in developing countries where small hydro development has taken place in recent years (see Table 1). Again, figures should be read with caution. The numbers have been taken from published and unpublished sources without site evaluation by the author; therefore, they may not reflect the true costs of the projects. Moreover (and this applies to virtually any source), these typically reflect only direct costs associated with the construction of small hydro plants. They do not take into account indirect or "intangible" costs that inevitably occur in the development process:

- Costs in the form of hidden subsidies;
- "Experience-building" costs that accrue over many years of a program; or
- Socio-cultural costs that may derive from site development. These are real costs, but are difficult to quantify and are therefore overlooked.

To identify an acceptable cost range for small hydro plants—the World Bank's target of $2,000-$3,000 per kW

TABLE 1. Survey of Installation Costs for Small Hydro Plants in Developing Countries

Country	Capacity (kW)	Head (m)	Cost per kW[a]	Equipment as % of cost	Comments
Thailand	800	40	$2,850	15%	Concrete construction for civil works
Ecuador	400	40	2,200	36%	Lined canal; imported equipment
Ecuador	400	19	2,700	30%	Lined canal; direct intake; imported equipment
Nepal[b]	200	58	900	36%	Partly lined canal; loose-packed rock dam
Nepal	120	14	900	21%	Masonry-lined headrace
Indonesia	120	15	1,300	58%	No headrace; local turbine
Thailand	100	79	950	21%	Concrete construction for civil works
Philippines[b]	100	27	750	38%	Local construction materials and turbine
Indonesia	90	19	1,050	54%	Concrete-lined headrace
Nepal	80	16	1,650	23%	Local materials and turbines
Nepal	80	34	1,050	31%	Local materials and turbines
Nepal	25	22	650	28%	Existing irrigation works
Indonesia[b]	15	22	600	30%	No headrace or governor, used alternator
Thailand	15	10	2,350	41%	Earth dam and headrace
Thailand	10	6	1,500	27%	Lined canal; local turbine
Pakistan[b]	10	c	270	61%	Local materials and equipment
Nepal	9.5	9	600	46%	Local materials and equipment, except penstock
Pakistan[b]	7.5	c	320	60%	Local materials and equipment

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

Sources: Thailand (NEA); Philippines (NEA); Indonesia (PLN); Nepal (BYS); Pakistan (ATDC); Ecuador (INECEL).

installed (11) notwithstanding—it is inadvisable to use numbers that do not consider several important factors:

- Energy demand characteristics (in quantity and quality terms) of the region served,
- Fuel transportation costs to the area,
- Distance from the existing grid, and
- Physical characteristics of the site itself.

Clearly, the acceptable cost range for a small hydro plant will depend on the relative costs of alternative energy options. The most popular alternative in the developing countries to date is the diesel generator. Fig. 1 gives an idea of comparable generating costs between a 100 kW hydropower plant and a similarly sized diesel plant, where the assumptions used for fuel cost, capital cost, and useful life period are very favorable, practically speaking, compared to the diesel option. Note that as the capacity factor increases, the hydro becomes increasingly competitive, because fuel cost is not a factor in the hydro alternative.

100

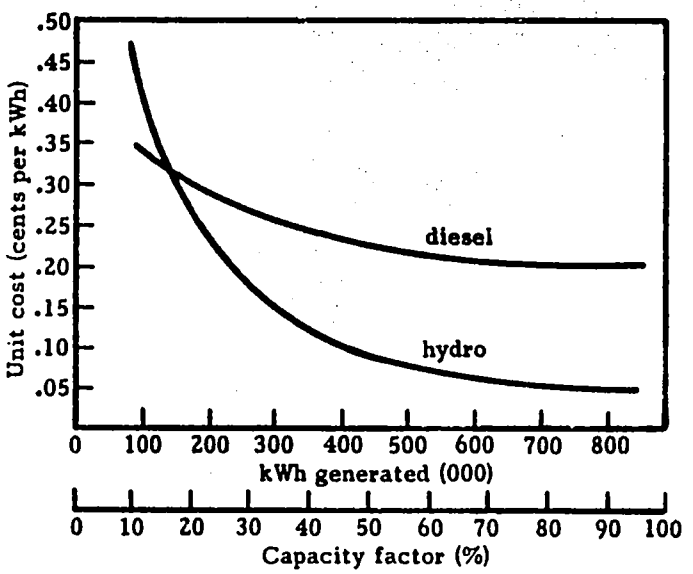

Fig. 1. Effect of capacity factor on unit cost of production (100 kW plant). These statistics assume that the hydro capital cost is $3,000 per kW; diesel capital cost is $450 per kW; annual O & M cost is 1.5% of capital cost for hydro, 4.5% for diesel; fuel cost for diesel is 18 cents per kWh; useful life is 30 years for hydro, 20 years for diesel; interest rate is 12%.

UNDERLYING ISSUES

Matching technology to need

As mentioned, costs taken out of context can be misleading, because the data are frequently incomplete or not quantifiable, and market values differ greatly from country to country and sometimes from region to region of the same country. Analyses based on cost alone—or even the partial cost of an installation, such as the equipment and civil works—cannot accurately specify the value of a project, because the economy of a project is determined by many more variables. The economic attractiveness of a project is a function of both the cost and the end use of the energy produced. Although it is appropriate to consider factors that can reduce the input variables (costs), it may be even more important to try to make maximum use of the energy; in other words, to maintain a high capacity factor. For this reason load planning is critical to the ultimate cost of the energy produced. Capacity utilization will depend on how well the technology is matched to the consumer's energy needs in terms of energy efficiency and the plant's capacity, efforts to promote energy use, and on the tariff policy.

First, the energy form must be appropriate. In the rural context, complex energy solutions for simple needs imply higher costs to the consumer. A corollary to the matter of appropriateness is the matter of timing. Because 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, the storage requirements that may be necessary can add enormously to the construction costs.

Second, capacity considerations are important. Plant capacity utilization should reach at least 15% for hydro to compete successfully with thermal energy systems (8). Domestic loads typically are very low in most of these regions. It is therefore important to emphasize daytime industrial uses, or "productive" end uses, especially where more expensive thermal generation currently serves existing demand, or where hydropower can serve new industrial demand that cannot be achieved economically by traditional energy means. When an industrial load has been established, domestic service can be provided at more feasible rates. Studies show that when modern power sources are introduced to an area and take hold in industrial uses, power demand from the general sector increases rapidly (3). Tables 2 and 3 demonstrate the relationship between the load factor and the costs of producing the energy. Note that the cost of the delivered energy drops as the load factor increases. Table 2 indicates that higher load factors allow a larger margin for capital costs at a standard tariff rate for the project to break even financially.

TABLE 2. Comparison of Load Factor to Capital Cost for Typical 50 kW Plant in Uttar Pradesh State, India[a] (5)

Load factor (%)	Capital cost per 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

[a] Assumes standard Uttar Pradesh State tariff rate and full capital recovery.

To help keep costs in line with the ability of the users to pay, the initial development of a new, isolated energy source may be scaled to the rate of demand in order to keep unit costs sufficiently low to the consumer to permit growth of the demand. This can be achieved by system designs that permit staged development and by tariff policies that induce consumption.

MAJOR COST-INFLUENCING FACTORS

Small hydropower costs can be affected by numerous factors pertaining to the site, the scale of development, the purpose of the project, and the technological approach used.

TABLE 3. Comparison of Load Factors to Generating Cost for Five 200 kW Projects in Uttar Pradesh State, India[a] (5)

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

[a] Assumes full depreciation over 6 years.

Site characteristics

Site selection is critically important to the project's ultimate cost. The chief aspects of site selection that will affect cost are:

- The site's relation to the load center;
- The availability of head and flow, particularly the former;
- The river slope, hence the distance over which the head is concentrated; and
- The accessibility of the site.

Sites are often selected on the basis of their technological merit. Equally important, if not more so, is whether the power can serve an adequate load near the plant. Thus, the foremost concern is to establish that the plant is located in a place where the energy can be used. The capacity factors may be very low if the selected site does not have a sufficient load center nearby (unless the site can be grid-connected).

Site selection is important also in terms of the type of scheme to be developed—low-head or high-head, and run-of-the-river type or storage (impoundment) type, which depends on the availability of natural head and flow.

Given the choice between sites appropriate for run-of-the-river schemes and those requiring the construction of new dams, it is generally more cost-effective to give priority to the former. The costs of dam construction and maintenance are high, particularly for low-capacity plants. Moreover, they can:

- Entail considerable environmental and health problems;
- Cause enormous damage in the case of failure during peak flows;
- Add considerably to the construction period;
- Require the relocation of buildings or entire communities upriver; and
- Interfere with the use of the river for navigation and fish migration.

Also, dams are susceptible to silting problems, which can complicate the design and upkeep of the intake structure, and can eventually render the dam worthless if it is used to impound 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. Diversion weirs are easier to construct and maintain in remote rural settings, and need not be of permanent construction; they can be formed by placing across the stream rocks and boulders that can be replaced easily after each peak-flow season. This would be the simplest design for a weir for a very small scheme, but permanent structures for larger sites can also be built at substantially lower costs than an impoundment structure.

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. Generally, the degree of head available to a small hydro site is the single most important determinant of cost; higher heads reduce the amount of water needed to create a given amount of energy, saving costs in the turbo-generating equipment and potentially in the civil works as well, depending on the slope of the river and the terrain. Since many 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 such cases, consideration should be given to reducing the length, hence the cost, of the penstock by covering as much of the distance as possible between the intake and the turbine by means of a gradually sloping open canal, to concentrate the head over a short distance (see Inversin, Small Hydropower Schemes, A Slide Presentation).

Low-head sites tend to be more expensive because of the large size of the machinery—which can account for up to 65% of the total cost (2)—and because dam structures are often required. Total costs for low-head plants (20 m or less) can be as much as two to three times as great as schemes with higher heads (7). Fig. 2 presents average proportional costs for plants with maximum and minimum civil features. For very small micro-hydro 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 that micro-hydro plants using local labor and materials appear to offer the best economies.

102

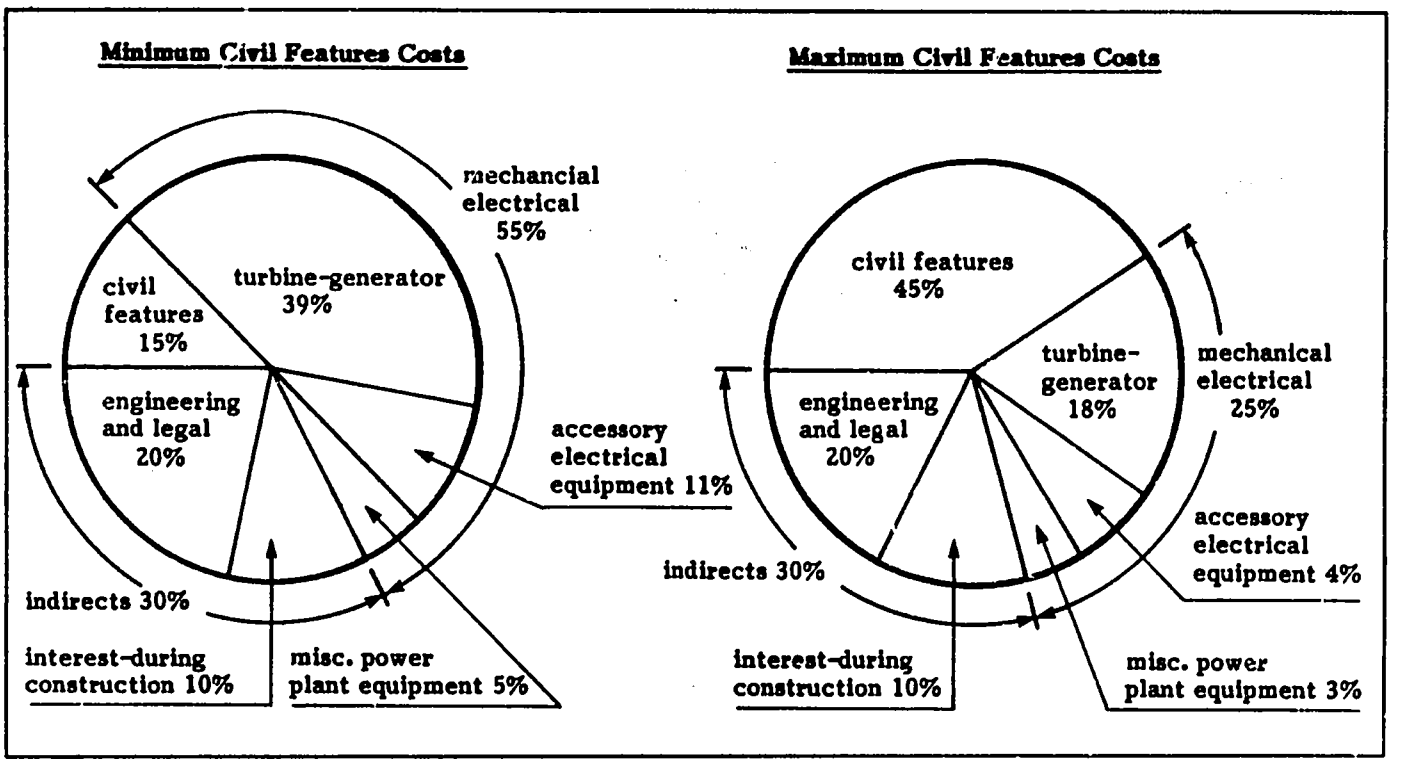

Fig. 2. Approximate proportion of project capital costs for conventional development (9).

Flow considerations are also important to the unit cost of energy supplied by a small hydro plant where flows are intermittent and varied, because the resulting loss of operating time raises the average unit cost of production. For this reason, the quality of hydrologic calculations can be critical to the ultimate cost of the plant by ensuring that the plant is properly sized.

Finally, the accessibility of the site may be important, especially for larger schemes where equipment and materials may be large or heavy, requiring roads. Frequently, the best high-head sites in tropical regions are in areas where the terrain is inhospitable or the forest cover dense. These sites may be best for very small schemes where equipment and materials do not require motorized transport, because the cost of building roads can be extremely high (about $50,000 per km in the United States) and population densities are likely to be low.

Economy-of-scale factors

Size of the plant

The record is not clear on the question of economies of scale for small hydropower. In general, the unit installed cost increases as the capacity of the plant decreases. Certain costs that are relatively fixed, such as the feasibility analysis, the engineering design costs, and training, tend to make lower-capacity plants less competitive with larger plants. The economies-of-scale rule applies more readily to low-head schemes requiring larger, more sophisticated equipment and impoundment structures.

This rule generally holds true where design and construction techniques for small projects derive from conventional engineering practices developed for large hydropower. However, significant economies can be achieved if an unconventional approach is taken, one that is based on smaller plants that emphasizes simpler designs and local expertise and materials. Economies of scale appear to operate in reverse when plants developed along these lines are taken into account, where unit capital costs increase with the size of the plant.

Programmatic considerations

Installation costs may also be a function of the size of the program, because certain costs may be spread among several projects. It may be particularly advantageous to establish 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 undertaken, thought should be given to standardizing the techniques used, the general design, and the equipment. Because conditions from site to site are likely to differ, 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 head and flow characteristics and by standardizing equipment packages to operate within those conditions. Standardization of the turbo-generating equipment not only reduces the design and fabrication costs, but shortens delivery time. It also permits a spare parts

inventory to be shared among various sites, minimizing the number of spare parts each site must keep in stock. Project costs can decrease 10%-15% where standardization of equipment is possible (2).

It should be noted that overstandardization of equipment can reduce operational efficiencies of plants. It is therefore valuable to use turbines that can operate under a wide range of head and flow conditions, such as crossflow types and converted centrifugal pumps used in multiple-unit configurations.

Timing of development

It is possible to improve economies of scale by approaching site development on an incremental basis, rather than developing the full energy potential of the site at the outset. Because load factors and overall capacity utilization are low during the initial years of operation, excess, unused capacity results in high unit costs during this period. For incremental development, the headworks and penstock should be designed to capture the full amount of head feasible, so that larger flows could be accommodated for future capacity growth—assuming that the water supply is adequate. The penstock should be large enough to withstand larger volume and pressure than are initially required to accommodate larger or additional turbo-generating units at some future point, as demand for power increases. The design should make allowances in the excavation depth and floor space of the powerhouse for these future additions. This approach avoids making the power cost to consumers excessively high initially, which could retard the demand growth process. Staged development also permits experimentation with design innovations without laying too much money on the line.

Alternatively, a small diesel generator could serve initial demand, postponing construction of the hydropower plant until a later date. The diesel could then be relocated to another village, to begin the demand-building process at the new site (5).

Decisions about plant size and the timing of additional development should, of course, be predicated on the socio-economic feasibility study. However, because load growth is often difficult to predict in isolated regions of developing countries, the incremental design approach may be a useful way of "testing" demand projections.

Use criteria

Multiple uses

For low-head sites, priority should be given to projects where power generation can be one component of a multipurpose 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 multipurpose water projects that include power generation can yield better economies than a project where the only benefit is energy. Although in absolute terms costs would be greater for multipurpose projects, their unit energy costs would be significantly lower, because they can be shared among the various purposes, including municipal water supply, irrigation, flood control, fish breeding, navigation, and recreational uses. Sites 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 multipurpose projects, because the irrigation works can reduce the cost of the power, and the power can reduce the cost of distributing the water. Note, however, that timing and design circumstances can lead to competitive uses of the water, which can indirectly raise the cost of the other water use. An example is power generation when the water is diverted to irrigation.

Project purpose

Use criteria can also be evaluated in terms of the purpose of the project: whether it is for fuel substitution or for rural development, two purposes that are not necessarily mutually exclusive. Even for small isolated plants, where fuel substitution is minimal from a national perspective, 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 be economical only where the cost of fuel is particularly high due to transportation costs over long distances. However, when the primary objective of the project is to reduce the national trade deficit, the technological approach—issues of plant capacity and the size of the program—become critical.

The greatest economies are achieved under conditions that permit the development of very small plants based on unconventional technology (see Table 1). Yet from a national perspective, import substitution is limited by the low aggregate capacity of even a large number of such sites. In the Ivory Coast, more than 1 million MWh of thermally powered electricity is now produced each year. If 50 plants of 25 kW were installed throughout the countryside, assuming a relatively high capacity factor of 50%, the annual potential of fuel substitution would be only 5,500 MWh, or only 0.5% of the total currently produced. Only with much larger sites, where cost-effectiveness may not be as great, is this objective better served. From a national perspective, small hydro technology may be cost-effective as an import substitution at present only in an average size range of 1 MW, where economies of scale apply more readily.

Tariff policy considerations

Tariff policies can be an important determinant of the cost per kilowatt-hour of an isolated plant. Because there is no fuel cost associated with hydropower generation, unlike thermal stations, high-capacity use reduces unit costs, whereas it tends to have the opposite effect with fuel-based generation. Hence, the objectives should be twofold: to match the installed capacity to peak demand on an incremental basis (design

function) and to maintain a high load factor (tariff function). In other words, tariff policies should encourage energy consumption and demand growth with hydropower plants, particularly during "off-peak" periods. Therefore, the key element with small hydro plants is to keep installation costs low (operation and maintenance costs are minimal) to allow low unit costs to the consumer, which in turn improves load factors. Even if installation costs are low, however, it may be necessary to provide power below cost for a while 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 "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," (2) and where residents are usually too poor to pay much for such a service.

Experience has shown that it is best to rely on nondomestic, or "productive," uses to achieve economic success with isolated small hydro projects. Where power is generated for industrial uses, plant capacity factors appear to be twice as high as those where electricity is used only for domestic and public lighting (1). On this point, it might be appropriate to charge domestic consumers on the basis of a flat-rate tariff (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.

Development approach

There are two general technological approaches to small hydropower: "conventional" and "unconventional." The conventional approach employs standards established in the construction and management of large hydroelectric powerplants and scales down the designs to smaller sizes. In developing countries, this approach is often associated with programs initiated and managed by central agencies. These projects frequently use imported equipment and predominantly permanent materials, such as reinforced concrete, for the civil structures. In the unconventional approach, the project usually is initiated and managed locally. In these projects, the designs are simpler, and they use locally supplied equipment and design principles based on techniques for irrigation and primitive hydraulic energy that are familiar to villagers.

A key difference between these two approaches is that conventional development emphasizes maximum use of resources—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 also less efficient and less durable construction (7).

These differences reflect a fundamental trade-off between cost and performance. Yet, contrary to conventional thinking, it may not be cost-effective to attempt to squeeze every ounce of efficiency from a plant; the greater costs implied with this approach may not be worth the additional energy conversion it achieves, particularly for smaller isolated plants. (See Table 4 for a general description of the elements typical to each of these approaches.)

The unconventional approach is 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. Nevertheless, it offers cost savings for the following reasons:

- The technology is simpler and can be grasped easily by villagers.
- Greater innovation in design is possible.
- Maintenance is simplified, because the materials are provided locally.
- Community participation, upon which this approach is based, reduces labor, engineering, and management costs and provides greater assurance of long-term success.

The importance of the last point cannot be overemphasized. Self-generated local involvement saves costs by eliminating the need for constant supervision by a remote central agency. It also improves the chances that the project will be designed to serve the local population's needs, because the residents will participate in its design and construction, and the people will be able and willing to pay for the powerplant and keep it running.

COST TRENDS

Taking into account the major cost-influencing factors, particularly those related to the scale of development, the historical cost data available suggest some interesting trends. Fig. 3 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 that emphasize local approaches to development (as in Pakistan and Nepal), compared to the costs of similarly sized plants under the more conventional approach.

Between the categories of conventional and unconventional is a curve showing the costs of plant designs where civil structures are of a conventional nature, but the turbo-generating equipment is not—using standard off-the-shelf centrifugal pumps run in reverse. Note that each curve shows economies of scale where the unit capital costs decline as the size increases, but that taken together, diseconomies of scale occur; the curves show that, as the capacity increases, so do the unit installed costs.

Fig. 4 gives a curve resulting from the cost data for the 18 projects listed in Table 1. This sampling of actual costs tends to confirm the diseconomies trend.

TABLE 4. Conventional and Unconventional Approaches to Small Hydro Development

	Conventional	Unconventional
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-the-river, medium and low head, on small rivers and streams
Technological approach	Conventional hydro; emphasis on efficient imported equipment for resource maximization	Unconventional, 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, large-scale 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 for consumption enhancement

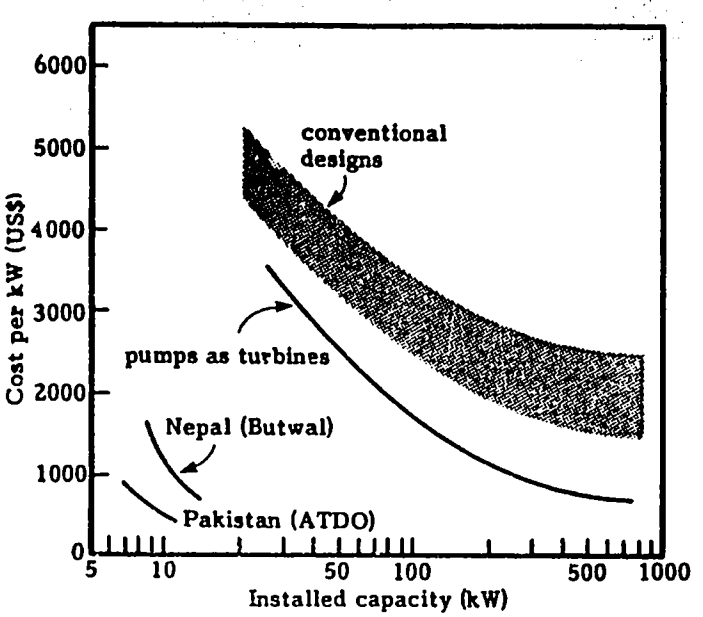

Fig. 3. Cost curves for different approaches to small hydro development.

Sources: Pakistan (ATDO), Nepal (Butwal), New York State Energy Research and Development Authority.

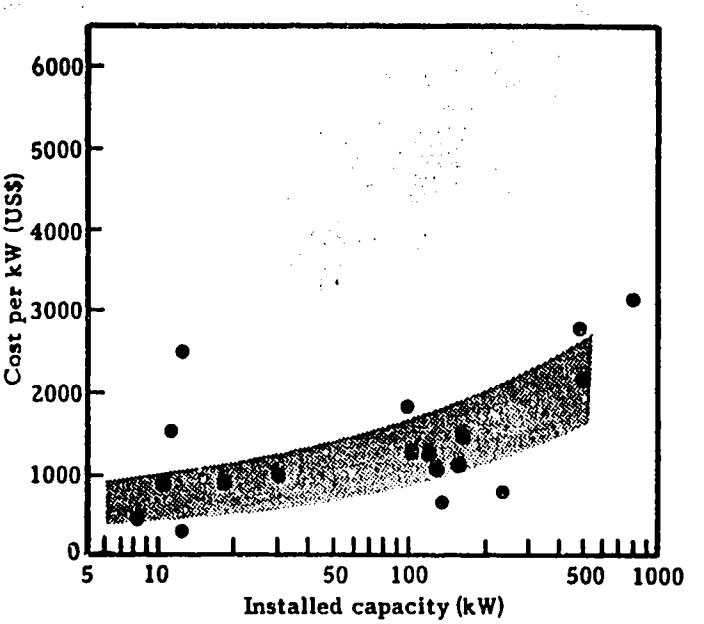

Fig. 4. Cost curve of small hydro plants listed in Table 1.

106

One might conclude from Figs. 3 and 4 that, where hydraulic conditions permit the development of only very low capacity plants (100 kW or less), conventional development approaches are not as cost-effective as unconventional approaches. The data show that, with large-capacity schemes (more than 500 kW), economies are not as great, but the curve tends to flatten out and then move downward.

What is left is the least economical range, between 100-500 kW, where local technologies presently are difficult to apply, but where economies of scale with more conventional approaches tend to auger against the small hydro option. For plants in this range, it may be best to adapt certain aspects of civil works used in local schemes that minimize the use of concrete and steel and substitute standardized pumps for custom-made turbines (as proposed by the New York State Energy Research and Development Authority).

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 factors are considered as a whole. A technically ideal project may result in a misuse of resources if socio-economic factors have not been considered sufficiently:

- 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 in the project from the start—in the design, collection of technical information, construction, and management and maintenance of the system—can help make a small hydropower project cost-effective, in terms of the capital cost and the extension of its useful life.

Experience suggests that small, micro-sized (less than 100 kW) hydropower systems that are developed along the "unconventional" lines may offer 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, foreign engineering standards, and substantial use of expensive materials such as steel and cement for civil works, does not allow as much opportunity for flexibility in design and construction. These systems should be based on:

- Maximum use of local expertise and materials;
- Acceptance of a lower, but acceptable, standard of efficiency; and
- Simple and easily maintained machinery.

There is a fundamental trade-off between cost and operational reliability and efficiency in selection of the development approach. However, plants that are simply constructed 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.

REFERENCES

1. Mohammad Abdullah (ATDO) in a conversation with Paul Clark (NRECA) about experience in Pakistan (NWFP) with micro-hydro projects, 1982.
2. Allis-Chalmers. Standardization of Hydroelectric Generating Units for Low-Head Hydro. York, PA: Allis-Chalmers, 1979.
3. Dickinson H, and Whittington HW. Rural Electricity Supplies. Edinburgh, Scotland: University of Edinburgh School of Engineering Science, 1978.
4. Goldenberg J. "Energy Consumption and Decentralized Solutions," Energy and the Developing Nations. Palo Alto, CA: Electric Power Research Institute, March 1980.
5. Henwood M. "Economics of Mini-Hydropower Development." Proceeding of NRECA Workshop on Small Hydropower for Asian Rural Development, Bangkok, Thailand, June 1981. Washington, DC: National Rural Electric Cooperative Association, 1983.
6. Marshall K. Micro-Hydro in U.P. State, India: Past Experience and Lessons for the Future. Rugby, England: Intermediate Technology Industrial Services, 1980.
7. Meier U. Local Experience with Micro-Hydro Technology. SKAT publication Vol. 1, No. 11. St. Gall, Switzerland: Swiss Center for Appropriate Technology, 1981.
8. NRECA. Small Hydropower for Asian Rural Development. National Rural Electric Cooperative Association, 1983.
9. NRECA. Small Hydroelectric Powerplants. Washingon, DC: National Rural Electric Cooperative Association, 1981.
10. Tudor Engineering Company. Simplified Methodology for Economic Screening of Potential Low-Head, Small-Capacity Hydroelectric Sites. Palo Alto, CA: Electric Power Research Institute, 1981.
11. World Bank. Energy in the Developing Countries. Washington, DC: World Bank, 1980.

Financing Small Decentralized Hydropower

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INTRODUCTION

Money for financing development projects traditionally has been a scarce resource. The availability of funds for development projects, including small decentralized hydropower (SDH), has become even tighter as a result of the recent world economic downturn. Therefore, borrowers for projects such as small hydro dams must be aware of any and all available resources to finance their capital and technical needs.

The need for expertise in the field of financing small hydro dams is particularly acute because the nature of such projects—the high cost per capita, the uncertainty of consumer response in rural areas, etc.—makes funds difficult to obtain. However, the provision of financial resources will be a crucial element in the maximal realization of this important source of renewable energy.

AID SOURCES

Public sector funds

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 are organizations with distinct objectives and lending criteria.

Certain key criteria are common to all donors in the public sector. As a borrower or grant recipient, one should be aware that public sector donors typically consider two factors: the project's priority and its socio-economics.

Priority projects

Donors will finance only projects that are considered priority projects in the country. Donors will request clearly defined development plans showing that the project is indeed a priority. In the context of small hydro dams, donors will hesitate to fund SDH projects, because such an action could be viewed as patchwork assistance in the absence of an overall scheme.

Therefore, before making specific project requests, the government of the borrowing entity should formulate an overall, macro-development plan.

Socio-economics

If the borrower presents the project in the context of a 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. They will compare the economic returns and social benefits of the SDH project to the same returns they would earn from using the money in alternative development projects. There is an opportunity cost of available capital for donors. Even if SDH projects were the government's top priority, donors would hesitate to lend to such projects if they were considered too costly for the desired goals or if the donors believed that there were more appropriate uses for the funds.

Therefore, borrowers should focus a portion of their SDH request on the socio-economics of the project; they should stress the macro-economics of the project, such as its impact on the region's income, employment levels, and secondary industry. Donors do not consider the provision of electricity alone as development; rather, they see the productive uses of this energy as true development. The micro-economics of the project, such as cost estimates, rates of return, cash flow, energy production, source of equipment, local input, and time to completion, are also integral elements in an aid request.

Multilateral sources

Multilateral sources cover a wide variety of organizations, including: United Nations agencies and the World Bank; regional aid organizations such as the European Common Market's Economic Development Fund; nongovernmental organizations (NGOs) such as Oxfam and Catholic Relief Services; and regional development banks such as the African Development Bank (BAD).

Multilateral sources can be tapped for both technical assistance and capital assistance. Both forms of assistance are of importance in the realization of SDH development. The technical assistance could include the financing of feasibility studies, training, and

*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.

technical experts; 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 Programme (UNDP) could finance a feasibility study and, if the results were positive, UNDP could finance training programs for the technicians as well as the provision of technical advisors. Complementing this technical assistance, another U.N. agency specializing in capital assistance, the Capital Development Fund (CDF), could fund the purchase of necessary equipment and the construction of the project.

Those seeking funding for SDH projects should be aware that the institutions providing money have clearly defined mandates on the kind of assistance they can be provide for various projects. Knowing the domain 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 projects, which generally have a low rate of return and cash flows that can ill afford to pay back a nonconcessionary loan. Only when an SDH project has a specific end user that could rapidly reimburse a nonconcessionary loan should other sources be considered. Even then, nonconcessionary sources should be used only as a last resort.

The United Nations and the World Bank. These institutions have specialized divisions and sources of funds for rural projects such as SDHs, and should be approached in the formulative stages of an SDH project. They represent tremendous sources of expertise in the energy and hydroelectric field, as well as excellent sources of financing with desirable concessionary terms.

The United Nations has a representative office in almost every developing country in the world. The appropriate authorities should approach the Resident Coordinator in this office when an SDH project is being considered. The Resident Coordinator can direct the inquiry to one or several agencies within the United Nations that would be concerned with this type of project. Because SDH projects can have a multitude of end uses, this type of project would fall into the domain of several U.N. agencies that could provide the necessary capital and/or technical assistance.

The World Bank's Representative, located in most developing countries, plays a role similar to the U.N.'s Resident Coordinator. This person can direct appropriate requests and inquiries to the proper experts within the organization. Within the World Bank, the three sources of funds—the International Development Association (IDA), International Bank for Reconstruction and Development (IBRD), and International Finance Corporation (IFC)—can provide different degrees of concessionary loans.

Regional aid organizations. These groups, 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.

Arab organizations. 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 from petroleum receipts.

Nongovernmental organizations. Such organizations fall within the category of regional aid organizations, but they are not affiliated with any government and are usually funded by private, charitable donations. In most cases these organizations are created to serve religious or humanitarian goals. NGOs have a much smaller monetary base than other multilateral or bilateral organizations, but they are certainly a viable source of funds for rural SDH projects. Because their funds are limited, NGOs 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, NGOs should generally be approached for individual SDH projects rather than for a comprehensive program of SDH projects for the country.

Regional development banks. These are also possible sources of funds for financing SDH programs. Examples of such organizations include the BAD, BOAD, and the BDEAC. The long payback terms (10-15 years) and reasonable interest rates that are usually fixed (less than 10%) are attractive for such projects. However, because the assistance is in the form of a loan, the borrower will have to show sufficient cash flow to reimburse the loan. Regional development banks tend to be more lenient than commercial banks on this latter point of repayment.

Because these development banks are regional in nature, they often prefer projects that will benefit several states. This factor works against the financing of SDH projects by regional development banks, because the electricity output of SDH plants covers only a small area. Nonetheless, these banks are viable sources of financial assistance.

The above-mentioned donors can provide attractive concessionary financing as well as technical expertise. Because they are multilateral in nature, there are rarely nationalistic or political criteria attached to the financial assistance.

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, the nature of bilateral aid—one state directly assisting another—means that political and strategic concerns play a role in the assistance programs.

Bilateral donors have dual objectives in their development assistance. On one hand, bilateral donors have the humanitarian goal of assisting in the development of a country. On the other hand, their assistance has certain nationalistic goals; 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 their goods. Bilateral assistance often requires that the goods used in the SDH project originate in the donor country. Furthermore, foreign technical assistance, if needed in the project, must favor persons of the donor's nationality. Like multilateral assistance, bilateral assistance can be in the form of grants or concessionary loans.

Supplier credits from governments of countries that manufacture equipment can sometimes be obtained for SDH plants. However, these loans have stricter credit standards and more severe terms than concessionary grants or loans. Supplier credits are generally for less than 10 years and have fixed interest rates, varying around 10%. Supplier credits are provided primarily to stimulate the manufacturing country's exports rather than to achieve development objectives.

National sources (public)

Within the public sector, national sources are an excellent source of funds to finance local inputs. As a general rule for SDH plants, making maximum use of local resources is desirable to assure delivery, facilitate repairs, and avoid the outflow of precious foreign exchange. National sources will also be concerned with the priority of the project and its socio-economic justifications. Political considerations such as the regions being served and politics of these regions also will play a role in the national decision-making process.

The government budget. This is a possible source of funds for local materials, equipment, and labor. However, this source of funds is very limited in many African states, where governmental revenues often fall short of desired expenditures.

National development banks. These offer another potential source for financing local needs. Such banks know the local conditions very well and will generally follow the government's priorities. Sufficient cash flow will need to be generated from the end users to reimburse the medium-term, fixed-rate loans of these banks.

Individual communities. The communities using the SDH plant may not be able to provide cash for the project, but they can provide valuable labor, local materials, and transport. The more these resources are used, the fewer funds are needed from multilateral, bilateral, and other national sources. Experience indicates that local populations fully support these projects.

No set formula can be used to determine what source of funds is available from the public sector or how to obtain these funds. The varying politics and economics of the country involved and the economics of each SDH project make such formulae impossible. However, in knowing the organizations that are interested in SDH projects and their major financing criteria, the borrower improves the chances of raising funds successfully.

The borrower must identify the project's needs in terms of grant vs. loan, technical assistance vs. capital assistance, multilateral vs. bilateral, and then approach the appropriate institutions in a prudent, scientific manner.

Private sector funds

The private sector can finance a project via two classic methods: capital injection as a shareholder, or loans with set payback periods and interest rates. Unfortunately, the high-cost, low-return, infrastructural nature of SDH projects effectively minimizes private sector participation in such projects. However, this sector should not be ignored.

Private shareholders

Private shareholders in a project can be either individuals or corporations. Because the return on investment from an SDH program is marginal at best, the only individuals or corporations that would be interested in investing would be the end users of the electricity from the SDH unit. For example, the owners of the forestland surrounding the SDH unit may be willing to invest in the SDH project, which would provide power to their proposed sawmill. Thus, private investment in SDH projects would be seen only when the investor has an interest in the end use of the generated electricity.

Private lenders

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 bank funds

Commercial lenders in most cases will not be interested in SDH projects, because their cash flows usually are not strong enough to service a medium-term loan. Only where a specific end user can ensure an adequate cash

flow might commercial lenders be interested in assuming the risk of lending to an SDH project. The national banks of the country may be willing to assume this risk, because they have an intimate knowledge of the local environment and the creditworthiness of the end user. International banks, which usually are unfamiliar with the end users, may make a loan to an SDH program with specific end users, but only with the full guarantee of the government.

In any case, the nonconcessionary nature of commercial lending (medium term, higher interest rates) makes this source of funds the least desirable of all those mentioned.

Several African states are able to borrow under their government's name and provide these funds to certain projects such as SDH programs. International commercial banks, which would not lend directly to infrastructural projects such as SDH projects, may be willing to lend to the government of the country, which would use the funds for a variety of projects. Such commercial loans have a maximum term of 10-12 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. They use numerous economic measures in their analysis, including the country's GNP, existing debt levels, balance of trade, balance of payments, and percentage of export receipts needed to service debt. Banks will also consider the policies of the government and its attitude toward foreign debt; they will scrutinize closely the government's track record in servicing other debt. These banks are not as interested in the details of the SDH project because the borrower is the government; therefore, their lending decisions are based more on macro-economic considerations.

The fundamental goal of such an analytical 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 because the life of the loan can extend for 10-12 years.

Borrowers should approach international commercial banks only as a last resort—the base rate of interest for these floating-rate loans (LIBOR) has surpassed 7.0% in recent years. A profit margin of from 0.5%-2.5% is added to this base rate. Finally, borrowers should be aware that international commercial lenders are relatively inflexible about rescheduling loans if conditions that temporarily impede repayment arise.

The end user of the electricity is the key in attracting private capital or local commercial loans for the financing of SDH projects. The low return of SDH systems reduces 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 use these funds for SDH programs.

Summary of public and private sources

Donor organization funds can be ranked by the desirability of the financial conditions (repayment term and interest rates). From the borrower's perspective, this ranking of desirability will be the same regardless of the end user. If the end use of the SDH project 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 ensure 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 that 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), and
5. Commercial credits (short to medium term, high interest).

This ranking views only the financial terms of the grant or loan. The borrower must weigh other variables, such as the amount of the assistance, availability of funds, and the possible conditions that may be attached, on a case-by-case basis. In general, this ranking suggests that SDH projects require the longest term and lowest rate possible.

Packaging the request

The experience of donors on previous projects naturally affects their decision-making process on subsequent projects. They will view general problems that have arisen on earlier projects as potential roadblocks to a successful SDH program. If the borrower can mitigate these concerns, the possibility of obtaining funds will improve.

Three common nemeses that have often plagued development projects are 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 handled during the life of the project.

Maintenance

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 will consider the availability of proper technicians and the training of mechanics to maintain the equipment. They also prefer to see a large degree of standardization in the equipment.

The planners of the project should analyze the performance of proposed equipment in the desired terrain and climatic conditions, reviewing the experiences of surrounding regions and neighboring countries with SDH equipment. Donors want to see that the equipment they are financing is appropriate for the environment.

Sound cash flow is important to maintenance, because the project must be able to generate sufficient revenues to purchase spare parts and to pay technicians. Donors are extremely apprehensive about seeing well-intentioned projects fall into disrepair from a lack of operating funds.

Management

The donors will carefully analyze the proposed management of the project, because 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, and the training of local technicians. They will scrutinize the success of the proposed management in earlier energy projects. Therefore, when formulating any SDH programs or aid requests, borrowers should place heavy emphasis on the capabilities of the project's management. If managerial capabilities are weak, the borrower should not hestitate to seek training or experts in the aid request.

Cost overruns

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 that boost the overall price tag. Cost overruns can be avoided by proper pricing of anticipated needs and building in of adequate margins for unforeseen contingencies and for inflation. The organization that provides the initial grant or loan should not be counted on to provide additional funds to cover cost overruns.

SDH projects can avoid the problems of maintenance, management, and cost overruns through prudent planning and research at the start of the project. The final presentation to the proper donor should manifest the detailed research and planning that has brought an SDH program to the formal request stage.

Ideally, the presentation should include a clear statement on the short- and long-term objectives of the project, and the major technical and financial specifications. By also including a well-planned implementation and execution scheme, the SDH request moves from the domain of the theoretical to that of a fully realizable project. An implementation and execution scheme should include precise timetables with clear delineations of the responsibilities of all parties involved in the construction and management of the project.

The financial and technical justifications of the presentation to the donor must show that hydropower is the most appropriate energy source. The traditional alternative to hydropower has been oil-based thermal power. A comparison of hydropower to this traditional source is recommended. Such a comparison should focus on the technical viability of the two sources and contain detailed financial comparisons on the cost of investment, the cost of production, and the cost to the consumer.

The final elements of the presentation are the market studies, hydrology studies, cost/benefit analyses, etc. These are indispensable in making a prudent investment decision and should be appended to the presentation. The presentation will include concepts from such studies, but the full documents should also be available to the donor. One can never provide too much project information to the proper donor.

CONCLUSIONS

The financing of small decentralized hydropower projects, either individual dams or a regional program of hydropower units, is a complex task. A tremendous amount of work and creativity is required to raise the funds necessary to realize this renewable source of energy.

Before formulating such projects, the government of the country will have to prepare comprehensive development plans with ancillary energy/hydro schemes. When the government has delineated its energy priorities in such plans, specific programs such as SDH projects can be presented.

Donors are particularly sympathetic to the need of African countries, which are dependent on expensive oil imports, to develop sources of locally generated energy. Therefore, SDH programs that meet the energy needs of rural populations fall nicely within the movement of aid organizations to finance the development of alternative energy sources.

Public sector donors share the objective of providing electricity for viable development purposes. They impose certain restrictions on their funds simply to maximize the use of their scarce resources. When a donor finances an SDH project, it becomes a partner with the originators, with an equal interest in seeing the project successfully implemented.

(Editor's Note: Gaston Dossou, workshop moderator and Director of the African Development Bank's Infrastructure and Industry Division, responded to Mr. Gardner's presentation. His comments follow.)

Mr. Gardner's speech, while by his own admission is quite general, raises some interesting points regarding the conditions under which financial institutions participate in small rural infrastructure projects such as small hydro projects. As a representative of one of those institutions, I feel obligated to address this subject in the specific: Is the BAD ready to accept applications to undertake small hydropower projects, and under what conditions? I do not presume to make any commitment by the BAD in addressing this question, but I would ask the indulgence of the audience to permit me a few minutes to comment on Mr. Gardner's paper in the context of this institution, the BAD.

The African Development Bank actually consists of three organizations:

- The African Development Bank (BAD). This is the "mother" institution, which was created to promote solidarity among African countries through market exchanges and economic development.

- The African Development Fund (FAD). The African countries' resources are insufficient, and they must look for financing where it is available. The FAD was created to help the economic and social development of the most deprived African countries through funding and any other internal resources.

- The Nigerian Trust Fund. Because the BAD's financial participation in the development field was limited for each state, the wealthy African countries were asked to provide for other funds. This is how the Nigerian Trust Fund was created.

The financing mechanisms of the three organizations differ. The BAD, which deals with a variety of activities, has the most rigid funding criteria. The BAD provides long-term loans at 8%-20% interest with a maximum of 5 years for reimbursement. A commission of 15% is added for funds that have not been withdrawn.

Can the bank provide loans for the development of energy and hydroelectric resources? The answer is yes.

The FAD is the most flexible organization. Its loans are interest-free; however, it does charge a 15% commission for funds that have not been withdrawn. The reimbursement term is 40 years, commencing after a 10-year grace period during which no payments are required. Although this fund is highly flexible, its resources are not substantial, which is the reason it can provide loans only to the poorest countries. Within this category fall the Sahelian countries, and countries handicapped by their geographic situation, such as the small islands. These criteria reduce to a total of about 20-25 the number of countries that are eligible for the FAD's funds. With its limited funds, the FAD makes loans to develop those resources that can further the development of the area's social sector—in particular, projects of micro-powerplants for irrigation or small industry purposes.

The Nigerian Trust Fund functions almost like the BAD, but like the FAD, only certain countries are eligible for its loans.

In addition to these direct project funding sources, the BAD also has funds for technical assistance to promote preinvestment studies. Here too, only the poorest countries are eligible for assistance. Funds for these purposes also are limited, but prefeasibility or feasibility studies can be undertaken at no cost. For any lending institution, the criteria of intervention will always require an overall evaluation of the economic and social advantages that can accrue from the development of small-scale hydropower plants. The problem is how to determine the economic and social feasibility of these projects. The local output is one important consideration. Another is the use of local equipment and manpower, which can reduce costs and, consequently, justify these development projects. The level of investment of each project will determine the depth of the study, but in general, very elaborate studies are not conducted. For small powerplants, the feasibility criteria are relatively easy to determine. For more important powerplants, much more complex economic methodologies must be considered, because these projects entail investments and operating and maintenance costs that must be recoverable in great part, at the risk of total failure.

Another factor must be taken into account: the level of the investment. If the investments are too small, none of the three above-mentioned organizations will be able to intervene directly. For a direct intervention, a minimum investment level, arbitrarily defined as more than $1 million, is necessary. If the projects concerned do not reach this minimum, they can be grouped into one category.

113

Cost Aspects of Mini-Hydropower Systems

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INTRODUCTION

The two principal impediments to rapid development of mini-hydropower projects are initial high capital cost (two- to threefold that of thermal plants) and a lack of financial resources to develop small dispersed energy sources. These factors keep mini-hydropower programs at the discussion and project documentation stage. Ways of reducing costs must be sought. Possibilities include streamlining the project development cycle and the use of labor-intensive construction techniques and locally manufactured equipment. Ways must also be sought to improve the system's load factor, and, therefore, its economic benefits.

COST OF THE TECHNOLOGY

Small waterwheels and turbines have a long history of providing both mechanical and electrical power. Traditionally, mini-hydro units were more expensive than diesel-powered generators; this situation is changing as a result of technical breakthroughs, such as electronic load controllers to replace conventional governing devices. Estimates of total installed costs (1978) for micro- and mini-hydro units in Asia range from $400-$2,000 per kW or more, 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 a 5 kW, micro-hydro unit to be $438 per kW, compared to $580 per kW for a diesel generator of the same size (3). 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 India's irrigation canal systems (2).

The low demand in most remote rural villages is an obstacle to cost-effective use of mini-hydro units, whose operating costs are comparatively low. The operating costs for petroleum-fueled engines, on the other hand, often dependent on shipments of diesel or gasoline fuels over difficult terrain or poor roads, are 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 reduce the foreign exchange costs of imported petroleum. This is especially true for more expensive middle distillate products other than crude oil, which are frequently imported because local refineries are unable to meet the heavy demand for these products.

Mini-hydro technology is attractive for social and political reasons. Government leaders in developing countries must address the urgent need to expand rural productivity and provide employment. Political instability is often associated with the failure to modernize rural areas and with the increasing migration of unemployed and underemployed rural people to overcrowded urban centers. Micro- and mini-hydro systems can offer a cost-effective way to electrify rural villages, increase the efficiency of traditional tasks (e.g. grain grinding), and stimulate the development of new rural industries (e.g. machine shops making agricultural implements). The importance of electricity is summed up in the words of 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." (4)

Although politicians in many developing countries have made rural electrification 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 are 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 (2).

Mini-hydro technology is a possible approach to maintaining this political commitment. It can provide service to remote areas more quickly and less expensively than grid expansion. The problem of high transmission losses may exist, however, for mini-hydro systems as well. Losses in rural Chinese systems are as high as 25%, a factor that encourages the construction 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 United Nations Industrial

Development Organization (UNIDO)/Economic and Social Commission for Asia and the Pacific (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". (4) This is occurring in many countries, including Thailand, India, Nepal, Papua New Guinea, Indonesia, Colombia, Peru, and the Philippines, but others import mini-hydro systems generally on concessional terms as part of foreign assistance or export promotion programs.

The issue of imported vs. locally made equipment often revolves around the question of reliability and efficiency. The national utilities prefer systems with high efficiencies and few maintenance problems, especially at sites that are remote from centers of technical expertise. There is a considerable difference in the cost of a locally made unit and a more efficient imported foreign system. The Chinese mini-hydro units are among the cheapest foreign units available; yet, at approximately $1,000 per kW for a 5 kW unit, they are more than twice as expensive as the locally made unit in Papua New Guinea, even before installation. Generally, it is not cost-effective to use imported equipment to gain a few percentage points of efficiency.

PRICING AND CREDIT POLICIES

Mini-hydro technology may offer a cheaper alternative than diesel in off-grid locations, but pricing and affordability of the electricity remain fundamental issues. The cost of wiring a house 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, because there is no fuel cost. Unlike diesel units, which require an additional cost for each kilowatt-hour supplied, pricing strategies with mini-hydro can be designed to encourage (up to a limit) the consumption of electricity. Higher load factors lower the cost per kilowatt-hour. 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 for their houses.

Although most governments have established mechanisms to provide low-interest loans for energy production projects to local communities and to cooperatives, programs to support the increase in the productive uses of electricity have been inadequate. Until recently, rural electrification programs emphasized lighting of households and were not closely coordinated with agricultural development projects.

ECONOMIC ANALYSIS OF A TYPICAL MICRO-HYDRO PROJECT

Life-cycle costing can be used to compare the economics of alternative energy systems. The rationale for using this approach instead of traditional methods is the rising price of conventional fuels and the need to consider full costs—both operating and capital—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 the system's useful life. Life-cycle costing, often referred to as discounted cash flow analysis, is not new. The 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 costs are given in constant dollars. By reducing all expenditures to a single figure, it is possible to compare costs of alternative energy systems that have very different capital and operating cost profiles. This method is becoming increasingly popular as a means of providing a single economic yardstick to compare, on a "least-cost" basis, projects with high investment costs but low operating costs and long useful lives (hydro plants) with alternatives which have low investment costs but high operating (future-year) costs and relatively short useful lives (diesel plants).

The entire process of life-cycle costing is linked by a common method of treating capital expenditure, unit operating and maintenance costs, residual (salvage) values, project life, future energy prices, and the opportunity cost of capital.

Case study: Swaziland mini-hydro project

In this case study, life-cycle costs for a diesel pump are compared with a mini-hydro/electric pump combination. Within the United Nations Environment Programme (UNEP)/United Nations Children's Fund (UNICEF)/World Health Organization (WHO) Integrated Water Supply and Sanitation Demonstration Project (1), located in the Shiselweni district of Swaziland, seven diesel pumps are to be installed to supply potable water to approximately 1,000 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.

TABLE 1. Life-Cycle Costing Basic Assumptions

Project life	10 years
Discount rate	10%, 20%, 30%
Residual (salvage) value	10% of capital cost
Diesel fuel price increase [a,b] (Base price, $1.50/gallon, 1979)	5%, 10%, 20%

[a] 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 ($1.50); f is annual increase (10%); and t is years (5).

[b] The diesel fuel price increase does not include inflation because a constant-dollar analysis is used to calculate all costs.

115

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 8-10 years and for micro-hydro plants, 15-20 years. For simplicity, a figure of 10 years is used for both. Discount rates of 10%, 20%, and 30% are applied, because the higher rates are likely to occur. Of course, for very high discount rates, choosing a long-time horizon may be irrelevant, because expenditures after a certain period would be inconsequential. (For example, 90% of the total present value of a constant stream of revenues is captured within 13 years at a discount rate of 20%.) Residual or scrap value is difficult to determine; however, a 10% figure for mechanical equipment is not uncommon. Diesel fuel prices in Swaziland were in the neighborhood of US$ 1.50 per gallon during August 1979. Diesel fuel prices will continue to rise, although 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. Table 1 shows three projections: high, intermediate, and low. Because 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. Diesel Pump Costs, December 1979

Capital costs	
Listor diesel, 10 kW[a]	$1,000
AC pump, 500 ft. head	600
Frame, controls, miscellaneous equipment	400
Total	$2,000
Annual operation and maintenance costs	
Diesel fuel at $1.50/gallon, pumping 4 hours per day yields $16.48 per day, or	$2,370
Maintenance, 10% of capital cost	200
Total	$2,570

[a] Total head is 163 m at Matimatima, which includes a well 42.6 m deep. No pressure drop is assumed due to friction, because 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 1/s (approximately 50 gpm) over a 163 m head requires a 4.7 kW machine; with a 50% efficient engine/pump, it requires a 10 kW machine.

Table 2 outlines diesel pump capital and operation and maintenance costs. Capital costs are US$ 2,000 and operation and maintenance costs are US$ 200, exclusive of diesel fuel expenses. Table 3 outlines the mini-hydro/electric pump capital and operation and maintenance costs. As expected, capital costs are higher, but operating costs will be lower because of the absence of fuel. Note that the civil cost of US$ 3,000 is approximate, because some rather detailed engineering is necessary to make an exact determination.

TABLE 3. Mini-Hydro/Electric Pump Costs, December 1979

Capital costs	
Electromechanical equipment:	
10 kW turbine/generator	$ 6,000
Extension line, 900 V:	
1 km	4,000
Civil works (impoundment, penstock, powerhouse)	3,000
AC electric motor pump:	
500 ft. head, 50 gpm	1,000
	$14,000
Annual operation and maintenance costs	
6% of capital costs	$ 840

Results

Sensitivity analysis was carried out to determine the effect of different fuel costs and discount rates on the projects' costs:

- 5%, 10%, and 20% annual price increases for diesel fuel, and
- 10%, 20%, and 30% discount rates.

Figs. 1 and 2 illustrate the constant chronological dollar cash flows for the diesel pump and the mini-hydro/electric pump projects, respectively. On the basis of constant dollar cash flows, the diesel pump is cheaper for the first 5 years. However, thereafter, escalating fuel prices more than compensate for the high capital cost of the mini-hydro installation, despite the application of various discount rates. Because hydropower is so capital-intensive, life-cycle costs are particularly sensitive to discount rates.

Fig. 3 shows life-cycle costs or present worth of all future expenditures as a function of discount rate. With "severe" discount rates, the diesel pump becomes competitive with the hydro. However, it is likely that the discount rate will move up or down with energy price increases since rapidly increasing fuel prices tend to nudge the inflation rate, and with it interest rates, upward. Therefore, a real fuel price increase of only 5% or 10% percent will not be likely to coincide with discount rates rising above 20%. A discount rate of 15% and an annual real fuel price increase of 15% appear

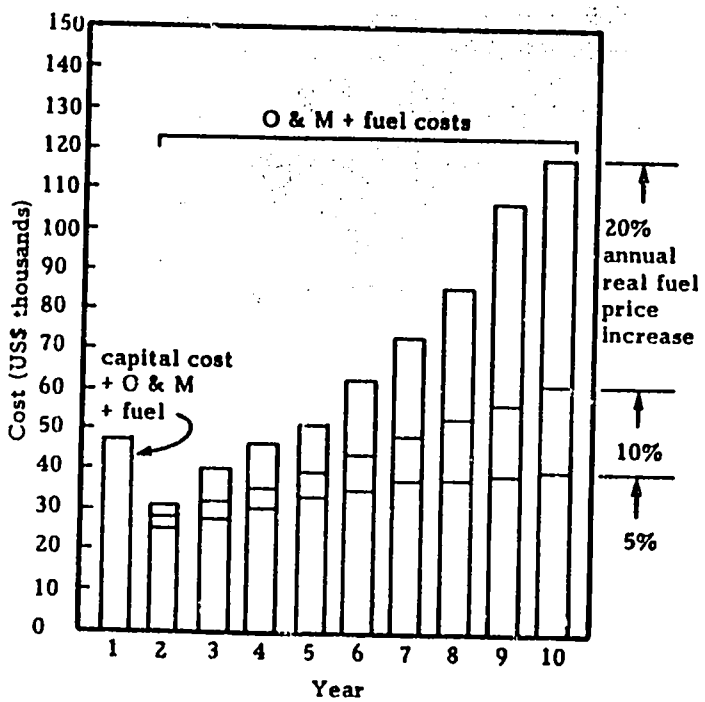

Fig. 1. Constant dollar cash flows for mini-hydro/electric pump project, 1979-89 (nondiscounted).

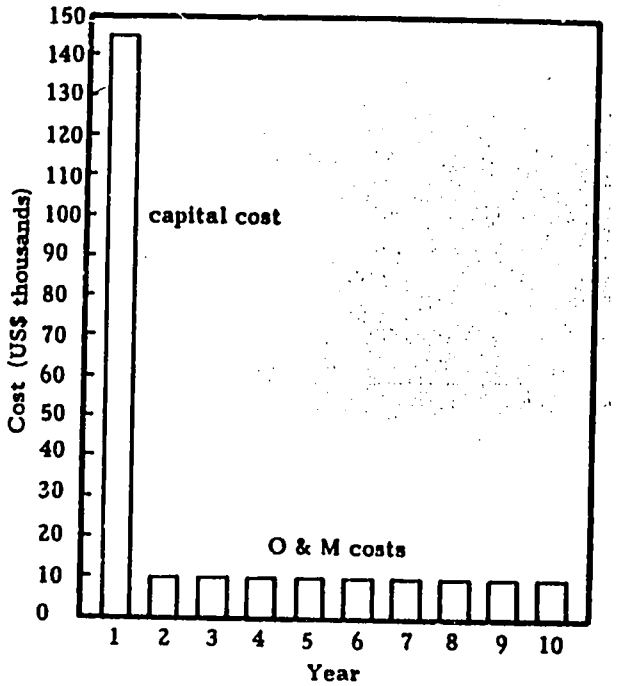

Fig. 2. Constant dollar cash flows for diesel pump, 1979-89 (nondiscounted).

more probable in this particular scenario, although even a 15% real annual increase in fuel prices is unlikely to be sustained over a long period of time. Under these circumstances, the mini-hydro scheme is favored.

An additional factor is that the project life for the micro-hydro/electric pump generally exceeds 10 years, whereas, for the diesel pump, it is often less than 10 years. A replacement cost was not considered. If it had been, micro-hydro would have appeared to be even more attractive.

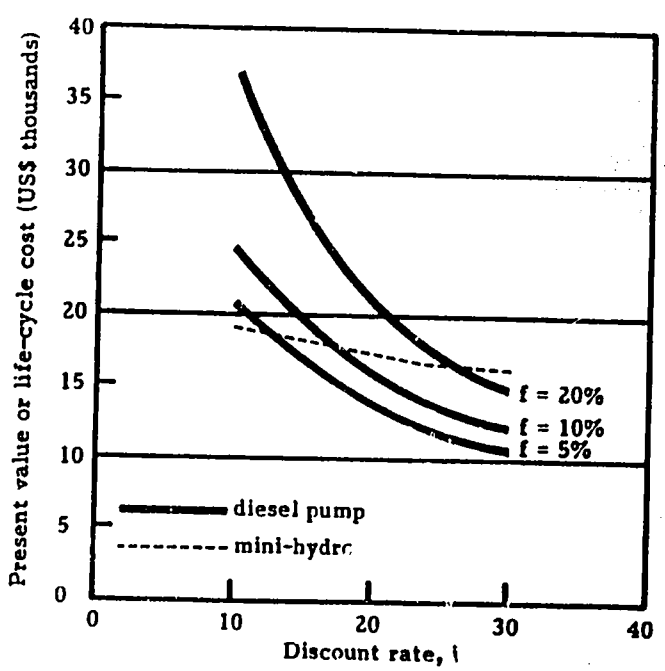

Fig. 3. Sensitivity of life-cycle costs to discount rate for three diesel fuel price increases (f).

The calculations used to develop the present worth (PW) of all future expenditures for the two schemes are as follows:

Micro-hydro

$$PW = 14{,}000 + 800 \sum_{j=1}^{10} \frac{1}{(1+i)^j}$$

Diesel pump

$$PW = 2{,}000 + 200 \sum_{j=1}^{10} \frac{1}{(1+i)^j} + 2{,}370 \sum_{j=1}^{10} (1+f)^j \frac{1}{(1+i)^j}$$

PW = present worth

f = annual diesel fuel price increase, exclusive of inflation

i = discount rate.

The PW of life-cycle costs of the mini-hydro/electric pump are limited to capital and operation and maintenance costs subject to the discount rates. The PW of the diesel pump system costs include capital

costs, operation and maintenance costs subject to the discount rate, and fuel costs subject to annual real increases as well as the discount rate.

The above analysis shows that the micro-hydro system is cost-competitive, based on broad assumptions. If only the constant dollar cash flow is used, the micro-hydro is competitive after 5 years' service. If life-cycle costs are chosen, the discount rate should govern the decision. However, because it is acknowledged that diesel fuel prices will climb severely and the discount rate is unpredictable, it appears prudent to spend more dollars today to avoid uncertain expenses tomorrow.

CONCLUSION

It is clear that costs must be closely examined in the planning of a mini-hydro project. In the economic analysis, the choice of assumptions may determine project feasibility. It is important to determine what the costs will be by obtaining accurate prices from manufacturers and engineering contractors. Often these prices will vary widely, and additional questions of quality and reliability will arise. Unfortunately, costs are so site-specific that reasonable estimates can be made only through extensive experience.

REFERENCES

1. Fritz JJ, and Graham T. "Swaziland Renewable Energy Project," AID Project Paper. Washington, DC: AID, 1979.

2. Government of India, Planning Commission. Report of the Working Group on Energy Policy. New Delhi, 1979.

3. Inversin A. "A Pelton Micro-Hydro Prototype Design." Lae, Papua New Guinea: Appropriate Technology Development Unit, PNG University of Technology, 1980.

4. Vin MW, and Li DB. "An Introduction to the Development of Small Hydropower Generation in China." Presented at UNIDO/ESCAP/RCTT Seminar on the Exchange of Experiences and Technology Transfer on Micro-Hydro Electric Generator Units, Kathmandu, Nepal, September 1979.

Electricity Tariffs for Rural Communities

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INTRODUCTION

One of the common problems facing electric utilities in the developing countries is determining an appropriate tariff structure for rural communities that are often isolated from the rest of the country. Different countries have adopted different approaches to solve this problem, depending on their respective socio-economic and political conditions. One such approach is based on marginal cost pricing modified to suit the electricity sector and the social and economic environment of rural areas.

EXISTING TARIFF STRUCTURES

During the 1973-74 energy crisis, many developing countries experienced oil price increases of 400%. Oil price escalation had a serious effect on electric utilities: existing tariffs did not incorporate fuel prices, and tariff adjustment required lengthy procedures. Tariffs that were based on traditional historical costs no longer adequately financed new investment to meet the additional demand of existing or new consumers. To address this problem, many electric utilities carried out tariff studies based on marginal cost pricing and started applying them, with appropriate modifications based on their country's socio-economic conditions.

MARGINAL COST PRICING

The concept of marginal cost pricing has been discussed widely during the last decade. An investment program provides incremental costs of generating, transmitting, and distributing electricity at different places (or voltages) to meet estimated demand for a period of about 10 years. A tariff is then devised to reflect these costs and the operating costs.

One of the objectives of marginal cost pricing is the efficient allocation of resources, which is achieved by charging the consumers for the cost of meeting their new or additional demand. In practice, the tariffs derived from this procedure are modified to meet other objectives, including social and financial development.

After the costs of supply have been calculated, 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 should generate revenues that achieve the goals of marginal cost pricing. This departure from the original concept achieves equity among consumers; it also simplifies metering. Tariffs for rural communities require special attention, because these communities generally are in areas of poverty and low productivity and may be unable to pay for their consumption.

RURAL ELECTRIFICATION

Many African countries are promoting rural electrification in order to raise standards of living, establish a regionally balanced industrial base, prevent rural drift, and create more jobs in rural areas. Electricity is introduced into rural areas in the following ways:

- Grid extension. Generally, this approach is used in countries that have an existing network.
- Diesel generators. This is a very common method. It was the cheapest way of supplying consumers before the energy crisis of 1973-74.
- Micro-hydropower stations. Since the oil crisis, many micro-hydropower stations have been installed to supply electricity to rural areas.
- New and renewable sources of energy. Many rural localities have been supplied with electricity on an experimental basis by new sources of energy such as biomass, wind energy, and solar energy.

COST ANALYSIS

The costs of these different methods vary considerably; consequently, tariffs based on these costs also differ.

Grid extension

This is generally the most expensive way of supplying rural consumers, but it has the long-term benefits of high reliability, optimum use of available plant capacity, and rapid development of the rural areas. The costs of supply could be $4,000-$40,000 per km of line, depending on system voltage. In the case of grid extension, tariffs should be based on marginal costs of supply for the entire system; the tariffs should be applied uniformly, regardless of the location of the consumer. Tariffs would be prohibitive if rural

consumers were charged on the basis of grid extension costs.

Diesel generators

Medium-sized diesel units currently can cost about $1,000-$1,200 per installed kW. Distribution costs would raise this to about $1,500-$2,000 per installed 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 per gallon; the monthly cost per kW would be $25, assuming a 14% discount rate. Distribution losses and billing and maintenance costs would raise this figure to around 30 cents per kWh:

$$\text{Cost per kWh} = 15 + \frac{2{,}500 \times 100}{24 \times 30 \times 30} \quad \text{(assuming a 30\% load factor for domestic consumers)}$$

$$= 15 + 11.6 = 26.6 \text{ cents.}$$

Micro-hydropower stations

The costs of micro-hydropower stations can vary from $500-$5,000 per kW. Assuming a 14% discount rate with an average life of 30 years and a 30% load factor for the plant, the monthly costs per kW and kWh would be from $6-$60 per kW per month, or 2.6-26 cents per kWh per month. With maintenance and billing expenditures, the cost per kWh would be from 7.6-31 cents per kWh per month.

New and renewable sources of energy

In recent years, special efforts have been made to reexamine the use of new and renewable sources of energy for electricity production. The application of these new sources of energy is still on an experimental basis; costs are quite high. Solar energy in photovoltaic cells is likely to be developed for industrial use. Although the cost of these cells in expected to be competitive with conventional sources of energy in the coming decade, their present high cost prohibits their use for rural electrification.

TARIFF POLICY

After calculating the costs of supplying a rural community, it is necessay to determine a pricing policy that satisfies both the goals of marginal cost pricing and the "willingness to pay" criterion. A compromise can be reached by setting tariffs for lighting that are high enough to recover fixed cost as well as running cost. For off-peak loads, tariffs could be based on marginal costs of supply. This policy would provide an incentive to increase consumption; it would also improve the load factor.

Experience shows that in rural areas, electricity is used for lighting, radios, pumping, and to some extent, small industry. For lighting, consumers generally can afford to pay the cost of diesel alternatives because the consumption for lighting usually is low. Because pumps generally operate during off-peak hours, a low tariff based on marginal cost pricing could be appropriate. In addition, it could improve the load factor of the system.

Rural electrification schemes ultimately will be connected to the national grid; therefore, it is necessary to adopt the same tariffs for all consumers, regardless of their location. However, it is necessary also to base these tariffs on marginal costs of supply, with modifications to suit local conditions.

Tariff policy can be used to accomplish other goals. It can discourage consumers from wasting electrical energy and motivate them to use the energy in its most economical form. For example, in rural communities supplied by diesel generators, tariffs can be sufficiently high to encourage the use of alternatives such as gas and wood for heating and cooking. Micro-hydropower stations, however, may be able to supply the most economical form of energy, thus giving micro-hydro schemes an advantage over the other alternatives. It is clear that micro-hydro is economical and competitive in the small and medium cost ranges; even in the large cost range, escalating fuel oil prices make micro-hydro schemes attractive in comparison to diesel generators.

CONCLUSION

For extremely poor areas, electrification should be part of a broad, integrated rural development program. As such a broad program is implemented, it helps to increase the incomes of the rural community to the extent that consumers become able to pay the costs of the infrastructure, in particular, electricity.

INSTITUTIONAL CONSIDERATIONS

Management Approaches to Small Hydropower Systems
Richard H. Brown

Management, Training, Operation, and Maintenance of Small Hydropower Plants
Rupert Armstrong Evans

Institutional Aspects of Mini-Hydropower Programs
Jack J. Fritz

Management Considerations for Small Hydroelectric Powerplants
Hédi Messolli

Staffing and Record-Keeping for Mini-Hydropower Plants
Aboki Semanou

The Process of Introducing Hydropower to Rural People
Anton Soedjarwo

Legislative Contributions to Private-Sector Development of Small Hydropower Plants
Donal T. O'Leary

Management Approaches to Small Hydropower Systems

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INTRODUCTION

There are two major approaches to electrification using small hydropower systems. The first—a centralized program with a national grid—is the best known and the most often used, particularly in West Africa. This approach has proven its effectiveness in many countries and situations. But there is a second approach, one that is much less well-known and much less widely used. This is a decentralized approach, using isolated small hydropower plants throughout the rural areas. The major distinctions between centralized and decentralized small hydropower approaches to national electrification programs are:

- A centralized approach is capital-intensive, emphasizes sophisticated technology, is hardware-oriented, and requires deterministic control.
- A decentralized approach is labor-intensive, emphasizes simple technology, is people-oriented, and requires open-ended coordination.

The most embracing distinction between the centralized and decentralized approaches to electrification using small hydro systems 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 that their results, designed to stimulate the major industries, are expected eventually to reach or trickle down to the average citizen. Advocates of the trickle down strategy of development, "centralists," 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, "decentralists," speak the language of national autonomy, resist dependence on foreign capital and technology, and favor numerous widely dispersed projects that are scaled to the capital, technical, and organizational resources of the rural people. Each of these positions constitutes a comprehensive theory and practice of social change.

Several other distinctions exist between the two strategies. One distinction has to do with technology. Centralists tend to favor sophisticated, capital intensive hardware, while decentralists favor simple, labor-intensive technology. Another distinction is the basic focus and style of management in an electrification program. Centralists emphasize the end product or hardware of the system; decentralists focus more on the human and social processes. Moreover, centralists usually prefer deterministic planning and tight managerial control; decentralists incline toward open-ended coordination and an integration of planning and implementation.

Each of these two economic strategies—trickle down and bubble up—is compatible with one of these two development approaches. 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 installing and operating the expensive hardware, because 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, because it views poverty as a product of a poor nation's dependence on wealthier nations, rather than on any "backwardness" within the poor nation. 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 people who reside mainly in the rural areas. From this premise, it follows logically that electrification should proceed using simple technology, elementary management systems, low levels of capitalization, and as much labor as possible. Given this approach, it further follows that management will focus on stimulating this broad participation—generating a mass social process, rather than constructing massive physical hardware. Such a process is more of a social movement than a formal organization; therefore, the appropriate style of management is one of open-ended coordination. Deterministic planning and control either would be impossible or would preempt the local initiative upon which the program's success depends.

APPROPRIATE TECHNOLOGY

There are major factors to consider in assessing the technology appropriate for an electrification program, including:

- The geographic characteristics of the area to be served,
- The number of consumers who 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 $1 billion structure with a capacity of 2,100 MW of electricity. Although start-up costs were very high, the Aswan High Dam represents an economical investment in electric power, especially in light of the social benefits associated with it. By contrast, such sophisticated technologies would not be appropriate in Nepal, whose far-flung villages are often in the vicinity of small, steeply dropping mountain streams. In this case, micro-hydro technology is highly feasible and cost-effective.

In contrast to the sophisticated technology of the centralized grid programs, a decentralized, small hydropower approach favors simple, low-cost technology. Simple technology is not necessarily equated with small-scale projects or low kilowatt output; however, simple technology must be geared as closely as possible to the capital, technical, and managerial resources of the owners, builders, and users of the system—the local people themselves. A technology that emphasized relatively large labor investments and was simple to manage would qualify as "simple technology," even if it were large in size or kilowatt output. For example, consider a rural municipality near a large natural basin, one that could be easily made into a lake by blocking one end with an earth dam. With such a large storage capacity, which simple construction by local labor largely could create, a relatively inexpensive hydropower scheme might be able to provide more than enough power to meet demand. Such a facility would be well within the technical and managerial capacities of the townspeople themselves.

In most Third World countries, the unused labor power and simple skills of rural villages are great resources. Simple technology is intended to fit more smoothly in the rural environment of most developing countries, where massive labor resources reside but where capital is scarce. The simple technology of the decentralized approach keeps hydro equipment fairly basic so that it can be built, used, maintained, and repaired in-country without dependence on trained engineers, mechanics, and imported parts. With this approach, hydropower sites are constructed to less exacting specifications with less exotic materials. Also, the marketing of power, which is primarily for the local community itself, is far less vulnerable to fluctuations caused by regional blackouts, transmission breakdowns, and other factors the users cannot control. Because the overall system is less sophisticated, individuals 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 developing nations, the gap between the "million-dollar technology" of sophisticated generators and the "ten-dollar technology" of kerosene lanterns is so gigantic that a quick, massive, and direct transition from one to the other may be impossible. Even if it were successful, such a shift might destroy the traditional workplaces and displace much of the populace. For a decentralized approach, what are needed are small projects in the $1,000-$100,000 range—immensely more effective than indigenous sources of lighting or power, but also immensely cheaper than the highly capitalized technology of most modern hydrogeneration. This range of capitalization could lead to many small hydro installations and, hence, create numerous work opportunities in remote rural communities.

Simple technology is 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, simple technology permits the development of many small sites, mainly through local effort and investment. This approach makes the ratio of local investment high in relation to outside investment.

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 it shows that similar opportunities are within the reach of other communities and individuals within the rural district if they are progressive and enterprising.

APPROPRIATE MANAGMENT

The orientation of management can heavily influence the nature and structure of a national electrification program. In the centralized approach, management usually focuses 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 believe that creation of the hardware will lead to improvement in the socio-political processes in the long run. Conversely, process-oriented managers believe that, if community development is working well, the technology will easily fall into place.

A product-oriented approach assumes that project factors are susceptible to prediction by experts, which operate under the control of a centralized executive. Most physical and social structures, such as industrial plants, large hydroelectric dams, and even systems of administration, usually are built according to predetermined forms and procedures. A deterministic approach to electrification is appropriate where the environment is predictable, the context is static, agreement is well-established, or where the central authority controls all the resources needed to accomplish its objectives—that is, where the hardware is crucial, such as large-scale, capital-intensive sites that employ sophisticated technology. Such an environment can readily and efficiently adopt to centralized managerial and technical control.

An approach that emphasizes hardware, however, may sometimes overlook local initiative, openness to opportunities, and respect for tradition—all important factors in an overall development program. The development of rural communities, which is one goal of electrification programs, may be frustrating to the managers and brutalizing to the local people if it is attempted with the same managerial approach that is appropriate to developing highways, bridges, or large-scale hydroelectric dams.

Difficulties encountered in the implementation of a project often are viewed as impediments to the final electrification system, rather than as sources of insight into the basic premises of the system itself. Because the deterministic approach strictly separates planning and implementation, the entire process has little flexibility to respond creatively to the unforeseen difficulties that inevitably arise. With this approach, one solution often appears to be to "overcome" the difficulties—usually with more expenditures and sometimes by authoritarian methods. The implementation of master plans for rural electrification, therefore, almost invariably exceeds the initial estimates of project costs.

In most centralized electrification programs, a feasibility study is undertaken to determine the practicality of a project. Such studies start with a fixed premise and work out a scheme that somehow shows the premise will work. When a project appears impractical, alternatives usually are recommended to show that the project can be feasible if its scope is increased to produce more revenues or reduced to require 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 for assessing the unique development opportunities available to a decentralized small hydro program. In the decentralized approach, the initial start-up capital required for a national program is relatively low, because the projects are smaller and the local communities bear much of their cost. 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.

COMMUNITY INVOLVEMENT

One key point in the open-ended, process-oriented approach is that the project and its components, such as hydropower plants and irrigation canals, must be adapted to the specific site in order to be accepted by that particular community. For example, many local people perceive a hydro facility as "the government's project," rather than as "our project." If it is defined as something alien, the facility will be underused; it may even generate fear and suspicion. The local people may not see maintenance of canals or power lines as a civic responsibility, and may resent payment of rates, or even refuse to pay entirely.

The emphasis on process, then, is based on the 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. The process-oriented approach understands that management is not merely a technical undertaking, but a process of building a constituency for the program that is to be managed. This approach views hydro development 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-oriented approach also suggests that many projects can be undertaken simultaneously in colloboration with many local communities, including communities that may come into the program at a later date. Projects are started in those communities that are most enthusiastic and willing to contribute to their own development; where such community projects may fit into an ultimate national grid is given only secondary consideration. A process of self-selection, rather than preselection, is built into the program from the beginning. This may not be the most efficient approach technically, but it does stimulate participation from groups that otherwise might have been excluded from the development program.

Such growth in local capacities for self-improvement is likely to have additional benefits. 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, each project fosters the demonstration effect for other rural communities.

In the decentralized approach, rural electrification is an orchestration of processes that begins with the arrival of the first survey team and continues beyond the commissioning of the plant. The system must function appropriately and adequately for each particular stage of development and locale. This approach thus maintains a perception of continuing progress and of the decentralized small hydro system is never finished; it is always being improved.

The process-oriented approach does have disadvantages, which are closely tied to project scale. It can be insensitive to the technical requirements of all but the simplest electrification projects. When levels of capitalization are high, the technical requirements of the project can assume an overwhelming urgency, to which process-oriented managers often find it difficult to respond; process orientation has an innate difficulty in moving from the micro- to the macro-technical levels; larger-scale projects are beyond the capital, managerial, and technical resources of local communities that might be involved in a collaborative process. Because large-scale projects usually require dependence on outside help for these resources (and may place relatively little importance on local labor), they reduce significantly the role of local participation and make the process orientation less appropriate

Another difficulty with the process-oriented approach is that it requires a flexible and egalitarian style of management. To motivate local initiative and self-help, the program officer must avoid encouraging habits of dependence on outsiders, yet in the eyes of villagers, the officer himself is an outsider. To engender a decentralized process of small hydro development, therefore, it is necessary to create a cadre of field officers who possess very unusual skills. They must be specially trained in the technical as well as the social aspects of electrification. Moreover, they must be highly mobile in order to serve numerous entrepreneurs and communities that may wish to participate in a small hydro program. Such an extensive scope of field work can create other problems for a process-oriented approach. For example, the field officers should have a jeep or, in some areas, access to light airplanes or motor launches to cover large territories. Because field officers of government programs usually are considered to be of low bureacratic status, however, and because transportation often is considered a privilege and symbol of high status, it may be difficult to provide field officers with the mobility that is necessary to their success.

THE ROLE OF SMALL DECENTRALIZED HYDROPOWER IN A NATIONAL DEVELOPMENT PLAN

In the overall development process context, it is important to note that small decentralized hydropower programs provide a technology appropriate to national development strategies that are geared to the rural town and village level:

- A major goal of small decentralized hydropower programs is rural development; small decentralized hydro projects are located in dispersed and often remote towns and villages.
- The range of small decentralized hydro technologies, from 1 to 1,000 kW in capacity, is appropriate only for centers with relatively (by Western standards) low power needs, whether the projects are centrally or locally managed.

In addition, a national decentralized small hydro program provides an organizational infrastructure that can facilitate centralized grid programs in a number of ways. Suppose, for example, that the government decides to build a large hydroelectric dam to encourage new industries and bring more land under cultivation. It makes arrangements for all the ancillary activities that will ensure that the greatest benefit is derived from the very high initial investment.

- Dikes and secondary dams are to be built upstream to prevent siltation and erosion;
- Settlements are to be established in the reclaimed farmland and provided with schools, dispensaries, and other services;
- Roads are to be built to link the villages and the market town;
- Agricultural and veterinary services are to be set up;
- Formation of cooperatives is to be stimulated; and
- Village industries are to be encouraged.

In all, funds may be allocated to 10-12 different ministries or bureaus that are supervised by a central planning board. However, a central planning board cannot work out details such as where to locate a school in relation to a branch road or clinic. It can only inform the other ministries that building the dam places certain obligations on them for which they will be assigned a specific budget, and that they will receive the money when their plans are approved. Even so, it is normally 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 to the original proposal only in name.

Such fruitless efforts of centralized planning and control can be particularly harmful to projects derived from a "bubble up" strategy. For example, a municipality may propose a hydropower scheme for which the Ministry of Public Works may have the major responsibility. If the project is to work, however, the technical and material services of many other ministries must be involved. It might be necessary to consult the Ministry of Lands about public domain and riparian rights; the Ministry of Agriculture, about extending cultivation; the Ministry of Economic Development, about assisting power-related industries.

These examples illustrate the need for an intermediate coordinating mechanism to integrate governmental services and ensure that they are appropriate to the needs of local people and their capacity to absorb them. A national small decentralized hydro program can help create such a mechanism because its focus is local but its scope is national. In the context of total national development, small decentralized hydro programs can provide a bridge between the immense concentrations of capital and technology used for the centralized grid and the small-scale, decentralized

125

projects at the local level. By using small decentralized hydropower as part of a broader strategy of national electrification, a country may also strengthen ties between its central government and its local communities.

CONCLUSION

Although there are advantages and disadvantages (see Appendix), small decentralized hydropower can play a crucial role in national electrification programs. 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 insofar as possible. To achieve this goal, labor-intensive but appropriate technology and industry are necessary. Small decentralized hydropower is a prime example of such a technology, as well as a potential source of energy for many other such industries. A small decentralized hydro program, therefore, can have a significant impact upon the struggle of African nations for political autonomy and economic growth.

APPENDIX

Advantages and Disadvantages of Small Decentralized Hydropower

There are many advantages of small decentralized hydropower as part of a national electrification program:

- Lower capital costs because cheaper equipment is used.
- More easily installed by using local labor and materials.
- Better prospect for implementation and viability, because it can be administered locally, thus circumventing bureaucratic delays. People are more easily trained and repairs can be made more quickly.
- Can provide a positive demonstration effect to motivate other communities.
- Expands commitment and constituency, thereby facilitating implementation, use, operation, and maintenance.
- Develops a system of relationships that may involve other products. (Example: community or entrepreneurial organizations developed to build a dam can be used to initiate a fisheries industry or a mosquito eradication program.)
- Focuses discussion in local communities on positive local choices rather than on polemics or personalities.
- Engenders habits of entrepreneurship and community initiative.
- Enhances community input to process of planning and implementing projects, thereby ensuring better fit between technical requirements as seen by experts and community needs as seen by users.
- Uses the national small hydro authority as a catalyst and liaison that links the needs and contributions of local groups with the resources of public and private institutions.
- Involves many communities through its extensive outreach activities.
- Allows greater space for feedback from experience gained in the process of planning and implementation itself.
- Maintains flexibility in responding to unforeseen contingencies, thus avoiding problems and exploiting opportunities.
- Can be interrupted until additional funds become available, rather than terminated if resources run dry.
- Puts host country agency in greater control of workflow by depending less on outside consultants and making them more pragmatically oriented to the needs of the local community.
- Enhances the participation and capacities of persons and groups that might otherwise be excluded from, and therefore hostile to, the development process.
- Can respond to a wide range of community initiatives with a variety of technical and organizational methods.
- Capitalizes on local resources in remote areas at low opportunity cost.

The disadvantages of small decentralized hydropower include:

- May not fully use the potential of the site.
- Might not provide sufficient amounts of electricity after demand from local community grows.
- Could be subject to more frequent breakdown and malfunctions.
- Requires large amounts of time for discussion. Risks involving the "wrong people."
- Diffuses effort of small decentralized hydropower team. Requires them to be skilled in community development which is unusual for persons trained as field technicians or engineers.
- Disrupts traditional habits and may raise expectations beyond what can be fulfilled.

- May make local communities more powerful and demanding of government.
- May give excessive influence to incompetent persons.
- Reduces the role and power of the national small decentralized hydropower authority to that of a consultant and broker without a large capital budget.
- Requires specially trained and dedicated field officers and transportation for them.
- Allows less space for advance planning, thereby inviting more unforeseen obstacles and difficulties.
- May become unrelated to overall national priorities or even its own program priorities through overresponse to local initiatives.
- Lacks sufficient advance planning and study to assure international lending agencies that their investments will be well spent.
- Forces host country into greater dependence on its own resources, thereby making national leaders more dependent on their own populations.
- Increases levels of expectation and autonomy of local communities, possibly creating centers of power that compete with the national government and national elite.
- May become too diffuse, even disintegrate, by seeking to be all things to all persons.
- Overlooks opportunities at national and international levels because of micro- rather than macro-perspective.

Management, Training, Operation, and Maintenance of Small Hydropower Plants

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INTRODUCTION

Suitable management, training, operation, and maintenance for small hydropower plants are determined by the size of the plant, the load development, and the staff levels, which are partly determined by the national policy.

The policy behind small hydropower projects usually is loosely defined as "rural development" or "rural electrification." Within this policy there may be a whole range of programs in areas such as education and agricultural and industrial development that are intended to satisfy numerous political and socio-economic objectives. Whatever these objectives are, it is important to define them.

There are two general policy approaches to hydropower development: centralized and decentralized.

Centralized policy

The centralized policy hinges on building as many plants as possible and using engineering staff as efficiently as possible in order to spread the overhead of the operation. This type of development implies that the government, the electricity department, or both will be involved and that the plant size will be about 200 kW. To handle smaller schemes, such an organization must achieve some economies of scale by spreading the cost of operation and maintenance staff among a number of installations. Many small plants cannot justify the salary of a full-time operator; these plants must be run automatically, or part of the operator's salary must be met by the development of a suitable small industry on the plant's premises. With careful and flexible management, the electricity board may be able to operate plants as small as 25 kW.

Decentralized policy

The decentralized policy involves the manager in motivating people through field officers, agricultural groups, and similar channels. This system can be successful only if the local community asks for what is technically and economically feasible. It is dangerous to consider starting a micro-hydro development program with turbines in the 15-50 kW range, because this size may be too small for the electricity department to run economically and too large for the local population to run totally independently.

In its simplest form, decentralized development consists of small turbines of a few horsepower which should be regarded more as agricultural implements than as hydro installations. They are suitable for driving grinders, water pumps, and battery-charging plants, and can be supplied through local outlets and agricultural extension groups. They are capable of producing power at the same cost as a multimegawatt unit.

The decentralized system is, in itself, a training program for local people. As the number of these small plants increases, the technology spreads. More plants will be built as the demand for power increases, and plant size will increase as the installers become more competent.

MANAGEMENT'S RESPONSIBILITIES

It is the responsibility of management to interpret the policy objectives of the project and to formulate a workable plan. Management's job is to explain what is possible—not to become involved in the "nuts and bolts" of the project, unless the managers are technically oriented. If a hydroelectric scheme is uneconomical or unworkable, management has failed at some level. For example, the basic policy may have been wrong, or the plant operator may not have been trained properly.

Projects often have failed for another reason: management assumed that, if the plant was built, a way would be found to operate it economically. Undoubtedly, it will cost more to install the first plant, but this cost should be the result of "learning time," rather than overly elaborate engineering; engineers should not become accustomed to planning on a grand scale. It is not realistic to spend a large sum of money on an elaborate pilot project and then reduce the costs on subsequent projects; this practice increases the danger that the pilot project will bear little or no resemblance to subsequent plants.

The different approaches to micro-hydro generation make different demands on management. For every size of plant, there is a suitable size of organization to install and maintain the plant without being "top-heavy"; small hydro is not merely large hydro scaled down. For this reason, the appropriateness of the design is critically important to the efficient operation and maintenance of the plant.

PLANT DESIGN AND MAINTENANCE

Progressive failure, rather than catastrophic failure, should be the goal of hydropower designs. The design should create systems that will fail progressively from wear and tear, but that are repairable or able to operate at reduced power until repairs can be made. For example, flat belts may break, but with a little ingenuity, they can be repaired and can continue to operate at reduced power.

If a plant is the only electric supply for a hospital, repairability of components is especially important. If some critical items of equipment, such as water pumps and grinders, are driven from the turbine shaft, an electrical failure will not impede these activities.

Catastrophic failure is much more likely if a gearbox is used and the oil is not changed; it is not possible to operate at reduced power with stripped gears. The consequences of such a failure may extend beyond the component that fails. If a bearing fails, it may damage the shaft and create a much more serious problem. Because repairs may take many months, it is important to limit the number of components whose failure would cause a total shutdown. When possible, spares should be kept on site and the operator should know how to replace them.

Dams and channels

The civil works comprise a large proportion of the total budget and are subject to considerable variation according to the site, the method of construction, the use of local materials, and many other factors. The design of dams and power channels can significantly affect initial costs and maintenance costs. With a limited budget, it is better to design dams and channels that can be built with local materials and easily repaired rather than to risk failure of a more elaborate structure. Most projects use a dam or weir to divert the flow into the penstock or channel (flume). This can be a very modest structure of rocks from the river, or a concrete structure costing thousands of dollars. Although the modest structure (seasonal intake) may be partly or totally destroyed during floods, when the water level has fallen, it is a simple matter to rearrange the rocks to divert the water. Numerous projects have been abandoned because a breach in the dam lowered the water level so that it would no longer flow into the intake.

On the other hand, although concrete channels are relatively easy to maintain, their cost is prohibitive. Using stone from the site to protect the bank is a cheap alternative to concrete. If it is necessary to cross a landslide area, however, the flume should be constructed from wood. If a slip occurs, the flume can be dismantled and rebuilt on a new alignment, and at least some of the materials are likely to be reusable.

Desilting devices and trashracks

Desilting arrangements often cause problems, because the designer gives too little attention to removing the silt from the chamber. It is not realistic to expect the maintenance staff to dig it out, because silt usually is deposited very quickly during floods and may accumulate at the rate of several tons per hour. Another frequent design fault is putting baffles in the chamber. This increases the velocity and turbulence, the opposite effect of what is required.

Screen (trashrack) clearing was one of the main reasons for the decline of micro-hydro in the Western world. Most plant operators do not have the time or inclination to clear bar screens every few hours. The cost of making the screen larger is prohibitive. The solution is to make turbines that cannot be obstructed, or to install a system of self-cleaning screens. However, self-cleaning screens are not always reliable. Although it is a simple matter to get the debris out of the water and onto the screen, very few screen-raking devices will operate unattended for long periods.

Pipelines

Because the pipelines of medium- and high-head installations account for a significant portion of the total cost, it is important that they last a long time. Major considerations are the pipe's initial cost, the installation cost, and the maintenance costs, which depend on the kind of pipe used:

- Steel pipe is very strong and easy to weld in large diameters; smaller diameters are less attractive, particularly if the pipe is flanged. With steel pipes, the protective coating is of utmost importance.

- PVC is very easy to handle and join and is about half the price of steel. However, it is vulnerable to impact damage from falling rocks and can be degraded by sunlight (this is a surface effect, but cracks can propagate under surge conditions). PVC pipe should be painted if it cannot be buried.

- Polyethelene pipe is now available in large sizes and is joined by heat fusion. It is very strong, and is flexible enough to bypass obstructions. Its application in the micro-hydro field looks promising.

Turbines

The turbine is a simple machine and is usually very reliable, but the associated electrical and governing equipment is another matter. Maintenance may be carried out on a day-to-day basis, but monthly or yearly inspections tend to be ignored on the grounds that "if it is working, why do anything?" It is now possible to make a plant virtually maintenance-free so that, apart from clearing the screens, the customer is required to make only rudimentary maintenance checks. For example, the bearings can be sealed units, which prevents damage to bearings from overgreasing or dirty

grease. With sealed bearings, it becomes the supplier's responsibility to arrange for servicing.

Using modern flat belts can make the drive virtually maintenance-free and very efficient. V-belts are very durable but are less efficient and emit a lot of dust. Dust itself is not a problem, but it makes the powerhouse dirty. This may reduce the operator's pride in the machine, which often results in a slack approach to maintenance.

Alternators

The alternator is often the weak link in the system, because it is difficult to effect quick repairs in the event of a winding or control failure. The cheaper construction methods used in modern machines can lead to sticking brushes; this may remain unnoticed until damage has occurred. Because accumulation of "brush dust" on the holder is a common cause of "flashing over," regular cleaning is advisable. Some plants have found it essential to use only brushless alternators, because even the minimal maintenance of slip-ring machines often is forgotten. It is unfortunate, however, that with the introduction of brushless machines has come the automatic voltage regulator (AVR). The AVR undoubtedly is their weak point, and they appear to have a limited life. On most hydro applications, a static (transformer-controlled) excitation system offers the best option, because of its simplicity and reliability.

Governors

Governors for traditional plants usually are complex hydraulic or electromechanical systems. Because of their complexity, they are vulnerable to abuse and inadequate maintenance. However, if they fail, the plant can continue running at fixed load or with a full-time attendant to vary the power.

The electronic load governor has been developed over the past 30 years, and many plants are now using this system. It is an inexpensive item, operates much faster than traditional units, and allows the use of a very cheap turbine.

Control systems should be as simple as possible; an excessively complex system of safety devices can cause the very situation that it is designed to avoid. Problems may arise because of corrosion caused by humid conditions, or because the safety relays will not function and have to be wired out by the plant operator.

Successful small hydro systems

Examples of successful systems of hydro plant operation and maintenance include the following:

- A Sri-Lankan tea factory, a Welsh slate quarry, and a New Guinea gold mine all have water turbines to drive their own machinery; surplus power is supplied to the local community or the "grid system." The plants range in size from 100 kW to about 3 MW. Their own engineers perform all the maintenance and are involved with the main commercial operation. The electricity produced can be regarded as a by-product of the main operation.

- A blacksmith shop in Wales and a rice mill in Nepal work on the same principle as the previous example, but each employs only two or three people, and the plants range from 5-25 kW. When the day's milling is completed at the rice mill, the belts are changed over to the generator and the village is illuminated. No house can switch off its lights; therefore, the load is constant. At about 10 p.m., the plant is shut down for the night.

- A forestry station in Thailand and an old plant in Nepal that generate 25 kW-3 MW are run by a centralized electricity authority, with backup and maintenance provided by a team who service diesel stations in rural areas. To be successful, this system requires a network of all-weather roads.

Unsuccessful small hydro systems

The following are examples of unsuccessful systems of hydro plant operation and maintenance:

- Three turbines designed for a specific site in a mountainous country were installed on a totally unsuitable site, because this site was a few miles nearer the village from which the project engineer came. As a result, the waterflow is sufficient to supply only one of the turbines.

- Another site has a dam 10 m high that failed during a flood. The station functions at a head of more than 100 m and supplies a substantial amount of power to electric pumps, which lift the water from the river into the intake channel. However, the channel is now too high for the water to flow into without this dam.

- A multimegawatt plant with Francis turbines had to renew the runners after 18 months at a cost of more than 100,000 pounds sterling each because of inadequate desilting.

- In a 5 kW plant, the silt eroded the pipe bend under the turbine and then removed half the foundation of the powerhouse.

- A 30 kW plant operated by an electricity board had a full-time staff of 10, and another, a 2.5 MW plant, had a staff of 35. Neither plant was economical to operate.

- A micro-hydro progam director ordered approximately 30 standard turbines from a European manufacturer and then had considerable difficulty finding standard sites in which to install them. Only a few have been installed and are operating.

Many micro-hydro plants have a very uneven "load curve," resulting in a low overall "load factor" and then a period of "overloading." It is essential that the load

be developed in an efficient manner that includes both industry and off-peak load, such as heat storage cooking.

TRAINING REQUIREMENTS

The program director should have a general knowledge of all facets of engineering. A knowledge of agricultural and small rural industries is also useful. He or she should be able to provide backup for the project engineers and be able to specify, order, and choose all the equipment required on site. The director should have a working knowledge of project planning procedures and be prepared to learn how to use a microcomputer. The program director must have control over the budget.

The project engineer should be involved with the project from survey through design, construction, and commissioning. This engineer must be a practical multidisciplined engineer who can survey, make basic drawings, and select and lay out the site. He or she should be able to weld; perform basic machining and fitting; and be capable in rigging, building, and electric wiring. A working knowledge of electronics, control systems, and plant design is also necessary. The project engineer is the key person working in the field and should be backed up by the program director; working from a central office, the program director should be able to work with three or four project engineers. Depending on the size and location of the sites, the project engineers can be working on several sites simultaneously.

A team of three project engineers, one program director, and one secretary should be able to install at least 20 hydropower schemes of 10-50 kW per year with a labor force of 12 persons.

The plant operator can be trained to start and stop the plant and carry out basic maintenance checks, but should be backed up by the services of an engineer if anything goes wrong. Such a system requires a network of all-weather roads. Alternatively, the plant operator may be a technician who is running a business in or near the powerhouse and is trained to carry out all the necessary maintenance.

On larger programs, a liaison or field officer may be required to find customers, negotiate wayleaves (rights-of-way), and generally handle the public relations problems.

SUMMARY

The main problem with micro-hydro generation is project management. The size and the type of project determines appropriate management training. The best sources of training are irrigation or water supply organizations. In some countries, there may be scope for involving the Army Corps of Engineers. Management should:

- Give the site engineer as much responsibility as possible,
- Beware of overspecifying projects or writing inappropriate regulations, and
- Be flexible.

Operation and maintenance are closely tied to the initial design of the project. Those who design should be involved with the installation and fully understand the commitments of manpower and materials that are necessary for successful operation and maintenance of the project. They should:

- Keep it simple,
- Be aware of the consequence of a failure, and
- Assume that if something can go wrong, it will.

Institutional Aspects of Mini-Hydropower Programs

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ENERGY AND RURAL DEVELOPMENT: A NEW POLICY AREA

Energy and rural development has become a new policy arena. Until recently, the problem of providing energy to rural areas was merely a matter of extending urban grids and petroleum distribution. In many developing countries, these two functions are in different hands: the government operates centralized electricity systems, and foreign oil companies, with private entrepreneurs, own and operate a network of oil refineries, oil product transportation facilities (pipelines, trucks, railroad tank cars) and distribution depots and retail outlets.

During the 1970s, the international oil cost and supply crisis and its convergence with the fuelwood and traditional energy crisis in certain countries highlighted 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 combine to stimulate interest in this technology.

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. A growing number of studies suggest that, given this pattern of consumption, a demand for electricity for productive uses will not develop in the absence of many factors. Some of these are:

- The actual or potential existence of adequate transportation facilities to and from markets and sources of raw materials;
- Availability of an adequate supply of other forms of energy needed for a particular industry or industrial complex;
- Sufficient investment capital, in the form of credit or savings;
- The presence of trained technicians and managers familiar with problems of marketing, cost accounting, personnel management, and business operation;
- The existence of a market town or small city in which a complex of mutually supporting industries can be established; and
- 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 centralized national power organization may view the development of decentralized power facilities as a threat to its own generation capacity and to the development of an integrated national grid. In some countries, however, the unreliability of power from the national grid is 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.

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.

Single utility

In countries with a socialist tradition, a single national utility may be involved in the generation, transmission, and distribution of electricity to both rural and urban areas. This situation exists, 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.

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 division, in part, reflects the large subsidies that are allowed to rural electrification programs. These rural electrification boards (Bangladesh), corporations (India), or administrations (Thailand, Ecuador, and Bolivia) may or may not own and manage the distribution system. In Bangladesh, India, Bolivia, and the Philippines, the government authority has given technical, managerial, and financial support to establish cooperatives for this purpose. Some of these rural systems have mini-grids into which they distribute power from diesel units. However, 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 the grids.

Autonomous mini-hydro authority

Although institutional responsibility for mini-hydro generation usually resides in the national power organization or the rural electricity corporation, in some places (Nepal and Peru) 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 Division of the Department of Electricity, which also works with villages to construct small hydro plants. In Peru, an ad hoc commission coordinates the planning and execution of mini-hydro projects.

Local community

In a growing number of cases, local communities install micro-hydro units, sometimes with the assistance of faculty and students from nearby technical universities. 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 assisted in local hydro development for many years. 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; commune members receive training in all aspects of hydraulic machines at colleges and vocational institutes. The Peace Corps in Liberia is promoting a micro-hydro installation (30 kW) in a remote village.

COMPARATIVE CASE EXPERIENCES

The development of mini-hydro programs in two Asian and two Latin American countries can be examined from a comparative institutional perspective.

The Philippines and Thailand

The Philippines and Thailand are among the top 10 oil-importing developing countries. Both have approximately the same per capita income levels and have fairly advanced rural electrification programs that make extensive use of small diesel generators. In Thailand, there are approximately 400 diesels ranging in size from 50-6,000 kW. Both countries are trying desperately 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 (PEA) in Thailand. 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% of the barrios and 20% 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. 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. Thailand has identified several hundred sites; one source estimates a potential capacity of 800 MW of firm, dry-season, unregulated power.

In Thailand, responsibility for mini-hydro development is dispersed; in the Philippines a Presidential Directive gave NEA sole jurisdiction in this area in 1979. This directive was part of an overall policy decision to promote energy self-sufficiency in all rural cooperatives. Under this policy, NEA has begun working with rural cooperatives to plan for the introduction either of mini-hydro systems or "dendro-thermal" units (wood-burning steam or gas-fired powerplants). NEA has signed agreements with China and France to provide credits for hydro units and gas-turbine powerplants. NEA will provide loans and technical assistance to cooperatives that adopt these technologies.

Thailand also has a National Energy Administration (NEA), and both NEA and PEA are installing mini-hydro units in rural areas. The Royal Forestry Department and the Royal Irrigation Department also operate small, locally made units. PEA reports to the Ministry of Interior and is the Government agency responsible for distributing electricity to rural consumers. NEA is under the Ministry of Science, Technology, and Energy. It 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.

133

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 that the local cooperatives can build and manage micro-hydro systems effectively at significantly lower costs than imported units. NEA has obtained assistance from the United Nations Development Programme, 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 and from Finland.

The main entity responsible for economic planning in Thailand is the National Economic and Social Development Board (NESDB). The NESDB currently is considering the program and structure of the mini-hydro sector in Thailand and is preparing an overall Energy Master Plan 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 nationalization of this sector may occur in the future.

The pace of development in mini-hydro clearly is accelerating in both the Philippines and Thailand. The growth of decentralized generating capacity is necessitating increased investment coordination in the power sector. The World Bank has stressed to the Philippines Government the importance of coordination between NEA and the National Power Corporation, which is embarking on a major program to build large generating plants based on geothermal energy and domestic and imported coal. Similarly, 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 and benefits of the two approaches, in particular to see whether the policy in the Philippines of rural energy self-sufficiency stands the economic test of time.

Peru and Ecuador

Peru and Ecuador currently are oil-exporting countries whose petroleum resources will be diminished severely by 1990 as a result of high domestic consumption encouraged by Government subsidies. Policy-makers 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% (60,000 MW) is exploitable; to date, only 3% of this has been developed. ELECTROPERU is the public-sector enterprise charged with system operation and project execution. ELECTROPERU has five operating regions; 87% of the electricity demand is concentrated in the region around Lima.

As of 1979, approximately 73% of Peru's electricity generation (5,470 GWh from 1,397 MW of capacity) came from hydropower, primarily large plants. Within ELECTROPERU, small and mini-hydro plants are within the purview of the Office of Applied Technology (OPTA) under its small hydroelectric program. MEM began its program of mini-hydro development in 1978 by studying of power systems of 50-1,000 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 the construction of 50 plants between 1980 and 1985. Foreign assistance will finance many of these.

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 usually is sought, particularly during the construction phase. Local authorities operate the system; ELECTROPERU provides the training. This approach has proved successful in effecting cooperation between rural people and Lima decision-makers.

Ecuador, on the other hand, has only begun to exploit its hydroelectric potential. Ecuadorian hydro potential is an estimated 22,000 MW. Installed capacity in 1977 was 612 MW, thermal and hydro, which was developed on a large scale only during the 1970s. Roughly 60% of Ecuador's population remains without electric power.

Except for a small number of regional power companies, the National Electrification Authority (INECEL) is under the jurisdiction of the Ministry of National Resources and Energy (MNRE). Until the creation of the National Energy Institute (INE) in 1978, the development of energy resources in Ecuador was not coordinated. INE coordinates energy policy and recommends courses of action. Ecuador's oil reserves are being depleted rapidly; importation is expected to begin in the late 1980s. Initial planning efforts, followed by conservation and exploitation of the vast hydropower base, are expected to begin in the early 1980s.

Development of hydroelectric power is one of the cornerstones of the national development plan. The contribution of hydro plants to electricity generation is expected to increase from 32% in 1978 to 80% in 1985. INECEL will execute and manage the grid and the large electric generating projects; local authorities will manage regional and municipal power. It is expected to provide power to 60% of the rural population. The program is principally a grid extension effort suitable for communities that are near major roads, have high agricultural productivity, and have populations of more than 500. Because these conditions disqualify many isolated villages, INECEL formulated a mini-/micro-hydroelectric plan.

Before the construction of a national grid, INECEL had built some 50 mini-/micro-hydropower systems; some of these subsequently were abandoned. Under the new plan, retired plants will be brought into operation or the equipment will be 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 on the characteristics of existing local organizations. INECEL will provide management expertise and training. This type of organizational structure is similar to that found in Peru, in that a central decision-maker determines how energy technology will be applied in rural areas. Often this structure can lead to misperception of needs or concentration solely on the urban centers. A balanced program meeting the needs of both urban and rural populations is necessary.

CONCLUSIONS

The role of mini-hydropower in developing countries is caught in current policy debates 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 groups 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, providing tangible proof of the government's commitment 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 effects 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.

I wish to express my sincere thanks to Robert Ichord, Asia Bureau of AID, and Adriane Wodey of Experience Inc. for help in preparing this paper.

REFERENCE

1. Revelle R. "Future Energy Resources and Use in Asia: The Needs for Research and Development." Proceedings of USAID Asia Bureau Conference on Energy, Forestry, and Environment, Manila, Philippines, November 1979, p. 46.

135

Management Considerations for Small Hydroelectric Powerplants

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INTRODUCTION

Anyone visiting a small hydropower plant for the first time will be surprised by the very small staff employed there. Man has adapted nature to his needs so well in the field of small hydropower that everything seems to work without his intervention. However, those in charge of the management, operation, and maintenance of the installations must be familiar with all aspects of the field. With its modernization, small hydro equipment has become more and more complex. Therefore, the engineers and technicians in charge are obliged to dedicate an increasing amount of time in their professional lives to stay abreast of developments.

MANAGEMENT

During the implementation stage of a country's small hydro plant development, the most cost-effective method of managing these generally remote isolated schemes would be to rely on the staff of the nearest large hydroelectric plant. As these small hydropower plants proliferate, they can be managed from a centralized small hydropower plant.

TRAINING

Staff training is indispensable, because the success of a project depends so heavily on human factors. The staff of hydroelectric plants must be trained in many areas, including electricity and electronics, mechanics, and hydraulics. This training should involve the operating staff, whose job it is to ensure the remote management of the equipment, and the maintenance staff, whose essential task it is to ensure that the installations are in good operating condition.

Such staff training can be handled effectively by either an equipment manufacturer or an electric utility.

Equipment manufacturer training

An equipment manufacturer can train the operation and maintenance staff of a small hydro plant at its factory during the equipment manufacture stage. This training should include both theoretical and practical aspects of the equipment to be used. On site during the different phases of assembly and operation, the manufacturer should provide practical "hands on" training to staff members selected by the foreman of the small hydro plant.

The training provided by the manufacturer will acquaint the staff with the essential, fundamental characteristics of the equipment, and preventive maintenance and repair procedures (detection, location of defective pieces and their repair, etc.). If the manufacturer is to train the operation and maintenance staff, the bidding documents prepared for the necessary small hydro equipment should describe the training requirements.

Electric utility training

The staff training handled by manufacturers can be reinforced by an electric utility that has operating hydroelectric plants. The staff can receive theoretical training at the utility's training center, followed by a practical "hands-on" course at one of the utility's hydroelectric plants. This kind of training would result from a previous agreement between the foreman of the hydro plant and the electric utility.

Following training, it is necessary to introduce periodic refresher courses to improve the output and productivity of the staff of these small hydroelectric plants.

OPERATION

Hydroelectric powerplants should possess the most up-to-date equipment possible so that they can be remotely controlled by the nearest generation or transmission station. This procedure reduces the cost of producing electricity, in part by keeping the cost of labor to a minimum. Of course, on a short-term basis, this solution would not benefit countries that have abundant, inexpensive labor.

MAINTENANCE

Hydroelectric equipment, like any equipment that involves moving parts in the production of electricity, requires a schedule of regular inspection.

The corrosion of wheels and seals that come in contact with the water results in losses from leaks, shocks, and hydraulic friction that can reach 20%—with a proportional reduction in output. This corrosion may be due to particles, such as sand or mud, suspended in the water, cavitation, or the chemical composition of the water.

Consequently, some devices, such as wheels, wheel casings, labyrinth seals, and draft-tubes—depending on the type of turbine—require maintenance ranging from simple but regular inspections to more complex work that involves a series of tasks. Operating experience at each plant will determine the frequency of these inspections.

These inspections and the maintenance and repair work require the intervention of an adequately equipped mobile team of engineers who are available on demand. Under normal circumstances, this team should handle the inspection, maintenance, and repair work according to a preset schedule. However, the team must be available after hours and during holidays in case of equipment malfunction or breakdown.

CONCLUSION

During the course of feasibility studies for small hydro plants, it is necessary to set up a managerial structure, a plan for staff training, and operation and maintenance procedures and schedules that are suitable to each site and each country. Although closely related, each of these aspects depends on such factors as the number, type, and importance of small hydro schemes to a country's overall energy plan; therefore, each country's approach to management, training, and operation and maintenance is, by necessity, unique.

137

Staffing and Record-Keeping for Mini-Hydropower Plants

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INTRODUCTION

Once consumers acquire electrical service, they quickly come to rely on its quality and continuity. For this reason, hydropower plants must be operated and maintained by properly trained and experienced personnel. For the different phases of a mini-hydro project, the training requirements will differ:

- Site inspection. This task should be performed by a specialist; no basic training can prepare an inexperienced person for this job.

- Prefeasibility and feasibility studies and final design. Specialized advanced-level professional training is required for each of these tasks. Such training should employ an integrated approach to these tasks, rather than viewing them as requiring unrelated skills.

- Ground-breaking. Ground-breaking is the first major task requiring specialized training that can be undertaken on the job.

- Site construction. In most cases, these jobs are handled by construction firms preselected by financial institutions. These tasks are undertaken by both unskilled workers and the country's own skilled and specialized workers.

  As work progresses, it will be necessary to gauge the workers' aptitudes for leadership, detailed and delicate tasks, physically demanding work, and discipline, organization, and follow-through in handling assigned tasks.

  When the construction firm will not be operating the completed plant, it is the firm's responsibility to identify the strengths and weaknesses of the construction crew and staff. The firm's firsthand knowledge of the workers, acquired during the construction period, is valuable in locating and training personnel to operate the plant. For example, the best plant operator knows where cables or pipes fit without needing to refer frequently to the original plant designs, which generally are not available as a complete set. A person who has followed the construction from the beginning to the end will probably be a good plant operator, and those in charge of the construction are likely to know such a person.

- Plant operation. On-the-job training for future plant operators from the moment of ground-breaking remains the ideal. However, at any site, the turnover of personnel is high, in part because numerous subcontractors are involved. Thus, plant operators are often recruited after the plant is already completed and operational. This procedure is not desirable because, for industrial equipment in general and electricity generating equipment in particular, the crucial steps include commissioning the plant, undertaking the required tests, and making the necessary adjustments. The absence of the operator at this stage of the project can cause problems in the long run. When the plant is ready for operation, all the staff in charge of its technical and financial management must be ready.

THE BASIC FILE

To operate a mini-hydro plant efficiently, it is necessary to keep a "basic file" of several kinds of documents. These include the plant's design plans, execution and other records important to operation and maintenance, and technical manuals.

Design plans

For various reasons, the original designs of the plant are often modified during construction. Therefore, it is absolutely essential to reassemble plans. Although necessary for the efficient continued operation of a plant, this step is often neglected. Design changes made by the construction supervisors are often sent to the engineering firm to be incorporated in the plant designs but are never returned. Consequently, the operator has only the initial project plans. Because well-designed, well-constructed work may show no serious problems for 5 or more years, this revision of the original drawings may not become important to maintenance and repair until enough time has passed to make identification of the changes difficult.

Records

Numerous kinds of records are necessary at different stages of the plant's operation. The most elementary is the materials record card which includes the inventory of equipment. It records the symbol, function, specification, manufacturer, and quantity in use and in storage, of every piece of equipment in the plant, the plant schematics in which it can be found, and all

relevant remarks. The basic file therefore includes a materials record card of each item, which functions as an identification card.

At times, unexpected failures occur during the operation of a plant. These incidents must be listed on the materials record card of the involved parts, followed by a detailed incident report. The report should include all relevant statistics, and contain a description of the action taken and suggestions for improving operation.

Technical manuals

It is common practice for the manufacturer to supply a technical manual describing the equipment. The manual usually includes:

- Procedures for handling, storage, and installation;
- Descriptions of the equipment's parts;
- Start-up procedures; and a
- Maintenance plan, which contains instructions for disassembly.

Such manuals emphasize the importance of maintenance on periodic (daily, weekly, monthly, annual, biennial) and cyclical (1,000, 5,000 and 10,000 working hours) schedules; the actual frequency depends on site-specific conditions.

In addition to the technical manual, the manufacturer can provide other useful information. For example, management can request a list of equipment parts that need frequent maintenance or replacement, and a list of the tools required to operate and maintain the plant.

All manuals should be indexed and filed with the materials record cards. The quality of the maintenance and, thus, the life of the plant will depend on the attention given to this basic work.

TWO SMALL HYDRO PLANTS

Kpimé

The 1.7 MW Kpimé plant utilizes two Pelton turbines operating under a head of 200 m. A 13 m high dam forms a reservoir of 860,000 m^3 which furnishes water to the plant through a power tunnel and penstock. The staff consists of the powerplant supervisor, the caretakers, and the operators:

- The powerplant supervisor. The supervisor is thoroughly familiar with the units because he was involved in the construction of the plant. He maintains the technical data and keeps the records up-to-date.

  He is responsible for supervising the caretakers and operators. He schedules periodic and cyclical maintenance, devises cost charts, delineates and supervises the operational tasks, and determines when outside assistance is needed. He is responsible for ensuring adequate supplies such as lubricants, maintenance products, and spare parts. His job also entails writing the monthly and annual reports.

- Caretakers. The caretakers register the dam's water level and maintain the buildings. There are three caretakers at Kpimé who work back-to-back 12-hour shifts.

- Operators. The operators work as a two-person team composed of a machinist and an electrician. They handle maintenance and other operations according to a schedule established by the supervisor. They also handle the operation tasks assigned by the regional power dispatcher. Their daily tasks include cleaning, maintenance, hourly readings of the various meters, daily reports, and incident reports. Their reports are incorporated in the plant's records.

Aledjo

At the micro-hydro plant at Aledjo, a Pelton turbine utilizes a design flow of 4.5 l/s to generate slightly less than 10 kW. Automation proved to be the best solution at this plant because it lessened the impact of the site's difficult accessibility and reduced the operating costs (including labor costs) and, consequently, the cost per kWh.

All the units at Aledjo are serviced by a general workshop supervised by a chief. The plant is not grid-connected and the energy is not sold; consumers are not metered.

At this plant, the turbo-generating set runs continuously, and the alternator's circuit breaker is remotely controlled. The command switches are spread among the buildings; when necessary, the breaker is opened and the alternator grid is separated.

The maintenance of this plant consists of a simple inspection visit every 2 weeks. The Aledjo plant has had specific operational problems, largely environmentally induced. These include effects of lightning, sea spray, and dust.

Lightning

Lightning is a major obstacle to the operation of the powerplant. The following devices have been installed:

- Pointed spark gaps;
- Antibird spark gaps at the beginning of the medium voltage transmission line;
- Lightning protectors at the beginning of the medium voltage transmission line; and
- Lightning rods with Elita radioactive point on hilltops.

Everything is connected with a good ground in water.

The spacing of the gaps and the resistance of the grounding are checked periodically. This information is recorded and used to modify O & M scheduling requirements.

Sea spray

Near the sea, a very humid and salty environment can cause problems. The sea spray leaves a salt deposit which, as a conductor of electricity, provokes breakdown of the insulation and flashover. To combat this problem, the following actions and devices have been used:

- Cleaning with water,
- An insulating compound, and
- Air conditioning.

Dust

This is the principal enemy in the generation of electricity and with electronics, and it must be attacked systematically. The harmattan (hot and dry wind found in western Africa) brings the peak dust problems. The following measures have been taken to alleviate these problems:

- Cleaning,
- Blowing, and
- Air conditioning.

In both the Kpimé and Aledjo plants, the principal maintenance operation is the bimonthly lubrication of equipment.

MANAGEMENT OF HUMAN RESOURCES

The Union of Producers, Conveyors, and Distributors of Electrical Energy in Africa is committed to the management of human resources. For this reason, it created a Human Resources Management Committee divided into subcommittees on vocational training and management planning.

Human resources management must be flexible; it must be able to evolve to encompass all aspects of recruiting, training, and promotion.

Any investment program in the developing countries must be integrated and global; that is, it must include a training component. Projects must be carefully analyzed to ensure the continued operation of the plants. This task cannot be delegated randomly; it is in the best interest of all concerned—planners, financial institutions, builders, and operators—to make a careful selection of properly trained and motivated staff to operate a hydropower plant. A multidimensional human resources management policy can further this goal.

The Process of Introducing Hydropower to Rural People

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INTRODUCTION

From the planning through the operation stages of a decentralized small hydropower plant, the condition and perceptions of the rural people must be considered. Introducing small hydropower to rural people involves more than installing the equipment; it also involves an understanding of numerous social factors.

PROJECT IMPLEMENTATION

There are two major methods of introducing small hydro to rural areas; each method has advantages and disadvantages. In one method, either governmental or nongovernmental organizations implement the project, and the local people purchase power from them. With this method:

- The local people usually will have a passive attitude toward the project, because they take no part in it and purchase the power from others.
- The project will neither motivate the local people nor help to develop their self-confidence, because they neither originate the idea nor implement the project. Motivation and self-confidence are very important for rural development in general.
- The project will emphasize technology and management only.

In the other method, the local people implement the project cooperatively. With this method:

- Because the idea comes from the local people themselves, they will gain a sense of achievement, self-confidence, and self-reliance, rather than depending on help from others. Experience shows that local involvement influences the use of the electricity generated by the project.
- Technicians must devote considerable time and patience to the project to achieve the type of success described above.
- Engineers and technicians should have a working knowledge of—or at least be aware of—the social condition and perception of the local community. In developing countries, such persons are still rare.

No matter which approach is used, the local people must be prepared to accept hydroelectricity.

Most rural people identify electricity with the diesel engine. To change perceptions about electricity among rural populations and to ensure the success of a small hydro program, a long-range strategy and a program to implement that strategy must be developed. Experience shows that film is the most effective method to change attitudes about electricity, especially within a country like Indonesia which consists of thousands of islands. (In film, or any other medium, it is important to emphasize that electricity has many uses, such as providing power for equipment for grinding and oil-expelling and refrigeration, and that it is not just for lighting.)

OPERATIONAL COST

Rural people do not fully understand the concepts of operational costs and depreciation of small hydro. To rural people, water is something that comes from nature. For hydropower projects, rural people consider only the cost of initial implementation because they regard water—and thus waterpower equipment—as something that will last forever. They do not readily comprehend why operation and maintenance procedures entail costs. This attitude may pose an obstacle to management of the project. Moreover, in many developing countries, rural projects are implemented at no cost to the rural community. This policy may reinforce the lack of understanding of the nature of post-implementation costs of small hydro projects.

Changing misperceptions is a long process. Studies should attempt to determine the readiness of the society for small hydro by examining the country's social groups, economy, and traditional ways of managing credit, finance, sharing, etc. Experience shows that standard management techniques will face many obstacles and, therefore, will be difficult to use.

If a study of these aspects of a society indicates that change is possible, the community's leaders can be offered Achievement Motivation Training (AMT). Experience shows that AMT greatly influences attitudes and can be used to influence rural people's management methods. Then the use of electricity for productive activities will become feasible.

Legislative Contributions to Private-Sector Development of Small Hydropower Plants

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INTRODUCTION

The private sector's involvement in small hydroelectric projects in developing countries can help these nations develop their hydroelectric resources effectively. By their nature, small hydro projects are attractive propositions for the entrepreneur because:

- Geographic dispersion of sites minimizes the stress on a nation's infrastructure.
- Project scale permits development by a small group of professionals in a relatively short time.

The development of small hydropower plants by the private sector is helped when there is a guaranteed market for the plant-generated energy at an attractive price. The developer can then negotiate a capital loan from a bank to finance the plant's construction and operation.

In this context, the Public Utilities Regulatory Policies Act (PURPA), passed by Congress in 1979, is a very promising development. Of particular relevance are Secs. 201 and 210. These sections mandate that electric utilities purchase electricity from a qualified small producer at a price that reflects the incremental cost to the electric utility of alternative electric energy. On the other hand, PURPA mandates that sales of supplementary and backup power by a utility to a small producer shall not be discriminatory and that they reflect the utility's average cost of electricity generation.

THE PUBLIC UTILITIES REGULATORY POLICIES ACT

The Public Utilities Regulatory Policies Act has played a major role in renewing interest in the development of small hydroelectric powerplants in the United States. Extracts from Sec. 2 of the Conference Report show the interest of Congress in this issue:

"The Congress finds that the protection of the public health, safety and welfare, and the preservation of national security . . . require:

- A program providing for increased efficiency in the use of facilities and resources by electrical facilities, and
- A program to provide the expeditious development of hydroelectric potential at existing small-scale dams to provide electric power." (24)

Title II of PURPA contains provisions that are without precedent worldwide (23): the use of legislative fiat to govern the purchase of power from two types of electric power generators—small power (including hydropower) producers and cogenerators. Specifically, Sec. 210 of PURPA was designed to circumvent three obstacles previously faced by small power producers that desired to interconnect with an electric utility (22):

- Electric utilities were not required to purchase electricity generated on either an "as available" or firm contract basis, even if the electricity were offered at a favorable rate.
- Sales of backup power to small power producers, which usually met all or most of their own needs, were often priced at a discriminatory high rate.
- Even if a small power producer were permitted to sell energy to a utility, it risked being deemed a utility and thereby being subject to numerous federal and state regulations. Compliance with such regulations often could cost much more than any economic benefits derived from the sale.

Secs. 201 and 210 address these impediments and, to varying degrees, eliminate or substantially reduce them.

Secs. 201 and 210 of PURPA

The important provisions of Title II provide the framework that determines the purchase of electricity by an electric utility from qualified small power production facilities at a rate consonant with the incremental cost to the utility of alternative electrical energy. A "qualified facility" is defined as one that has a capacity of no greater than 80 MW that produces electric energy primarily by the use of a renewable resource (including hydropower), and that has no more than 50% of its equity interests owned by an electric utility.

PURPA also requires that the rates for the sale of electricity by a utility to a qualified facility shall not be discriminatory, and that qualified facilities be exempted from federal and state laws and regulations that pertain to electric utilities. 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 utilities during emergencies." (20)

Additionally, Congress directed the Federal Energy Regulatory Commission (FERC) to promulgate rules to guide the implementation of Secs. 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, Sec. 210(f) requires 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." (20)

In summary, the five principal elements of Secs. 201 and 210 of PURPA are that:

- Only qualified facilities can sell electricity to the utility. The qualified facility will be defined in terms of its ownership structure, its size, and the resources it uses to generate electricity.
- The utility will purchase electricity at a rate consonant with its incremental cost of generating electricity.
- The utility will not discriminate in its sale tariffs against qualified facilities.
- The qualified facilities will be exempt from the legal and regulatory requirements governing the organization and financial reporting of electric utilities.
- The qualified facilities will be expected to meet minimum specified reliability requirements.

FERC promulgation of rules

On February 25, 1980, FERC issued its final set of rules under Secs. 201 and 210 of PURPA (to be codified as 18 CFR Section 292). Broadly, the regulations cover the following issues:

- Electric utility reporting requirements;
- Purchase rates;
- Sales rates;
- Interconnection costs;
- Required characteristics of qualifying facilities, such as ownership, operating and efficiency standards, certification, and exemptions from federal and state law.

In general, the rules are designed to make it exceedingly worthwhile for qualified facilities to sell electricity to any (inter)connected utility at an agreed purchase rate. The purchase rate of electricity from a new qualified facility (one built after November 1978) by an electric utility will depend on the "avoided costs" (the FERC term for the "incremental costs" mentioned in PURPA), plus the characteristics of the qualified facility's 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." (Sec. 292.101(b)(6) (45 FR 12214 (2/25/80)).

The data reporting requirements of the utilities have been designed to assist state regulatory agencies in determining the avoided costs. These include:

- The estimated avoided energy costs (cents per kWh) for various levels of purchases from qualified facilities. Data must include costs of daily and seasonal peak and off-peak periods for the current year and each of the next 5 years;
- 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 10 years; and
- Estimated capacity costs ($ per kWh) and associated energy costs (per kWh) for each planned capacity addition or planned firm purchase. (45 FR 12214 (2/25/80)).

Data provided by the qualified facilities that may also be considered in calculating the avoided costs include:

- Availability of capacity or energy during daily and seasonal peak periods, including dispatchability, expected or demonstrated reliability;
- Contract terms with the utility, including duration of purchase obligations, termination notice requirements, and sanctions for noncompliance;
- Coordination of scheduled outages;
- Usefulness of the qualified facility's capacity and energy during emergencies, including ability to separate its load from its generation;
- The individual and aggregate value of energy and capacity to the electric system; and
- 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. (Sec. 292.304(E)).

Each state regulatory authority has the option of weighing the above factors as it sees fit, of using and promulgating standard purchase rates throughout its service area for each type of qualified facility (such as wind energy conversion systems or small hydropower plants) 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 qualified facilities are couched in terms of average costs of electric energy generation and provisions of generating capacity. Rates shall not discriminate against any qualifying facility in comparison to other customers of the same class that 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 qualified facility and the utility's facilities.

It bears noting that small projects, such as small hydropower plants, will gain substantial allowances for avoided capacity costs only if considered in the aggregate for both size and reliability criteria.

More detailed analyses of Secs. 201 and 210 of PURPA are available from other sources (5,8,21,22). The work of Fox (6) is particularly useful for calculating avoided cost.

Implementation of FERC rules by state regulatory authorities

PURPA and pertinent FERC regulations 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 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, have a rule-making procedure that minimizes demands on state fiscal and administrative resources, and address directly the issues relating to rate structure and design on a technology option basis. Then, the state would establish regulations that would be applicable statewide to all utilities and qualified facilities.

The state utility commissions were required to promulgate implementation plans for Secs. 201 and 210 of PURPA by March 20, 1981. As of early June 1981, only 15 states had implemented FERC rules (9). 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 (see Table 1).

TABLE 1. Sample Purchase Rates (17)

State	Intermittent power (cents per kWh)	Constant power (cents per 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

IMPACT OF PRIVATE SECTOR INVOLVEMENT ON SMALL HYDRO DEVELOPMENT

The objective of PURPA is to encourage the rapid development of renewable resources, including hydropower, through a partnership of the public and private sectors. Two measures of its efficacy will be the rate at which new renewable systems, including small hydropower plants, are integrated into the national grid and the reliability of the new systems.

In April 1980, FERC issued an environmental impact assessment estimating that PURPA would stimulate non-utility-controlled entities to build 12,000 MW of capacity by 1995 (for all renewable resource technologies plus cogeneration).

However, FERC's estimate already seems unduly conservative. In 1981, FERC expected to receive 1,800 applications to study hydro generation at existing dams and at development sites—a 100-fold increase from the 18 applications received in 1977 (14). As of April 1, 1981, private entrepreneurs had filed applications representing a potential 5,674 MW (7). Most of the applications are for sites that meet PURPA requirements; approximately half of them compete for the chance to develop existing dams.

The proposed projects are scattered throughout the country and involve installing small hydropower plants 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 managing a project through all its regulatory, technical, and financial aspects; developing a contract to sell the small hydropower output; and formulating a scheme to attract investors.

A typical contract between a qualified facility and a utility would require that:

- The qualified facility would 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 qualified facility and the utility.
- The qualified facility would reimburse the utility for all the initial distribution and substation facility connection costs and pay an annual fee to the utility for operation and maintenance of the facilities (1).

Technical issues

Incorporating qualified facilities in a utility's generator and load mix will force the utility to review its planning and operating practices, including:

- Safety to personnel and equipment,
- Quality of service,
- Operational accommodations,
- Metering,
- Sizing procedures and interconnection limits, and
- Installation data needs.

Prichett (19) has delineated possible procedures for dealing with these issues. However, it will be necessary to establish clear guidelines about which entity is going to pay for any special equipment and labor that will be involved.

APPLICABILITY OF PURPA TO DEVELOPING COUNTRIES

The circumstances that induced Congress to enact PURPA in 1978 exist even more pressingly in developing countries whose economics have been devastated by the oil price increases since 1973. Massive payments for oil imports have soaked up a growing share of the export earnings of these countries, straining their ability to pay for essential imports and slowing down their economic development. Thus, the development of all viable renewable sources of energy, including small hydro, is imperative to the national security and economic well-being of developing countries.

In many countries, the optimal development of indigenous hydroelectric resources will require a partnership arrangement between the public and private sectors within the context of each nation's legal and socio-economic conditions. Legislation such as PURPA, which guarantees an attractive market price for electricity generated by qualified facilities, is a prerequisite for involving the private sector in the development of small hydroelectric powerplants in developing countries. However, legislation alone is not enough. Other factors can significantly influence small hydropower development by the private sector.

Factors that influence small hydro development

Numerous factors must be considered in judging whether small hydropower development by the private sector is viable (see Table 2 for an analysis of such project development in the Dominican Republic):

- A national awareness of the importance of developing small-scale energy projects is vital to rapid action. It is especially important in countries where the production potential of small energy resources is large enough to make a significant contribution to energy supplies nationwide.

  In practice, 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 also is important. By law in India, for example, small hydropower projects cannot be developed by the private sector (2). In most Latin American countries, water use for food production has the priority; 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 (10).

- Energy organizations charged with planning the development of the nation's energy resources can highlight the importance of developing hydroelectric and other renewable resources. They can also influence electric utilities to develop tariff structures that reflect the true cost of fossil fuels and encourage the incorporation of hydroelectric and other renewables into their energy supply mix.

  Because many small hydropower plant service areas are in rural areas, such an organization could also coordinate the activities of energy development entities with those of agriculture and rural development agencies.

- Existence of a public utility commission with responsibility for regulating electricity tariffs and development of the electricity sector is critical.

- Availability of capital for construction is a major concern to private developers. Clasgens and Rothschild (4) have listed many mechanisms for financing small hydro projects, including tax-exempt bonds and debt service 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 small hydro projects. It may be interesting to monitor the situation in California, where already a number of utility-private sector small hydropower contracts have been signed (1), to learn what kinds of arrangements are proving to be the most satisfactory.

  Government debt service guarantees reduce project risk, and thus stimulate private sector interest in small hydro development, at little or no cost in tax revenues. If projects are rigorously screened to minimize the possibilities of default, such a program can operate at virtually no cost. A standardized procedure for technical and financial project appraisal is also necessary to minimize program costs (12).

145

TABLE 2. Analysis of Small Hydro Development by the Private Sector in the Dominican Republic

Factor	Situation
A national awareness of the importance of fomenting small hydro development	Small hydro feasibility studies have been conducted under the aegis of many foreign governments and agencies (including USAID, KIW, Canada, France, Norway, development and Spain) in conjunction with Dominican Republic Government agencies: 2 small hydro plants 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.
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 analyze the national energy situation, and identify and promote appropriate energy policies and programs. CNPE has established a hydroelectric unit that is responsible for preparation of short-, medium-, and long-term plans and policies for hydroelectric generation. The national electric 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. The legal situation on the development of hydroelectric resources is very unclear and has led to battles between CDE and the National Hydraulics Development Institute (INDRHI). A comprehensive study of the legal structure of the electricity sector, planned to begin shortly, will eventually lead to the drafting and promulgation of a modern and efficient electricity sector law. The law may mandate the operation of an electric 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 commerical banking system and more than 15 development lending institutions with ties to the central bank. One development institution (FIDE) has a policy of nearly 2 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	Not available.
Flexibility in contracting arrangements between the utility and the small hydro developer	Not applicable.
Availability of programs to train possible project managers and technicans	The Dominican Republic has a cadre of well-trained professionals who are familiar with all aspects of small hydro development. CDE has a training program in operation and maintenance for small hydro plant 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.

- The availability of drought insurance, especially for the early operating years of the small hydropower plants, is important.

- Flexibility in the possible contracting arrangements between the utility and the small hydropower developer is another important issue. A utility contract that allowed the small hydro plant to pay back all loans in the first 5 years after the plant is operating would make many projects very attractive (13).

- Availability of programs to train project managers, technologists, and technicians for planning, design, construction, and operation of the small hydro plants is vitally important. Where 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 lower project costs (especially civil engineering costs). It also improves reliability of operation through maintenance of the watershed upstream from the headrace entry point and concern for proper plant operation.

PURPA does not address one element that requires attention in many developing countries: the active participation of the local community in the construction and operation of the small hydro plant to help ensure its reliability of performance. Experience has shown that small hydro plants are often out of service because of poor maintenance of the watershed upstream of the diversion dam. This situation can be avoided when the local people know that the continuation of their electricity service depends on how well they conserve "their" watershed.

DRAFT POLICY

In many countries, the optimal development of indigenous resources will require a partnership arrangement between the public and private sectors through a PURPA-style initiative. Public policy can achieve the vitality of the private sector's contribution to small hydro development. For example:

- The national legal infrastructure (including the pertinent electricity sector and water resources law) can permit private-sector participation in the development of small hydro sites and guarantee the sale of subsequently produced electricity to the electric utilities, using a wide range of possible contract mechanisms.

- An energy planning organization can be created to plan for the rational development of the nation's energy resources and to coordinate all energy development activities.

- Capital for small hydropower construction can be made available through mechanisms such as tax-exempt bonds and debt service guarantees.

- Clear rules can be promulgated to delineate responsibilities of foreign resources (capital, technical), including guidelines for the establishment of joint ventures with host country firms.

- Drought insurance can be made available, where appropriate.

- Training programs for small hydropower project managers and technicians can be established.

- Educational outreach programs can highlight the role of local communities in the development and operation of small hydropower plants by promoting the benefits of electricity and the important role these communities can play in guaranteeing reliability of its supply. Fig. 1 shows the interrelationships of the public and private sectors in the development of small hydro plants when a PURPA-style initiative is implemented.

SMALL HYDRO DEVELOPMENT IN THE DOMINICAN REPUBLIC

In the Dominican Republic, the application of a key provision of Sec. 210 of PURPA (that the purchase price of electricity by a utility from a small producer should reflect the utility's avoided cost) made the development of a small hydro plant very attractive to the private sector. The situation described below is a summary of a detailed study (16) that was conducted using a special site selection methodology (15) that reflected current standard engineering practice in the United States and the Dominican Republic.

Site characteristics

The site is in Azua Province. The proposed location of the powerhouse was about 1 km from a 12.5 kV 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 streamflow data were available.

Design considerations

Using information provided by a flow duration curve and the site selection methodology, a design flow (Q_d) of 1.5 m^3/s was determined. A number of project configurations, suitable for different project layouts and single or multiple turbine arrangements, were considered. The configuration chosen was a crossflow turbine of 726 kW capacity, based on a design head of 61.75 m and potential annual generation of 2.41 GWh.

The plant design also included the following features:

- A rock and concrete diversion dam 36 m long and 3 m high;

- A 2.3 km trapezoidal rock and mortar headrace with a gradient of 0.01 and a flow capacity of 1.7 m^3/s;

- A 36" diameter steel penstock 8 mm thick and 100 m long, with a flow capacity of 1.5 m^3/s;

- A synchronous 726 kW generator with a voltage rating of 4,160 V at 60 Hz and a speed of 1,200 rpm (through a stepped speed increaser); and

- A 12.5 kV transmission line of 7 km.

Project costs

The following assumptions prevailed in determining the costs:

- The equipment and material costs reflected the price of delivery to the site.

147

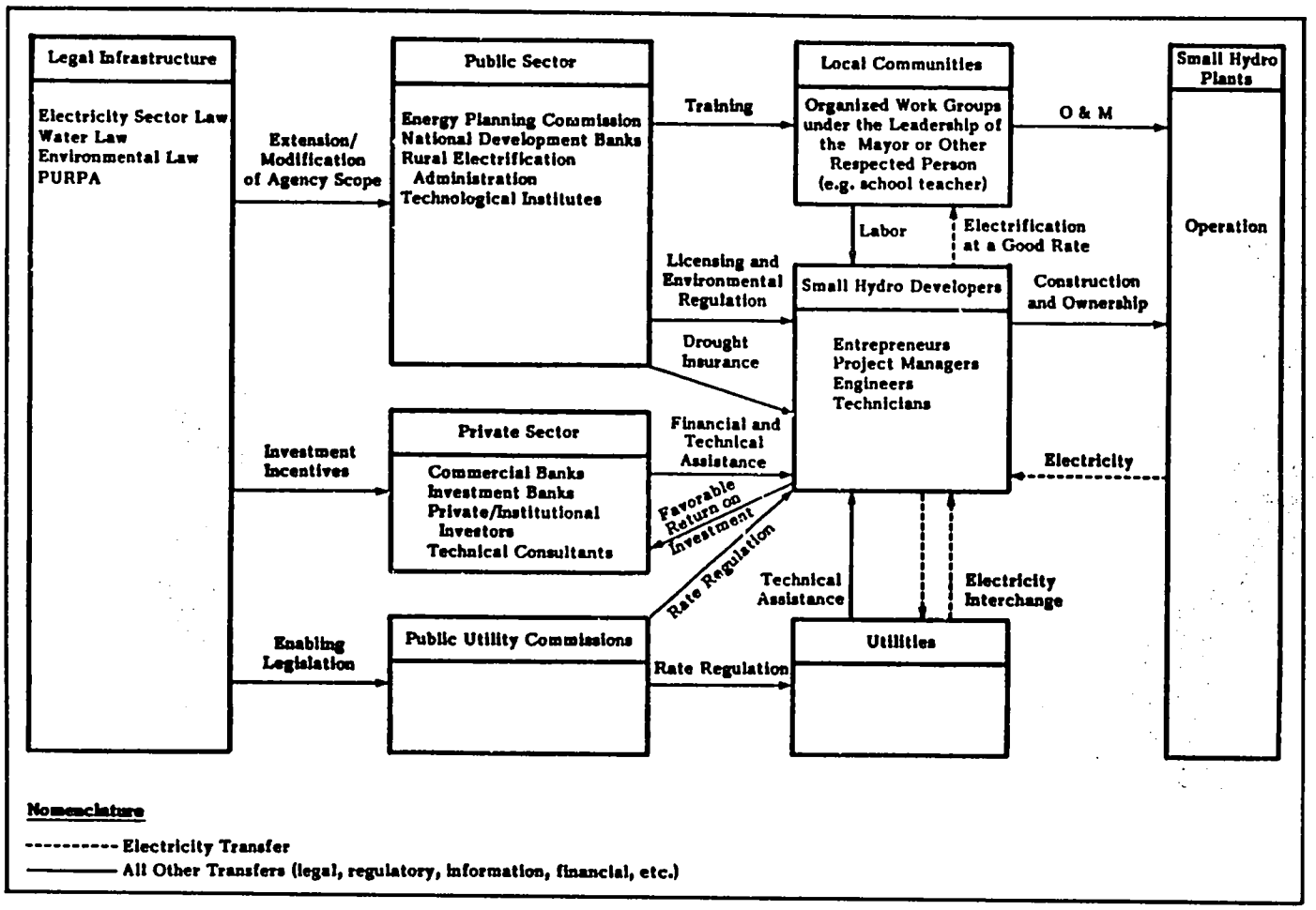

Fig. 1. Interrelationship of the public and private sectors in the development of small hydropower plants.

- All costs were expressed in terms of 1981 Dominican Republic dollars (RD$). All equipment that would be procured abroad was costed at the official exchange rate of RD$ 1 = US$ 1.

- The cost of labor in construction and installation was assigned a value that is a weighted average of local labor and semiskilled labor cost.

Table 3 presents a summary of estimated project costs prepared by a team of professionals from the Dominican Republic.

Project benefits

The project's benefits are calculated as the revenues from the sale of the reported annual amount of electricity generated at the assumed grid purchase rate of 11 cents per kWh. This is the average cost of electricity generation for the national electric utility (3), calculated as follows:

$$\text{Operation + maintenance} = 9.15 + 0.42 = 9.57 \text{ cents per kWh.}$$

At an annual inflation rate of 15% for 1981, this comes to 11.12 cents per kWh. The following additional assumptions were made:

- All capital costs would be incurred before the first year of operation (C_0).

- Recurring costs per year i (R_i) included 1.28% for operation and maintenance and 0.01% for administration and general expenses, as percentages of capital cost.

- The discount factor represents the opportunity cost of capital, which was officially set at 12%.

TABLE 3. Estimated Project Costs

	RD$
New dam and spillway	105,000
Power canal	198,700
Power intake	24,000
Penstock	56,000
Powerplant and electrical equipment	405,800
Transmission line, transformer, and protection equipment	102,000
Land clearing and access	14,000
Subtotal	950,000
Administratrive and general expenses (10%)	95,100
Contingencies (15%)	142,600
Total	1,188,200

Table 4 shows the procedure used to calculate the present value of the project benefits, costs, and net benefits. The results follow (1981 RD$):

- Total present value of the project benefits (PVB_{30}) = RD$ 3,415,720.
- Total present value of the project costs (PVC_{30}) = RD$ 1,311,665.
- Total present value of the net project benefits ($NPVB_{30}$) = RD$ 2,104,055.
- Benefit/cost ratio = 2.60.
- Project internal rate of return = 34%.

Institutional considerations

The financial and technical feasibility of developing a real site in the Dominican Republic have been discussed. Financially, the project is very attractive. In fact, its benefits have been underestimated, because the analysis assumed the utility's average rather than marginal cost of electricity generation, and no real increases in imported petroleum costs.

The prima facie evidence shows that this project is extremely attractive for the private sector. However, other factors that could affect the feasibility of this project's development by the private sector were also analyzed (see Table 2). The results of that analysis show that, essentially, the prognosis for private sector development of small hydro sites in the Dominican Republic is good, but not at this time.

TABLE 4. Calculation of the Present Value of the Project Benefits, Costs, and Net Benefits

For a planning horizon of 30 years, the total present value of the benefits (PVB_{30}) is:

$$PVB_{30} = \sum_{i=1}^{30} B_i \frac{1}{(1+r)^i} \qquad (1)$$

In this case, B_i is constant (B) for each year of the planning horizon, and

$$B = \$0.11/kWh \times 3.855 \times 10^6 \text{ kWh} = RD\$\ 424{,}050.$$

The present value factor PVF_T is defined as:

$$PVF_T = \sum_{i=1}^{T} \frac{1}{(1+r)^i} = \frac{1-(1+r)^{-T}}{r} \qquad (2)$$

where T is the length of the planning horizon (11).

In this case,

$$PVF_{30} = 8.055.$$

Thus, Equation 1 may be rewritten as:

$$PVB_{30} = PVF_{30} \times B$$

$$= 8.055 \times RD\$\ 424{,}050 = RD\$\ 3{,}415{,}720.$$

The total present value of the project costs (PVC_{30}) is:

$$PVC_{30} = C_0 + \sum_{i=1}^{30} C_i \frac{1}{(1+r)^i} \qquad (3)$$

In this case,

$$C_i = (0.0129)C_0, \quad i = 1, 2, \ldots, 30.$$

Thus, Equation 3 may be reformulated as:

$$PVC_{30} = C_0 + 0.0129\ PVF_{30}\ C_0$$

$$= C_0\ (1 + 0.0129 \times 8.055)$$

$$= RD\$\ (1{,}188{,}200 \times 1.104)$$

$$= RD\$\ 1{,}311{,}655.$$

The net project benefits ($NPVB_{30}$) are calculated as follows:

$$NPVB_{30} = PVB_{30} - PVC_{30} = RD\$\ 2{,}104{,}055.$$

149

The current impediments to private-sector development of small hydro sites in the Dominican Republic are primarily institutional. They can be overcome by the following:

- 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 development of hydroelectric resources;
- The establishment of a public utility commission, mandated by the ESL, that will oversee the rational development of the electricity sector;
- The promulgation of a PURPA-style law to motivate the participation of both the public and private sectors in the development of small hydropower and other renewable resources.

REFERENCES

1. Barkovich BR. "Creating a Market for Small Power." Presented at the UNITAR Conference on Small Energy Resources, Los Angeles, California, September 1981.
2. Barnea J. "The Future of Small Energy Resources." Presented at the UNITAR Conference on Small Energy Resources, Los Angeles, California, September 1981.
3. Corporación Dominicana de Electricidad. General Balance and Supplementary Accounts. November 1980.
4. Clasgens H III, and Rothschild AF. "Some Mechanisms for Financing the Development of Small Energy Resources." Presented at the UNITAR Conference on Small Energy Resources, Los Angeles, California, September 1981.
5. Energy Law Institute. PURPA Section 210: Final Regulations, Section-by-Section Analysis. Prepared for the U.S. Department of Energy, Region I. Concord, NH: University of New Hampshire, June 1980.
6. Fox J. "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, March 23, 1981.
7. Gallant FK. "Small Hydro's Second Coming," Rural Electrification, June 1981.
8. Golden WB. State Implementation of Section 210 PURPA Regulations: A Federal Experiment in Decentralized Policymaking and Implementation. Cambridge, MA: Kennedy School of Government, Harvard University, April 1981.
9. Hydrowire. Boston, MA: Hydro Consultants, Inc.
10. Indacochea E. Requirements and Methodologies for the Massive Implementation of Small Hydroelectric Power Plants in Latin America (in Spanish). Quito, Ecuador: Latin American Energy Organization, 1980.
11. Maass A. Design of Water Resources Systems. Cambridge, MA: Harvard University Press, 1962, p. 105.
12. Marsden K. "Creating the Right Environment for Small Firms," Finance and Development, September 1981, pp. 13-16.
13. Philip Merrill, president of Maine Waterpower. Communication with Donal O'Leary, October 7, 1981.
14. Norman C. "Renewable Power Sparks Financial Interest," Science, June 26, 1981, pp. 1479-1481.
15. NRECA. Site Selection Methodology for Small Hydroelectric Plants. Washington, DC: National Rural Electric Cooperative Association, June 1981.
16. NRECA. The Viability of an AID Financed Small Hydro Program in the Dominican Republic. Washington, DC: National Rural Electric Cooperative Association, July 1981.
17. Pope C. "U.S. Entrepreneurs Fall for 'Patriotic' Power Source," Canadian Renewable Energy News, July 1981, p. 34.
18. "The Power Line." Washington, DC: Environmental Action Foundation.
19. Prichett W. "Concerns of Rural Electric Systems with Interconnection to Small Power Producers and Cogenerators." Presented at the NRECA Engineering and Operations Conference, Kansas City, Missouri, November 2-5, 1981.
20. Public Law 95-617 (H.R. 4028). Public Utility Regulatory Policies Act of 1978; Title II--Certain Federal Energy Regulatory Commission and Department of Energy Authorities. Washington, DC: U.S. Government Printing Office, November 8, 1978.
21. Silverstone D. PURPA: Promise, Performance and Prologue. Prepared under DOE Contract No. DE-FG01-79IR10802. Washington, DC: Environmental Action Foundation, July 1981.
22. Silverstone D. PURPA Provisions on Cogeneration and Small Power Production. Prepared under DOE Contract No. DOE-FG01-79IR10802. Washington, DC: Environmental Action Foundation, November 1980.

23. Taubman E, and Weingart J. 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, Nairobi, Kenya, April 1981.

24. U.S. Congress. House Report 4028 on Public Law 95-617: Public Utilities Regulatory Policies Act (PURPA). Washington, DC: U.S. Government Printing Office, 1978.

151

CONCLUSION

Summary of the Aboisso Small Hydropower Working Group Exercise
Paul H. Kirshen

Closing Remarks
Gaston Dossou

Summary of the Aboisso Small Hydropower Working Group Exercise

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To expose conference participants to some of the realities of conducting a small hydro feasibility study and to integrate the multidisciplinary material presented at the workshop, participants visited a nearby small hydro site at Aboisso to be developed by the national electricity company of the Ivory Coast. The workshop participants considered several design alternatives for developing the site. Presented in this report are the procedures followed, the site description, the four design alternatives, the cost and other data provided, and the results of the exercise.

PROCEDURES

Each of the conference participants was placed into one of four multidisciplinary working groups. Several workshop "resource" people were assigned to advise (but not lead or guide) each group. Each group was assigned a particular alternative (Group One was given Alternative One, etc.) to evaluate various factors, including those shown in Table 1, and was provided with background information on site configuration, energy potential, and unit costs. The four alternatives had been preselected by the conference staff and ranged in size from approximately 500 kW to 15 MW.

On Tuesday afternoon of the workshop week, the purpose of the exercise and the four design alternatives for the Aboisso site were explained to the participants. Later that day, each group discussed project organization and responsibilities and data collection for the site field trip. Most groups divided the various tasks of the feasibility study by traditional disciplines such as hydrology, turbine/generator selection, cost, etc.

The participants arrived at the site at midmorning on Wednesday and spent about 2 hours collecting data for their group's alternative. Types of data collected included head, size of dams, canals and penstocks needed, and impacts of project on other water users and the environment in the vicinity of the project. Each group then met twice to analyze its findings, which were presented on Thursday afternoon.

SITE DESCRIPTION

The site is located just north of the mouth of the Bia River at the village of Aboisso (population of 30,000) in southeastern Ivory Coast (see Fig. 1). It is crossed by a bridge on the major east-west coastal highway. The terrain upstream of the site is flat (part of the coastal plain) and is dotted with numerous farms and scattered dwellings, which lie in the flood plain and are unprotected by walls or levees. The village of Aboisso lies on the western bank of the site and apparently uses the river as a local source of water. Downstream from the bridge, the river goes through several rapids and

TABLE 1. Partial List of Evaluation Factors

Construction Costs
Dam/diversion
Cofferdams (if necessary)
Canal
Penstock
Turbine/generator
Design and engineering (25% of construction costs)
Total cost
Also consider possibility of using local labor and its impact on costs
Operation and maintenance
Amount of operator training
Annual costs (2% of capital costs)
Environmental effects
Primary impacts
Induced impacts
Power and energy products
Peak power
Firm power
Appropriate end uses of energy
Alternative form of generation for benefit/cost analysis
Financing
Possible means of financing construction of hydro plant
Other
Cost per kW
Extent of surveying and flow data collection required
Flexibility of power production

contains a few islands. The total change in water-surface elevation from the bridge to the base of the rapids on the west side of the river is about 3.2 m. The distance from the bridge to the rapids is about 400 m. On the east side of the channel downstream from the bridge is a hill.

Two large hydroelectric storage reservoirs and powerplants are located a considerable distance upstream from the site. Because their influence on the flow regime was not accurately known, it was assumed that the mean monthly flows at the site were those shown in Tables 2A, 2B, and 2C.

DESIGN ALTERNATIVES

The four alternatives were selected to cover the range from very small projects to larger projects. Shown in Tables 2A, 2B, and 2C are basic data for each alternative.

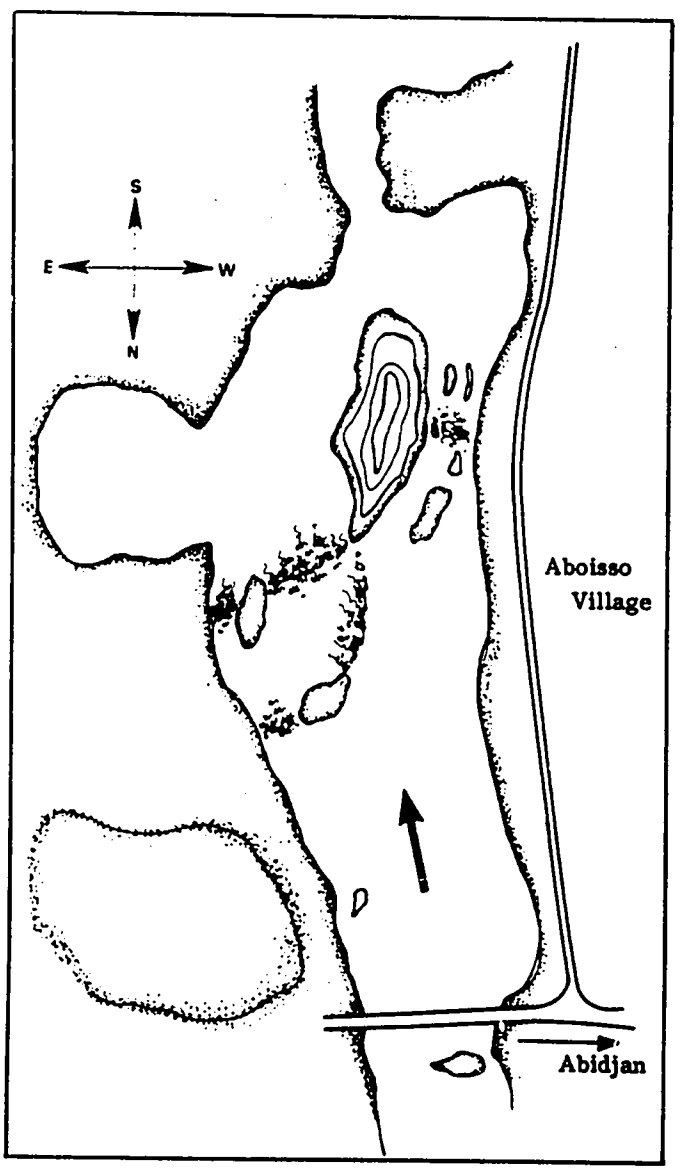

Fig. 1. Site map (not to scale).

TABLE 2A. Commercial Unit Costs[a]

Excavation - earth	1,500	CFA/m^3[b]
- rock	6,000	CFA/m^3
Installed canal - 50 m^3/s	160,000	CFA/m
- 100 m^3/s	240,000	CFA/m
Installed penstock - 50 m^3/s	300,000	CFA/m
- 100 m^3/s	600,000	CFA/m
Turbine generator	240,000	CFA/kW
Dam	45,000	CFA/m^3
Cofferdam (sand bags)	90,000	CFA/m

[a] The data are hypothetical and do not represent actual data from the site.

[b] CFA francs.

TABLE 2B. Site Data[a]

Alternative	Elevation of top of dam below roadway (m)	Cross-sectional area of dam (m^2)	Installed capacity (kW)	Design flow (m^3/s)
One	1	30	14,000	200
Two	7	2	6,000	200
Three	7	2	3,000	100
Four, Stage A	N/A	N/A	700	50
Four, Stage B	N/A	(to be estimated)	4,500	200

[a] The data are hypothetical and do not represent actual data from the site.

TABLE 2C. Hydrology[a]

Month	Mean monthly flow discharge (m^3/s)[b]
January	45
February	35
March	20
April	200
May	180
June	640
July	480
August	130
September	440
October	920
November	55
December	50

[a] The data are hypothetical and do not represent actual data from the site.

[b] Low flow = 10 m^3/s.

154

Alternative One (see Fig. 2)

Alternative One was to construct a large concrete and rock dam just upstream from the bridge. A canal would be built to carry the diverted water along the side of the hill on the east side of the river to a penstock leading down to the powerhouse and turbine. A spillway would be built around the east side of the hill for flood protection. This scheme captured all of the head available at the site and was the alternative with the largest capacity, originally 14 MW.

Alternative Two (see Fig. 3)

Alternative Two was to construct a low diversion dam under the bridge. A tailrace would be excavated downstream from the dam and protected by a retaining wall. A turbine (approximately 6 MW capacity) would be placed just downstream from the dam.

Alternative Three (see Fig. 4)

Alternative Three was to build a diversion dam as in Alternative Two, but to divert the water into a canal running along the west bank of the river to the rapids. There a tailrace would be excavated downstream from the rapids and a turbine installed in a flume configuration. The capacity would be about 3 MW.

Alternative Four (see Fig. 5)

Alternative Four evolved into a two-stage project. Stage A was to excavate a space for a small turbine (approximately 700 kW) at the foot of the western rapids. No diversion structure would be built for this project. Stage B would be in approximately the same location, but a diversion structure would be constructed across the river by filling in space between the rock outcroppings with concrete, with additional excavation for the turbine. A turbine of 4.5 MW would be installed.

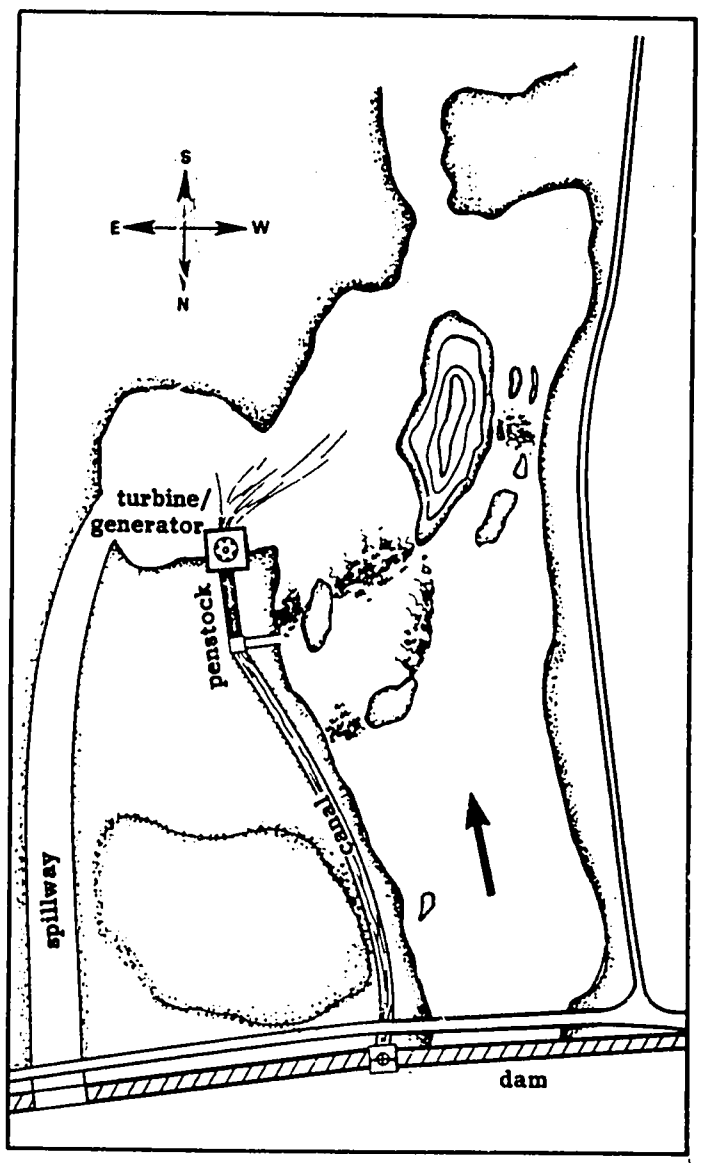

Fig. 2. Alternative One.

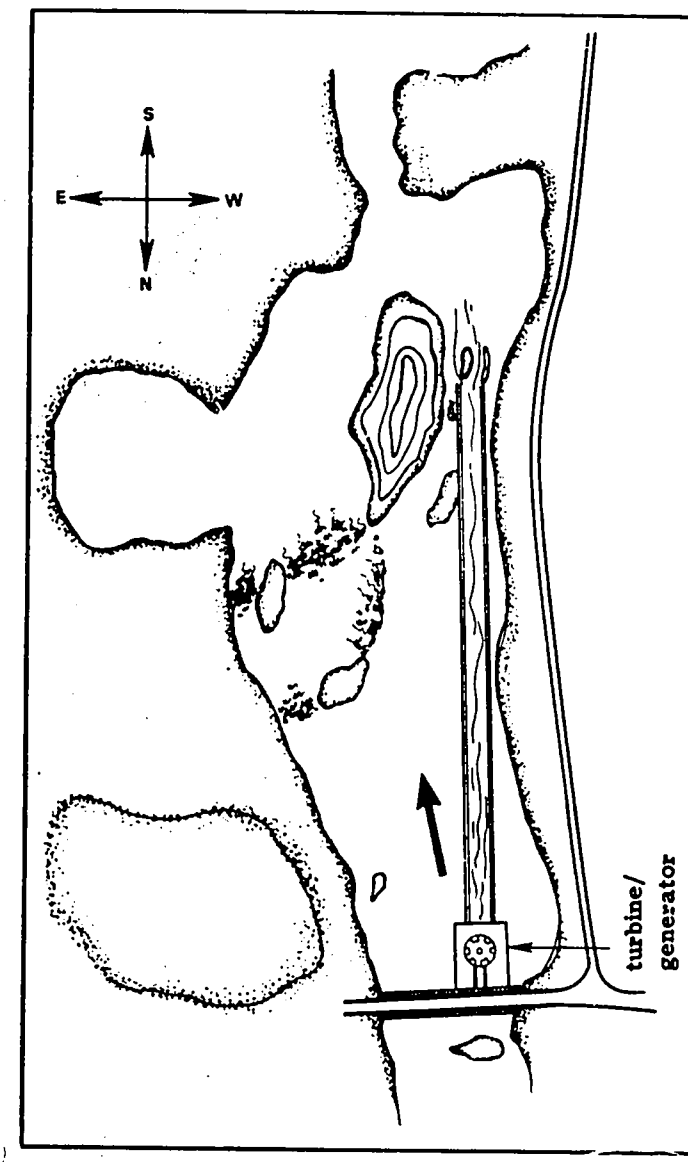

Fig. 3. Alternative Two.

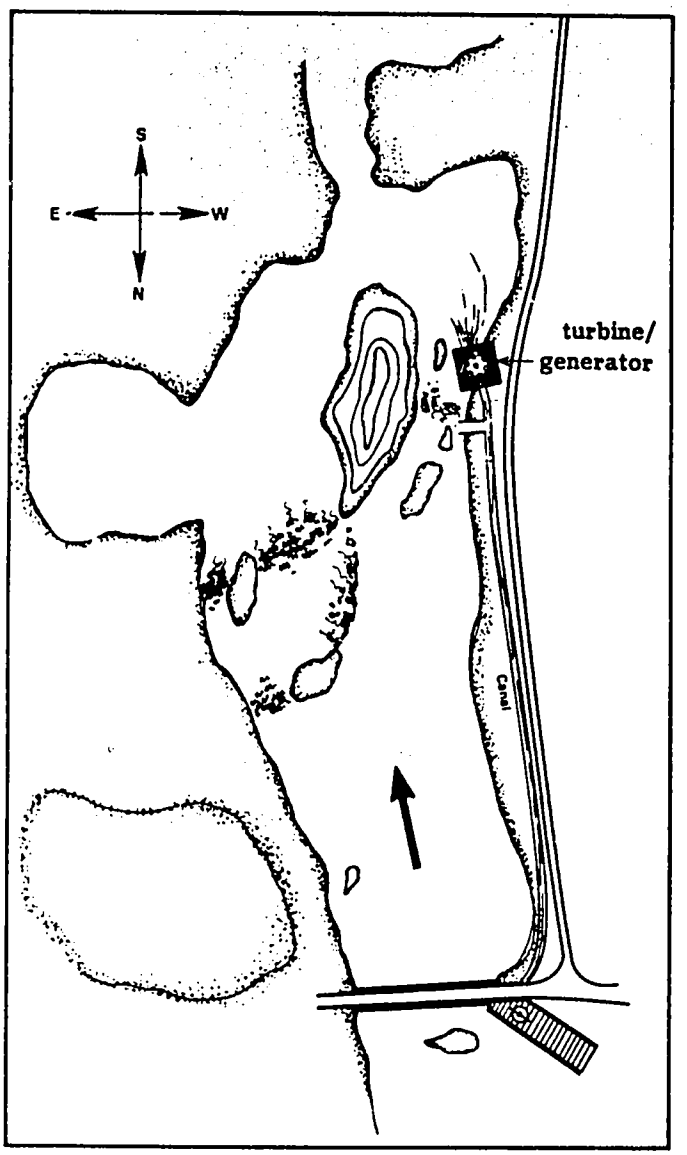

Fig. 4. Alternative Three.

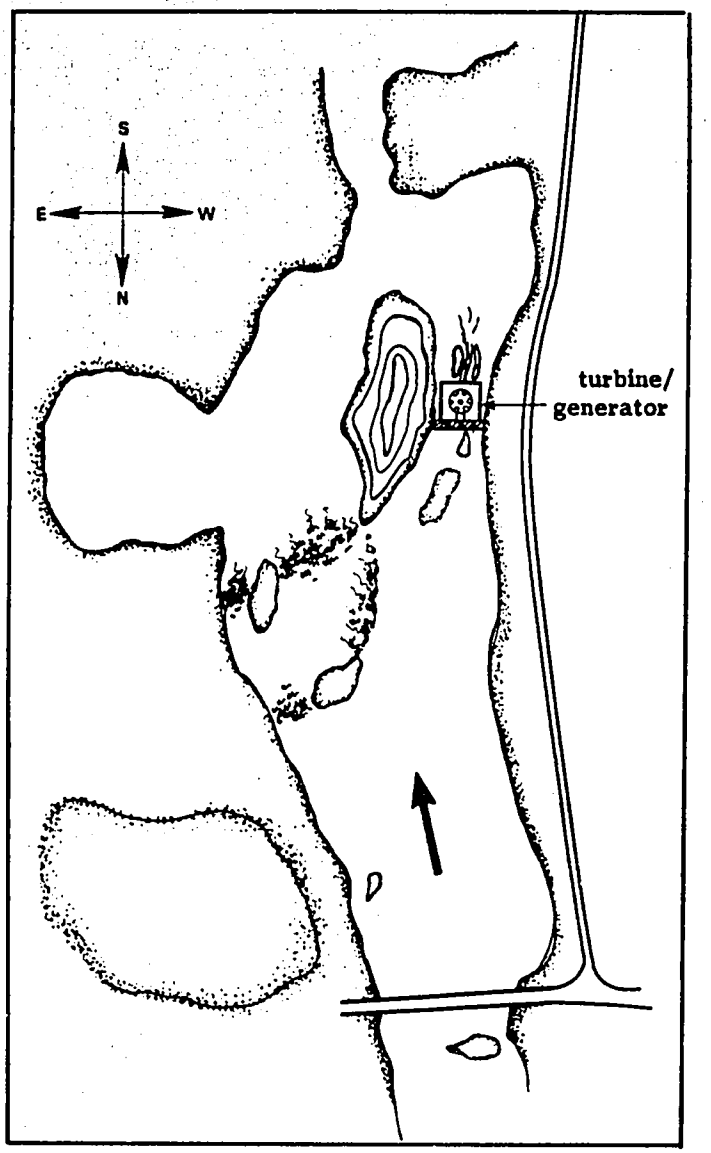

Fig. 5. Alternative Four.

COST AND OTHER DATA

Each participant was provided with the basic data shown in Tables 2A, 2B, and 2C. It was the responsibility of each group to estimate the available head, required quantities of material, and the final recommended installed capacity (the installed capacities listed were guidelines only, provided by the conference staff).

RESULTS

The results of the working group exercise were outlined in discussions on Thursday afternoon and Friday morning of the workshop week and in the written project recommendations of the participants.

The cost estimates of the projects are shown in Table 3. These cost estimates may be low in terms of actual 1982 costs, but are probably correct in relative magnitude. It is noteworthy that the unit costs of the larger and smaller alternatives are less than that of the intermediate project; the larger project shows economies of scale, and the smaller project allows the use of local labor and materials. Alternative Two has the largest unit cost because of the large amount of channel excavation. Many participants noted that these costs do not include the costs of operator training, purchase of land that will be flooded by a project (Alternative One will cause major upstream flooding—perhaps as far as 4 km upstream from the dam), relocation of flooded villagers, and substation and transmission costs. The costs also may not reflect enough of the influence of economies of scale or the use of local labor.

Several groups recommended modifications in their alternatives. Group One recommended that a 12 MW turbine be installed instead of a 14 MW unit because it would operate at a higher capacity factor. To capture the energy of low flows with minimal storage

156

TABLE 3. Cost of Alternatives

Alternative	Capacity (kW)	CFA francs per kW	US$ per kW
One	1,200	455,000	1,500
Two	6,000	604,000	2,000
Three	3,200	391,000	1,300
Four, Stage A	400	450,000	1,500
Four, Stage B	4,800	330,000	1,100

efficiently, Group Two recommended that two 3 MW units (each unit is able to operate efficiently at flows as low as 40 m^3/s) be installed instead of one 6 MW unit. Group Four also recommended multiple units—one 400 kW unit for Stage A and three 1.2 MW units and one 800 kW unit for Stage B. In addition to allowing the efficient capture of low flows, multiple units also allow flexibility in financing, construction, and maintenance. Because of the high cost of the protective cofferdam for the tailrace in Alternative Two (equal to the cost of the dam), some members of Group Two suggested that the basic design of this alternative be reconsidered to decrease these costs.

All groups reported that it was necessary to study the social and environmental impacts of each alternative and the end use of the energy before any alternative could be fully evaluated. In fact, the participants in Group Three divided themselves into technical and management/sociology groups for this purpose. This group's report concluded that it is essential to study the following socio-economic considerations of project implementation:

- The overall development plan of the country where the dam will be built; and
- The end use of the energy. Will this dam be used to provide energy to the populations affected directly, or will the energy produced be integrated into the grid?

Group Three concluded, "Taking all these aspects in account, it will be possible to make a better estimate of the project cost. Our site visit allowed us to realize that the populations have an intense economic activity: they are fishermen. The implementation of such a plant should also be accompanied by social improvements. We also observed that the tariffing problem will need to be studied; it will be necessary to know if the energy output will be used for industrial, artisan, or simply domestic purposes."

Many participants were also concerned about the flood damage that would occur if Alternative One were developed. They noted that, in many cases, the major issues of development in the developing countries are social, political, environmental, and managerial, not technical.

At the close of the workshop, each participant was asked to recommend one alternative. Alternatives One, Three, and Four were each recommended frequently. Because of its high cost, Alternative Two received few recommendations. The reasons for recommending each project are given below:

Alternative One

- It is relatively inexpensive.
- The site should be developed to maximum energy potential because excess power can be inexpensively supplied to Ivory Coast's electric grid through high-tension lines near the site.
- A large dam might encourage multipurpose uses at the site.
- It is a relatively standard, proven hydropower configuration.

Alternative Two

- It is a very simple (though expensive) configuration.
- It needs no canals that might endanger local residents.
- It causes little environmental impact.

Alternative Three

- It is inexpensive (the least expensive after Alternative Four).
- It is sufficient to supply the needs of Aboisso.
- It causes little environmental impact.

Alternative Four

- It is inexpensive.
- It is a simple configuration.
- Stage B is sufficient to supply the needs of Aboisso.
- Because the project is staged, the construction has the flexibility to allow for changes in energy needs, financing, social needs, etc.
- It causes the least environmental damage or disruption.
- It entails no upstream flooding impacts.
- It causes the least downstream erosion.

CONCLUSION

The final conclusion of the case study is evident: each alternative design for a hydro site has many factors to recommend it. As stated by the workshop participants, the final selection depends on a range of specific economic, environmental, social, technical, and energy goals. If these goals are not clearly stated, final selection is not possible.

Closing Remarks

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On behalf of the BAD and its President, I would like to express our thanks to the sponsors of this workshop, in particular NRECA, USAID, and UPDEA, and the distinguished participants and speakers. During these 5 days, delegations from 30 different countries have assembled to discuss the development of small-scale hydropower plants. Their positive reactions allow us to declare that the goal of this small hydro workshop, despite the time limitations and its ambitious scope, has been reached. As a learning experience, it has been extremely enriching.

This workshop should not end without our drawing some general conclusions from the discussions of this week. It is difficult to do justice in a few brief minutes to the many fine presentations that have been made, but by way of summarizing, I would like to review some of the key points raised by the speakers.

This workshop has set guidelines for the terminology of small hydropower. We have learned that micro-hydropower plants have a capacity of up to 100 kW, mini-hydropower plants, 100 kW-5 MW, and small hydropower plants, more than 5 MW. These powerplants generally require a simple technology, and are often adapted to require relatively low investments by emphasizing major participation of the direct beneficiaries through local manpower, local manufacture of equipment, and local funding. The objective of this type of construction is to produce cost-effective electricity for domestic consumption. Often, however, the small-scale hydropower dams have promoted the development of other rural activities and small industry. Envisioning small hydro projects as a multipurpose approach to rural development makes these investments more cost-effective, and promotes rural development as an integrated process.

In principle, small hydropower systems are not different from the larger systems. The essential difference is that the small-scale powerplants require a simpler technology that is adapted to local conditions and permits the significant use of local resources. It is often sufficient to provide simple data, because the project's financial, physical, economic, and social risks are low. For example, because small hydro frequently uses a run-of-the-river design, such risks—and the capital costs of building the plant—are minimized.

The goal of the site selection process is to create cost-effective projects, and the process entails multiple social and economic considerations. Environmental factors (such as downstream floods leading to the evacuation of populations) and sanitary and territorial problems must be considered from the start.

The choice of the site will have an impact on the cost of the investment. Generally, the cost of the installation will be higher with a low-head site (which can double the cost); moreover, as a general rule, unit installed costs decrease as the plant size increases. However, the cost of the system is highly variable and depends on the characteristics of the site, the system's size, the technological approaches adopted, and the degree and type of the uses of the energy (lighting, energy production, agricultural or small industry production). The experience of several countries shows that, by seeking the participation of the beneficiaries, particularly through local management and manufacture of equipment, costs can be very low, even with the smallest plants. This approach allows reduction of expenses, but it also favors the long-range development of a small local industry with the manufacture of most of the equipment needed for the projects. This factor is important, because most developing countries have financial difficulties. Therefore, projects that allow the use of local resources make development easier.

To determine the economic feasibility of these projects, the classic methodologies are appropriate. However, it is necessary to know the importance of the economic and financial analyses to the final decision before the analyses begin. The importance of these analyses will depend essentially on the level of the investments concerned, and on the financial, economic, and social risks that these projects will entail. In one way or another, however, the various repercussions of the project must be identified in advance.

Small-scale hydro projects have many potential sources of funding: national, regional or subregional, bilateral, and private organizations. This funding can be in the form of grants or nonreimbursable loans. When the funding comes from organizations such as the BAD, the loans are made in foreign currencies. The BAD has very few funds of this kind, and must reimburse these loans. For this reason, a technology that calls for substantial participation of local people and resources is a major advantage for a small hydro project as mentioned.

The subject of the management of these projects has been discussed in depth. Numerous options exist, but

each potential developer must decide on a centralized or decentralized approach, after considering the national options and the possibilities for management and financing. I think we are going to see a mixture of the two approaches, from the design through the operation and ma .gement process. However, the advantages of decentralized management are more suitable to small hydropower development. Because it asks for local participation from the beneficiaries, decentralized management makes the operation and maintenance of small hydro plants much easier. In many countries, however, whether the centralized or the decentralized approach was chosen, the promotion of small-scale hydropower often has been the task of national organizations such as the EECI in Ivory Coast, the ATDO in Pakistan, and INE in Ecuador. The global planning has always been performed by an international organization that determined the preliminary data and gave to the local organizations the supervision they needed for the development of small hydropower projects.

I would like to conclude by saying that I personally learned a great deal from this workshop, and by expressing my appreciation for having had the opportunity and the honor to serve as its chairman.

Thank you. The workshop is adjourned.

159

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