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Zaire

Private voluntary organization (PVO) approach to mini-hydropower development

A case study for Africa

NRECA Small Decentralized Hydropower (SDH) Program

Zaire: Private voluntary organization (PVO) approach to mini-hydropower development

A Case Study for Africa

Walter Lawrence

with contributions by Robert Thornbloom and Bard Jackson

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EXECUTIVE SUMMARY

Recently attention has refocused on small hydropower as an appropriate technology for meeting isolated energy needs for power and addressing the problem of rural underdevelopment. Although small hydropower is a proven technology, there have been a number of obstacles to its widespread development. Most of these stem not from the technology itself but rather from the manner in which it has been implemented. Programs developed by donor organizations in conjunction with central government agencies, such as electric utilities, have typically been associated with high project costs, underutilized capacity and maintenance problems. Alternative institutional frameworks are needed.

This case study documents the development of a locally available renewable energy resource by a private voluntary organization (PVO) in order to better provide basic services to the local community and as a stimulus to its development. In many parts of Africa, PVOs, such as religious missions, carry out a wide range of development activities, helping to perform some tasks which cannot as yet be carried out by inadequately developed local institutions faced with the formidable tasks of rural development. The Zulu Falls mini-hydropower project was undertaken by the Evangelical Covenant Church of America, which operates the Karawa Mission Hospital facility in Northwestern Zaire. This study assesses the effectiveness of the approach and its appropriateness for meeting similar needs elsewhere.

A special combination of characteristics make the PVO approach to development projects unique and form the basis for a PVO model of small hydropower implementation. These include: the PVO's access to a range of technical services, its role as a community leader with strong communication and transportation networks, the established loads constituted by their other activities, access to foreign exchange, and its management expertise.

A major problem with the development of very small hydropower has been the cost of providing the technical expertise necessary for its planning, implementation and operation. The majority of PVO missions in Africa are staffed with a technical officer who is familiar with the area and able to work with projects over an extended period of time. The resident technical services officer at Karawa had been there for 20 years and was, for example, responsible for the observations of river flows used in project design. The Mission's Technical Services Department will be particularly important during the operations stage, since minor faults often lead to long outages if they cannot be dealt with promptly at the site. The hydropower installation benefits from the Technical Services Department while being responsible for few of its costs, since the department exists to serve the primary activities of the Mission. Neither a private contractor nor a public entity would have the resources to devote technical staff over the long term to such small isolated systems.

In addition to local staff, PVOs often have access to support groups worldwide. The Mission had been assisted since 1970 by members of the sponsoring church in the U.S., who volunteered for short-term assignments. A total of 15 short-term mission volunteers worked at Karawa for one to three years at a time during the construction phase. In addition, three engineers who were members of the church in the U.S. made significant contributions to the planning and design of the project. Mission staff also corresponded regularly with specialists and were able to consult with them on visits to the U.S.

Another characteristic of the PVO model is established loads. One of the major obstacles to small hydropower development has been that insufficient attention is often paid to the development of economically and socially productive end-uses. These are not only critical to the economic and financial viability of projects, but should be the reason for developing them in the first place. Frequently productive uses of the energy generated by small hydropower schemes have been either sought as an afterthought, or expected to follow as a matter of course. When projects are developed by PVOs, productive uses are built into the projects, avoiding one of the obstacles to their success and replication. At Karawa, for example, the hospital, school, workshop and agricultural processing facilities complemented the residential services to offer very favorable demand characteristics for small hydropower.

The role that PVO missions in Africa play as community leaders makes them an excellent channel through which to both mobilize the local population and assess their needs. Furthermore, PVO missions have strong communication and transportation networks and often constitute the only institutional infrastructure outside of the major cities. The Karawa Mission was able to use this role effectively to maximize the use of both the physical and human resources of the community. Based on its familiarity with the region, the Mission was able to devise approaches and techniques particularly appropriate to the area. For example, the project included an earth fill dam packed with termite dirt, instead of a concrete structure, because cement has to be imported and spoils in the humid atmosphere. The mounds, which are abundant in this part of Zaire, have been processed by the termites in such a way that they are impervious and constitute a suitable fill. In addition, an earth fill dam makes use of straightforward techniques that allow maximum use of semi-skilled labor from the community. Another example of successful adaption to locally available materials was the use of 30 caliber rifle casings to detonate dynamite, since blasting caps could not be found on the local market. Such versatility is unlikely to be found in organizations that are not as familiar with the area.

Compared to public authorities, PVOs tend to have the minimum of bureaucratic structures, support staff and overhead costs. This is an advantage in project implementation since funding can be transferred directly to the project without the need to pass through several layers of government structure, leading to reduced delays and more efficient use of monies. In the Karawa case, field administration of the project was streamlined and capable of reacting promptly to the many problems and delays that inevitably arise.

Access to foreign currency also characterizes the PVO model. Missions generally have greater access to foreign exchange, and therefore to good equipment and spare parts, than other local organizations. While this is largely irrelevant during the implementation stage--given external funding for the projects--it can be a major advantage as the need for spare parts arises over the long term. In developing countries, lack of access to foreign exchange for spare parts is one of the major causes of operational problems.

In addition to illustrating these advantages of the PVO approach to small hydropower development, the Karawa project suggests a number of shortcomings in the model as it applied to this case.

Despite the advantage of minimal bureaucracy within the Mission organization, its dependence on outside sources of funding caused severe delays. High inflation and frequent devaluations lessened the purchasing power of the fixed local currency allocation and complicated the procurement of supplies from the local market. Supplemental allocations were often delayed so long that the cost of the item had increased substantially by the time it arrived. AID is attempting to resolve this problem

by delegating a single PVO to act as program manager, and channeling all funds through that PVO in order to shorten these delays.

The approach at Karawa did not overcome the problem of high project costs. Both civil works and construction equipment were particularly costly for this project. Efficient use of capital equipment will be an obstacle to the PVO approach in future projects, since purchase of equipment on a site-by-site basis is neither possible nor desirable. If costs are to be kept down, some mechanism will have to be established to make equipment available on a more centralized basis, although transportation to and from remote sites will still be expensive. Civil works were also costly on this project, largely due to the need to construct a substantial dam and other control features. However, most mini-hydropower projects are run-of-river type that do not require a dam. Also, projects that utilize a higher head and smaller flow tend to require less civil works. These interrelated problems--of high equipment and civil works costs--could thus be reduced if projects implemented by PVOs in Africa focused on run-of-river projects with higher head and lower flows.

A potential disadvantage of the PVO approach, illustrated at Karawa, is that lessons learned are not effectively transferred to an institution that can apply them over the long term. A particular PVO mission will generally only implement one project, making little contribution to a national program of small hydropower development. This shortcoming could be compensated for in some degree by having engineers and planners from the national utility seconded on a medium-term basis to the PVO mission implementing the project. In this way, technology transfer and institution-building would be added to the direct benefits accruing from the project.

This case study suggests, therefore, that PVOs can indeed constitute just as effective a vehicle for the development of small hydropower in isolated areas of Africa as they have demonstrated in the provision of health, educational and other facilities. Each experience, of course, throws further light on the strengths and weaknesses of the approach. On the one hand, some advantages of PVOs over other potential institutional frameworks (such as private companies, public utilities or ministries) have been shown to be particularly important. On the other hand, this experience suggests that the model may not be so appropriate for larger projects that involve substantial and sophisticated civil works construction. Secondly, Karawa illustrates the importance of a streamlined funding system that takes advantage of the PVO's organizational structure. Finally, the selective involvement of local organizations in all stages of the projects may lead to greater benefits of technology transfer.

Under these conditions, donors should work with PVOs to develop small hydropower, thereby facilitating the provision of essential services to the most isolated communities, stimulating the development of productive activities in depressed rural areas, and contributing to the strengthening of national institutions.

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PURPOSE OF PAPER

Despite several decades of foreign assistance, Africa remains a region of growing human misery in the midst of vast natural resources. The full reasons are beyond the scope of this paper, which addresses a few of the critical elements in that overall picture. Zaire, like many developing countries, faces the following mutually reinforcing problems:

- pressing energy crises, for both commercial and traditional fuels;
- acute foreign exchange shortages;
- chronic underdevelopment of rural areas, often lacking the most basic infrastructure;
- daunting administrative and institutional weaknesses.

The purpose of this Case Study is to document the Zulu Falls mini-hydropower project, undertaken by a private voluntary organization that sought to face these issues in a way that might constitute--or at least suggest--a model for further efforts.

Hydropower is a resource in which Zaire is particularly rich. Huge projects such as the Inga dam, although they confront the energy shortage at a national level, make little or no impact on the problems of rural underdevelopment. Very small-scale hydropower has been proven as a technology appropriate to meeting isolated rural needs in developing countries. There remain, however, a number of obstacles to its widespread development, many of which relate to planning and administrative as well as technical and financial aspects.

The study has been written in the belief that others may learn from the experiences gained in this project. It is the third in a series of Case Studies* by the Decentralized Hydropower Program of NRECA, created in 1980 in conjunction with USAID to help developing countries harness this resource. Aspects discussed in this study include the following:

- assessment of the needs and available resources;
- interaction between international lending sources and implementing agencies in the field;
- the role of technical assistance;
- the construction process and problems encountered;
- project management during planning, implementation, and operation.

It is hoped that this paper will be useful to a wide audience of planners and project managers in both public and private organizations devoted to funding, technical assistance, and project implementation at all institutional levels. Although technical issues are dealt with in depth, the study assumes neither an engineering background nor experience with the technology on the part of the reader.

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* The others are Nepal: Private sector approach to implementing micro-hydropower schemes (Oct. 1982) and Pakistan: Village-implemented micro-hydropower schemes (May 1983).

INTRODUCTION

ZAIRE

Zaire, located in central Africa, covers about 2,345,000 km^2 and has a population of about 31 million. The population is concentrated in about 10% of this vast country, and enormous distances often separate settlements. Transportation and communication links among these centers are poor. Although French is the common language, there are some 250 ethnic groups with four primary and dozens of minor languages. About half of the total population of Zaire practices traditional African religions; the other half is Christian, as a result of the influence of the numerous missionary groups that have been in the Congo region for many years.

Of the African countries, Zaire was one of the least prepared for independence. In 1960, it had neither the trained manpower nor political institutions necessary for its transition to an independent state. Although many of the institutions required to operate the economy were in place, they were entirely staffed with Belgians at the professional and managerial levels, and oriented to serve the interests of the mother country. When the Belgians left, the highly centralized institutions and organizational infrastucture collapsed. Most donor groups have cited the weakness or lack of institutions as the major constraint to sustained development.

Zaire has been slow to recover from the disruptions caused by independence; only after several years of chaos and civil war did political stability begin to reappear. A growing professional manpower base has begun to take on a role in development, yet expatriates continue to play an important part in the upper levels of the government and the economy. Like most African countries, Zaire has a dual economic structure. The majority of the population is dependent on subsistence agriculture, and a small, urban commercial sector engages in mining, trade, and light industry. Copper accounts for more than half of the country's exports.

Annual electricity consumption in Zaire is particularly low, about 144 kWh per capita. Of this, large industrial plants account for about 65%, and the annual domestic consumption is only about 15 kWh per capita. Only 2% of the total population, and less than 1% of the rural population, has access to electricity. The global economic recession brought on by the international energy crisis of the 1970s has had a devastating effect on Zaire's ability to purchase energy on the world market. As in many African countries, petroleum prices increased 10-fold during a period when foreign exchange earnings from exports plunged. The result is that even when rural areas have access to electricity, supply is limited to a few hours a day because of rationing of fuel for diesel-driven generators. This inability to meet electrical demand has, in turn, aggravated other development efforts.

Hydropower in Zaire

Zaire's hydropower potential, estimated at more than 1 million MW, is about 13% of the world's total.* The number of feasible sites probably exceeds 1,000. Large-scale

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* Mulamba wa Kabasele, "Small Hydroelectric Power Development In Zaire," in Small-Scale Hydropower in Africa: Workshop Proceedings, NRECA, 1982, p. 31.

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hydropower developments supply many of the major cities. At a cost of more than US$ 1 billion, Zaire has completed the Inga hydroelectric generating station and Inga-Shaba 1,000 kV direct current transmission line. Yet of this plant's ultimate generation and transmission capacity of 1,120 MW, the anticipated peak demand may not exceed 150 MW over the next decade.

Only recently has attention turned to small, decentralized hydropower as a technology appropriate for meeting isolated loads in Zaire, although private firms and religious groups have installed about a dozen such projects. The Government of Zaire has begun to develop an inventory of potential sites, and the U.S. Agency for International Development (AID) has also assisted in carrying out a preliminary survey and recommending institution-building for an extensive program of small hydropower over the long term. The Karawa project is one of 23 for which AID assistance has been requested.

KARAWA

Karawa is a rural community in the Ubangi-Mongala region of the Equateur Province in northwestern Zaire (see Fig. 1). This is one of the poorest and least developed areas of the country. It has a government administrative post, around which a small commercial sector has grown. An American church-sponsored health care Mission is located a few kilometers away and shares the same name (see Fig. 2).

Transportation around Karawa is reasonably good by road, the more important one going to Businga, the river port where most of the heavy freight is handled. Bridges are adequate for trucks up to 10 tons gross weight. Businga Port normally functions all year, but occasionally the Mongala River drops to levels that make river freight deliveries impossible for several months.

It is estimated that about 60,000 people inhabit the Karawa Mission service area, mostly in clusters of mud-walled, grass-thatched roof houses. They live primarily on a barter economy, supplemented by an average annual cash income equivalent to about $150 per capita, earned mostly from cash sales of coffee, peanuts, and corn. These products are traded or sold at the markets when road conditions permit access to them. Pineapples, papaya, and mangos are consumed or traded locally, or are sold to the Mission personnel. Other subsistence crops are manioc, maize, rice, millet, sorghum, bananas, and sweet potatoes. Cattle, sheep, and goats are raised in the vicinity, and Mission personnel conduct training programs aimed at improving local livestock breeding and care.

One of the main markets in the area is on the road between the Mission and the Karawa government post. Most of the cash trading takes place here (see Fig. 3). A second market is near the new hydropower plant, on a road that crosses the new combined bridge and water control structure between the forebay and the reservoir. This is a significant side benefit from the hydropower project: villagers now have continuous access to the market from both directions, whereas they previously had to wade through the river (see Fig. 4).

As is fairly common in African cultures, women perform most of the laborious tasks in the house and the field, in addition to raising children. However, when there is work for hire--such as construction, road work, or similar labor--the men do it. The Mission has made an effort to upgrade the women's role in the village by training them to serve as nurses and paramedics in the Mission hospital.

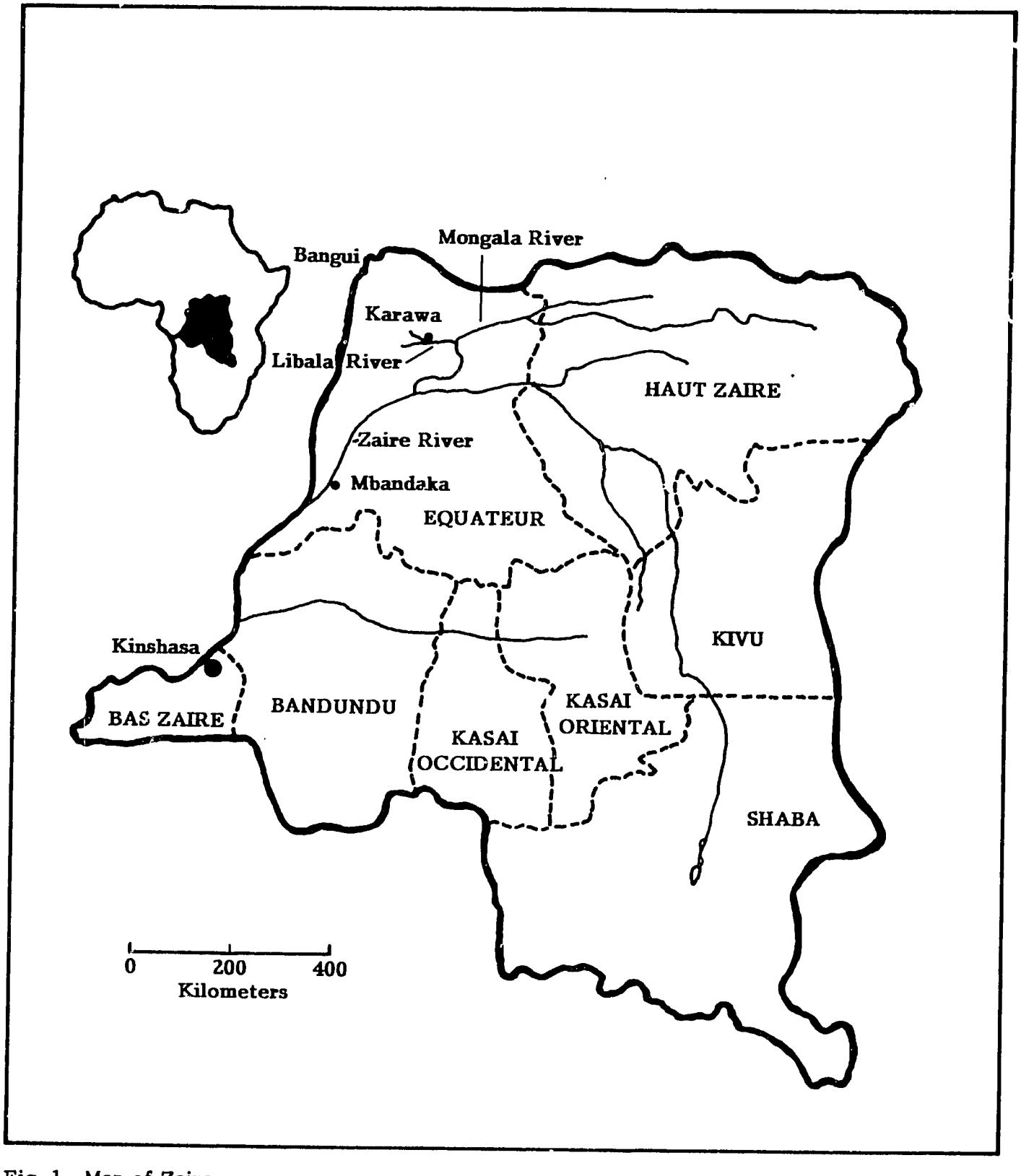

Fig. 1. Map of Zaire.

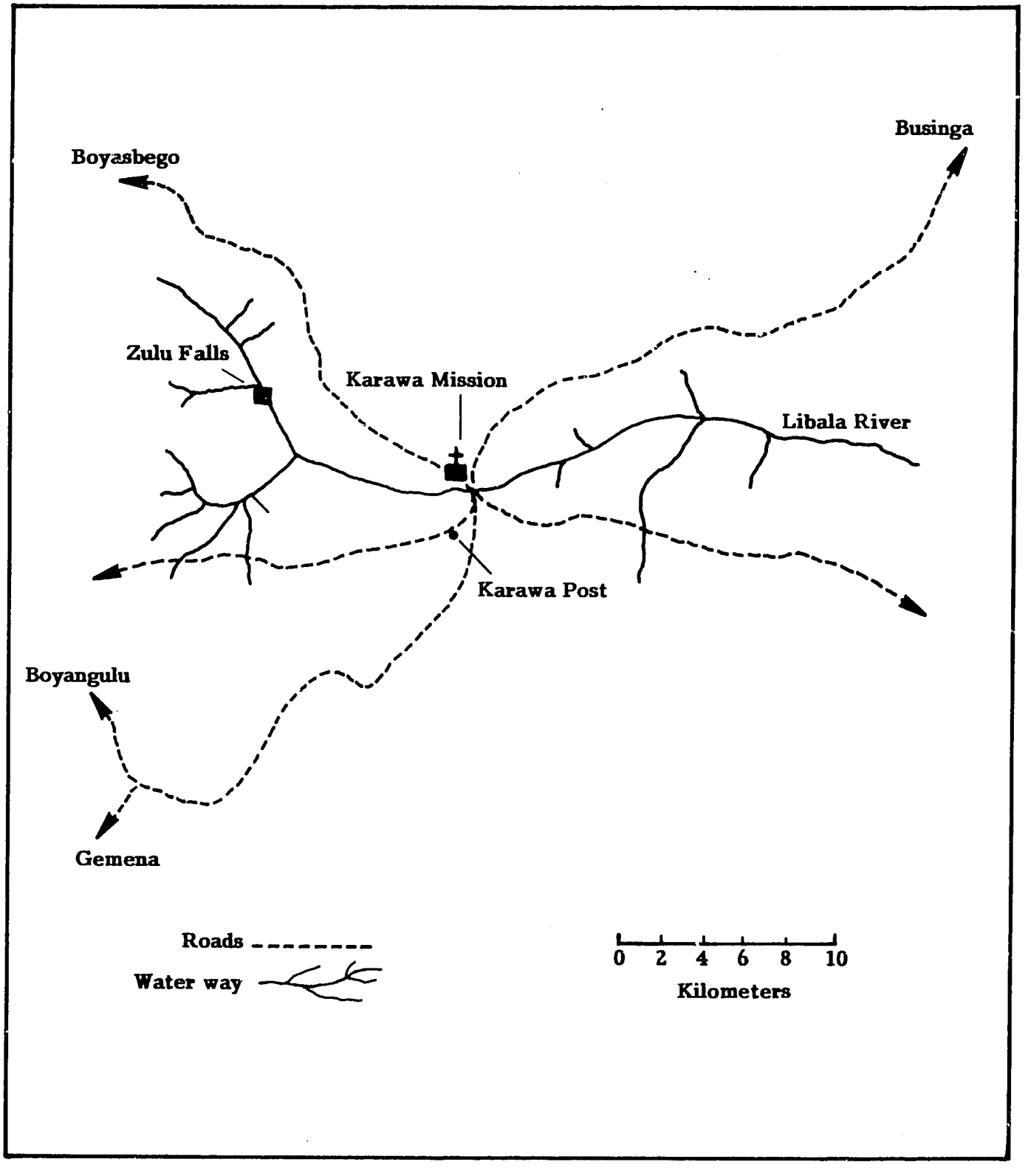

Fig. 2. Map of Karawa.

Fig. 3. Marketplace near Karawa.

Fig. 4. Villagers crossing the Libala River.

Population growth rates in the region are not known. The patient load at the hospital and clinics has risen steadily, which may reflect a general population increase on the order of 2%-3% percent annually. Women in the maternity section of the hospital receive instructions in family planning, particularly those with large families. Because African culture, like many others in the developing world, considers a large number of children as a form of old-age security, the concept of family planning has been difficult to impart to the local population.

INSTITUTIONAL SETTING

Private voluntary organizations (PVOs) in Zaire are extensive, well organized, and often represent the only effective institutional base outside of Kinshasa. The Protestant Mission system (mostly American) has a network of 67 hospitals, 500 dispensaries, and some 2,000 employees. In addition, this system effectively manages some 3,000 primary and secondary schools for the Government. The Missions have joined together into a countrywide organization called the Eglise du Christ au Zaire (ECZ) for better communication, coordination, and representation with the central government. The ECZ represents 6 million Zairian members, with facilities in 11,200 locations throughout the country. It also acts as a national institution for development planning and implementation, and numerous donor groups channel assistance through its programs. The survival of the national Mission structure during difficult periods has earned the Missions credit as reliable, dedicated, and stable organizations.

Although the Government of Zaire (GOZ) has a post in Karawa, it does not have the capability to meet the rural health needs of its population; hence, PVOs do most of this work. The Karawa Mission is the hub of activities of the Communaute Evangeline en Ubangi-Mongala (CEUM) to furnish improved health and education services throughout that region. Eight smaller rural Mission stations depend on the Karawa Mission for special services. It is estimated that improved service at Karawa would directly improve the living standards of 60,000 people, mostly farmers in the immediate target area. The Mission's primary and secondary school education offers young people their best opportunity for better employment. An additional 100,000 people within a 60 km radius of Karawa walk to the Mission to receive help and low-cost health care.

THE MISSION

A Swedish missionary established the first medical facility in Karawa in 1923, because it was near several population clusters and a water supply. From 1923 to 1947, the original clinic grew into a hospital, serving as a nucleus from which similar satellite facilities were formed. During the next 13 years, the Karawa Mission gradually expanded its medical capabilities and area of operations with the support of the Evangelical Convent Church of America. From 1960 to 1964, however, the Simba rebellion swept through the Congo and drove out out most of the expatriate missionary personnel. The Karawa Mission was abandoned. By 1965, the regional political situation had stabilized and the church committed funds for a central medical supply, storage, and administrative facility at Karawa. Since then, the facilities and permanent staff of the hospital have expanded to include two operating theaters, dental facilities, laboratories, wards, an optical shop, a school for expatriate students, and training facilities for local medical technicians. Also included in the Mission complex are support facilities such as machine and carpentry shops, staff residences, a potable water distribution system, and an electric energy supply and distribution system.

The Karawa Misson has a dirt air strip that can handle small twin-engine aircraft. Passengers, mail, and light freight are handled by the Mission Aviation Fellowship (MAF),

which operates and maintains a single-engine Cessna on a nonprofit charter basis for the Mission. Most of the Mission personnel in and out of Karawa, as well as light freight and mail, are flown from Bangui, the capital of the Republic of Central Africa just across the Ubangi River. This trip takes a little more than an hour, including a stop for customs and visa check at Gemena or Libenge. Gemena is a fairly new commercial air terminal and has a hard-surface runway capable of handling large aircraft. However, commercial air service is virtually nonexistent. Some project air freight has come into Gemena for transport to the Mission by truck, a journey of 4-6 hours. One of the more important uses of the small aircraft is transportation of persons to the Karawa hospital from the eight outlying clinics, where the facilities may not be adequate to care for the very seriously ill or badly injured (see Fig. 5). Most of the clinics are within a 130 km radius of Karawa.

There are no telephones, either at the Karawa Mission or at the government post. Fortunately, the GOZ allows the use of radio and has allocated a frequency for the general use of missionary groups, which operate a net on a shared basis during restricted hours. This radio network enables them to maintain contact with their offices in Kinshasa and Gemena, as well as with each other. Similarly, a shared frequency is available for use by the aircraft.

Compared with many other parts of Africa, the areas served by the Mission hospital and clinics are reasonably well endowed with water sources, around which the small housing clusters tend to form. The Karawa Mission water source is a potable spring about 4 km from the Mission. The water is carried in a flume at a low gradient to a point where it drops onto an overshot waterwheel (see Fig. 6) which powers a pump that forces the water through a pipe to a cistern on the edge of the Mission area. The cistern has sufficient elevation to deliver a continuous water supply around the entire camp. Two similar units were constructed at satellite Missions and have been in service for several years, providing low-cost potable water to the Missions and free service to the local populace.

The closest public utility power supply is a 600 kW diesel system in Gemena, 75 km west of Karawa. This station is barely sufficient to meet the demand in the city, much less take on any additional load. Because of this capacity shortage, the air terminal at Gemena has its own generator. The high cost and shortage of diesel fuel frequently make it necessary to operate the air terminal generation plant only when traffic is expected and power is needed for communication. One of the reasons for curtailment of commercial air service to Gemena is the high cost and frequent nonavailability of aircraft turbine fuel.

Fig. 5. Emergency patient being delivered to hospital.

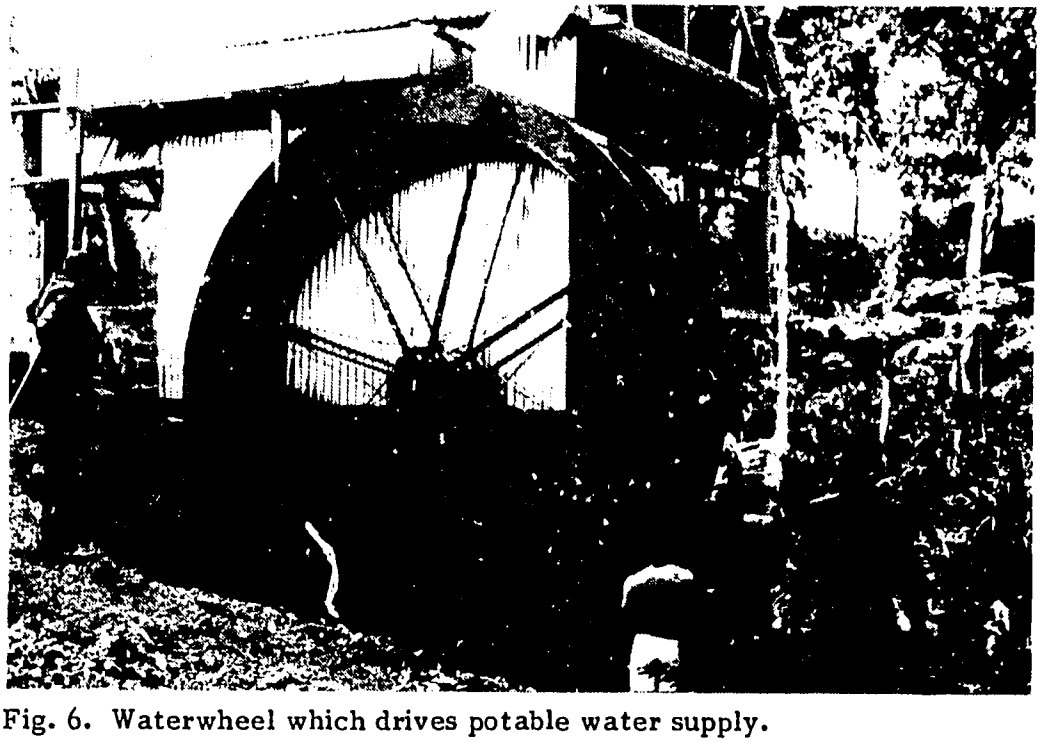

Fig. 6. Waterwheel which drives potable water supply.

NEEDS ASSESSMENT

Energy Use

Much of the energy used at the Karawa Mission was in the form of heat from kerosene. Major consumers were the hospital (for autoclaves, sterilizers, stills, water heaters, hot plates, incubators) and the residences and student dormitories (for stoves, water heaters, and hot plates). The old refrigerators used in the hospital and homes could also be considered heat devices, because they operate on heat from kerosene flames. Table 1 shows the Mission's dependence on kerosene.

Table 1. Kerosene Consumption for Devices Requiring Heat

Device	No. of liters used per week	No. of residential units	Total liters used per week
Refrigerators	10	18	180
Autoclaves	20	2	40
Stills	5	1	5
Totals	35	21	225

The Mission consumed approximately 225 liters of kerosene per week. At the 1978 price of Z 0.79 per liter (US$ 1.27), this constituted an annual cost of US$ 14,000. Most residential stoves have been adapted to the use of liquified natural gas cylinders. Both the gas and the kerosene must be imported by river barge, rail, and truck from the coast. Furthermore, large quantities of wood and charcoal are consumed in the hospital water heaters, even though Karawa lies on the edge of an area that is experiencing increasing fuelwood shortages. The Mission has experimented with solar water heating, which might eventually become practical for supplying the large quantities required in the hospital laundry. In the meantime, important benefits could be gained, in both cost and convenience, by converting the energy requirements for heat to electricity.

Lighting and motor-driven devices, such as workshop tools and hammer mills, constituted the other two forms of energy used at the Mission. In both cases, cost and inconvenience, as well as expected additions and improvements to Mission facilities, pointed to the inadequacy of the existing power supply.

Previous power supply

Before construction and operation of the Zulu Falls hydroelectric powerplant, the Mission's electrical energy supply consisted of a number of small diesel electric units, placed close to the several load centers to minimize voltage drops. No overall

distribution system existed, and the hospital requirements were given priority in the allocation of generation capabilities. Those generator units operated at 120 V or 240 V, single-phase, 60 Hz, tabulated as shown in Table 2.

Table 2. Diesel-Electric Generating Sources as of March 1978

Unit	kW	Make	Load served	Year installed
1.	16.0	Witte	Hospital and homes	1967
2.	9.0	Witte	Hospital and homes	1967
3.	6.5	Lister	Dormitory and schools	1967
4.	3.5	Petter	Dormitory and schools	1967
5.	10.0	Deutz	Shop	1955
Total	45.0			

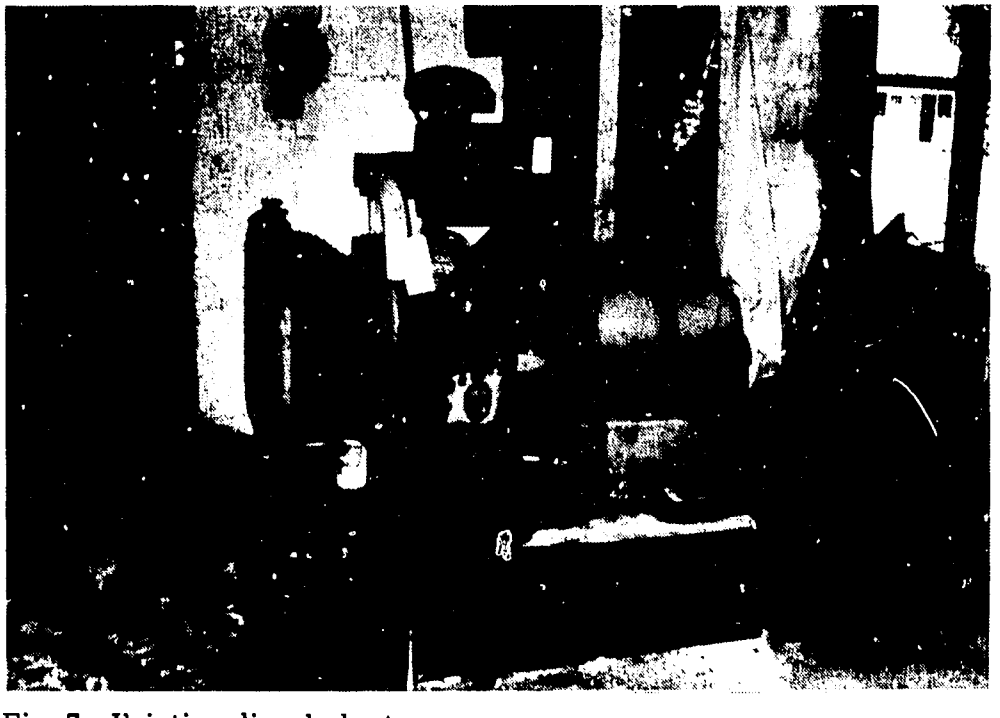

Fig. 7. Existing diesel plant.

In March 1978, when the electric supply and loads were surveyed for the purpose of preparing a feasibility report on the Zulu Falls project, the total connected load on the diesel units was on the order of 20 kW of lights and essential small appliance loads, including one freezer in the hospital and another in the laboratory. Most of the residential units had kerosene-operated refrigerators.

Primarily as a result of high generating costs (US$ 0.17-US$ 0.20) and frequent shortages of diesel fuel, the electrical energy consumption was limited by restricting the supply to the residential areas to 6-8 hours per day (7-11 a.m., and 5.30-9.30 p.m.). Hospital lighting loads were also restricted to ensure that essential laboratory, refrigeration, and other process loads could be supplied during the 12-hour working day. Under these conditions, the consumption of diesel fuel for the generators listed above was about 100 liters per day. (This is roughly equivalent to 270 kWh per day, a 12-hour average demand of about 22 kW.) At the time of the 1978 study, annual diesel consumption was thus about 36,000 liters at a cost of Z 540,000, or about US$ 15,000. Compared to fuel, the consumption and cost of lubricating oil were small, averaging Z 350, or US$ 10, per month for all machines combined.

Table 2 indicates that the Mission has used the generating units for periods of time ranging from 17 to 29 years. Because not all the machines were new when installed, they have all served more than their normal useful lives. Maintenance has become increasingly costly and difficult, because there are four different makes of engine and spare parts are hard to obtain locally. Furthermore, a number of expansions of Mission services depended on improved power supplies--not to mention air conditioning and modern refrigerators in the residences:

- The Medical Services Department needed improved office and ward lighting; refrigerators and freezers for pharmaceuticals; blood and x-ray storage; air conditioning for operating theaters and laboratories; and hot water for bathing and laundry (see Figs. 8 and 9).

- The Educational Department needed power for improved classroom lighting, as well as audio-visual and laboratory equipment.

- The Technical Services Department needed an adequate supply of energy for power tools for construction and repairs, and for electric hammer mills to grind corn and manioc for the surrounding communities (see Figs. 10 and 11).

- Finally, a recently completed community library also required lighting.

For all these reasons, it was clear that a major improvement was needed in the Mission's electricity supply system.

LOAD PROJECTIONS

On the basis of the preceding **Needs Assessment**, a detailed estimate was made of every component of electric load, by considering the probable connected power demand in kilowatts and the hours of the day that each would be in operation. The probability that not all of the appliances would actually be operating at any one time also had to be considered by applying an appropriate "coincident demand factor" to the sum of connected loads in a given category. For example, autoclaves and storage water heaters in the hospital were assumed to operate for most of the day, so a high coincident demand factor of 0.85 was applied. Air conditioners in the operating theater, maternity room, and laboratory were assumed to run continuously, whereas the laundry water heater was expected to operate about 20 hours per day. In the workshop, although the various tools and equipment constitute a total connected load of about 10.5 kW, the coincident load was estimated at half that amount because each tool would be used only sporadically. The hammer mills were likely to operate steadily during daylight hours, one in the market area near the powerhouse and the other close to the Mission compound.

Fig. 8. Operating theater.

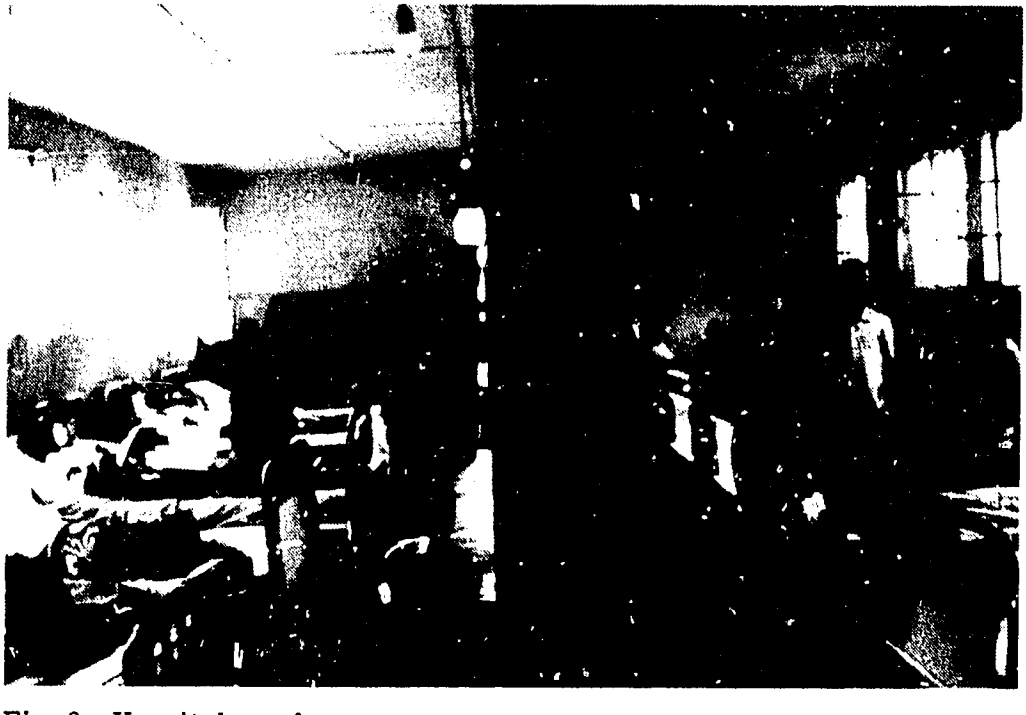

Fig. 9. Hospital ward.

Fig. 10. Wood shop.

Fig. 11. Hammer mill for grinding corn and manioc.

It was assumed that there would be little difference in the operation of the hospital system over weekends and holidays. Furthermore, the length of the day changes very little seasonally at the 3° N. latitude of Karawa. Annual energy requirements could thus be calculated as 365 x the daily kilowatt-hour figure, as shown in columns 3 and 4 of Table 3. Daily and annual energy requirements, and coincident demand (kW) of the several load components, were estimated as follows.

Table 3. Power and Energy Requirements of the Karawa Mission

(1) Facility	(2) Coincident demand (kW)	(3) Energy (kWh) Per day	(4) Energy (kWh) Per year	(5) Percent of total
Hospital and related housing	40	433	158,000	38.0
Mission staff housing	100	620	227,000	55.0
School	2	16	6,000	1.4
Shop	5	17	6,000	1.4
Hammer mill	3	48	18,000	4.2
Total use	150	1,134	415,000	100.0
Losses*	25	136	50,000	
Total demand	175	1,270	465,000	

*Assumed 16% on peak power demand and 12% on energy.

Based on the above forecasts, it was necessary to derive the shape of the load curve over a 24-hour period in order to verify that the proposed hydropower project could generate the required power when needed The following load profile (Table 4) was estimated (note that the total daily kilowatt-hour energy requirement is somewhat higher than that in Table 3, because of the rounding of numbers).

Table 4. Estimated Daily Load Profile

Time period	Average demand (kW)	Consumption (kWh)
0600-0900	80	240
0900-1200	140	420
1200-1700	40	200
1700-2000	100	300
2000-2200	30	60
2200-0600	20	160
Total		1,380

RESOURCE ASSESSMENT

Climate

Karawa lies between the dry northwest of Zaire and the higher rainfall of the central zone. December, January, and February are generally the dry months, with peak rainfalls occurring August through October. Much of the rain comes in brief but intense storms. Interspersed with storms are occasional slow rains lasting 1 or more days. The area around Karawa is characterized by undulating plains covered with grass between patches of forest. The soil drains well, and standing water is seldom seen. During the dry season, the grass cover becomes tinder-dry and highly flammable. Electrical storms will occasionally ignite grass fires which sweep across the countryside, often destroying the small clusters of grass huts which are the typical abode of the local population. The area outside the Karawa hospital and residence complex is kept clear of the savannah grass, and the area inside is covered with greenery to avoid any possibility of fires there. At an elevation of about 500 m above sea level, the climate around Karawa is warm, 80°-90° F (27°-32° C) during the day and 70° F (21° C) at night, and the humidity level is reasonably comfortable.

Hydrology

The Libala River flows by the Karawa Mission and into the Mongala River east of Karawa. The Mongala River then flows south until it meets the Zaire River (see Fig. 1). As it flows southward toward Kinshasa, it joins the Ubangi River, which forms the border between Zaire and the Republic of Central Africa. Karawa is just within the drainage area of the Mongala River and on the northern edge of the heavily forested central area of Zaire. Moving northwest from Karawa, the land becomes drier, and forest cover gives way to grassland and wasteland covered with termite mounds.

A tributary of the Libala River begins about 30 km west of Karawa and drains a small sub-basin of about 176 km^2. As it works its way eastward toward its confluence with the Mongala River, the Libala flows over a 7 m rock cliff called Zulu Falls (see Fig. 12). "Zulu" in the Ngbaka language means "to pour out." The Karawa Mission has been interested in the waterpower potential of the Libala River since about 1968. Staff personnel observed the flow rates during both the rainy and dry seasons and collected topographic information to determine the best possible site. Two other sites are close to Karawa, but both of these would require much larger civil works and would be much more costly than Zulu Falls.

Formal hydrologic data for the Zulu Falls site and the Libala River were sought in various GOZ offices in Kinshasa. If any records were kept before independence, they are not now available. Consequently, riverflow data are largely a matter of observation. Fortunately, Mr. Robert Thornbloom, Chief Engineer for the Karawa Mission and for the power project, is a skilled observer and has been recording riverflow information for more than 20 years. His findings indicated that the dry season is from late December through March; rainfall builds up in April, peaks in August, and tapers off through November. Riverflows lag behind the rainfall pattern by about 3 months, remaining high until late November/December. During hard rains in the wet season, the runoff quickly follows the rainfall.

In assessing the reliable electric power supply and the need for storage facilities, it was important to determine minimum flow. During the site feasibility investigations (March 1978), it was not possible to intercept the total flow because a part of it bypassed the

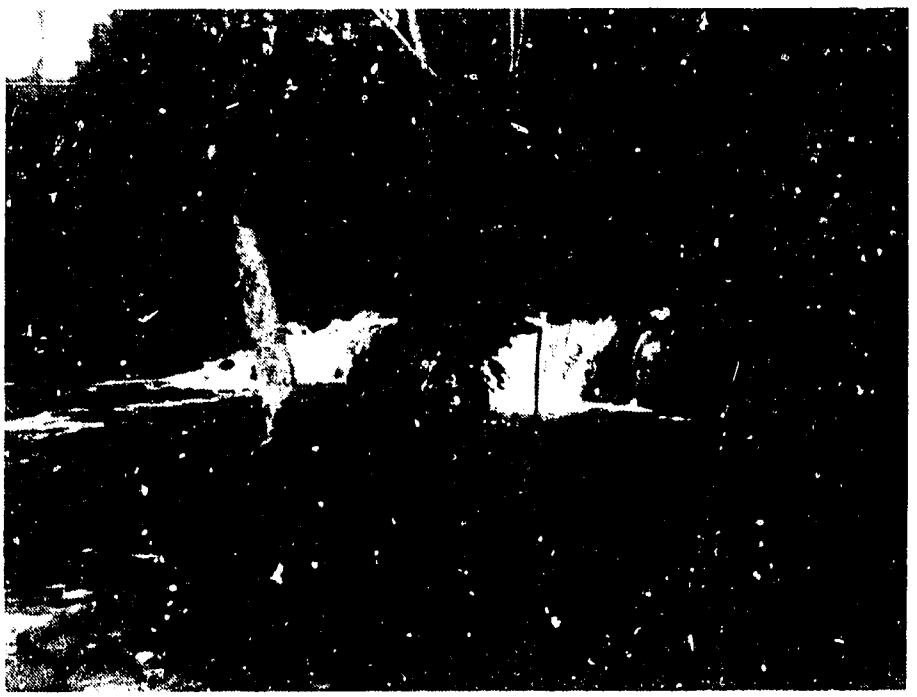

Fig. 12. Zulu Falls before construction.

falls through a number of small rivulets. However, the low flow at the falls was measured, by means of a temporary weir, at 1.08 m^3/s. With 7 m of head (or drop), this flow would produce about 60 kW of continuous electric power. The Mission requirements were estimated (see **Needs Assessment** section) to be 175 kW and 1,270 kWh per day. Because 60 kW for 24 hours yields 1,440 kWh per day, slightly more than the minimum required, the possibilities for energy storage were investigated. With water pondage (daily storage), it would be possible to supply the higher daily peak loads and the energy needs during the dry season. Because the area just above the falls was fairly flat, the investigation began with consideration of a dam of 2 m height directly above Zulu Falls.

A ground survey of the area above the falls was impossible because of the thick forest cover. Aerial photographic surveys, made when the flows over the falls were more than 1 m deep, showed the outline of the submerged forest area, thus indicating an approximate reservoir area. Soundings, taken from a boat, and other depth readings provided reservoir depth information (see Fig. 13). From these two values an approximate reservoir volume was calculated. It was determined that varying the water surface elevations by 1.5 m would make possible an active storage volume of 52,000 m^3. The 1.08 m^3/s value was selected as a conservative minimum flow because the control structures and forebay wall were designed to intercept all the rivulets that had bypassed the falls.

The maximum probable riverflow is also important in designing the control structures, spillway capacity, and dam freeboard. Data required to conduct flood forecasting, control, and streamflow routing were not available for the Libala River. Rainfall data were reportedly gathered before independence, but it is unclear whether flow data were ever gathered. The paucity of flood information did not allow formal flood flow calculations. It was therefore decided to estimate the largest known flood flow, multiply

it by a safety factor of 10, and design the control works accordingly. This procedure yielded a flood flow of 80 m^3/s. During such a flood, the falls would be submerged, trees would be washed downstream, and the areas above and below the falls would be scoured. There is no evidence that this has ever occurred. The spillways were designed to pass the estimated flood flows without using expensive gate structures, and are described in detail in the chapter on **Project Features.**

Fig. 13. Measuring the river bottom profile.

Land rights and the environment

The Karawa Mission is a nonprofit organization that is built on land granted in concession by the Government of Zaire for that purpose. A request must be submitted to the local government office for permission to build, expand, draw water from a spring, build a powerplant, etc. The reservoir area could not be formally surveyed, but the perimeter was derived from topographic maps. This land, together with that for the powerhouse and forebay, was granted for Mission use as a reservoir. In this early stage, the project will generate power only for the Mission's needs and does not conflict with the national electric utility company.

A further consideration was the preservation of Zulu Falls as a recreational area for local people and Mission staff. Fortunately, the dam structures could best be built well upstream of the falls, and most of the time sufficient water will flow over the spillway to preserve their natural beauty.

RESERVOIR OPERATION

The next task was to calculate a hypothetical daily reservoir operation, based on the assessments of resources and needs, to verify that the generation schedule could conform to the variable power and energy requirements during the day. The **Resource Assessment** had identified a minimum flow of 1.08 m^3/s and active storage capacity behind the dam of 52,000 m^3; the **Load Projections** had indicated the power and energy requirements estimated in Tables 3 and 4.

In Table 5, columns 1-3 indicate the average power requirements at given times of day. Columns 4 and 5 indicate the average and total water drawdown that will be necessary to meet the energy requirements (given the equipment used and the available head of 7 m). Column 6 shows the minimum water inflow during each time period, at 1.08 m^3/s. Column 7 shows the water in storage at the end of the period, starting from the capacity of 52,000 m^3 (i.e., adding the inflow and subtracting the drawdown from the figure at the end of the previous period).

Table 5. Hypothetical Daily Reservoir Operation

(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Water drawdown			
Time period	Hours	Average (kW)	rate (m^3/s)	volume (m^3)	Water inflow (m^3/s)	Storage at end of period (m^3)
						52,000
0600-0900	3	80	1.5	15,900	11,664	47,764
0900-1200	3	140	2.6	27,800	11,664	31,620
1200-1700	5	40	0.7	13,200	19,440	37,868
1700-2000	3	100	1.8	19,800	11,664	29,732
2000-2200	2	30	0.6	4,000	7,776	33,508
2200-0600	8	20	0.4	10,600	31,104	54,012
Totals	24			91,300	93,312	+ 2,012

This table indicates that adequate storage will be available for daily operation of the generating units in accordance with the load requirements. The call on active storage is only 22,000 m^3, out of the available 52,000 m^3, indicating that the system could cope with a much greater range of load variations. Furthermore, with the dam intercepting flows that previously bypassed the falls, it was expected that the minimum flow would significantly exceed the 1.08 m^3/s rate used in this study. Additional storage not included in the original survey would improve the operation by reducing reservoir depth

variations, providing holdover storage and allowing for any additional losses caused by greater reservoir area--which may be particularly important during the dry season.

FUNDING SOURCES

The financial base of the Mission, its legal status in Zaire, and the difficulty of obtaining foreign currency made it virtually impossible for the Mission to obtain commercial financing for its small hydropower project. Such organizations work, almost by definition, in areas that are unattractive to private investment. Like most PVO groups, the Mission first turned to the various donor agencies operating in Zaire to solicit their interest in providing grant funds. After extensive contacts, AID funded a feasibility study for the Zulu Falls power project in March 1978. In this study, cost estimates for the project totaled $500,000 in foreign currency (mostly for imported equipment and transmission cable) and $408,000 in local currency (for civil works, labor, etc.).*

Before the AID agreement, contacts had also been established with the Ossberger Company in Germany. Its equipment would have been preferred (some of its advantages are noted in the chapters on **Project Features** and **Implementation**), although it could not be purchased with funds from AID. These contacts eventually resulted in a grant from EZE, an official German development assistance organization, for a turbine generator unit from Ossberger. A German mission organization, WEM, dealt with the paperwork and ensured equipment delivery to Zaire. The value of that grant is not known because the transaction did not flow through Mission project accounts. It was thought to be DM 300,000, and the nominal dollar equivalent is given as $100,000 in Table 6.

On the basis of the feasibility study, AID authorized grants for US$ 500,000 for imported capital equipment (including a turbine and generator) and construction equipment, and Z 322,400 for locally available construction equipment, material, and labor. When the local currency grant was made, the amount was set at the dollar equivalent of $410,000.**

As a consequence, the project at Karawa has two sets of turbines and generators. It should be stressed that the degree of security afforded by this arrangement, while typical in developed countries, is exceptional in rural areas of developing countries, where resources for capital development are scarce. The major advantage is that essential loads, such as in the hospital, will not suffer if one of the units breaks down or is shut down for maintenance. This is particularly important when parts are difficult to obtain, but it is more common for an old diesel generator to serve this backup function.

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* Actual project costs are detailed in Table 9, page 48.
** See page 47 for a discussion of local currency costs.

Table 6. Donor Financing

Source	Grant as issued	US$ equivalent
AID	$500,000	500,000
AID	Z 322,400	410,000
EZE	DM 300,000	100,000
	Total	1,010,000

DAM AND SPILLWAYS

The layout of these major civil works features is shown in Fig. 14, where dotted lines indicate the original course of the river and the shape of the island. Elevations are relative to an arbitrary fixed point, rather than the actual site elevation of approximately 500 feet above sea level.

The concerns of the design engineer included the following:

- minimizing construction costs;
- making maximum use of locally available skills and resources, as opposed to sophisticated construction techniques that require imported materials;
- ensuring that the dams, control works, and spillways would be able to cope with unusually high floods;
- simplifying operation, maintenance, and repair tasks;
- preserving the natural beauty and recreational value of Zulu Falls.

By locating the dam to incorporate the island, rather then just above the falls, the engineer was able to limit its height to a maximum of 2.5 m. This also simplified the construction of temporary cofferdams that diverted the river during construction, and minimized the heights of control and spillway structures.

In developed countries, a likely procedure would be to use reinforced concrete in the construction of such civil works. At Karawa, however, concrete was avoided as much as possible throughout because of the high cost and poor quality of cement, and the likelihood of losing large quantities of cement as a result of humidity, lack of proper aggregate, poor quality of reinforcing steel, lack of workers skilled in the techniques involved, and lack of large mixers.

One alternative is an earthfill dam, which has the advantages of relatively straightforward construction techniques and simple foundation requirements. Most earth is permeable, however, and these dams usually require an interior core of impervious material to make the structure watertight. In this region of Africa, thousands of termite mounds dot the grasslands. The termites have processed the dirt in the mounds in such a way that it is extraordinarily impervious, as indicated by its resistance to wind and rain erosion. Samples had been laboratory-tested in the United States and found to be suitable for damfill, thus avoiding the need for an inner core. These tests specified the ideal moisture content and compaction procedure.

Because the Mission had the manpower and machinery to gather, move, and place the mounds, it was decided to construct an earthfill dam using this material. Bulldozers knocked down the mounds, and loaders put the chunks into trucks that transported them to the site. There they were spread roughly, watered as necessary, and compacted by tractor treads or tamped by laborers where tractors could not go. The dam was placed on bedrock that was mostly exposed, although up to 1 m of earth was removed in some areas. In some places the rock was layered, and the cracks had to be hand-packed with cement grout (see the **Problems Encountered** section).

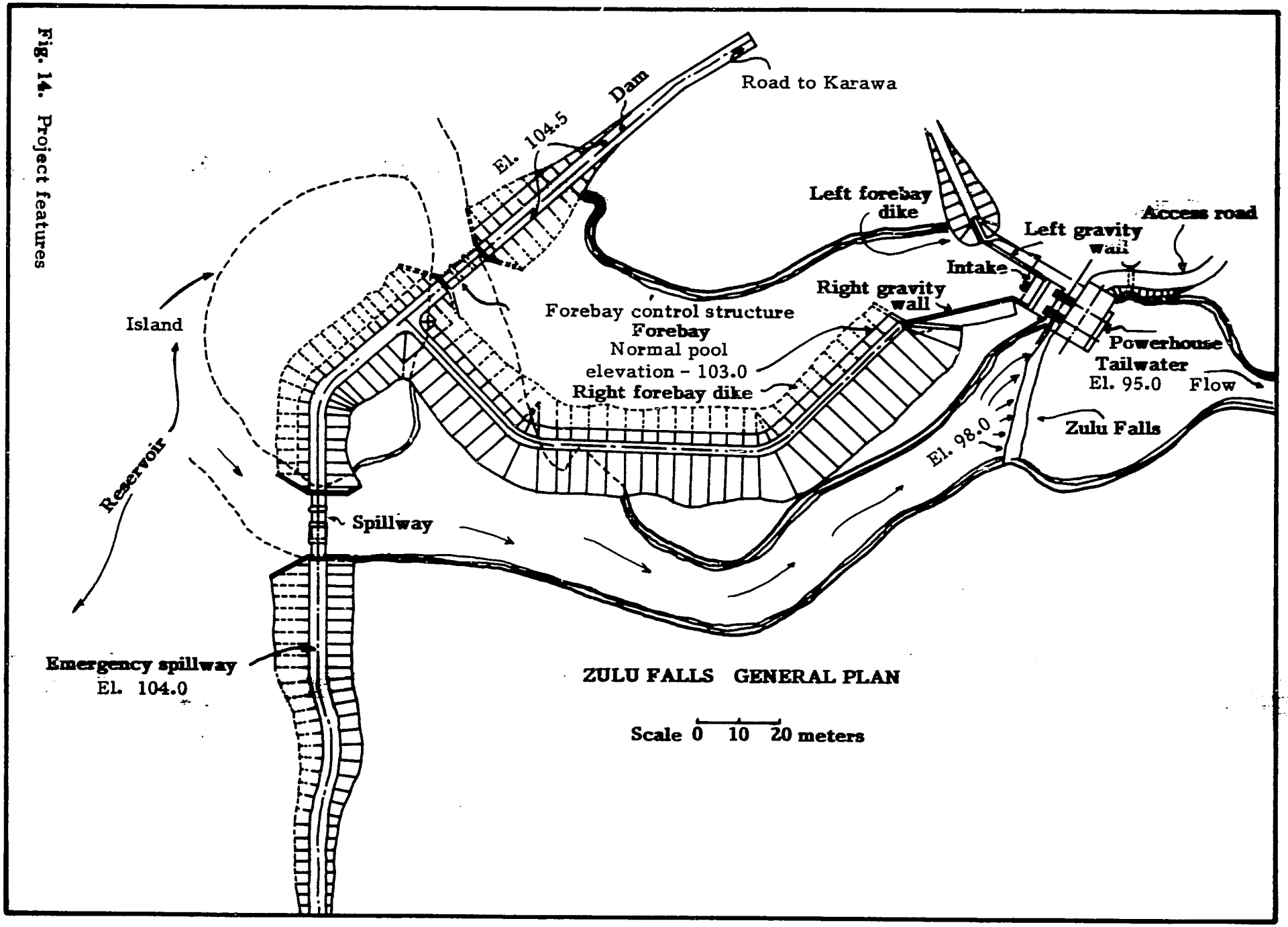

Fig. 14. Project features

Because it was impossible to predict the maximum flood accurately, the spillways were designed with substantial additional capacity. Rather then design one large concrete spillway to handle the largest potential flood flow, a two-stage spillway system was constructed. Observed flood flows would be discharged by the service spillway, and any unusually large flood flows would pass through both the service and auxiliary spillways. These spillways are of the simple "overflow" type that does not require gate structures or related operating requirements, thereby minimizing costs. The service spillway was designed with a crest elevation of 103 m and a crest length of 12.6 m. Should the water level reach 103.5 m, it would discharge about 10 m^3/s.

Work is not yet completed on the 20 m long auxiliary spillway. To expedite completion of the dam, the section where the auxiliary spillway will be located was initially built to the same level, and with the same material, as the rest of the dam. During the 1985 dry season (January through March), the existing crest will be cut down from 104.5 m to 103.7 m. A small backhoe will dig a trench about 2 m deep, which will be filled with concrete to the 102.5 m level, to form the spillway crest. The termite mound material will then be removed, down to the level of this crest, and replaced with ordinary dirt back up to 103.7 m.

The service spillway is designed for floods that exceed the 103 m level by 1/2 m or so. Should any flood exceed the 103.7 m level, the auxiliary spillway will be topped and the ordinary soil will be rapidly washed away down to the concrete crest. With the pool at 103.7 m, a flow of about 16.4 m^3/s would pass over the auxiliary spillway--about four times the maximum recorded. Added to the 10 m^3/s passing over the service spillway, this provides for a flood flow of 26 m^3/s. Together, the two spillways thus provide an ample safety margin, bearing in mind that operation of the auxiliary spillway is a remote possibility.

Following eventual operation of the auxiliary spillway, the forebay and reservoir would remain at the 102.5 m level until the earthfill was replaced. Fortunately, another feature of this layout (as opposed to locating the dam just above the falls) is that it allows for greater ease and flexibility in maintenance tasks. With the stoplogs removed from the forebay control structure and the sluice gate next to the intake works opened, the water level can be permitted to fall below 102 m while the earthfill is replaced in the emergency spillway. This gate also serves to sluice out debris collected at the trash racks (see Fig. 18). Similarly, with the stoplogs in place, the forebay can be drained quickly for repairs to the dikes or gravity walls.

Under normal circumstances, the reservoir will be at a level slightly above 103 m. A small amount of water will flow over the service spillway to the falls, and over the control structure to the forebay (see Fig. 15). The small drop in elevation between the reservoir and the control structure results in a slight head and energy loss during times of surplus water. On the very rare occasions when reservoir inflow is low and system demand at its peak, the stoplogs in the control structure may be removed. This will bring the reservoir and forebay pools to the same level and cut off the flow over the falls.

Fig. 15. Control works.

The forebay alignment was designed to allow adequate passage of water between the control structure and the intake works. The right forebay dyke curves to follow the original contour, thereby maintaining uniform height throughout its length and enclosing the maximum storage volume. Again, sophisticated construction techniques were avoided. The retaining walls are gravity structures, using cyclopean rather than reinforced concrete. This procedure allows for larger rocks in the aggregate mix and permits the use of smaller mixers. The fairly constant humidity and temperature allow cyclopean concrete to cure without appreciable cracking.

A roadway runs along the top of the dikes, on bridges over the control works and service spillway. This road constitutes a major improvement over the previous situation, when people going to and from the market had had to wade through the river, which was dangerous or impossible at times of high water.

POWERPLANT

Given the assumed minimal flow of 1.08 m^3/s and the recorded flood flow of 8 m^3/s, plans had proceeded on the assumption that continuous power would be 60 kW and peak power capability would be 120 kW. Accordingly, in 1978 preliminary quotations had been obtained from the Ossberger Company for a 125 kW unit, although no funds were available from that source at the time. Later in 1978, the AID grant was approved, and a 120 kW unit was ordered from the Leffel Company in the United States (the AID funds could not be used for German equipment). At the time, it was hoped that if the AID grant provided sufficient funds, a second 120 kW unit could be ordered later.

The Mission was advised that, largely because of the decision to lay the transmission line underground, the 120 kW Leffel turbine would actually operate with a power factor close

to unity, enabling it to produce 150 kW while staying within its rating of 150 kVA. Although peak power requirements at the Mission had been estimated at 175 kW, that load will require several years to develop. Simple load management practices, such as scheduling the autoclaves and water heaters for off-peak periods, could easily limit peak demand to 150 kW.

Meanwhile, early in the construction work it became apparent that the actual minimum flow would be almost double the earlier estimate of 1.08 m^3/s, because many small rivulets that had bypassed the falls were closed in. Under these conditions, continuous power of 120 kW and peak capability of 240 kW could be developed. Although the AID grant would not finance a second unit, contacts with Germany led to the grant of a 200 kW unit from Ossberger (see **Funding Sources** section).

Mechanical/electrical equipment

Although both units have the same hydraulic head rating and the same penstock diameter, the Ossberger features a crossflow type of turbine, whereas the American-made Leffel unit employs a Francis type of turbine. Both turbines are horizontal-shaft units driving separate synchronous generators through speed increasers. The nameplate data are given in Table 7.

An important feature of the crossflow turbine (see Fig. 16) is the gate linkage, which allows water to enter over one-third, two-thirds, or the entire length of the runner. This enables the turbine to operate at a high efficiency rate over a wide range of power loadings, particularly when the full turbine capability is not needed or when water supply is limited. For example, the initial loading of the plant was about 30% of the turbine capability, and it was set up for the one-third mode even though surplus water was spilling over the falls. The turbine must be shut down to shift the linkage; consequently, this operation is done only seasonally or when long-term changes in the electrical load levels are made. For testing, the linkage was changed from the one-third to the two-thirds rating. It was found that, before the connecting pin could be pressed into place, the holes in the yoke to the turbine gate mechanism had to be aligned precisely with the hole in the governor actuating shaft. This procedure took about 30 minutes. Although that time could be reduced, because the technique of aligning the shaft and the yoke was discovered during this operation, it was decided that any linkage change would be made during other maintenance work, while the standby generator was carrying the load.

The speed increaser increases the turbine shaft speed to that required by the generator. It is a double step-up gearbox with roller bearings, completely enclosed and running in oil, with flexible couplings on both the input and output shafts. The governor is totally enclosed, filled with oil, and driven directly from the turbine shaft. Its holds the turbine within 2% of its rated speed. A "black start" (with no external source of electric power) can be made by manually opening the wicket gates to bring the machine to about 20% of rated speed. At this point, the mechanically driven governor oil pump delivers sufficient pressure to open the gates further to "speed no load," and then to open them further still when the load is switched on.

Table 7. Turbine and Generator Nameplate Data

Unit No. 1

OSSBERGER crossflow turbine; 315 CV (hp), 141 rpm, H = 7.4 m

OSSBERGER generator - Selbstvegelander (self-regulating) Type AVK, 250 kVA, 230/400 V, 361 amperes, 0.8 power factor, 50 Hz, 1500 rpm

Unit No. 2

LEFFEL Francis turbine; 180 hp, 425 rpm, H = 26 feet

KATO generator - rotating field, 120 kW, 150 kVA, 0.8 power factor, 1500 rpm, 50 Hz, 230/400 V, 217 amperes. Exciter field, 1.4 amperes, 50 V

The Francis unit shown in Fig. 17 was manfactured by Leffel and drives a Kato synchronous, brushless exciter generator at 1500 rpm through a multiple V-belt speed increaser. The governor, made by Woodward, has a fractional horsepower motor to develop the hydraulic pressure for the actuator (also by Woodward). Once the generator has been started, this motor runs continuously. A hand pump is provided as part of the governor package to develop initial hydraulic pressure. This pump, in turn, opens the turbine wicket gate to enable the unit to make a "black start."

Both the gear-driven speed increaser on the crossflow unit and the belt drive on the Francis unit are standard manufacturer's designs. The gear drive is slightly more efficient, but the difference is insignificant. Initial cost favors the belt drive, but changing belts and adjusting tension would require more frequent attention. On the other hand, shaft alignments between the turbine, the increaser, and the generator, are more critical for the gear drive. Also, because the drive unit is totally sealed, the special oil provided in the gear drive should last a long time. If a choice had to be made between the two types, the belt drive would be more suitable because it would be simpler to set up in the field by persons with average technical capability.

The decision was made to convert the existing operating electrical frequency of the Mission from the U.S. frequency standard of 60 Hz to the African standard of 50 Hz. This conversion would avoid any future problems in interconnecting with central station systems that might extend into the area.

Each generator has a control panel supplied as part of the package, providing a combination toggle- and overcurrent-operated circuit breaker, switch-selected volts and amperes indicators on each phase, and a reed-type frequency indicator. A selector switch connects either of the units to the power transformer. For the two units to be operated in parallel at a later date, an additional control panel would have to be added (see **Operations** chapter).

As is typical on small units, the control panels do not provide alarms or indicators for generator winding or bearing temperature. However, a trained operator can monitor such temperatures and other operating conditions by sound and feel, as well as by reading indicators. The continuous presence of guards on a three-shift basis will provide not only

for monitoring of the plant equipment, but also for patrolling of the dam and reservoir areas and general security of the site.

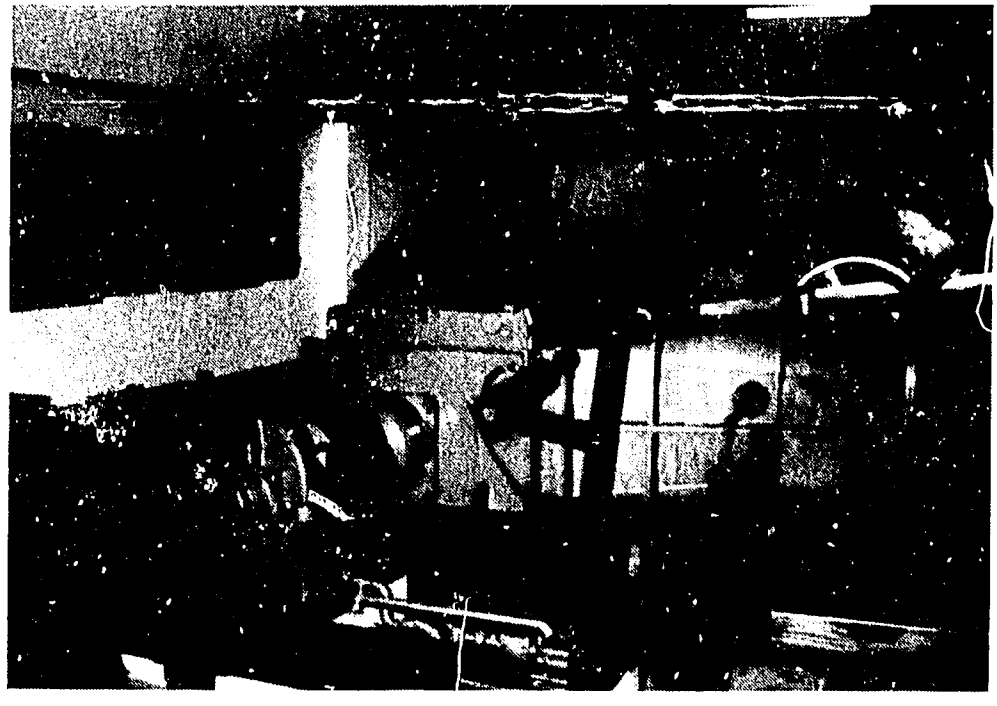

Fig. 16. Crossflow unit.

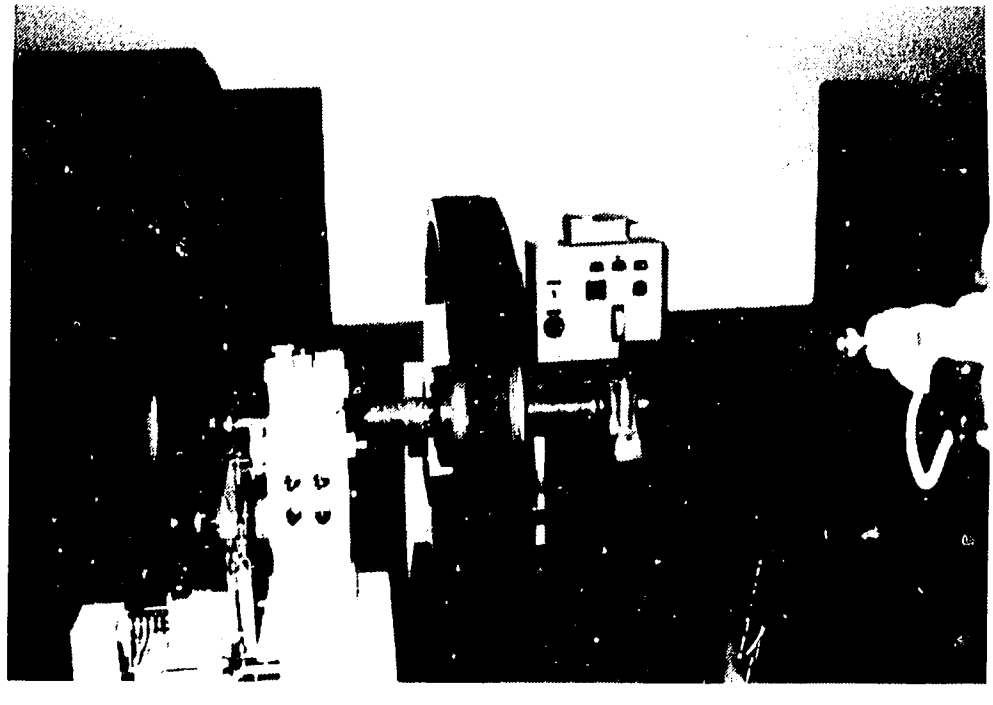

Fig. 17. Francis turbine.

POWERHOUSE

The powerhouse is located just below the forebay and intake structure (see **Problems Encountered** section). Because of the limited space between the forebay walls and the powerhouse walls, it was decided to install two independent penstocks rather than just one penstock with a bifurcation to both turbines. The penstock for the Ossberger unit was included in the package; that of the Leffel unit, together with the sliding gates and transition sections, was fabricated in Kinshasa to fit the same inlet diameter of 140 cm (see Fig. 18). Mechanical configurations for the two turbines are quite different, however, requiring different dimensions of the draft tubes, or water outlets (see Fig. 19).

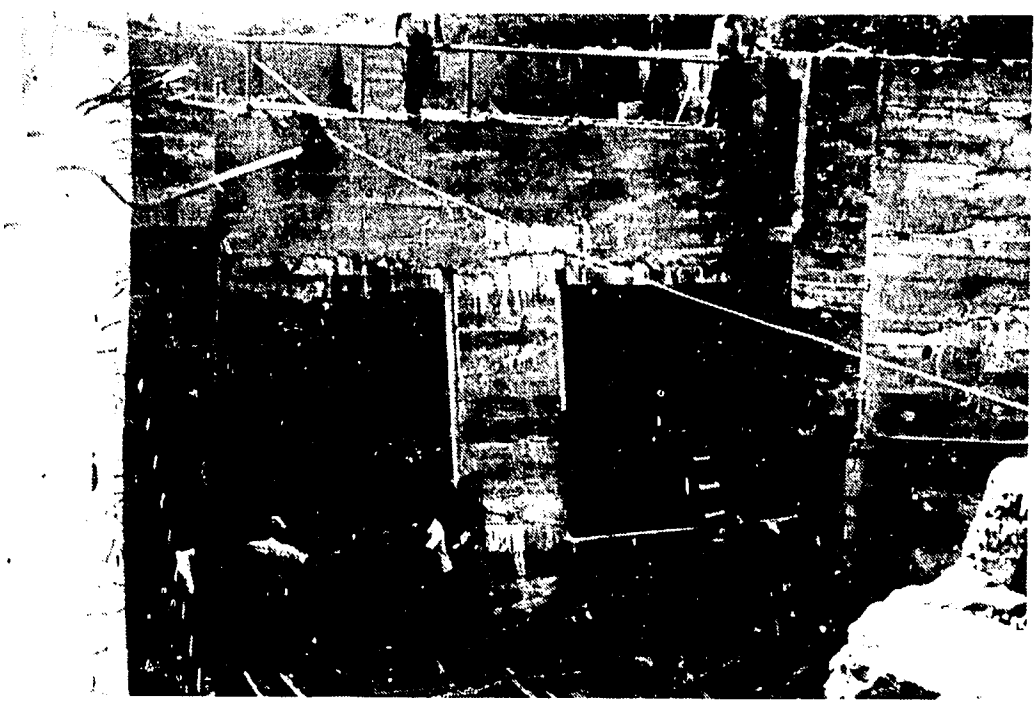

Fig. 18. Intake structure.

Fig. 19. Powerhouse.

ELECTRICAL DISTRIBUTION FEATURES

Because the hospital, residential, and school facilities are about 11 km from the powerplant, it was necessary to step up the generation voltage to a suitable primary distribution level. A preliminary comparison of 2.4/4.1 kV with 7.2/12.5 kV made for the AID feasibility study indicated that the higher voltage level would be the more suitable. Later studies verified this conclusion, showing that the lower losses would offset the somewhat higher costs. Furthermore, 7.2/12.5 kV is a widely used American standard, and equipment for it is readily available.

Overhead lines and underground cable were the two alternatives of primary distribution considered for this project. Three conditions unique to this area had to be considered in making the choice: the presence of termites, severe storms with very high lightning levels, and frequent grass fires during the dry season. Termites will attack any wood placed in the ground, including the local hardwoods such as mahogany, unless it is fully pressure-treated. If Zaire has any treating facilities, they would be in Kinshasa, making the initial procurement of poles and their shipment to the site both difficult and costly. Dry season brush fires, usually started by lightning, often sweep across the grassland where the line would go and could set fire to any wood pole. Lightning of the severity and frequency encountered around Karawa would be likely to overstress the insulation protection normally provided for overhead distribution lines, damage other equipment, and interrupt vital electric service.

The alternative was to lay underground cable. Except for making splices, the laying of cable can be done by semiskilled labor. On the other hand, skilled workers would be required to erect poles, attach hardware, and string overhead conductor. Cost comparisons in the feasibility report between overhead lines on steel or wood poles and

underground cable indicated that the latter costs would exceed the former by 13% at the most. Underground cable was chosen because of its superior reliability in being protected from lightning and grass fires. Voltage drop calculations made during the detailed system design allowed a somewhat smaller cable size to be used in the actual installation, thereby reducing the cost to about that of overhead lines. Costs were further reduced by training three local craftsmen in cable splicing, thereby avoiding the expense of hiring expatriate splicers. The cable used is three-conductor, #2 solid aluminum, 175 mils, cross-linked polyethylene-insulated (see Fig. 20).

Fig. 20. Cable trench.

The cable routing essentially followed the road connecting the powerplant to the Mission compound; deeply driven steel stakes mark the exact alignment. A concrete vault was built about midway, with cable terminations and connectors. This construction facilitates testing for faults by permitting the cable to be sectioned.

Distribution within the Mission compound generally follows U.S. underground residential distribution practices. The same size, three-phase underground primary distribution cable feeds three main distribution points, and single-phase underground primary feeds seven others. Secondary, 120-240 V, three-wire distribution cable is also underground for protection against lightning. Having all the lines underground serves aesthestic as well as security purposes. The only visible parts of the system are the metal distribution transformer and terminal cubicles serving the residential areas. These are painted green and are not very noticeable (see Fig. 21).

Fig. 22 shows the present and near future distribution system layout. It shows 10 transformers, with a total capacity of 355 kVA, which allows for considerable load growth. Because it is a major load center, the hospital service was divided into six secondary feeders, each of which is fed by a fused switch of suitable ratings for loads

such as air conditioners, sterilizers, autoclaves, dryers, and lighting (see Fig. 23). Meters will be installed throughout the system.

Although the new hydropower system is proving to be reliable, some of the existing diesel engine-driven generators will be kept in running order as emergency standbys. A used 75 kW unit will be installed at the delivery end of the incoming cable from the hydropower plant, with switching which will enable it to pick up critical loads whenever the plant or the cable might be out of service. Other units are or will be located to serve the hospital as top priority, and other areas as conditions allow. Appropriate switching will isolate sections of the system in order that load can be trimmed or limited to the capabilities of the standby units. Fig. 24 shows a sectionalizing panel.

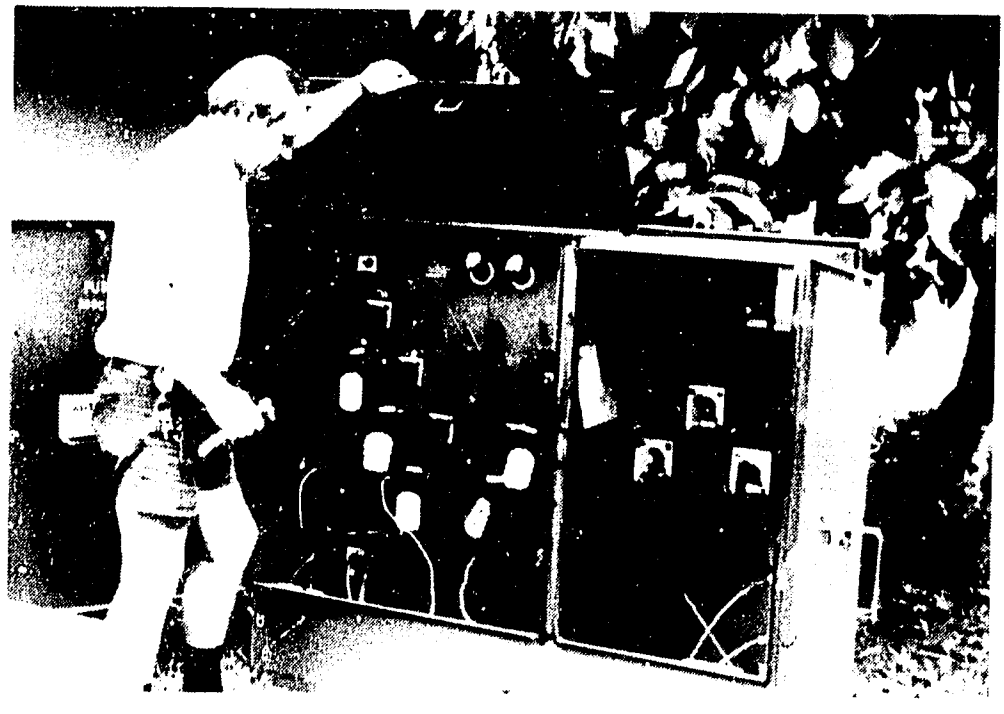

Fig. 21. Distribution system cubicle.

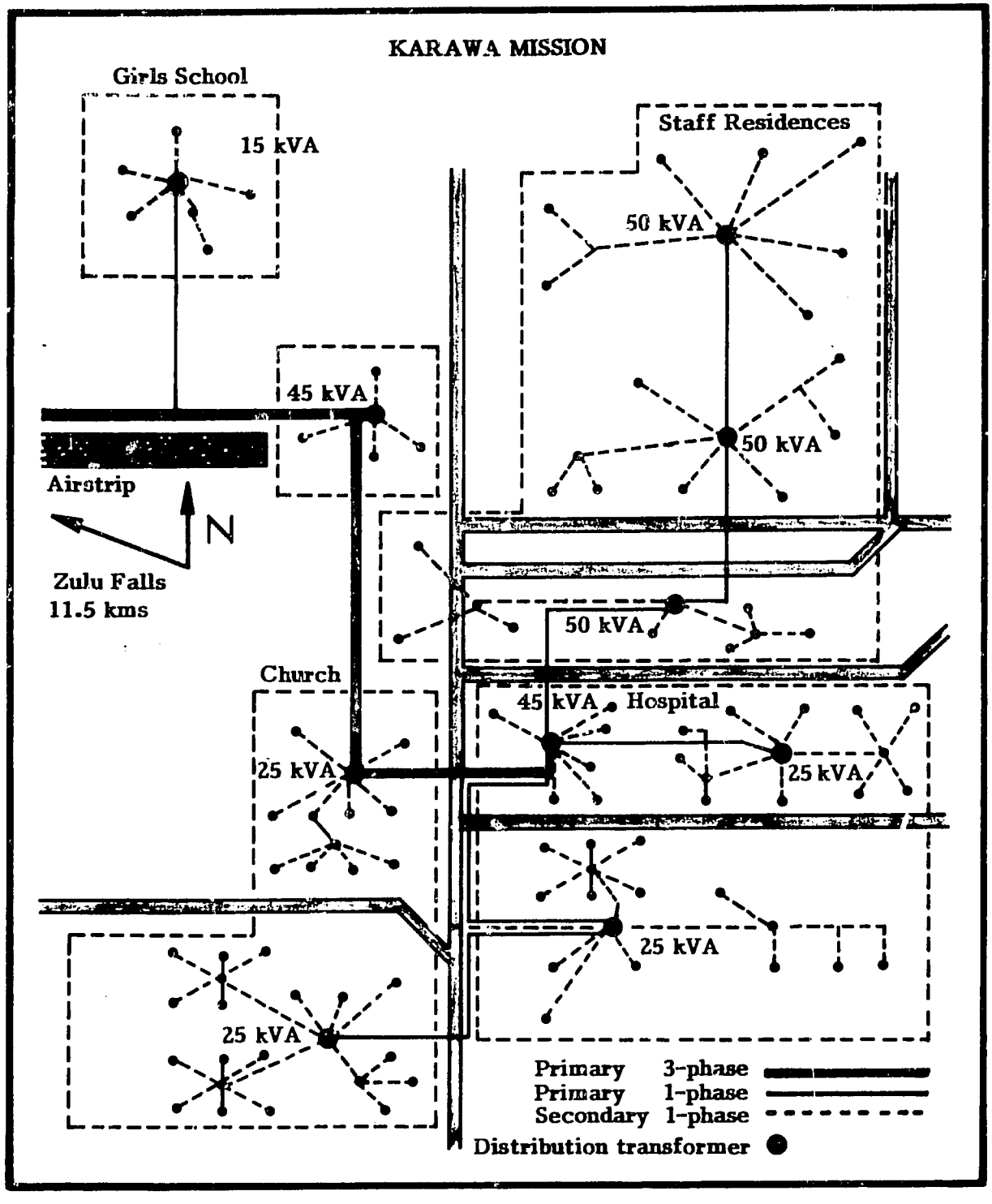

Fig. 22. Karawa Mission distribution plan.

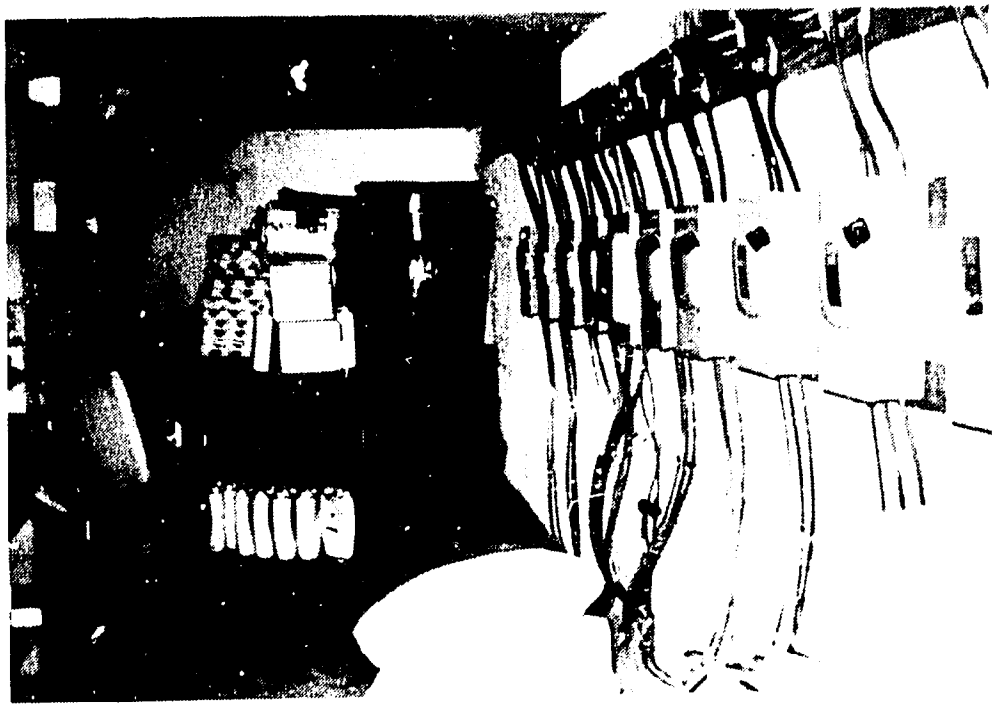

Fig. 23. Hospital branch feeder distribution.

Fig. 24. Sectionalizing panel.

TECHNICAL ASSISTANCE

The Karawa Mission has a Technical Services Department, responsible for maintaining trucks, water systems, light plant, air strips, buildings, etc. in the Ubangi region. The director of this Department, Mr. Robert Thornbloom, made systematic observations of the river regimen--the times of low and high flows and preliminary estimates of flow rates--through the 1960s. A choice was made in favor of the Zulu Falls site, because the alternative sites downstream would have required more costly civil works. The Mission staff included seven persons with capabilities in civil, mechanical, and electrical technology who were to supervise and train the villagers working on the project during the construction stage.

Since 1970, the Mission has also been helped in developing the project by members of its sponsoring church in the United States. Mission staff corresponded regularly with specialists and consulted with them on periodic visits to the United States. A total of 15 short-term missionary volunteers, selected for their skills and experience in overseas projects, worked at Karawa for 1-3 years at a time during the construction stage, 1978-84.

Three sources of high-quality technical expertise were particularly important:

- In 1972 a member of the sponsoring church, who is also an engineer and official with a large consulting firm in Chicago, made his first visit to Karawa. His initial contribution was for preliminary designs of the civil works. From 1978 onward, when it appeared that funding would be available for the project, his work progressed to structure analysis and final designs of dams, control works, spillways, turbine settings, etc. This engineer visited the site again in 1980 and 1982, as construction work progressed, to verify designs and assist in resolving the inevitable problems that arose.

- In March 1978, AID financed a feasibility determination which included a formal load development study, hydrologic analyses of river low flow and flood flows, basic powerplant and distribution system characteristics, and cost and benefits analyses.

- From mid-1978 onward, an electrical engineer with a public utility in Chicago, also a member of the sponsoring church, contributed assistance. He verified the basic distribution system characteristics derived earlier in the feasibility report and undertook detailed designs. These included equipment and material specifications, layout, lists of equipment and materials, installation instructions, testing procedures, and a list of test equipment. Another electrical engineer and church member made significant contributions to the design of the distribution system and procurement of equipment.

CONSTRUCTION

The dry season is from late December through March, and as much construction as possible must be done during that period. Given the vagaries of river shipments, keeping supplies on hand frequently involved problems of scheduling, ordering, and delivery of materials. The scheduling of unskilled labor had to take into account the fact that most

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of the laborers in the Karawa area are farmers, who want to be at their farms during the growing season, from September through November.

Construction of the dam, control works, powerhouse, and bridges was a combination of labor-intensive and mechanized practices. Although the dam is a small structure by ordinary standards, moving and placing the amounts of earth involved by manual labor alone was considered impractical for the following reasons:

- A large labor force was difficult to maintain in the project area, 11 km from Karawa.
- The availability of manual labor decreases during the rain and harvest seasons, reducing the effective work period during a year to about 8 months.
- The Mission already had trucks, tractors, and other equipment, plus a well-equipped workshop for maintenance and repair of equipment.

A tractor and a backhoe were rebuilt at the Mission. A rock crusher was reclaimed from President Mobuto's equipment scrap pile, reconditioned, and equipped with a new engine. New equipment procured for the project included a front loader, trucks, dumpers, concrete vibrators, small pumps, a sawmill, wheelbarrows, and parts for reconditioning existing equipment. In addition, used equipment was obtained from the U.S. Excess Property program, including two loaders, a truck, a ditcher, water tanks, fuel tanks, and air compressors (see Figs. 25 and 26).

Fig. 25. Construction phase.

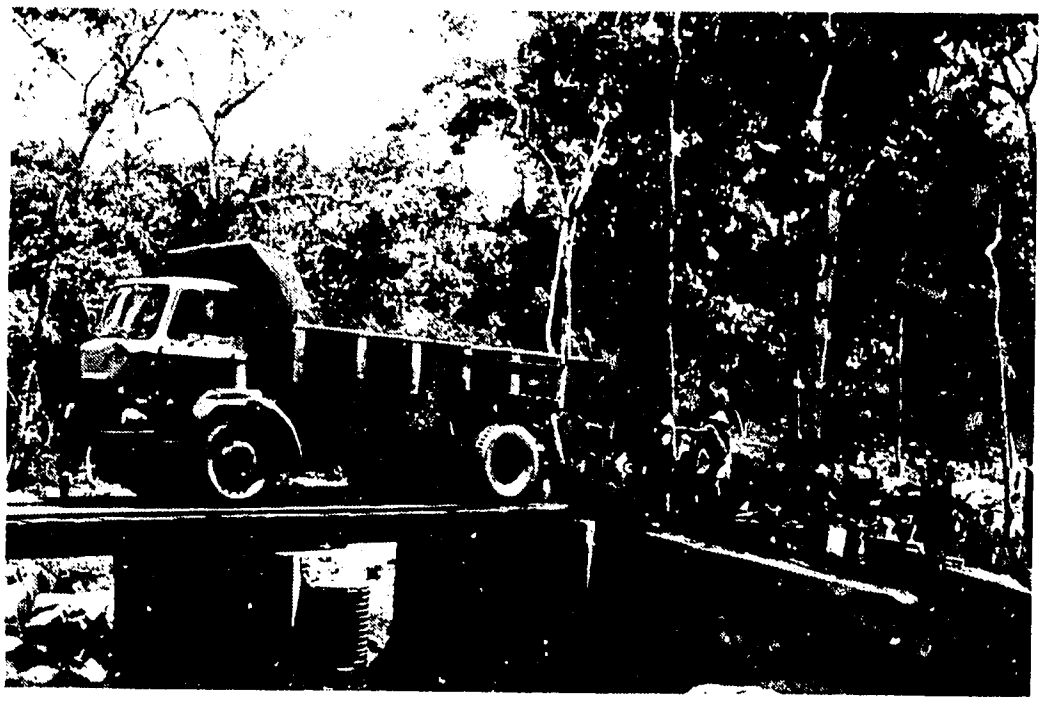

Fig. 26. Truck offloading dam fill material from control structure bridge.

The basic dam construction events were:

- o removing overburden to uncover the rock for placement of the fill material;
- o constructing cofferdams to drain the work areas;
- o gathering damfill material;
- o processing, placing, and compacting of fill material;
- o placing rock riprap on the reservoir pool side of the dam on and below the auxiliary spillway.

Tractors, front loaders, and dumpers removed overburden. Cofferdams were built during low waterflow periods by driving posts into holes drilled into the rock by jack hammers, piling brush against the posts, and compacting dirt against the brush to form a temporary structure of a typical gravity dam cross-section (see Fig. 27).

Termite mound material was used for damfill (see **Project Features** chapter). The dark brown mounds are roughly conical and frequently 2.5 m high. The termite secretions cement them into a hard and water-impervious mass. Tractors knocked down and broke up the mounds, front loaders put the pieces into dumpers, from which they were piled up and crushed by tractor treads. Tractor blades and hand shovels then worked the piles into a homogeneous fill mixture. After the irregular rock surface was covered up with fill, a flat and level surface was formed. Dumpers could develop the trapezoidal shape of the dam by placing a layer of fill roughly 15-20 cm thick on each pass. The mixture was watered as necessary for proper compaction, which was done by controlling the traverses

of the dumper wheels and by tractor treads. Some tamping by hand labor was necessary where the heavy equipment could not reach (see Fig. 28).

Fig. 27. Cofferdam construction.

Structures formed of concrete include the control works, spillways, powerhouse lower walls, and inlet works and foundations. Good coarse aggregate for concrete was obtained from the rock crusher, from fist-sized rocks down to chips. River sand was used sparingly for fine aggregate. Very fine riverbank sand was used in a rich cement mortar mix for finishing walls and floors. Formwork was mostly wood planks sawed from trees cleared from the construction areas. A sawmill was procured for that purpose. The sawmill will meet the continuing requirement for lumber shapes of various kinds at the Mission.

The dam, control works, and spillway structures are cyclopean concrete--large rock aggregate with no reinforcing. The more critical structures, such as the intake works and foundations, used the limited amount of available deformed bars supplemented with smooth bars as necessary. Transition sections, from the 3 m x 3 m square inlet gates to the circular penstocks for the two turbines, were formed in plywood before the concrete block joining the dam and the powerhouse was poured. That block provides additional anchoring between the powerhouse foundation and the rock at the left-hand base of the falls. The penstocks also required concrete support piers. Just before the Francis turbine inlet, a short steel flanged transition section was installed, linking the 140 cm diameter penstock section to the 122 cm diameter turbine throat.

During removal of overburden from rock for the powerhouse foundation area, it was found that the upper layer of rock was not suitable for a good foundation. While removing that layer, additional fissured rock was found and it became necessary to excavate a sizable hole. A number of discarded truck frames were cut up, cleaned, and

placed in the foundation in order to reinforce it and reduce the volume of concrete, which was poured in an essentially continuous operation. The powerhouse walls are of formed, reinforced concrete to a height of about 1/2 m above the floor slab, except for piers at the ends and midway along the walls, which were extended to roof level. In the future they may support steel beams for a possible bridge crane above the turbine generators. As the powerhouse concrete was formed and poured, the penstocks and inlet sliding gates were embedded. The remainder of the walls were built of concrete blocks which were made at the site. Both interior and exterior walls were finished with the mortar mix.

Fig. 28. Tamping earthfill material.

Turbine generator installation

Installation of the turbine generator sets followed standard practice, carefully leveling and finishing the machine pedestals before placing the anchor bolts. The heaviest piece (8 1/2 tons) was the crossflow turbine, which was transported on a heavy dump truck from the Businga riverport to the project. At the site, a ramp was built to move the turbine off the truck and down a slope to the powerhouse floor level. The powerhouse roof and crane were not yet in place, so heavy timbers and tackle were set up to lift the turbine onto its pad. The generator was handled in a similar fashion. The Leffel unit was put into place first, because it is farther from the door, but the heavier Ossberger was the more difficult to handle. The Mission resident staff performed or supervised all the heavy hauling, moving into place, leveling, and alignment of turbines, speed increasers, and generators, as well as the initial operation and testing (see Figs. 29 and 30).

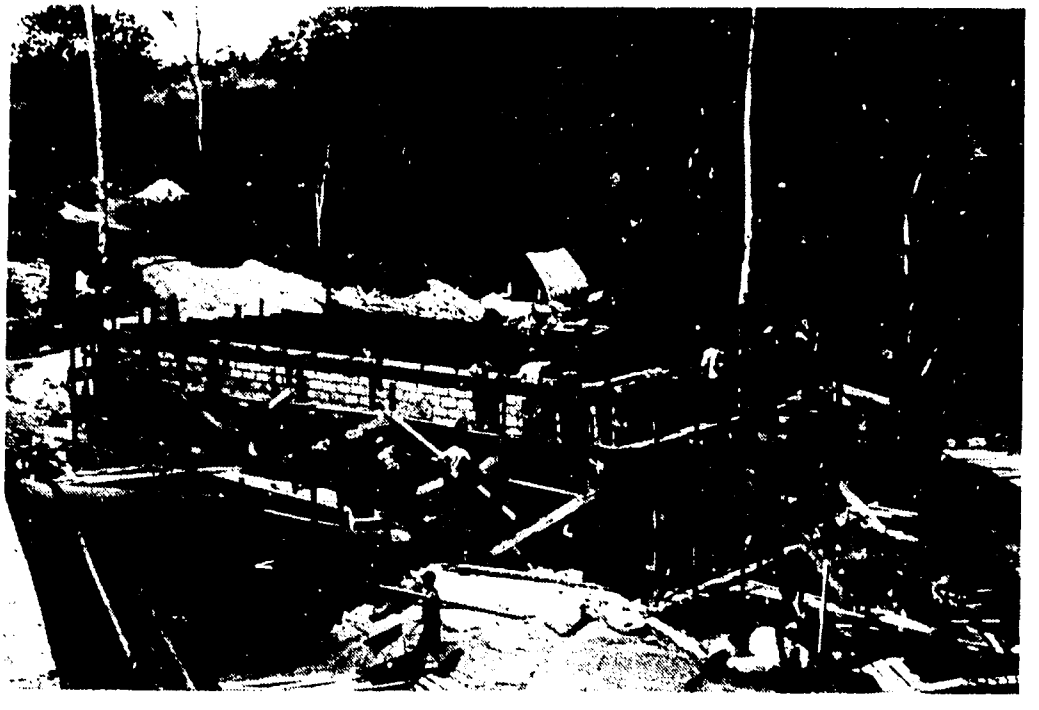

Fig. 29. Powerhouse construction.

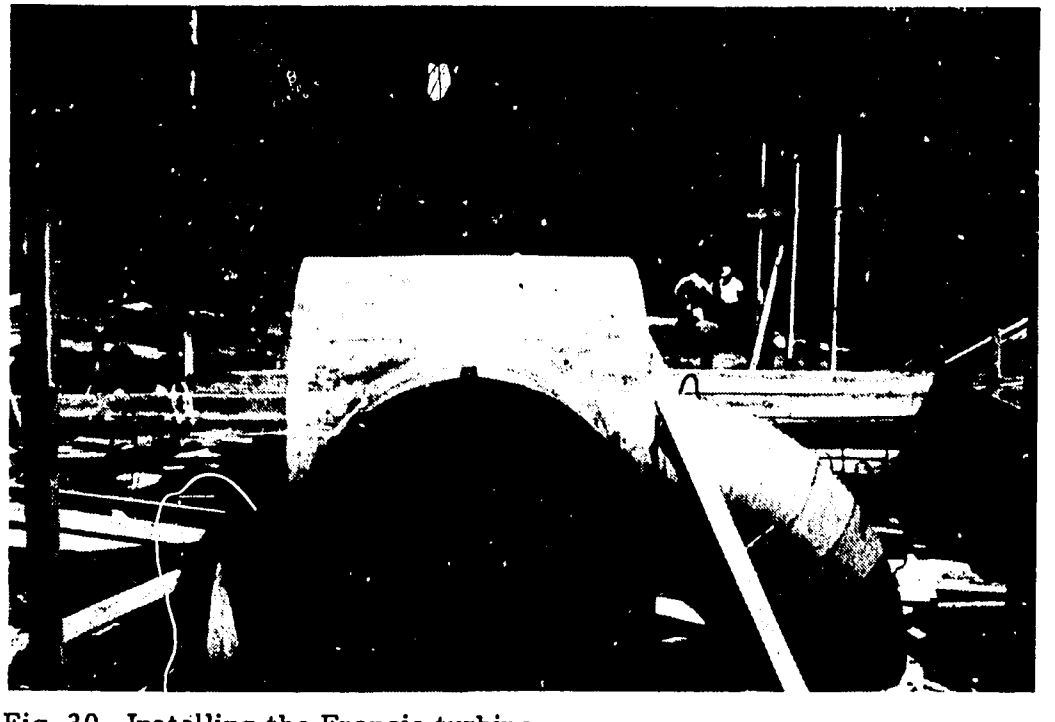

Fig. 30. Installing the Francis turbine.

Distribution system

Installation of the primary cable system consisted of cutting and smoothing trenches, paying out and placing of cable in the trenches, splicing cable sections, and fitting terminations onto the cables. Local manual labor was used to cut the trenches 1/2-1 m deep, and to cover the bottom with sand. With one exception, trenching and placement of the cable presented no particular problems. A small stream was crossed, by digging a trench below the normal surface when the stream was dry, threading the cable through Transite pipe, placing the pipe on a layer of sand, backfilling with sand, and then covering it all with riprap.

A truck-mounted reel was made in the shop for paying out the cable into or alongside the trench. Each reel was tested with the impulse fault locator before it was spliced and placed in the trench. When one reel was found to have a fault, that section was cut out and the ends were spliced. Cable splicing is a skilled job which two local Mission electricians learned by following diagrams supplied with the splicing kits, under the supervision of a short-term technical volunteer, assisted by the Mission engineer. Individual cable sections were tested as they were spliced in. After it was completed all the way from the powerplant to the termination point of the Mission area distribution system, the entire cable was tested and found to be satisfactory. The cable had been energized for several months by the time this report was researched, a good indication, in addition to the tests, that the splicing and termination work was properly done.

Installation practices for the distribution system were essentially the same as for the main incoming cable. Three-phase primary cable was laid underground to the larger load centers, such as the hospital and shops; single-phase primary cable was used elsewhere. U.S. underground residential distribution practices were followed for installation of the transformers and the totally enclosed steel distribution panels, all of which are set on concrete pads. Secondary leads to the individual loads were also buried. The only visible parts of the system are the transformers, distribution panels, and the risers that come out of the ground on the walls of the buildings.

PROBLEMS ENCOUNTERED

A variety of problems delayed the construction schedule and increased the project cost. The major problems are discussed in this section.

Conceptual design

As noted in the chapter on **Project Planning**, the lack of basic hydrologic data, and the problems involved in measuring the entire minimum flow over the falls, made it difficult to establish spillway design capacities. It was thus necessary to base them on observations of river stages at different times of the year and such flow measurements as were possible. Consequently, the spillway design had to have a generous allowance for uncertainties, because the safety of the dam, reservoir, and control structures depends on the ability of the spillways to pass any conceivable flows.

Supplies

Aside from its effects on power production, the rainfall cycle influences the river shipment of freight, the crop cycle, and construction work. From April to June/July 1982, the Mongala River level fell so low at 60 km below Businga (the river delivery point for goods going to Karawa) that the river barges could go no farther upstream. Unfortunately, when the goods are already on the river there is no solution to this

problem except to wait for the river to rise. In a few cases, when the goods were still in Kinshasa and were badly needed, they were air-freighted to Gemena and transported by truck to Karawa.

Purchase, shipping, and storage of cement has been a recurring problem on this project. Cement has a limited storage life, much of which is taken up by shipment from Kinshasa, and some of it arrives in an unusable condition. At best, it has to be used quickly or the high humidity will cause it to set. By exchanging cement with others in the Karawa area, ordering at different times, and using older bags first, cement spoilage was reduced for all.

Foundations

Before construction started, it was known that the rock around Zulu Falls is fissured. Fortunately, the strike is upstream (the fissures go down in elevation as one looks upstream), which decreases the tendency of the layers to slip when weight, such as concrete structures, is put on the rock. During a time when the reservoir area was dry, the fissures were packed with a grout prepared from the termite mound material. This practice was not entirely successful. After the leakage at the left abutment of the dam near the powerhouse inlet works was observed, the forebay was briefly emptied to enable more packing to be put in. As of May 1984, the leakage was down to a trickle that was channeled around the powerhouse.

As noted, fissures at the left base of the falls made it necessary to excavate greater quantities of unsound rock than had been initially thought, providing a sounder foundation for intake structure, penstock piers, and powerhouse foundation (see Fig. 31).

Fig. 31. Fissured rock.

Major equipment

Problems with the major powerplant equipment have not interfered with powerplant operation. The Francis turbine has a typical electrohydraulic governor, which has a fractional horsepower electric motor to develop hydraulic pressure for the gate mechanism actuator. This motor gradually lost torque and finally would not start, indicating a defective running capacitor. The manufacturer replaced the motor, and the governor is now working normally. It had never been possible to close the wicket gates on the Francis unit completely, with the result that the turbine shaft had to be blocked to keep it from slowly rotating. When an inspection showed that nothing was caught in the gate mechanism, the servo motor operating the gates was dismantled. The piston was found to be contacting the end of the cylinder before the gates were completely closed. An adjustment to the linkage cured that problem.

Construction equipment

Rebuilding the discarded rock crusher turned into a major job. It was an old Belgian-made machine for which parts were impossible to find. The crusher jaws were built up by welding and a new engine was installed. The cracked flywheel was welded and a steel plate shroud was built around it in case the welding did not hold. Mission dollar funds ($15,000) were used to procure the new engine and other parts for the restoration work. A well-equipped shop, with trained mechanics, was found to be essential for reconditioning and repairing construction equipment.

Mission experience with the distribution cable reels provides another illustration of the value of having a well-equipped machine shop and a stock of basic materials. In that case, when the reels were to be loaded onto the truck which held the payout hub, the reels disintegrated, having been riddled by termites. Typically, the damage to the reels was mostly inside the wood and not readily visible. A new, makeshift payout hub was made out of an old plow disc and bearing to provide greater support to the termite-damaged reels (see Fig. 32).

Blasting

In Zaire, permission for the use of explosives for construction is closely controlled. Even when it is allowed, dynamite is difficult to obtain. For these reasons, the initial designs and construction criteria provided for the treatment of rock only with jackhammers, bars, and picks. However, a proper powerhouse foundation required the removal of quantities of rock which could be handled only by blasting. Supplies of dynamite were obtained, but blasting caps could not be found when needed. Waiting for them to be available on the local market would have delayed the powerhouse work, so caps were improvised from 30 calibre rifle casings. One end of a nichrome wire was soldered to the inside of the narrow end of the casing; the other end of the wire was insulated and passed through the hole where the detonator had been. The casing was refilled with black powder, and a hard-nosed slug was pressed into the end. Wires were soldered to the outside of the casing and to the insulated end of the nichrome wire, forming an electrical circuit via the casing. These assemblies were taped to the ends of the dynamite sticks and placed in the rock. When heated by an electrical current, the nichrome wire would ignite the black powder, firing the slug into the dynamite stick and detonating it. These substitute blasting caps worked without a single failure (see Fig. 33).

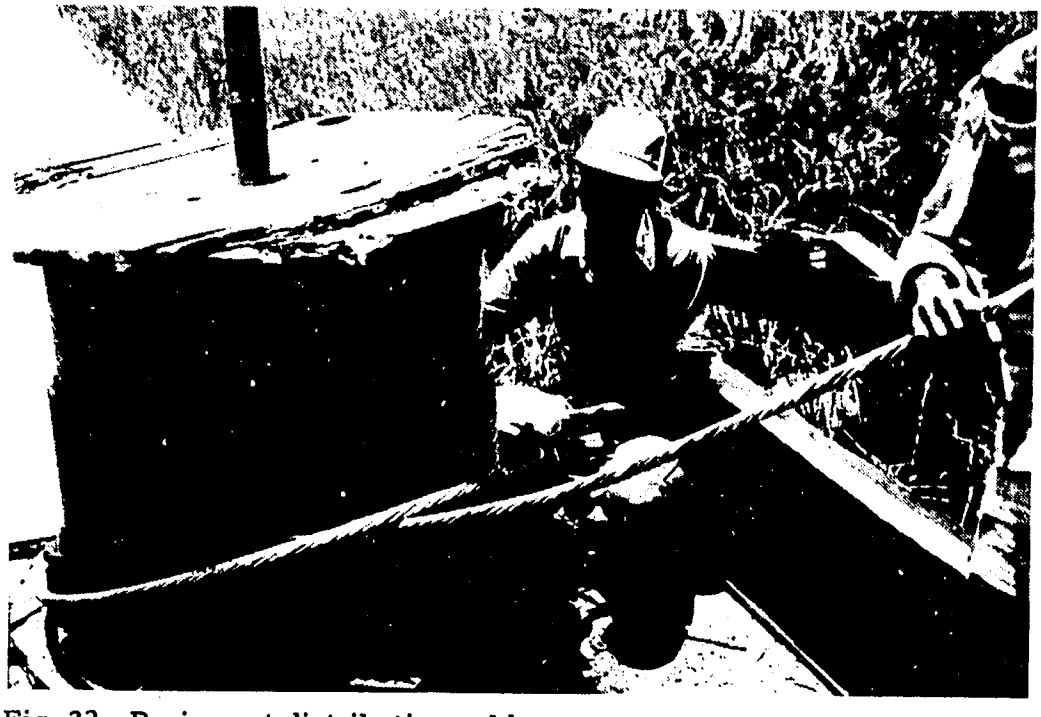

Fig. 32. Paying out distribution cable.

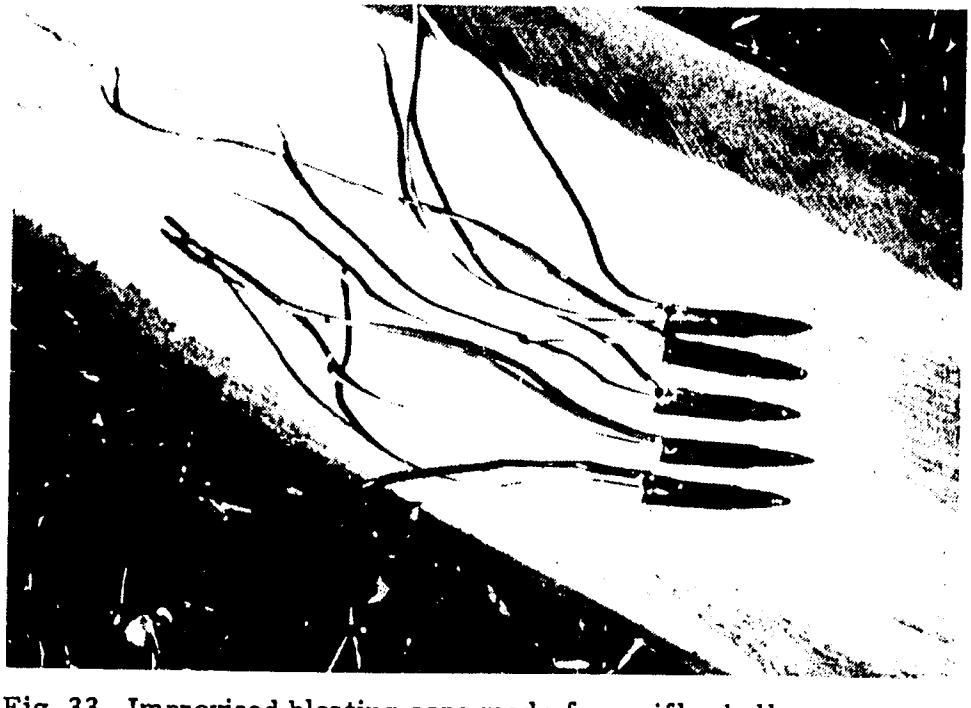

Fig. 33. Improvised blasting caps made from rifle shells.

Inflation

For much of the time, the project was working with fixed annual local currency allocations that had progressively less purchasing power on the local market. As a result, supplemental allocations had to be requested repeatedly, but were often delayed so long that the cost of the item had again increased significantly by the time they arrived. This situation complicated the procurement of most of the supplies from the local market.

Zaire costs are more difficult to detail than dollar costs because of devaluation over the 6 year implementation period. One U.S. dollar was worth Z 0.8 in 1978, Z 6 in late 1983, and Z 35 in August 1984. This devaluation was accompanied, of course, by chronic inflation. For example, cement cost Z 3 per sack in 1978, and was budgeted in the feasibility report at twice that cost. The first shipment of cement, in 1979, cost Z 16 per sack. By 1984, the price had risen to Z 350. Other commodities followed similar patterns. Whenever the official rate lagged behind the real exchange rate, however, it was necessary to request additional amounts of local currency from AID. In view of these difficulties, it is assumed here that devaluation kept pace with inflation, and that the original estimate of US$ 410,000 is a reasonable representation of the actual local cost. Table 9 identifies the dollar costs.

Table 9. Expenditures Charged to the Dollar Grant, October 1978–September 1982[a]

Item	US$	Percent of total
1. Turbine generator (Leffel)	69,273	
2. Power transformer	14,917	
3. Auxiliary mechanical/electrical equipment	16,374	
4. Communications equipment	554	
5. Miscellaneous equipment	121	
Subtotal	101,239	21.1
6. Distribution equipment		
a. transformers	17,528	
b. cable	100,497	
c. service connections	15,418	
Subtotal	133,443	27.9
7. Spares and parts	9,059	1.9
8. Electrical test equipment	8,357	1.7
9. Electrical supplies	1,532	0.3
10. Other mechanical equipment	24,730	5.2
(Subtotal capital equipment, items 1-10)	278,360	58.1
11. Construction equipment		
a. trucks/loaders	79,998	
b. transport equipment	1,800	
(Subtotal, item 11)	81,798	17.1
12. Tools	3,724	0.8
13. Shipping	92,091	19.3
14. Administration	22,554	4.7
Grand total	478,527	100.00

[a]The records used as the basis for Table 9 end at September 1982, when AID disbursements terminated.

Identifiable costs are combined in Table 10.

Table 10. Actual Funded Costs

AID grant disbursements	$478,527
AID Zaire allocations-equ. dollars	$410,000
German grant-equ. dollars	$100,000
Total	$988,527

Using this total and an installed capacity of 200 kW, the project capital cost is approximately $4,900 per kW. Using the future potential capacity of 320 kW, the project cost would be $3,082 per kW (although there will be additional costs in reaching this capacity).

A substantial contribution, in the form of volunteer consulting services provided by church members and others, is not reflected in the costs. Similarly, no account is taken of Mission staff time allocated to the power project. On the other hand, a fuller analysis would discount the residual value of all the construction equipment that was procured.

MANAGEMENT

The Zulu Falls hydroelectric plant was finally inaugurated on June 3, 1984, although it had been providing the Mission with electricity for 2 months before that date. The ceremony was attended by President Mobutu Sese Seko, U.S. Ambassador Peter Constable, and AID Director Richard Podel (see Fig. 34), as well as church officials and some 5,000 local people.

Fig. 34. President Mobutu, U.S. Ambassador Constable, and Mr. Thornbloom (center) at the powerplant inauguration.

A group called the Local Church Committee for Service of Electricity/Zulu has been formed to carry out the administrative, operational, and maintenance functions of the project. This committee consists of the national hospital administrator, the African administrator of the five local schools, the local pastor, the local foreman of base maintenance, and two expatriate missionary staff--including the engineering representative of the missionary group. From among them, a chairperson will be chosen. Duties will include:

- implementation of tariff and metering policies;
- derivation and implementation of policy regarding electric service outside the Mission;

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- delegation of routine power production, distribution, operation, and maintenance responsibilities;

- implementation and budgeting of system improvements.

Metering and tariffs

Provisional tariffs have been established as follows:

- Some local staff quarters will have a connected load of four lights and one outlet for a small appliance, such as a radio. On the basis that kerosene lighting for such a house would cost Z 60 per month, there will be a flat charge of Z 40 per month for electricity.

- Other local staff quarters will be connected with six lights and two outlets, one of which might be used for a small hotplate, and will be charged Z 60 per month.

- Mission staff residences will be equipped with electric stoves and metered at Z 0.3/kWh, as will major load centers such as the hospital, schools, workshops, and other public users.

Metering is primarily to regulate energy consumption, rather than to produce revenue, because staff members receive an allowance for energy. The various departments of the Mission, such as the schools, hospital, and workshop, are also allocated allowances for utilities such as water and electricity, for which they pay the Technical Services Department.

Electric service outside the mission

Consideration is being given to extending service outside the Mission, which will depend on a number of factors. The first to be taken into account will be the supply of power (kW) and energy (kWh). Minimum flow data will have to be gathered, over at least two dry seasons, to determine the amount of power and energy available for other loads. Flows through the turbine will have to be calculated with reference to the energy generated; the crest with a staff gage will determine flows over the spillway.

The first consequence of likely excess flows will be the possibility, not of increasing peak power availability, but of allowing generation at that level for a greater number of hours, thus increasing the supply of energy.

Should the minimum flow turn out to be as high as 2 m^3/s, both power and energy capability will increase still further. The reservoir operation detailed in the chapter on **Project Planning*** would then be adequate for the generation of two times the present power levels, provided that the shape of the daily load profile remained much the same. Sufficient hydraulic resources will thus be available for the two generating units to be operated in parallel, although this will require additions and modifications to the control equipment.

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* See Table 5, page 20.

A second factor to be considered will be the growth of demand at the Karawa Mission, which will take priority. Now that continuous, reliable, and relatively cheap power is available, the church intends to continue expanding Mission services and installing new equipment, particularly in the medical facilities. As noted, simple load management techniques will enable this increased load to be spread over off-peak hours if necessary.

After these two factors have been considered over a few years, it may be possible to extend service outside the Mission. The only structured village in the area includes a school and 35 houses and lies within 1 km of the transmission cable. The school could be developed into a community center and used at night. Such a load would not significantly affect plant capacity, and the major constraint would lie in financing, constructing, and operating such facilities.

The Karawa post would constitute a typical small village load. It has local government offices, a few stores, about 35 houses, and a school. A 50 kW diesel generator owned by the shipping company is not used because the load is too small and the fuel is too expensive. Possible uses of electricity include lighting, some small commercial activities, and a cold storage motor. Such a demand would complement the Mission load curve, which is expected to be low during the night. A brief analysis in the feasibility study indicated that a 4 km underground cable, together with a transformer and other apparatus, could provide power at substantially lower costs than the diesel set (omitting generation costs, which are, for the moment. unknown). The diesel set could be kept as standby capacity.

Another beneficial use Mr. Thornbloom proposed is that of battery-charging facilities near the market areas, one of which is adjacent to the powerplant and another adjacent to the Mission compound. Villagers could have access to second-hand automobile batteries, small automotive lamps, and the necessary wire and hardware. The batteries would be brought for charging to a small, rain-proof shelter, housing perhaps four to six chargers of a suitable current capacity. The villagers would thus have access to free electric energy.

OPERATION AND MAINTENANCE

During the writer's visit, the crossflow unit had been running for more than 2 months, a sufficient time for operating conditions to have stablized. Operation of the unit sounded and felt smooth, with minimal vibration noted. Generator casing temperatures at the low load (about 60 kW) were correspondingly low. The turbine, gearbox and generator all have enclosed roller bearings on each end of their respective shafts. These were all running cool except for the gearbox bearing on the generator side, which was noticeably warmer than the one on the turbine side. The alignment of the gearbox and the generator had been checked and found to be within tolerances. It was assumed, accordingly, that the cause of the gearbox bearing temperature difference is that the warmer one is on the high-speed (1,500 rpm) shaft.

Operation and maintenance of the generation plant will require more attention by skilled personnel than will the distribution plant. The local operator/technicians were trained in the observation and measurement of bearing and generator stator frame temperatures, listening for unusual noises and watching load indicators during initial start-up. After several months of trouble-free operation, one of the two qualified technicians checks these items during daily visits to the plant. In addition, watchmen in charge of the dam and related structures have access to the powerplant and are trained to look, feel, and listen for abnormal conditions and to report them to the technicians.

Because the electric power cable is underground, and the transformers and distribution posts are enclosed in metal cubicles, they are virtually immune to damage by lightning, which is the main cause of damage and maintenance expense on overhead lines. Mechanical damage to the buried cable is unlikely, because the cables are buried deeply, and no mechanized plowing or digging is done in the area. Electric faults in cables are rare, but in case of such an event, the Mission has an impulse-type fault locator which can quickly find the fault with an accuracy of 1 m or less. Splicing techniques learned during cable installation enable local technicians to make rapid repairs, using splicing kits from the spare parts stock. Several primary cable cross-connections within the Mission compound are planned, allowing power to be routed around faulted cables if necessary.

Operations staff

Permanent Mission expatriate staff, consisting of the chief engineer and at least one other technically qualified and experienced person, manage operations and maintenance work. When either of these goes on furlough, a short-term volunteer is provided from an apparently sizable roster of technically oriented people available to the church. The expatriate permanent staff all are fluent in Lingala, and even the short-term volunteers can manage some of the local language.

Shift operators

Two Zairian men completed an electrician's training course in Kinshasa during the powerplant construction and assisted during installation and testing of the turbo-generators and controls. Four additional men are scheduled for this training the next time it is offered and will become members of a Mission pool of technicians.

Electricians/specialists

Three Zairian men who are qualified for high-voltage cable splicing made many of the splices during installation of the main primary cable and the distribution system. They also unreeled and laid the primary and secondary cables, as well as the cable terminations to the transformers and junction boxes (see Fig. 32). They are familiar with U.S. distribution practices and materials.

Mechanics

One of the three Zairian shop mechanics has completed a General Motors training course in Kinshasa. Another has shown unusual initiative in learing to read, write, and speak English. All three were much involved in the installation of the turbo-generators and auxiliary equipment.

Guards

The Mission maintains a sizable staff of guards to patrol both the compound and the powerplant area. Guards assigned to the powerplant have been trained in adjusting the stoplogs in the control works which regulate the water inflow to the forebay. This is particularly important during times of low flow, to keep as much water as possible in the reservoir pool. These men also are trained in observing the powerplant equipment for signs of trouble. They live near the powerplant; the Zairian mechanic uses a motorcycle to supervise daily chores.

Other staff

During construction, a large staff of carpenters, stonemasons, drivers, and other specialists were employed, as well as semiskilled and unskilled laborers. In the operations phase, selected men are kept on the payroll, including drivers and operators of special rigs. A few of these are apprenticed to the mechanics to learn the trade.

By local standards, the Karawa hospital system is a large and complex operation, requiring a sizable skilled staff to keep it going. The electricians, mechanics, and other skilled staff work on hospital apparatus, automobiles, trucks, motorcycles, heavy equipment, and, to some extent, the airplane. They also take care of utilities such as the water distribution system. These craft persons are available for work on the power system as needed, even though they are not listed here as part of the power system operations staff.

Operating conditions

As noted, the two turbo-generator sets cannot be operated in parallel, and each has separate control panels and protection features.

The cable connection between the plant and the Mission load center has more capacitance per unit length than standard overhead line, resulting in a leading power factor. The generator has to absorb some of the magnetizing current produced by the cable, and the field rheostat on each generator is set near its minimum current value. This condition was considered in the feasibility study, checked in the distribution system design, and confirmed during start-up tests. Each generator can charge the cable and the rest of the system without trouble. As demand at the Mission grows, particularly air conditioner and refrigerator motor loads, the burden of this magnetizing current will decrease.

Table 11 shows load readings taken at the plant on June 1, 1984, with the crossflow unit in operation.

Table 11. Generator Load

Time	Instrument readings[a]			Calculated kVA	Power factor [b]
	kW	Amperes	Volts		
1500	60	140	400	97	0.62
1900	70	140	400	97	0.72

[a]None of the workshop tools, with a total connected load of 10 kW, were on at either time.

[b]Power factors are leading (volt-amperes/reactive into the generator).

Installation of the operating room air conditioners will soon add about 5 kW of steady load, increasing the early evening load to about 75 kW.

It would be useful to install a kilowatt-hour meter on the plant output circuit to provide data on hourly, daily, and monthly usage. Load patterns, growth trends, and reservoir operations could then be monitored more closely.

IMPLICATIONS FOR PVOS AND SMALL HYDROPOWER

APPROACHES TO SMALL-HYDROPOWER DEVELOPMENT

Some donor agencies have recently funded renewable energy projects that attempted to test the appropriateness of small hydropower in Africa, implementing them as "pilot" or "demonstration" efforts. Typically, donor groups funded these projects through central government agencies that dealt with both administrative and technical aspects of project implementation. In general, the results have been discouraging: costs are often as high as $5,000 per kW installed, capacity remains underused, operations are beset by maintenance problems, etc. Evidence from around the world suggests that, as one might expect, a "centralized" or "top-down" approach is not the best way to implement small, isolated projects in which the involvement of local groups is critical.

Yet Karawa is but one example of numerous small hydropower installations in Africa that PVOs have implemented and operated since as far back as the 1900s. The history of these projects confirms that small hydropower is a proven technology that can be highly appropriate for rural Africa, given an equally appropriate framework for its implementation. Indeed, the Ossberger used to be known as the "missionary" turbine because of its suitability in these circumstances.

Because small hydropower has been implemented successfully, not only in Africa but throughout the developing world, it may be useful to focus on the appropriateness of approaches to its development rather than on the viability of the technology itself. These two are linked: choices between a number of technical design options are heavily influenced by the background of those implementing the project, the resources available to them, and the institutional and administrative contexts in which they operate.

Given that a centralized approach does not seem appropriate, a number of options exist for the alternative approach of incorporating local participation into the planning, implementation, and operation of rural energy projects such as small hydropower. Local participants may include individual farmers and entrepreneurs, village leaders and councils, cooperatives, and local government agencies. In view of the vital role of PVOs in development programs, particularly throughout Africa, a major objective of this study has been to analyze, in light of the Karawa experience, the model in which a PVO acts as a vehicle for local participation.

ADVANTAGES OF THE PVO APPROACH

It is argued that PVOs, by working in the field at the "grass roots" level over extended periods of time, are capable of mobilizing and leading the community to an extent that no centralized agency can match. Their organizations tend to be relatively free of bureaucratic obstacles, and their field staff are technically resourceful and have access to communication, transport, and hard currency. Their primary activities, notably health care and education, constitute all-important economically and socially productive end uses. Each of these points will be examined in conection with the Karawa project.

Community leadership

In many rural regions of Africa, the PVOs provide the social, health, and economic centers for the rural populations. People come to the PVO Missions to seek health care, to attend schools, to have food processed, and to attend religious services. Many PVOs

also train local farmers in new cultivation techniques, introduce new crops, and provide adult education. These and other services place the PVOs in a unique leadership role. Furthermore, staff often have very good management skills and either live in the community or maintain very close contact over the long term. Hence, the PVOs have gained the trust of the local population and are able to rally its members to work for projects with community benefits.

All these characteristics undoubtedly contributed to the success of this project. The Karawa Mission has existed since 1923, and the project manager, Mr. Thornbloom, has been director of the Technical Services Department for more than 20 years. The Mission was in a unique position to identify the needs at Karawa and mobilize the local population to work on the project. In this case, the PVO was the primary motivating and implementing force behind the project.

PVOs already carry the bulk of the burden in providing developmental services to remote areas of Zaire. Given this role in the society, it is logical that they should be involved in some way with small hydropower projects, if only because their activities constitute the major end users in such areas.

Technical resources

Most PVO Missions in Africa are staffed with a technical officer who will often be the person in the region best qualified to conduct field engineering and develop local designs. When additional expertise is needed, Missions can call on support groups around the world for technical, financial, or political assistance. Also, the Missions usually have machine shops and the only locally available repair facilities.

Again, Karawa represents a good example of this point. This study has documented the extent of technical expertise required for the project and the Mission's effectiveness in supplying or obtaining it. Problems such as those encountered in the implementation phase could have held up the project for much longer periods in other cases. Mission technical skills will also be particularly important during the operation stage; examples abound of small-hydropower installations where relatively simple faults lead to long outages because they cannot be dealt with promptly onsite. In the case of Karawa, the Technical Services Department exists to serve the primary activities of the Mission, and most of its costs are not directly attributable to the hydropower plant.

A competent private firm could have been contracted to provide technical services during the construction stage, and may even have been able to anticipate some of the problems. The costs of such an alternative generally preclude it, however. Similarly, a government agency may include staff with some of the requisite skills, but centralized administration would have led to other problems. Some of the delays and cost overruns were unavoidable, regardless of the source of technical expertise. Factors such as the currency devaluation and transport difficulties were beyond anyone's control, and could be expected under the difficult circumstances of implementing projects in a country like Zaire. With neither a private contractor nor a public entity would the presence of a Technical Services Department such as that at Karawa have been guaranteed over the long term; few public or private utilities in the developing world have the resources to provide operating and maintenance staff to such small, isolated systems.

Established loads

The economic and financial viability of small hydropower projects is critically dependent on the extent to which the energy generated is put to socially and economically

productive use. In particularly underdeveloped areas, PVO Missions may constitute the only established loads and the best focus around which to establish them in the future. These loads are presently served, at very high cost, by diesel generators.

At Karawa, the hospital, schools, workshop, and agricultural processing services complement the residential facilities to offer very favorable demand characteristics for the small-hydropower plant. Electricity demand outside the Mission is overwhelmingly for domestic lighting and small appliances. This type of load is rarely sufficient to generate the requisite economic benefits for a major investment such as this, especially considering the scarcity of investment capital in Zaire.

A major weakness of many rural energy projects is that insufficient attention is given to the applications to which the energy will be put. Yet the objective of development projects is not the generation of energy for its own sake, but the socially and economically valuable activities that depend on it. All too often these activities are assumed to follow as a matter of course. For these reasons, the current emphasis is on so-called needs-driven energy planning processes. Often, some attempt is made to implement productive uses promotion programs, but these are not always successful.

Development of small hydropower through PVOs, whose primary activity is not energy generation and distribution but health, education, etc., ensures that these activities are built into the project at all stages--indeed, they are its whole raison d'etre.

Minimal bureaucracy

Funding from donor agencies can be transferred directly to the PVOs with minimum interference from central government offices. Funds accordingly are used for purposes "closer" to the rural target population rather than for the support of central government staff and offices.

It would be difficult to contemplate the delays and difficulties which could have been encountered if the GOZ had attempted to implement this project without the presence or involvement of the Mission. To a large degree, the Mission acted independently in carrying out the project. When problems arose, it did not have to await a reaction from a distant bureaucracy to implement changes or solutions. Given the means to resolve problems, delays were generally limited to logistical difficulties which were unavoidable under any development approach.

Communication and transportation networks

PVO Missions usually have well-established roads and the means for maintaining them, and a landing strip for light aircraft. Radios are usually used for communication to the capital city.

Once again, the existence of rural infrastructure--including transportation and communications--in remote regions of Zaire can be credited largely to the active involvement of PVOs in these areas over the years. To some extent, this infrastructure could be used no matter what the implementation model. Nevertheless, project site selection should obviously favor those sites where this important supporting infrastructure exists, which is another reason why the better sites will at least be associated with PVO Missions.

Access to hard currency

PVOs, staffed as they usually are with expatriate personnel, are usually allowed to deal with foreign currencies, which gives them greater access to goods, equipment, and spare parts.

This is a minor argument for using PVOs in the implementation of externally supported projects, because foreign currency availability under these circumstances has little to do with the participation of PVOs. Over the long run, however, the availability of hard currency to purchase spare parts, lubricants, and replacements could be a major concern. It is a well-known shortcoming of rural development projects in Africa that they tend to suffer from operation and maintenance inadequacies. The lack of foreign exchange to import needed goods is often one of the contributing causes of project breakdown after construction. Added to the presence of resident technical services, this is another reason that PVO management of these projects could help mitigate against early failure.

DISADVANTAGES OF THE PVO APPROACH

Citicis have claimed that expertise is not effectively transferred by the PVO approach, and that experience is lost. Construction can be expensive, and the impact on the national energy profile is minimal. Each of these points will be discussed in relation to the Karawa experience.

Experience is lost

Typically, a PVO Mission will install only one hydropower plant. Personnel learn the methodology for site assessment, design, equipment selection, and construction and then move on to their next project. Technical officers are often on a 2-year assignment and leave the host country soon after a site becomes operational. The lessons learned are rarely transferred to an institution that applies them in a long-term continuing development effort.

The Karawa project must be categorized as basically a self-help project in which the beneficiary (Karawa Mission and local populace) received funding through foreign official channels to construct its own scheme. Although the PVO entered the project with a considerable level of technical know-how and ingenuity, it was basically a learning experience for those involved. From an economic point of view, the time and effort spent developing the expertise to tackle the project bore a project cost. This "experience-building" cost would certainly be worthwhile if it could be applied to future projects. Unfortunately, it probably will not, because it is unlikely that future projects will be constructed by the same group that installed the Karawa scheme. In this sense, although local Zairians did receive training in aspects of project implementation, operation, and maintenance, from the national perspective, most of the technical experience is lost.

Construction can be expensive

Establishing the wherewithal to construct relatively large projects on a site-by-site basis is an expensive proposition. This applies not only to the technical expertise, but to the acquisition of physical resources as well. Heavy construction equipment is difficult is obtain, and can be very expensive if the PVO Mission must purchase the equipment. Approximately 22% of the foreign exchange component of the capital equipment cost went to the purchase of equipment used to construct the Karawa project. This

equipment will be used again, possibly in the plant's future upkeep and refurbishment. Nevertheless, the purchase of similar equipment for each project constructed by PVOs would represent a large and unnecessary expense. Even if it could be made available for successive projects on a more centralized basis, substantial costs would be involved in transporting heavy equipment to and from locations such as Karawa.

It should be noted, however, that government-implemented projects in Africa have been notoriously costly, exceeding $5,000 per kW installed in many cases. Centrally administered projects often have many "hidden" costs which do not show up in the numbers given. The use of private contractors would not avoid this problem, because they typically include the entire cost of required construction equipment. Furthermore, it can be argued that the equipment and facilities that were already available at Karawa might not have been present under different circumstances.

As a general point, however, a small hydropower project that uses relatively low head and high flows, such as at Karawa, can be expected to require more civil works than one of the same power capacity that uses smaller flows over a higher head. Whereas circumstances dictated the need for a dam and spillways to provide storage capacity at Karawa, most mini-hydro projects are "run-of-river" type. Such projects require the construction of a much simpler weir, the primary purpose of which is to divert the flow toward the penstock rather than to provide storage capacity. The problem of construction equipment and costs could thus be reduced substantially by focussing on run-of-river projects for implementation under the PVO model.

Small national impact

Some critics contend that a few scattered mini-hydropower plants will have a slight impact on a national effort to stem diesel fuel imports. From a technical point of view, viable small-hydropower projects in Zaire alone probably number in the thousands. Those located near concentrated village loads may be in the hundreds. To date, although funding requests have been made to AID for 16 other PVO projects, only one more is being implemented. For reasons mentioned earlier, these sites are likely to be among the most economically feasible in Zaire. The fact remains, however, that a small-hydropower program limited to helping PVOs install projects will have a very small impact on developing the national small-hydropower potential. Unless steps are taken to develop capabilities outside the PVO context, only a small percentage of this potential will be developed.

This issue can be viewed from other perspectives, however. In principle, the impact of the Karawa project can be assessed at any number of levels. The above argument focusses on the national energy situation and finds minimal impact; it could have focussed on the energy profile of Africa, or of the developing countries as a whole, and found still less impact. Alternatively, one could see some effect on the energy situation in the Province of Equateur, and the impact at Karawa is enormous.

Clearly, a very large number of small-hydropower projects would have to be implemented before one saw an effect on national oil imports, for example. If that is the objective of development assistance, it should concentrate resources on oil exploration and the extension of major grids from large-hydropower plants. If the concern is with rural development, however, projects such as that at Karawa can be seen to have a very large impact.

ALTERNATIVE INSTITUTIONAL ARRANGEMENTS

The preceding discussion has sought to evaluate the experience at Karawa from the standpoint of planning future small, decentralized hydropower programs in Africa. On balance, if the choice must be made between a PVO-implemented program and a government-implemented program, the Karawa project suggests that the PVO approach is preferable.

The above discussion suggests ways in which the PVO approach can be improved, however. The major criticism of the model--that of its minimal stimulus to a nationwide small-hydropower program--remains. How can a PVO approach to small-hydropower project development be modified to retain its advantages, while facing the institutional and financial challenges of developing hundreds of projects throughout Zaire? How can the learning process be improved, to give every project implemented a "multiplier" effect on further small-hydropower development by efficiently transferring skills and expertise? Finally, how can scarce foreign currency resources be used as effectively as possible to develop a large number of economically and technically viable sites, to replicate the impact observed at Karawa in dozens of other rural communities?

The first major modification to the model concerns the financial arrangements. At Karawa, some of the bureaucratic advantages of PVOs were reduced by the financing mechanism, which involved delays in disbursements at a time of chronic inflation. AID has attempted to respond to this by channeling its funds for a number of projects through one major PVO, which would act as a program manager. The more important point is that although rural energy projects (even in the United States) generally require concessionary financing, they should not be seen as social welfare programs that must be grant-funded. Future funds from AID and other donors should be in the form of loans, at perhaps 1%-5% interest rates over 20 years, with a few years' grace period. This funding approach has two effects: it lends further stimulus to the development of economically valuable end-use applications, and it provides a continuing source of funds for future projects.

The second task is to institutionalize some structure in which the experience gained from planning, implementing, and operating each small-hydropower plant can be used to repeat the process elsewhere in Zaire. Those involved in the Karawa project underwent a valuable learning process. Broadly speaking, they fall into two categories. The first group is made up of the Zairians and expatriates based at Karawa, who will continue to apply what they learned in maintaining the plant in good working order and perhaps expanding it at a later date. The second group comprises those experts and technical volunteers from the United States who contributed to the project for limited periods of time. They, too, increased their stock of experience and expertise, and some will continue to apply it to small-hydropower projects in the United States and elsewhere. What is missing is a group of participants who will go on to apply their expertise in developing further sites in Zaire.

To provide this missing component, engineers and planners from the public utility, SNEL, might be seconded to PVO-implemented projects on a medium-term basis. They would contribute a degree of technical capability to the project, and leave with practical experience that may be applied elsewhere. This practice would require a commitment from SNEL, and flexibility on the part of the donor and implementing organizations. In the long term, a Zairian public authority would be accumulating valuable experience and technical capability, thus progressively diminishing the institutional void that currently blocks development efforts throughout Africa.

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