Sudan

An assessment of decentralized hydropower potential

NRECA Small Decentralized Hydropower (SDH) Program

Small decentralized hydropower program

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Sudan: An assessment of decentralized hydropower potential

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Section 1

Summary and recommendations

The Sudan must find new sources of affordable energy to achieve its economic development goals. Decentralized hydropower facilities — those generating from 50 kW to 15 MW of electricity — cannot solve the national energy problem, but they can provide valuable reserve power and they can potentially make major contributions to local energy needs in some areas of the Sudan, especially the southern region of the Sudan, along the White Nile from Malakal to the border with Uganda. However, in many parts of the country opportunities to develop decentralized hydropower facilities are limited by seasonal variation in stream flows, heavy siltation in many streams, the relatively small number of potential sites with adequate head, and the distance between suitable sites and potential users. The present lack of necessary hydrologic, topographic, and socioeconomic data makes it difficult to identify and evalute sites for decentralized hydropower development. Nevertheless, there are clearly some attractive opportunities for decentralized hydropower development that can be realized in the near future.

These tentative conclusions were reached on the basis of a three-week reconnaissance by a consulting team sent to the Sudan in May, 1982, by the U.S. Agency for International Development (USAID). The team was made up of staff of the International Programs Division (IPD) of the U.S. National Rural Electric Cooperative Association (NRECA) and from the Office of Engineering Design and Construction (CEDC) and Office of Natural Resources (ONR) of the Tennessee Valley Authority (TVA). They were asked to assess the contribution that decentralized hydropower development could make to the economic development and energy goals of the Sudan and to evaluate the availability and quality of information which would be needed for efforts directed to that end.

The Sudan, struggling for economic development, has been badly hurt by the rising costs of imported oil. Additional electrification is needed to increase agricultural productivity, encourage industrialization, produce exports to improve Sudanese foreign exchange, and raise the standard of living for the people of Sudan. There is a strong interest in the development of additional hydropower to reduce the need for imported oil, but the relatively high front-end costs of hydropower are a serious problem.

The Public Electricity and Water Corporation (PEWC) now operates a system with a total installed capacity of 280 MW. Another 100 MW is produced by private power generation. The number of consumers being served with electricity in the Sudan is estimated at no more than 200,000.

About 57 percent of the public power is hydropower, but it is concentrated in a few areas. The hydropower is generated at three stations, at the Roseires and Sennar Dams, which feed the Blue Nile Grid, and at the Khasm El Girba Dam on the upper Atbara River, which supplies nearly all the electricity for the Eastern Grid. These are the only two grids. In most of the Sudan, such electricity as is available must be supplied by dispersed diesel generators with very low voltage distribution systems.

A plan for expansion of generating facilities throughout the country, POWER III, is designed to meet a forecast demand of 460 MW for 1985. Longer range plans have also been developed. But it is already clear that economic pressures on the Sudan will make it extremely difficult to meet these goals. Construction of large dams will become increasingly difficult given world economic conditions at present and in the foreseeable future.

Decentralized hydropower to serve local needs would have great advantages for the Sudan, especially if it could be developed in conjunction with major irrigation schemes. About 85% of the Sudan's workers are engaged in agriculture, and many of its agriculture-based communities have no affordable source of power to increase agricultural productivity and improve village living conditions. But there are problems which constrain the development of small hydropower. There is a substantial amount of sediment in many of the rivers in the Sudan. Flows in many streams are seasonal, with low or no flow during at least two months of the year, and reduced power output because of flooding at other times. Irrigation takes primacy over all competing uses of water, and evaporative and absorptive losses of water from impoundments are a serious problem. Maintenance and repair of equipment is another serious problem. Trained technical people are in short supply. Transportation is not well developed and fuel is scarce and costly.

The assessment team developed a set of simple criteria for assessing sites for decentralized hydropower development in the Sudan, related to:

- adequate and sustained stream flow, including both seasonal variations and silt loading
- competing, alternative, and complementary uses of water
- the projected demand for power and its proximity to sites
- land use considerations and constraints
- capital costs.

At the beginning of the survey, the White Nile from Malakal to the border with Uganda was selected as the primary focus of the assessment; secondary emphasis was to be given to the upper Atbara and Setit Rivers, the new Halfa Irrigation Scheme, the Gezira/Managil Irrigation Scheme and the Sennar Dam, the Rahad Irrigation Scheme, the Jebel Aulia barrage, and the Sixth Cataract of the Nile. However, Bonifica S.p.A., Government consulting engineers from Italy, were conducting a major study of hydropower in the Southern Region (including the target area along the White Nile). This study appears to present a major opportunity for the Sudan because it should provide a wealth of information about potential hydropower sites in the southern region which has not hitherto been available. The Sudan should plan to take full advantage of this opportunity. The study's report should be available by the end of 1982. Under these circumstances it was decided to limit the assessment of the primary target area to a review of prior studies and existing data, and to concentrate ground and aerial reconnaisance on the other target areas.

In the northern regions of the Sudan along the upper Nile appropriate sites for decentralized or small scale facilities on the rivers are few. Diversion of a part of the Nile flow at the Sabaloka gorge is the most attractive possibility.
As new irrigation schemes are designed and built, facilities for hydropower generation should be an integral part of the planning from the beginning. Retrofit of existing irrigation schemes for hydropower generation, however, is of dubious merit. Heads are generally inadequate for economical generation. Construction costs would be very high because irrigation must not be interrupted during construction, and transmission costs would be high because of the distance

between regulators and transmission facilities. Specific conclusions and recommendations for the northern regions are summarized below:

- The possibility of diverting a portion of the flow of the Nile at the Sabaloka gorge, to generate about 5 MW of electricity, should be further evaluated. It will be necessary to develop better topographic data and to recalibrate the Hunga gauge before a reliable assessment of this site can be made.
- If the Rumela dam on the upper Atbara is constructed the feasibility of small hydropower development in combination with irrigation should be thoroughly examined.
- No further development of decentralized hydropower along the upper Atbara and Setit Rivers should be attempted because of excessive siltation, limited elevations, and inadequate flows.
- A more detailed evaluation is merited of construction costs and capital investment requirements for a small facility at the Jebel Aulia barrage. Opportunities for serving local needs and for displacement of imported fuel may justify development.
- In the Managil and Gezira canals from Sennar dam, substantial power could be generated during some seasons, but for two months of the year flows are very low. Only innovative design and construction could overcome this substantial difficulty.
- In summary, attractive opportunities for decentralized hydropower development are limited in the northern regions, with their large rivers, low elevations, and relatively large concentrations of demand. Hydropower development within existing irrigation schemes is in most cases not feasible for technical and economic reasons. But planning for new irrigation schemes should include serious and detailed evaluation of opportunities for power generation.

In the western Sudan the Jebel Marra region may have considerable power potential because of its mountain streams, lakes, and irrigation storage facilities. However, it is uncertain how much demand there is for power in this region since there is little recent information available.

In the southern part of the Sudan decentralized hydropower development looks more promising as a source of affordable energy. In this region rainfall is heavier, there are higher elevations, and few potential sites have as yet been developed. However there are also problems: demand for power is not large or concentrated, transportation is poor making construction difficult, and much of the data needed for identifying and evaluating sites has not been available. The Bonifica study now underway may help to remove this problem. Some specific conclusions and recommendations are summarized below:

- On the Bahr El Jebel reach of the Nile, the proposed development of the Upper Fola Rapids is promising. Phased development of the site is merited but before the work proceeds far, additional data must be developed. Cost-saving measures such as use of local wooden poles may make this development more cost-effective than originally estimated.
- The most promising site along the Kinyeti River appears to be the proposed development at Katire.
- In and around Juba and Torit there is a growing, unsatisfied demand for power.
- There has not been adequate assessment of the hydropower potential of river basins secondary to the southern reaches of the Nile: for example, the Assua, Ateppi, Kit, Kaia, Yei, Naam, Tonj, Sue, and Busseri river basins. This is largely due to lack of cartographic, hydrologic, and socioeconomic data which may soon be supplied by the Bonifica study.

Management of public power systems must be strengthened and improved if expanded electrification, by whatever means of generation, is to play its full potential role in meeting the national goals of economic development, a better balance of trade, and improved quality of life for the Sudanese people. Throughout the Sudan and especially in the southern region there are serious management problems indicated by the small number of trained personnel, dispersion of load centers, inadequate transportation, and fuel shortages. Difficulty in maintaining equipment is being experienced. Necessary information for planning and management is often not available.

The public power sector has just been reorganized. For this reorganization to be successful there must be a major effort to develop and train manpower in both the newly formed National Electricity Corporation (NEC) and the regional ministries. The government should give immediate consideration to:

- carrying out a comprehensive management review to determine exact manpower and training needs
- sending staff members from NEC and each regional ministry to the U.S. or other countries for both intensive training and observation courses
- making plans for development of training courses in Sudanese universities;
- working out a comprehensive plan for electrification of the regions, which will be consistent across the regions but flexible enough to meet local needs
- fostering rural cooperatives as a viable technique for local electrification;
- creating a department of rural electrification within NEC.

As better data becomes available, beginning with the results of the Bonifica study in coming months, the Sudan should continually search for opportunities and reappraise possibilities for development of decentralized hydropower. At a time when very large construction projects are almost impossible to finance, decentralized hydropower can provide affordable power in many localities. While it cannot solve the Sudan's energy problems, in realistic planning for the future of the Sudan there is a role for decentralized hydropower.

Section 2

The Sudan and its goals

A. Introduction

The people of the Sudan are determined to move steadily toward the goal of economic development and modernization. Like all developing countries, the Sudan has been badly hurt by the rapidly rising costs of fuel. The country needs electricity for its nascent industries, for irrigation and increased agricultural productivity, and for an improved standard of living in cities and in villages. Small scale, decentralized hydropower should be able to make a positive contribution to these goals. However, the paucity of hydrological and other data about many of the possible sites for small hydropower makes it impossible to speak definitively about the size of that contribution in the future.

In May 1982 the U.S. Agency for International Development (USAID) sent a team of U.S. specialists in small, decentralized hydropower development to the Sudan. The team consisted of two staff members from the International Programs Division (IPD) of the National Rural Electric Cooperatives Association (NRECA), and two staff members from the Tennessee Valley Authority (TVA). The four person team was given the assignment of assessing the extent to which electricity from decentralized hydropower facilities could contribute to the national energy requirements and to the economic development goals of the Sudan, both in the near term (to 1990) and the longer term (1990-2000). The team reviewed existing and on-going studies and available data, conducted aerial surveys and ground studies of selected sites, and held discussions with Sudan officials and foreign experts, during a three week visit to the Sudan. This report summarizes their conclusions. Members of the assessment team are listed in Appendix C.

B. About the Sudan

The Sudan is the largest country in Africa -- more than 967,000 square miles, or nearly one-third the size of the continental U.S. It lies across the middle reaches of the Nile River, south of Egypt and north of Zaire, Uganda, and Kenya. The confluence of the White and Blue Nile is the site of Khartoum, capital of the Sudan. In the South, the Sudan has tropical forests and savanna, swamplands, and semitropical savanna; in the north it has scrublands, arid hills, and vast deserts. In the northwestern deserts agriculture is completely dependent on irrigation; in the South there is enough rainfall for cultivation and grazing. The climate varies with terrain and latitude, but it is hot the year round.

The population of the Sudan is estimated at 16.4 million, with an annual growth rate of 2.5 percent and an average density of 6.6 people per sq. km. (17 per square mile). More than two million people are concentrated in a 166 sq. km. area at the juncture of the White and Blue Niles, where the principal cities of Khartoum, Omdurman, and Khartoum North form a single metropolitan area.

There are two distinct cultures. The twelve northern Provinces, as shown in Fig. 1, almost two thirds of the Sudan, include most of the urban centers. The people are largely Arabic speaking Muslims, divided into several tribal groups. The three southern Provinces hold about four million people with many tribal groups and languages, mostly non-Muslim. The economy of the southern Provinces is largely based on subsistence agriculture.

About 20 percent of the land in the Sudan is arable. The chief crops are cotton, peanuts, sesame seeds, and gum arabic. About 86 percent of Sudan's labor is devoted to agriculture and about 6 percent to industry, with cement, textiles, pharmaceuticals, shoes, and food processing as the largest activities. The country exports cotton, peanuts, gum arabic and livestock. It imports manufactured goods, machinery, transport equipment, and food. There are modest reserves of iron ore, copper, chrome, and other industrial minerals. There is a vast livestock-producing potential; and at present camels and sheep are exported to Egypt and other countries. Transport is a major problem in economic development, and the Sudan has no ready source of cheap power.

The Sudan became independent in 1956 and its present constitution was adopted in 1973. It is a republic, under military rule; the single political party is the Sudanese Socialist Union (SSU). The government actively seeks to encourage foreign investment.

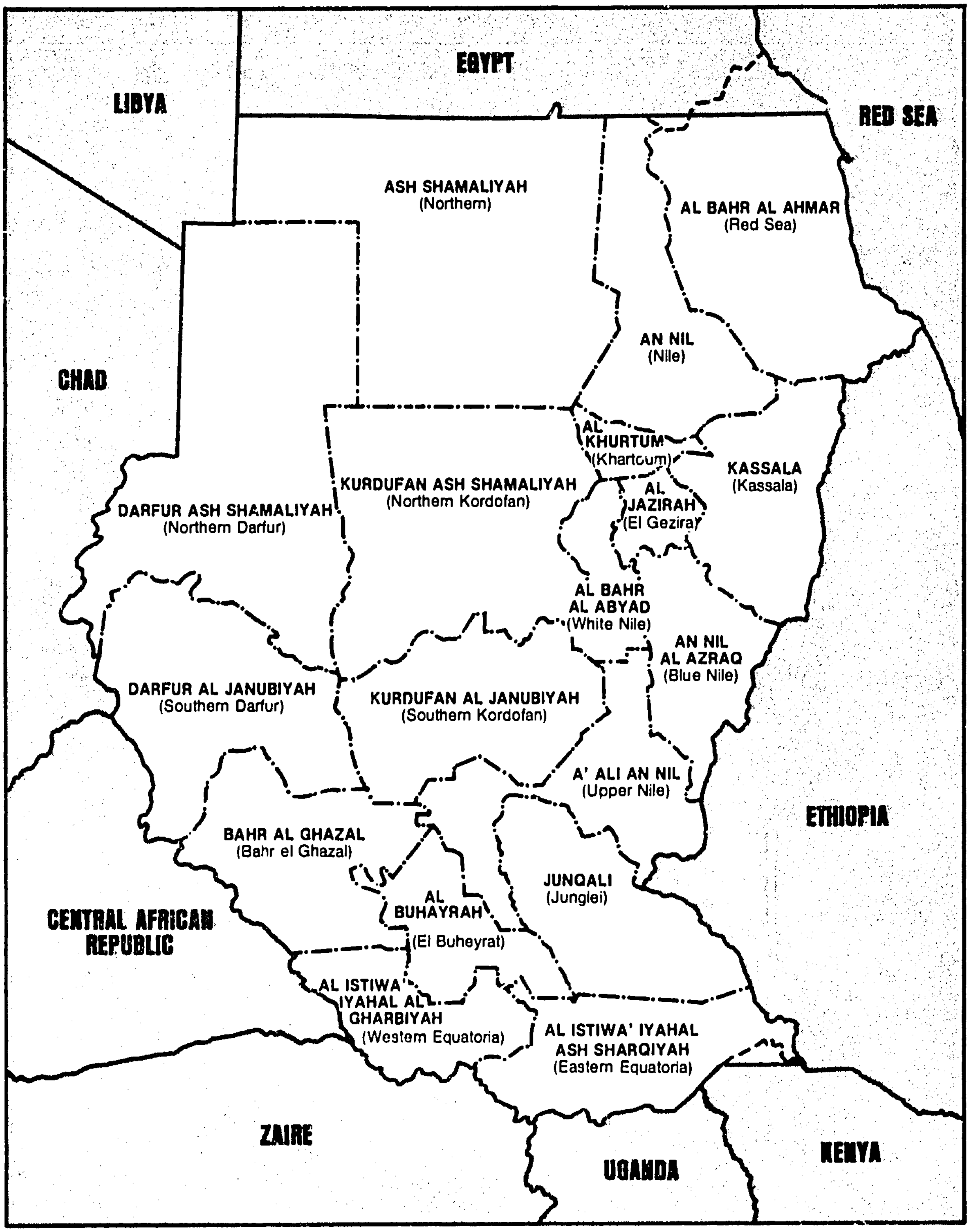

Fig. 1 SUDAN PROVINCES

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C. Economic development and energy

While the Sudan's physical and national resources are in many ways impressive, it will take an enormous effort to transform these assets into a better life for its citizens.The six year development plan unveiled in 1977 projected a strong and viable economy by 1983, with great progress in almost all areas of development. A scant three years later it was abundantly clear that these projections had been overly optimistic. Reassessment of the future development program was necessary. The Three Year Public Investment Program (TYPIP) then prepared by the Ministry of National Planning appeared to be somewhat more realistic, objective, and frank in assessing the country's difficulties and in attempting to reorder its development program. The investment criteria laid down at that time were:

1. Completion of ongoing projects which promised acceptable economic benefits
2. rehabilitation of that productive capacity which will give the highest net foreign exchange benefits in the short term
3. limitation of new projects to those which alleviate infrastructure bottlenecks, with emphasis on those that support the productive sector — power, transportation, and communications.

The plan took into account the need for both sectoral and regional balance. Ceilings for individual projects were set at Ls 120 million* for 1980/81 and Ls 150 million each for 1981/82 and 1982/83. The total investment projected for this period is Ls 1,343 million, of which Ls 1,079 million would come from government and Ls 264 million would be self-financed. Of the total investment, agriculture would get 32 percent, power 16 percent, services 12 percent, communication and transport 11 percent, industry 5 percent, and water 4 percent; self-financing projects would account for the remaining 20 percent.

The rapidly increasing cost of oil imports has been a serious problem for the Sudan. Oil imports increased during 1976-1980 from Ls 40.2 million to Ls 168.2 million, which was 30 percent of the value of all imports in 1980. Another serious

*/ Ls 1 (a Sudanese pound) is equal to $1.25 U.S.

problem was a production downturn in the agricultural sector because of reduction in capital stock, bad weather, and deteriorating world prices for the country's principle exports. Industry's performance, strongly linked to processing of agricultural commodities, was highly erratic. Transportation needs were growing fast; while road transportation was increasing, the railroad system was deteriorating badly.

In the electricity sector, installed capacity grew by approximately 8 percent per year from 1976 to 1980, but demand was increasing by 12 to 14 percent per year. A demand backlog was building up in the agricultural and industrial sectors as well as in the domestic sector. In short, the existing infrastructure in both transportation and power was proving to be woefully inadequate.

In the agricultural sector, the new plan called for major emphasis on irrigation with particular attention to the intensification and expansion of established schemes — the Gezira, Rahad, Blue and White Nile, New Halfa and Suki projects and the Jonglei Canal in the South. Rain fed agriculture was also to be enhanced particularly with regard to major export components - dura, groundnuts, sesame, cotton, but investments were to be directed toward the completion of rain fed agricultural schemes rather than toward new projects.

In industry also no provision was made for new projects. New investment was limited to the completion of projects already started and rehabilitation of those in trouble.

Transport and communications projects were to include the completion of roads presently under construction, the rehabilitation of river transport operations, and civil aviation. The oil pipeline from Port Sudan to Khartoum is being rehabilitated to make it operate at full capacity.

Two new projects which were authorized were the Sudan Telecommunications Development Plan, Phase I, and the Suakin new Harbor project. Along with the proposed new Khartoum International Airport, these were considered longer term projects. Only 4 percent of the TYPIP budget was to be utilized for these projects and extra budgetary sources will be sought.

In the services sector, general education, vocational training, university improvement and preventive medicine were identified for special attention. Modest investments in these areas were to be limited to 12 percent of the overall investment plan.

Special priority was given to enhancing power generating capacity and distribution networks. Power III (scheduled to be completed by 1936) is directed towards full utilization of the Roseires hydropower complex, the installation of thermal stations at Burri, Soba and North Khartoum, and diesel units to be placed in a number of outlying towns, especially Juba. Some transmission lines were to be strengthened. The location of new petroleum reserves has recently encouraged the construction of a refinery at Kosti with an initial throughput of 10,000 bbls per day. Serious consideration is being given to the construction of an oil-fired steam plant at Kosti that would generate from 60 MW to 100 MW of electric power, using residual fuel.

However, the modestly positive tone of the 1980 TYPIP has, like the earlier plan, proven to be more optimistic than realistic. Government expenditures are continuing to rise, revenues are declining and foreign exchange reserves are diminishing rapidly. A new plan is presently under development. It will point to a more stark immediate future.

D. Electricity and planning in the Sudan

As of May 1st, 1982, seventeen generating systems are operated by the Public Electricity and Water Corporation (PEWC). These have an installed capacity of 280 MW covering nine different areas throughout the country. In addition, estimated private power general capacity provides approximately 60 MW and 40 MW more are generated at the Kenana sugar refinery. Much of the private capacity is in Port Sudan and Juba.

Of the 280 MW of public power, the Blue Nile Grid (BNG) shown in Fig. 2, has a rated capacity of 238 MW or approximately 85 percent, although the present maximum capacity is 175 MW. Most of the power for the BNG comes from the hydropower stations at Roseires and Sennar. The rest is provided by steam (30 MW) and diesel (30 MW) plants at Burri, gas turbine (15 MW) at Kilo and diesel

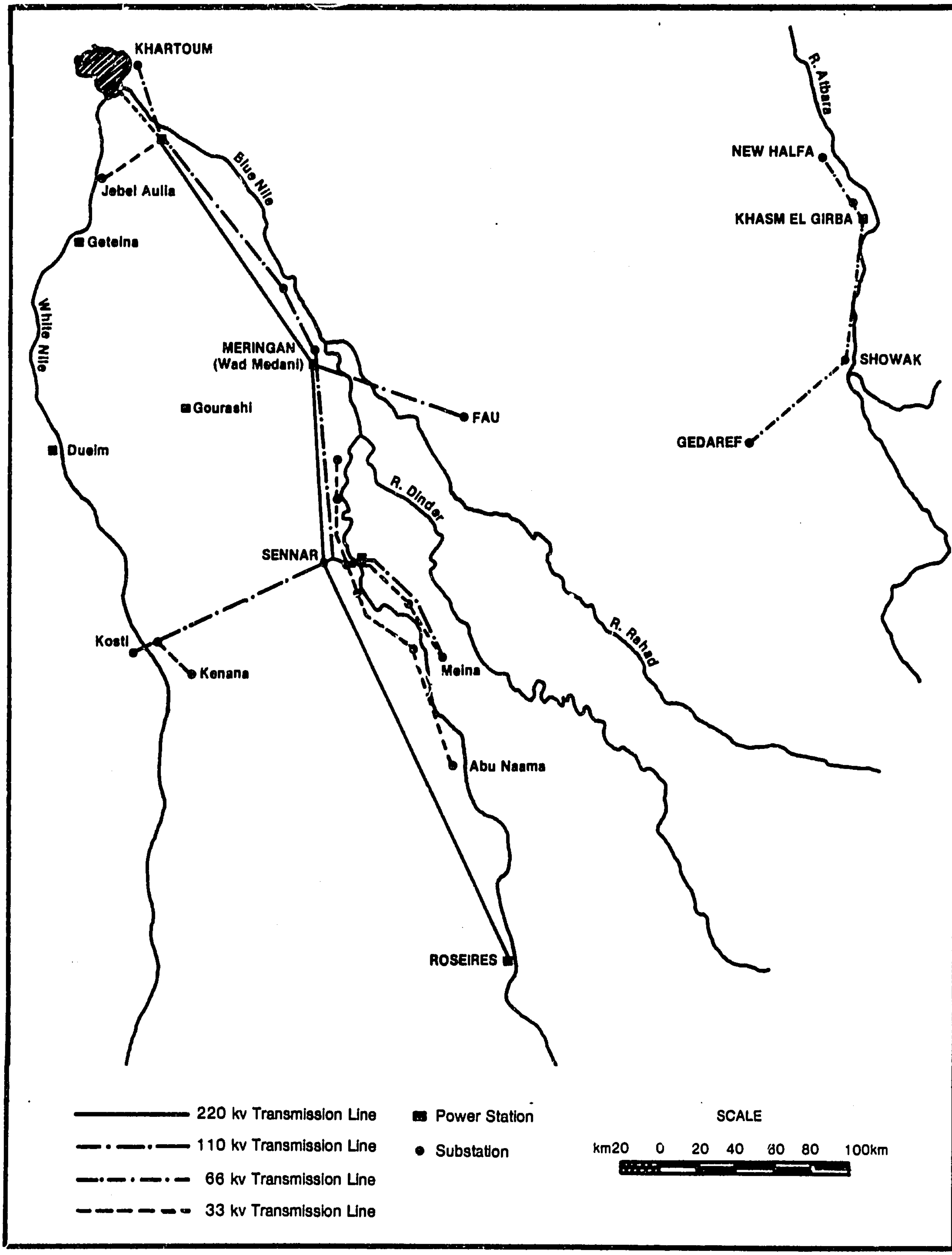

Fig. 2 BLUE NILE GRID AND EASTERN SYSTEM

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(8 MW) at Wad Medani. The only other grid system in the Sudan, the Eastern grid, derives its power primarily from the Khasm El Girba Dam on the upper Atbara River, with a rated capacity of 11.6 MW.

These two grids cover three of the nine areas referred to above (Khartoum, Blue Nile and Eastern). In the other six areas power is generated almost completely by diesel, with about 167 generators in place. Only the Blue Nile Grid and Eastern Grid have networks, which transmit power at 220 kV and 110 kV. The rest have low voltage distribution systems at 33 kV, 11 kV and 415 V.

During the flood season (June, July, and August) there is a substantial loss in generating capacity — up to 50 MW — at both Roseires and Sennar and therefore in the entire power system operated by the PEWC. In addition, the lack of effective maintenance of many of the diesel units is causing a steady decrease in their collective output. The Burri steam plant, now almost twenty-five years old, is operating at approximately one third its rated capacity. Some improvement in this situation has occurred over the past year, however, 10 MW of power has become available from the Kenana Sugar Refinery, a new 15 MW diesel plant has been commissioned at Burri and two of the steam plants at Burri are being overhauled.

The load growth on the Blue Nile Grid over the twelve year period 1968-1980, has been impressive: from 293.4 GWh to 821.8 GWh with yearly average increases ranging from eight to fourteen percent. The load factor has grown steadily from 58.8 percent in 1968 to 82.0 percent in 1980. During the three year period 1977-1980, demand for agricultural pumping alone has increased from 28.5 GWh to 51.6 GWh. This is primarily due to increased electric pumping in the Blue Nile area. In the area served by the BNG, electricity consumption appears to be distributed approximately as follows: residential 28 percent, industrial 42 percent, agricultural 21 percent, others 9 percent. With the exception of Port Sudan, load growth in other areas of the country has been relatively stagnant. But this is because power is not available; the suppressed demand may be very substantial. The number of consumers presently being served in the Sudan is estimated at 200,000.

A planned expansion of generating facilities throughout the country — Power III — is presently underway. It is designed to meet a forecast demand of 460 MW by 1985. The major components of this program, as modified in the PEWC's 1980-1985 plan, are 40 MW (four units, 10 MW each) of additional diesel power at Burri near Khartoum, installation of units 5 and 6 and the embedded parts of unit 7 at Roseires, and a new oil-fired steam plant at Khartoum North with a total capacity of 120 MW, of which 60 MW (two units, 30 MW each) are to be commissioned by 1986. Except for one diesel unit at Burri (15 MW), none of these units have yet come on line.

In addition to this BNG expansion program, seven towns are to be provided a total of twenty-one diesel plants with a total generating capacity of 38 MW. It is also proposed to interconnect the Eastern Grid with the Blue Nile Grid with a 95 km 110 kV transmission line from El Gedaref to Fau and to reinforce some present transmission lines, particularly from the Roseires power station to Khartoum.

Planning for the longer term is presently underway to meet an estimated demand of 971 MW for the BNG by the year 2000. This includes among other projects the heightening of the Roseires Dam by nine meters to a reservoir level of 490 meters; extension of the Sennar power station, the installation of unit number 7 at Roseires, the addition of 350 MW of additional thermal power and a major new hydropower scheme at Merowe (600 MW). For the rest of the country consideration is being given to a program designed to meet a demand forecast of 534 MW by the end of the century. This would include the installation of 184 diesel generators with a total capacity of 632 MW and the interconnection of a number of towns; the construction of a dam at Rumela on the upper Atbara River with an initial capacity of 20 MW (two units). The construction of an oil-fired steam plant with a generating capacity between 60MW and 100 MW is presently being studied in conjunction with the construction of the new oil refinery at Kosti. Plans are also being developed for the interconnection of the Eastern Grid with Port Sudan. Other studies are underway concerning the development of hydropower resources in the Southern Region. The majority of those projects would produce 20 MW or less.

Sir Alexander Gibb and Partners, Merz and McClellan are presently developing "Power IV," a plan for the intermediate range, 1988/89, as well as for the longer term, to 2000. Power IV includes many of the above projects.

E. Hydropower and the Sudan

Most of the electric power now generated in the Sudan is hydropower. Some 159.6 MW out of the total public capacity of 280 MW is being produced at Roseires (two units of 30 MW, one of 40 MW), Roseires Service (two units, 1 MW each), Sennar (two units, 7.5 MW each), Khasm El Girba (two units, 3.3 MW each), and Khasm El Girba pump turbines (three units, 2 MW each). Oil-fired steam accounts for 30 MW, diesel 75.3 MW and gas turbines 15 MW. Under the current Power III plan, hydropower generating plants, to be completed by 1985, are limited to the installation of turbines number 5 and 6 at Roseires (two units, 40 MW each). Unit number 5 is now scheduled to be commissioned in 1983, with unit number 6 coming on line in 1985. This would bring the total rated capacity of hydropower to 239.6 MW by 1985. With an additional 179 MW being added with diesel (119 MW) and steam (60 MW), 539 MW of power would be generated by 1985. However, while Roseires units number 5 and 6 are scheduled to be commissioned on schedule, some slippage is occurring in commissioning many of the other units. Even so, it appears that the demand forecast of 460 MW by 1985 will be accommodated.

For the longer term — from 1989 to the end of the century — a number of planned expansions of presently operating hydropower systems are being seriously considered. Others are being examined as possibilities. In the first category are the heightening of the Roseires Dam by 9 meters to add 80 MW generating capacity, the extension of Sennar to add another 30 MW, the construction of a dam at Rumela with a generating capacity of 20 MW, and the installation of Roseires unit number 7 which would generate 40 MW. The increase between 1985 and 1990 would be 170 MW, to bring total hydropower generation capacity to 409.6 MW. Potential schemes under consideration for the year 2000 include a major 600 MW dam at Merowe, a dam at the 6th Cataract (Sabaloka) that could produce up to 120 MW, Shereik 240 MW, Shirri Island 450 MW and Dal 600 MW. However, only the Shirri Island and Merowe projects now indicate an internal rate of return of over 10 percent. There are two options at the Beddan Rapids site south of Juba with possible installed capacity that ranges from 100 MW to

400 MW. A smaller project at the Fola Rapids, also south of Juba on the Bahr El Jebel, could generate up to 10 MW.

The overall growth of hydropower has been impressive in terms of maximum rated capacity. But a number of factors must be taken into account in computing power available to end-users throughout the year. Power output is reduced during the flood season due to rising tailwater levels. Less water is available from January to May, the dry season. The flushing of reservoirs during the main flood period, turbine clogging problems and limited transmission and transforming capacity also reduce power output at times. At the Roseires, a power drop of as much as 50 MW has occurred. At Sennar, output can fluctuate from a high of 15 MW to a low of 8.1 MW. At Khasm El Girba, including pump turbines, the range is from 11.7 MW to 3.3 MW.

The most recent calculations of the capital costs of increments of power generation for the Roseires extension are Ls 230 (US $ 287) per intalled kW. The estimated cost of extending the power facility at Sennar to add 30 MW generating capacity (including civil, electrical, and mechanical engineering and administration) is presently calculated at Ls 24,000,000, or Ls 800 (US $ 1,000) per installed kW. Cost estimates for the Rumela Dam on the upper Atbara River (which includes civil, M&E, E&A and transmission costs) are Ls 94,000,000 for 30 MW or Ls 3,133 per installed kW. Sabaloka, which would produce 120 MW, would require Ls 148,000,000 for capital costs including river diversion and transmission, or Ls 1,233 per installed kW. The project at Merowe is perhaps the most ambitious one being seriously considered. It would require about Ls 535,000,000 for an installed capacity of 400 MW or Ls 1,337 per installed kW. Thus the costs of additional hydroelectric power range from $287 to $3,133 per installed kW, depending on the type of construction and the purpose of the project.

Attempts by the team to locate reliable figures on the costs of production of electricity proved to be very difficult and no precise figures were ever agreed to. Indeed, it appeared that very little effort had ever been made to determine these costs relative to any of the generating facilities in the Sudan. The reason for this may be the difficulty in computing such costs when so many intervening variables have to be accounted for such as seasonal loss of capacity, erratic generating performance, severe maintenance problems, high system losses, etc., and the realization that any figures on real costs would be generally unreliable in the long run.

The presently operating hydropower facilities, i.e., Roseires, Sennar, Khasm El Girba, were all constructed primarily for irrigation with power as a secondary objective. The operation of these dams has in the past, therefore, been almost completely guided by irrigation requirements, which has caused significant fluctuations in the power output of the generating facilities. Recently however, because of the growing power shortages in the Blue Nile Grid system, an effort has been made to balance, at least to some degree, the power requirements of the region with the irrigation needs of the various irrigated agricultural schemes supported by these dams. A complicating factor is the rapid increase in power demand from the number of electrically driven pumps on the Blue Nile and the steady increase in the industrial load on the Blue Nile Grid. Much the same conditions exist at Khasm El Girba. Of the future planned expansion of hydropower in the Sudan, two major schemes are still aimed primarily at increased storage for irrigation, i.e., the heightening of the Roseires Dam and the Rumela Dam project.

The development of decentralized hydropower in the Sudan has not yet been worked into a total development plan. It would however be focused on electric energy for rural development and for fuel displacement. Irrigation would be incidental to the main purposes of the program, but in many cases it would have to be factored into an economic analysis of the viability of a project. Displacement of petroleum fuel is a factor, primarily with possible projects in the major irrigation systems within the Blue Nile Grid system. Decentralized hydropower in the southern region would contribute to rural development; the primary objective here is the electrification of villages and small industry. In many cases the direct contribution to irrigated agriculture or fish culture would be an important consideration.

Section 3

The Sudan assessment: rationale for the study

The hydropower potential considered in this survey is that which would have installed generating capacity between 50-100 kW and 10-15 MW. The potential scheme might be either grid-connected, decentralized (i.e., stand alone to serve an isolated area or community); or part of a combined operation (i.e., cogeneration).

The combined NRECA/TVA team was instructed to assess the contribution which hydropower facilities generating between 50 kW and 15 MW might make to the energy requirements and development goals of the Sudan. Specifically, the team was asked to:

- assess the availability and quality of hydrologic survey data
- review and appraise the conclusions and recommendations of existing waterpower studies
- provide an estimate of the hydropower now produced and its applications and costs
- develop criteria for assessing and ranking potential sites
- carry out preliminary assessments of selected sites
- discuss alternatives for selection, development, financing and management.

For the purposes of this discussion, the Sudan can be divided into several areas related to major river systems (see Fig. 3):

- The Nile, from the confluence of the Blue Nile and the White Nile northward to the Egyptian border, together with the Nile's tributaries
- The Blue Nile and its tributaries
- The White Nile from Khartoum south to Malakal
- The White Nile and its tributaries from Malakal south to the Ugandan border.

AREA 1.6 MILLION SQ. KMS. POPULATION 16 MILLION

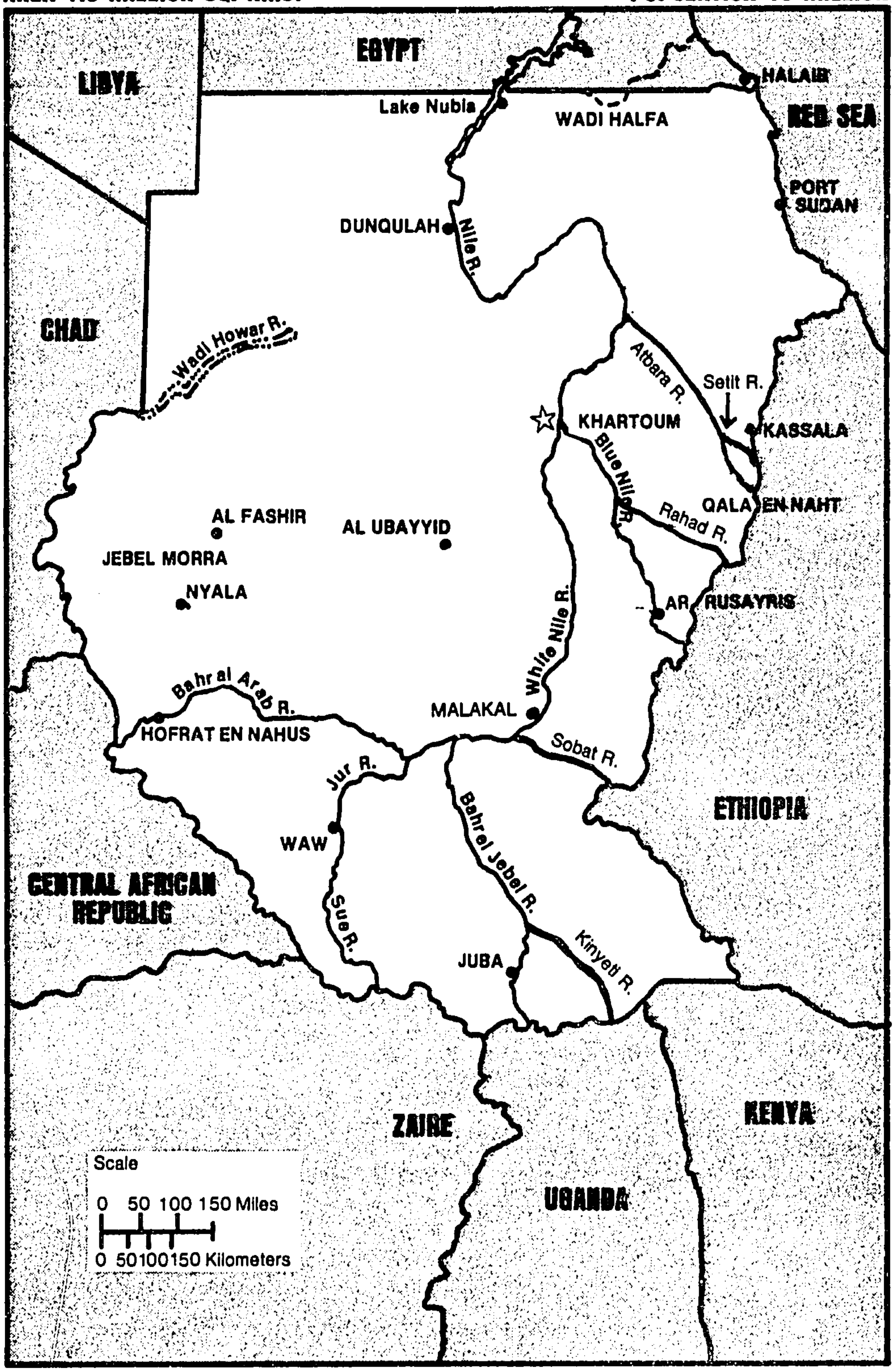

Fig. 3 SUDAN–Major Cities and Rivers

The Nile, one of the major rivers in the world, is in general an unlikely place for small generating units. However, the area around the Sixth Cataract, about 80 km north of Khartoum, was considered as a possible site for a diversion scheme. This area also has been studied for a possible major generating site at Sabaloka. The Atbara River flows into the Nile. The upper Atbara from Khasm, El Girba to the Ethiopian border, including the Setit River, were considered to be definite possibilities. Another possibility was the main canal system of the New Halfa Irrigation Scheme.

The Blue Nile is itself a major river with large dams, generating much of the country's electricity at Roseires and Sennar. The tributaries Rahad and Dinder are areas of low topographic relief but provide water for irrigation. The extensive canal works for the Gezira/Managil Irrigation scheme and the Rahad Irrigation Scheme were selected for possible reconnaissance.

The White Nile from Khartoum to Malakal is a large river, better suited for large scale development than for small scale development. However the existing barrage at Jebel Aulia was selected as a site where some small scale development might be feasible.

The White Nile from Malakal to the Uganda border contains numerous potential sites for small generating facilities on the Kinyeti River and other tributaries and on the White Nile (Bahr el Jebel) below the town of Juba.

The White Nile from Malakal to the border with Uganda was selected at the beginning of the survey as the primary target for assessment because of its relatively good topographic characteristics, perennial flow, and lack of other hydropower development. Soon after the team's arrival in the Sudan, however, this decision was reconsidered. Bonifica S.p.A., an Italian Government consulting engineering firm, is conducting a comprehensive study of hydropower potential in the area. The assessment team therefore decided with the concurrence of USAID/Khartoum to limit its efforts in this area to a review of existing studies and data and to concentrate its efforts, especially ground and aerial reconnaissances, in other areas. These areas included:

- The upper Atbara and Setit Rivers
- the New Halfa Irrigation Scheme

- the Gezira/Managil Irrigation Scheme, including the Sennar Dam
- the Rahad Irrigation Scheme
- the Jebel Aulia barrage
- the Sixth Cataract of the Nile.

The assessment team used a set of simple criteria or diagnostic questions in evaluating possible hydropower sites. These had to do with —

- adequate and sustained stream flow
- alternative or complementary uses of the water
- projected demand for power
- land use considerations.

The one essential requirement for hydropower development obviously is a flow of water. For most hydropower generation, an operating head of at least two to three meters must exist. Assuming an overall conversion efficiency of 65 percent, flows on the order of 0.5 Mm^3/day* are required to generate 100 kW of electricity, and on the order of 8 Mm^3/day to generate 15 MW. But in the Sudan, flows tend to be quite seasonal. In many streams, water does not flow at all during summer months. Many streams carry great loads of sediment and reservoirs can be silted up in a relatively short time.

Use of water for irrigation is paramount in the Sudan. Any impoundment of necessity increases evaporative losses, and in many parts of the Sudan these losses are significant. Since parts of the Sudan are underlain by porous sandstone, reservoirs may also cause water losses by absorption of the water. Where impoundment of water for generation would in these ways reduce the amount of water available for irrigation, hydropower development incurs a substantial penalty when costs and benefits are weighted.

However, any scheme which can produce new benefits in addition to power, such as irrigation, navigation, or flood control capability is, of course, more economically attractive. While capital costs for installation are important, high

*/ Mm^3 is one million cubic meters, or one milliard

capital costs per kilowatt for small hydro installations may be offset under certain conditions by the relatively short time needed for commissioning and by the relatively low cash flows compared to large units.

Proximity to load centers or to connecting facilities with the Blue Nile or Eastern Grids would reduce the costs of transmitting power. Proximity to population centers which may in the future develop load, or proximity to industrial facilities which could be served, was also considered. With decentralized hydropower the possibility of cogeneration is important. Hydro and thermal (diesel) generation can sometimes be combined to serve a local load and at time provide excess electricity to a grid.

With new reservoirs for hydropower, land use considerations are of key importance. In the Sudan, where only 20 percent of the land is arable, farmland is at a premium. Villages which might be displaced, rare wildlife, and antiquities which may be at risk of innundation must also be considered. Access to the site by road, river, or rail for transport of equipment and workers is important. Lack of adequate site access may be a significant cost item. Proximity to suitable construction materials is also a factor.

When all of these criteria are taken into account, small hydropower or decentralized hydropower can be an excellent way to achieve rural electrification, increased agricultural productivity, industrial development, displacement of imported oil, and other objectives. In the Sudan, it might encourage cotton gins, fertilizer production, saw mills, irrigation, etc., contributing to all of these objectives.

Since small units tend to have higher costs per kilowatt than larger units, first priority should be given to sites where some of the capital cost can be avoided; for example, existing dams, canals, barrages, and places where water can be abstracted from irrigation facilities.

Section 4

Summary of information about decentralized hydropower in the Sudan

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Part of the team's assignment included a review of some of the more important studies already carried out concerning hydropower resources in the Sudan. Existing studies of the selected reconnaisance areas were summarized as well as existing studies of the southern reaches of the White Nile. The findings of the assessment team with regard to specific sites are summarized in Section 5.

It should be noted that in reviewing these studies and in the process of assembling data on other potential sites it became apparent to the team that the data available, although unexpectedly extensive in volume, did not appear to be consistent. This unreliability of data became a major factor in the tentativeness of the teams final recommendations and resulted in the clear feeling that much more precise information was needed in almost all instances before further action could be taken. The exception to this could be the findings of the Bonifica study group in the Sudan, although this remains to be seen.

A. The reconnaissance target areas

1. Report on Investigations of Hydro-Electric Sites in the Nile Basin at Sabaloka and Jebel Aulia for the Democratic Republic of Sudan, Public Electricity & Water Corporation, by Sir Alexander Gibb & Partners, April, 1980.

Sabaloka. The report finds that it is technically and economically feasible to construct a 120 MW station here including a navigation lock. This will not be firm capacity during peak flood flows even though an average annual energy output of 750 GWh will be achieved. The study provides a complete prefeasibility evalution with an excellent hydrologic simulation study of the White and Blue Nile Rivers, estimating monthly flows, discharges, evaporation rates and demands. Site characteristics, a potential construction program and a power generation scheme are described. The economic evaluation indicates that the project should be postponed until 1990 or beyond. The Hunga gauge elevation is questioned which could seriously affect stage/discharge curve estimates. With resolution of the gauge elevation, questions over flooding of Khartoum could be answered and the economic justification improved.

Jebel Aulia. This potential site involves an existing structure located on the White Nile about 40 km south of Khartoum. The primary purpose would be to depress peak Nile flood flows by reducing White Nile flows coincident with Blue Nile flood flows. With or without conservation flows due to the Jonglei canal and Machar marshes, but with the Roseires Dam heightened and Sennar power stations fully developed, an installed capacity of 35 MW is technically feasible. However, a low return on investment in the range of 5-6 percent is calculated primarily due to lack of appreciable tailwater height during three months of the year. Only a different mode of operation will allow sufficient capacity benefits to justify the project economically. The use of small hydro was not considered. The assessment of large scale renovation is particularly well done.

2. Study on the Installation of Low Head Turbines at Jebel Aulia for the P.E.W.C. by Escher Wyss, Ltd., December 1981. Emphasis in this study, which also covers installations at Sennar and Roseires Dams and Gezira Irrigation canals, was on the importance of the Blue Nile Grid. The study used load allocation to illustrate that new installed capacity is required after the next 3-4 years. The assumption was made that existing capacity will fill demand over the interim. The data illustrates that the output as planned may not meet the characteristics of the demand as estimated in the "Long Term Power Plan (1985-2000) analysis of the Blue Nile Grid" (September 1979). This study concludes that 30 MW installations will be required in May 1986, again in 1987, and again in May 1988. Jebel Aulia is recommended as an alternative to the 30 MW thermal power planned for 1986, with other extensions to be continually studied. Beyond 1986, the need for firm capacity requires new plants. These would probably be thermal, but if low head hydro extensions can be shown to save sufficient fuel to justify their construction, they should be built. Jebel Aulia is economically attractive at a discount rate of 11.5 percent, using conservative assumptions.

The study establishes that Jebel Aulia as a regulating structure now serves no useful power purpose having been designed for irrigation, fishery development, and shoreline development. These factors however preclude removal of the dam.

Without considering the possibility of increased conservation flows from completion of the Jonglei Canal, the study recommends installation of seven single regulated STRAFLO or rim generator type turbines at 7 MW each to be installed in existing blocked off sluices. This would yield a minimum peaking capacity of from 9-46 MW during 9 months of the year. There would be no power production for a period of three months of the year due to high tailwaters at Jebel Aulia from Blue Nile flood waters backing up into the White Nile. An annual energy generation of 242 GWh is estimated.

3. Showak Dam. Paper by Habbani & Siraz for the Ministry of Energy and Mining. This proposal was presented to the First Energy Conference, April 1978, in Khartoum. The paper emphatically proposed (but without supporting information) that Showak Dam would be the largest, most dependable source of hydroelectric power in the Sudan. The site would be near the town of Showak in a section on the Atbara River just downstream from the junction of the Setit and the upper Atbara Rivers. The dam would store irrigation water and develop hydroelectric power using head from a 300 meter penstock. It would also protect from siltation the Khasm El Girba Dam downstream. Unfortunately, the proposal did not reflect the negative factors of consumptive diversion of about 7 milliards of water nor the high construction costs and short expected life of the project due to siltation.

4. Upper Atbara Feasibility Study for Republic of Sudan, Ministry of Irrigation. This report summarizes data reported previously in 1973 when more than thirty sites were considered (between 1956-1973) for hydroelectric development. The thirty were narrowed to seven and finally to two sites after various factors were considered. Neither the thirty sites nor the selection factors are described. However, the two sites, Burdana on the Setit and Rumela on the Atbara, near the confluence of the two rivers, were chosen primarily on the basis of the extent of land to be inundated.

Burdana was eliminated because of the extensive siltation problems on the Setit. The recommendation was made that the Rumela Scheme be implemented on the east bank of the Atbara River near Kassala. Water would be transported to an expanded irrigation scheme east of the New Halfa scheme by a 102 km canal passing east from Purela by siphon across the Setit River. This feeder canal would follow the topographic contour of 505 throughout its length, which might cause siltation problems and would preclude small hydro opportunities. Rumela is designed for a storage capacity of 1,350 Mm^3 with an installed capacity of 30 MW and annual generating capacity ranging between 65 GWh and 84.6 GWh. The proposed project would extend the life of Khasm El Girba by decreasing siltation and would supply water to the New Halfa scheme. The regulation of water at Rumela on the seasonal Atbara (which is dry 6 months of the year) will also increase the annual generation at Khasm El Girba to 48 GWh.

Since the emphasis in that study was on irrigation, a simulation study was done to evaluate how power generation could be fit best into the irrigation priority. At peak canal discharges of 90-165 m^3/sec, 92 percent of the water requirements can be satisfied at an annual energy output of 65 GWh.

5. The Blue Nile Waters Study, Phase IA, Availability and Use of Blue Nile Water, Vol. 3, Supporting Report IV, Irrigation, April 1978. Description of the Rahad and Gezira/Managil Irrigation Schemes are documented in detail in the Blue Nile Waters Study, including description of the main canal works.

The Gezira/Managil Scheme. An inlet canal on the left side of Sennar reservoir provides water to gated sluices in Sennar Dam. They in turn feed water to two canals which flow, side by side and parallel for a distance of 57 km from Sennar to the Blue Nile, where they empty into a common pool. The Managil and Gezira canals separate coming out of the pool and feed the two irrigation schemes. Along the way to the common pool, water is pumped from the Blue Nile into the canal by diesel-driven pumps at three points: Taiyiba Gondal, Hag Abdullah and Wad en Nan. However, most of the flow from Sennar is driven by gravity. Minor schemes pump from the main canals at 11, 13, 29, and 42 kilometers, some by diesel and some by electric powered pumps. The Gezira/Managil scheme had a net cultivation area in 1975/76 of about 2,100,000 feddans (one feddan equals 0.42 hectare or 0.96 acres). The flow in the main canals is minimal in April and May, and peaks in October and November, reaching 800 - 1000 Mm^3/mo.

Different data is given by different sources for flows at the same point. Data taken from the Sennar Dam Log Book, the Ministry of Irrigation at Wad Medani, Joint Technical Council Data Centre Khartoum, and the Dams Division, Ministry of Irrigation Khartoum, differ widely.

The Rahad Scheme. Water is pumped from the right bank of the Blue Nile just upstream from Meina Village, into a supply canal which travels about 80 km in a northerly direction, passing under the Dinder River at Dinder Siphon and discharging into the Rahad River just upstream of the Rahad Barrage. The feed canal for the Rahad scheme takes off from the right bank of the Rahad River upstream of the barrage. The Meina Pump Station has 11 electrically driven pumps, each of which delivers 9.5 m^3/sec. at a head of 10.2 m. Irrigation officials at Wad Medani say that the flow from the Blue Nile is consumed by the Rahad scheme so that there is minimum discharge (5 m^3/sec) into the Rahad downstream of the barrage for approximately eight months of the year.

6. Other irrigation scheme studies. The Gibb study of the Sabaloka and Jebel Aulia projects mentioned use of horizontal-shaft machines with straight-flow or rim-type generators (STRAFLO) at Jebel Aulia. The study concluded that STRAFLO turbines (made by Escher-Wyss) may be feasible although they tend to exhibit "inherent problems of instability due to the low inertia constant of these machines, and detailed investigation may indicate their application is not feasible due to electrical problems."

Escher-Wyss made a prefeasibility study of the use of STRAFLO machines at Jebel Aulia, Sennar, and Roseires. The Sennar Extension is a large hydro scheme and the Gezira/Managil canal headworks is a small hydro scheme. The Sennar Extension was evaluated for three STRAFLO units of 16 MW each to generate an estimated 166 GWh annually. After a cost analysis, these schemes promised an internal rate of return of approximately 11 to 12 percent.

Escher-Wyss studied the feasibility of an installation of two STRAFLO units of 4 MW each in the Gezira Canal, and two units at 3.4 MW each in the Managil canal. There annual generation was estimated at 43 GWh. No costs were reported, since ". . .the installed capacity is an order of magnitude lower than the other schemes. . ." and "the low head will make it expensive to develop."

B. The Southern Region

Among the studies variability will be noticed in power potential, demand forecasts and other figures. This apparent discrepency is actually due as much to lack of adequate data as to approach to development or other subjective variables.

1. Nile Water Study. Volume 4: Power Development in the Southern Region. The potential of the h . and low level dams proposed in 1974 by the Ministry of Irrigation and Hydroelectric Power is assessed through the application of a computer-adapted model of reservoir operation, and by taking into account some detailed hydrologic data. Because of the uncertainty that a dam will be constructed in Lake Albert, the assessment is based on unregulated river flows into the reservoir. Such unregulated flows are also employed to assess the potential of an alternative site on the Bahr el Jebel in the Nimule reach.

The hydroelectric potential of the southern region of the Nile is considerable, but the regional demand for electric power is small; also the region is altogether too remote for inclusion in a system of hydroelectric power generation of national extent.

The hydroelectric output from the Bahr el Jebel installation will far exceed local demand until the turn of the century unless the load is increased because of industrial development such as metal processing or fertilizer extraction.
The principal site of hydroelectric power generation is at the Bedden Rapids, which are located 36 km upstream of Juba. both low-level and high-level dams are considered. In the former case, the hydroelectric potential is predicted on the basis of power units, each having an output capacity of 25 MW when the head is 9.2m; in the latter case, each power unit is rated at 100 MW at a head of 30m. The results are in Table 1.

Table 1
Hydroelectric potential at the Bedden Rapids Dam

Scheme	Installed Capacity (MW)	Minimum Peaking Capacity (MW)	Average Annual Energy (GWh)
Low-level dam	100	69	620
Low-level dam	120	83	640
Low-level dam	150	104	660
High-level dam	300	280	2000
High-level dam	400	374	2200

The alternative site is at the Fola Rapids, which are 7 km downstream north of Nimule. A dam 40 m high is assumed. The results are in Table 2.

Table 2
Hydroelectric potential at the Fola Rapids

Installed Capacity (MW)	Minimum Peaking Capacity (MW)	Average Annual Energy (GWh)
200	186	1500
300	280	1600

The supply of electricity at Juba, Wau and Malakal totaled 3.2 GWh during the biennium 1974/75. The PEWC forecast annual growth rates of 5 percent at Wau and Malakal and of 8 percent at Juba. These results are used to obtain the projected demand. For the results see Table 3.

Table 3

Projected electric power demand in the southern region (MW)

Town	Actual Demand	Projected Demand			
	1974-75	1980/81	1983/84	1990/91	2000/2001
Juba	0.7	3.3	4.5	7.8	25
Wau	0.4	1.7	2.0	2.8	6
Malakal	0.3	1.1	1.3	1.8	3

Although additional sites will be electrified, the authors feel it is unlikely that their total power load will exceed one MW.

Three possible projects of small scale are considered in the report. These are:

(a) a storage dam located on the Kaia River, (a tributary of the Bahr el Jebel) about 50 km south of Juba

(b) a high head run-of-river project on the Kinyeti River at Katire in the Imatong Mountains, and

(c) a small scale run-of-river project on the Bahr el Jebel.

Flow records contained in the report suggest a dry season of four to six months duration, whereas rainfall records for a basin adjacent to the Kaia catchment area suggest a dry season of only one to two months.

The report describes the salient particulars of these small scale projects as follows:

Kaia River Project. If the dam is 45 m high, a flow of 15 to 20 x 10^6 m^3/month would produce about 1.5 MW of firm power. If the load factor is assumed to be 45 percent, the installed capacity results as 3.3 MW.

Kinyeti River Project. The head of water is 600 m. If several canals are laid out in a manner to collect a combined flow of 2 to 3 m^3/sec the installed capacity is about 8 MW.

Bahr el Jebel Project. In this project the river flow is diverted via a shallow gradient canal to a pressure penstock. A net head of 30 m and a flow of 40 m^3/sec yield a firm installed power of 10 MW. These calculations show a surprisingly high net head efficiency. The feasibility of the project depends on the topography of the area: this must be suitable for constructing a canal for a flow of 40 m^3/sec.

The large distances over which the power must be transmitted may make the costs of power tranmission high. These distances are 60 km from the Kaia site, 150 km from the Fola Rapids and Kinyeti sites. All distances exceed 50 km.

The following references constitute the source of data for the study:

The Bedden Rapids Dam. Ministry of Irrigation and Hydroelectric Power, 1975.

The Nile Basin. Vol. VII - The Future Conservation of the Nile - Cairo. Hurst, Black and Simaika, 1951.

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The Nile Basin. Vol. IV - Cairo. Hurst, Black and Simaika (unpublished as of 1979).
Power Market Survey. British Electricity International Ltd., 1976.
The Equatorial Nile Project and Its Effects in the Anglo Egyptian Sudan. Jonglei Investigation Team - circa 1954.
Natural Resources and Development Potential in the Southern Provinces of the Sudan. Southern Development Investigation Team, 1954.

According to the report, the engineering data found in the references appear to be adequate with the following exceptions:

- Topographic data in the MIHEP Report are lacking; consequently, it was not possible to consider the design of the dams proposed in this report.
- Only a single assessment of power use in the southern region appears to be in hand: the one by PEWC dated 1974/75.
- The engineering data on the small scale projects are insufficient for making firm recommendations.

2. Study on the Increased Utilization of Renewable Energy Sources in the Democratic Republic of Sudan; Summary of the Conclusions and Recommendations. Lahmeyer International GMBH, Frankfurt a.M., March 1980. The purpose of the study, which was carried out by the German Agency for Technical Cooperation (GPZ), is to:

(a) Evaluate technical expertise in the field of renewable energy in the Sudan, especially in the Energy Research Institute (ERI)
(b) Survey technologies for the utilization of renewable energy, including mini-hydropower
(c) Propose specific projects for development.

An evaluation of the expertise in various governmental institutions was completed and the recommendation is made that the ERI assume the principal technical role for all renewable energy projects.

Several specific projects are proposed. These include: cooking stoves, mini-hydropower, wood production, solar-operated rural TV, vocational training, solar-powered hospitals and solar-powered devices for dispensaries.

General criteria are given for the location of renewable energy plants. Favorable locations are found in the upper reaches of rivers flowing on the plateau along the Ethiopian Border, on the West Bank of the Nile, along streams flowing down from the Imatong Mountains, east of the Nile. Favorable opportunities exist for mini-hydro systems in the irrigation canals, e.g., at Gezira. Prior to the advent of diesel-generators in the region, mechanical hydropower was utilized for pumping stations and mills. It has not been possible to find any local information on the subject because of the disappearance of such facilities and the consequent loss of competence in their design and operation.

The following recommendations are made in the report:

- Build one or two plants along the Yei and Kinyeti Rivers. Their capacity should be in the 50 to 100 kw range and they should be integrated with the ongoing forestry project. Potential utilizers of such plants are health centers and coffee or tea factories.
- Set up flow-gauging stations on other promising streams in the southern Sudan.
- Construct along the Yei River a pilot water mill designed to operate on a low water gradient.
- Establish training in hydraulics at vocational centers.
- Carry out studies for developing water wheels and turbines for locations in the Sudan.

No statement is made in the report as to the availability of environmental data pertinent to the development of the above listed projects. It is difficult to evaluate this study since only the summary of the conclusions and recommendations was available. A proper evaluation would require that the body of the report be in hand.

3. <u>Report of the Mission to Evaluate Small Hydropower Sites in Sudan</u>, 27 November - 15 December, 1981. United Nations, Department of Technical Cooperation for Development. An assessment is made of the potential of small hydropower plants at two sites: the first located at the Fola Rapids on the Bahr el Jebel, the second on the Kinyeti River; the former would serve primarily Juba and secondarily Nimule, while the latter site would serve the town of Torit. Small hydropower plans appear to be cost effective when compared with diesel plans and

a recommendation is made to develop both sites and to consider also sites on other small streams in southern Sudan.

The present electrical capacity in Juba (population 85,000) is nominally 1.0 MW (actually probably 750 kw); there is, however, an additional privately-generated capacity of about 4.0 MW. The plant at the Fola Rapids site, where the water head is about 9 m and the average flow is about 125 m^3/sec, could have a capacity of approximately 9 MW and a yearly output of about 47 GWh. The cost of generation, of transmission to Juba (135 km) and to Nimule (7 km), and of local distribution is estimated to amount of $25 million at the mid-1981 price level. At the Kinyeti site, the water head is approximately 600 m. A flow of 0.5 m^3/sec would generate about 1.5 MW of power and would produce an output of 8 GWh/year. The cost of power generation, of transmission to Torit (population of 10,000 and 50 km distant), and of local distribution is estimated at $5 million.

The results of the analysis are summarized in Table 4:

Table 4
Cost comparisons at Fola Rapids and Kinyeti River

Site	Cost at bus bar (¢/kwh)	Consumer's cost (¢/kwh)	Interest (%)	Annual Energy output (GWh)
Fola Rapids	6	9	10	47
Kinyeti River	6	11	10	8

The following recommendations are made, namely that:

- o The sites at the Fola Rapids and on the Kinyeti River be exploited immediately
- o The potential of other sites on the Yei, Ibba, Sue, Kayu, Assua and Theba Rivers be investigated
- o The United Nations provide funds and technical assistance.

References are made in the report to the lack of flow and cartographic information.

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4. Eastern Equatoria Hydro-Electric Power Study. Feasibility Study, 1981. Hafslund Consulting Division, Oslo, Norway. The objective of this study, which was sponsored by the Norwegian Church Aid, is to assess sites in the Juba and Torit areas suitable for the construction of hydroelectric plants proportioned to the expected power demand. The sites considered are located at the Fola Rapids and on the Kinyeti River.

The study found that the Fola Rapids site, which would serve the Juba area, has a head of 10 m and a flow of 120 m^3/sec ; its power potential is 10 MW. The power potential developable by three power stations at the Kinyeti River site is 3 MW. The only other rivers attractive for the installations of plants furnishing power to the Yei, Juba or Torit area are the Kaya on the West Bank of the Nile and the Asua on the East Bank; the potential of these is 1-2 MW of firm power. The total power potential in Eastern Equatoria is estimated to lie between 250 and 300 MW.

The present power capacity at Juba, according to the report, is approximately 1.3 MW and the annual energy yield is 5.1 GWh. Based on a growth rate of 7 percent per year, increased capacity and load factor, the energy demand is predicted to rise to 12 GWh/year by 1986 and to 40 GWh/year by 1999. The capacity of the Kinyeti site is now 370 kW and its annual energy yield is 0.6 GWh. At a growth rate of 7 percent the yearly energy demand will become 2.5 GWh in 1986 and 5 GWh in 1999.

Power at Fola Rapids will be developed in four steps; with 5 MW being developed the first year, and 1.7 MW each succeeding year. The power will be transmitted by 66 kV line to Juba some 160 km distant.

5. Land and Water Resources Survey in the Jebel Marra Area of the Sudan. FAO, Rome, 1968. This United Nations Development Program (UNDP) report presents the results of a four year long search for technical data relevant to the development of agriculture in the Jebel Marra and Wadi Azun areas of West Darfu. The project included establishing an inventory of the area's land and water resources. The report includes recommendations for a number of practical demonstrations including those for: agricultural developments that emphasize adaptable high gross-value crops like deciduous fruits, grapes, vegetables, tobacco and chilies; irrigation techniques; use of livestock; development of forestry

products and resources; potential for hydroelectric power; and better communications, including roads.

Only those findings dealing with hydroelectric potential will be discussed. Potential sites for development include those on:

(a) mountain streams, the most promising of these being the falls of the Wadi Nyertete which could sustain a 97 kW facility

(b) irrigation storage facilities in the piedmont -- power generation would be seasonal in these facilities, except for service to the nearby orange groves

(c) the Dariba Lakes region where, by draining one lake into the other, 3 MW of power could be produced.

Problems with these sites as of 1968 are a perceived low demand for power and a possibly unacceptable increase of salinity in the lake to be drained. Rainfall in the region varies widely, from as much as 1000 mm/yr in the east of the Jebel Marra area, to as little as 400 mm in the west. The report presents an examination of the potential for power to: electrify the towns of Zalingei and Nyala; electrify irrigation pumping at the impoundment sites; and develop, or improve upon, existing forest industries and agricultural processing facilities. Potential flood control benefits are also discussed. An existing installation at Suni could serve as a prototype for the hydroelectric development feasible in this area. Rainfall data were obtained for this study from existing gauges and plentiful statistical records, as well as from gauges added during the course of the project. Additional information was gained concerning: streamflow (mean, maximum, and minimum), sedimentation, soil composition, the state of the animal husbandry, forestry activities, and the economic and social structure of the rural population. The project team also mapped substantial portions of the area, and developed preliminary designs for irrigation dams in the piedmont region.

The report indicates that further information concerning the salinity of the upper Dariba Lake and the low power demand of the region is needed before complete recommendations can be made. This seems to be a well-executed study. It provides a firm base of information upon which a reassessment of the potential of decentralized hydroelectric power can be built. The consultants', subcontractors', and experts' reports that were included in the overall report add to its reference value.

6. The Bedden Rapids Dam: Part 1, Basic Water Resources Studies; Part 2, Hydroelectric Power Potential, Ministry of Irrigation and Hydroelectric Power, February 1974. The potential for hydroelectric power of the proposed Bedden Rapids dam was the focus of these studies. The report notes that the proposed dam is to work in conjunction with existing irrigation and flood control projects on the Nile. The sponsors intend the proposed claim to benefit the area's irrigation as well as its power system. The report presents two possible utilizations of the proposed dam: regulating it in phase with a proposed dam at Lake Albert; and employing it for the generation of power prior to the construction of the proposed dam at Lake Albert.

The hydroelectric potential of the Bedden Rapids site is described. A survey map supplements the narrative text. The hydroelectric potential of the series of rapids between Numule and Rajef is also noted.

The report includes hydrographic information and a discussion of the procedures for regulating the reservoirs at Nimule and Lake Albert or at both of them. Maps of pertinent areas are included in the report. Descriptions of dams, tables of calculation of heads, a flow duration curve, and power calculations are part of the report.

The report indicates that if the dam at Bedden Rapids were constructed prior to the construction of the Lake Albert Dam it would have a head of between 9 m and 12 m. Output would range between approximately 36 MW and 75 MW depending on flow, and whether two, three, or four turbines were used. If the dam at the Bedden Rapids were used in phase with the Lake Albert Dam, the head would vary between 15 m and 35 m, and the power output would be in the 100 MW to 245 MW range.

The report includes discharge and "hydromet" tables.

Although not expressly stated in the report, information is lacking in several areas. Needed are: detailed maps (from aerial surveys); subsurface geological information, including geological maps; and technical and economic feasibility information. This report is a collection of preliminary calculations of questionable use. The dearth of narrative makes it lack focus. The Nile Waters

Study Vol. IV, which evaluates this report and presents a different set of calculations, is probably a better source for this information.

7. Development of Hydroelectric Potential of the Southern Sudan, Bonifica S.p.A. ENEL Italian Electricity Board. No Date. This is a work plan for a study that is now going on. It has two objectives — to determine the feasibility of supplying electricity to Juba, and to design a plan for exploiting available hydropower in Eastern Equatoria, Western Equatoria, el Buheyrat, and Bahr el Ghasal. Design of the regional plan would depend upon completion of a power market survey. The rivers to be examined are the Bahr el Jebel between Nimule and Rejaf, and the following secondary rivers: Kinyeti, Kit, Kaia, Yei, Naam, Tonj, Sue, and Busseri. The study has two stages.

In Stage One, based on data from official records, the power market survey will include: sectoral analysis, population determination, income analysis, and load forecast for the year 2000.

Hydrological, topographic, and geological data will be utilized in establishing a plan to exploit the hydropower of the Bahr el Jebel. It is estimated that the five rapids in this section of the river will produce a head of 170 m, based on a flow of 750 m^3/sec. This will yield 1.2 MW of power.

Examinations of secondary rivers should include consideration of:

(a) The potential of small dams on source streams, which have as their purpose both the generation of electricity and the irrigation of coffee and tea plantations, and fruit orchards

(b) The potential of medium and high dams, which have as their purpose the generation of electricity, the development of irrigation systems, and flood control

(c) The potential of extensive water storage units (low to medium head) downstream from potential dam sites, which have as their purpose irrigation and water regulation.

In Stage Two, a site in each of the following regions will be selected for a prefeasibility study: the West, the East, and along the Bahr el Jebel. Each candidate site will be evaluated according to analyses of its conceptual design, cost, and benefits — including its potential for downstream irrigation and flood control. The first priority project will be selected on the basis of this evaluation.

Information requirements are suggested by the work plan. For the Bahr el Jebel site the following items are needed:

- o Additional power market information, obtained through limited site surveys in the main load centers
- o Analytic information obtained by forecasting demand to the year 2000 — such predictions should focus on the changing demand at Juba
- o A photo mosaic (1:40,000) of the Bahr el Jebel between Nimule and Rejaf, to be composed from existing aerial photographs
- o A stereoscopic geomorphologic study and a topographic survey leading to the production of a topographic map in a scale of 1:10,000, of each of the five rapids areas, to be based on aerial photographs (1:20,000) from Nimule to Rejaf
- o Analytic information about the water in the Bahr el Jebel River including the level of silt, information to be based on samples of river water.

For sites on the secondary rivers the following items are needed:

- o The shape and dimensions of the catchment area, which can be determined from maps in a scale of 1:250,000 based on satellite photographs
- o Stereoscopic geomorphologic information for the drainage areas 5 km on either side of the stream, which can be determined from aerial photographs
- o Increased flow rate information, which can be obtained by correlating generated runoff coefficients for catchment areas whose rainfall and discharge are known with similarly shaped and sized catchment areas
- o Information on flood discharge under varying conditions, which can be generated from existing data.

The Second Stage requirements are:

- o aerial photographs, at a scale of 1:20,000, of two secondary river sites suggested for use as reservoirs
- o aerial photographs, at a scale of 1:10,000, of the three selected dam sites
- o topographic maps, at a scale of 1:10,000, of the reservoir sites, such maps to be based on aerial photographs of reservoir sites mentioned above

- topographic maps, at a scale of 1:5,000, of the three selected dam sites, such maps to be based on the aerial photographs noted above

8. <u>Development of Hydroelectric Potential of the Southern Region: Progress Report</u>, Bonifica S.p.A., April 1982. This is the first progress report on the project described in No. 7 above. It describes work performed from the time of the signing of the contract on December 30, 1980, to April 20, 1982. Much of the field work specified for the first stage has been completed, and an impressive amount of information has been acquired and processed.

Delays in initial payment and intergovernmental currency exchange difficulties caused the starting date of the project to be delayed from March 15, 1981 to November 7, 1981. Research for the power market study has been conducted, but the report is not completed. The aerial photographs of the Nile between Nimule and Rejaf produced pictures in two scales (1:40,000 and 1:20,000) instead of a single scale. A preliminary geological map, in a scale of 1:20,000, of the area between Juba and Nimule on the Nile has been produced and a ground truth survey, which included the collection of rock samples for petrographic analysis, has been performed. On the basis of these actions the contractor will produce a 1:50,000 geological map for the area between Nimule and Rejaf on the Nile. This map will be for superimposition over a matching, topographical map.

A ground survey of the site area was made and the map is in preparation. A hydrographic map, in a scale of 1:250,000 has been prepared for each of the secondary river sites. Topographic maps, in a scale of 1:250,000, aerial and Landsat photographs and other sources were used as sources for these maps.

Morphological narrows suitable to dams or barrages have been identified by use of aerial photographs of the Kinyeti, Kit, Kaia, Yei, Sue, and Busseri Rivers. The characteristics of each of these narrows have been inventoried, and a list of geologic characteristics has been generated for each potential site.

Through use of aerial inspection and site reconnaissance a decision was made to develop plans for dam sites on the Kinyeti, Kaia, Yei, Sue, and Busseri Rivers. The plans have been drawn up. Potential dam sites on the Kit, Naam and Tonj Rivers have been eliminated due either to their small size, or isolation from users.

If the Sue River site is deemed acceptable, the first phase priority scheme calls for power from that site to go to Juba and Wau and, secondarily to Tonj. Incomplete data hindered completion of the hydrological study. To overcome this a mathematical model is being prepared. This model will generate runoff statistics on the basis of available data. The sources for the hydrological data being used in the model are: the Ministry of Irrigation, the Nile Waters Department, the Egyptian Irrigation Department, and the Sudan Meteorological Department.

Data concerning meteorological and hydrological conditions in the Sudan are very sparse, and much information is needed. Much cartographic information is also needed, and a substantial amount of topographical, geological, and hydrological mapping should be conducted. There is also a critical lack of information concerning such matters as: population size, growth rate of population, public and private power demand, and the potential for agricultural development, mining, and industry. Since virtually no information on any of these areas exists, meaningful market surveys cannot be made. This information must be collected if the government of Sudan is serious about developing its Southern Region.

This is an impressive "first-of-a-kind" study. The contractors are generating much of the needed information as they progress. The information generated, the lessons learned and the techniques applied should be of benefit to similar studies in the future. The government of Sudan could benefit from further utilization of the project consultants in the following areas: generating information regarding flow schedules of other streams in the southern region, mapping areas of importance to the government, training the Sudanese to survey for information useful in market studies, establishing stream gauging stations, and providing overall assistance in collecting general information important to the development of the southern region.

Section 5

Summary of site-specific conclusions and recommendations

The northern portion of the Sudan has large, broad rivers with heavy siltation and seasonably variable flows. In some months the flow in some streams is almost non-existent; at other times there is extensive flooding. This is also relatively flat country. These factors severely limit the opportunities for development of decentralized, small scale hydropower facilities.

In spite of this, in a world situation in which funding for major construction projects such as large dams is increasingly non-available, small-scale, decentralized hydropower as a possible source of affordable power merits continuing reappraisal. There are clearly some opportunities for decentralized development in these regions; to realize these opportunities will require concerted efforts to providc better geophysical and socioeconomic data for assessment and planning, and to develop and use innovative designs for facilities.

Retrofit of existing irrigation schemes for power generation does not appear feasible, primarily because the necessity of uninterrupted irrigation during construction would greatly increase the costs of retrofit. But in all future irrigation projects, power generation should be an important consideration from the earliest phases of planning and design.

Upper Atbara and Setit Rivers

This region includes that portion of the Atbara River upstream from its confluence with the Setit, and the lower portion of the Setit River. Over thirty sites in this area have been studied or considered for decentralized hydropower development. Studies have focused on sites at Burdana and Rumela on the Setit and Atbara Rivers respectively, with the primary objectives of protecting Khasm El Girba from further siltation while providing irrigation storage for the New Halfa scheme. The studies tend to eliminate the site at Burdana because extreme sediment loads made it infeasible. The site at Rumela was recommended to provide the necessary additional storage capacity for irrigation and to generate up to 30 MW of electric power depending on irrigation flows. The primary limitation on power generation from the upper Atbara is the great seasonal variation in flow. There is essentially no flow during six months of the year.

An overflight of the region was conducted by the team on May 16th. Although there was some flow in the Setit River (the early rains in the highlands had begun), the heavy silt burden was readily apparent from the chocolate brown dense water and the extensive shoal and silt bar. There was no flow in the Atbara, only some separate pools of water showing. Again extensive silt deposition was evident. Several narrow gorges were identified where potential water control could be implemented, but there is almost no topographical relief.

Recommendations

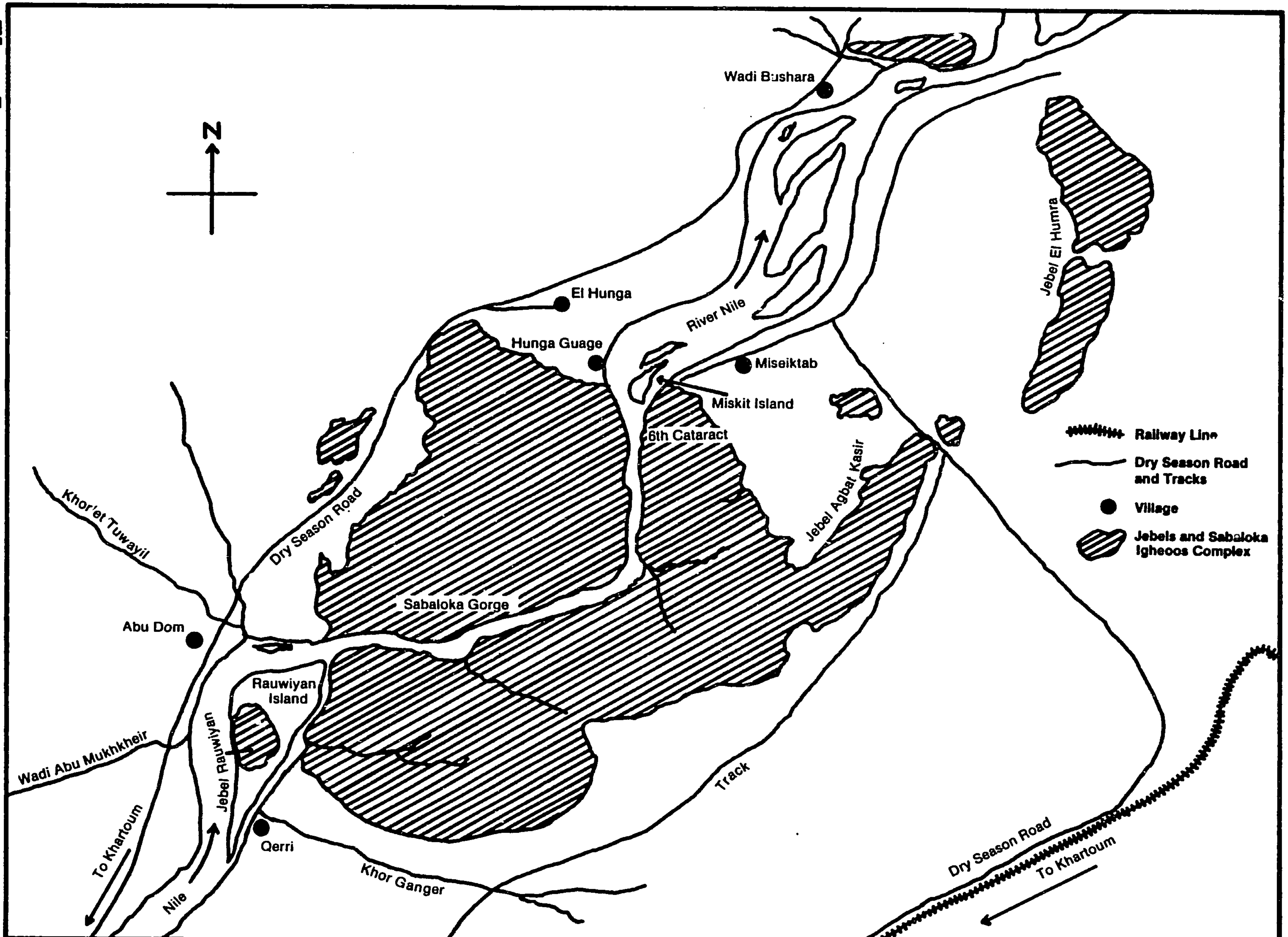
(1) Due to the extensive siltation, especially on the Setit, and the lack of flow and elevation change on both the Setit and Atbara, no further consideration should be given to decentralized hydropower development in this region.

(2) If the Rumela dam is built as planned, it may then be appropriate to reinvestigate small hydropower development in connection with irrigation flows.

Jebel Aulia

A reconnaissance survey was made of the Jebel Aulia dam, a water regulation structure on the White Nile immediately upstream from the confluence with the Blue Nile. Previous studies such as the Nile waters study and the prefeasibility study on Jebel Aulia had indicated that an optimum 35 MW of installed capacity could be technically feasible, however, the hydrology and mode of operation reduce generation benefits. Follow-up studies by Escher-Wyss indicate smaller scale turbine generator sets with an installed capacity of up to 50 MW and an annual output of 242 GWh may be considered feasible considering investment costs, existing operations, hydrology and turbine availability. The team survey verified the existence of a masonry water control structure containing a navigation lock and operational sluices. Ten blocked off sluice openings were located adjacent to the left bank. There was sufficient clearance for breaching one or more of these openings to install small turbine generator sets. There is room at the foot of the dam for construction of a small powerhouse.

Fig. 4 SABALOKA GORGE (6TH CATARACT)



Since this is a low head structure with a maximum head of 7.3 m and without any operating head for three months out of the year (during the Blue Nile flood peak of June, July and August) any significant capacity benefit at Jebel Aulia is doubtful. However, a program to install several smaller (up to 1.5 MW per opening) turbine generator sets to provide service to the immediate vicinity should be investigated. The extent to which such development is undertaken will be limited primarily by construction costs, balanced against savings from fuel displacement and/or improved reliability. Looked at from another point of view, if a low cost scheme for 3-15 MW could be built in the near term, the additional capacity (up to 35 MW) might be installed later, as a second phase. Design of the first phase should incorporate features to allow for the second phase.

It is possible that with improvement in flows in the future, more extensive development may be feasible. This will require improved river flow operation to capture the increased flows into the reservoir. Increased capacity, with improved head and flow at the dam, may provide sufficient power to justify both the increased evaporative losses from the reservoir and the necessity of adjusting the irrigation pumping heights.

Cursory studies of Jebel Aulia indicate two schemes may be feasible. Scheme 1 has a downstream powerhouse and horizontal shaft turbine-generators. Maximum unit size for this scheme would be about 1.5 MW per sluice opening. The limit on the unit size is set by achieving a reasonable inlet velocity. Scheme 2 would consist of an upstream powerhouse with vertical shaft turbine-generator units. Unit size would be limited to about 0.3 MW per sluice opening. Unit size in this scheme is limited in order to fit the draft tube within the existing sluice openings. Construction problems with this scheme would be less than the scheme utilizing a downstream powerhouse due to difficulties in coffer dam construction, provisions for unit removal, and other uncertainties.

Recommendations

(1) Further evaluation of the construction costs and capital investment requirements of limited small hydropower development at Jebel Aulia should be undertaken.

(2) The development of small hydro generation at Jebel Aulia should proceed as far as it can be justified by fuel displaced, improved reliability, and local service.

(3) Hydrologic investigations should be undertaken to determine if the capacity benefits from conservation flows can be realized.

Sabaloka

The Sabaloka gorge, on the main Nile near Khartoum is an attractive site for hydroelectric development. Development of the site does appear to be technically feasible with an operating head range of 2 m to 11 m. A project with an installed capacity of 120 MW and an average annual energy potential of 750 GWh has been proposed, but is probably not feasible since a flooding of Khartoum would be expected every twenty years and siltation would limit the project life to fifteen years.

A reconnaissance survey by the team was made of the Sabaloka gorge. Elevation changes would probably allow for operating heads of 2 m or more. Either a run of the river (straight flow) or a diversion to an off-channel turbine generator could be implemented here, with a potential for up to 10 MW. However, firm conclusions about the potential for either large or small scale hydropower development at this site will require more reliable data than now exists, particularly with regard to the elevation of the Hunga gauge, which may be off as much as 1 m.

Recommendations

(1) The following small hydro development scheme should be studied further: A diversion of part of the Nile above the cataract, through a gated intake structure into a canal or flume which would form a headrace, an overflow structure with an outlet through a pressure penstock to a powerhouse with tailrace discharging into the Nile below the cataract.
Such a scheme, with estimated fall through the cataract of about 9 m,* could generate 5 MW or more with a diversion of about $90m^3$/sec and an

*/ The team was unable to verify the fall (or profile) through the 6th cataract.

overall efficiency of about 65 percent. At a velocity of 2m/sec, a cross section of about $45m^2$ would be required. Further evaluation of this scheme will require detailed topographic maps of 1 m or less contour intervals and a detailed hydrologic profile through the gorge. Such a scheme could involve considerable rock excavation for the inlet works and possibly a bench to carry a flume. Siltation of the inlet could also be a problem and careful location and shaping of the inlet would be required. Costs of transmission lines must also be considered. If a diversion dam is required consideration must be given to navigation of the river.

(2) The Hunga gauge elevation should be recalibrated so that existing and potential impounded water levels could be reliably estimated.

Major irrigation systems

The Sudan's extensive system of canals, barrages, regulators, and other irrigation works was investigated. The Sennar-Gezira-Managil Scheme, the Rahad Scheme, and the New Halfa Scheme, shown in Fig. 5, were selected for more detailed study. The investigation included aerial reconaissance of all three schemes and visits to Sennar Dam and the Kilo 99 regulator on the Gezira Irrigation Scheme; study of reports — notably the Nile Waters Study and Blue Nile Study by Gibb and others and the Escher-Wyss studies; and discussions with key members of the Ministry of Irrigation, the PEWC, and the NEA in Khartoum and at Wad Medani and Sennar. Table 5 lists the important components of quantitative data that were collected.

Examination of the data, the team's observations, and discussions with cognizant Sudanese engineers disclosed that:

- Head in the canals at regulating structures are consistently less than 2 m, almost all being on the order of 1.2 m to 1.5 m.
- Discharges in the canals, particularly in the main canals, are substantial over much of the year. However, at least in the Gezira Scheme, flows are minimal during the months of April and May. At Kilo 99 an esimate of the annual average daily flow in both canals is about 3.7 Mm^3/day for the last twelve months, with a maximum average of about 5.8 Mm^3/day and several days in April and May with no flow.

AREA 1.6 MILLION SQ. KMS.

POPULATION 16 MILLION

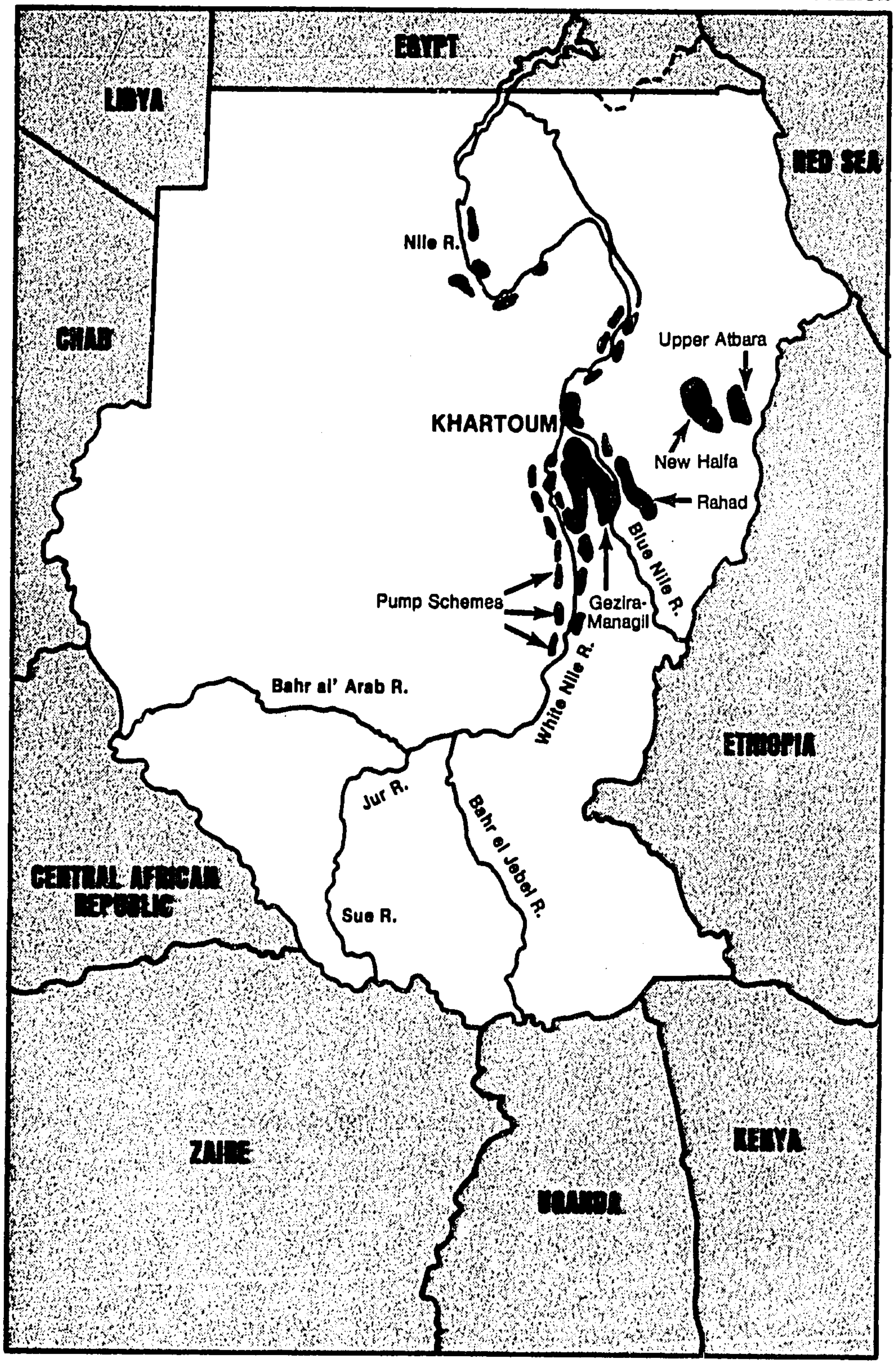


Fig. 5 SUDAN IRRIGATION AREAS

- Regulators are mostly manually operated with frequent changes daily during the rainy season.
- Maintenance of canal flows is essential. Any scheme to retrofit power generating facilities must allow sustained irrigation operation during construction of the generating facilities.

Table 5

Data collected for assessment of hydropower potential on irrigation schemes

Head and flow at Sennar Dam for Gezira and Managil main canals.	Ten day averages of July 1980 June 1981.
Cross sectional dimensions for outlet sluices through Sennar Dam.	
Head and flow at Khasm El Girba dam for the New Halfa Canals	Ten day averages for July 1980 through June 1981.
Head and flow at Kilo 99 regulator on Gezira Canal. May 1982	Daily averages for period June 1981.
Design heads and flows in the west branch canal of the New Halfa Scheme.	
Head data at the Rahad barrage.	

These observations lead to a set of conclusions, namely:

- Heads in the present irrigation system are insufficient for economical installation of generating facilities (shown in Fig. 6)
- The requirement that irrigation must continue with current levels of control on discharges during construction will increase substantially
- Since there is generally a considerable distance between transmission facilities and regulators, there may be substantial costs involved in transmitting power. However this could provide an opportunity for rural electrification schemes.
- Head and flow at Sennar Dam into the Managil and Gezira canals are such that substantial energy could be generated. However, there are low flows, further exacerbated by leakage, in April and May so that there is minimal sustained capacity. Annual generation was estimated by Escher-Wyss at 42.6 GWh.

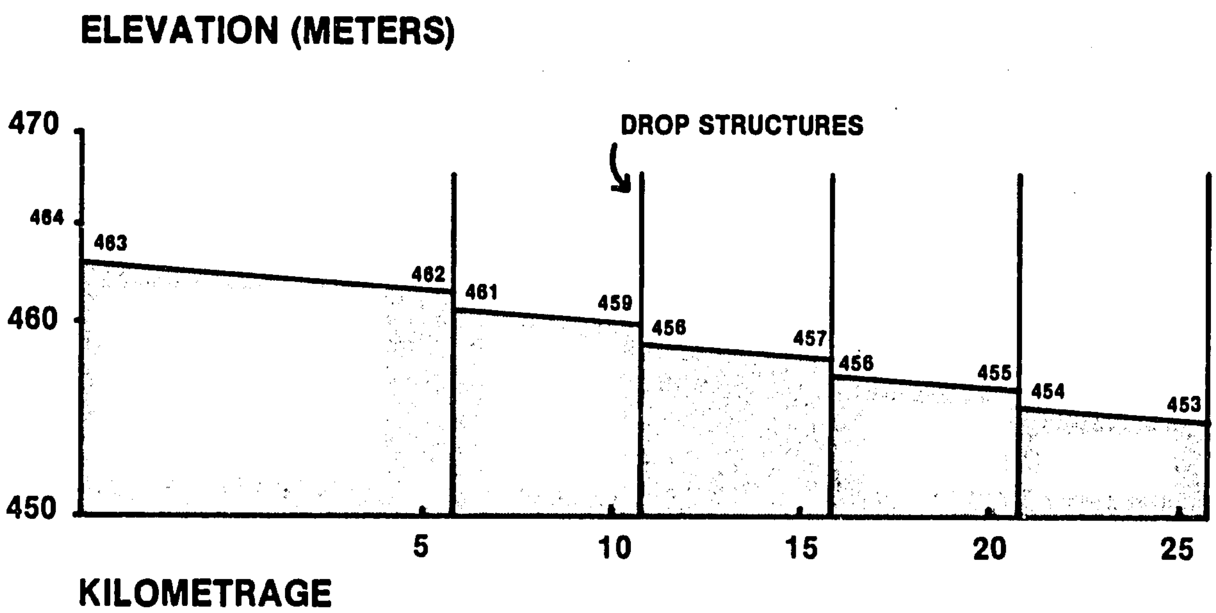


Fig. 6 KHASM EL GIRBA IRRIGATION PROJECT PROFILE

- Unless an innovative way is found to design and construct generating facilities at Sennar headworks, the requirements to maintain flow in the canals will make construction difficult and costly.
- At present the development of decentralized hydroelectric power in irrigation canals in the Sudan appears unattractive because of head problems and potentially high capital costs. In spite of this, there are still some opportunities to be considered.

Recommendations

(1) The possibility of developing generation capacity at Sennar dam headworks should be further investigated to demonstrate whether or not it is a viable project. If the 42.6 GWh estimated by Escher-Wyss represents fuel displacement, a case can be made for further study. U.S. manufacturers of turbine generators (e.g., Allis-Chalmers, Leffel) should be contacted for possible interest in innovative design.

(2) New irrigation schemes or major rehabilitation projects of existing schemes should be evaluated for generating capability. Such an evaluation would, of course, balance the additional costs associated with providing sufficient head at the regulators (probably a minimum of 3.5 m) by deeper excavation, installation and transmission, against the benefits of the energy generated. Preparation of a conceptual design scheme would be appropriate, and would benefit by participation of Sudanese engineers. For perspective, in the West branch of the New Halfa Scheme, if a head of 3.5 m could be developed the design flow of about 55 m^3/sec would generate, at an assumed overall efficiency of 65%, about 1,225 kW. This is a significant amount of power.

The southern Sudan

Decentralized hydropower development can provide an affordable source of power in the southern portions of the Sudan, where little power is now generated and developing load centers are still small and relatively dispersed. In these areas the sparseness of hydrologic and other geophysical data has been a serious constraint on power planning, as has been the lack of current census data and projections. The Bonifica S.p.A. study now underway is the most comprehensive hydropower assessment yet undertaken in the Southern Region. When the results become available later this year, it will provide an opportunity for reappraisal of the future role of decentralized hydropower in development of the southern Sudan, and of the several sites which have been proposed for development.

There is evidence that effective demand for power in this region, although still small, is growing and in some cases may be pressing. Public power generation here will face several difficulties: especially the lack of trained personnel, the difficulty of maintaining equipment because of the remoteness from urban centers and the very poor transportation, and the lack of information necessary for planning and efficient operation.

Because of the lack of data forecasts of population and load are generalized, vague, and unreliable. There is little information at present on the size of village populations, their growth rates and activities in the local economy including agriculture and village industry. Basic cartographic and hydrologic information for site evaluation has also been lacking. As already noted, the Bonifica study will help alleviate this problem; the few decentralized hydropower facilities in operation also provide an opportunity for collecting data on system cost, reliability, and servicing requirements.

Very little power is now generated in the Southern Region, which is sparsely populated compared to the irrigated North-Central. In Juba, installed capacity in the public sector is about 1 MW, with approximtely 4 MW of private sector installed capacity. This is chiefly diesel power. In Torit no power is yet generated; generating sets were purchased but the government is still collecting funds for installation and distribution. The problem is in both places unreliable delivery and high costs of diesel fuel. Equipment maintenance and system reliability have been serious problems in Juba's public power sector, with frequent outages. It may therefore be difficult to get private sector owners of generating units to switch to public power when it becomes available.

In Juba, 5 MW of added public capacity is already five years behind schedule. Yet many power-consuming projects are planned or already committed including commercial and public sector projects and housing developments. Some are completed and awaiting connection. There is also substantial interest in electrification in Torit, a city of 15,000 people with no power generation, which is expected to grow to 55,000 people by 1995. Already there are shops, small scale crafts, and government offices. Two projects, the Imatong Forestry project extension and the Talanga Tea Estate project, with associated housing, would be primary power users. Around Juba and Torit there are other towns and areas which could use electricity for housing, agriculture, and light industry: Nimule-Madi, Mongalla, Kajo-Kaji, Iwatoka, Tei, and Kapoeta areas.

Rural cooperatives may be a useful model for electrification of this part of the Sudan. Smaller generating stations may work better if managed on a local level with local investment. The generating sets already purchased for Torit (but not yet installed) were purchased with local funds raised by the Torit City government. It has been suggested that local electrification efforts can both stimulate and benefit from development of a local industry of wood pole production, both for domestic transmission and for export.

The Southern Region has some natural advantages in terms of hydropower compared to other parts of the Sudan; it has the heaviest rainfall and the highest elevations, especially near the southern border. It also has serious problems: relatively sparse population and few towns, rough terrain and poor transportation. Fuel supply is unreliable and costs are very high; this is what makes decentralized hydropower development attractive as a source of less costly power. As already noted, two major problems will have to be overcome before development can proceed very far: the lack of data and the lack of trained personnel.

The assessment team tentatively concluded:

- o Of the sites examined on the Bahr el Jebel reach of the Nile between Nimule and Juba, the proposed development of the Upper Fola Rapids is probably best suited for development. It would provide 5.1 MW initially, followed by 1.7 MW in each of three successive steps, supplying power to Juba and Nimule.
- o Of the sites examined on the Kinyeti River, the proposed development of Katire seems to be the best suited for development. It would supply a total of 3.5 MW in four phases, supplying power to Torit and Katire.
- o A number of river basins secondary to the Nile have been surveyed only cursorally because of the inadequacy of geophysical and socioeconomic

data. No conclusions can be reached at present about sites on these rivers, which include the Assua, Ateppi, Kit, Kaia, Yei, Naam, Tonj, Sue, and Busseri.

Recommendations

(1) There should be phased development of the Katire site on the Kinyeti River (pending confirmation of this finding by adequate flow and cartographic information) to electrify Torit, Katire, and nearby agricultural and industrial needs. The estimated cost for generation, transmission, and distribution ($7.7 million U.S.) should be re-evaluated to include such savings as the use of local wood poles and other possible cost savings.

(2) The phased development of the Upper Fola Rapids site on the Bahr el Jebel should be implemented to electrify the Juba area, Nimule, and associated agricultural and industrial needs. The estimated cost for generation, transmission, and distribution ($26.7 million U.S.) should also be re-evaluated.

(3) Other sites on the secondary rivers should be identified as soon as feasible — that is, when better data, technical assistance personnel, and/or additional resources are available. Since much of the data to be developed by Bonifica will be related to development by impoundment, a future survey should give particular attention to comparing development by impoundment with development by run-of-river diversion.

(4) The feasibility of local fabrication of turbines for use in the South and for possible export should be studied. Particular attention should be paid to these possibilities:

- o the Juba Boat Works and other similar shops as potential facilities; the design and operation of the river turbines currently being tested in Juba, as examples of a new type of small turbine to be fabricated,
- o the design and development of pelton and Francis turbine as an example of an older, but reliable type. Attention should be paid to any lesson learned from the 40-odd years of operating the hydro plant at the Imatong Forest Project.

The Jebel Marra area

It is thought there is significant power potential in the mountainous streams and lakes and piedmont storage reservoirs of the Jebel Marra area in the western part of the Sudan. It has been estimated (in a 1968 FAO study) that 100 kw could be generated from Jebel Marra's streams and as much as 3 MW from the lakes. At the time of the study there was no demand for power in this area, but over the last fourteen years it is likely that significant demand has developed.

Recommendations

The team recommends a re-evaluation of the Jebel Marra area should be undertaken with particular attention to:

(1) Power demand estimates for Nyala, Zalingei, irrigation pumping in the Nyertete

(2) benefits from irrigation (from impounded sites), water balance (rainfall vs. irrigation vs. power generation)

(3) industrial demand from forest industries and agricultural processing. Information from an existing prototype installation at Suni should be used for typical information on operations, servicing and costs.

(4) confirming power potential at identified sites, i.e. mountain streams and the Dariba Lakes.

Section 6

Management and training

A major reorganization of the Public Electricity and Water Corporation (PEWC) was announced by the government during the course of this study. The reorganization, in effect, split up the PEWC into two separate components — the National Electricity Corporation (NEC) and the Greater Khartoum Water Authority. The Presidential decree also spelled out in some detail the authority of the NEC and how it was to relate to the Regional Ministries of Housing and Public Works. The breakdown of responsibility for the generation, transmission, and distribution of electricity in The Sudan, is to be as follows:

- The NEC will have complete responsibility for the management and operations of the (BNG). This responsibility for operations will supercede any authority that the regional governments have where the BNG operates. Presumably this authority would expand with any expansion of the BNG.
- The NEC will provide power to the regions as bulk consumers; this will be metered and charged on the 11 kV side.
- The NEC will provide technical assistance to the regions as requested.
- The Regional Ministries of Housing and Public Utilities will be responsible for generation, transmission and distribution in all areas not served by the BNG. In those areas served by the BNG, they will be responsible for the distribution and commercial aspects of the operations.
- The Regional Ministries of Housing and Public Utilities may request technical assistance from the NEC. Should they wish assistance from other agencies or bodies (either national or international), this can only be done through the NEC.

The full implications of the Presidential decree are not yet clear. However, it does appear that much more will be expected in terms of management and operations from local authorities than has hitherto been the case. This may, in the long run, be beneficial to those areas of the country not now served by the BNG. In the short run — unless assistance is quickly provided to the local authorities — there may be further decline in electric services in those areas which already have a dangerously low level of service. Much effort will probably have to be directed towards building capability in the Regional Ministries if continued deterioration of plant and services is to be halted and reversed.

While most of the cities and towns outside the BNG and Eastern Grid are now bring served by isolated diesel units, the construction and operation of decentralized hydroelectric power systems will bring with it a new set of operational responsibilities with which local or regional authorities are not yet experienced. Considerable attention, therefore, will have to be given to just how these responsibilities can be met, both by the Regional Ministries and the NEC in its role of technical advisor to the ministries.

From a practical point of view, the issues being faced by the Central Government concerning the interrelationship between power generation and irrigation will not be as much of a concern to the regional authorities. But interministerial or interagency cooperation and coordination to the regional level will be required in many cases to effectively maximize the investments made in decentralized hydropower development. The procedures necessary to ensure the required coordination need to be established quickly.

The team has not had the opportunity to examine in detail the overall operations of the electric power sector in the Sudan. This, coupled with the fact that the final organizational structure of the electric power sector was in a state of flux at the time of the team's visit to the Sudan, made it appear unwise to consider further any organizational models that might be proposed for the development and management of decentralized hydro power systems, whether under the control of the NEC or the Regional Ministries. Further study of this aspect of the assessment should be undertaken at a more appropriate time. However, two important operational aspects of the operations of the government's electric generating, transmission and distribution functions seem to dictate an early need to develop a comprehensive manpower development program for electric power sector staff at all levels.

First and most importantly, the recently announced restructuring of the national electric and water utility entities will result in an altered set of responsibilities for the newly created NEC. While the NEC will be responsible for the continued operation of the major portion of the generation and transmission functions within the country, it will also be required to provide support and assistance as requested to the distribution, operations and maintenance and the commercial functions which will now be the responsibility of the Regional Ministries of Housing and Public Utilities. In those areas outside the BNG these Regional Ministries will also be responsible for both generation and transmission as well as distribution.

The team believes this move to decentralize the electric power development and operations activity within the country is a step in the right direction. It will contribute to more effective operations outside the BNG. To carry out these new responsibilities effectively will require a major manpower development effort within each of the Regional Ministries. The NEC will need as well to strengthen its organizational and professional capacity, to provide the kind of support to the Regions envisioned in the new reorganization plan.

Secondly, the steady deterioration of the many isolated generating facilities throughout the country is of much longer standing. The resulting deterioration of electric service indicates that there is urgent need for intensive training in system management, operations and maintenance procedures for staff with direct responsibility for these isolated operations. Improved management procedures and improved maintenance and operation practices can have a significant impact on the long term viability of these systems and the level of services. The lack of spare parts also compounds the problem of reliable electric service.

Recommendations

(1) A comprehensive management review of the NEC and the regional ministries should be undertaken immediately. It should determine the most effective operational structures to carry the new responsibilities of these organizations, and it should identify as precisely as possible their short and long term manpower requirements.

(2) A uniform plan for the electrification of each of the regions should be carried out, with particular emphasis on those areas presently served by isolated diesel generation, as well as those to be served eventually by decentralized hydropower (primarily the Southern Region). The plan should consider a number of management options to insure that local interests are adequately met. It is the team' understanding that in some cases cooperatives have been formed to provide electric service to isolated

towns. Further investigation should be given to this form of small electric utility management. Such an approach has been successfully implemented in a number of developing countries including the Philippines, Bangladesh, India and Argentina. Rural cooperatives in the United States are a good model.

(3) The assessment team encourages the NEC to consider creating within its own structure a major department concerned solely with the rural electrification aspects of the national electric energy development plan. Ths would include decentralized hydropower development outside the BNG. This Department of Rural Electrification would provide technical assistance and funds on both a grant and lending basis to the regional ministries in support of their regional rural electrification efforts. The Department of Rural Electrification would channel funds from international sources to regional ministries managing disbursements, repayments schedules, etc. Only in this way will the necessary attention be effectively focused on those areas in need of electric power outside the BNG. India, the Philippines, and Bangladesh, have found this strategy to be both necessary and effective.

(4) For its long term manpower development needs the NEC, perhaps in cooperation with the Universities of Khartoum and Juba, should develop and institutionalize a capacity to conduct intensive short term courses in all apsects of the management, operations and maintenance of rural electric utility systems, from initial generation to consumer services. Courses of this nature have proven to be necessary for the successful operations of small utilities in the U.S. and other countries. Adequate funding for follow-up increases in personnel will be essential to a manpower development program.

(5) In anticipation of the early development of decentralized hydropower facilities in the southern region, selected staff should receive both classroom instruction and hands-on experience in the development and operation of decentralized hydropower systems. Special emphasis would be given to resource assessment, feasibility analysis, site development and end use planning. Courses of this type are presently available in the United States and elsewhere.

For the immediate future, consideration should be given to sending staff from the NEC and the regional ministries to such courses that are available in the United States. The USDA/NRECA six week course in the management and operations of rural utility systems is one such course. It provides both formal management training and field observations, and has been given effectively to electric utility staff from countries throughout the world over the past twenty years. Other courses focusing on the engineering aspects of rural operations are offered at the University of Missouri at Rolla and at several other locations.

(6) Also for the near term, selected staff from the NEC and appropriate regional ministries should have the opportunity to observe at close hand, the operations of the Tennessee Valley Authority and the U.S. Bureau of Reclamation. Both of these organizations have direct relevance to the effect of the Government of Sudan in comprehensive development of its water and power resources. Particular attention should be given to the mathematical simulation model now being used by the TVA for use in managing navigation, power production and flood control systems. Other areas of interest include regional resource management and maintenance management. The TVA also provides an example of interaction and management of centralized and decentralized functions.

Section 7

Possible funding sources for hydropower development in the Sudan

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Many of the traditional donor agencies with historical interest in hydropower development are already present in the Sudan. In addition to USAID, chief among those are the International Bank for Reconstruction and Development and the International Development Association of the World Bank group. The United Nations Development Program and the UN Capital Development Fund also have demonstrated interest in the Sudan in the energy field. The UNDP, for instance, has funded recently a study of the Fola Rapids and Kinyeti River sites for small hydropower development. It is not unlikely that the UN Capital Development Fund might be interested in follow-on construction funds in modest amounts for one or both of these.

The African Development Bank also has evinced interest in the development of the Fola Rapids site and perhaps may be interested in co-financing with the UN Capital Development Fund. Also, the Italian Government funded the presently ongoing study of hydropower potential in the South. It is not unreasonable to expect that additional funds from this source may be available after the study is complete, either directly or from a large number of missionary groups already operating in the southern region.

One of the largest such groups is the Norwegian Church Aid and, here again, it is probably not unreasonable to expect that some smaller hydro development projects might be considered by this group, with possible assistance from the Norwegian Government. The Swiss already have demonstrated interest in decentralized hydropower development through the support of the Escher Wyss study of Jebel Aulia.

The Kuwait Fund for Arab Economic Development has a strong interest in the development of the power sector and historically has expended about 25% of its aid funds in this area. Soundly conceived and well designed decentralized hydropower projects in the Sudan might be attractive to this funding agency, particularly as an alternative to larger scale, more expensive hydropower projects. For similar reasons, other Arab funding source. .ight also be interested.

Countries with a particular historical interest in the Sudan include England and its Overseas Development Agency and The Federal Ministry for Economic Cooperation of West Germany. British interest has heretofore been focused primarily on the larger scale projects associated with the development of the Blue Nile and White Nile Rivers proper, but with the financial constraints now facing the Sudan, smaller more manageable projects may become attractive.

Appendix A

Candidate sources* of funds for energy development in the Sudan

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1. ADFAED
   Abu Dhabi Fund for Arab
   Economic Development
   P.O. Box 814
   Abu Dhabi
   United Arab Emirates

2. AFDB
   African Development Bank
   B.P. 1387
   Abidjan 01, Ivory Coast

3. Arab Fund for Economic and Social
   Development
   P.O. Box 21923
   Kuwait

4. BADEA
   Banque Arabe de Developpement
   Economique en Afrique
   P.O. Box 2640
   Baladia Road
   Khartoum
   Sudan

5. BMZ-Germany
   Federal Ministry for
   Economic Cooperation Bundesministerium
   fuer Wirtschaftliche Zusammenarbeit
   Karl-marx-strasse 4-6
   53 Bonn 12
   Federal Republic of Germany

*Some of these sources already have funded projects in the Sudan; others have not. Detailed investigation of each candidate in this preliminary list would have to be carried out before a definitive list could be presented.

6. EEC
European Economic Community
Secretariat General
170 Rue de la Loi
B-1040
Bruxelles
Belgium

7. FAO
Food and Agricultural Organization of the UN
Via delle Terme di Caracalla
00100 Roma
Italia

8 IFAD
International Fund for
Agricultural Development
107 Via del Serafico
00142 Roma
Italia

9. IFC
International Finance Corporation
1818 H Street, N.W.
Washington, D.C. 20433
USA

10. IMF
International Monetary Fund
700 19th Street, N.W.
Washington, D.C. 20431
USA

11. Islamic Development Bank
Al-Niaba Palace
Jeddah
Saudi Arabia

12. KFAED
Kuwait Fund for Arab Economic Development
P.O. Box 2921
Kuwait

13. NORAD
Norwegian Agency for Development
Box 8142
Oslo-DEP
Oslo
Norway

14. ODA (formerly ODM)
Overseas Development Administration
Eland House, Stag Place
London SW1E-5DH
England

15. RMEA
World Bank Regional Mission in East Africa
P.O. Box 30577
Nairobi
Kenya

16. Saudi Fund for Development
P.O. Box 5711
Riyadh
Saudi Arabia

17. UNDP
United Nations Development Program
1 United Nations Plaza
New York, N.Y. 10017
USA

18. UNIDO
United Nations Industrial Development Organization
Lerchenfelderstrasse 1
A-1070 Vienna
Austria

19. UNCDF
United Nations Capital Development Fund
633 3rd Ave.
New York, N.Y. 10017
U.S.A.

20. USAID
United States Agency for International Development
320 21st Street, N.W.
Washington, D.C. 20520
USA

Appendix B

List of individuals contacted

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1. D. Michael Bess, Field Manager
   Sudan Energy and Planning Project

2. Paul Cough, Deputy Project Manager
   Sudan Energy and Planning Project

3. Eng. Abdel Bagi
   Public Electricity and Water Corporation

4. Eng. Hashim Mutassim, Acting Director
   Public Electricity and Water Corporation

5. Eng. Abbas Hassim, Hydropower Development
   Public Electricity and Water Coporation

6. Eng. Ibrahim Ali, Chief Hydro Engineer (Power III & IV)
   Public Electricity and Water Corporation

7. Keith Sherper, Deputy Director
   USAID/Sudan

8. Eng. El Syr El Khartim Mohamad Saleh, Acting General Manager
   Public Electricity and Water Corporation

9. Eng. Mohamad El Amin Mukhtar, Acting Undersecretary
   Ministry of Mines and Energy

10. Eng. Kamal Ali, Director General
    Nile Water Affairs and Dams, Ministry of Agriculture and Irrigation

11. Eng. El Tayeb Tag El Din, Director General, Irrigation Affairs
    Ministry of Agriculture and Irrigation (Wad Medani)

12. Eng. Mohamad El Hadi Abdel Malik, Director General, Projects
    Ministry of Agriculture and Irrigation (Wad Medani)

13. Gaafar Mahgoub, Deputy Director, Agricultural Production Schemes
    Ministry of Agriculture and Irrigation (Wad Medani)

14. Eng. Abdel Moneim Adeel, Chief Engineer - Gezira
    Ministry of Agriculture and Irrigation (Wad Medani)

15. Eng. Mohamad El Hassan Taha, Assistant Divisional Engineer
    Ministry of Agriculture and Irrigation (Basadtha Sub-division, Gezira)

16. Eng. Mohamad Abdallah, Resident Engineer
    Public Electricity and Water Corporation (Sennar)

17. Eng. Bushra Omar Nabaj, Assistant Generation Engineer
Public Electricity and Water Corporation (Sennar)

18. Kamal Mohammad Abdo, Director of Irrigation Services
Ministry of Agriculture and Irrigation (Sennar)

19. Eng. Hamad El Tom
Public Electricity and Water Corporation

20. Eng. Gaffar El Faki Ali, Acting Director General
National Energy Administration

21. James R. Shaw, Consulting Engineer
Merz and McLellan

22. Nigel Widgery, Consulting Hydrologist
Sir Alexander Gibb and Partners

23. Arthur Mudge, Director
USAID/Sudan

24. G. William Kontos, Ambassador
U.S. Embassy, Khartoum

25. H. E. Shareff El-Touhami, Minister
Ministry of Mines and Energy

26. Dr. Ing. Roberto Gila, Project Manager
Southern Sudan Hydropower Evaluation Team
Bonifica, S.p.A.

Members of assessment team

Dr. Ralph H. Brooks is presently Director of the Water Resources Division of TVA. This Division, a part of the TVA's Office of Natural Resources, is responsible for all aspects of operating the reservoir system for flood control, navigation, and power while ensuring good water quality and a healthy fishery. The Division is also responsible for conduct of water project planning for the agency including small hydro evaluations. Dr. Brooks received his B.S. in Biology and Chemistry from the Citadel in Charleston, South Carolina, and his M.S. and Ph.D. in Environmental Engineering from the University of Florida in Gainesville, Florida. After graduation he worked as a project engineer for Engineering Science, Inc. in Oakland, California, primarily in water supply and wastewater outfall problems. He then briefly worked for Westinghouse Electric Corporation before joining Pacific Gas & Electric Corporation in San Francisco, California, where he was responsible for ensuring compliance of that company's construction and operations with water quality regulations. Since joining TVA in 1975, he has served as Chief of TVA's Water Quality Branch and in other senior water resources management positions. He is an active member of: (1) American Water Resources Association, (2) Water Pollution Control Federation, (3) American Water Works Association, (4) Sigma XI Research Society (Florida), and (5) National Management Association.

Mr. Samuel E. Bunker is currently Administrator of the International Programs Division, National Rural Electric Cooperative Association (NRECA). He is responsible for administering a world-wide program of technical assistance in planning, developing and managing rural electric systems in developing countries. Multi-year rural electrification projects are currently being carried out in Jamaica, Egypt, Indonesia, Bangladesh and N. Yemen. Mr. Bunker received his B.A. in Political Science (International Relations) from Yale University and his M.A. in Public Administration from Harvard University. Before coming to NRECA Mr. Bunker had 17 years' experience in management and policy level positions in development assistance programs in the Ford Foundation. Specifically, he served as Deputy Head, Middle East and Africa Office in New York, Acting Regional Representative for Middle Eastern affairs in Cairo, Associate Representative for the Middle East regional office in Beirut, Program Officer in New York for South Asia with particular concern for India, Nepal and Sri Lanka and Assistant Representative in the India-Nepal field office in New Delhi. Mr. Bunker currently serves on the Boards of CARE, Cooperative Housing Foundation, International Development Conference, Cooperative Travel Services and is Chairman, Cooperative Resources Committee. Mr. Bunker served as Team Leader of the consulting team for this decentralized hydro assessment requested by USAID.

Dr. Ronald Domer is presently Assistant Manager of Engineering Design, Office of Engineering Design and Construction at TVA. In his position he is responsible for design of fossil, hydro, and special projects such as highways, railroads, bridges, ports, buildings, and other facilities. He joined TVA in 1959 and has been involved in the design and construction of TVA's hydro, fossil, and nuclear plants; site studies for thermal generating stations; and engineering activities. Prior to assuming his current duties, he was Chief of TVA's Civil Engineering Branch for seven years. He received his B.S. in Mechanical Engineering, his M.S. and Ph.D. in Engineering Mechanics from the University of Tennessess in Knoxville. He is a registered professional engineer in the State of Tennessee and is current Chairman of the Structural Division of the American Society of Civil Engineers. He is also a member of the United States Committee on Large Dams, Construction Specifications Institute, Concrete Reinforcing Steel Institute, and National Management Association.

Dr. David R. Zoellner is presently Assistant Administrator of the International Programs Division, National Rural Electric Cooperative Association (NRECA). He is responsible for managing the NRECA small decentralized hydropower program providing technical assistance to developing countries via a Cooperative Agreement with the U.S. Agency for International Development. Program assistance, to date, has been provided to 16 countries in resource assessment services; regional workshops have been held in Latin America, Asia and Africa for over 300 attendees; seminars with specialized publications have been developed and a training program plan is underway. Dr. Zoellner received his B.S. and M.S. in Biology from the University of Alabama and his Ph.D. in Civil Engineering (Environmental Engineering) from Texas A&M University. Before coming to NRECA, he held responsible positions in the field of natural resources with the Corps of Engineers Institute for Water Resources, Stanford Research Institute, the National Academy of Science, and Travelers Research Corporation. Dr. Zoellner is a member of science and international professional societies and has authored several publications.

Appendix D

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