RUFIJI BASIN
MULTIPURPOSE DEVELOPMENT
THE UNITED REPUBLIC OF TANZANIA

MAMLAKA YA UENDELEZAJI WA BONDE LA MTO RUFIJI

RUFIJI BASIN DEVELOPMENT AUTHORITY

STIEGLER'S GORGE POWER AND FLOOD CONTROL DEVELOPMENT

NORAD

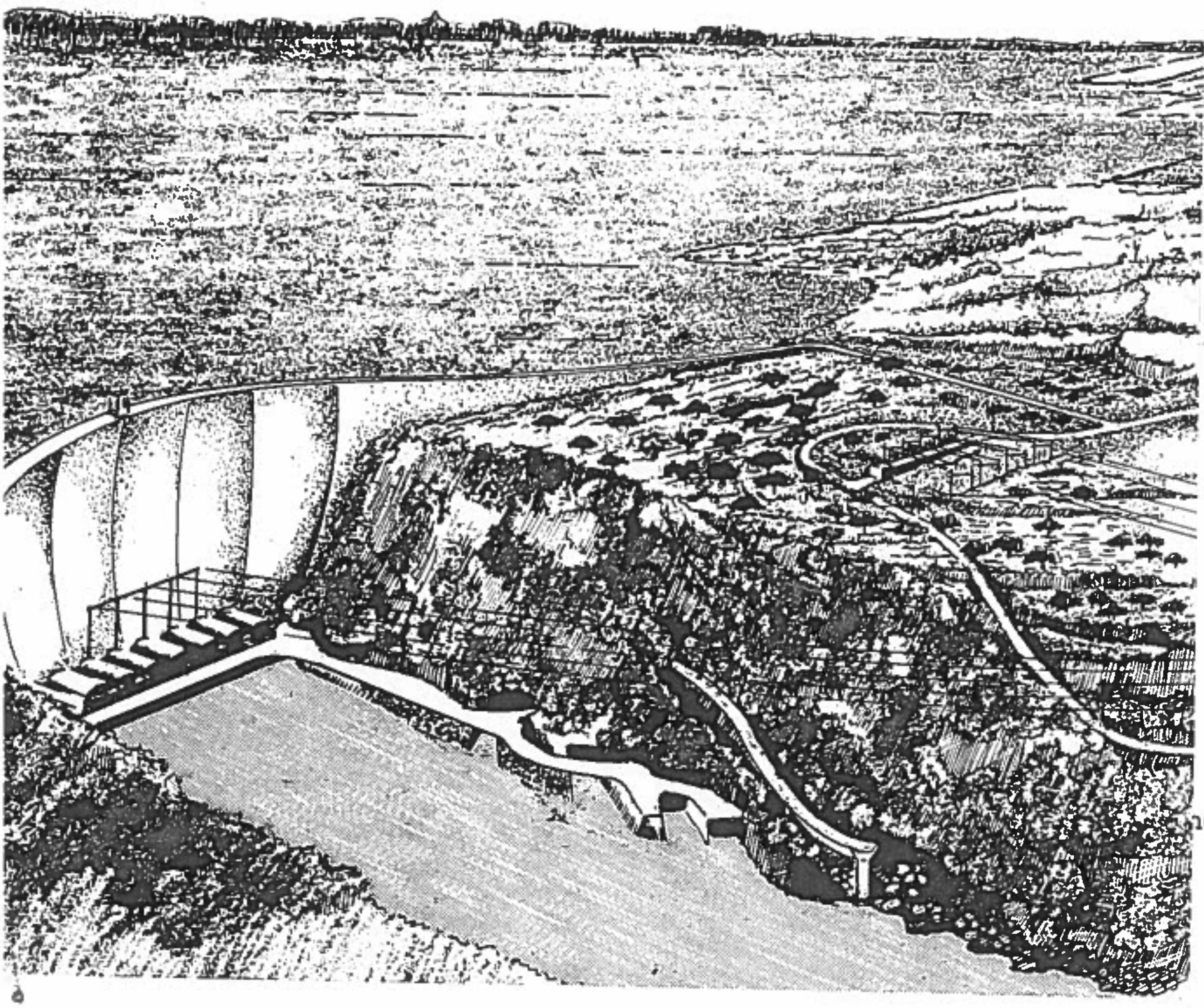
PRELIMINARY PROJECT REPORT
VOLUME 1

APRIL 1979

STIEGLER'S GORGE POWER AND FLOOD CONTROL DEVELOPMENT

MAMLAKA YA UENDELEZAJI WA BONDE LA MTO RUFIJI

RUFIJI BASIN DEVELOPMENT AUTHORITY



in design and thereby in costs, are envisaged. These changes should, however, not alter the main conclusions of this report.

The project planning and project economics are closely linked to the power forecast used. This forecast is to our knowledge not yet officially accepted, although our use of it was accepted by RUBADA. It would greatly strengthen the report if this forecast was officially approved for power supply planning in Tanzania. If another forecast than the one used here is officially accepted, we will, of course, make the necessary changes in the report. The official forecast document together with a major power sector study is needed to firm-up the power sector presentation (Chapter 2) and should accompany the present report for financial appraisal.

Another document that should follow the loan applications is a feasibility study of the agriculture potential of the Rufiji flood plain. This study should, if possible. be integrated with the present report in order to present a more complete picture of a multipurpose development. The studies initiated by RUBADA should result in such a document within an acceptable time period.

The critical activities for the implementation of the project by 1987, are mentioned in the report as:

- financing arrangements
- year round road access to Stiegler's Gorge
- establishment of a functioning project management organization

We are certain that you are aware of these activities and that the utmost will be done to meet the possible commissioning year of 1987. We do realize, however, that this is a tight schedule and are prepared to assist you in analyzing the consequences of postponement. Such consequences are again closely linked to possible power forecast alterations already mentioned.

The detailed design will now commence and next year we will submit to you:

- Final Design Report with updated cost estimates
- Tender Documents for the Stiegler's Gorge Power and Flood Control Development Phase I
- Documents for information purposes on local conditions, construction materials,geology, hydrology and meteor-ology

A close cooperation with RUBADA and other parastatal and government organizations will be necessary, especially for the contractual aspects of the tender documents.

We will be pleased to answer any questions arising from your study of this draft report so that the final document may be to your complete satisfaction.

Yours faithfully,
AKTIESELSKABET HAFSLUND

Kjell Rosenberg
Technical Director

Nils-Isak Fossen

STIEGLER'S GORGE POWER AND FLOOD CONTROL DEVELOPMENT

PRELIMINARY PROJECT REPORT
APRIL 1979

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Volume 2	Annex	I - IV
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Volume 4		Drawings

NORAD

A/S HAFSLUND NORPLAN A/S
Prosject Adm. by A/S HAFSLUND
Box 5010 Mj.
OSLO 3, Norway

NORAD
Norwegian Agency for
International Development
Box 8124 Oslo-Dep.
OSLO 1, Norway

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Currency equivalents used:

US$ 1.00 = Tanzanian shillings (Tshs) 7.70 (1978 average)
US$ 1.00 = Tanzanian shillings (Tshs) 8.25 (1979)

Weights and measures:

1 metre (m)	= 39.37 inches
1 hectare (ha) = $10^4 m^2$	= 2.47 acres
1 cubic metre (m^3)	= 35.31 cubic feet (ft^3)
1 million cubic metres (Mm^3) = $10^6 M^3$	= 810.7 acre feet
1 kilogram (kg)	= 2.206 pounds
1 metric ton (t) = 1000 kg	= 1.10 short tons
1 kilowatt (kW)	= 1000 watts (W)
1 megawatt (MW)	= 1000 kW
1 gigawatt hours (GWh)	= 10^6 kWh
1 kilovolt (kV)	= 1000 V
1 megavolt ampere (MVA)	= 1000 kilovolt ampere (kVA)
1 grad (1^g)	= 1/400th part of a circle
1 degree (1^o)	= 1/360 part of a circle

Abbreviations:

RUBADA	- Rufiji Basin Development Authority
NORAD	- Norwegian Agency for International Development
VHL	- Vassdrags- og Havnelaboratoriet (The Norwegian River and Harbour Laboratory)
TANESCO	- Tanzania National Electric Supply Company
FAO	- United Nations Food and Agriculture Organization
UNEP	- UN - Environmental Programme
WHO	- UN - World Health Organization
El	- Elevation above mean sea level in metres
HFWL	- Highest flood water level
HRWL	- Highest regulated water level
LRWL	- Lowest regulated water level
M US$	- Million US dollars
M Tshs	- Million Tanzanian Shillings
PV (NPV)	- Present Value (Net Present Value)

P R E F A C E

Tanzania is currently planning a very large hydro-electric power and flood control project based on a 130 m high arch dam at Stiegler's Gorge in the Rufiji River. The project is large, generating 12 times the current electricity demand, and is a milestone in the country's development. Tanzania's willingness to undertake such an extensive project and the financial burdens involved signifies the country's need for the project, and its confidence in the future.

Tanzania has established a river basin authority to implement and manage the project. This authority is called the Rufiji Basin Development Authority (RUBADA). RUBADA is also concerned with other aspects of development within the river basin which covers one-fifth of Tanzania's land area, has one-tenth of the country's population, and receives one-third of the country's total rainfall.

The basin has three major flood plains: Usangu, Kilombero, and lower Rufiji, all suitable for large scale irrigation and totalling two-thirds of such land in Tanzania. The project will provide flood control for the lower Rufiji flood plain, thus making agricultural development possible through large scale irrigation. Today frequent damaging floods on this flood plain are suppressing development.

The power available from the project will be utilized to pursue Tanzania's industrialization policy. Forecasts show that demand will exceed supply by 1987. The Stiegler's Gorge project will meet the electricity demand for the following two to three decades, and can be developed in three main phases.

A dam at Stiegler's Gorge has been envisaged for some fifty years. A feasibility study was completed by Norconsult in 1972. The current report to RUBADA by Hafslund-Norplan is a project report on completion of the preliminary design, including cost estimates and an economic analysis. The planning of the power project is now substantially complete.

At the same time RUBADA has initiated other studies to define the costs and benefits of agriculture, fisheries, tourism and communication. Studies are also in progress on the ecological, environmental and social aspects of the project. These are being carried out by UNEP, FAO, WHO, and the University of Dar es Salaam. The results will be incorporated in a final review of the project due in 1980. Studies that are completed include a river hydraulic study by the Norwegian River and Harbor Laboratory (VHL), flood plain mapping, and road access tender documents both by Norplan A/S.

The aim of the current report is to provide RUBADA with the necessary documents for approaching financing institutions with loan requests. Meanwhile Hafslund-Norplan is continuing with final design, and tender documents are expected ready by late 1980. A large part of the current planning costs are being met by grants from the Norwegian Agency for International Development (NORAD).

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SUMMARY AND CONCLUSIONS

1. INTRODUCTION

In 1975 the Rufiji Basin Development Authority was established with responsibility for all development associated with the River Rufiji including hydro-electric power, flood control, industry, agriculture, forestry, fishing, river and road transport, and tourism. The Stiegler's Gorge project forms the central feature in the multipurpose development plan adopted by the Authority. The project is primarily a hydro-electric power project comprising a very large storage reservoir (ultimate total storage 35000 Mm^3) with power stations at the gorge with potential for energy generation of about 6000 GWh/year. The reservoir is also able to provide another and important function, namely flood control which is directly related to agricultural conditions downstream on the Rufiji river plain. Thus the Stiegler's Gorge project is a power and flood control development. In its broader context, the development also requires a 200 km permanent access road and a power transmission system connecting the plant to the Grid. Development of agriculture downstream would constitute a separate but closely inter-related project.

2. JUSTIFICATION FOR PROJECT

The present 132/220 kV Coastal Grid connects the major centers of Dar es Salaam, Morogoro, Tanga and Moshi. Extensions are currently being implemented to Arusha in the north and Zanzibar in the east, and scheduled for completion by 1980. Plans are under preparation for further expansion to form an extended grid by 1985, with a north west extension linking Dodoma, Shinyanga, Mwanza and Musoma, and a south west extension linking Iringa, Mufindi and Mbeya.

Over the past decade, capacity demand has been increasing at an average rate of 7.5% and energy demand at 9.5% per annum. However, the annual rate of growth of energy demand has been falling during the same period. Based on identified, approved and funded development plans, an increased growth rate is envisaged throughout the third five year plan up to 1985. Based on detailed forecasts for increased demands in the Coastal Grid, Zanzibar, and the north west and south west extensions, capacity and energy requirements are expected to increase from totals of 123 MW and 736 GWh in 1978, to 263 MW and 1965 GWh in 1985. This is equivalent to an average annual growth rate of 11.5%. After 1985, detailed development plans have not yet been identified, and demand forecasts have to be based on projected statistical trends of the main factors involved such as population and gross national product. A moderate average annual rate of 6.5% has been adopted for planning purposes.

To meet demands up to 1978, the major new source of supply will be the Kidatu Phase II scheme 110 MW capacity providing 500 GWh of firm annual energy. Additional hydro firm-up capacity could be obtained by rehabilitation of existing thermal plants, sufficient for the balance required. This should satisfy demand into the late 1980's. Thereafter, further major development is needed: either thermal (coal or oil), hydro-electric, or a combination. Taking into account coal mining development and transportation factors, oil importation factors, and hydro-electric development factors, it has been concluded that hydro-electric is the most attractive development in terms of both economics and long term reliability. Of the potential hydro-electric projects, the Stiegler's Gorge project is particularly favorable, providing a single compact scheme capable of development in stages, with good hydrological and engineering features, massive potential for medium and long term demands, and a high rate of economic return on investment. Cost estimates and economic evaluation are discussed below in Section 5.

For the reasons outlined above, the Stiegler's Gorge project has been selected by the Government of Tanzania for priority development. Planning and design have been taken to an advanced stage, and sufficient details have now been confirmed for financing commitments for the first phase of development to be secured.

3. PROJECT WORKS AND PHASES OF CONSTRUCTION

The project works comprise the main dam and low level outlets in Stiegler's Gorge, an underground power station in the northern abutment (Station A) and a second station in the toe of the dam (Station B), a flood spillway at a natural saddle 8 km south of the gorge, and a series of low dams at saddles along the eastern boundary of the reservoir. The reservoir area will occupy the entire upstream valley of the Rufiji river proper, extending south-westwards to the Shuguri Falls at the confluence of the Kilombero and Luwegu rivers.

The works have been designed and programmed for construction in three main phases (Phase I, II and III), with plant units installed in subsidiary phases as and when required. The general arrangement of dams and topography suits two stages of impoundment. In the first stage, the construction works would be sufficient for a reservoir with maximum level determined by the saddle spillway sill (high flood water level El. 177.8). In the second stage, the saddledams would be heightened and the reservoir level raised to a high flood water level El. 188. The power stations are also suited to two stage construction. Station A would be constructed at the same time as the main dam (but, being underground, would be independent of river diversion problems), and Station B later, after completion of all the first stage works. Thus, the following phases were adopted:

PHASE I	Main dam and low level outlets. Spillway sill Power Station A Administrative buildings and infrastructure.
PHASE II	Power Station B
PHASE III	Spillway Saddledams

The highest flood water level for the reservoir at the final phase was optimized to obtain maximum power production at a competitive price combined with effective flood control in relation to agriculture and irrigation downstream on the Rufiji plain. [illegible] years of hydrological records are available, with river flows ranging from minimum 70 m^3/sec (in the dry season, June to November) to maximum 10,150 m^3/sec (in the flood season December to May). Annual flows range from 16,000 to 60,000 Mm^3 with an average of 28,000 Mm^3 (equivalent to 900 m^3/sec). Based on the records, a 300 year series of flows has been generated stochastically. Reservoir operating rules have been devised for various flood conditions. The reservoir would be operated to maintain spillage to less than 2,500 m^3/sec to the greatest extent possible to minimize flood damage downstream. A reservoir operation simulation study was carried out using the 300 year flow series, to obtain power generation and downstream releases for a series of highest flood water levels. An economic present value assessment was made taking into account project works costs, flood damage costs, and power benefits. As a result of this analysis, a reservoir highest flood water level of El. 188 was determined for the final phase. For the initial phase a similar study was made and El. 171 chosen as spillway sill crest.

The spillway facilities were designed after a flood routing analysis for an outflow of 12000 m^3/s.

A summary of project works data is given in Table 1.

Main Dam:
Arch type with gravity type shoulders.
Foundation rock: layered sandstone and mudstone.
Lowest foundation level El. 57.
Crest level El. 190.0, top of wave wall El. 191.3. Overall height 134 m.
Arch span 350 m. Total shoulder length 500 m.
Arch thickness : base 22 m, crest 10 m.
Total volume of concrete 750,000 m^3.
Intake for Power Station B - see below.

Low Level Outlets:
Two tunnels, one in each abutment.
Each with steel lined control section comprising a set of 3 conduits and regulating gates 2mx6.5m, hydraulically operated by remote control, with bulkhead gates for dewatering.
Gate sill level El. 111.5,
Capacity 2x1000 m^3/sec for lowest reservoir level El. 158.
Flip bucket type flume.
Overall tunnel and outlet length, 2x440 m.

Saddledam 1 and Spillway:
Spillway design capacity 12,000 m^3/sec.
(Phase I and II).
Two-level ungated concrete sill, lower part with sill level El. 171 with 140 m length, upper part with sill level El. 174 with 400 m length
(Phase III).
Rockfill saddledam: height 25 m, length 2.2 km,
Gated spillway: one lower level gate 13.0 m x 13.0 m with sill level El. 171, seven upper level gates 13.1 m x 13.2 m with sill level El. 174.
Structure crest level El. 193.

Saddledams 2, 3 and 4:
(Phase III)
Earthfill dams: heights up to 10 m, crest level approximately El. 193.
Total length 16.7 km.

Power Station A:
Underground in north abutment: machine hall length 110 m, width 15.5 m.
4 No. Units each with:
Intake: mouth sill level El. 144.0, height 12 m, width 8.5 m, concrete lined penstock 6 m dia. Francis turbine with butterfly valve, central axis El. 63.0. 100 MW generator (see Table 2). Steel draft tube, sump level El. 51.5. Draft tube gates, 2 No., sill level El. 54.0. Gate and transformer gallery, floor level El. 82. Transformer 115 MVA, 15-16 kV/220 kV
2 No. tailrace tunnels, lengths 125 m and 165 m. Single tailrace canal.

Power Station B:

On toe of main dam.
Main hall, length 106 m, width 19.5 m.
4 No. Units each with: Intake in dam, mouth sill level El. 88.3, three openings 3.5 m x 9.5 m high.
Steel penstock, 8.0 m dia. converging to 6.5 m dia. Francis turbine with butterfly valve, central axis El. 63.0. 200 MW generator (see Table 2). Draft tube gates.
Bulkhead stop logs at outlet.
Transformer 225 MVA, 15-16 kV/220 kV.

River Canalization:

River channel downstream of tailrace excavated to reduce tailwater level by an average of 4 m.

Pothead and Switchyard:

220 kV oil-filled cables connecting transformers to potheads on north bank.
Overhead lines from potheads to switchyard on north bank.

Buildings and Infrastructure:

Administrative buildings 150 m from switchyard. Operation staff housing, 150 No. plus temporary housing.
Internal road system.
Services.
Airfield

Transmission Lines:

220 kV lines to suitable points in the grid.

TABLE 1 - PROJECT WORKS DATA

The arch type design for the main dam was selected after detailed consideration of alternatives. The first suggested alternatives were a concrete faced rock-fill dam and a mass concrete gravity dam. However, the arch dam proved to be the most feasible and economic with particular advantages concerning availability of materials, power station design and the river diversion and construction program.

The gorge has a narrow width for the first 100 m of height and then widens out. Consideration is being given to construction of the arch dam in two stages. However, at present a single stage construction of the arch dam to its full height has been presented.

The low level outlets are required for flood irrigation releases. Until controlled lift irrigation on the river plain has been developed, flood releases of 2,000 m^3/sec are to be provided, adjusted to take account of turbine discharges, flood discharges, and rainfall. After development of controlled lift irrigation, the turbine flows will be sufficient for irrigation requirements, but a system of flood flow releases is expected to be required for river channel maintenance and for conditions in the delta including fish ecology.

In addition to the permanent works, river diversion arrangements during construction would include two upstream and two downstream cofferdams and two temporary tunnels around the north abutment.

Plant unit sizes and timing of installation for Power Station A and Power Station B were selected to suit the power forecast adopted, taking into account grid stability, voltage and frequency control and reserve spinning and stand-by capacity. The adopted capacities are shown in Table 2.

	Phase I and II		Phase III	
	Unit Capability	Total Capability	Unit Capability	Total Capability
Station A - 4 units	75	300	100	400
Station B - 4 units	150	600	200	800
TOTAL - 8 units	-	900	-	1200

TABLE 2 - POWER PLANT CAPACITY (MW)

Phase	Contract	Start:	Finish:
I	Road access and bridge	1980	1983
	Preliminary contract works	1981	1983
	Main contract works (+ units A1, A2)	1982	1987
	Transmission lines	1984	1986
	Generating unit A3	1988	1989
	Generating unit A4	1990	1991
II	Power Station B (+ unit B1)	1990	1993
	Generating Unit B2	1995	1996
	Generating Unit B3	1998	1999
	Generating Unit B4	2000	2001
III	Works for heightening reservoir		
	Downstream canalization	2001	2004

TABLE 3 - DEVELOPMENT PROGRAM

4. DEVELOPMENT PROGRAM AND IMPLEMENTATION

Based on the power demand forecast for construction and installation have been programmed as shown in Table 3.

Initial implementation is concerned with the program up to 1987 when the first stage of reservoir works, Power Station A, and the first two generating units are scheduled to be commissioned. The project planning is however flexible to postponements. To complete Phase I of the development, additional provision for the third and fourth generating unit in Station A is required.

At the present stage of project preparation, design and tender documents for the Access Road contract have been completed. Commencement of the tendering procedure is scheduled for July 1979 and a contract agreement concluded February 1980. Arrangements for financing require to be made before the contract agreement is concluded.

Preparation for the main project is in hand, with completion of design and tender documents in 1980. Financing arrangements require to be initiated immediately to complete loan agreements and a financing plan before the end of 1980. Tendering procedures for the preliminary and main project work contracts would commence at the start of 1981, and conclusion of contract agreements in June 1981 and December 1981 respectively. The transmission line contracts would be arranged in due course.

The key factors in this very tight program are the financing arrangements, year round road access and the establishment of a functioning project management organization within the Rufiji Basin Development Authority.

5. COST ESTIMATES AND ECONOMIC EVALUATION OF PROJECT

Cost estimates have been prepared using bills of quantities with measured project works and estimated unit rates and prices appropriate for international competitive bidding. The costs are exclusive of all taxes and duties, and assume that adequate provisions would be

	Phase I	Phase II	Phase III	Total
Road access and bridge	42	-	-	42
Project Works:				
Main dam	169	-	-	169
[illegible]	[illegible]	-	-	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]
[illegible]	[illegible]		-	[illegible]
[illegible]	-	[illegible]	-	[illegible]
[illegible]	-	-	[illegible]	[illegible]
[illegible]	-	-	[illegible]	[illegible]
[illegible]	[illegible]	-	-	[illegible]
Mech. and elec. works	69	106	3	178
	359	121	114	594
Transmission lines	47	29	14	90
TOTAL	448	150	128	726

TABLE 4 - SUMMARY OF ESTIMATED CAPITAL COSTS (1978 US $ MILL.)

included in the contracts for adequate initial advance payments to contractors in currencies acceptable to the creditors. Allowances have been included for physical contingencies and for the costs of engineering and administration. A summary of capital costs expressed in US dollars at 1978 prices and exclusive of price escalation contingencies, is given in Table 4.

To obtain financing costs for budgeting purposes, separation into local and foreign currency elements and allowances for price escalation have to be made. The proportions of local and foreign currencies have been estimated from the contractor's point of view with regards to origin of materials and labor. Assumptions concerning price escalation have been made using current rates for the local and foreign currencies of 15% and 6% per annum, both decreasing to a standard 5% per annum by 1989. Thus financial costs have been estimated for Phase I to a total of Tshs 2577 M plus US$ 429 M, phased over the development period 1981 to 1989. Of this total Tshs 1352 M and US$ 134 M is price escalation from 1978.

An overall economic evaluation has been made (excluding price escalation) for the power element of the development, (excluding an estimate of project costs associated with downstream benefits), by determining the marginal costs savings compared with the next most economic equivalent power project. For this purpose the total costs including running costs of the alternative thermal power project have been assessed. Thus the difference between the thermal project and the Stiegler's Gorge project (in present value terms) is used as substitute measurement of net benefits.

The results of the evaluation indicate a rate of return on Stiegler's Gorge of 14%. Results are given in Table 5. Sensitivity tests were made, assuming increased project costs, decreased power demand growth, and increased thermal costs. In view of the lack of data concerning development of coal production or the alternative of oil fired plant, it seems probable that higher thermal costs are likely. Thus an rate of return in excess of 14% may be expected.

A seperate timing analysis done in Tanzania indicates that an early commissioning of Phase I is economically favorable.

	Discount rate		
	7%	9%	12%
Benefits	1075	713	413
Costs	450	385	319
Net benefits	625	328	94

TABLE 5 - RESULTS OF ECONOMIC ANALYSIS (1978 US$ Million)

It is concluded that the Stiegler's Gorge project would provide Tanzania with a reliable source of power sufficient to meet all demands in the foreseeable future, and that despite the high capital investment involved, the project is economically justified.

CHAPTER 1

PROJECT AREA

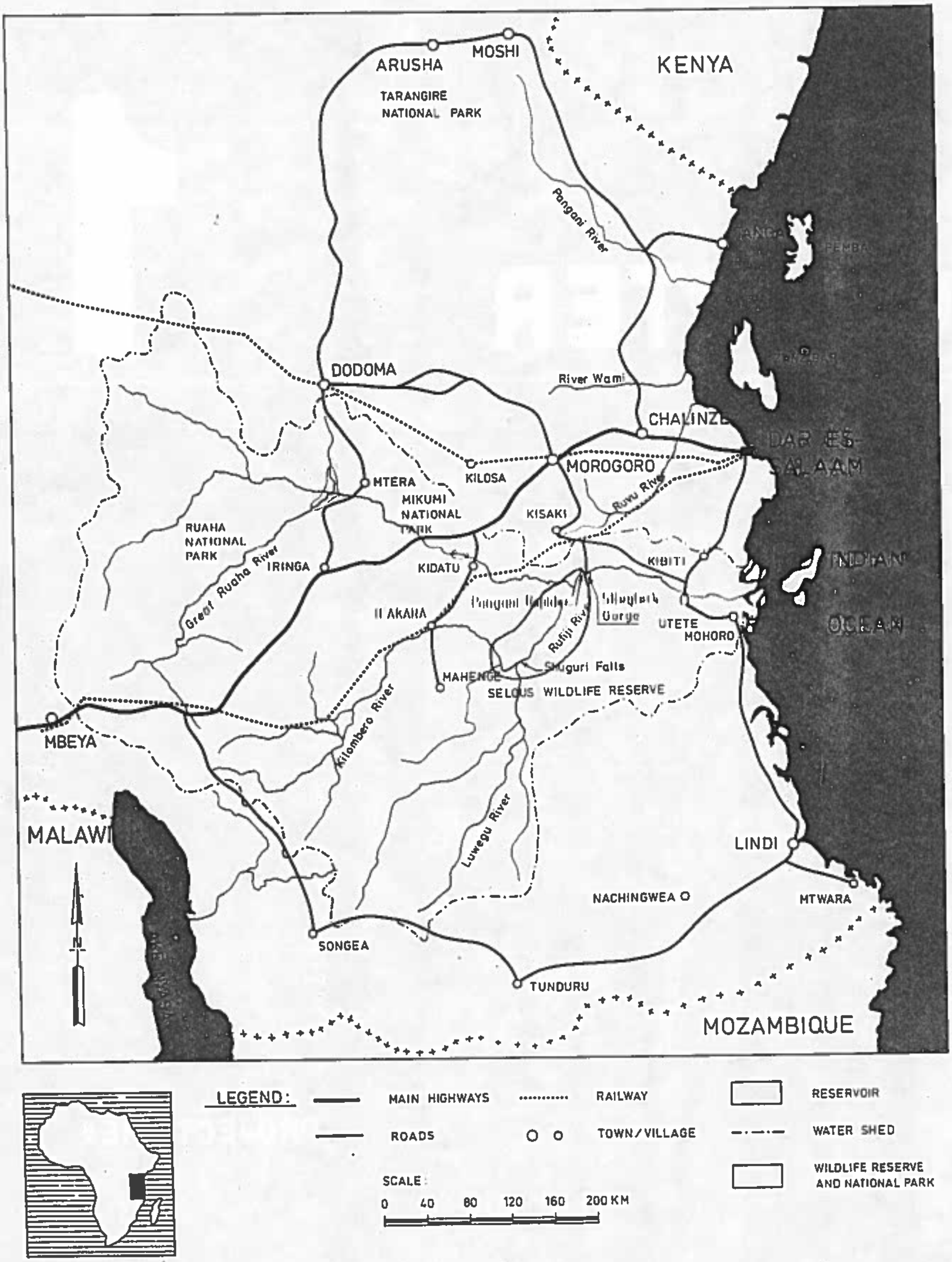


FIG. 1.1 Project Location Plan

THE PROJECT AREA

1.1 General Description

The Rufiji river basin is the largest in Tanzania, covering an area of 177 000 km^2. It extends from Mbeya in the west to the Indian Ocean in the east, a distance of about 700 km (See Figure 1.1). Land elevation ranges from 3000 m down to sea level, with corresponding climatic conditions from temperate to tropical. Vegetation is generally of the savannah type with scattered trees and bushes which become denser in the vicinity of the rivers.

The Rufiji river has three main tributaries:
The Great Ruaha catchment extends over the northern and western half of the basin, with a total area of 84 000 km^2 comprising a series of subsidiary hill catchments and plains. Because of its relatively low rainfall, the Great Ruaha contributes only 15% of total inflow to the Rufiji river. In 1975 a dam and hydro-electric power station at Kidatu on the Great Ruaha was commissioned, with a reservoir live storage capacity of 125 Mm^3. A dam at Mtera is presently under construction with a reservoir capacity of 3200 Mm^3.

The Kilombero river occupies the central and south-western part of the basin, with a catchment area of 40 000 km^2. It is the main source of supply to the Rufiji, providing 62% of the total inflow. A small amount of water is abstracted for irrigation in the Kilombero valley, but there is considerable potential for further irrigation development including storage reservoirs, which could both reduce and regulate the inflows to the Rufiji.

The Luwegu river has a catchment area of 26000 km^2, and contributes a further 18% of total inflow to the Rufiji.
The Rufiji river, with a direct catchment area of 27 000 km^2, has a local inflow equivalent to only 5% of the total. The Rufuji starts at the junction of the Kilombero and Luwegu rivers at the Shuguri Falls. It then flows in a generally north-easterly direction for about 100 km to the Pangani Rapids at the entrance of Stiegler's Gorge. Here the river has cut through a low ridge, forming a steep-sided narrow gorge 8 km long. The river emerges from the hill catchment just after the gorge at an elevation of about 65 m above sea level. It has formed a deep alluvial flood plain contained within a relatively narrow valley of residual soils, extending over 200 km to the delta at the coast.

The Stiegler's Gorge project is concerned directly with conditions in the gorge in relation to the construction of a dam and hydro-electric power station, and with the reservoir area in the Rufiji valley upstream. The project area consists of the reservoir area and the areas affected by the construction works. The area lies entirely within the Selous wildlife reserve, the largest in Tanzania, covering 45 000 km^2 and containing a large and varied stock of unique wildlife. There are no permanent villages within the project area.

1.2 Climate

Representative climatic data for the project area are given in Table 1.1. Normal temperatures are relatively constant, but extremes vary from maximum of about 39°C to minimum of 15°C. The average annual rainfall is 1000 mm. The main rainfall occurs between November and May, generally in two periods: November to January and March to May. The rainfall is variable, but March and April are generally the wettest months. Annual isohyets for the whole basin are shown in Figure 1.2. Mean measurements of Class A evaporation can give rates varying from 6.3 to 3.2 mm/day, and a mean annual total of 2 000 mm.

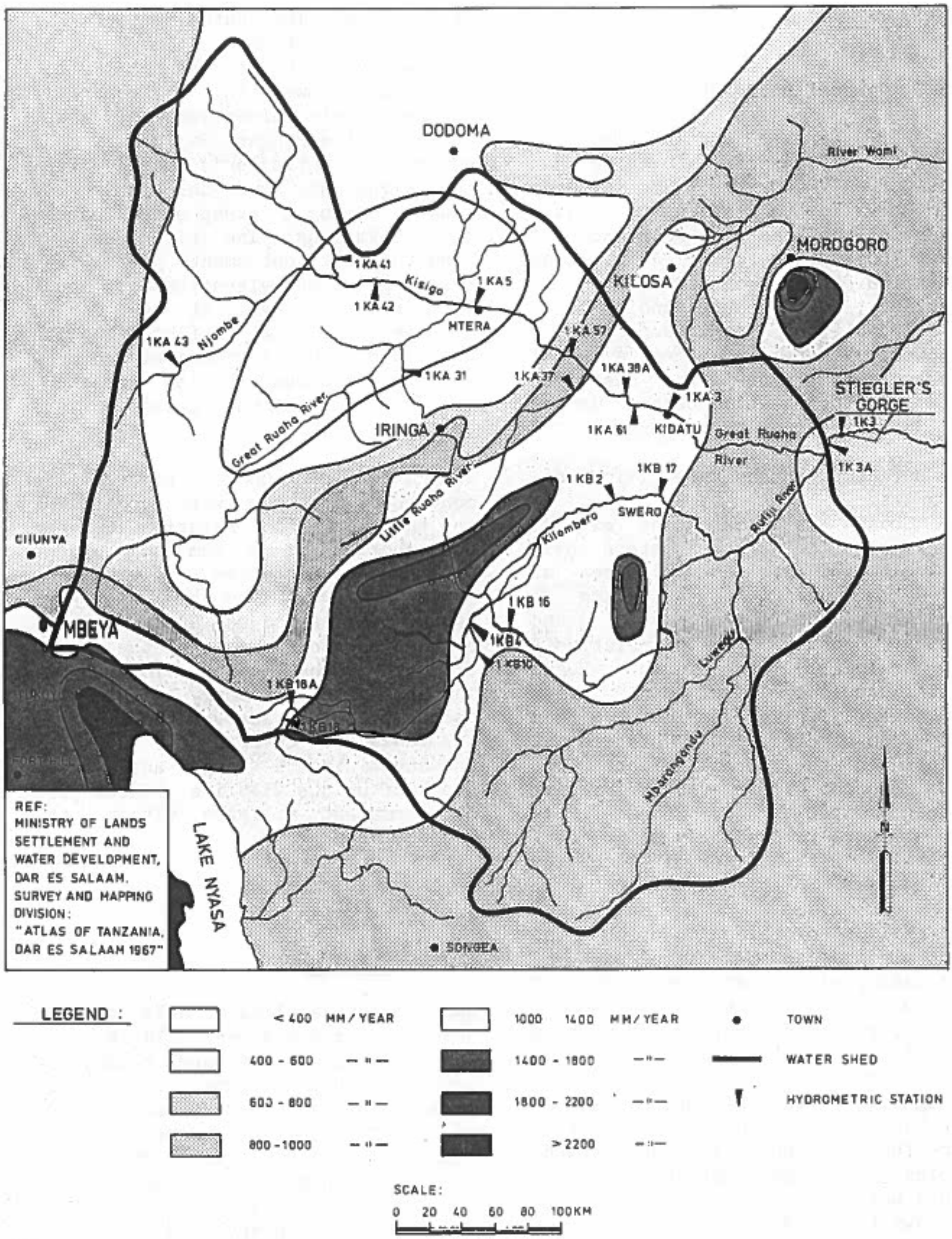


FIG. 1.2 Isohyets and River Flow in the Rufiji Basin

Month	Mean rainfall (mm)	Mean evaporation (mm)	Mean Max.Temp. (°C)	Mean Min.temp. (°C)	Mean Relative humidity (%) 0900 hrs.
January	137	204	31	23	81
February	101	153	31	25	84
March	167	173	31	23	85
April	221	129	29	23	88
May	86	122	29	22	84
June	26	125	28	19	74
July	12	131	28	19	75
August	8	154	30	20	74
September	16	171	30	20	72
October	35	213	32	22	75
November	78	222	32	23	72
December	115	203	33	24	76
Annual Total Average	1002	2000	30	22	78

TABLE 1.1
Project Area Climate
Metereological Station IKIRI at Stiegler's Gorge

1.3 Hydrology

River flow data based on measurements at stations in the basin as shown in Figure 1.2 are available over the past 22 years. The Stiegler's Gorge station (1K3A) was established in 1956 at site 1K3, within the gorge. In 1963 a second station was established at a more suitable site at the Pangani Rapids at the entrance to the gorge. Since 1975, flows have been marginally affected by the Kidatu hydro-electric scheme on the Great Ruaha. From 1980 the Mtera development will also affect the flows. (See Section 1.1.)

The hydrograph for the river at Stiegler's Gorge for the period 1957 to 1978 is shown in Figure 1.3. The recorded flows range from a minimum of 70 m^3/s to a maximum of 10000m^3/s. Annual flows range from 16000 to 60,000 Mm3 with an average of 28,000 Mm3 (equivalent to 900 m^3/s).

The suspended sediment load at Stiegler's Gorge varies from about 200 ppm at low flows to 20000 ppm at high flood periods. Most of the sediment is derived from the Luwegu and the direct Rufiji catchments. The effects of the Kidatu and future Mtera reservoirs on the Great Ruaha on the sediment at Stiegler's Gorge are not significant. The average annual suspended load at the gorge is estimated at 18 M tons. The sediment contains a very high proportion of sands, over 75% having been recorded. No measurements of bed load have been made. From visual observations and grain size analysis, the estimated bed load is equivalent to about 30% of the suspended load.

1.4 Geology

The general geology of the project area is shown in Figure 1.4. The main geological formation within the project area is the Karroo System of sedimentary rocks, mainly sandstones and mudstones, of Permian and Triassic age. The boundary between the Karroo and the gneissic Basement runs approximately parallel to the Rufiji river 15 km to the north-west.

East of the Rufiji river the bedrock is partly covered by loose deposits of Tertiary age, consisting of slightly cemented gravelly sands. Elsewhere the bedrock is covered by residual soils to varying depths. In the valleys of the Rufiji and the main tributaries there are minor deposits of fine uniform sands.

Stiegler's Gorge is a deep cut gorge with a depth of about 100 m within generally undulating ground above elevation 170 m. The side slopes are inclined at about 50g, consisting partly of near vertical rock outcrops and partly of talus. The bedrock consists of near horizontal sandstone strata interbedded with mudstones and siltstones. The flat-lying bedding joints are often schistose or even brecciated. The bedrock is generally covered by a shallow (0-3 m) overburden of residual soils. In the gorge the bedrock is covered by talus with a thickness of several metres.

Near vertical faulting and jointing

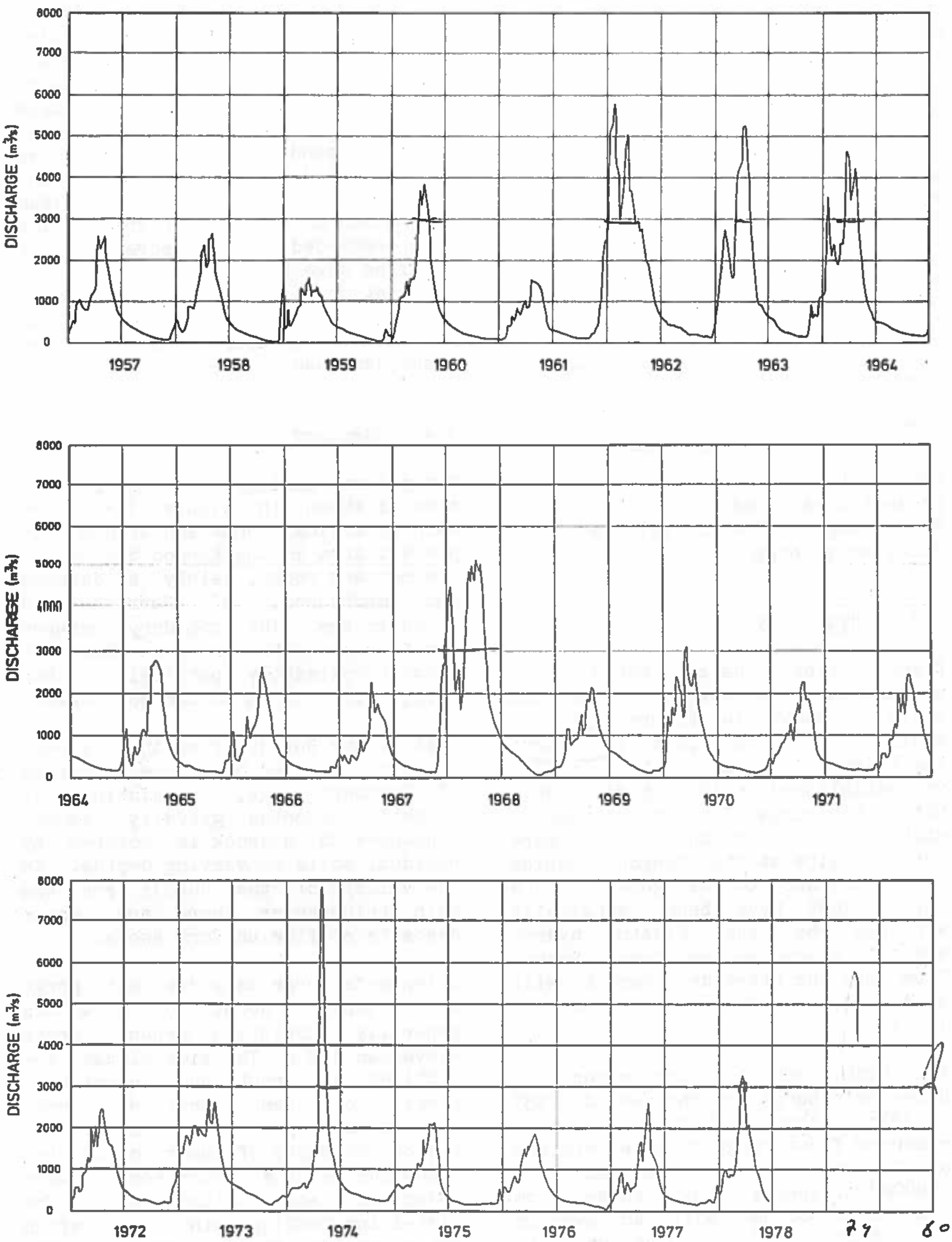


FIG. 1.3 7-Day Discharge Hydrograph at Stiegler's Gorge

are abundant in the gorge area, with a dominant NW-SE orientation (strike 140-160^g). Brecciation and slickensides are commonly associated with these structures. The degree of jointing and the width of joint zones related to the faults vary. Indications of at least four stages of faulting have been observed, but according to geological literature probably no movements have taken place since Cretaceous times. A secondary near vertical conjugate joint set with an orientation of 30^g-50^g is also well developed throughout the area.

1.5 Seismology

The seismicity of Africa south of 10^{o}N is dominated by the East African Rift system, which is one of the few areas of land characterised by major extensional tectonics. The system branches into two sections south of 5^{o}N. The Western Rift follows lakes Tanganyika and Nyasa, while the Eastern (or Gregory) Rift extends in a south eastward direction from Lake Victoria towards the Rufiji basin. It is the Gregory Rift which is most pertinent concerning seismic risk in the project area.

From the available seismicity data for Eastern Africa, locations of a total of 4 061 reported earthquakes are as shown in Figure 1.5. About 90% of the earthquakes have occured since 1940.

The available historic seismic data show that earthquakes of magnitude 7 have occurred along the Gregory Rift zone, while the largest known earthquakes in the upper Rufiji basin have had magnitudes in the range of 5-6.

An engineering geological survey has been carried out in the project area, and filal observations (supported by geological literature) suggest that the Tagalala Fault, which is situated approx. 15 km north-east of the damsite, is probably an active fault,. i.e. a fault along which earth movements are taking place. None of the other faults in the project area are thought to be active, and there has probably been no movements along these faults since Cretaceous times.

1.6 Access

The nearest major town to the project area is Morogoro on the Tanzanian highway from Dar es Salaam. From Morogoro a secondary road, about 100 km in length, leads to Kisaki, some 60 km north west of Stiegler's Gorge. The alignment of the Morogoro - Kisaki road is winding and steep in parts, with narrow bridges of limited load capacity.

Morogoro is also on the Tanzania Railway Corporation line. The Tanzanian Zambia Railway Authority line passes within 35 km of Stiegler's Gorge on route to Lusaka.

From Kisaki to Stiegler's Gorge there is a road track.

There is also a track passing down the north side of the Rufiji River to Mkongo near Utete, which connects with the main road to Dar es Salaam. (See Fig. 1.1.)

There is an airstrip at Kibeza on the south side of Stiegler's Gorge and a vehicle cable way across the gorge. By the Stiegler's Gorge camp there is a heliport.

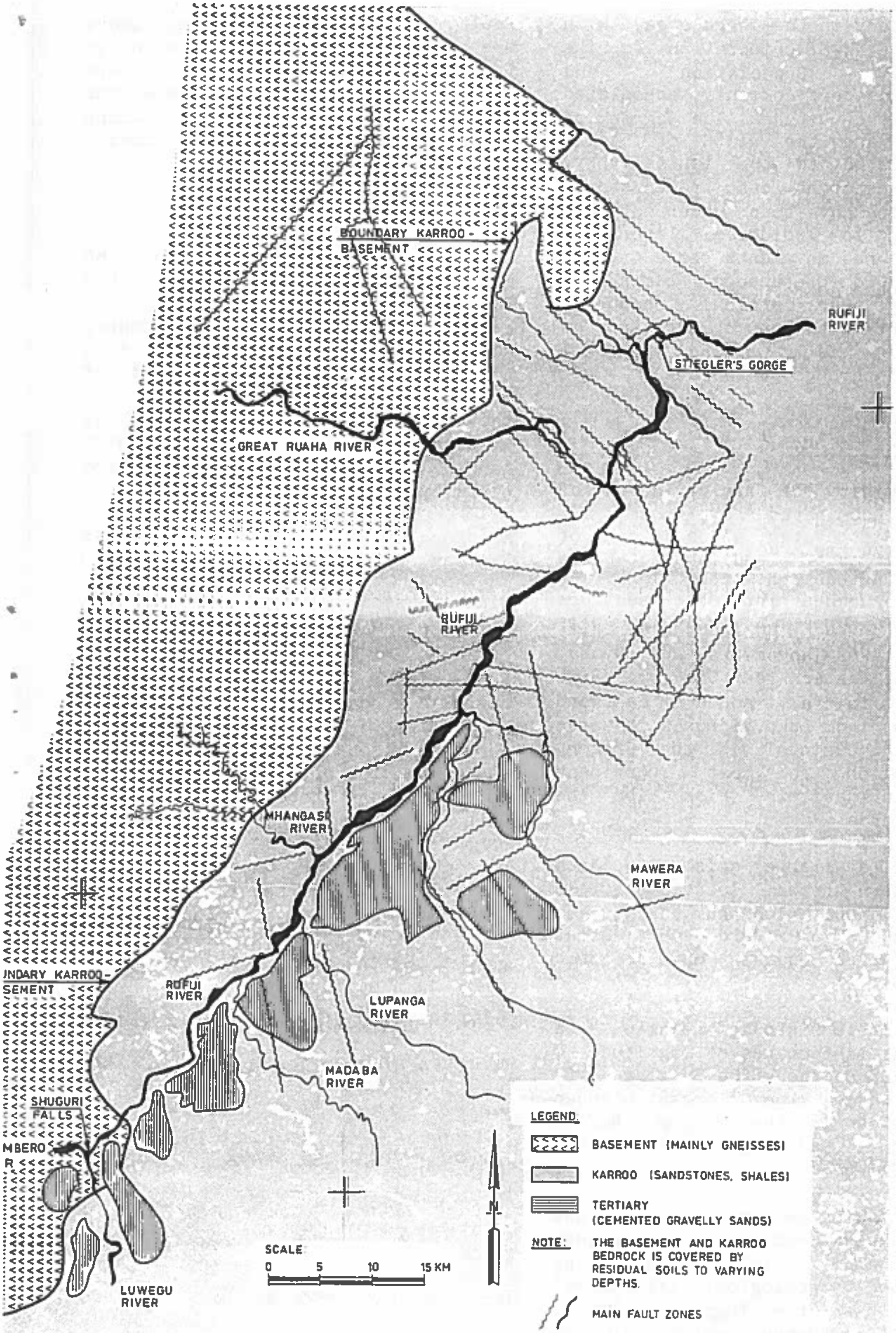


FIG. 1.4 Geology of the Rufiji Basin

FIG. 1.5 Record of Seismological Events in Tanzania

CHAPTER 2

POWER AND ENERGY SECTOR

POWER AND ENERGY SECTOR

2.1 Coastal Grid

The coastal grid connects the major towns of Dar es Salaam and Morogoro with Tanga, Moshi and Arusha (see Fig. 2.1). The grid supplies about 85% of the present national demand. The supply comes from hydroelectric power stations at Kidatu on the Great Ruaha river, Pangani Falls, Hale and Nyumba ya Mungu on the Pangani river, and from a thermal power station at Ubungu, Dar es Salaam.

The generating capacity of the coastal grid system is shown in Table 2.1. The hydroelectric capacity is located on the Pangani and the Great Ruaha rivers. The Pangani river has four plants, the oldest dating back to 1936. The present installed capacity at Kidatu is 110 MW commissioned in 1975. The station is presently being increased by 110 MW to be commissioned in 1980 (55 MW) and 1981 (55 MW). As a part of this development a storage dam is being built at Mtera to increase the firm power output of the station.

The transmission system comprises a

FIG. 2.1 The Coastal Grid and Power Demand Centers in Tanzania
(1978 Figures)

132 kV grid linking Dar es Salaam, Morogoro, Hale, Tanga, Moshi. A 220 kV line (312 km) was commissioned in 1975, linking Kidatu with the coastal system at Ubungu. A 66 kV line connects Nyumba ya Mungu station to Moshi and Arusha. 33 kV lines supply towns in the coastal grid area such as Ifakara, Mtibwa and Bagamoyo.

Present plans provide for extending the 132 kV line from Moshi to Arusha, a submarine cable connecting the island of Zanzibar to the coastal grid, and 90 MVA of transformer capacity at Morogoro to interconnect the 132 kV and the 220 kV system. The 220 kV system is planned to be extended from Kidatu to supply a paper mill at Mufindi.

There are also 17 isolated branches supplying areas as shown on Figure 2.1. These are separated from each other and the coastal grid by 200 km or more. Most of them are powered by diesel sets with station capacities ranging from 390 kW (Mpwapwa) to 18,000 kW (Mwanza). Figure 2.1 shows the maximum demands for the various systems in 1976. Table 2.2 shows the generating capacities.

Some of the isolated systems are becoming important load centers and plans for interconnecting Mwanza and Musoma are at an advanced stage.

Station	Generating Capacity (kW)	
	Installed x)	Capability
Nyumba Ya Mungu	8,000 H	8,000
Hale	21,000 H	21,000
Pangani Falls	17,500 H	14,000
Ubungu	13,230 T	2,000
	18,411 T	2,000
	15,000 T	10,000
	15,000 GT	(13,000) xx)
Kidatu	110,000 H	110,000
Total Installed	218,141 kW	
Total Capability		167,000 kW

x) Generation types are indicated: T = thermal (diesel) H = hydro GT = gas turbine

xx) Very high operating costs discourages use.

Source: Ref. no. 14

TABLE 2.1 - Generating Capacity - Coastal Grid System (1978)

System	Generating Capacity (Kw)	
	Installed x)	Capability
Iringa	1,220 H	1,220
Zanzibar	9,000 T	
Lindi/Mtwara	3,995 T	3,995
Nachingwea	600 T	600
Mpwapwa	390 T	390
Mafia	780 T	780
Songea	660 T	660
Mbeya	2,900 T	2,900
Tukuya	1,200 T	1,200
Dodoma	2,630 T	2,630
Singida	480 T	480
Kigoma	905 T	905
Shinyanga	1,300 T	1,300
Mwanza	9,000 T	27,000
	18,000 T	
Musoma	840 T	840
Bukoba	1,340 T	1,340
Tabora	1,910 T	1,910

x) Generation types are indicated: T = thermal (diesel) H = hydro

Source: Ref. no. 14

TABLE 2.2 - Generating Capacity - Isolated Systems at January 31, 1977

2.2 Power Demand Forecast

A number of studies have been carried out in recent years in an attempt to determine the most reliable forecasts of power demand for the short, medium and long terms, to provide a sound basis for power planning and implementation of power projects. Short term plans are now reasonably well defined with provisions included in the present 5-year initial plan and projects identified up to 1985 for thermal and hydroelectric developments and for extension of the coastal grid to a national grid comprising: -

- present coastal grid
- northwest extension (Dodoma, Singida, Mwanza, Musoma)
- southwest extension (Iringa, Mufindi, Mbeya)
- Zanzibar extension

The only recent forecast available to the Consultant was included in a report to the Ministry of Water, Power and Minerals and the Ministry of Industries of Tanzania, awaiting official approval. It was based on the short term plans mentioned above. The strength of this forecast is that it is based on approved and partially funded projects. A drawback is that the forecast has not been checked against common methods such as Scheer's model and GNP model.

The methodology used in this short term forecast is quoted from the report "Economic Choices for Electrical Energy Supply in Tanzania" (Ref. no. 14) paragraph 14, 15 and 16.

"The Demand for Electrical Capacity and Energy Methodology:

14. There are numerous approaches to estimating future demand for electricity. The approaches most suitable for Tanzania must respond at least to the following factors:

    (1) the relatively small size of the system,
    (2) the importance of forth-coming development projects relative to the existing base,
    (3) the high variability of year to year growth rates experienced in the past, and
    (4) the possibility of lags relative to planned project implementation schedules and capacity utilization.

15. Under the circumstances it is best to estimate demand over the short and medium term by evaluating the specific load development expected from known and committed power consuming development projects, of which industrial projects would be the major element.

16. This is not an operational approach to account for the load development of very light industry (VLI), commercial (C) and domestic (D) classes of consumers, because their growth & requirements are not planned and known to the same extent as the larger industrial, habitational and infrastructural development projects. Furthermore, in some instances the composition of future load development for a whole area may be only generally understood. This is particularly the case for Zanzibar. For these situations, one approach may be to determine a base corresponding to the non-specific load, and estimate future growth by projecting an average annual percentage from the past into the future. In some cases where the base is particularly insignificant, but where important specific development projects are expected to occur, it is appropriate to estimate some induced demand of commercial and domestic classes from specific industrial developments."

A detailed application of these methods to the cases of Zanzibar, the present grid and the isolated branches then follows.

The resulting forecasts up to 1985 are shown in Figure 2.2 and summarized in Table 2.3. The report (Ref. no. 14) assumes extension of the grid by 1985, resulting in a total demand on this extended grid of 263.4 MW and 1564.9 GWh in 1985, a load factor of 0.678. Diversification between the isolated branches being connected to the grid has not been incorporated in the forecast and could yield a lower demand for the extended grid.

For the medium and long term forecasts, demands are much less predictable. Although in the early years of the short term forecast, growth rates are of the order of 10% per annum, there is a slowing down in the second half, and this may be expected to extend into the medium term. However, in common with general expectations for developing

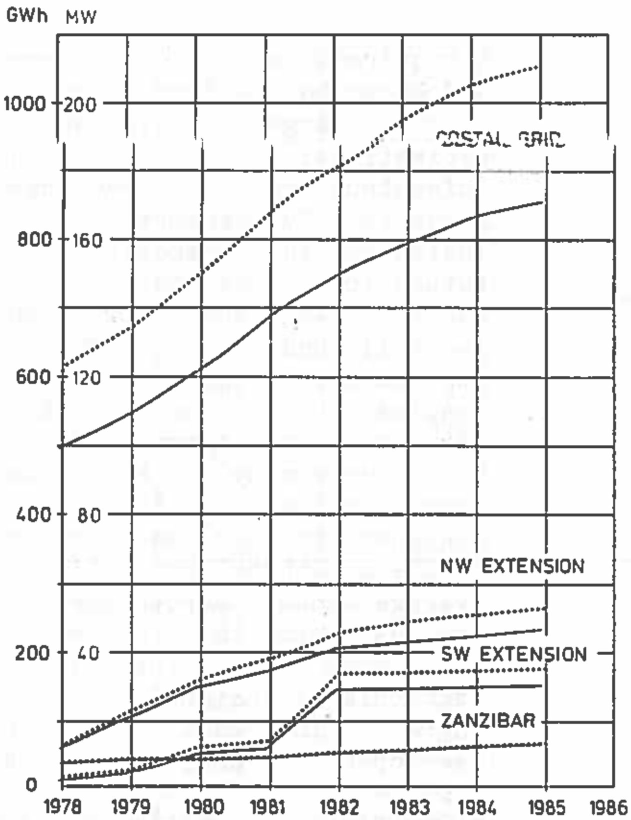


FIG. 2.2 Short Term Energy and Capacity Forecast

countries, steady growth is anticipated of somewhere between 5% and 8% per annum (see Reference no. 8).

For project planning purposes a rate of 6.5% per annum from 1986 onwards has been adopted, corresponding to the basic long term forecast of the report quoted earlier (Ref. no. 14). The corresponding capacity and energy demands for the extended grid are given in Table 2.4.

It has been assumed that the system load factor will be constant at 0.678. This assumption is a perpetuation of the 1985 load factor. The historical data show very little seasonal variation in the load and no evidence of annually repeated patterns. The hourly load variations are less pronounced in towns with a domestic load (Dodoma).

2.3 Existing and Committed Grid System Generating Capability

The generating capability of the existing grid (the coastal grid) is summarized in Table 2.5. The table also includes additional capacity and energy that will be available when the committed extensions to the Kidatu hydro-electric scheme including the Mtera storage dam are completed. According to the construction schedule, one unit will be com-

	Coastal Grid		NW Extension		SW Extension		Zanzibar	
	MW	GWh x)	MW	GWh	MW	GWh	MW	GWh xx)
1978	100.0	613.2	12.5	65.7	2.6	14.6	7.8	39.0
1979	109.6	672.1	21.9	113.9	5.1	28.3	9.0	45.0
1980	122.7	752.2	30.2	159.8	11.2	63.2	9.0	45.0
1981	137.1	840.8	35.2	189.0	12.4	70.0	10.1	50.0
1982	150.1	920.6	42.0	229.3	29.9	168.2	11.0	55.0
1983	159.2	976.5	43.7	243.9	30.2	171.3	12.0	60.0
1984	167.3	1025.8	45.4	256.0	30.6	174.4	13.0	65.0
1985	171.8	1053.3	46.6	264.8	31.0	176.7	14.0	70.0

TABLE 2.3 - Short-Term Power Demand Forecast

x) load factor 0.70
xx) load factor 0.60

Year	Capacity (MW)	Energy (GWh)
1985	263.40	1564.86
1986	280.52	1666.58
1987	298.75	1774.90
1988	318.17	1890.27
1989	338.86	2013.14
1990	360.88	2143.99
1991	384.34	2283.35
1992	409.32	2531.77
1993	435.93	2589.84
1994	464.26	2758.18
1995	494.44	2937.46
1996	526.58	3128.39
1997	560.80	3331.74
1998	597.26	3548.30
1999	636.08	3778,94
2000	677.42	4024.57
2001	721.46	4286.17
2002	768.35	4564.77
2003	818.29	4861.48
2004	871.48	5177.48
2005	928.13	5514.01
2006	988.46	5872.42
2007	1052.71	6254.13
2008	1121.13	6660.65
2009	1194.01	7093.59
2010	1271.62	7554.67
2011	1354.27	8045.73
2012	1442.30	8568.70
2013	1536.05	9125.66
2014	1635.89	9718.83
2015	1742.22	10350.56

Comment: The annual growth rate is 6.5%. The Isolated Branches (Mbeya, Dodoma, Tabora, Shinyanga, Mwanza, Musoma) total forecast is 29.5% (capacity) and 28.2% (energy) of the figures shown above.

TABLE 2.4 - Medium and Long Term Forecast on Extended Grid

missioned in 1980, the second in 1981, together with the Mtera dam.

In keeping with normal practice, the largest hydro-electric unit of the system will be kept in reserve (i.e. one of the Kidatu units). For existing thermal capability, the annual energy capabilities are based on 75% availability due to problems facing many of the thermal units. After the present rehabilitation of the thermal stations, an additional 125 GWh are expected to be produced.

In Ref. no. 14 a detailed analysis of the present and future supply is given. Special care has been given to the "firm-up" potential of the Kidatu hydro system. This calculation shows that an additional 397 GWh can be drawn from the Kidatu hydro system when a minimum of 60 MW thermal is available as back-up. The analysis is based on a probability of energy shortage statistically once every 30 years. Ref. no. 14 also includes an analysis of the supply in the isolated branches, showing both retired units and necessary new units beyond 1985. A summary of the generating capability in 1985 on the extended grid shows a net capacity of 290 MW capable of producing 1937 GWh (Table 2.5). This supply is sufficient to meet the demand forecasted for 1985 of 263.4 MW and 1564.9 GWh. Due to retirement of some diesel units and the increase in the demand, a deficiency in capacity appears in 1986, building up to 21 MW in 1987. A deficiency in energy appears in 1989. However, it must be stressed that these figures, taken from Ref. no. 14, have not been subject to transmission system power flow analysis and that the treatment of transmission losses in the reference is unclear. A general conclusion of the supply and demand analysis (Ref. no. 14) is that a deficiency in supply will occur on the extended grid during the latter half of the 1980's.

When the next major power development is commissioned, such as Stiegler's Gorge in 1987, the diesel units are assumed to be retired due to political reluctancy to oil imports, even though some can technically be operated up to 1995. If the next major power development is hydro and the diesel units are retired, the remaining supply level on the extended grid is the hydro total of Table 2.5, i.e. installed capacity 263 MW, reserve 55 MW, net capacity 208 MW. A hydro development will not be capable of "firming up" the Kidatu system as is the case for a thermal develop-

1995 (1000 GWH)

ment. For hydro development planning purposes the conservative supply level of 1000 GWh should therefore be used.

	Installed capacity	Reserve capacity	Net capacity	Firm annual energy
Plant	MW	MW	MW	GWh
HYDRO				
Nyumba Ya Mungu	8	-	8	
Hale	21	-	21	500
Pangani Falls	14	-	14	
Sub-total	43	-	43	
Kidatu Phase I	110	55	55	
Sub-total (present system)	153	55	98	
Kidatu Phase II with Mtera Storage	110	-	110	
System Hydro Total	263[x]	55	208	
THERMAL				
Ubungo Diesel	46		14	92
Ubungo " rehabilitated	-		19	125
Gas Turbine	15		-	-
System Thermal Total	61		[illegible]	217
Generating capability 1985 on extended grid (Ref. no. 18)				
Total hydro	263	55	208	1000
Hydro "firmed up" by min. 60 MW thermal				[illegible]
Old thermal coastal grid	(61)	-	14	92
Rehabilitation coastal grid	-	-	19	125
Isolated branches	65	16	49	323
	(389)	71	290	1937

x) Recent information showed that although individual Kidatu units are rated at 55 MW, the total station output is only 200 MW, thereby reducing this figure to 243 MW.

TABLE 2.5 - Existing and Committed Grid System Generation Capability

2.4 Potential Projects for Future Requirements

To meet requirements after 1985, major development of either thermal, hydro-electric or a combination of the two, is required. The use of indigenous resources is clearly desirable, and in the absence of any proven oil resource, the choice is between coal fired thermal and hydro-electric power.

Present production of coal at the Ilima colliery near Mbeya is 3000 t/year. For each 50 MW coal-fired thermal plant about 147000 t/year would be required. Thus any significant development would be dependent on a major expansion of coal mining. The feasibility of such expansion is not yet known but preliminary assessments of the economics of coal-fired thermal power are available, based on the assumption that coal supplies could be developed to a limited extent (see Chapter 9). A major factor associated with coal-fired power would be transportation or transmission. The average distance from the mine to the major load centers would be about 800 km. In addition to limitations in existing rail capacity, some 70 km of new rail track would have to be constructed if the power stations were to be placed at the major centers. The combination of high cost and the limitations in coal development indicate that thermal production is not a feasible long-term solution.

Hydro-electric development is a very attractive proposition, but inevitably involves major capital investment in the early stage of any project. Nevertheless, it appears to be the most economically viable solution and would provide a firm basis for future natural growth resulting in a wide range of associated benefits.

Potential hydro-electric projects capable of serving the national grid are summarized in Table 2.6. Studies are available for the projects on the Kagera, Wami, Rufiji and Great Ruaha rivers. For the Kilombero and Rumakali river projects, feasibility studies have not been made. Only for the Stiegler's Gorge project have designs been prepared, and the earliest date for initial production would be 1987. For all other projects earliest production would be later than 1987, except a power station at the Mtera dam. The Stiegler's Gorge project is the only project capable of meeting the whole of the power demand forecast well into the next century. It can be developed in stages to match demand growth.

Project	Units	Install. capacity	Net Head	Annual energy 98% probability)	Plant factor
	(no.x MW)	(MW)	(m)	(GWh)	(percent)
KAGERA RIVER					
Rusumo Falls	2 x 50	100	47±6	500	57
Kishanda Valley	3 x 60	180	92	955	61
WAMI RIVER					
Pongwe I	2 x 30	60	109.8	265	50
Pongwe II	2 x 30	60	115.9	275	52
RUFIJI RIVER					
Stiegler's Gorge					
Phase I	4x 75	300	93±	2243	100
GREAT RUAHA RIVER					
Mtera	2 x 30	60	91+8	210	40
KILOMBERO RIVER					
Kingenenas	2 x 45	90	23±3	360	46
RUMAKALI RIVER	2 x 80	160	1200	900	65

Source: TANESCO.

PF852.

TABLE 2.6 - Potential Hydro-Electric Power Projects

CHAPTER 3

AGRICULTURAL AND ENVIRONMENTAL SECTOR

THE AGRICULTURAL AND ENVIRONMENTAL SECTOR

3.1 Introduction

The agricultural and environmental sector in relation to the Stiegler's Gorge project is directly associated with the Rufiji basin upstream of the Selous wildlife reserve (i.e., the Great Ruaha upstream of Kidatu, the Kilombero west of latitude 37°E, and the upper part of the Luwegu) and with the Rufiji river plain downstream of Stiegler's Gorge. In the upstream area, agriculture is not a very significant factor, although any changes in river flows as a result of storage or irrigation abstractions require careful consideration in relation to their effect on inflows to the Rufiji river and any future reservoir. RUBADA is responsible for managing the water resources of the Rufiji Basin.
Environmental aspects upstream as a result of reservoir development, demand the most careful attention. Downstream of the gorge some 75,000 people are at present dependent on flood irrigated agriculture, whilst potential exists for an increase in agriculture and expansion of the dependent population. These aspects are further discussed in Sections 3.2 to 3.4, and special features are examined in Annex IV.

3.2 Selous Wildlife Reserve

The Selous is the largest wildlife reserve in Africa and the second largest in the world. It covers 45,000 km^2, some 6% of Tanzania's land surface. With no human right of settlement or entry, the Selous is a complete natural wilderness or refuge. It includes some 750,000 animals, including Africa's largest elephant, buffalo, hippopotamus and crocodile populations. Habitats vary from lowland and riverine forests, through thickets and woodlands, to wooded grasslands, short grasslands and tall grass flood plains and swamps.

Ecologically the area is extremely rich and as yet undisturbed by man. Its value lies not only in its immediately available resources but also in its future potential as a genetic store. Being virtually a complete ecological unit there is no necessity for the animals to move out to seek food.
The Selous reserve is dissected by the Rufiji river system into a number of natural units.

These units are:

1. The area north of the Ruaha-Rufiji rivers.
   In the eastern part of this area the Rufiji flows through a maze of channels and swamps connecting five major lakes. This area has a high tourist potential due to the high animal density and easy access from Dar es Salaam.
2. The Ulanga segment between Ruaha and Kilombero rivers.
3. The Mahenge segment south of the Kilombero and west of the Luwegu. This is the most inaccessible and unknown segment.
4. The eastern part, south of the Rufiji and east of the Luwegu.

In general the Selous reserve is low-lying, hot, tsetse fly infested and difficult to reach, and has low potential for agriculture and livestock use. Neighboring areas have low population densities and recent resettlements have moved people away from its boundaries.

3.3 Agriculture upstream of the Selous Reserve

The potential for agricultural development within the Rufiji basin upstream of the Selous Reserve is of importance to the Stiegler's Gorge project to the extent that it might affect the river flows. Thus it is the development of irrigated agriculture which is of particular interest.

At present irrigation is practiced to only a very limited extent, and abstractions of water have no significant effect on inflows to the Rufiji. In the Great Ruaha basin, the northern area drained by the Kisigo river and its tributaries is a low rainfall area with generally poor soils and little potential for development of irrigated agriculture. Between the Kisigo and Great Ruaha rivers, an extensive area is occupied by the Ruaha National Park and the Rungwa River Wildlife Reserve. Upstream of the Ruaha Park the Usangu plain is an extensive alluvial area. In 1960 a reconnaissance soil survey was carried out of some 2500 km^2, and preliminary planning studies made, as a result of which it was indicated that some 200,000 hectares would be suitable for irrigation development, but would involve major storage works. Subsequent development of a rice project consisting of about 3000 hectares at Mbarali has been established. A new study of the Usangu plains was completed in 1978 (Ref. no. 13). Immediate plans envisage further expansion to 6000 hectares. A sugar estate downstream of Kidatu covers about 4000 hectars of which half is irrigated. Thus the present effect on river supplies is not significant, and even if major expansion takes place, inflows to the Rufiji river will be little affected.

The other area of significant potential for irrigated agriculture upstream of the Selous Reserve is on the Kilombero river. Reconnaissance soil surveys covering over 4000 km^2 were carried out between 1952 and 1960 as a result of which some 300,000 hectares were identified as irrigable. The Kilombero valley has relatively high rainfall and flood protection and control would be a prerequisite for development of much of the area. In addition seasonal storage of irrigation water would also be needed for complete development. Relatively little has been developed so far, and it appears unlikely that development in the near future will have any significant effect on inflows to the Rufiji. In the long term, seasonal storage and abstractions could have some effect on Rufiji inflows in the dry season but are unlikely to be significant compared with the large storage capacity of a reservoir at Stiegler's Gorge.

3.4 The Downstream Area

The downstream area comprises the Rufiji plain, extending for 200 km with a general width of about 0 km, bordered by residual soil escarpments about 10 m in height. The elevation of the plain varies from 60 m at the head to sea-level at the delta. Topographical variations across the plain are generally less than 5 m. To the downstream area one can also include the Rufiji river delta and Mafia ocean channel.

The plain is subject to flooding when flows at Stiegler's Gorge exceed about 1500 m^3/s. It is estimated that with a discharge of about 2000 m^3/s, moderate flooding occurs over the greater part of the plain and provides a precarious system of irrigation. Greater flows tend to be more damaging than beneficial, although the particular nature and the timing of the flood result in varying effects. For flows in excess of 2500 m^3/s severe damage generally occurs.

As a direct result of natural flood irrigation, maize and rice are cultivated during the rainy season. During the dry season crops of maize and cotton are grown, utilizing residual moisture stored in the soil after flooding.

Present cultivation amounts to about 14,000 hectares per year, equivalent to about 12% of the potential cultivable land. Production is extremely variable due to variations in flooding. Both too much flooding at the wrong time and too little flooding combined with poor rainfall cause severe damage to crops.

It is estimated that there is about a 50% chance of obtaining a good harvest. Cultivation standards are very low and production on average is at about subsistence level.

Subject to the provision of adequate control of flooding and irrigation there is potential for a very large increase in agricultural production. The soils are of good quality and there is abundant high quality water available. Also the climate is favourable for a wide range of valuable crops, and there is a basic infrastructure for external communications with important facilities for supplies and markets.

There is a well established infrastructure of towns and villages with interconnecting roads (including two ferries across the Rufiji river). Except in the delta, the villages are located off the river plain on the adjacent higher ground safe from flooding. The total population is estimated to be 75 000. Average family holding sizes in the river plain are 1.25 ha. There is little or no livestock.

Fishing is an important source of food and cash income with an estimated annual production of about 2 000 tonnes of fresh water fish. In the delta, sea fishing is important but on a relatively small scale. Little information is available concerning the interaction of fresh water and saline water conditions in relation to fish ecology. Special studies are needed to obtain a thorough understanding of this, to enable the effects of any future changes in river flow as a result of the Stiegler's Gorge project to be assessed. With such knowledge it may be possible to introduce beneficial short floods down the river to develop a more suitable form of fish culture.

CHAPTER 4

PROJECT PLANNING

PROJECT PLANNING

4.1 Introduction

This chapter summarizes the planning work which has been carried out to arrive at the scheme described in this report. Such a large multipurpose development scheme requires considerable planning work in order to meet its requirements in the optimal way, and therefore most of the design effort to date has been concentrated on this aspect.

Section 4.2 describes the full Rufiji Development, which includes the downstream studies, transmission lines and road access, and then defines that part of the development referred to as Stiegler's Gorge Project which is this consultant's responsibility and is described in detail in this report. An outline of the project is given in Section 4.3.

Section 4.4 describes the determination of irrigation and flood control requirements to be set in planning the power project.

Section 4.5 explains that phased development of the project is desirable and describes the various possibilities which exist for phasing the project construction to suit the increasing power demand, including progressive installation of generating units. Finally, the order and timing of the phases chosen to meet the power demand forecast is described.

Section 4.6 describes the major decision in the planning process, namely choice of the highest reservoir level in the ultimate phase, which determines the height of the main dam and saddledams. This level (known as highest flood water level, HFWL) is determined by an economical optimization process between the benefits dependent on HFWL, namely power production and flood control, and costs dependent on HFWL, namely dams and power plant. The optimization requires that power output and flood control be simulated for a range of proposed reservoir retention levels. The computer simulation program including the assumed scheme for regulating the reservoir is described in Section 4.7.

Determination of other reservoir operating levels, including those for the earlier phases, occurs after HFWL in the final phase has been chosen, and are discussed in Section 4.8. Section 4.9 discusses the environmental effects of the project.

The determination of reservoir levels as summarized in Section 4.5 to 4.8 inclusive is described in detail in Annex V, and an explanation of terms used in connection with the project planning is found at the front of the same annex.

4.2 Definition of the Project

The possibility of hydro-electric development by controlling the Rufiji river by construction of a dam at Stiegler's Gorge was recognized many years ago. The natural conditions are extremely favorable in terms of a good dam site, large reservoir storage and suitable inflows. In the report on The Rufiji Basin (FAO 1961), the benefits of a dam were studied in relation to agricultural development on the river plain downstream. In addition attention was drawn to the hydro-electric potential at the dam and the advantages to be obtained by joint development for both agriculture and power.

The Stiegler's Gorge project forms the central feature of the Rufiji Basin Multipurpose Development Plan. In 1975 the Rufiji Basin Development Authority (RUBADA) was established as a para-statal organization responsible for development and operation. The project is primarily a hydro-electric power project comprising a very large potential storage reservoir (of the order of 35,000

Mm3) with power stations at the gorge with potential for energy generation of approximately 6000 GWh/year. The reservoir is also able to provide a secondary but important function of flood control directly related to agricultural conditions downstream on the Rufiji river plain. Thus the Stiegler's Gorge project is defined as a power and flood control project. Development of agriculture downstream constitutes a separate but closely inter-related project, as do fisheries, tourism and road communication in connection with the dam. These studies are being carried out separately under the coordination of Rubada, and are not discussed in detail in this report. A survey of the downstream area has been carried out and described in Annex IV, from which irrigation and controlled flood requirements on the project were set (see Section 4.4).

The Stiegler's Gorge Project refers specifically to the project works associated with the reservoir and power stations. These aspects are dealt with in detail in this report. In its broader context, the development also includes as road access to the site consisting of a 200 km part of the southern link highway to Lindi from the Tan-Zam highway, and a power transmission system connecting the switchyard to the extended Grid. The road access, together with a bridge across Stiegler's Gorge downstream of the dam, has been the subject of designs and tender documents, which are now available together with cost estimates (Ref. no. 16). The route of the road is shown in Fig. 4.5. For the transmission system, final planning has not yet been concluded as this is dependent on the grid design. In order to include the transmission costs in the economic evaluation of the power project (see Chapter 9), a preliminary plan and estimate has been prepared, including connections to Dar es Salaam and to Morogoro (see Annex VIII).

4.3 General Description

The general layout of the project is shown in Fig. 4.1 and the details of design are described in Chapter 5.

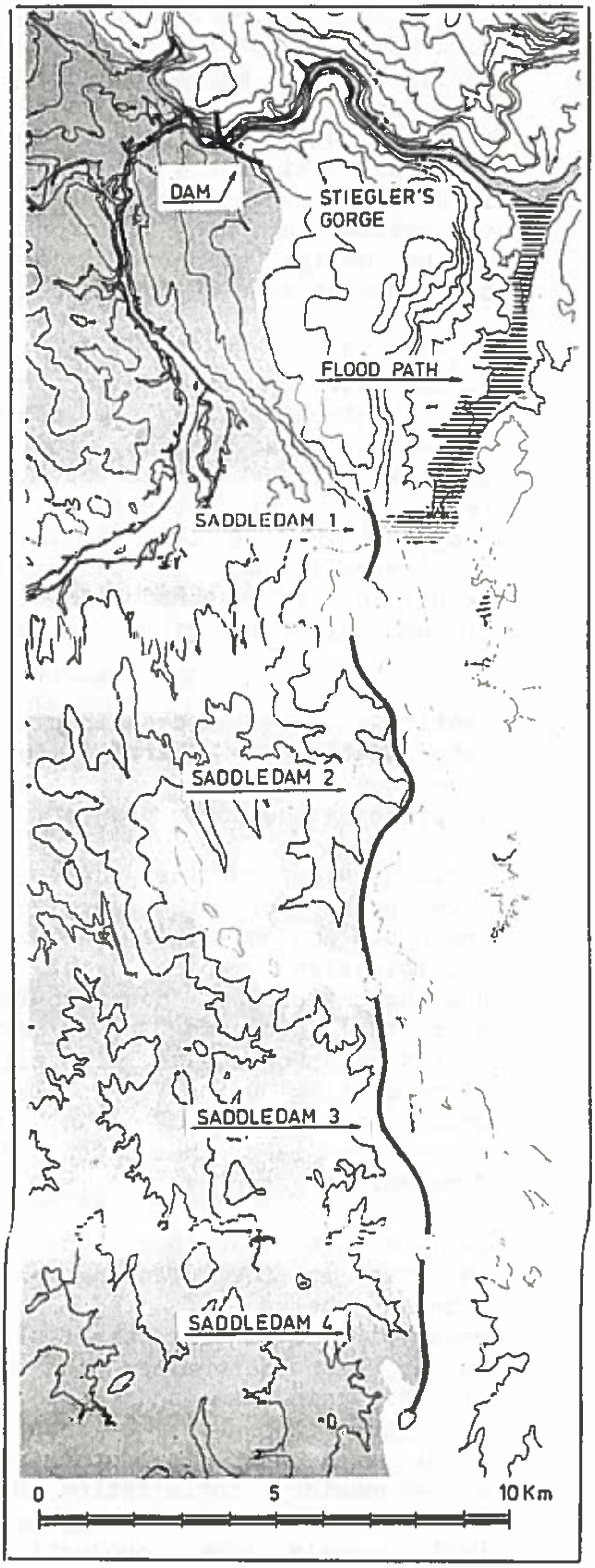


FIG. 4.1 Project Area

Ch.

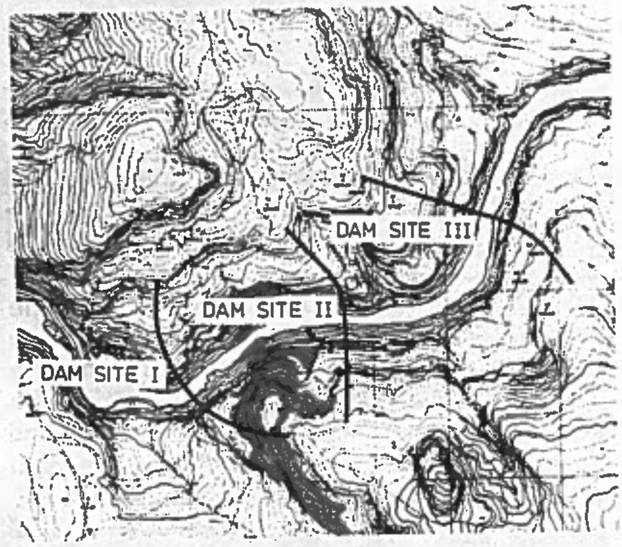


FIG. 4.2 Possible Dam Sites

An investigation into choice of dam type and site was carried out, which incorporated six different dam types and three different sites (shown in Fig. 4.2). A present value economic analysis showed that an arch dam at Site I, the most upstream site would be the cheapest, and this was consequently adopted for design. Full details are given in Annex VII.

Figure 4.3 shows the cross section of the gorge at Site I. From bed level at elevation 70 m the sides of the gorge rise to level 160 m. Above 160 m the ground continues to rise, but less steeply, to well above 200 m. However, along the ridge to the south east, there are a number of saddles with elevations of between 170 m and 190 m over a distance of some 25 km, and below 200 m for some 40 km. According to the reservoir retention level adopted (as discussed in Section 4.4) not only is a main dam required, but a number of secondary saddle dams also. Curves of reservoir volume/retention level and reservoir surface area/retention level are shown in Figure 4.4.

The project will have two separate power stations:
Station A underground in the northern abutment, and Station B at the foot of the dam itself. Station A contains 4 No. 100 MW units, and has a relatively high level forebay leading to four intakes to four concrete-lined penstocks, inclined downwards at 45°. The machinery hall and transformer hall are separate chambers, and the four draft tubes lead to two tailrace tunnels discharging into the gorge 200 m downstream of the dam. Station B contains 4 No. 200 MW units and has four low level intakes immediately upstream of the dam with steel penstocks passing through the dam. The machinery hall, transformers, turbines and draft tubes are positioned immediately downstream of the toe of the dam.

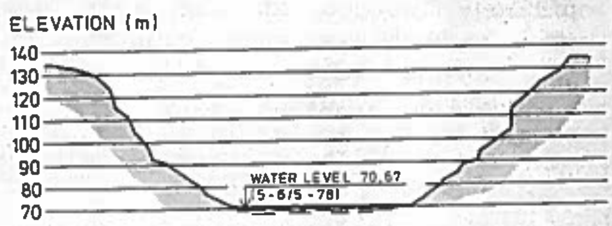


FIG. 4.3 Cross Section of Damsite

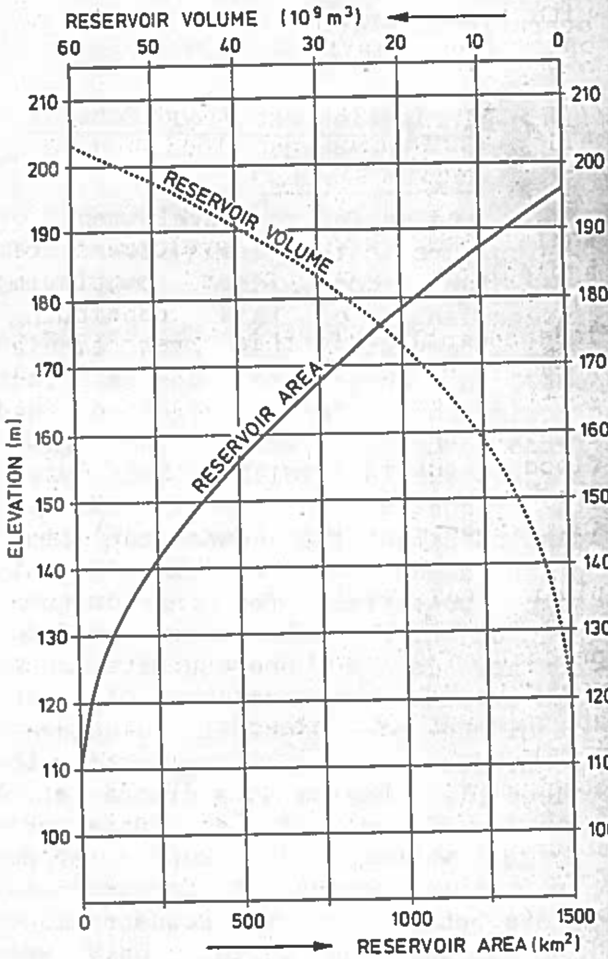


FIG. 4.4 Area and Volume Retention Curves

Two low level reservoir outlets are planned, primarily for irrigation releases. They comprise of gated tunnels passing through either dam abutment, with downstream flumes and flip-buckets discharging into the gorge.

Because the ultimate reservoir level required the construction of saddledams along the south side, the overflow spillway could be located at one of the saddledam sites, 8 km south of the gorge, discharging into a valley leading to the river some 8 km downstream of the dam. This arrangement had advantages over a spillway located at the main dam site, in that the main construction site became less crowded, energy dissipation problems were reduced, and the tailwater levels at the main dam site were lowered, giving greates power production.

The project works also include an administration building and housing with infrastructural facilities for operational staff.

4.4 Irrigation and Flood Control Requirements.

While studies for the development of agriculture in the areas downstream of the dam are continuing independently of this report, a preliminary study has been carried out in order to assess the requirements for irrigation and flood control which the power project should fulfill. This study is reported in Annex IV and concludes that the downstream flood plain areas have an exceptionally high potential for agricultural production, for which adequate flood control is a prerequisite. An approximate assessment of the magnitude of bankfull discharges concludes that spilling onto the flood plain begins at a discharge of about 1500 m^3/sec at Stiegler's Gorge whereas at 2000 m^3/sec overtopping occurs at frequent low spots between 75 km downstream of the dam and the delta. Only when the flow at Stiegler's Gorge exceeds 3000 m^3/sec is the Upper Zone above chainage 75 km flooded, but flooding in the areas further downstream is so great that damage to crops is almost certain to occur.

For the purpose of planning the power project, two flood parameters are defined: the "irrigation flood" and the "controlled flood". The irrigation flood is a deliberate release from the reservoir of such a magnitude that the flood plain areas are irrigated by controlled flooding, and the timing of such releases is suited to the crops. The controlled flood is a release of excess water from the reservoir at a maximum discharge which does little or no damage to the crops, but the timing of the release is dependent only on the flood conditions in the reservoir and cannot be timed to suit the crops.

The preliminary studies led to the conclusion that irrigation flood releases of magnitude 2000 m^3/sec were necessary for effective flood irrigation of the downstream areas. Since these releases may be necessary also when the reservoir level is low, the full requirement for the outlet design was defined as follows:

The irrigation flood release of up to 2000 m^3/sec irrespective of turbine discharge may be required at all reservoir levels down to lowest regulated water level (LRWL). A minimum annual volume of 1.47 x $10^9 m^3$ of water has been reserved for providing these releases at times unsuitable to power production requirements.

Initial studies for determining the degree of flood control and power production expected from the project described later in Section 4.7, indicated that a maximum controlled flood magnitude of 2500 m^3/sec gave a reasonably low frequency of uncontrolled flooding (releases greater than 2500 m^3/sec) of approximately 13 in 300 years. This discharge appears from the downstream studies to be on the

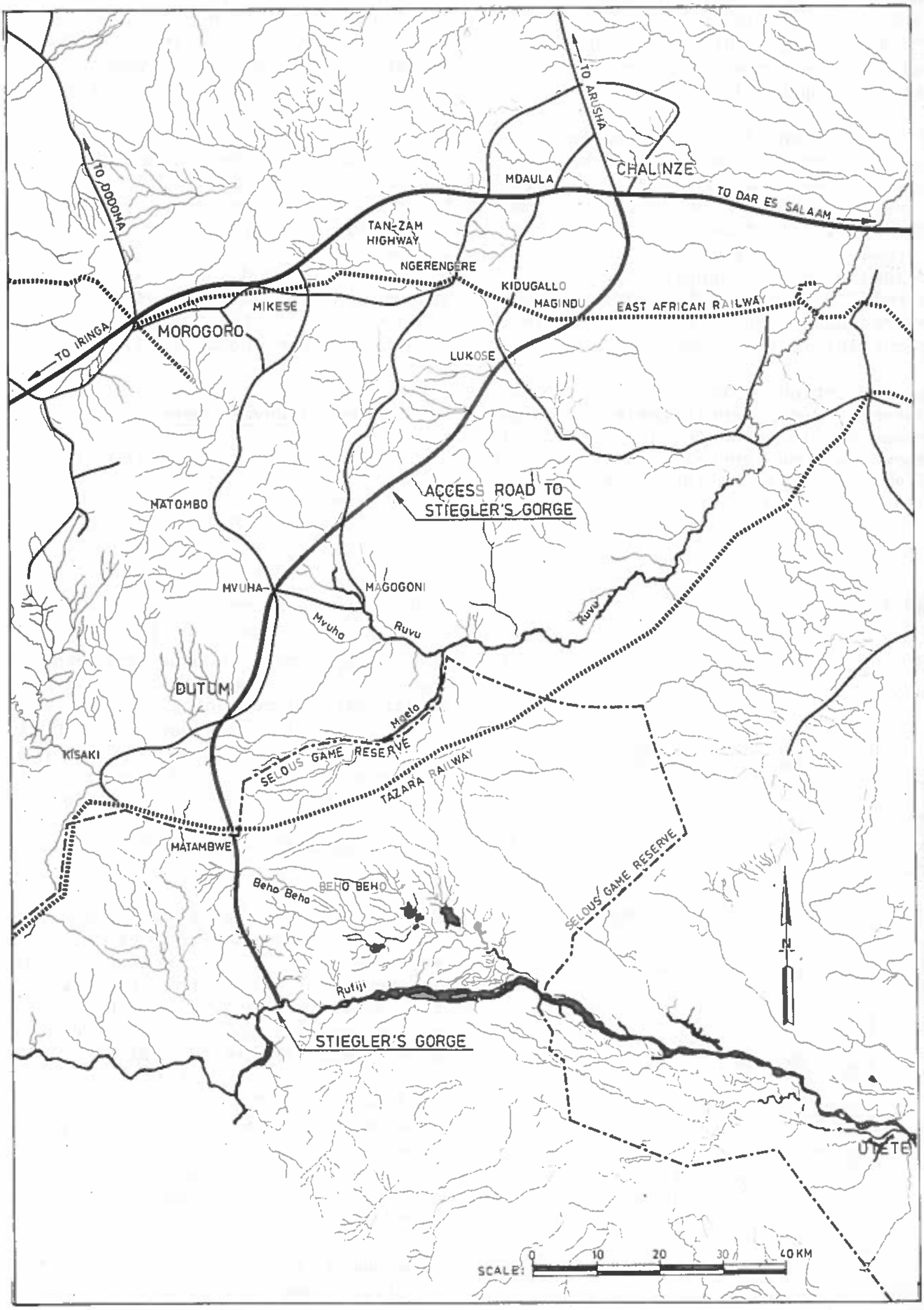


FIG. 4.5 Access Road Plan Ch. 1.

threshold of causing damage to a large part of the cultivable areas. The following requirement for flood releases from the power project was therefore adopted:

A controlled flood is defined as total releases from the reservoir of up to 2500 m^3/sec of unlimited duration and at any time. Uncontrolled floods are total releases of greater than 2500 m^3/sec and should only be permitted for safety against dam overtopping when large flood inflows occur into a full reservoir.

An indication of the separate use of water from Stiegler's Gorge reservoir is given in Fig. 4.6 which shows the mean annual inflow to the reservoir divided into its various uses according to the proposed

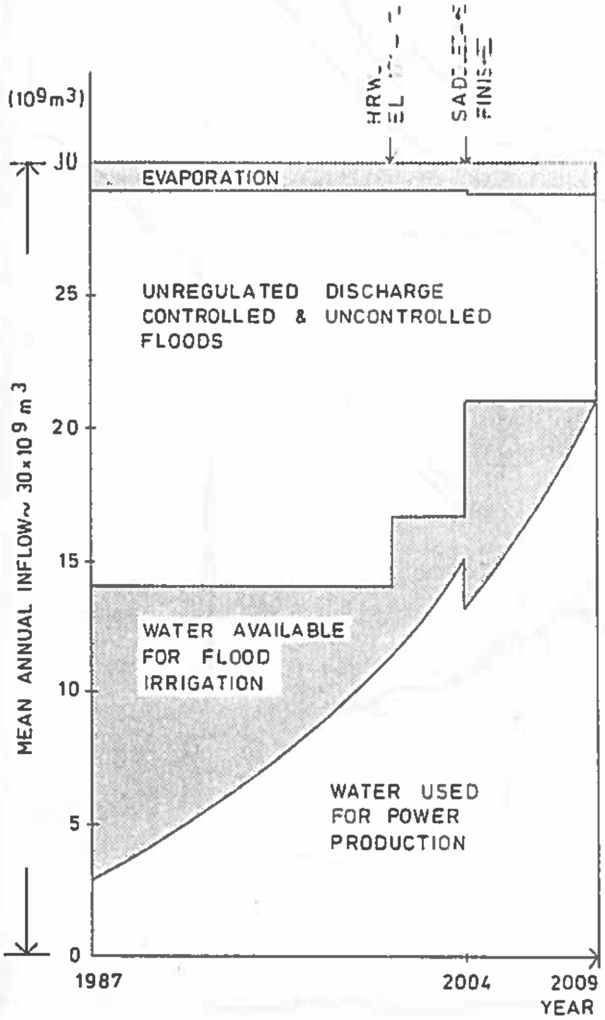


FIG. 4.6 Water Distribution amongst Various Uses

development schedule. As can be seen a considerable quantity of water is available for irrigation releases in the early years, but this water becomes valuable for power production at the end of the development (2009). By this time degradation of the river due to interruption of the flow of sediment to the downstream reaches is likely to make flood irrigation increasingly difficult. A change over to pumped irrigation is expected to have occured by this time, this releasing irrigation water for power productions.

4.5 Phased Development

4.5.1 Choice of Construction Phases

For a power project which is required to meet a steadily increasing demand over a long period, a phased development program is obviously the most suitable for both technical and economic reasons. However, practical considerations limit the phases to a relatively small number concerning the civil engineering works. Electrical and mechanical plant can be installed at more frequent stages. It was concluded that three main phases, I, II and III were most suitable, as defined in the complete schedule of works, Table 4.1, and shown diagramatically in Fig. 4.11.

The general arrangement of dams and topography described in Section 4.1, suggests two stages in construction. The first stage would involve impoundment up to the level of the lowest point in the saddledam area (approximately El. 170), without the construction of saddledams. The reservoir thus obtained only necessitates a lower level main dam, and the possibility of two-stage construction of the arch dam and shoulder dams is therefore being considered. For the purpose of this report, however, it is assumed that the main dam and shoulder dams are constructed to full height in Phase I.

The other major item of civil engineering works which can be constructed in stages is the power stations. The adopted arrangement of one power station underground (Station A) and one at the foot of the dam (Station B) means that the initial station can be constructed underground without the constraint of a dry flow working period in the gorge , and is reasonably secure from a civil defence point of view. Station B foundation excavation must be carried out together with the dam but the superstructure can be deferred until a later stage.

If in the long term, capacity additional to the accomodated in Station A and B is desirable, a third station (Station C) may be constructed.

Phase I:

- Construction of the main dam with cofferdams and diversion tunnels and necessary preparations for Power Station B.
- Construction of Power Station A with two units each producing 75 MW, installed and commissioned as soon as possible, followed by the third and fourth units in due course.
- Construction of low level outlets for irrigation releases.
- Construction of the spillway sill at Saddledam 1 with two level crest at El. 171/174.
- Erection of administration and control building, switchyard and necessary power lines.
- Construction of camps, dwellings, water supply, internal electricity supply, and sewers.
- Quarries and associated plant, internal roads and bridges, and airstrip.

Other works in this phase may include:

- Forest clearing of the reservoir area.
- Animal rescue operations.
- Installation of a flood warning system.

Phase II:

- Construction of Power Station B with installation of four units each producing 150 MW as and when required.
- Further power lines.
- Extention of switchyard and control room.
- Quarries and associated plant.

Phase III:

- Construction of saddledams (total length 16.6 km).
- Construction of spillway structure with flood control gates in saddledam No. 1.
- Further power lines.
- Quarries and associated plant for saddledam area.
- Internal roads to saddledam area.

TABLE 4.1 - Schedule of Project Works

4.5.2 Plant unit sizes

Plant unit sizes have to be selected to suit the present and planned grid extensions, the present and anticipated load pattern and characteristics, and the present and planned production units apart from Stiegler's Gorge. These aspects are outlined in Chapter 2, resulting in the following main factors affecting selection:

- grid stability
- voltage and frequency control
- spinning reserve and stand-by capacity.

In addition, the characteristics of the hydro turbine impose certain restrictions. In accordance with standard practice recommendations, 50% load of maximum unit capability should be the minimum for free running for cavitation control. Other restrictions that could be imposed are maximum transport dimensions and weights, and power house and cavern sizes.

Based on the grid restrictions, the maximum recommended load per unit was found to be approximately 50 MW in 1987, rising with the power demand to approximately 60 MW in 1990, 95 MW in 1995 and 125 MW in 2000. Taking into consideration the advantages of economy of scale, and ample reserve provisions units, with a maximum capability of 75 MW are acceptable for Phase I and 150 MW for Phase II.

Phasing the total potential (some 1200 MW or more) to the demand forecast, the two station concept combined with the two stage reservoir raising, gives the following unit sizes based on the restrictions mentioned above:

		Capability at low level:	Rating at high level:
Station A	approx.	75 MW	100 MW
Station B	approx.	150 MW	200 MW

Thus the same units producing a maximum of 75 and 150 MW at a low retention level (Phase I and II) will produce a maximum of 100 and 200 MW at the high retention level (Phase III).

The number of units necessary to utilize the potential energy depends mainly on the load factor of the grid, but also on the reservoir retention level and the value placed on surplus power. However, a final decision is not needed at present as a possible third station (Station C) can be built in the distant future. A minimum installation of 1200 MW will be necessary to utilize the firm energy available under normal reservoir operation conditions.

		Phase I + II		Phase III	
	No. of Units	Unit Capability	Total Capability	Unit Rating	Total Rating
Station A	4	75 MW	300 MW	100 MW	400 MW
Station B	4	150 MW	600 MW	200 MW	800 MW

TABLE 4.2 -
Generating Unit Rating and Capacity

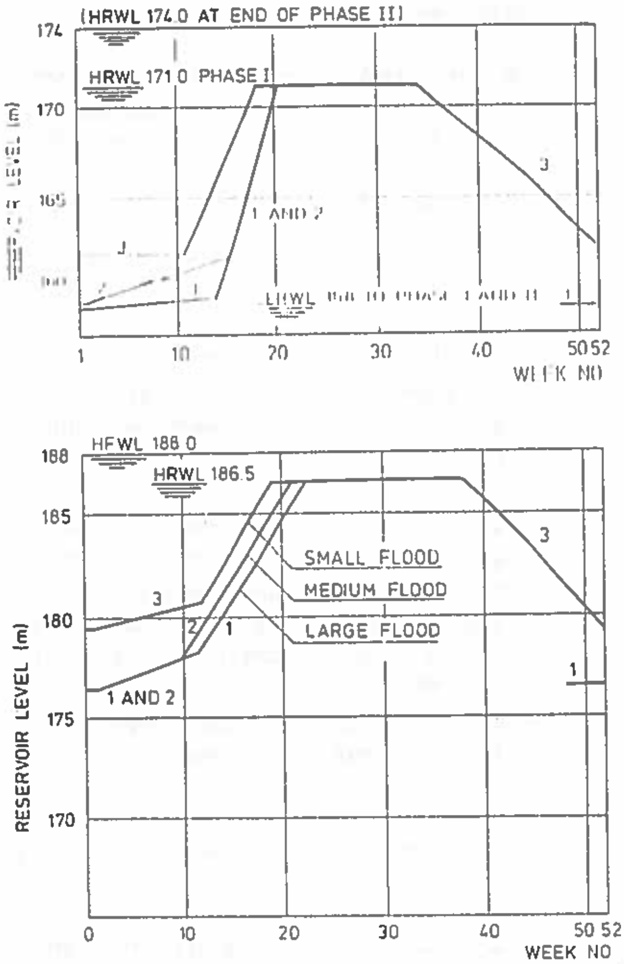


FIG. 4.7 Reservoir Regulation Curves

This installation has been distributed between the two power stations as follows in Table 4.2.

Technical data on the stations and the generating units are given in Annex VIII.

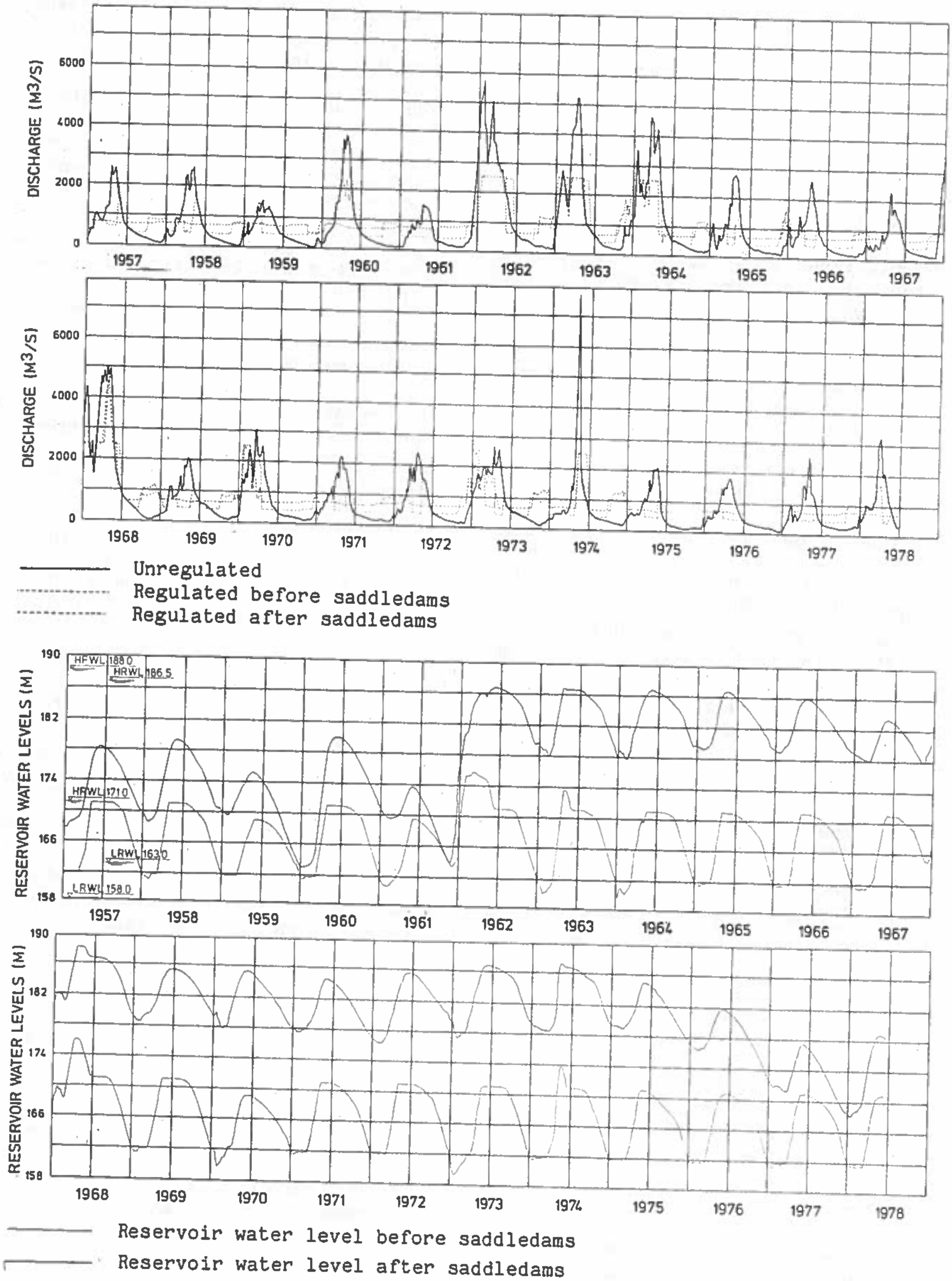


FIG. 4.8 Reservoir Simulation Output

4.5.3 Orders and Timing of Phases

The planning of the development of the Stiegler's Gorge project is based on the power demand forecast presented in Section 2.2. The forecasts for energy or continuous average power demand and peak power demand each set different requirements for the scheme. Energy production is in effect limited by the active storage available in the reservoir, while peak power capacity is limited by the installed capacity. The phased development planning therefore aims at catering for these two different requirements in the simplest and cheapest way.

Fig. 4.10 illustrates how the chosen scheme for development meets the two power demand curves. The upper figure shows how the energy demand can be met up to the year 2004 by utilizing the active storage available in Phase I and II between LRWL at El. 158 and HRWL of El. 174. In that year it becomes necessary to increase the active storage by raising the reservoir level. The lower figure shows the curve of power capacity demand increased by 20% as reserve, representing the total grid requirement for installed capacity. By 2004, the capacity required at Stiegler's Gorge is 782 MW. Of this, 708 MW can be achieved with LRWL at El. 158 by installing all units in Power Stations A and B.

This figure is increased to 754 MW if the tailwater level is lowered by 4 m by canalisation of the river downstream. If such work is necessary (see Section 4.9 on degradation of the river bed) it is natural to carry it out as part of the saddledam construction contract when heavy earth and rock moving plant is on site.

It can be seen that the raising of saddledams is required to be completed in 2004 both to meet the increasing energy demand by providing additional continuous average power production through increased active storage, and to meet the increasing capacity demand by providing additional capability through an increased LRWL.

The delaying of saddledam construction means a delay in obtaining the full flood control benefits of the larger reservoir. The degree of flood control in the earlier phases (I and II) are, however, significant due to the adoption of a relatively high value for HRWL (El. 174, see Section 4.8.2). This can be seen from the historic simulation results of the historic inflow record shown in Fig. 4.8.

A present value analysis was carried out to determine whether saddledams should be built before Power Station B, but this proved to be more costly than the reserve order for all 3 discount rates 7, 9 and 12%. The optimum order of development is therefore as shown in Table 4.3, where the dates correspond to the power demand forecast of Chapter 2.

The project is defined as the three phase development described above. The possibility of further development has also been investigated on the basis of a continually increasing power demand.

If the demand for peak power capacity continues beyond that provided by Phase III, it may be more economical to install another power plant at Stiegler's Gorge (Power Station C) than to build a completely new power station elsewhere. No preparatory work for a third station is involved in Phase I and therefore the final size and position of Power Station C would be decided according to the power requirements existing at the time. It would be possible, however, to install say 3 No. 300 MW turbines in an underground station in the south abutment or in a station constructed in the open on the north side of the gorge, using the diversion tunnels and the low level outlet as inlet penstocks.

The total continuous average power production from Stiegler's Gorge

Phase	Development Step	Completion Date	Total Capability at LRWL (MW)
	Main dam, P.St. A, Units A1, A2	1987	130
Phase I	Unit A3	1989	192
	Unit A4	1991	252
	Power Station B, Unit B1	1993	369
Phase II	Unit B2	1996	484
	Unit B3	1999	597
	Unit B4	2001	708
	Raise HRWL to El. 174	2001	708
Phase III	Lower tailwater by canalisation	2003	754
	Saddledam construction	2004	938 (LRWL at 172)

TABLE 4.3 - Phased Development Plan

after Phase III is estimated at 6040 GWh/yr. This figure assumes that irrigation water can be supplied by turbine discharge and that the 1.47 x 10^9 m^3 of water reserved for irrigation releases in the earlier development phases is used for power production. This implies that a change-over from flood to pumped irrigation in the downstream areas should be complete by 2009 at the latest. The cost of the necessary irrigation works is expected to be significantly less than the additional power plant that would be required if flood irrigation were maintained.

Furthermore, the 6040 GWh figure assumes that LRWL is reduced to El. 163, whereas the 938 MW capability is based on LRWL of El. 172 (see Section 4.8.3). The drop in the installed capability to 865 MW shown by a curve in Fig. 4.10 (b) represents this change in LRWL. In reality, however, this only means a need for further capacity to cover the demand for reserve. The cost of such further capacity has therefore been excluded from the economic analysis of Chapter 9.

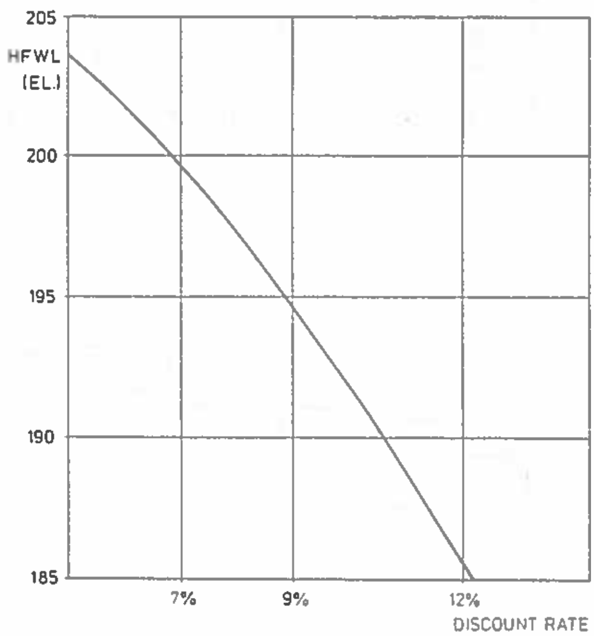


FIG. 4.9 Optimum HFWL against Discount Rate

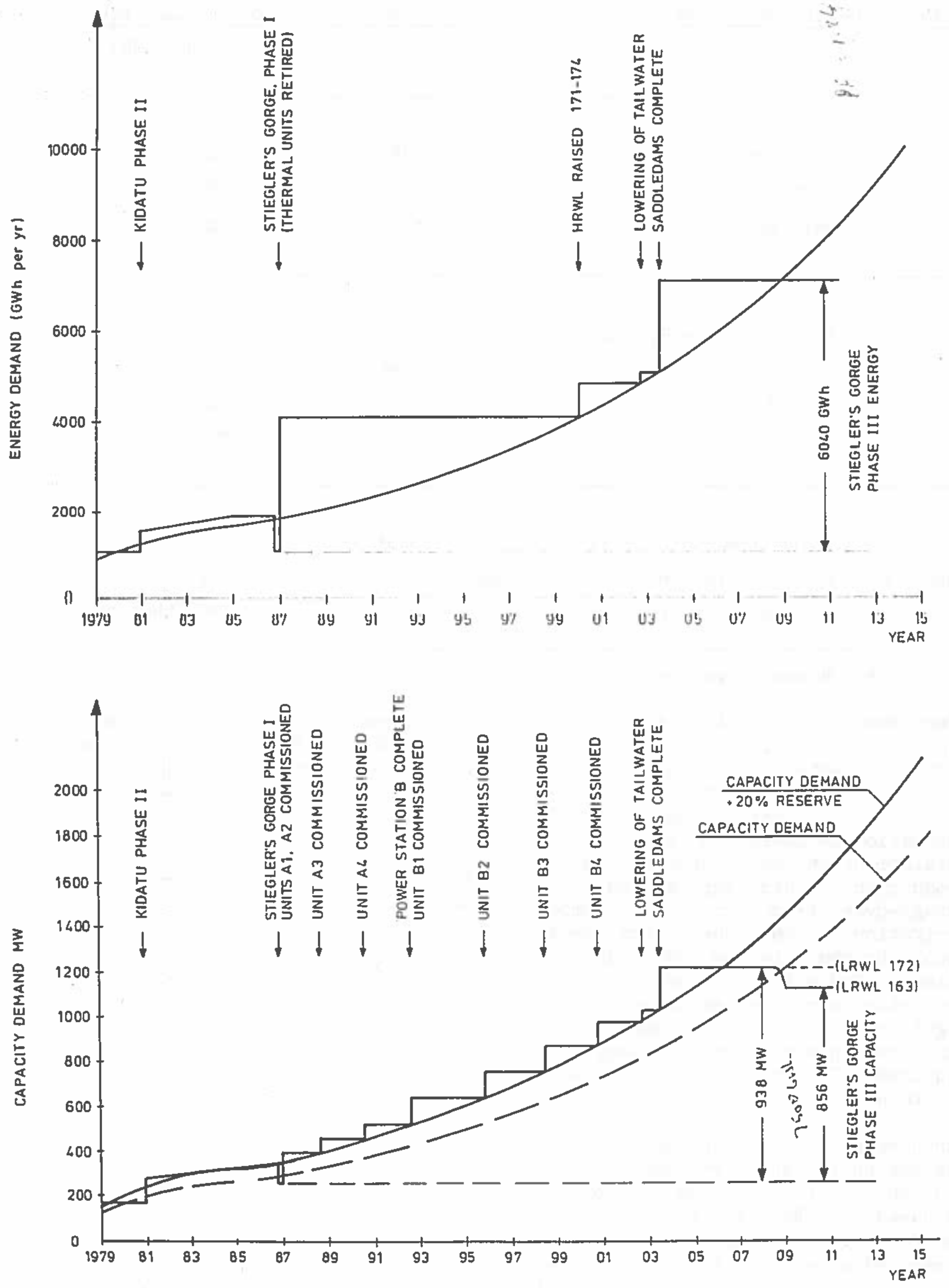


FIG. 4.10 Phased Project Planning According to Extended Grid Forecast

4.6 Economic Optimization Highest Flood Water Level in the Final Phase

4.6.1 Description of Method

A major decision in the planning prices is the choice of maximum reservoir retention level for the fully developed scheme (Phase III) which determines the height of the dams. In theory, determination of maximum retention level is possible by mathematical optimization analysis. In practice, however, such an analysis involves making a number of technical and economic assumptions, so that any optimization studies inevitably involve some judgement decisions and interpretation. The analysis is complex, taking into account all the phases of construction. An initial study was made (in order to enable more detailed designs and thereby more reliable cost estimates to be prepared) in 1977 which indicated a Highest Flood Water Level (HFWL) for the ultimate phase of El. 188. Further studies have been carried out to test this conclusion. These are briefly described below and set out in detail in Annex V.

The three levels HFWL, HRWL and LRWL are interrelated, but a preliminary study showed that HFWL was the critical level to be optimized when investigating the final phase development.

Preliminary studies showed that the optimum HFWL lay within the range El. 180 - El. 210 and that HRWL fixed at 1.5 m below HFWL gave the best power production and flood control results. Initially LRWL was fixed 30 m below HFWL for turbine operational reasons.

An economic analysis was carried out to determine the present value of net benefits for various schemes with levels for HFWL differing by 5 m intervals within the chosen range. Only costs and benefits which were dependent on HFWL were included in the analysis. All other costs and benefits were considered to be common to all alternatives and therefore ignored. Thus the following costs and benefits have been included.

Costs:	Main dam Saddledams Power Plant
Benefits:	Power sales from continuous power production Flood damage costs (negative benefit).

The costs were assessed by taking quantities from each prospective scheme and using the unit rates estimated in preliminary design at 1978 prices. The three construction phases and unit installations were assigned to fixed years according to the build-up in Fig. 4.10 and the various costs discounted at three discount rates, 7, 9 and 12% to give a figure for present value costs for each scheme.

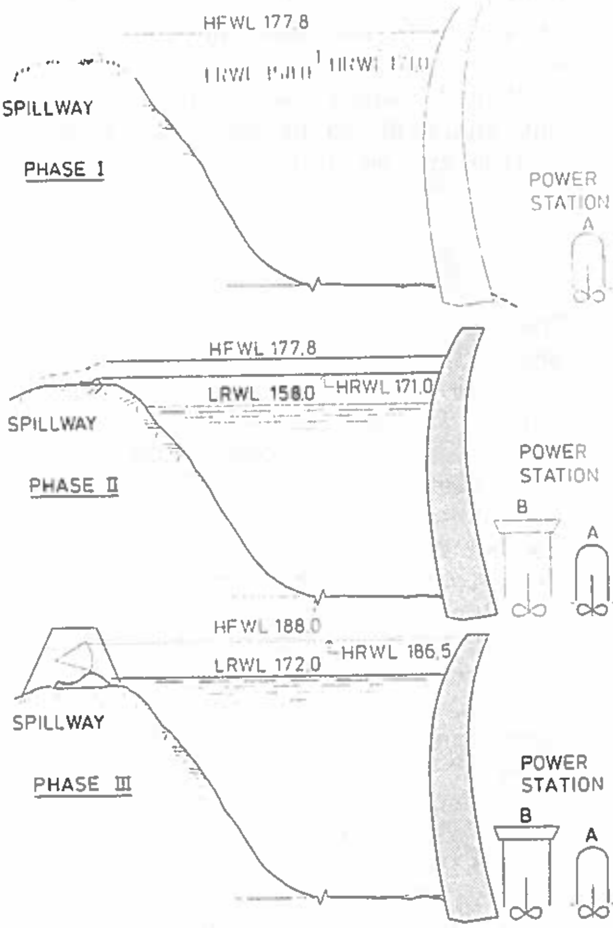


FIG. 4.11 Diagram of 3 Phases

The benefits were assessed by taking the continous power production figure provided by the simulation program (see Section 4.7) and multiplying it by a power price of 4-5 US cents per kWh according to discount rate. This was assumed to be a realistic 1978 price level for large quantity power sales, based on a coal fired power development alternative (see Annex V).

Flood damage costs were assessed by assuming a flood damage cost function according to the magnitude of each uncontrolled flood. Full details of the function are given in Annex V. Both of these benefits were also discounted at the three discount rates: 7, 9 and 12% to give a figure for present value benefits for each scheme.

The net present value of each scheme was determined by the arithmetic difference of the present value costs and benefits determined above. These net present values were plotted against HFWL for each of the discount rates and hence the optimum HFWL value was determined as giving the maximum benefit.

4.6.2 Results

The results of this analysis is shown in Figure 4.9 which plots the optimum HFWL value against discount rate. It was concluded that a dam height at the lower end of the possible range was justified in veiw of doubts about the long term power demand forecast, the possibility of revisions in flood control criteria in the long term (due to river degradation and flood protection and irrigation developments on the river plain), and finally the necessity to minimize financial investments in view of the restricted availability of capital. Taking account of the many assumptions involved in the analysis, it was concluded that an HFWL of El. 188 as adopted in the preliminary study and used for detailed design to date, could be confirmed as satisfactory. This value corresponded approximately with the optimum calculated with a discount rate of 11%.

Sensitivity tests were carried out to determine the effect on the results of variations in certain important assumptions. It was concluded that large variations in flood damage cost function had little variation on the result, whereas power price and project costs had a more significant effect. By far the greatest variation, however, was due to the discount rate assumption as shown by Fig. 4.9.

The power forecast assumed for the timing of phases, power sals build-up etc. was based on a value of 282 MW capacity demand in 1985 and a load factor of 0.65 with a 6 1/2% increase per annum. This is slightly higher than the later forecast described in Chapter [illegible] and subsequently used in the economic analysis of the project. This results in installation dates approximately 2 years earlier than for the later forecast, but the resultant optimum levels are changed to an unsignificant degree.

4.7 Reservoir Operation Simulation

4.7.1 Reservoir Regulation Curves

An initial study was carried out to devise a suitable set of rules to be used as a basis for reservoir operation during the flood period. This study concluded that best results were obtained if the yearly natural floods were first divided into three categories:

Category 1: Years with floods having a discharge greater than 1000 m^3/sec for a period of two weeks before January 1st.

Category 2: Years with floods having a discharge greater than 1000 m^3/s for a period of two weeks before February 1st, except those years included in Category 1.

Category 3: Minor floods which do not come under Categories 1 and 2.

Category 1 floods are usually heavy with large total flood volumes, and are the most difficult to control. Category 2 floods are lighter but large flood volumes can be expected during the end of the flood season. These floods can usually be controlled. Category 3 floods contain medium to low water volumes. These floods may not contribute enough water to fill the reservoir unless releases are kept at a minimum.

Reservoir operation curves were devised for each of the flood categories showing the desired reservoir level changes over a year for best security against both loss of power production and uncontrolled flooding (see Fig. 4.7). If the inflow into the reservoir is so large that the reservoir level corresponding to that particular week of the year on the operation curve is exceeded, then a discharge of up to 2500 m^3/sec including turbine water ("the controlled flood") is released. Normally the water level will follow the operation curve value and releases seldom reach the controlled flood value. However, if the inflow is very large, the water level will continue to rise. When reaching HFWL the full inflow must be discharged to prevent a further rise in the reservoir level. Such a release is called an "uncontrolled flood".

Irrigation water releases are accounted for separately by reserving a fixed volume of water for irrigation flood releases each year (1.47 x 10^9 m^3).

4.7.2 The Simulation Method

In order to quantify the energy available (continuous average power production) and the degree of flood control available from a proposed scheme, it is necessary to simulate the operation of the reservoir over a long time period. For Stiegler's Gorge this was achieved by a computer program using as input a 300 year series of stochastically generated inflow data. This series contains the statistical properties of the 22 year historical series, since it is build up from the historical series as described in Annex I. Weekly average data values were used.

The simulation program treats the inflow data by electing to follow one of the three operation curves described above for the coming year in the inflow data. The program contains all functions such as evaporation, turbine efficiency, tailwater level (listed in Annex V) necessary to simulate the pattern of reservoir level and outflow variations over the following year. Thereby it procedes through the inflow data year by year reproducing the following output data corresponding to the 300 year input series:

- discharge through turbines
- power production
- reservoir level
- total outflow from the reservoir.

4.7.3 Reults

As an example, the simulation has been carried out on the actual historic inflow record for the situation before the construction of Saddledams at the end of Phase II, and for the situation after Saddledam construction with LRWL at El. 163. The results are shown graphically in Fig. 4.8.

The reservoir outflow is plotted as a coloured line superimposed on the inflow hydrograph and the corresponding reservoir levels are shown underneath.

For the optimisation study each scheme with its proposed value for HFWL was run through the simulation programme assuming final phase development and an unlimited demand for power production. In this way the maximum continuous average power production and the corresponding degree of flood control for each scheme was assessed from the 300 year output series, and the resulting benefits calculated for use in the economic optimisation of HFWL.

4.8 Determination of Other Reservoir Levels

4.8.1 HRWL and LRWL in Phase III

The value of HRWL is represented by the top line in the reservoir regulation curves of Fig. 4.7. This value was kept constant 1.5 m below HFWL for all proposed schemes in the optimisation study. With an HFWL of Wl. 188 and an HRWL of El. 186.5, the flooding risk would be very low, with about 13 occurrences in 300 years compared with 177 in 300 years at present. A lower HRWL was found to reduce power production significantly, but not decrease the uncrontrolled flood frequency significantly. This value of HRWL initially chosen was therefore adopted for further planning, but will be reviewed during the "Extended Flood Control Studies" to be carried out in 1979. HRWL has no influence on design of the project work, only on the operation rules.

The minimum possible value for LRWL was determined at El. 158 so that the minimum head available for power generation should be not more than 30 m below the maximum head. This is the maximum range of head for satisfactory turbine operation with the same runner. Examination of the relationship between installed capacity and continuous power production showed that the optimum LRWL value for Phase III varies from El. 172 immediately after saddledams are constructed, reducing finally to El. 163. These values meet the demand forecast as discussed in Section 4.5.

4.8.2 Reservoir levels in Phase I and II

The lower limit of LRWL at El. 158 was already set for Phase III. A maximum active reservoir volume with minimum construction costs is desirable in Phase I, thus LRWL of El. 158 should be adopted for this phase also. With LRWL fixed, several different values for HRWL in Phase I were considered within the range of elevations 168-176 suggested by the topography of the spillway site at Saddledam No. 1. A similar optimization study as for Phase III was carried out by performing reservoir simulations and assessing the power production and flood control benefits. The results show that net present value saddledam costs are overriding compared with sill constructions costs, flood damage costs and earlier power plant installation costs. On this basis HRWL was chosen at El. 174 for Phase II, although a lower value of El. 171 will suffice for Phase I.

The value for HFWL for Phases I and II is determined in conjunction with the overflow sill design. With the present design now undergoing model tests, HFWL corresponds to El. 177.8.

4.9 Environmental Impact of the Project

The major physical effect of the project within the catchment area will be the creation of the reservoir flooding some 1300 km^2 of uninhabited land. Although it is a great advantage that the impounded area is uninhabited, an immediate problem requiring careful attention will be the evacuation of wildlife to avoid trapping on islands during initial reservoir impounding and possible drowning. Plans will be made well in advance and carefully implemented. No insuperable difficulties are envisaged.

With the operating range between El. 158 and El. 188, a zone of seasonal (or over-year) transition will be created, and some clearance of forest may be desirable between these levels. A study of the degree of clearence necessary within the entire reservoir will be carried out in the near future.

Stratification of the reservoir and the subsequent stagnation of water in the layers below a certain depth has been identified as a possible problem and is now the subject of a separate study. No results are available at present.

The creation of the reservoir will have an effect on the management of the Seleous Game Reserve, although the habitat for wild life is likely to be enhanced.
As far as known, no special animal migration routes will be affected by the reservoir. It will, however, create a new environment for aquatic life and become a major repository for fish. Aquatic plant growth cannot be accurately predicted. This could create problems for operations at the dam and power station, and flooting plants such as water hyacinths can affect reservoir evaporation. Preliminary investigations show that the reservoir is in an area hitherto unaffected by water hyacinths. Such problems would have to be dealt with as and when they arise, but should be identified at the earliest possible stage by a careful program of monitoring. The monitoring program should be devised well in advance of reservoir impounding.

It has been established that the project will have a major effect on the Rufiji river plain downstream of the dam. The immediate effect will be to reduce flooding. In particular the highly precarious occurance of floods between December and June will be reduced and also the size of floods. Instead it is planned that controlled floods will be released when determined by the reservoir operation rules. Irrigation floods of suitable size and at most appropriate times for irrigation of crops will also be released in agreement with the local farmers. It is expected that these will be most beneficial in the lower part of the plain, particularly for rice cultivation. Thus economic benefits from agriculture are to be expected as a result of the project.

A further effect is expected downstream as a result of trapping of sediment in the reservoir. Due to the large proportion of sand in the sediment and the impossibility of regulating the reservoir in such a way as to reduce sedimentation significantly, almost total trapping is inevitable. The most fundamental effect will be to cause degradation of the river channel in the plain, particularly in the upper reaches. River hydraulic studies indicate significant degradation which might be expected to occur rapidly in the reaches immediately downstream of the dam. The existence of a natural lake (Lake Tagalala) some 70 km downstream of the dam may limit or delay degradation to the reaches upstream of the Lake, but the results of a study on this effect are not yet to hand. Such degradation would have a radical effect on flooding of the plain, as much greater flows will be contained within the river channel. Thus to maintain irrigation, particularly in the upper and middle zones of the river plain, the introduction of lift irrigation will become progressively necessary. Although this will involve additional cost, it is expected to result in greatly improved irrigation control and reliability, and the agricultural benefits resulting should far outweigh the costs involved. It is important that planning and preparation for the introduction of controlled irrigation on the Rufiji plain are undertaken well in advance as a considerable period will be needed for implementation.

Although the river floods will be controlled to a great extent by the project, occassional uncontrollable floods will inevitably occur (see

Annex V). These will result in damage to crops (but to a much lesser extent than at present) and subsequently to irrigation works, roads, and other infrastructural facilities which will be developed in the future. Further studies are to be investigated to plan and evaluate flood protection works for the development areas downstream. Section 8.1 mentions the various studies which are to be carried out under coordination from Rubada with assistance from FAO, UNEP and the University of Dar es Salaam.

A secondary effect of trapping of the sediment in the reservoir and the reduction of land flooding, is the reduced land conditioning effect. Flooding is particularly beneficial in ensuring that salts are leached downwards out of the root zone and maintaining the soil structure during subsequent drying and cracking. Absence of sediment deposits would have an effect (but not necessarily very great) on fertility in terms of nitrogen and potassium (Ref. no. 5). There may be some small adverse effect in the delta due to some seasonal reduction in freshness of water in the delta channels as it meets the sea water, but this generally occurs beyond the cultivated area. The effect of this on fish ecology also requires some further special study.

As regards health hazards the introduction of perennial irrigation canals could lead to creation of an environment favoring schistosomiasis (bilharzia). Suitable preventive measures should be introduced at the earliest stages of design and implementation to minimize the risk. As a direct result of the power project no extraordinary changes in health conditions are envisaged. Studies on these questions have been initiated.

CHAPTER 5

DESIGN OF PROJECT WORKS

DESIGN OF PROJECT WORKS

5.1 Introduction

The project works consist of the main dam and saddledams, spillways and outlets, power stations and switchyard, and the associated administration building and housing. The preliminary design of the project works has been completed and is described in this report. Final design will be carried out during 1979 and the first half of 1980, culminating in the production of tender documents together with a Final Design Report in the latter half of 1980.

5.2 Geological Aspects

A general description of the topography and geology of the project area is given in Chapter 1, and a description of the type and extent of field and laboratory investigations carried out to date is given in Annex II, together with a description of the geological conditions at each part of the construction works. This section is confined to the geological conditions in relation to the design of the project works.

5.2.1 Foundation Conditions at the Main Dam Site.

The main characteristics of foundation rock conditions at the arch dam site may be summarised as follows:

- The estimated excavation depths for the dam foundation vary between 5 and 15 metres with the deeper excavation in the gorge slopes.

- The foundation rock is generally slight to medium-jointed.

- Results from in-situ and laboratory tests on rock deformability have not been finally assessed yet. It is not expected, however, that the deformability of the foundation rocks will pose any major problems for the design of a concrete arch dam.

- Provisional rock mechanics calculations indicate that of the two dam abutments, the southern exhibits the less favourable conditions with regard to abutment rock stability. They do indicate, however, that with properly designed grout curtains and drainage systems for the dam foundation, any risks of abutment instability may be eliminated.

The erection of cofferdams for the main dam will be more a problem of construction than of design. The upstream cofferdam is situated at or near several faults located close to each other, but these are unlikely to have any effect on the dam's foundation or stability. There are no geological irregularities at the site of the cofferdam.

5.2.2 The Tunnel System

The tunnel system consists of tunnels of different sizes. They are located in different types of rock, and the joint density will vary along the length of each tunnel. Blasting and lining works will therefore be considered individually as each situation demands.

Generally tunnels with larger cross-sections will need a full concrete lining. In some places this lining will have to be applied at the working face, whereas in other places the conditions will be better. However, when permanent lining is not applied directly at the working face, some kind of temporary lining will have to be carried out between the working face and the place where permanent lining already has been constructed. Such temporary lining should be applied as soon as possible after blasting.

The methods to be used for temporary lining works will be: rock bolts, shotcrete and reinforced shotcrete. Bolts and shotcrete may also be used in combination.

5.2.3 Saddledam and Spillway Area

Saddledam No. 1:

With the exception of the extreme northern part of the northern abutment the bedrock is covered by 1-3 m of erodible soils.

Within the central parts of the dam the bedrock consists of very jointed and highly weathered mudstone, which is also judged to be highly erodible to higher water velocities. These layers have a depth of 10-12 m.

A brecciated fault zone with a near vertical dip complicates the geological picture to some degree. This zone is running through the area from northwest to southeast.

The detailed foundation solution of Saddledam 1 will have to be chosen with special regard to safety against erosion.

Saddledams No. 2, 3 and 4:

Auger borings, test pits and seismic measurements have shown a somewhat variable thickness of soil overburden, with an average thickness of 2-3 m for Saddledam 2, 3-4 m for Saddledam 3 and about 4 m for Saddledam 4 although thicknesses of up to 8 m are also indicated. The soils consists of silty sands, and sandy, silty clays, the latter being more predominant in Saddledams 3 and 4.

The Overflow Area:

Boring and seismic measurements have shown an average thickness of soil overburden of between 1 and 2 m in the area affected by spillway overflow, and of 10 - 15 m at the outlet of the overflow into the Rufiji River. The soil overburden must be considered as erodible.

5.2.4 The Reservoir Area

The description given of the general geology of the project area in Chapter 1 will also serve as a description of the geology of the reservoir area. An engineering geological survey of the reservoir area has been carried out, and concludes that leakage from the reservoir will not be significant.

Erosion along the shores of the reservoir is also considered not to be serious because the cover of residual soil overlying bedrock is relatively thin. The only place where some amount of erosion can be expected to take place, is on the eastern side of Rufiji River between Shuguri Falls and Mawera River, where loose deposits of Tertiary age occur.

5.2.5 Seismology

The seismology of the project area is described in Chapter 1. The earthquake risk at the main dam and saddledam sites has been estimated on the basis of the past seismic history of the area. At a probability level of 10^{-3}/year, it is estimated that the maximum bedrock acceleration at the site will not exceed 0.2 g. The criteria adopted for earthquake design are therefore maximum ground accelerations of 0.2 g horizontally and 0.1 g vertically.

As no strong-motion data are available for East African earthquakes, it will be necessary for design purposes to use the close distance time records of several large earthquakes, such as those of El Centro (1934, 1940), Parkfield (1966), San Fernando (1971) and Gazli, USSR (1976), or the Atomic Energy Commission's "Safe Shutdown Eartquake" which incorporates several of the above records, all scaled to the appropriate acceleration level.
The seismic risk analyses performed so far have not taken into account the possibility of induced seismi-

city (i.e. earthquakes caused by the impounding of the reservoir). It appears that the Stiegler's Gorge area has a potential for induced earthquakes, and this factor will therefore be taken into account in the final assessment of the seismicity.

A network of seismic stations has been set up around Stiegler's Gorge to monitor the seismicity of the area. It is expected that the data being recorded at these stations will give information also on the issue of induced seismicity.

5.3 Dam Design, River Diversion and Impoundment

5.3.1 Main Dam

Extensive investigations have been carried out to determine the most suitable site for the main dam in Stiegler's Gorge, and the most suitable type of dam. Three possible sites were identified as shown in Fig. 4.2 and six different types of dam were considered.

Initial investigations narrowed the possibilities down to three dam types, namely concrete-face rockfill, arch concrete and concrete gravity dams, at two sites (Sites I and II on Fig. 4.2). Each of the six alternatives was costed from a preliminary design taking into account power stations, spillway and diversion facilities, availability of materials and all other variables. The costs were discounted to present value terms and indicated that a concrete arch dam at the most upstream site was the most economic (see Annex VII). Geological investigations also confirmed that this site was the most suitable for arch dam construction, therefore an arch dam at Site I was selected for further design.

The main dam is an arch concrete dam of maximum height approximately 130 m and maximum span approximately 350 m bounded on both sides by shoulder dams of a concrete gravity design. The main dam design is based on a finite element computer analysis of both the dam and the abutment rock. Separate stability analyses for the two abutments have been made.

The dam is assumed to be symmetrical and the half dam profile is divided into 40 elements. The following loading conditions are applied:

(i) Dead load with no contact between adjacent monoliths, no impoundment, no tailwater.

(ii) Full impoundment to crest level El 190, with no tailwater,thermal stresses due to temperature decrease after grouting.

(iii) As (ii) above but with the design earthquake simultaneously.

Inherent in the design are the following assumptions:

(i) Full water pressure on the dam foundation upstream of the grout curtain, negligible water pressure downstream.

(ii) No silt load on the structure. (Negligible sediment deposition is anticipated at the dam site, as discussed in Annex I.)

(iii) Thermal stresses accoring to a $10^{o}C$ drop in temperature after grouting.

(iv) Penstock openings deform as if the relevant concrete element were whole.

(V) A design earthquake according to the Atomic Energy Commissions "Safe Shutdown Earthquake" with maximum ground accelerations of 0.2g horizontally and 0.1g vertically.

The finite element program output is the reaction onto the rock abutment and the stress pattern in the concrete surfaces of the dam itself. The forces from the dam are then used in the separate stability analysis of each of the rock abutments, which include the following assumptions:

(i) Rock elements divided up by 3 fault planes indicated by the geological report, assumed to be planes of weakness.

(ii) Each element non-deformable, and stability depending on limiting friction angles assigned to the three predominant fault plane directions.

(iii) Water pressure causing uplift and side pressure according to values which assume an effective grout curtain and drainage system.

The design dam profile adopted has been shown to be stable for both the first two loading conditions with acceptable stresses in the concrete. Both rock abutments are also stable. A preliminary earthquake dynamic analysis was carried out on an earlier dam profile and indicated that when the final earthquake analysis is completed, little change may be expected in the dam profile. Further details of the analyses are given in Annex VII.

The demand for dam freeboard above HFWL is calculated from the effective reservoir fetch length of 32 km and a wind velocity of 20 m/sec corresponding to a moderate storm. The requirement is 2.63 m (i.e. a crest level of El 190.63) for protection against the estimated maximum wave height. This is achieved by building the dam body to El 190, topped by a wave wall with reflector to El 191.3. For catastrophic flood water level at El. 188.7 caused by the assumed maximum flood a minimum freeboard of 2.6 m is thus provided.

The main dam is subject to the approval of the Norwegian Civil Defence Authorities and is therefore designed in accordance with their requirements.

The foundation rock will be sealed by a grout curtain beneath the dam, with pressure relief drainage drillings downstream. A drainage and inspection gallery will also be constructed in the body of the dam.
The dam and foundations will be instrumented to monitor water pressures, deflections and stresses and thus keep a regular check on its safety.
The possibility of constructing the main dam in two stages is being considered, the first stage up to crest El 180 and the second stage from El 180 to El 190 in Phase III. This possibility appears to be technically feasible and could prove economically viable after further analysis, but for the purpose of this report, full height construction in Phase I is assumed.

5.3.2 River Diversion

The peak flood discharge adopted for design during the construction period is 12,000 m^3/sec as described in Annex VII. It would, however, be economically prohibitive to divert such a flow around the dam site. For the design of diversion works it has been assumed that the peak flood flows would overtop the cofferdams and pass through the gorge at the dam site. Furthermore, it is assumed that the four dry working periods are restricted by the occurence of consecutive flood periods, with durations as long as the longest flood in the 22 year hydrological record. The construction of two diversion tunnels in the north bank passes a total of 2500 m^3/sec before overtopping of Cofferdam 3 and ensures a sufficiently long working period in the gorge during the dry season, with extra flexibility due to the conservative flood duration assumption. The various diversion stages are shown diagramatically on Plate 10, and described in detail in Annex VII.

5.3.3 Impoundment Procedure

The full discharge will pass through both diversion tunnels until about early July, when diversion tunnel 2 can be closed by steel arch sets placed over the inlet. A gated conduit will subsequently be installed in a concrete plug cast in the tunnel. The gate will serve to release the minimum compensation discharge during the impoundment of the reservoir. The penstocks of Power Station B will be closed by dome-shaped end pieces welded to the downstream end of the conical transition section.

The final closure will be effected by lowering a heavy gate in front of the inlet of diversion tunnel 1 as soon as the dam joints are grouted, the gate in diversion tunnel 2 is operative, and the arch sets removed. This will be in the low-water period from early September to mid-November. The diversion tunnel 1 will then be permanently closed by a concrete plug.

The gate in diversion tunnel 2 will be permanently closed as soon as the reservoir has reached the level giving sufficient discharge through the permanent low level outlets by the main dam (approx. El. 115). Diversion tunnel 2 will then be permanently sealed by a concrete plug just downstream of the gate.

5.3.4 Saddledams

In Phase I, an overflow sill is constructed at Saddledam 1 site, together with small earthfill bunds up to 3 m high to prevent erosion due to spillage of water at high flood levels.
The main saddledam construction occurs in Phase III, when 4 discrete embankment dams are raised, as summarised in Table 5.1:

Saddledam 1 is to be a rockfill dam with a central earthfill core of residual silty sand as shown in Plate 27. This material is readily available in the surrounding areas. Two transition zones separate the core and the rockfill shell. These zones consist of 2.5 m of finely crushed sandstone against the core, followed by 2.5 m of coarse fraction processed from the quarried sandstone against the shell. The shell material consists of quarried sandstone. The total area of the upstream face is protected by a 1.5 m thick layer of riprap. This riprap is made up of selected large size quarried sandstone. Riprap is also incorporated on the lower section of the downstream face in order to protect the dam where tailwater depths can become high enough to erode the dam toe.

A grout curtain is incorporated under the impervious core for all

	Dam type	Fill Volume (m^3)	Max Height (m)
Saddledam 1	Rockfill/central earth core	0.8×10^6	23
" 2	Earth embankment	2.7×10^6	15
" 3	" "	0.9×10^6	13
" 4	" "	0.1×10^6	5

TABLE 5.1 - Saddledam Data

parts of the dam where the existing ground level lies under El 188.0 m. The depth of the curtain is approximately 50% of the maximum water depth measured at the dam foundation.

The crest width is six meters to accommodate a road, and the dam fully complies with Norwegian civil defence requirements.

Saddledams, 2, 3 and 4 are to be earthfill dams with variable cross sections according to the height as shown on Plate 27. Plans and longitudial sections for these dams are shown on Plates 25 and 26.

For dam sections where the total height is less than the freeboard value, the dam consists of silty sand founded on top of the stripped overburden.

For sections of dam where the water depth is less than 3 m, the dam again consists of silty sand founded on top of the stripped overburden, but with riprap upstream protection. The coarse fraction processed from the quarried sandstone will be used as a transition zone between the riprap and the silty sand. The fine fraction processed from the quarried sandstone is laid along the dam overburden interface to allow free drainage. The downstream slope is of a stepped construction in order to collect rainwater run-off and discharge it via gullies or pipes down the slope.

For water depths greater than 3 m, the upstream toe is placed directly onto the rock surface after excavation of the overburden. Upstream slope protection consists of riprap from the crest to El 185 and cement-stabilized silty sand in the lower regions. An interceptor chimney drain is also incorporated within the dam, this having a crest elevation of 185.0 m.

5.4 Design of Outlets and Spillways

5.4.1 Low Level Outlets

The low level outlets comprise two similar tunnels, one on each side of the gorge designed to release the irrigation flood of 2000 m^3/sec at El 158. The main components are an approach tunnel leading to a concrete plug containing 3 steel-lined conduits controlled by regulating gates, and an exit tunnel connecting to a spillway flume. This terminates in a flip bucket which throws the discharge into the river downstream of the tailrace exit from Power Station A. The design is such that the two jets meet in mid air to reduce energy dissipation on the river bed. Each conduit contains a guard gate and a control gate. Provisions are incorporated for draining the approach tunnel and gate conduits by bulkhead gates. The gate sills are at El 111.5 and the gates are hydraulically operated by remote control.

Rather extensive scour is anticipated downstream of the flip bucket, although not to an extent where the stability of the side slopes of the gorge is impaired. The scour deposits may raise the tailrace water level. Consequently, partial removal may be required during operation of the scheme. The entire outlet is being checked by a hydraulic model prior to final design.

5.4.2 Determination of Floods for Spillway Design

Having decided the reservoir operating levels, the spillway facilities must be designed for releasing extreme flood flows, which are determined as described in Annexes I and VII. A mean of the Gumbel and Log Normal frequency distribution curves has been used for flood frequency analysis, as shown in Fig. 5.1.

The extreme frequency floods predicted by the distribution curve were confirmed by comparing Stiegler's Gorge data with extreme flood events from the African mainland. An envelope curve to this

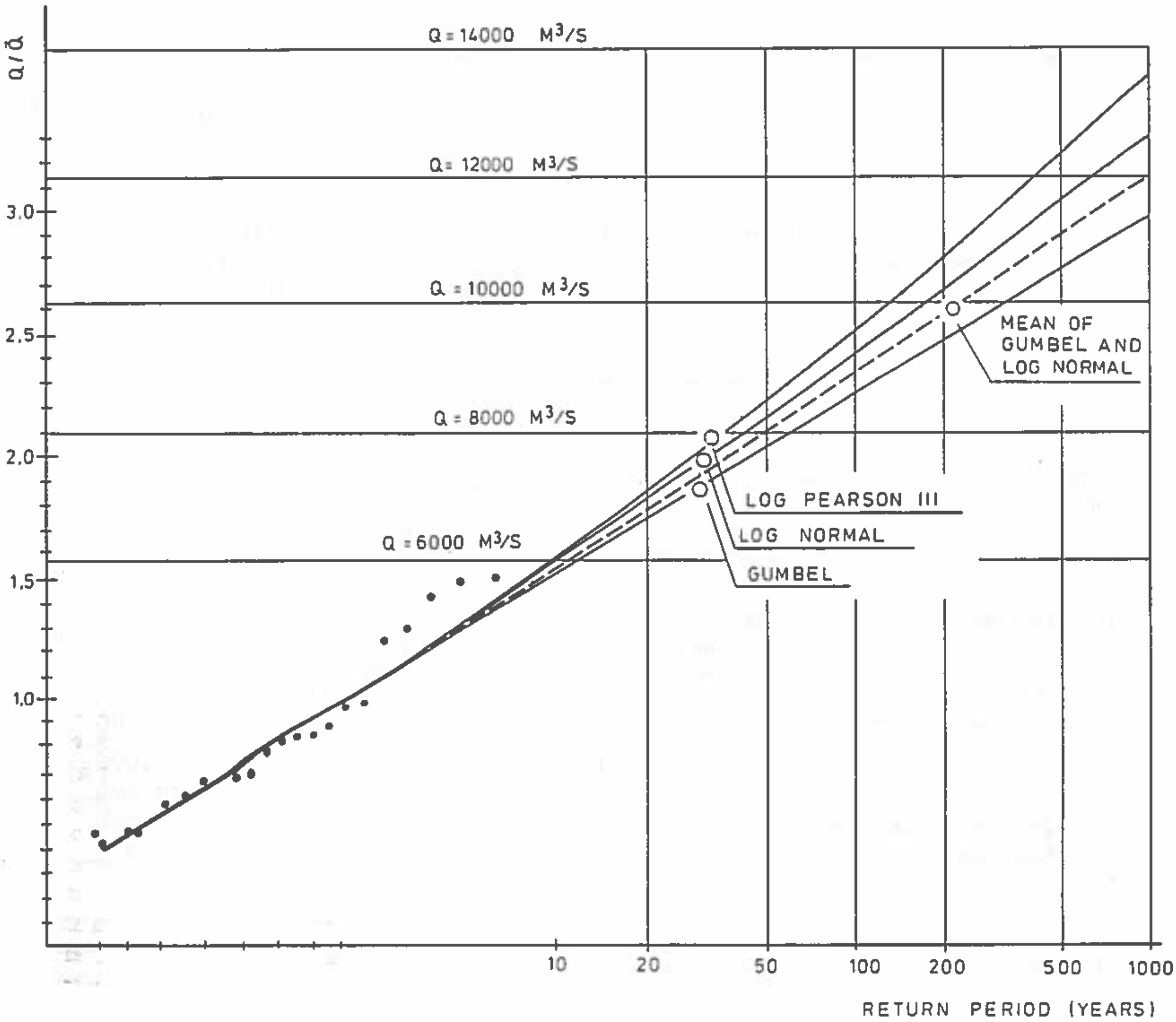


FIG. 5.1 Flood Frequency Analysis

data gives an indication of the value for the "assumed maximum flood" occuring at Stiegler's Gorge. Both these techniques resulted in the adoption of the following floods.

Peak inflow of 350 year return period	12,000 m^3/sec
Peak inflow 1000 year return period	14,000 m^3/sec
Peak inflow 10,000 year return period	19,000 m^3/sec
Assumed maximum peak inflow	20,000 m^3/sec

Two flood inflow hydrographs where designed with 14,000 and 20,000 m^3/sec peak values containing correspondingly large volumes. Assuming the preliminary design of spillway described in this report, these floods were routed through the reservoir from an initial water level at HRWL for Phase I and Phase III.

The resultant outflow and water levels are given in Table 5.2 and further described in Annex VII.

5.4.3 Spillway in Phases I and II

Spillway facilities in Phase I consist of an ungated overflow sill situated at Saddledam 1 site. The sill consists of two parts as shown in Plate 15: the first part a 140 m long concrete sill founded on fairly good sandstone with crest level El 171, the second part a 400 m long rockfill sill founded on weathered mudstone with crest level 174.

Problems are expected with erosion downstream of the sills, and the hydraulic flow conditions and stability against erosion are being in-

Phase:	Flood Category	Peak inflow (m^3/s)	Spillway Peak outflow (m^3/s)	Initial Reservoir Level	Highest Reservoir Level
I	1000 year return	14 000	12 000xx)	171.0	177.8
I	Assumed maximum	20 000	18 000xx)	171.0	179.4
III	1000 year return	14 000	12 000x)	186.5	187.9
III	Assumed maximum	20 000	15 000xx)	186.5	188.7

x) low level outlets closed
xx) low level outlets open

TABLE : 2 - 1000 year Assumed Maximum Flood Conditions

Maximum discharge through a 100 MW turbine (St.A)	95	m^3/sec
Maximum discharge through a 200 MW turbine (St.B)	190	"
Minimum permissible flow downstream of the dam	100	"
Maximum irrigation flood release (excl. turbine discharge)	2,000	"
Controlled flood release including turbine discharge	2,500	"
Spillway design discharge at HRWL	12,000	"
Assumed maximum flood outflow, Phase I	18,000	"
Assumed maximum flood outflow, Phase III	15,000	"
Maximum design flood during construction period	12,000	"

TABLE 5.3 - Summary of Design Discharges

vestigated by model tests. The proposed design is therefore only preliminary, and conservatively high rock quantities have consequently been estimated in the costs described in Annex IX.

The construction of the spillway structure in Phase III is to take place immediately downstream of the concrete sill at El 171, where moderately good rock is expected to be exposed by erosion.

It is at present suggested that construction work in Phase III be preceded by construction of a cofferdam in front of the concrete sill so that water is diverted over the rock sill at El 174. This also supplies additional energy by raising HRWL in the final years of Phase II operation to El 174.

The cofferdam may consist of an earthfill bund constructed from material found locally. The crest level can be decided when further information on spillway discharges, reservoir operation and site conditions is available for Phase III planning.

5.4.4 Spillway in Phase III

Spillway facilities in Phase III consist of a gated spillway structure built at the same site as the concrete sill for Phase I (see Plate 28). The structure has been designed to pass the 1000 year flood outflow of 12,000 m^3/sec at HFWL. A further design condition is that the assumed maximum flood outflow of 15,000 m^3/sec must be passed through both the spillway and the low level outlets with acceptable dam freeboard.

The structure consists of eight radial gates, seven of which have a sill level at El 174 and the eighth with a sill level of El 171 to enable floating debris to be collected and floated out at lower reservoir levels. The seven upper gates are 13.1 m wide by 13.2 m high and are designed for free water surface flow. The lower gate is 13 m by 13 m with top sealing designed for orifice flows. The gates are supported by concrete pillars 8 m wide by approximately 50 m long at the base, which are constructed as hollow boxes to reduce uplift and improve lateral stability against earthquakes. It is economically prohibitive to prevent erosion downstream of the spillway structure at the high design discharge, and it has been assumed that erosion will be limited to acceptable depths by the construction of a jet-lifting profile on the downstream edge of the sill. The exposure of the rock by erosion in Phase I and the results of model studies will give more information for the final design of Phase III spillway structure, but for present purposes and cost estimates, the preliminary design has assumed conservatively deep pillar foundation depths.

5.5 Power Station Design

5.5.1 Choice of Locations

The power stations could all be located in the open on the river bank. A location of Power Station A in the abutment rock was found desirable for civil defense reasons as well as making construction independent of river flooding. A location has been found in the northern abutment without entering weak breccia zones in the bedrock, and therefore adopted.

Power Station B has been placed in the open downstream of the main dam. The site in the poorer rock on the southern riverbank has been left as a possible site for a future third power station which is not designed in the present project. Further alternative sites are available in rock cuttings on either bank downstream of the dam.

5.5.2 Power Station A

The power station A is designed for four 100 MW units placed in a rock cavern machine hall. The main transformers are placed in a separate gallery along with the hoists for the draft tube gates. Plan and sections are shown in Plates 11 and 12,and a detailed description is given in Annex VIII. A large forebay is excavated to provide smooth hydraulic approach conditions for the intake structure. The four intakes are each 8.5 m wide and are protected by 12 m high trashracks of a removable frame design. Four 6.5 m dia. concrete-lined penstocks lead down at 45° to a transition section reducing to a 4.7 m dia. horizontal section. Steel lining is employed from the start of the transition section downstream. The turbine shut off valves are butterfly valves designed for closure at full load.

The turbines are of vertical shaft Francis type, rated at 100 MW, 214.3 r.p.m. A guide bearing will be located at the turbine cover making it possible to remove the runner and the guidevanes without moving any part of the generator, as the upper part of the draft tube is not embedded in concrete. The generator will have a combined thrust and upper guide bearing and a lower guide bearing, its axle directly connected to the turbine. The turbines will have electrohydraulic speed governors.

The draft tubes begin with a steel section transforming the circular section to a rectangular concrete section, containing a concrete support for the draft tube gates. Each draft tube will have two gates. Pumps situated in a separate sump will enable the draft tube to be emptied when the draft tube gates are shut.

There are only two tailrace tunnels for the four units as two draft tubes will each converge into a common tailrace tunnel. An access tunnel used for blasting will act as a surge chamber for the longest tailrace tunnel. For the shorter tunnel a separate surge shaft will be constructed. The two tailrace tunnels enter a common tailrace canal with a width of 30 m widening to 50 m. The tunnels can be drained by closing the openings with steel arch sets.

The 115 MVA/100 MW generators will be connected through circuit breakers to conventional bus-bars leading through shafts to the transformers in the transformer gallery. Each of the four transformers will have a capacity of 115 MVA, the voltage being stepped up from 15-16 kV to 220 kV. Two dry-type transformers, 11/0.4 kV, will supply the station with power. From the main transformers the power will be led by 220 kV oil filled cables through a cable duct to the pothead yard. Overhead lines will connect the pothead yard to the switchyard.

In the switchyard a double busbar arrangement with tubular aluminum conductors will be used. Four bays for feeders and two for power lines are needed for Power Station A. Circuit breakers may be oil-minimum or SF_6 type. An 11 kV switching station with two 10 MVA transformers is placed near the main switchyard for local power demand.

The control room for Stations A and B and for the switchyard will be placed in the administration building. Necessary relays and batteries will be placed close to the switchyard.

A small Francis unit with 1200 kVA capacity will be designed as a reserve power supply for Station A.

Necessary air conditioning and ventilation plant will be installed in the machine hall and transformer gallery. The machine hall will have necessary assembly bay, space and personnel rooms. Separate tunnels will give access to the machine hall and transformer gallery.

5.5.3 Power Station B

The Power Station B is placed in the open downstream of the main dam and designed for four 200 MW units.

The four intakes form a continuous front on the upstream face of the main dam, and are supported by the upstream concrete cofferdam. Each intake has 3 openings 3.5 m wide and 9.5 m high, fully protected by trash racks similar to the ones in Station A. From the intakes, a transition section leads to a circular concrete penstock of 8 m diameter. Steel lining commences at a conical transition from 8 m diameter to the 6.5 m diameter section further downstream.

During Phase I, the entire intake structure is completed and the conical transition section installed, with dome-shaped end plates welded on at the downstream end. In Phase II, the rest of the 6.5 m dia. penstock is erected and embedded in concrete.

Expansion couplings are provided between the penstocks and butterfly valves to accept deformations between the dam and the power station.

Butterfly valves are used as shutoff valves for the units. The turbines will be similar to those of Station A, except for shaft design and thrust bearing. Individual servomotors for each guidevane may be required. The upper part of the draft tube is steel lined, the lower part is of concrete. The draft tube gates are operated from shafts run-

CHAPTER 6

CONSTRUCTIONAL ASPECTS

CONSTRUCTIONAL ASPECTS

6.1 Construction Materials

6.1.1 Aggregates for Concrete

Sand may be obtained from natural deposits or by crushing of sandstone. Sand deposits are available upstream along the Rufiji River at a distance of 7-10 km but are of uniform grain size not ideal for concrete. Deposits at Behobeho River approximately 25 km from the site, contain large quantities of gravelly sands that are suitable for concrete. Potential rock quarries in sandstone are located within 2 km of the damsite (see Plate 20).

A test rock quarry has been opened and approximately 50 m^3 of sandstone have been crushed in a full-scale test. A test program is being executed to examine the aggregate properties, including soundness, porosity, density, water absorption, shrinkage/swelling, modulus of elasticity and compressive strength, coefficient of thermal expansion, particle shape and grading. The tests are being carried out according to relevant American (ASTM) and British standards.

Results so far indicate that crushed sandstone aggregates are suitable for concrete both in particle shape and grading and have normal shrinkage and temperature properies meeting the ASTM requirements. Results from natural sand tests are not yet conclusive (see Annex III).

6.1.2 Concrete Test Mixes

At present approximately 15 different mixes are being tested. Results from concrete mixes so far indicate that the crushed sandstone aggregates have strength limitations of no practical importance for production of concrete. Results from tests on mixes with natural sand are not yet available.

6.1.3 Cement

At present there is one cement factory in Tanzania located at Wazo Hill outside Dar es Salaam. This factory has a production capacity of 350 000 tons a year but is under reconstruction and expansion, and a capacity of 500 000 tons a year is expected in the near future.

Two new factories are being planned, one in Tanga with a planned capacity of 500 000 tons a year which will be ready for production in 1980, and one in Mbeya with a planned capacity of 250 000 tons a year - to be ready for production in 1981. The project will require about 90 000 tons of cement a year.

The cement produced at Wazo Hill is similar to an ASTM Type I. For mass concrete for the main dam and some other structures, it has, however, a rather variable and rapid development of the heat of hydration which requires extensive precautions to control the temperature development. An imported low-heat cement, or a mix of local cement with pozzolan, might prove to become more economic. Studies are being carried out to evaluate this, but there are no conclusive results so far. Further details are given in Annex III.

6.1.4 Water for Concrete

The Rufiji river water quality is suitable for concrete, except for the high suspended solids content which may require the water to be passed through a sedimentation basin. Tests are in progress to investigate this.

6.1.5 Rock and Earthfill for Saddledam Construction, Phase III

The main construction material for these dams is residual silty sand. Investigations carried out to date indicate that sufficient quantities of this material are readily available along the whole saddledam areas, and that the quantity is adequate for embankment core material. Prior to preparation of tender documents for Phase III, more detailed investigations will be carried out.

For Saddledam No. 1 crushed sandstone are also needed in the transition zones to the rock-fill. Quarried sandstone will be needed for the rock-fill and for the bigger blocks in the rip-rap. These materials could be taken from a quarry near Saddledam No. 1.

6.2 Construction Plant for Phase I

6.2.1 Aggregate Production Plant

The main rock quarry for Phase I will be sited on the south side of the Rufiji river upstream of the main dam . The rock crusher and the screening plant as well as the stockpiles for crushed rock and sand will be sited at the plateau east of the quarry. This place will be submerged after Phase I has been completed.

The plant will produce 25% in excess of the daily coarse aggregate consumption, i.e., 6500 tons per day. Dry screening is suggested for the coarser fractions (Ø 4 mm up) and wet screening for the finer fractions, in order to control the filler content. Storage capacity will be 10 times the daily production.

6.2.2 Concrete Batching Plant

It is envisaged that all concrete batching for Phase I will be carried out at the main dam site since all aggregate and water supplies will be concentrated in this area. Batching facilities will be required to reach a maximum production capacity of 10,000 m^3 per week.

The main batching plant will be situated on the south bank near the aerial cableway which supplies concrete to the dam. A second smaller plant on the north bank (1000 m^3 per week) will be required early in the contract period to provide concrete for the Rufiji bridge and diversion and access tunnel linings.

6.2.3 Cooling Plant

Due to the high temperatures and the thickness of the structures, the concrete will have to be cooled during the curing period. A central cooling plant will provide the cooling water. This water will be transported through a pipe system permanently cast into the mass concrete of the dam. Pre-cooling of batching water will also be carried out at the batching plant and the aggregates will be shaded from the sun and cooled by sprinkling water and/-or by forcing cold air through the bins.

6.2.4 Construction Water Supply

Water consumption for Phase I construction is estimated to be 7000 m^3/day maximum excluding cooling water.

Water for construction purposes will be pumped from the Rufiji river. No further treatment beyond removal of suspended solids is expected to be required for construction purposes. An extensive filtration plant will be necessary to deal with the large quantity required.

Several pumps and pipeline networks for industrial water supply will be established to cope with the large variations in water demand expected over the construction period.

6.2.5 Power Supply

The maximum annual energy demand during the Phase I construction period is estimated at about 25GWh. Maximum power capacity demand is estimated at 8-10 MW. This will be supplied by diesel generating sets based at the site. The possibility of early completion of a power line

to bring power to the site was investigated, but showed no economic advantage, since the supply system would probably have difficulty in meeting the additional demand from the construction site.
Power for Phases II and III construction can be supplied from installed units at Stiegler's Gorge.

6.2.6 Workshops and Compressor Station.

A central workshop will be placed on the hill southeast of the main dam, with smaller units at suitable locations as required. It is intended that the central workshop will last through Phases I-III. The workshop will contain tools to tackle any kind of repair job that may occur in connection with the construction works, since no other repair facilities will be available in the area.

A central compressor station has also been assumed for supply of compressed air by pipeline to the entire main dam site.

6.3 Camp and Infrastructure

6.3.1 Present Situation

At present there are two camps at Stiegler's Gorge both on the northern bank of the river. The workers camp houses approximately 1000 persons, and the staff camp can accommodate 30-35 persons. A temporary water supply using Rufiji river water serves the two camps. Diesel plants supply the camps with electricity. The internal roads are suitable for small trucks, and all-weather transport across the Rufiji river has been secured by erecting a cableway across the gorge.

6.3.2 Construction Camp

It is assumed that a total of 3000 local workers and a peak of 400 expatriates will be working at Stiegler's Gorge during the most intensive construction period.

The single expatriates are expected to be accommodated in barracks of a reasonably good standard. The expatriate families are to be accomodated in the permanent houses for future operating staff (see Section 5.6).

The water supply for domestic use could come from treated Rufiji river water. Domestic sewage could be treated biologically in oxidation ponds. Electricity could be supplied from the main construction plant's electricity supply. Large cold storage facilities for food will be needed.

Refuse could be treated centrally by incineration. This method would be combined with closed deposit pits needed because of the wildlife in the area.

6.3.3 Stigo Town Development

There are possibilities for an urban development at Stiegler's Gorge, which would also provide an alternative solution to the housing of construction personnel. This development has been called Stigo Town to separate it from the construction camp needed for the power plant construction. Such an urban development could be based on fishing in the reservoir and tourism in the wildlife reserve, as good communication lines will be available.

If such a permanent village is desired, the construction camp with its facilities should be built according to a master plan of the area. Permanent family housing of a good standard would be needed instead of the workers barracks. A less concentrated population would induce additional costs in roads, water supply, sewage, and electricity supply as well as the increased number of houses.

Studies are being carried out to plan this development.

6.3.4 Internal Access and Construction Roads

The permanent access roads to the power stations will be built to carry the same type of heavy load as the main access road to Stiegler's Gorge. The same basic design of the road structure has been adopted but with reduced carriage lanes and shoulder widths. The proposed layout of access roads for Phase I construction is shown in Plate 21.

6.3.5 Airfield

A new airfield will be located on a plateau northwest of the construction camp, with a runway of 1250 m along the direction of the prevailing winds, i.e., in an east-west direction. The ground consists mostly of red soil and smaller shallow patches of black cotton soil. It is suggested that the runway structure be 30 cm thick, the top layer being stabilized gravel. The airstrip as outlined would be sufficient to serve the construction of the project, i.e., able to handle medium sized aeroplanes.

In the future, however, a runway 2500 m long may be constructed on the same plateau crossing the airstrip described above.

6.4 Temporary Works

6.4.1 Cofferdams

Because river diversion is so important to the progress of the project, the diversion tunnels and concrete cofferdams 3 and 4 are to be fully designed, tested and specified by the consultant and therefore come under the category "permanent works". The rockfill cofferdams 1 and 2 and other temporary cofferdams may come under the category "temporary works". Model tests described in Annex VI have shown that cofferdams 1 and 2 can be completed using talus blocks at a discharge of 400 m^3/sec. Their exact design and position will be decided later when more information on river bed levels, block sizes, and access roads is available. The cofferdams will be destroyed when they are overtopped by flood water, but it is not intended to remove material which does not interfere with further construction or with the operation of the scheme.

6.4.2 Temporary Rock Support

It is anticipated that a high degree of temporary support will be required in underground excavations because of the large size of the caverns and excavations in relation to the rock quality. Rockbolting, reinforced shotcreting and steel shoring are likely to be used. In particular, mudstone must be protected from deterioration due to air and water by shotcreting. Separate items for temporary rock support are given in the cost estimates, Annex IX.

6.4.3 Local Access Roads

In addition to the permanent access roads described in Section 6.3.4, the contractor will construct temporary access roads as and when required.

All temporary other construction roads, unsubmerged quarries and borrow pits, and temporary buildings or structures will be removed or restored to a condition befitting the existing environment.

CHAPTER 7

COST ESTIMATES

COST ESTIMATES

7.1 Introduction

Cost estimates have been prepared as a basis for an economic evaluation of the project and for definition of financing requirements. For the economic evaluation detailed cost estimates for the Phase I, Phase II and Phase III project works have been prepared. In addition, costs have been included for the access road works (for which designs and estimates have been prepared under a separate assignment) and for the power transmission system as discussed in Section 4.1. Thus the costs of capital works for the total development have been determined. These have been related to a time schedule and combined with estimates of operation and maintenance costs to provide a complete stream of costs over the period covered by the economic analysis. Further details are given in Section 7.2 and 7.3.

Cost estimation has been carried out using rates in US$ and the total costs thus obtained have been allocated a percentage for local costs. The total costs expressed in dollars have a good degree of reliability. The proportion of the total which comprises local costs are preliminary estimates. All costs have therefore been expressed finally in US dollars, with the assessments in Tanzanian shillings converted at the 1979 exchange rate of T.Sh. 8.25 to US$ 1.00. The effect of devaluation of the Tanzanian shilling will be to reduce the amount of dollars required to meet that element in the first instance. Ultimately, however, the dollar equivalent will approximately correspond to the requirement in Tanzanian shillings due to additional increases in local prices. Thus the total cost expressed in dollars is considered to be the most reliable estimate.

The financial costs include any taxes and duties that may be involved, and price escalation (other than escalation directly associated with any devaluation as discussed above). The financial costs have been expressed in seperate local and foreign currency elements phased over the period of investment, thus providing a basis for budget financing for the total development.

Section 7.4 details the financial costs corresponding to the investment requirements for the project works included in Phase I, including transmission costs. In addition the estimated financing costs for the access road and bridge have been tabulated to obtain total requirements. However, it is possible that the access road will be considered a part of the national Southern Link Road and financed seperately (and in advance) of the other listed costs, and would be subject to seperate consideration.

On completion of the final designs and tender documents in 1980, a further estimate of project costs will be prepared. Estimates will be made for labour, materials, plant and consumables in relation to a detailed construction programme, and application of oncosts. This will result in a firm up-to-date estimate being available prior to conclusion of financing arrangements.

7.2 Project Capital Costs (Phases I, II and III)

7.2.1 Bills of Quantities

The project capital costs have been estimated using measured quantities for standard items and applying estimated units rates and prices. Items have been grouped in separate bills of quantities for appropriate components of the works as listed in Table 7.2.

In addition to the main civil engineering works separate bills have been provided for the following:

(i) camp and infrastructure,
(ii) site access roads apart from main road contract,

(iii) major static items of plant (listed in Annex IX),
(iv) contractors' staff salaries and expenses.

Quantities for items of the permanent works and the major temporary works have been based on designs, specifications and drawings. These have been determined in detail and are substantially complete, so that no special allowance for unmeasured items has been included. Thus in general the quantities have a good degree of accuracy based on present design. Unforeseen work and extentions to the measured quantities are covered by contingencies, see Section 7.2.3. Further details of quantities are given in Annex IX.

7.2.2 Unit Rates and Prices

The unit rates and prices used for the cost estimates have been determined as being applicable to contracts resulting from international competitive bidding. The main civil engineering contract would be a major undertaking by international standards, and would involve a very large component of constructional plant and equipment and a large number of expatriate personnel. In addition to an average of about 150 permanent expatriate personnel, some 3000 local workers would be engaged.

The rates and prices adopted assume that the conditions of contract, financing arrangements, and logistic support facilities would be given special attention by the Tanzanian Government to provide maximum possible security and reliability. Thus no contingency element or risk factor has been included in the rates. An adequate advance payment to contractors (completed to a suitable bond), and price escalation provisions would be particularly appropriate on a contract of this magnitude, and would have a significant effect in attracting a good response at tendering. It is also assumed that there would be complete exemption from all company, personnel and other taxes, duties and currency restrictions.

Apart from the provisions included in the billed items, the rates and prices are inclusive of all plant, labour and materials. In comparing the adopted rates for similar items elsewhere, it is important to note those elements which have been excluded and provided for seperately, particularly those mentioned in Section 7.2.1.

The rates and prices for the civil engineering works have been compiled from local and international contractors in Tanzania and other countries. Rates have been assessed from the same costs of locally produced and imported materials, plant, equipment and labour, together with general on-costs for office overheads, insurance, bonds, fees and profit.

Special attention has been given to determing the rate for concrete items, as these amount to some 35% of the Phase I civil engineering costs. A basic assumption is that all cement will be available from within Tanzania.

The rates adopted for major items are given in Table 7.1. For items in the electrical and mechanical plant contracts, prices have been obtained direct from major manufacturers and suppliers in Europe.

7.2.3 Physical Contingencies

In addition to the components dealt with above, an allowance for physical contingencies is required to cover possible changes in the project works which may be found necessary subsequently. These may result from omissions due to lack of details at the present state of design, inaccuracies in the estimates of quantities and unit rates, and subsequent changes due to presently unforeseeable

	Unit	US$
Earth and rock excavation		
Earth in dam foundation	m^3	7.00
Earth in forebay	"	4.00
Talus in dam foundation	"	12.00
Rock in dam foundation	"	17.00
Rock in forebay	"	8.00
Diversion tunnel, 120 m^2	"	30.00
Access tunnel, 46 m^2	"	21.00
Tailrace "	"	17.00
Penstock shaft	"	57.00
Machine hall	"	15.00
Draft tube	"	36.00-48.00
Concrete		
First quality in main dam	"	92.00
Second " " " "	"	87.00
Spillway	"	96.00
Machine hall	"	96.00-106.00
Cofferdam	"	96.00
Lining in tunnels incl. formwork	"	170.00-220.00
Formwork		
Plane surfaces in main dam	m^2	57.00
Arch surfaces in main dam	"	67.00
Spillway	"	67.00
Machine hall	"	76.00-86.00
Cofferdam	"	67.00
Reinforcement		
Spillway	t	857.00
Machine hall	"	800.00-1048.00
Fill for saddledams		
Rock fill built into dam	m^3	9.50
Residual soil	"	7.00
Filter	"	12.50-18.00
Rockfill for cofferdams	"	7.00
Grouting and drainage for arch dam	"	40.00
Internal roads	m	125.00-175.00

Note:
Construction plants and contractors administration are not included in the unit prices.

TABLE 7.1 - Important Unit Rates

circumstances. At the present stage with project designs well advanced, the least reliable factor in the estimating process is the valuation of unit rates. Thus, for the civil engineering works an allowance for physical contingencies equivalent to 15% of the total estimate has been assumed, and for the mechanical and electrical works, 8% of the total estimate.

7.2.4 Engineering and Administration

An allowance equivalent to 8% of the project works has been included in the cost estimate for engineering and administration. This is exclusive of costs previously incurred and for completion of the preparation of designs and documents up to tender stage, but includes for prepation of working drawings and all direct administration and supervision of construction in Tanzania and abroad, apart from the contractor's own staff.

7.2.5 Summary of Capital Cost Estimates

The summary of the project works capital costs derived from the bills of quantities included in Annex IX, is given in Table 7.2 covering Phases I, II and III. Table 7.3 shows the estimated costs for the total development, inclusive of the cost of the Stiegler's Gorge road access and Rufiji bridge contracts, and of the power transmission lines. The road and bridge costs have been obtained from the Engineer's Estimate for these contracts. Transmission line costs have been based on preliminary plans only and are subject to further refinement at a later stage (see Annex VIII).

	PHASE I		PHASE II		PHASE III		
	Total	local %	Total	local %	Total	local %	
Civil Works							
1. Camp and Infra-structure	19.500	60	-	-	-	-	
2. Site Access Rds.	10.100	30	-	-	1.000	30	
3. Admin. Buildings	3.400	60	-	-	-	-	
4. Diversion Tunnels	7.970	60	-	-	-	-	
5. Cofferdams	4.389	40	-	-	-	-	
6. Main Dam	87.279	40	-	-	-	-	
7. Power St.A	23.538	40	-	-	-	-	
8. Power St.B	6.192	30	10.050	30	-	-	
9. Spillway at S.D.1	7.053	30	-	-	9.184	30	
10. Saddledam 1	-	-	-	-	10.702	30	
11. S.D. 2,3,4	-	-	-	-	35.457	30	
12. Low lev. outlets	10.650	50	-	-	-	-	
13. Switchyard & Pot-head	1.200	40	-	-	-	-	
14. Canalization	-	-	-	-	15.000	30	
15. Constr. Plant	27.000	10	0.800	0	8.100	0	
16. Contractors Adm.	24.700	50	1.400	50	9.300	50	
Total	232.971	40	12.250	30	88,743	30	333.964
15% contingenc.	34.946	-	1.837	-	13,312	-	50.095
TOTAL CIVIL	267.917	-	14.087	-	102,055	-	384.059
Mechanical Works							
1. Turbines	14.300	10	29.400	10	-	-	
2. Gates, Valves & pipework	11.240	10	17.500	10	2.900	10	
3. Cranes and trashracks	4.300	10	0.500	10	-	-	
Total	29.840	10	47.400	10	2.900	10	80.140
8% Contingenc.	2.387	-	3.792	-	0.232	-	6.411
TOTAL MECH.	32.227	-	51.192	-	3.132	-	86.551
Electrical Works							
1. Generators	16.920	7	27.050	7	-	-	
2. Transformers	3.420	7	4.550	7	-	-	
3. Other Equipment	9.480	7	12.031	7	-	-	
Total	29.820	7	43.631	7	-	-	73.451
8% Contingenc.	2.385	-	3.490	-	-	-	5.875
TOTAL ELECTR.	32.205	-	47.121	-	-	-	79.326
TOTALS	332.349		112.400		105.187		549.936

TABLE 7.2 - Cost Summary (M US$)

	Phase I	Phase II	Phase III	TOTAL
Civil, Elec. + Mech. Costs	332.349	112.400	105.187	549.936
Engineering Supervision 8%	26.588	8.992	8.415	43.995
Total Project Costs	358.937	121.392	113.602	593.931
Access Road to Stiegler's Gorge	37.00	-	-	37.00
Rufiji Bridge	5.30	-	-	5.30
Transmission Lines Not directly linked with construction phases				90.25
			TOTAL	726.48

TABLE 7.3 - Summary of Costs for Total Development (M US$ - 1978 PRICES)

YEAR	Access R.	Rufi.Br.	Power Project				Trans. lines	TOTAL
			Civil	Mech.	Elect.	Eng.Supe.		
80	13.0							13.0
81	13.0	3.0	27.14			2.17		45.31
82	11.0	2.3	39.10			3.13		55.53
83			46.89	0.32	-	3.78		50.99
84			48.30	4.58	-	4.23		57.11
85			59.80	7.99	5.40	5.86	8.0	87.05
86			44.74	9.07	5.96	4.78	8.0	72.55
87			1.95	3.78	7.38	1.05	7.75	21.91
88			-	1.30	4.22	0.44	-	5.96
89			-	2.60	3.59	0.49	8.0	14.68
90			2.24	1.3	4.14	0.61	8.0	16.29
91			5.40	11.5	4.49	1.71	7.75	30.85
92			5.06	10.75	7.22	1.84		24.87
93			1.38	6.43	4.91	1.02		13.74
94				2.64	2.92	0.44		6.0
95				2.65	2.86	0.44	5.0	10.95
96				2.64	4.91	0.60	5.0	13.15
97				2.65	2.92	0.45	4.25	10.27
98				2.64	2.86	0.44		5.94
99				5.29	7.78	1.05	5.0	19.12
00				2.65	2.86	0.44	5.0	10.95
01			28.90	2.64	4.91	2.92	4.25	43.62
02			32.66	1.62		2.74		37.02
03			29.9	1.51		2.51	5.0	38.92
04			10.60	0		0.85	5.0	16.45
05			-	-	-	-	4.25	4.25
TOTAL	37.0	5.3	384.05	86.55	79.33	43.99	90.25	726.48

TABLE 7.4 - Annual Disbursement of Total Capital Costs (M. US $) 1978 PRICES

7.2.6 Annual Disbursement of Capital Costs

For the purpose of the economic analysis (see Chapter 9) the capital costs have been scheduled anually in accordance with the phased program of development (see Chapter 4) with construction commencing in 1980 as shown in Table 7.4. A detailed schedule is given in Section 4.5.3.

7.3 Annual Costs

For the economic analysis annual operating and maintenance costs are required in addition to the capital expenditure. Those have been estimated from previous experience of hydro-electric projects, as a percentage of the capital investment in the scheme. The percentages adopted are shown in Table 7.5.

Item	% of total investment
Insurance	0.1
O and M Costs:	
- Staff	0.3
- Expenses	0.3
Plant Replacement	0.4
Contingencies	0.1
Total Annual costs	1.2

TABLE 7.5 - Annual Costs

Insurance, and operation and maintenance costs are steadily returning costs throughout the life of the scheme. The expenses element applies to a variety of items, such as: structural works, hydraulic control equipment, power station plant, switchyard and transmission, buildings, vehicles and equipment for which a weighted average of 0.3% of the total investment has been obtained.

Replacement costs of plant and equipment over the assumed project economic life of 60 years, would run intermittently. A life of 15 years has been assumed for switchgear and control works, and 30 years for other works. For convenience of the analysis, these replacement costs have been expressesd in rows of regular annual investment equivalent to 0.4% of total project investment.

7.4 Financial Costs - Phase I

For financing of Phase I of the project, budgeting for all expenditure to be incurred is required. Thus any items not included in the total estimate in Table 7.3 such as taxes and duties and price escalation must be added to the total. Also seperate budgets for local and foreign currency are required.

An accurate estimate of taxes and duties which could be involved cannot be determined in detail, but may be expected to be approximately as follows:

	M US $
Custom duties on imported equipment and materials	14
Personal income tax	14
Other levies	5
TOTAL (US $)	33 M

This amount has not been included in the budget estimates given below, but seems to demonstrate the need for adequate inter-departemental arrangements to be made in order to avoid later complications. These items would be entirely in local currency terms, and would appear only as paper transfers between the appropriate government departments. Price escalation would have to be budgetted for. The importance of adequate budgetting cannot be over emphasised, particularly at the negotiation stage of any interna-tional loans. If inadequate provi-sion is made for price escalation, the shortfall will have to be met by the Tanzanian Government from inter-nal resources, and could create a major constraint in completion of the project. A rigourous system of annual monitoring of escalation should be established together with a readily workable procedure of dealing with any shortfalls encountered. Interest on loans and loan service is not included.

For present purposes current rates of inflation of 15% in Tanzania and 6% average for the foreign countries involved, have been assumed, and a sliding reducing scale adopted for the next ten years to reach a common rate of 5% per annum:

	1978	79	80	81	82	83	84	85	86	87	88	89
Local	15	15	14	13	12	11	10	9	8	7	6	5
Foreign	6	6	6	6	5	5	5	5	5	5	5	5

To determine the amounts of local and foreign currencies in the estimates, references have been made to the initial build up of unit rates and prices. It is assumed that maximum use will be made of local materials, including timber, cement and local labour. In addition a substantial element of the costs of expartriate staff will also be incurred in local currency. The proportions of local and foreign currency elements based on the economic costs and the corresponding price contingency and total financial costs are given in Table 7.6 for the period up to 1989. Local currency represents an estimate of the proportions paid in local currency by the contractor, not necessarily the same figure as seen from a national point of view.

Thus the estimated total financial costs for the Phase I period are as follows:

	Local currency component (M. Tan. shs.)		Foreign currency component (M.US$)
Road Access and Bridge	224.7	plus	22.43
Project Works (incl. engineering)	2067.4	plus	346.35
Transmission Lines	284.6	plus	60.57
TOTAL	2576.7	plus	429.35
With exchange rate of 8.25 T.shs = 1 US$: Equivalent total 6119 M Tshs or 742 M US$.			

TABLE 7.7 - Summary of Financial Costs, Phase I

		1980		1981		1982		1983		1984		1985		1986		1987		1988		1989		1990		1991	
		Tshs	$	Tshs	$	Tshs	$	Tshs	$	Tshs	$	Tshs	$	Tshs	$	Tshs	$	Tshs	$	Tshs	$	Tshs	$	Tshs	$
ACCESS ROAD AND BRIDGE	%	(49)	(51)	(49)	(51)	(49)	(51)																		
	Cost est.	52.6	6.63	52.6	6.63	44.5	5.61																		
	Price esc.	17.0	0.82	26.7	1.27	31.3	1.47																		
	Fin. cost	69.6	7.47	79.3	7.90	75.8	7.08																		
STIEGLER'S G. PROJECT WORKS	%			(34)	(66)	(41)	(59)	(39)	(61)	(37)	(63)	(33)	(67)	(32)	[illegible]	(12)	(88)	(9)	(91)	(9)	(91)	(9)	(91)	(9)	(91)
	Cost est.			83.4	19.20	142.4	24.97	162.3	31.32	172.9	36.15	216.7	52.78	[illegible]59.0	[illegible]	13.9	12.48	4.5	5.42	5.2	6.05	4.3	5.36	2.3	2.74
	Price esc.			42.4	3.66	100.2	6.54	147.4	10.21	193.3	14.17	288.2	24.33	259.4	[illegible]	24.5	7.63	8.7	3.75	11.0	4.70	9.8	4.64	5.6	2.62
	Fin. cost			125.8	22.86	242.6	31.51	309.7	41.53	366.2	50.32	504.9	77.11	[illegible]28.4	[illegible]	38.4	20.11	13.2	9.17	16.2	10.75	14.1	10.00	7.9	5.36
TRANSMISSION LINES	%											(25)	(75)	(25)	[illegible]	(25)	(75)	(25)	(75)	(25)	(75)	(25)	(75)	(25)	(75)
	Cost est.											16.5	6.0	16.5	[illegible]	16.0	5.81			16.5	6.0	16.5	6.0	16.0	5.81
	Price esc.											21.9	2.77	25.4	[illegible]	28.2	3.55			34.8	4.66	37.4	5.19	38.9	5.57
	Fin. cost											38.4	8.77	41.9	[illegible]	44.2	9.36			51.3	10.66	53.9	11.19	54.9	11.38
	Fin. total	69.6	7.45	205.1	30.76	318.4	38.59	309.7	41.53	366.2	50.32	543.3	85.88	[illegible]70.3	[illegible]	82.5	29.47	13.2	9.17	67.5	21.41	68.0	21.19	62.8	16.74

TABLE 7.6 - Financial Costs - Local and Foreign Currencies

CHAPTER 8

PROJECT IMPLEMENTATION

PROJECT PREPARATION AND IMPLEMENTATION

8.1 Procurement Plan

Procurement of the project works for the Stiegler's Gorge Power and Flood Control Development involves a variety of inter-related tasks and numerous organizations. The tasks fall into two broad categories: preparation and implementation. Preparation is at an advanced stage. The planning stage has been substantially completed except for the power transmission system and enviromental studies including irrigation on the Rufiji river plain. The design stage is well advanced. Tender documents have been completed for the access road contract and design and documents for the dam and power project are scheduled for completion in 1980.

The following associated studies are either being commissioned or envisaged in the next 12 month period (Ref. no. 15):

- economics of power production,
- flood protection
- potentials of agriculture, fisheries and forestry
- social impacts
- ecological impacts
- physical impacts
- Stigo settlement
- operation of dam.
- reservoir impoundment

Financing for the development for Phase I now needs to be arranged for continuity of the procurement program, followed by arrangements for placing construction contracts. The main parties concerned in this stage will be the Tanzanian authorities (in particular RUBADA, but also the higher authorities concerned with planning and financing approval, and associated authorities such as TANESCO), the international aid and loan agencies, and the project consultants, in addition to the prospective tenderers.

Financing of the development is likely to involve a number of lending agencies and a carefully coordinated financing plan will have to be prepared. Separate (early) financing for the access road is discussed below. Joint financing of the other works would be possible with one agency acting as coordinator. Parallel financing of various components (e.g. items of plant) would also be possible.

The final stage of procurement is the major task of construction and commissioning of the project works. During this stage the contractors will have the prime undertaking under the supervision of the consultants. Throughout the stage the Tanzanian authorities will be required to perform the overall administration and financial control in close association with the loan disbursement and supervision functions of the lending agencies.

The following contracts have been suggested for procurement of the total development during the Phase I period:

1. Access road (Part of Southern Link Highway).
2. Rufiji Bridge.
3. Preliminary contract. (Site access roads, base camp and diversion tunnel adit.)
4. Main Dam and power station contracts
   a) All civil works.
   b) Several mechanical and electrical contracts.
5. Transmission line contract.

The main activities involved in the procurement plan are set out diagrammatically in Figure 8.1. Times have been allocated to each activity taking into account interrelationships and practical aspects. A number of long decision stages occur, and these have been noted on the diagram. Numerous factors are involved in determining each program, and modifications will be inevitable. It is important that these are anticipated as much as possible and the plan updated accordingly.

STIEGLERS GORGE POWER AND

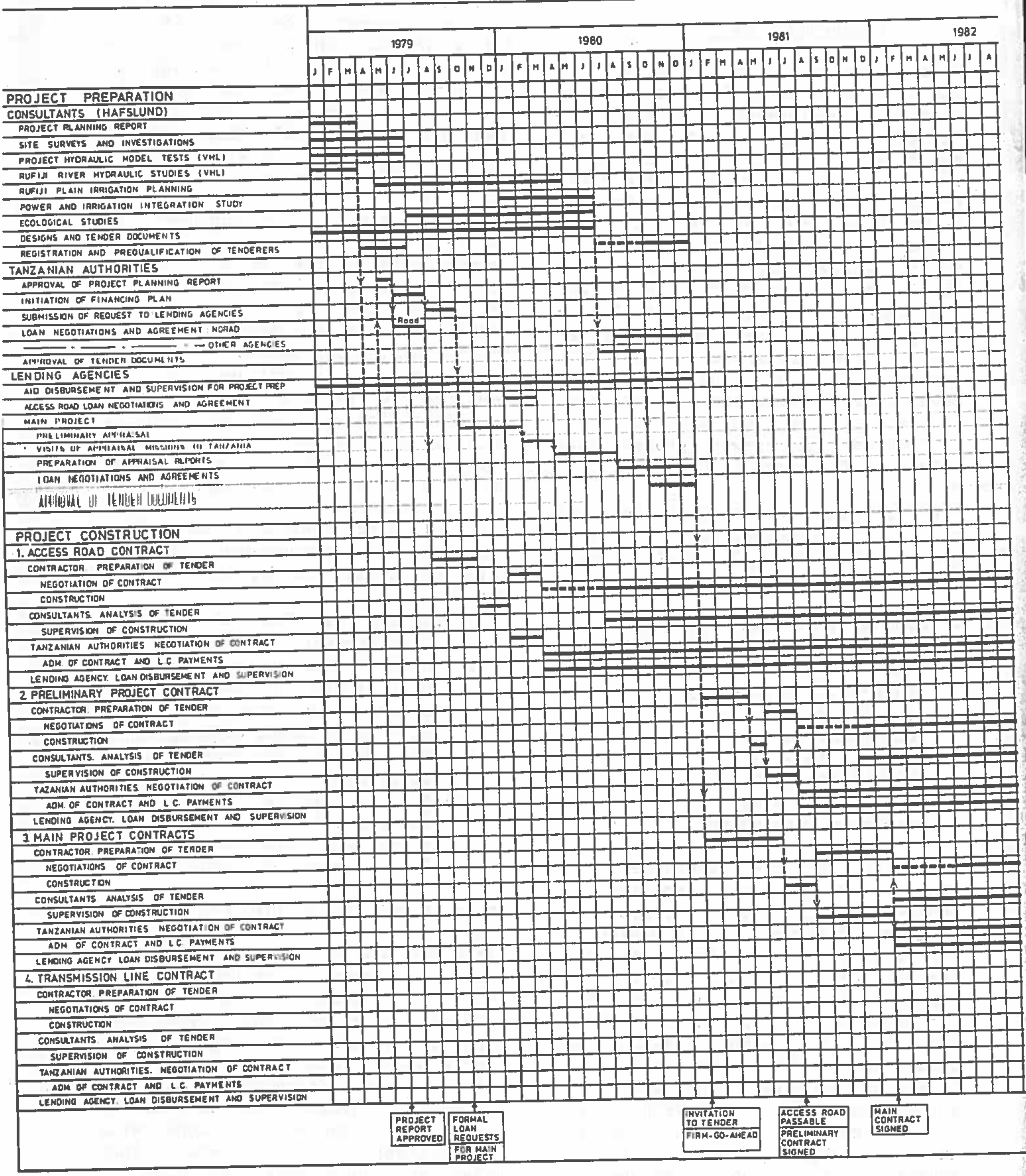
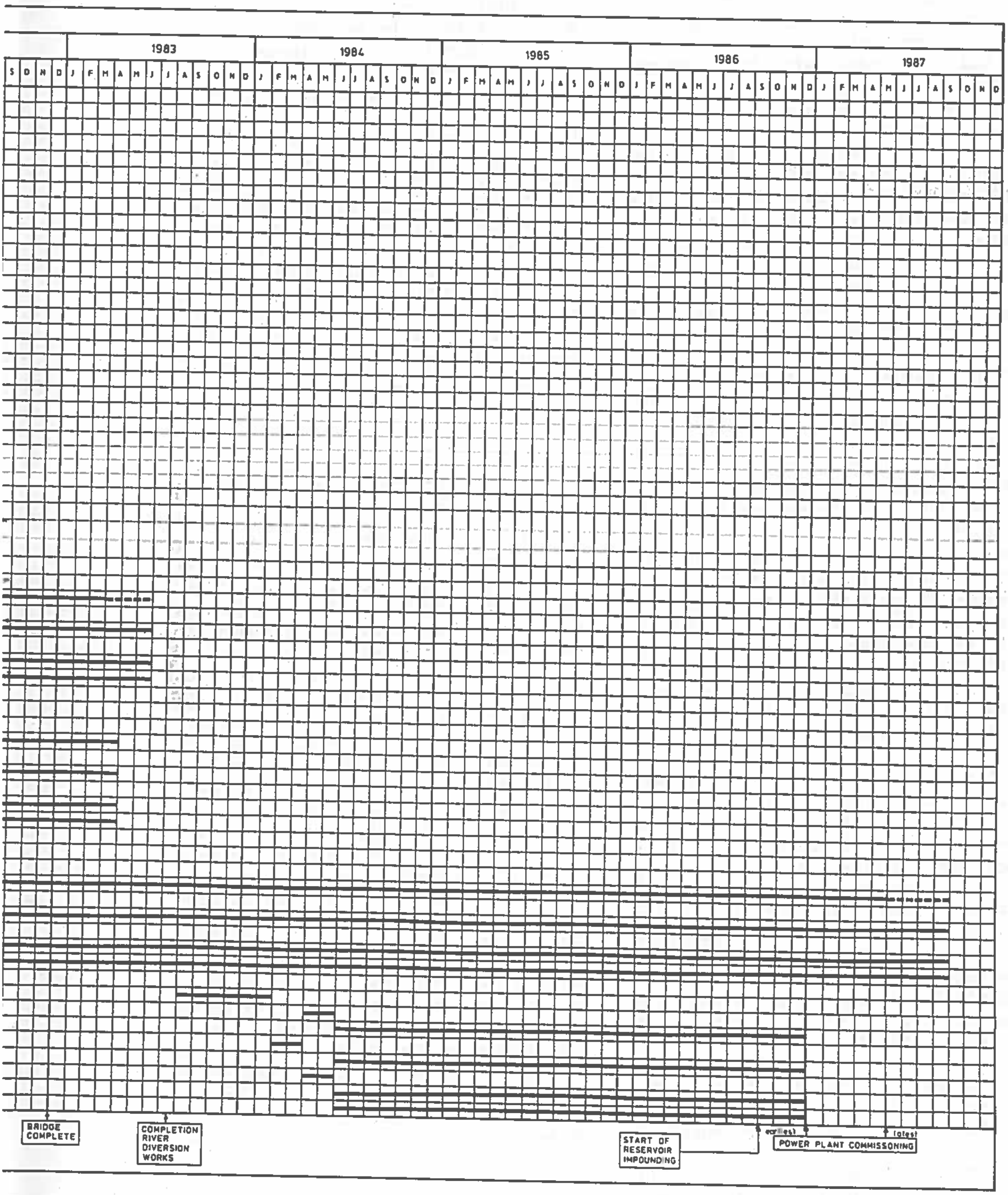


FIG. 8.1 Project Procurement Plan

FLOOD CONTROL DEVELOPMENT



It has been assumed that the access road contract will proceed at an early stage, so that the road will be useable prior to commencement of the main contract. To achieve this it will be necessary to arrange separate financing, as disbursement will have to commence well in advance of the earliest possible date for agreement for the major financing. The scheduled dates for this work are: placing of main contracts January 1982, substantial completion of road July 1981 and of the bridge January 1983. To meet this very tight schedule loan negotiations and tendering must be initiated immediately.

The preliminary contract for the site access roads, camp and diversion tunnel is expected to achieve a six months advance lead-in to the main contract and to affect commissioning accordingly. It has been assumed that tendering for this contract would not proceed before final agreement of loans for the main works. It may, however, be possible to proceed with tendering at an earlier date if it appears that the remainder of the program is likely to proceed as planned. In any event, placing of the contract could not take place until conclusion of the loan agreement.

For the main civil works a single comprehensive contract is proposed. This is considered the most appropriate arrangement for this large and complex project at a remote location. The main contractor would provide the major administration and coordination which would otherwise have to be undertaken by RUBADA. The mechanical and electrical works are proposed split into a number of separate contracts.

This system, currently adapted for similar projects, offers great flexibility in choice of supplier and thereby supplier's credit, but requires an extensive owner's staff for administration and coordination. It might prove advantageous to encourage suppliers to bid for larger packages of electrical and mechanical equipment, and when bids are received, decide on the number of contracts to be awarded.
It is important to insure that contract conditions are such that cooperation on site is encouraged.

For the transmission system, further planning is required before contracts can be detailed. Consideration also has to be given to the possibility of installing a line from the Coastal Grid at an early stage to provide power during the construction period and thus reduce transportation of fuel oil. One major problem with this possibility is the existing shortage of generating capacity in the grid at that time.

8.2 Construction and Commissioning - Phase I

The program envisaged provides for power generation to commence after the flood season during the first half of 1987. For planning purposes, generation is assumed to commence March 1987. To achieve this a critical program of construction involves diversion of the river via Tunnel No. 1 in August 1983 to enable the construction of the foundation of the dam and of cofferdams No. 3 and 4 by December 1983 when overtopping can be expected. Following the 1983-84 flood period, the dam must be raised to a high enough level before the 1984-85 flood season for continuous construction to be possible (whilst the flood flows pass through openings in the dam). Thereafter concreting, cooling and grouting must proceed on schedule (including closure of diversion openings during the three month period, July to September 1986) for reservoir impoundment to commence in October 1986. The construction program is shown in the Album of Drawings, Plate 19.

Sealing off both diversion tunnels and installation of the gates in Tunnel No. 2 (see Annex VII) will then enable impoundment to proceed with minimum downstream releases. The gate installation and various sealing operations are critical to the smooth fulfillment of the impoundment procedure.

Power generation will be able to commence once LRWL has been reached, i.e. at El. 158 corresponding to an impoundment of 9600 M m^3 (see Fig. 8.2). The timing of this event is therefore dependent on the volume of flood inflow during the impoundment season.

Power Station A construction, including installation of plant, will proceed in parallel with the dam construction and transmission line installation. Commissioning of the station is expected to follow the pattern shown in Fig. 8.2, involving RUBADA staff and the plant manufacturer's staff. Final trials cannot be carried out until the water level has reached El. 158.

8.3 Project organization and training

The Rufiji Basin Development Authority was established by the Government of Tanzania under Act. No. 5 of 1975, with responsibility for undertaking the following functions within the entire Rufiji catchment area, hereafter referred to as the Development Area:

a) to generate electricity by means of hydro-electric works in the Development Area and to supply, on such terms and conditions as the Board may, subject to the provisions of this Act, approve, electricity so generated for the promotion of industries and the general welfare of the people of the United Republic of Tanzania,

b) to undertake measures for flood control,

c) to promote and regulate industrial activities within the Development Area,

d) to promote and regulate agricultural activities within the Development Area,

e) to promote and regulate the development of forestry within the Development Area and to take measures to ensure the prevention or minimization of soil erosion,

f) to promote and regulate fishing industry in the rivers, lakes and dams within the Development Area,

g) to promote and regulate public inland water and road transport system within the Development Area,

h) to promote tourism within the Development Area and to provide

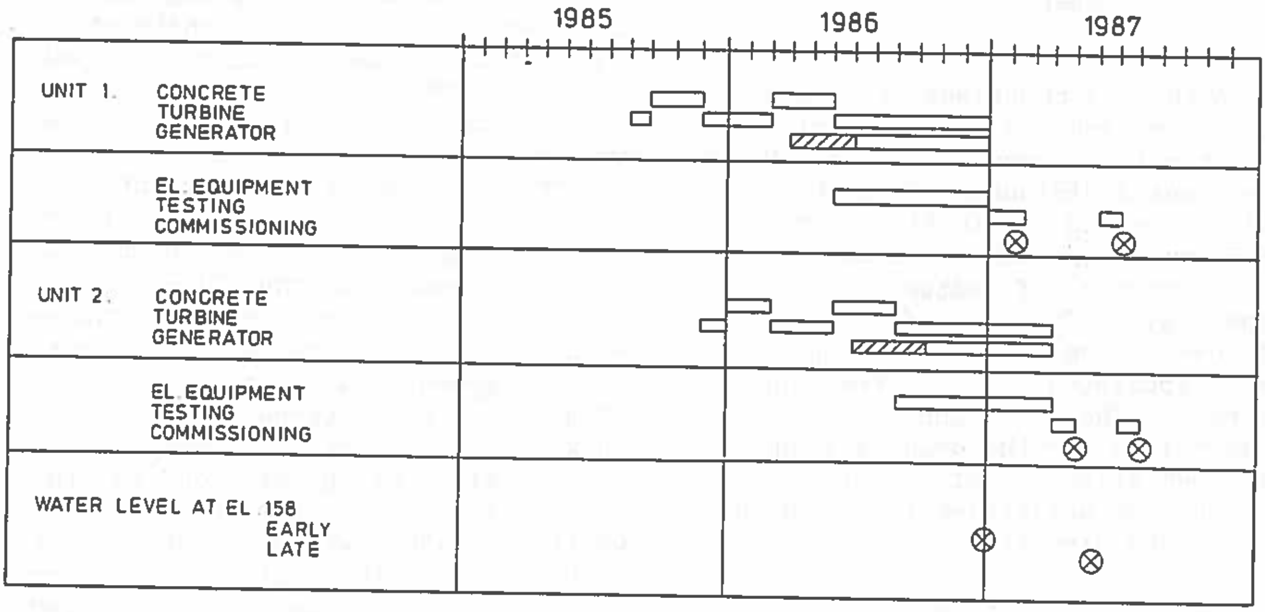


FIG. 8.2 Phase I Commissioning Plan

assistants, and electro-mechanics) and during the initial operating period. The personnel manager will have direct responsibility for organization of training, and will thus require to be appointed at an early stage.

	Part 1	Part 2	Part 3
Training place and personnel concerned	Training in Norway for the technical part of the management and shift charge engineers (chief dam inspector and foremen).	Training at Stiegler's Gorge for foremen, skilled workers, operatives assistants, dam inspectors and electro-mechanics.	Training in Stiegler's Gorge for all personnel categories.
Responsible body	Consultants.	The management after returning from their training in Norway, with assistance of the consultants.	The consultants and the plant manufacturers.
Extent of the training	18 weeks theoretical training at a Technical College in Norway. 22 weeks practical training at power plants and distribution systems.	Theoretical training courses. Practical training in workshops and station installation	Practical training.
Time for the training	At the end of the planning period or early in the construction period. About 1981-82.	In the construction and installation period. About 1982-86	The starting period and the first period of operation. About 1986-88

TABLE 8.1 - Training Program with Time Schedule

CHAPTER 9

PROJECT ECONOMICS

PROJECT ECONOMICS

9.1 Introduction

The economic evaluation has been strictly confined to the costs of the project and the direct benefits. This accords with normal practice for determining economic justification for project financing and implementation. However, it can be shown that additional benefits can be expected from a wide range of fringe aspects. Some of these are receiving attention by RUBADA, and when the additional benefits have been ratified, a revised evaluation should be possible, resulting in enhanced justification.

The economic analysis has been made in present value terms, taking into account the complete costs (capital and annual costs but excluding price contingencies) scheduled annually over the period 1980 to 2046 (covering the initial period of construction and a further 60 years from the first commissioning).

The analysis was made using three discount rates, 7%, 9%, and 12%, covering the range of possible opportunity cost of capital. While it can be argued that in real terms the oportunity cost for low risk long term investment the lower rate is applicable, projects for international financing are generally assessed using a rate of 10%. Arguments can also be advanced that even higher opportunity costs could be obtained.

for multipurpose project discount rate of as low as 3½ - 4% has been used in U.S. etc.

As the cost estimates have been made in terms of US$, the economic evaluation has been made in these terms also, and no shadow pricing introduced.

Important should be

9.2 Power Costs

The economic evaluation has been limited to the power project only, as it is not possible at the present state of the studies to undertake an overall evaluation involving the other benefits associated with the project. Although it would be very desirable to include net agricultural benefits in the evaluation, too many assumptions would have to be made in the assessment. To obtain a reliable value for absolute agricultural benefits is impossible without detailed agricultural studies for the river plain. It is intended that such studies will be made prior to completion of the design stage, including an economic evaluation of the total development.

It is therefore necessary at present to allot an element of the project works costs to flood control and irrigation and to exclude these from the economic analysis of the power project. No clear physical division of the works between power and flood control is possible, except for the power stations including the plant and electrical equipment. Simply as a nominal amount, it has been assumed that 15% of the value of the remaining works can be allocated in flood control. This is considered a conservative assumption, leading if anything to an over-estimate of the power costs of the project. Provided the project can be justified economically on this assumption, it may be reliably concluded that the total project is favorable.

Other costs that could be put to the project are land costs, forest removal costs and defence costs. However, these are not included in the present evaluation. On the other hand, the total costs of the road access and Rufiji bridge have been included although these investments also represent a part of the planned Southern Link National Highway.

The annual cost is based on 1.2% of the total investment including road access, bridge and transmission lines as presented in Table 7.4. The economic lifetime of the power plant is assumed to be 60 years, and that of the transmission lines is

* = make an alternative assessment of cash flow without ...

assumed to be 40 years. The PV calculation base year is 1980, the costs are in 1978 terms.

9.3 Power Benefits

Because of the relatively small present power sales in Tanzania compared with the very large projected increases, an economic price for power is not readily available. The value of power production cannot therefore be determined in economic terms, although a probable range may be known (see Section 9.6). Thus, as a substitute measurement of net benefits, the difference in total costs (in present value terms) between the Stiegler's Gorge project and the next most economic equivalent power project, may be used. In this way, net benefits are evaluated in terms of marginal cost savings.

For reliable assessment of the marginal cost savings it is important that the cost estimates of the two projects considered have a high degree of accuracy, as otherwise the difference in cost may be of the same order as the errors in the estimates.

Studies carried out by TANESCO have analyzed the possible alternative power projects, from which it has been concluded that thermal coal fired production would be the most feasible and economic alternative.

The investment costs are based on increments of 50 MW coal fired plant at 1978 prices. The cost of US$ 52.3 M per increment has been used (Ref. No. 14).

The increments are scheduled according to the same power demand forecast as the Stiegler's Gorge plant, including the same 20% reserve capacity and the same base system capacity. The economic lifetime of an increment is assumed to be 30 years.

Two locations of the coal-fired power plants are analyzed, the first location (A) being at the mine mouth with necessary 220 kV lines to a main distribution point in the grid, the second (B) being at the main load center of Dar es Salaam with coal transported by railway to the plant.

For the first 150 MW plant of the mine mouth location only the extra cost of a 220 kV transmission line above the planned south west extension (132 kV) has been allocated to the option. This extra cost is 13.4 M$ according to Ref. No. 14. The following increments will need new 220 kV lines to a main distribution point in the grid, and line costs for connection at Morogoro (800 km) has been used (see Annex VIII for line costs).

For the Dar es Salaam location no transmission line costs have been assumed.

A fixed operating and maintenance cost of $30 per kW installed has been assumed for the analysis. This sum is 3.15% of the investment cost. As it was desirable to account for the operating and maintenance costs as a fixed percentage of the investment, as done for the Stiegler's Gorge plant, the following annual cost was assumed:

Insurance	0.25%
O and M cost	3.15%
Plant re-placement	0.35%
Thermal annual cost	3.75% of investment.
Transmission line annual cost	1.2% of investment.

The cost of coal delivered at a thermal station is the most important cost in the thermal alternative. A preliminary study was available (Ref. No. 14) indicating the cost of coal at the mine mouth to be $0.0085 per kWh. (The heat rate of the indigenous coal is 11,200 BTU/kWh).

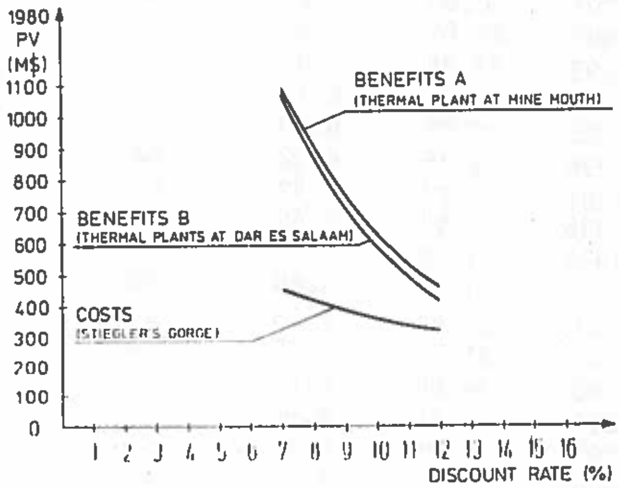
The cost of rail transport from the mine mouth to Dar es Salaam (approximately 950 km) has been estimated to be 210 Tshs per ton (1978 prices) or $0.0122 per kWh. (448 t coal is required to generate 1 GWh).

Compared to world oil prices it appears that the fuel costs, which represent 1978 prices, could be low. Consideration has been given to the effect of high cost in Section 9.6.

For alternative A (mine-mouth location), energy losses in the transmission lines have been assumed to be 15%. These losses are also reflected in increased need for capacity. A 15% increase in the PV investment and annual cost has therefore been included, together with the 15% increase in fuel costs. The increased investment cost includes transmission lines. The high losses and low capacity of 220 kV line on such long distances indicate that a 380 kV voltage level would be preferred. For simplicity, however, a 220 kV level was assumed for this analysis. It is considered that the costs used in the analysis would not be significantly affected if a 380 kV line were assumed.

9.4 Results

Table 9.1 shows the cost and benefit distribursement used. Table 9.2 and 9.3 summarizes the PV costs and benefits, while Table 9.4 shows the net benefit results. These result are plottet graphically in Figure 9.1.



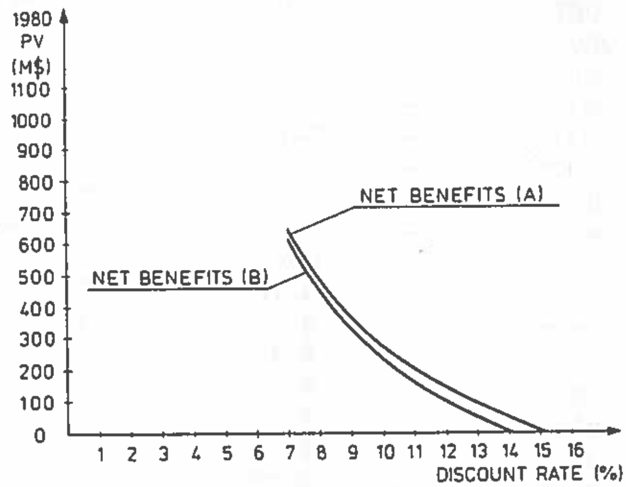


FIG. 9.1 Economic Analysis Result

	Costs		Benefits					
	Stiegler's Gorge		Coal Thermal Mine Mouth			Coal Thermal, Dar es Salaam		
Year:	Investm.	Annual	Investm.	Annual	Fuel	Investm.	Annual	Fuel
1980	13.00							
1981	40.91							
1982	48.33							
1983	44.29							
1984	50.41							

	Costs		Benefits					
	Stiegler's Gorge		Coal Thermal Mine Mouth			Coal Thermal, Dar es Salaam		
Year:	Investm.	Annual	Investm.	Annual	Fuel	Investm.	Annual	Fuel
1985	79.05					104.6		
1986	66.95		118.0			52.3	3.92	7.76
1987	21.91	4.57	52.3	4.08	3.19	-	5.88	10.14
1988	5.96	4.83	-	6.04	4.16	52.3	5.88	12.69
1989	14.68	4.90	128.3	6.04	5.21	-	7.85	15.40
1990	16.29	5.08	-	8.92	6.32	52.3	7.85	18.28
1991	30.85	5.27	52.3	8.92	7.51	-	9.81	21.36
1992	24.87	5.65	-	10.87	8.77	52.3	9.81	24.63
1993	13.74	5.95	52.3	10.87	10.12	52.3	11.77	28.11
1994	6.00	6.11	128.3	12.84	11.54	-	13.73	31.82
1995	10.95	6.20	-	15.71	13.06	52.3	13.73	35.77
1996	13.15	6.32	52.3	15.71	14.69	52.3	15.69	32.99
1997	10.27	6.47	52.3	17.67	16.42	52.3	17.65	44.46
1998	5.94	6.60	52.3	19.63	18.26	52.3	19.61	49.25
1999	19.12	6.67	128.3	26.60	20.22	52.3	21.57	54.34
2000	10.95	6.89	52.3	22.51	22.31	52.3	23.54	59.74
2001	39.68	7.03	52.3	26.44	24.53	52.3	25.50	65.52
2002	31.73	7.55	128.3	28.40	26.90	52.3	24.46	71.64
2003	34.08	8.01	52.3	31.27	29.42	104.6	29.42	78.38
2004	14.74	8.46	104.6	33.22	32.10	52.3	33.34	85.16
2005	4.25	8.69	128.3	37.14	34.97	52.3	35.30	92.57
2006	-	8.72	52.3	40.02	38.01	-	37.26	100.48
2007	-	8.72	-	42.00	41.26	-	37.26	108.90
2008	-	8.72	-	42.00	44.72	-	37.26	116.75
2009	-	8.72	-	42.00	47.94	-	37.26	116.75
2010	-	8.72	-	42.00	47.94	-	37.26	116.75
2011	-	8.72	-	42.00	47.94	-	37.26	116.75
2012	-	8.72	-	42.00	47.94	-	37.26	116.75
2013	-	8.72	-	42.00	47.94	-	37.26	116.75
2014	-	8.72	-	42.00	47.94	-	37.26	116.75
2015	-	8.72	-	42.00	47.94	104.6	37.26	116.75
2016	-	8.72	118.0	42.00	47.94	52.3	37.26	116.75
2017	-	8.72	52.3	42.00	47.94	-	37.26	116.75
2018	-	8.72	-	42.00	47.94	52.3	37.26	116.75
2019	-	8.72	128.3	42.00	47.94	-	37.26	116.75
2020	-	8.72	-	42.00	47.94	52.3	37.26	116.75
2021	-	8.72	52.3	42.00	47.94	-	37.26	116.75
2022	-	8.72	-	42.00	47.94	52.3	37.26	116.75
2023	-	8.72	52.3	42.00	47.94	52.3	37.26	116.75
2024	-	8.72	128.3	42.00	47.94	-	37.26	116.75
2025	-	8.72	-	42.00	47.94	52.3	37.26	116.75
2026	-	8.72	52.3	42.00	47.94	52.3	37.26	116.75
2027	23.75	8.72	52.3	42.00	47.94	52.3	37.26	116.75
2028	-	8.72	52.3	42.00	47.94	52.3	37.26	116.75
2029	-	8.72	128.3	42.00	47.94	52.3	37.26	116.75
2030	-	8.72	52.3	42.00	47.94	52.3	37.26	116.75
2031	23.75	8.72	52.3	42.00	47.94	52.3	37.26	116.75
2032	-	8.72	128.3	42.00	47.94	52.3	37.26	116.75
2033	-	8.72	52.3	42.00	47.94	104.6	37.26	116.75
2034	-	8.72	104.6	42.00	47.94	52.3	37.26	116.75
2035	-	8.72	128.3	42.00	47.94	52.3	37.26	116.75
2036	-	8.72	52.3	42.00	47.94	52.3	37.26	116.75
2037	14.25	8.72	52.3	42.00	47.94			

	Costs		Benefits					
	Stiegler's Gorge		Coal Thermal Mine Mouth			Coal Thermal, Dar es Salaam		
Year:	Investm.	Annual	Investm.	Annual	Fuel	Investm.	Annual	Fuel
2038	-	8.72	52.3	42.00	47.94	52.3	37.26	116.75
2039	-	8.72	52.3	42.00	47.94	52.3	37.26	116.75
2040	-	8.72	52.3	42.00	47.94	52.3	37.26	116.75
2041	14.25	8.72	52.3	42.00	47.94	52.3	37.26	116.75
2042	-	8.72	52.3	42.00	47.94	52.3	37.26	116.75
2043	-	8.72	52.3	42.00	47.94	52.3	37.26	116.75
2044	-	8.72	52.3	42.00	47.94	52.3	37.26	116.75
2045	14.25	8.72	52.3	42.00	47.94	52.3	37.26	116.75
2046	-	8.72	52.3	42.00	47.94	52.3	37.26	116.75

TABLE 9.1 - Schedule of Costs and Benefits (M US$)

Discount rates	7%	9%	12%
Investment costs	387.8	342.8	292.9
Annual costs	62.6	42.2	25.6
Total PV costs	450.4	385.0	318.5

TABLE 9.2 -
Present Value of Power Costs (M US$)

	A - (Mine Mouth Loc.)			B - (Dar es Salaam Loc.)		
	7%	9%	12%	7%	9%	12%
Investment Costs	545.2	401.2	271.5	396.0	302.1	199.9
Annual Costs	203.1	125.1	67.0	181.4	112.1	58.0
Fuel Costs	204.3	122.8	63.5	497.5	299.0	154.6
Losses in Power Trans (15%)	142.9	97.4	60.4	-	-	-
Total PV benefits	1095.5	746.5	462.4	1074.9	713.2	412.5

TABLE 9.3 -
Present Value of Power Benefits (M US$)

	A - (Mine Mouth Location)			B - (Dar es Salaam Location)		
Discount Rates	7%	9%	12%	7%	9%	12%
Power Benefits	1095.5	746.5	462.4	1074.9	713.2	412.5
Power Costs	450.4	385.0	318.5	450.4	385.0	318.5
Net Benefits	645.1	361.5	143.9	624.5	328.2	94.0

TABLE 9.4 - Net Power Benefits (M US$)

9.5 Sensitivity Tests

The effects of various changes in the factors in the economic analysis have been examined, including increase in project costs, decrease in power demand, and increases in thermal alternative costs (i.e. increases in power benefits). The sensitivity tests reported below are only on Alternative B, the thermal plant at Dar es Salaam, since this alternative is less favorable to Stiegler's Gorge. Corresponding sensitivity tests on Alternative A, the thermal plan at the mine mouth, show greater benefits to Stiegler's Gorge with rates of return approximately 1% higher. The Dar es Salaam location of the coal thermal plants has been argued to be doubtful due to the operational constraints of the TAZARA railway. A mine mouth location, however, may also cause technical and operational difficulties due to the long transmission lines needed.

Increased Cost of Stiegler's Gorge

The possibility of increases in project costs cannot be ignored as some uncertainty concerning market conditions at the time of construction and many unforeseeable factors causing repercussions, are inevitable. A sensitivity test on the economic evaluation has therefore been made, involving a major increase in Stiegler's Gorge costs alone of 30%. The results show that net benefits would be reduced as follows: (M US$)

Discount rates	7%	9%	12%
Net benefits from economic analysis	625	328	94
Reduction with 30% costincrease	135	116	96
Net benefits with 30% cost increase	490	212	-2

This shows that the rate of return would be reduced to 12%.

Decrease in Power Demand Growth Rate

A decrease in power demand of 23% has been tested. This amount corresponds to a growth rate of 5% after 1985. The resulting net benefits would be as follows: (M US$)

Discount rates	7%	9%	12%
Net benefits from economic analysis	625	328	94
Reduction with 23% demand decrease	240	180	120
Net benefits with 23% demand decrease	385	148	-26

The rate of return would be reduced to 11.5%.

Increased Costs for Thermal Plant

The possibility of increases thermal costs has to be considered in view of the relatively low values adopted in the estimates. Such increases would obviously increase the net benefit of the Stiegler's Gorge hydro project. This can be demonstrated assuming a 30% increase in both fuel and investment costs as follows: (M US$)

Discount rate	7%	9%	12%
Net benefits from economic analysis	625	328	94
Increase with 30% increase in thermal	173	124	77
Increase with 30% increase in fuel costs	149	90	46
Net benefits with 30% increase in thermal investment and fuel costs	947	542	217

These figures show very substantial increases. A corresponding major increase in the rate of return would result, bringing the value to 20%.

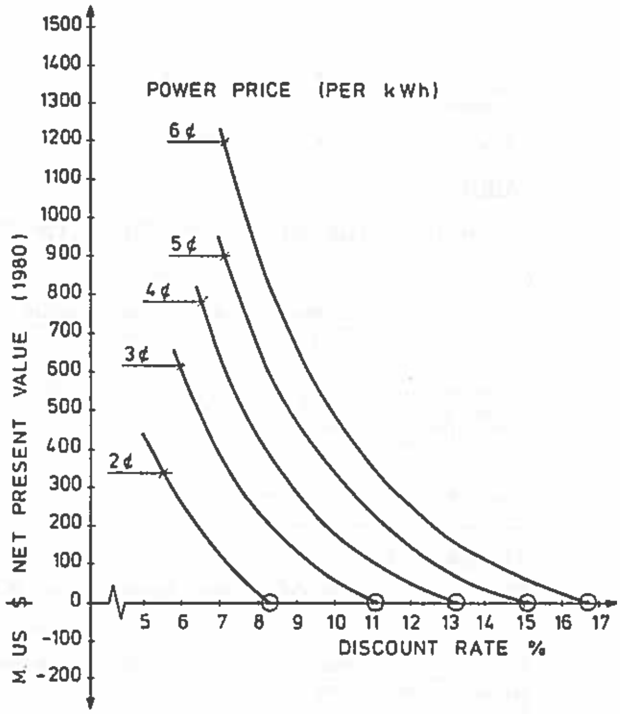


FIG. 9.2 Net Present Benefits based on Power Sales

Analysis using Power Price

A check on the economic results was made by using the present power cost in Tanzania as a measure for power benefits. The results are shown in Fig. 9.2 and show an internal rate of return of 15.8% for the present power cost, according to Tanesco, of 5.5 US¢/kWh (generation and associated transmission).

9.6 Conclusion

The economic evaluation indicates that the Stiegler's Gorge project is justified economically, with a rate of return of 14% and total net power benefits equivalent to some US$ 250 million at 10% discount rate. Whereas increases in project costs or decreases in power demand would reduce the return, it has been demonstrated that such changes would have to be very substantial (i.e. greater than 20-30%) before the viability of the project becomes doubtful.

9.7 Timing analysis of the project

As the project has been found economically viable it is necessary to analyze its optimum timing, i.e. the economically correct year for project commissioning. An extensive analysis of this problem is found in Ref. No. 14: Economic Choices for Electrical Energy Supply in Tanzania, Feb. 1979. The phase-in years analyzed in this reference are 1987, 1990, 1993, 1998. The analysis is done on both the central grid (today's grid plus Zanzibar) and the extended grid in order to show the viability of grid extension. Only the extended grid options and results are quoted here.

Timing options:

Option No.:	Phase-in year:	Fill-in MW:	Option
10	1987	0	- Stiegler's Gorge (S.G.) in 1987
11	1990	73.5	- 74 MW coal, then S.G.
11A	1990	73.5	- 74 MW oil, then S.G.
12	1993	158.3	- 158 MW coal, then S.G.
13	1993	"	- Mtera power house (hydro) with opt. coal back-up, then S.G.
14	1998	353.0	- 353 MW coal, then S.G.
15	1998	"	- Mtera power house with opt. coal back-up to 353 MW, then S.G.

The results are quoted from Table 43 in Ref. No. 14:

Present value cost summary and ranking of options (time period 1980 - 2030, 1979 as base year)

Option No.	8% discount rate PV in M US$	Rank	12% discount rate PV in M US$	Rank
10	348.4	1	293.2	3
11	424.0	3	303.7	4
11-A	399.4	2	281.5	1
12	431.8	4	292.3	2
13	459.4	5	312.3	5
14	495.1	6	317.9	6
15	503.3	7	322.6	7
16	617.7	8	352.9	8

Shadow pricing would change this ranking

The analysis in Ref. No. 14. concludes that:

"An early commissioning of hydro-electric power from Stiegler's Gorge appears to be the optimal strategy of the options tested, given the emerging level and patterns of energy consumption in Tanzania"

APPENDIX

10. Rodgers, W.A.: THE STIEGLER'S GORGE DAM AND ENVIRONMENTAL VALUES IN THE RUFIJI BASIN.
BRALUP, 1977

11. Temple, Sundborg: THE RUFIJI RIVER, TANZANIA HYDROLOGY AND SEDIMENT TRANSPORT
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Geological Survey of Tanganyika,
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13. Hazelwood, A.: THE USANGU PLAINS.
Commonwealth Foundation, Marlborough House,
Pall Mall,
London 1978.

14. Segal, Mosha: ECONOMIC CHOICES FOR ELECTRICAL ENERGY SUPPLY IN TANZANIA.
A report to the Ministry of Water, Energy and Minerals and the Ministry of Industries,
Dar es Salaam 1979.

15. RUBADA: RUFIFI BASIN STUDY PROGRAMME,
1979.

16. RUBADA: DRAFT FINAL DESIGN REPORT
Access Road to Stiegler's Gorge
August 1978

APPENDIX NO. 2

AERIAL PHOTOGRAPHY AND MAPS

The following aerial photography and mapping has been worked out for the Stiegler's Gorge Power and Flood Control Development.

AERIAL PHOTOGRAPHY

AREA	PHOTO SCALE
Saddle dams	1:20000
Dam Site	1: 6000
Reservoir	1:35000
Shuguri Falls	1:20000
Saddle dams	1:10000
Access road	1:10000
Downstream, Part 1	1:20000
Dam site	1: 3500
South of Shuguri Falls	1:25000
Stiegler's Gorge	1: 6000
Downstream, Part 2	1:20000
Delta	1:22000

MAPPING:

AREA	MAP SCALE	CONTOUR INTERVAL	COORDINATE SYSTEM
Saddle dams	1:10000	2 m	U.T.M.
Reservoir	1:20000	5 m	U.T.M.
Shuguri Falls	1: 5000	2 m	U.T.M.
Access road	1: 2000	1 m	U.T.M.
Dam site	1: 1000	1 m	Local
Saddle dams	1: 2000	1 m	Local
Flood Plain	1:10000	2 m	U.T.M.

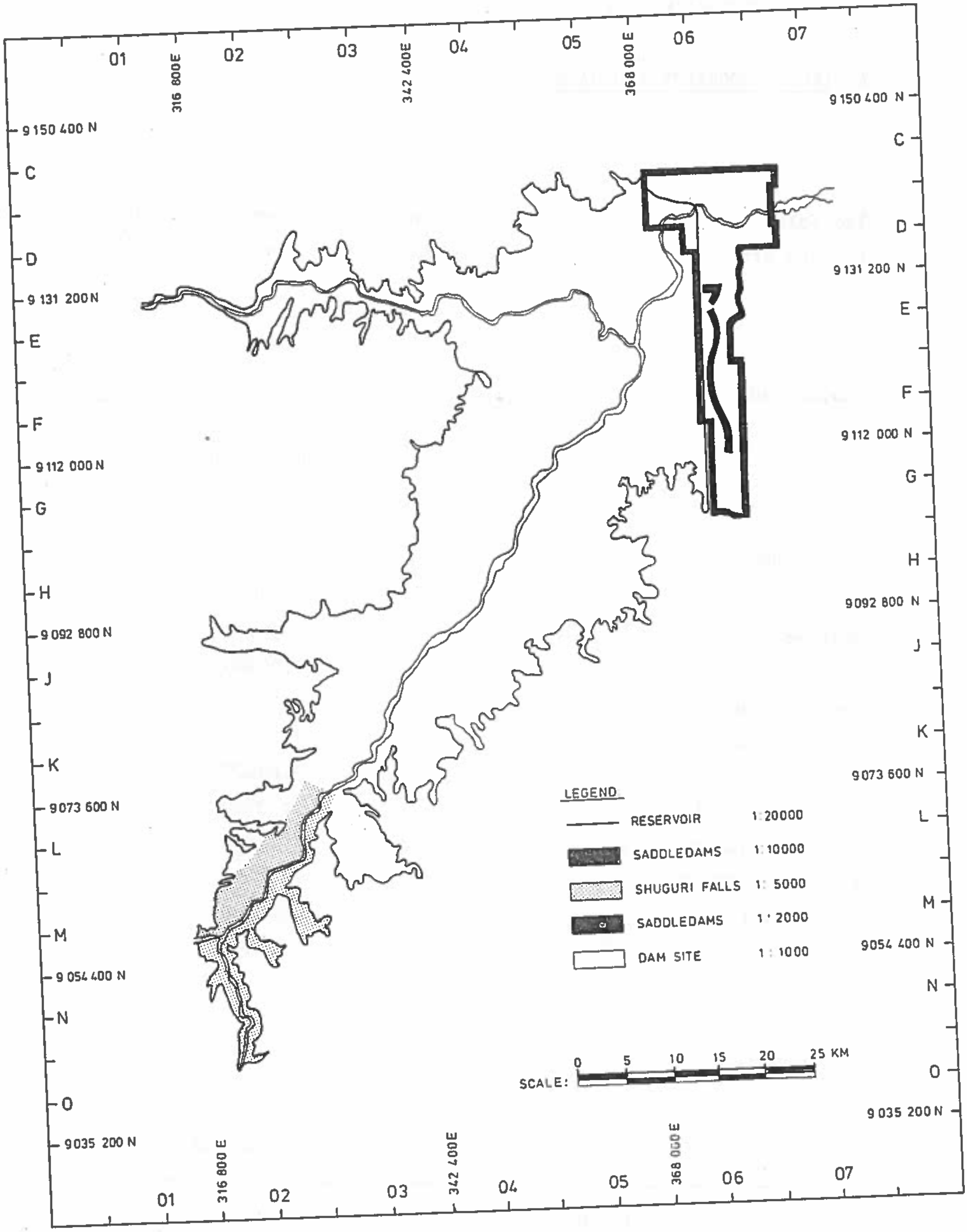

FIG. II - 1 The Rufiji Power Development at Stiegler's Gorge Available maps.