THE UNITED REPUBLIC OF TANZANIA

FEASIBILITY STUDY ON KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

FINAL REPORT

OCTOBER 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

THE UNITED REPUBLIC OF TANZANIA

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PREFACE

In response to the request from the Government of the United Republic of Tanzania, the Government of Japan decided to conduct a feasibility study on Kihansi Hydroelectric Power Development Project and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Tanzania a study team headed by Mr. Yasumasa Ebi of Electric Power Development Co., Ltd. six times from January 1989 to September 1990.

The team held discussions on the Project with the officials concerned of the Government of Tanzania and conducted field surveys. After the team returned to Japan, further studies were made and the present report was prepared.

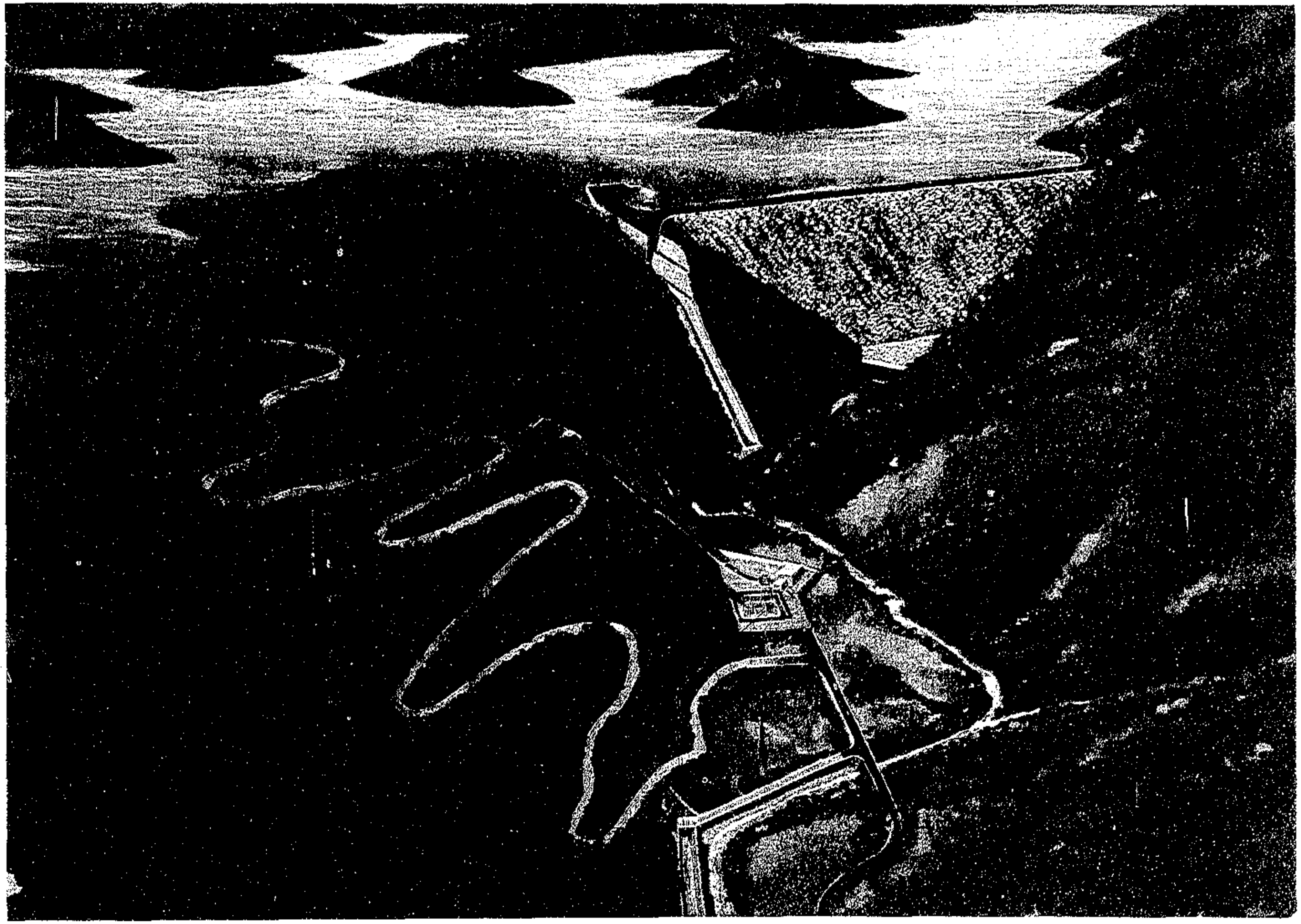
I hope that this report will contribute to the development of the project and to the promotion of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of Tanzania for their close cooperation extended to the team.

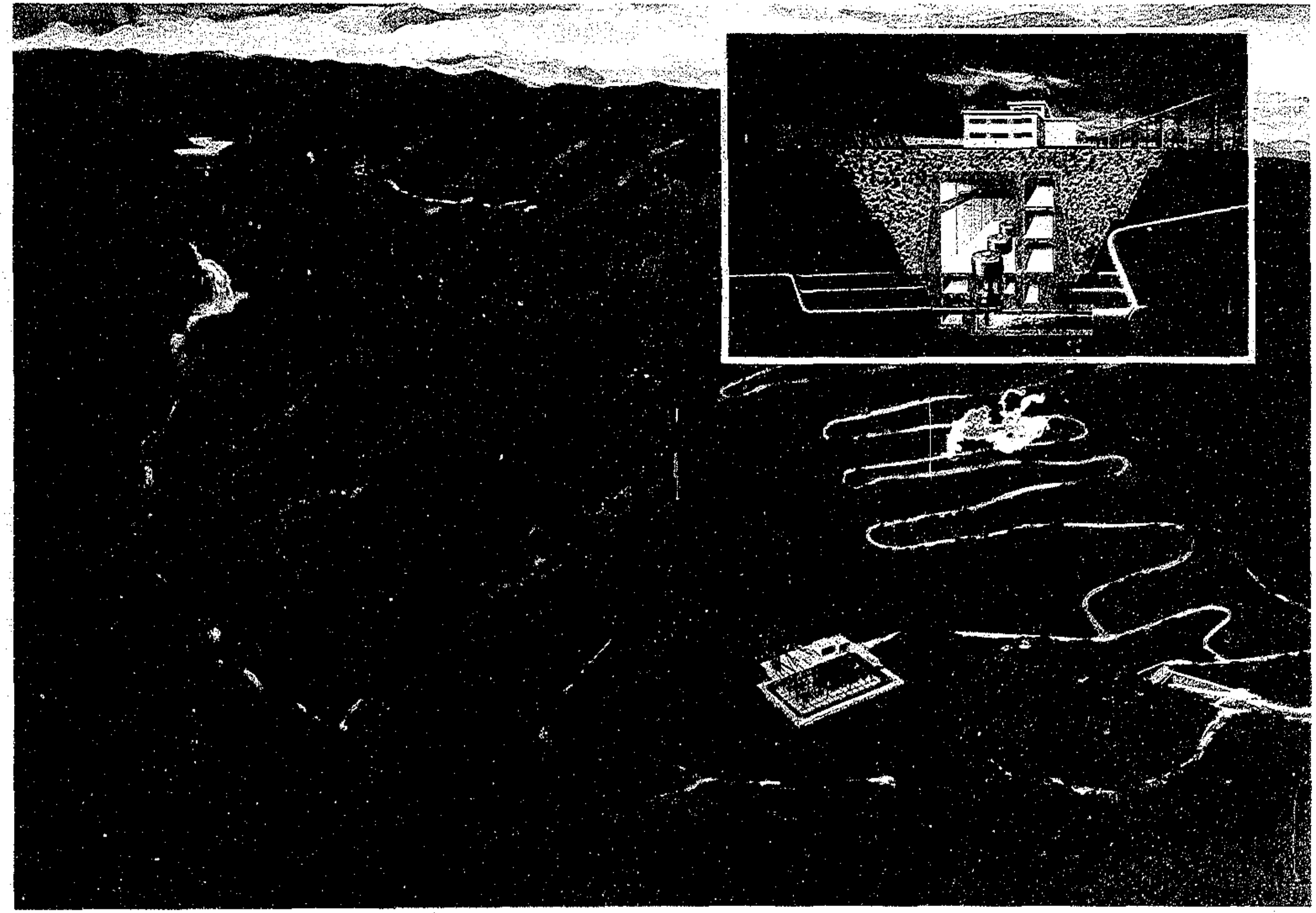
October, 1990

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency



Upper Kihansi Project

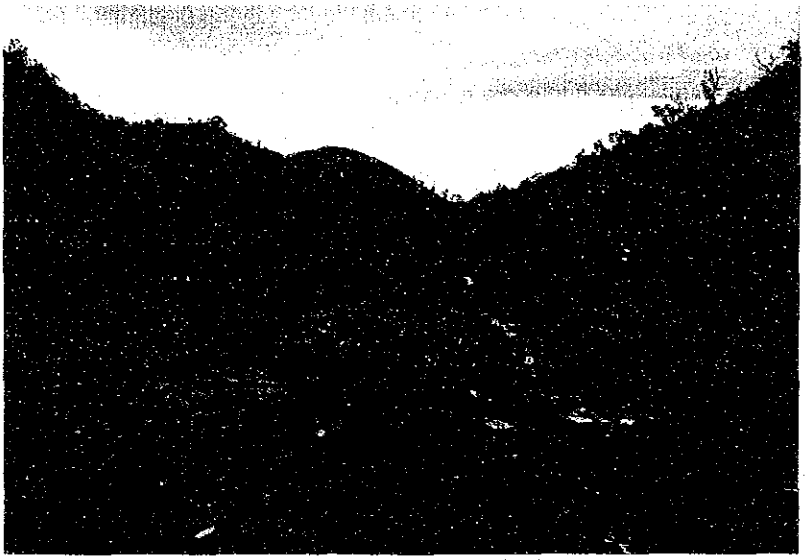


Lower Kihansi Project

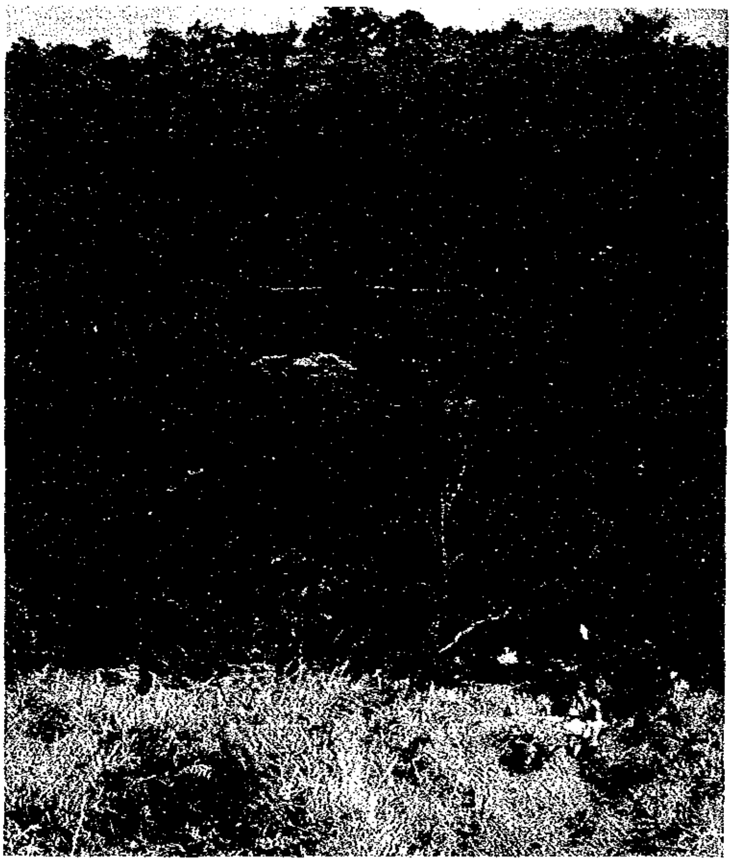
Upper Dam Site
View from the upstream left bank

Cascade of Kihansi River Between Upper Dam and Powerhouse

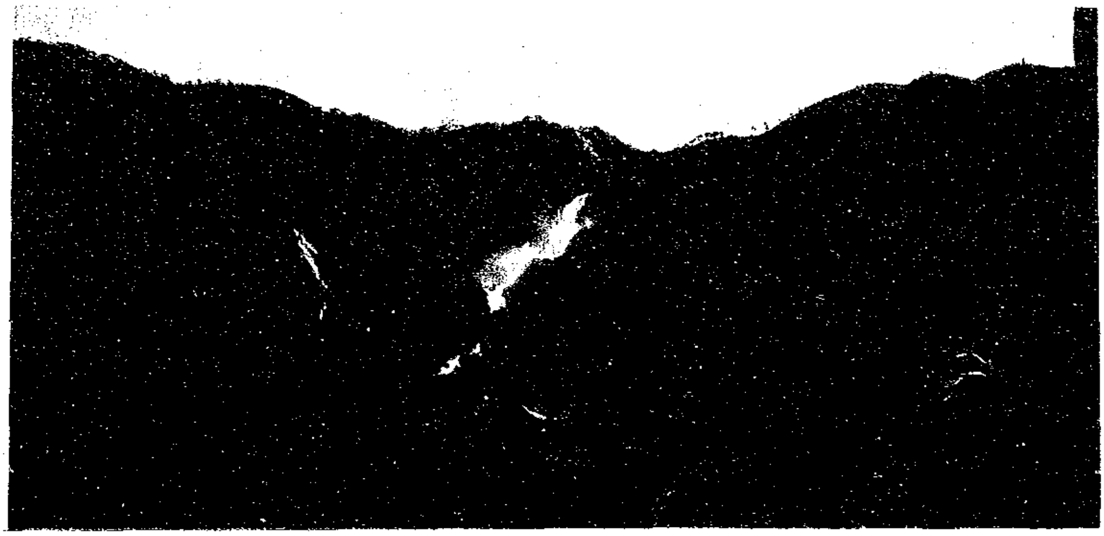
Upper Powerhouse and Tailrace Sites
View from the site of the upper part of penstock



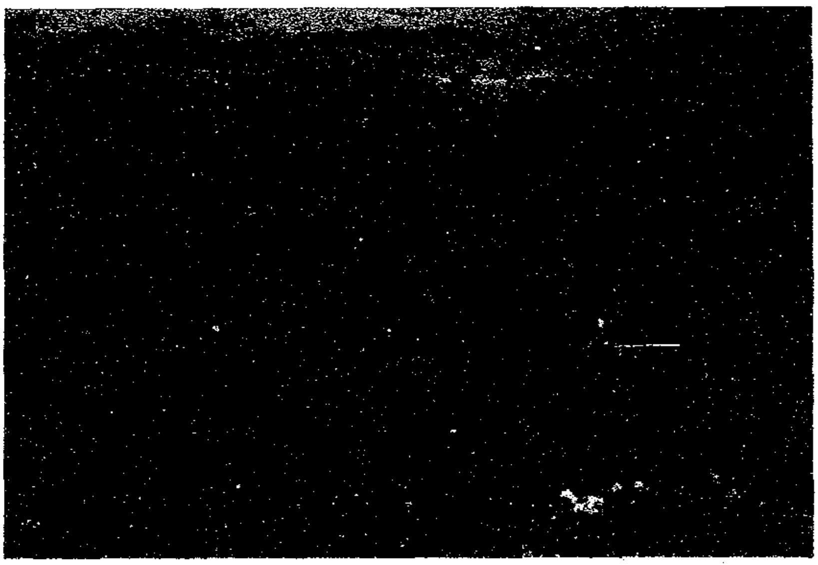
Lower Dam Site
View from the upstream left bank



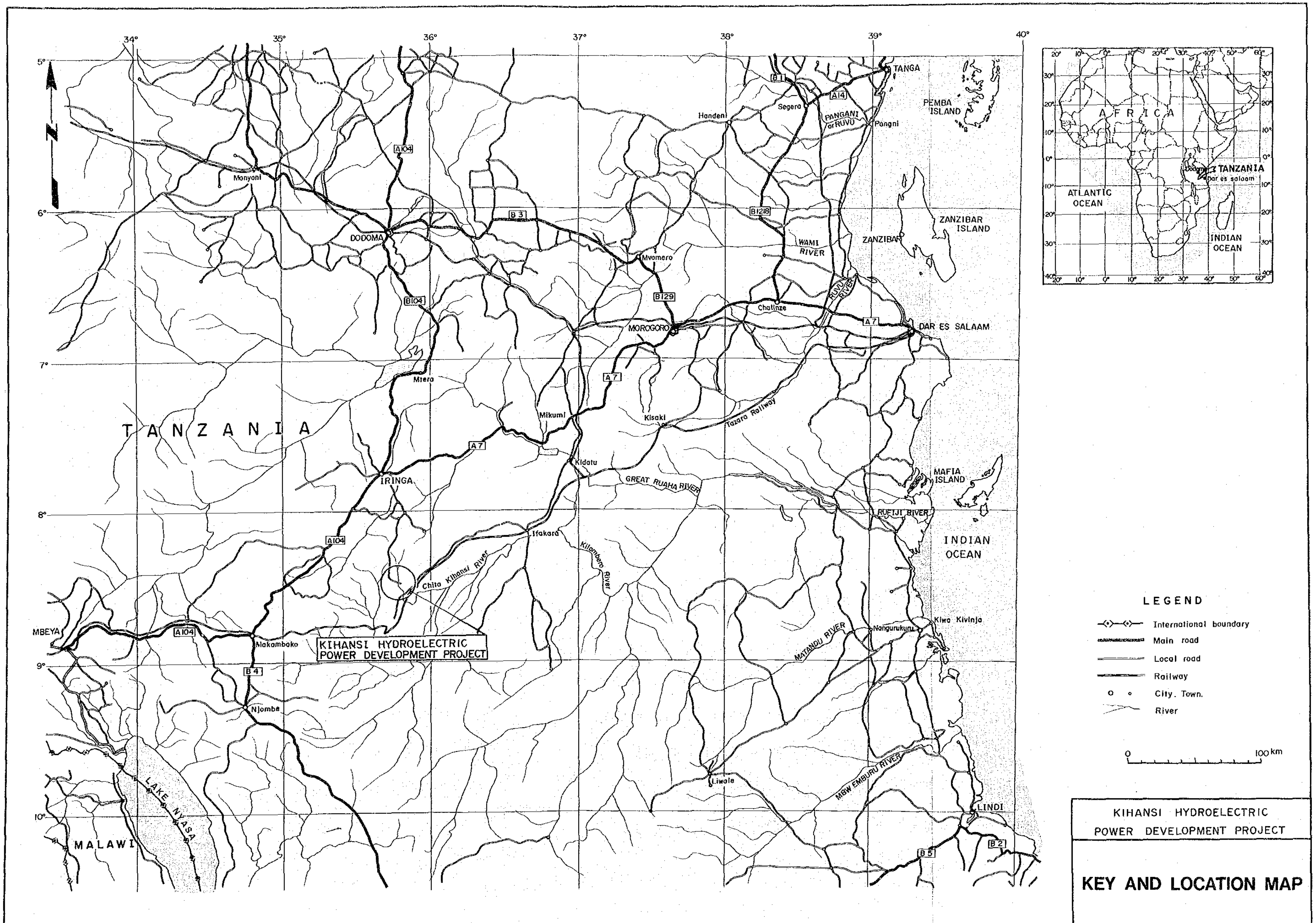
Lower Dam Axis
View from the high water level of left bank



Kihansi Fall
View from the downstream left bank



Lower Powerhouse and Tailrace Sites
View from the site of the upper part of penstock

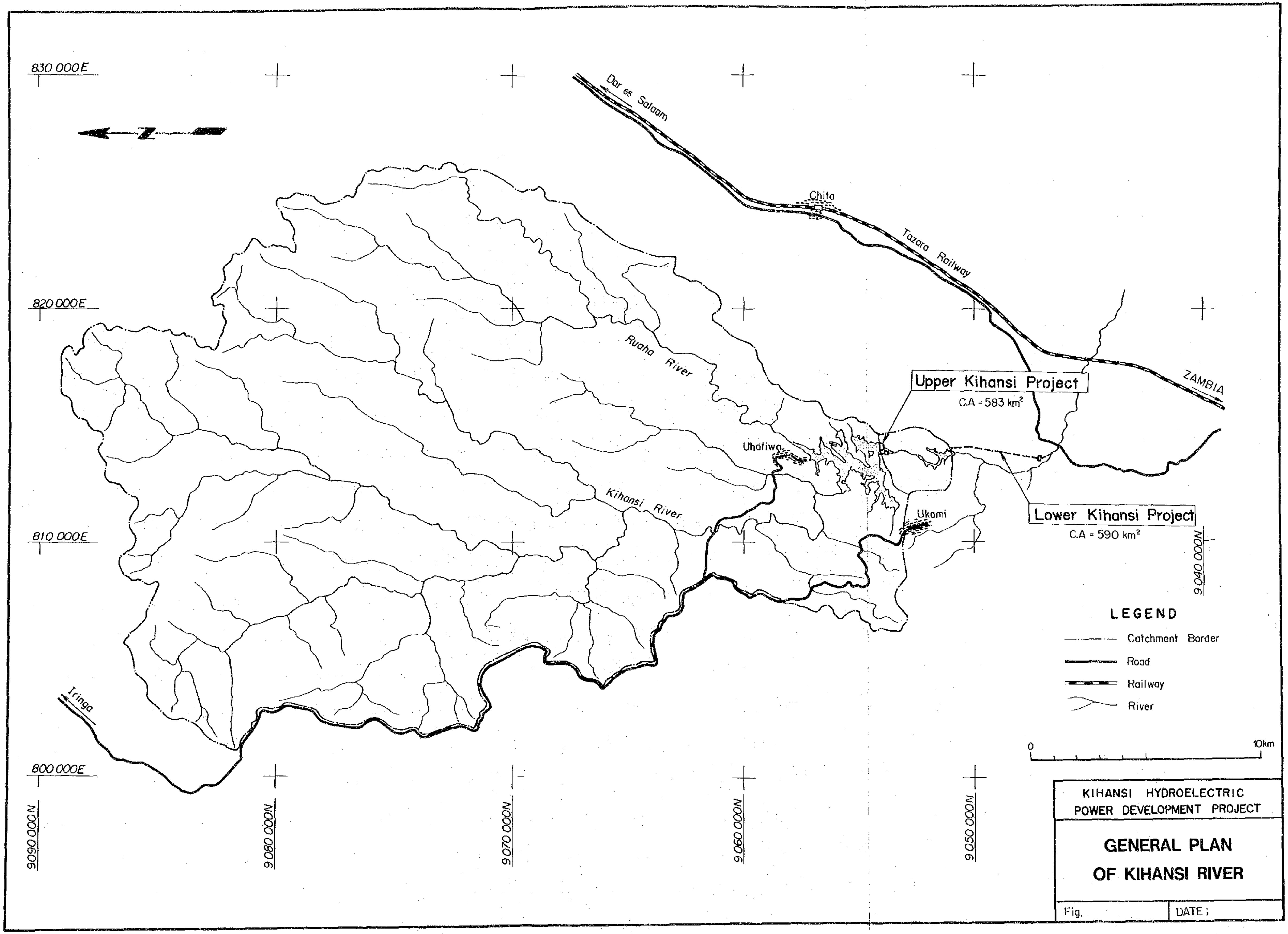


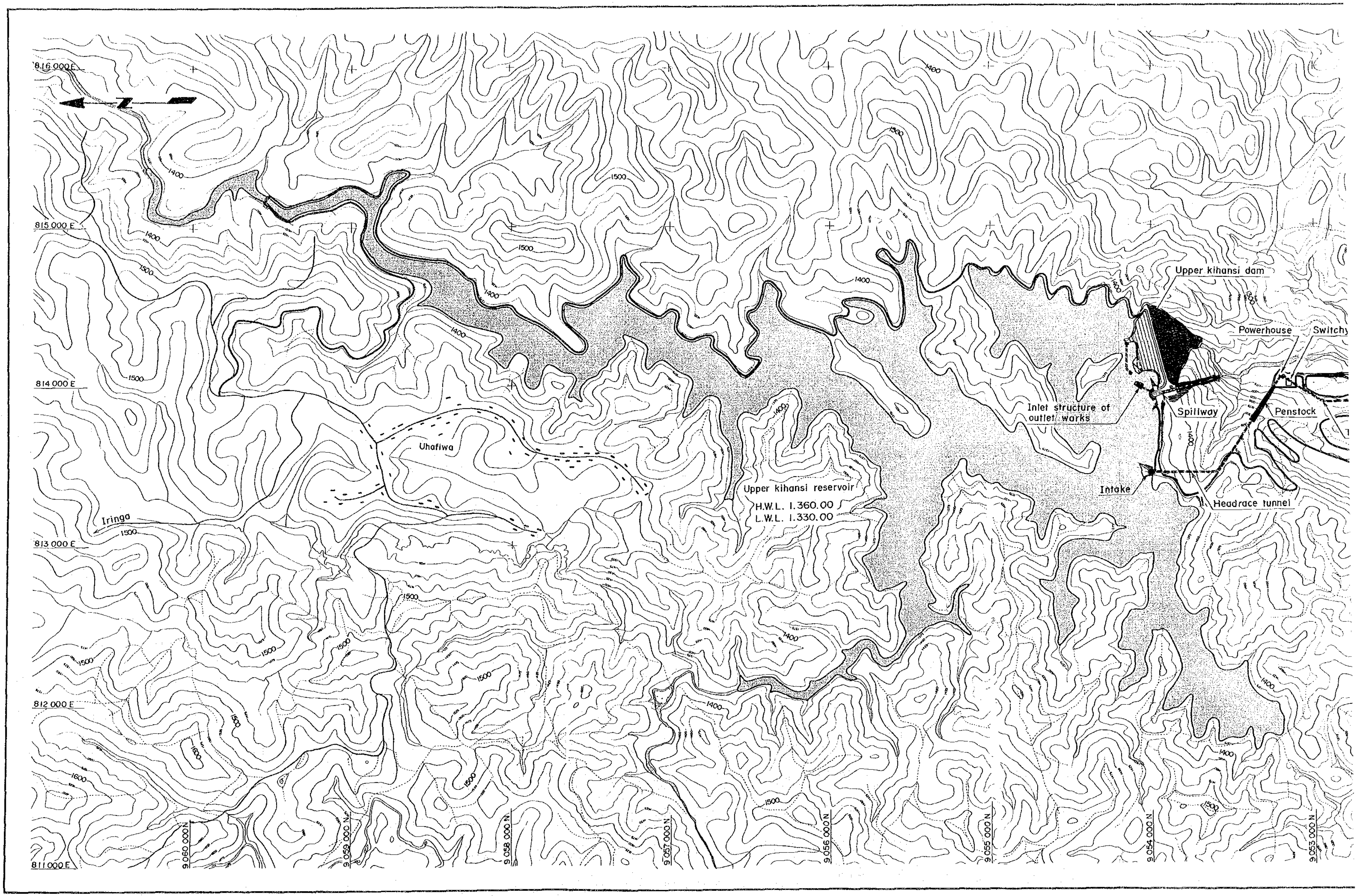
KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

KEY AND LOCATION MAP

Fig.

DATE;


830 000E
820 000E
810 000E
800 000E
N
Dar es Salaam
Chita
Tazara Railway
ZAMBIA
Ruaha River
Kihansi River
Uhafiwa
Ukami
Upper Kihansi Project
C.A = 583 km²
Lower Kihansi Project
C.A = 590 km²
Iringa
9 090 000N
9 080 000N
9 070 000N
9 060 000N
9 050 000N
9 040 000N
LEGEND
Catchment Border
Road
Railway
River
0
10km
KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT
GENERAL PLAN OF KIHANSI RIVER
Fig.
DATE ;



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816 000 E
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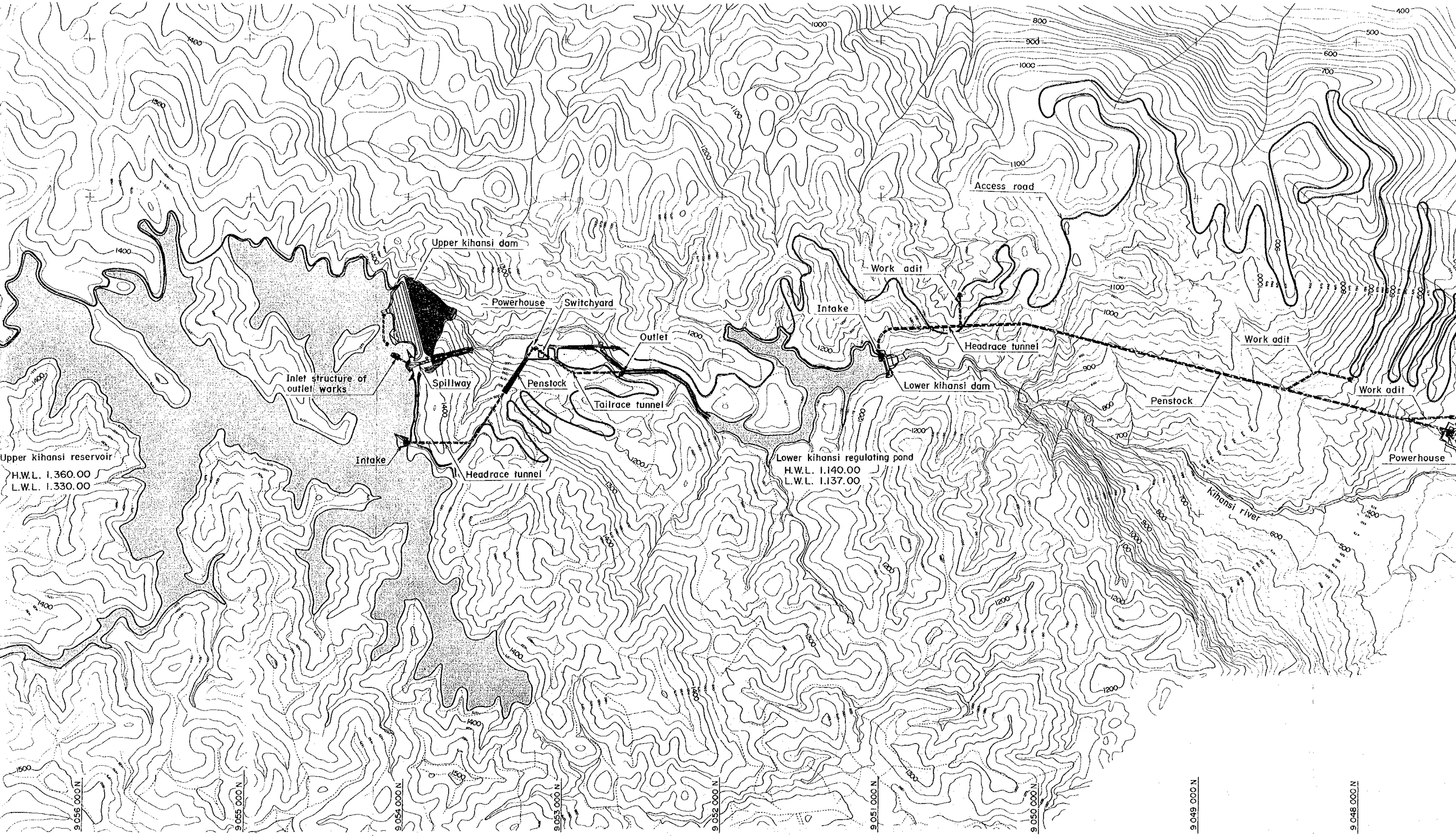
Upper kihansi dam
Powerhouse
Switchy
Inlet structure of
outlet works
Spillway
Penstock
Intake
Headrace tunnel
Upper kihansi reservoir
H.W.L. 1.360.00
L.W.L. 1.330.00
Uhafiwa
Iringa



Upper kihansi dam
Powerhouse
Switchyard
Outlet
Inlet structure of outlet works
Spillway
Penstock
Tailrace tunnel
Intake
Headrace tunnel
Upper kihansi reservoir
H.W.L. 1.360.00
L.W.L. 1.330.00
Work adit
Intake
Headrace tunnel
Lower kihansi dam
Lower kihansi regulating pond
H.W.L. 1.140.00
L.W.L. 1.137.00
Access road
Work adit
Penstock
Work adit
Powerhouse
Kihansi river
9.056.000 N
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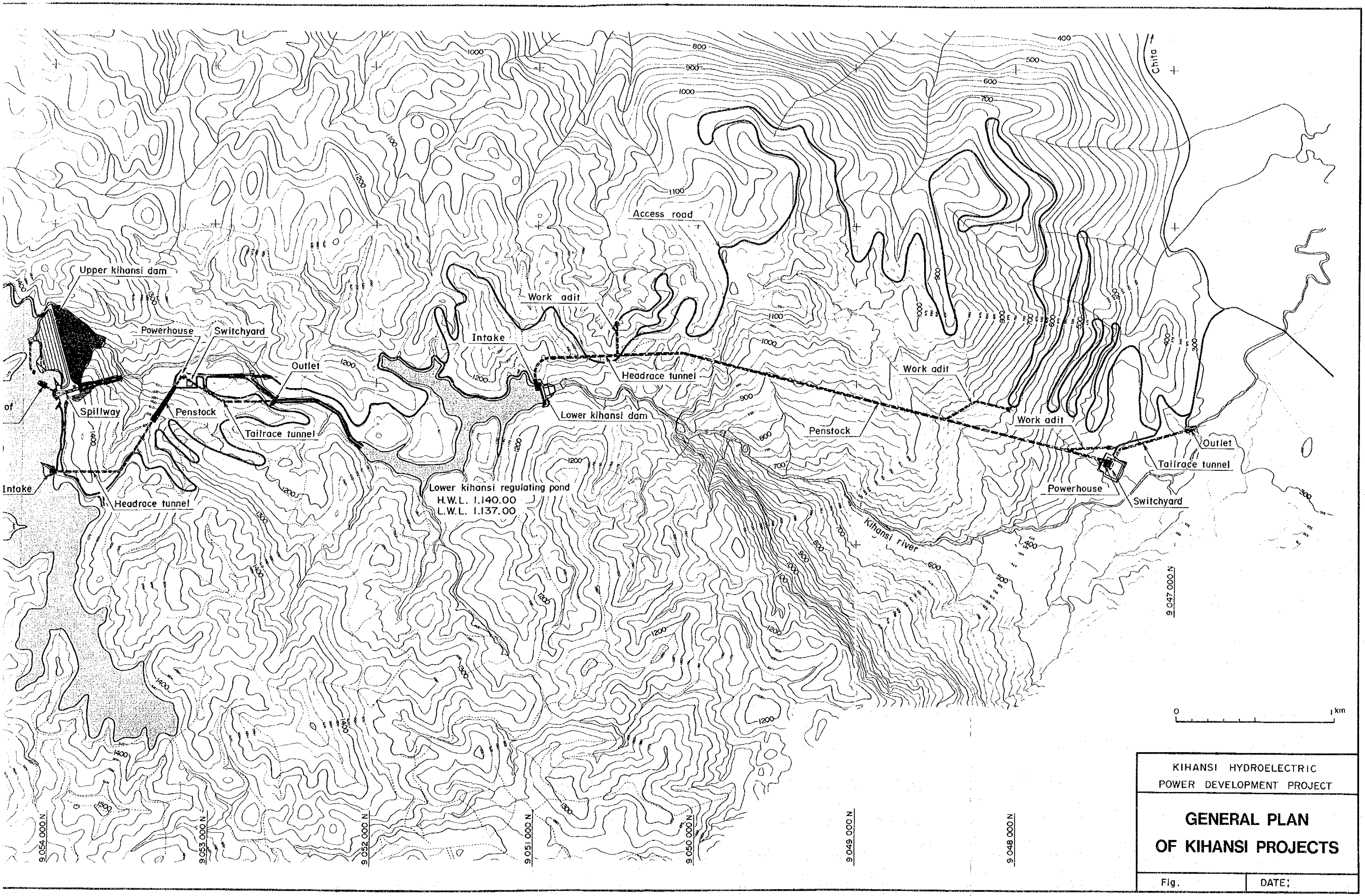

KIHANSI HYDROELECTRIC
POWER DEVELOPMENT PROJECT

GENERAL PLAN OF KIHANSI PROJECTS

Fig. | DATE;

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UNITS

m	-	meter, unit of length
mm	-	millimeter (1/1,000 m)
cm	-	centimeter (1/100 m)
km	-	kilometer (1,000 m)
m^2	-	square meter
mm^2	-	square millimeter
km^2	-	square kilometer
cm^2	-	square centimeter
m^3	-	cubic meter
m/sec	-	meter per second
m/sec^2	-	meter per square second
m^3/s	-	cubic meter per second
V	-	volt, unit of voltage
kV	-	1,000 volts
A	-	ampere
AH	-	ampere hour
Ω	-	ohm
Nos	-	numbers
W	-	watt, unit of active power
kW	-	1,000 W
MW	-	million watts (1,000 kW)
VA	-	volt ampere
kVA	-	kilovolt ampere
MVA	-	million VA (1,000 kVA)
kWh	-	1,000 Wh
MWh	-	million Wh (1,000 kWh)
GWh	-	million kWh
rpm	-	revolving per minute
Hz	-	hertz, unit of frequency
s, (sec)	-	second
hr, (hrs)	-	hour
g	-	gram, unit of weight
mg	-	milligram (1/1,000 g)
kg	-	1,000 g
kfg	-	kilogram force

t	-	ton (1,000 kg)
tons.	-	tonnes
MT	-	metric ton
ℓ	-	liter
BTU	-	British Thermal Unit
MBtu	-	million BTU
MVAR	-	million VAR
P	-	effective power
JQ	-	reactive power
cal	-	calorie, thermal unit
Kcal	-	kilocalorie (1,000 cal)
G	-	gal, unit of acceleration
°C	-	celsius degree, unit of temperature
%	-	percent
deg	-	degree

CURRENCY

US$	-	U.S. Dollar
Tsh	-	Tanzanian Shilling
MTshs	-	million of Tanzanian Shillings

Foreign Exchange Rate
1 US$ = 140 Tsh

ABBREVIATIONS

A.C	-	Aluminum Clad Steel
A.E.G.	-	Annual Energy Generation
AAC	-	Aluminum Alloy Cable
AC	-	Alternating Current
ACSR	-	Aluminum Conductor Steel Reinforced
AV	-	Average
AVR	-	Automatic Voltage Regulator
B/C	-	Benefit Cost Ratio
B	-	Annual Benefit
B-C	-	Annual Surplus Benefit
BOD	-	Biochemical Oxygen Demand
C	-	Annual Cost
C&F	-	Cost and Freight
CB	-	Circuit Breaker
CIF	-	Cost, Insurance and Freight
CL	-	Caliraya Lake
COD	-	Chemical Oxygen Demand
Comm	-	Commissioning
DC	-	Direct Current
Dep Enr	-	Dependable Energy
Dia	-	Diameter
DO	-	Dissolved Oxygen
DS	-	Disconnecting Switch
EDCOP	-	Engineering & Development Corporation
EIA	-	Environmental Impact Assessment
EIRR	-	Economic Internal Rate of Return
EL.	-	Elevation
ELC	-	Electroconsult
EPA	-	Environmental Protection Agency
ERP	-	Economic Recover Program
Ex Rate	-	Exchange Rate
FAO	-	The United Nations Food and Agriculture Organization
FC	-	Foreign Currency
FWS	-	Free Water System
G.S	-	Galvanized Steel
GCB	-	Gas Circuit Breaker

GDP	-	Gross Domestic Product
GNP	-	Gross National Product
GOV	-	Speed Governor for Water Turbine
H.W.L.	-	High Water Level
IDC	-	Interest During Construction
IKL	-	Isokeraunic Level
ITCZ	-	Intertropical Convergence Zone
JICA	-	Japan International Cooperation Agency
L.S.	-	Lump Sum
L.W.L.	-	Low Water Level
LA	-	Lightning Arrester
LC	-	Local Currency
LEI	-	Lake Evaluation Index
Lf	-	Load Factor
LOLP	-	Loss Of Load Probability
LT	-	Line Trap
M/P	-	Master Plan
MA	-	Mega Annum
MAF	-	Mean Annual Flood
Max	-	Maximum
MHz	-	Mega Hertz
Min	-	Minimum
NGR	-	Neutral Grounding Resistor
OECD	-	Organization for Economic Cooperation and Development
P.S	-	Power Station
PD	-	Potential Device
Pf	-	Power Factor
PH	-	The simbol for hydrogen ion concentration
PLC	-	Power Line Carrier
PMF	-	Probable Maximum Flood
PMP	-	Probable Maximum Precipitation
Pow	-	Power
PSDP	-	Power Sector Development Plan
r	-	Discount Rate
RUBADA	-	Rufiji Basin Development Authority
S.S	-	Substation
SCADA	-	System Control and Data Acquisition
SCR	-	Standard Conversion Factor
SER	-	Shadow Exchange Rate

SP	-	Station Post Insulator
TANESCO	-	Tanzania Electric Supply Company Limited
TSI	-	Trophic State Index
U.K.	-	United Kingdom
U.S.	-	United States
VAT	-	Value Added Tax
VHF	-	Very High Frequency
yr	-	Year

SUMMARY

SUMMARY

This report concerns the feasibility study of the Kihansi Hydroelectric Power Development Project of the Republic of Tanzania. The feasibility study has been conducted from 1989 to 1990 by the Japan International cooperation Agency (JICA) under a technical cooperation program of the Government of Japan.

This report is submitted by JICA, through the Ministry of Foreign Affairs of the Japanese Government, to the Tanzania Electric Supply Company Limited (TANESCO) of the Government of Tanzania.

A brief summary of the results of the feasibility study is presented in the following part of this section.

(1) Features of the Project

The Kihansi Hydroelectric Power Development Project consists of an Upper Kihansi Project located at the midstream stretch of the Kihansi River in the Rufiji River System, a project at a site for dam-type power generation with a reservoir capable of complete regulation of the annual inflow of a catchment area of 583 km^2, a Lower Kihansi Project downstream for waterway-type power generation with a regulating reservoir, and a power transmission line project to Iringa Substation. This Kihansi River rises from a hill area south of Iringa and the river channel meanders gently down to the Upper Kihansi Project site, but downstream of the dam, the river gradient abruptly changes to that of a swift stream, and in spite of the fact that the outlet point of Lower Kihansi Power Station is reached with a horizontal distance of 5 km, the river channel is so steep that the head is as much as 1,000 m.

Although annual rainfall ranges widely between 1,000 mm and 1,800 mm, this is a high-rain area with distinct rainy and dry seasons. However, the flow-duration curve of the project site indicates an extremely even shape and effects of the dry season are not prominent. In other words, contrasted to an annual average discharge of 15.9 m^3/s, the firm discharge (95%) is 11.8 m^3/s.

Consequently, the runoff regulation to be done in the Upper Project is for complete regulation with a small reservoir capacity of 75 x 10^6 m^3, and all of the runoff can be made effective.

Meanwhile, there are approximately 3,400 people living along ridges of hill areas in the vicinity of the project site engaged in subsistence farming based on slash-and-burn agriculture.

The slash-and-burn farmland to be submerged in the reservoir area as a result of this Project is a few and no resident exists, while there is nothing else at all, such as roads, public buildings, etc., requiring compansation.

The basement rocks comprising the geology of the river basin are Precambrian gneisses, and these are widely distributed. The geological structure has dykes running predominantly in the northeast-southwest direction, but prominent faults are not seen. However, at parts of high elevation, rain forest soils and laterite soils overlie the basement rocks, and these go down to depths of as much as 30 m in places.

The development program based on these conditions, considered from a physical development schedule, is for start-up of the Lower Kihansi Project to be in 1996, and that of the Upper Kihansi Project in 1999.

These timings can even be said to be almost too late considered on the basis of the power demand forecast, and it is desirable for the Kihansi Hydroelectric Power Development Project to start operation at an early stage as much as possible. It may be expected that the development of the Kihansi power generation project will contribute greatly to economic development in the project area.

(2) Hydrology and Meteorology

- Dam Site Runoff

The catchment areas of the Upper Kihansi and Lower Kihansi damsites are 583 km^2 and 590 km^2, respectively.

There are the three runoff gauging stations of 1KB28, NC3, and NC1 in the Kihansi Basin. Of these, water level observations have been continued at 1KB28 (catchment area, 618 km^2) since 1975, and the runoff at the dam site after 1975 was calculated mainly through catchment area conversions from measured data of 1KB28. Regarding 1974 and before, data were prepared by the methods described below.

1) 1957-1974

At the Mpanga River adjacent on the west of the Kihansi, there have been water level observations made at 1KB8 Gauging Station since 1957, and as the correlation with 1KB28 is good, the runoff of the 1KB28 site was calculated from the 1KB8 runoff by a regression equation.

2) 1927-1956

It has been confirmed through various meteorological data and literature that the general area of East Africa before 1955, compared with after that year, had tended to be droughty. To be able to set appropriate reservoir scales and reservoir operation rules, pre-1955 data observed at Ifakara since 1927 were converted to runoff by the tank model method.

The monthly runoff data for the Upper Kihansi and Lower Kihansi dam sites are given in Tables 6-4 (2) and 6-4 (3).

- Design Flood Discharge

Since runoff data sufficient for calculating statistic probability values were not available on the Kihansi and neighboring river basins, and in view of the importance of the Kihansi Project for the Tanzanian economy and society, and of the fact that Upper Kihansi Dam is to be a large scale dam of a height about 100 m, PMF techniques were adopted for calculating the design flood discharge, and 400 m^3/s was adopted for both Upper Kihansi Dam and Lower Kihansi Dam. Further, the flood discharge needed for care of river flow during construction was calculated by probability techniques and, for Upper Kihansi Dam, which is to be a rockfill type, the 20-year return period value of 90 m^3/sec was adopted, while for Lower Kihansi Dam, which is to be of concrete gravity type, the 5-year return period value of 80 m^3/sec was adopted.

- Sedimentation

For estimates of sedimentation, suspended load measurement data of the Kihansi River and data of neighboring rivers were used, with bed load and reservoir trapping effects taken into account, and the values for the project sites 50 years after construction of the dams were adopted. The results are as follows:

Upper Kihansi Dam	
sedimentation volume	$750 \times 10^3 m^3$
sedimentation level	1,300.00 m
Lower Kihansi Dam	
sedimentation volume	$125 \times 10^3 m^3$
sedimentation level	1,125.00 m

(3) Geology, Construction Materials and Seismicity

- Geology

The Upper Kihansi and Lower Kihansi project sites, as shown in Figs. 7-4 and 7-5, are composed of gneisses of Precambrian era, and Quaternary slope wash and alluvium which cover these gneisses at parts.

The "gneisses" mentioned here is a general term for biotite gneiss, quartz gneiss, amphibolite, and lamprophyre, and of these, biotite gneiss is distributed the most widely.

Slope wash and alluvium are mainly distributed downstream of the Lower Kihansi dam site, and are seen at the foots of cliffs and in the Kihansi River.

As for geologic structure, there is a foliation of gneisses striking in the NNE-SSW direction and dipping 20° to 70° to the west intersecting slightly diagonally the Kihansi River which flows approximately north-south. According to aerial photo interpretations, predominant lineament patterns are seen in the N-S, NE-SW, and WNW-

ESE directions. There are few faults confirmed through outcropping at the ground surface, and faults have not been confirmed at the ground surface at even the Uzungwa Scarp thought to be a fault scarp.

Although not shown in Figs. 7-4 and 7-5, a comparatively thick weathered layer covers the area upstream from the vicinity of the Lower Kihansi dam site. According to boring investigations made at the Upper Kihansi dam site, there are places where a weathered layer 30 m or more in thickness has been confirmed. Since outcrops of bedrock are seen comparatively frequently at the river bed of this area as a whole, it may be said there is a trend for the weathered layer to be thick at the gently-sloped ridges and thin in the vicinity of the river bed.

To summarize the engineering geological evaluations of the principal civil structure sites planned, the following may be said:

1) Upper Kihansi Project Site

- A soft, weathered layer of thickness approximately 20 m is distributed at the dam site, mainly at ridges. On the other hand, bedrock existing at deep parts and at the river bed is generally hard although deteriorated portions may be partially observed, and this is thought to possess ample suitability as the foundation rock for a rockfill dam of height approximately 100 m.

- It is thought that for the dam axis, the geological conditions are better with less weathering to shift approximately 80 m downstream rather than the line connecting the sites of boring (KU-1 and KU-3) performed at the slopes of both banks.

Consequently, the dam axis should be selected at this line.

- Of the waterway route, the ground surface of the section including the projected intake and the headrace tunnel is expected to have a distribution of a slightly thick weathered layer. However, if the tunnel elevation is as projected, the tunnel is to pass through comparatively fresh bedrock.

- It can be expected that sound bedrock is to be exposed as the foundation for the projected Upper Powerhouse.

2) Lower Kihansi Project Site

- The line connecting the boreholes at the both banks is thought to be most suitable for the Lower dam axis from the facts that it avoids waterfalls, the river width is narrowed by a ridge protruding out at the left bank, and surface deposits are small in quantity. The thicknesses of weathered layers here are estimated to be 5 to 7 m.

- For the headrace and the penstock, it is considered that a tunnel proposal is to be more advantageous than a surface proposal in view of the facts that there are many places of steeply-sloped topography and numerous scars can be seen.

- From the points of view of topography and geology, the location of the Lower Kihansi Powerhouse should be selected inside the gentle slope shown in Fig. 7-5. However, since it is possible the lineament pattern in the N76°W direction shown in Fig. 7-5 is that of a fault, it is desirable to avoid this.

- Construction Materials

With regard to borrow materials, it is considered most suitable for the residual soil and weathered rock widely distributed at the ground surface in the vicinity of the Upper Kihansi dam site to be used mixed with coarse material.

With regard to concrete aggregates, there are no sediments to be seen in this area which are available in large quantities. As a result of testing, the gneisses widely distributed as basement rock in this area can be used as concrete aggregates from the standpoints of specific gravity, absorption, alkali-aggregate reaction, and further, strength. Consequently, it is thought the best method for this Project is to select a quarry at the optimum location and obtain concrete aggregates in the form of crushed stone.

Furthermore, it is necessary hereafter to ascertain at the quarry site the quantity and properties of the weathered layer that can be furnished as borrow material, and to investigate the distribution of fresh rock that can be considered for blending with borrow material and that can be used as concrete aggregates. Particularly, with regard to fresh rock, confirmation of rock type is an important point in investigations since in the case of gneiss containing large amounts of biotite "abrasion loss" is presupposed to be high, and it is conceivable that securing the necessary quantity of coarse aggregate may be difficult.

• Seismicity

As a result of investigations, 349 earthquakes were found to have occurred during the 78 years from 1910 to 1987 within a radius of 500 km from the dam site. The magnitudes had all been under 7, with hypocenters concentrated along the Western Rift Valley passing the vicinity of Mubeya.

As a result of statistical analyses based on these earthquake data, approximately 13 gal was obtained as the design earthquake intensity of this project site in terms of 10,000-year return period.

Based on a comprehensive judgment of such statistical analysis results and existing data concerning earthquakes, the design horizontal seismic coefficient of the project site was set as 0.10.

(4) Electric Power Demand and Supply

The electric power systems of the Republic of Tanzania consists of the interconnected power system that links major cities of the country and isolated power systems which supply small settlements which are far isolated from the main interconnected power system. The interconnected power system has been expanded gradually, and most major cities of the country is today interconnected after the interconnection has been extended to the region of Victoria Lake of the northwest in 1988.

As of January, 1989, the total generating capacity connected to the interconnected system is 418 MW, with approximately 79% (329 MW) of the facilities consisting of hydroelectric power stations.

All thermal power generation facilities are small capacity of diesel and gas turbine plants. As all petroleum fuel is imported, the basic policy of TANESCO is to supply as much energy as possible from the hydroelectric power stations, and to use the thermal power stations as reserve capacities.

As the interconnected power system has been expanded by new transmission lines, the total demand of interconnected system is steadily increasing. The total energy consumption in 1988 was 1,123 GWh, and the maximum peak generation was 219 MW.

Power demand in Tanzania, reflecting stagnation of the economy, had shown an annual growth rate of 5.9 percent up to 1985, but as a result of the economy turning around favorably with an economy recovery programme receiving aid from the World Bank, the growth rate rose sharply to 10.3 percent in 1986 - 1988. Hereafter, from 1990 to 2005, it is estimated that the growth rate in power demand will be an annual 6.2 percent. The projection of energy generation and peak power generation for the period between 1991 and 2005 are presented in the table below.

	Energy Generation (GWh)	Peak Power (MW)
1991	1707	304
1992	1813	323
1993	1925	343
1994	2045	365
1995	2171	387
1996	2306	411
1997	2449	437
1998	2601	464
1999	2762	493
2000	2933	523
2001	3115	556
2002	3309	590
2003	3514	627
2004	3731	666
2005	3963	707

TANESCO plans to meet this demand growth totally by supply from hydroelectric power generation facilities, except for a thermal power plant (20 MW) which is to be constructed in 1992 as a supplemental measure. The hydroelectric power development program based on the plans of TANESCO and this case study are as presented below.

Year of Commissioning	Project	Installed Capacity (MW)
1995	Pangani Falls Redevelopment	60.0
1996	Lower Kihansi	153.0
1999	Upper Kihansi	47.0
2002	Masigira	80.0
2005	Rumakali	204.0
2009	Ruhudji Stage 1	250.0
2012	Mpanga	160.0

When the balance of supply and demand is examined from the demand projection obtained above and this development program, it is found that the pace of development is a little slow. That is, energy supply shortage is to be faced in case of a dry year in 1996, and shortage in both energy supply and reserve power capacity is also anticipated in dry years after 2000 and before 2005 when Rumakali is commissioned.

(5) Power System Analysis

As large supply sources of Kidutu and Mtera Hydroelectric Power Stations are situated in the central region of Tanzania, the demands are concentrated at Dar Es Salaam and on the substations along the 132 kV transmission system that extends from Dar Es Salaam to the north. Therefore, heavy power flows from Kidutu and Mtera Power Stations to Dar Es Salaam and then northward to Arusha which is located at the northern end of the power system.

Due to this power flow, the voltage of the interconnected system tends to be reduced in the eastern areas and tends to be raised in the western areas where load is relatively light. As this trend is to persist in future, it is required to install appropriate reactive power suppliers corresponding to the increase of load of the power system.

TANESCO plans to construct a new, single circuit 220 kV transmission line from Singida Substation which is in the western part of the interconnected system to Njiro Substation at Arusha. TANESCO also plans to construct a single circuit 220 kV transmission line from Kidatu Power Station to Ubungo Substation at outskirts of Dar Es Salaam, and construct a new substation along the 220 kV system of Dar Es Salaam.

Although such reinforcement of power system is to make it possible to deal with the demand increase in the interconnected power system, the effect of line failure, such as those caused by thunder strokes, is to be serious because most of transmission lines are of single circuit design. In particular, it is desirable to have the 220 kV transmission lines from Mtera Power Station through Iringa Substation to Kidatu Substation made to double circuits in order to improve the reliability of the interconnected power system.

It is planned that the transmission line from Upper Kihansi and Lower Kihansi Power Stations is to be directly connected to Iringa Substation which is the key substation in the interconnected power system. The length of transmission is 113 km (105 km from Upper Kihansi). The voltage is selected at 220 kV and the number of circuits to be two, by due consideration on the transmission capacity and reliability.

(6) Environment and Compensation

There are almost no residents and facilities to be affected by the construction of the power stations since Kihansi and Ruaha Rivers have no irrigation facilities. Part of the forest reserve with an area of 2.3 km^2 is to be submerged by the planned impoundment of the upper reservoir, covering only less than 1% of the total area of the forest reserve with an area of 300 km^2.

Aquatic animals such as fishes, etc., are scarcely seen in Kihansi and Ruaha Rivers since the water quality of both steep rivers with exposed rocks at the riverbed shows relatively strong acidity and sterility due to surface soil and burned/cultivated fields. The inhabitation of largesized animals has not been confirmed since the planned power station site area is widely cleared away as burned/ cultivated fields and their unused fields.

According to the on-site survey of the environment, there are two villages with a population of 3,400 and 540 houses. The planned power station site consists of these residents' burned/cultivated fields and their unused fields, and a great deal of nature there has been already changed. Residents live on a hill far away from the power stations except huts for agricultural work, and they scarcely have to move their houses.

It is possible to lawfully acquire land required for the establishment of the power stations under the provisions of the Land Act of the Republic of Tanzania. Since the compensation system for acquired land has been established and the amount of compensation money is small, this does not become a controversial issue at all.

The power stations are expected to largely contribute to the development of this region since public facilities such as roads, etc., are to be established following the construction and operation of the power stations. The upper reservoir will provide waterfowls with new habitats, and residents with the possibility of the cultivation of fishes such as introduced species and of water-borne traffic respectively. However, the occurrence of harmful plants and vermin should be carefully controlled.

As mentioned above, the power stations are expected to affect the natural and social environment scarcely as a whole while this power station project aims at the stable supply of power, largely contributing to the development of regional societies.

As a part of the maintenance of the power stations, the effects of the power stations should be environmentally monitored for grasping changes in the environment.

(7) Outline of the Development Scheme

The total of maximum outputs of the Upper Kihansi Project and Lower Kihansi Project of the Kihansi Hydroelectric Power Development Project is 200 MW. The annual firm energy from this hydroelectric power generation is calculated as 886.7 GWh.

When this is compared with coal-fired power generation, it corresponds to an annual coal consumption of approximately 680,000 tons. The principal specifications are as described below.

- The Upper Kihansi Project

This Project is located at the upstream of the Kihansi River, one of the tributary of the Rufiji River.

A rockfill dam with height 95 m and dam volume 5.35 x 10^6 m^3 is constructed to provide gross reservoir storage capacity of 94.9 x 10^6 m^3 with the effective of 75.1 x 10^6 m^3 at about 3 km downstream from the confluence of the tributary Ruaha River and average annual inflow of 494 x 10^6 m^3 is regulated in this reservoir.

The maximum available discharge of 25.7 m^3/s introduced to the intake at 500 m upstream of the right bank of the dam is conducted to the powerhouse situated at the right bank through the headrace tunnel and the open type penstock with total length of 1,163 m and generated maximum output of 47 MW with annual electric firm energy of 335.7 GWh with effective head of 214.5 m. The generated water is to be discharged to a regulating reservoir of the Lower Kihansi Project through a tailrace tunnel and open channel with length of 1,140 m.

The generated electric power at the Upper Kihansi Power Station is to be transmitted by the connecting transmission line from the switchyard to the 220 kV transmission line constructed from the switchyard of the Lower Kihansi Power Station to Iringa Substation.

- The Lower Kihansi Project

The dam site is located about 3 km downstream from the Upper Kihansi Power Station on the Kihansi River and the concrete gravity dam with height 35 m and dam volume 54,000 m^3 is constructed to provide gross regulating reservoir storage capacity of 1.4 x 10^6 m^3 and the effective of 0.48 x 10^6 m^3. The inflow into this regulating reservoir is to be daily regulated.

The maximum available discharge of 22.2 m^3/sec is introduced to the intake constructed at the left bank just upstream of the dam and conducted to the powerhouse situated at the left bank through the headrace tunnel and the embedded penstock with total length of 4,181 m and the maximum output of 153 MW with the annual electric firm energy of 551.0 GWh is generated with the effective head of 813.0 m. Generated water is to be outlet to the Kihansi River through the tailrace tunnel with length of 615 m.

The generated electric power at this power station is to be transmitted from the switchyard to Iringa Substation by the newly constructed transmission line.

- Transmission Line

The transmission line with 220 kV and 2 circuits is to be newly constructed starting from the switchyard of the Lower Kihansi Power Station via that of the Upper Kihansi Power Station to Iringa Substation with total length of 113 km.

(8) Construction Schedule and Construction Cost

- Construction Schedule

Considering the commissioning year of the Upper Kihansi Project in 1999, and the Lower Kihansi Project in 1996, preparations for construction should be made roughly according to the following time schedule.

1) Upper Kihansi Project

1989-2 - 1990-12	Prefeasibility Study	(1 year and 9 months)
1991-7 - 1992- 6	Feasibility Study	(1 year)
1992-7 - 1993-12	Definite Design	(1.5 years)
1994-1 - 1995- 6	Finance	(1.5 years)
1995-1 - 1995- 6	Preparation Works	(0.5 year)
1995-7 - 1999-12	Construction	(4.5 years)

2) Lower Kihansi Project

1989-2 - 1990-12	Feasibility Study	(1 year and 9 months)
1991-2 - 1992- 7	Definite Design	(1.5 years)
1991-1 - 1993- 6	Finance	(2.5 years)
1992-1 - 1993- 6	Preparation Works	(1.5 years)
1993-7 - 1996-12	Construction	(3.5 years)

The construction works of the Upper Kihansi Project and the Lower Kihansi Project require periods of approximately 4.5 years and 3.5 years respectively as a result of studying the meteorology and topography of the project area, the scale of construction, construction materials, layout of structures, preparatory works, etc. The work schedules of the projects are given in Figs. 11-5 and 11-6.

- Construction Cost

The construction cost of this Project is estimated assuming that design, construction methods, and materials and products according to the technological levels being able to be expected at the present are applied, with the geological and regional conditions of the project sites, construction scales and so on taken into consideration.

The total construction cost of this project is estimated dividing the local and foreign currencies and the costs of access roads, camp facilities, environmental counter-measures, transmission line, substation facilities, engineering fee and administrative expenses and interest during construction are included in the project cost itself, but inflation is not taken into consideration.

The cost estimation time is set in June, 1989 (exchange rate: 140 Tsh/1 US$).

The list of items of construction cost on this project is shown in Table 11-7.

(9) Economic Evaluation and Financial Analysis

- Economic Evaluation

As the method of the economic evaluation of this project, an alternative plant approach is employed to measure and evaluate economic costs of the proposed project and the alternative project.

The cost and benefit flow of the combined project on the Upper and Lower Kihansi Projects is presented in Table 13-1 and the results of evaluation of EIRR, B-C and B/C of the Upper and Lower Kihansi Projects and the combined project are as follows:

	EIRR	B - C	B/C
Upper Kihansi Project	11.26%	9,221 x 10^3 US$	1.07
Lower Kihansi Project	45.94%	129,236 x 10^3 US$	2.32
Combined Project	39.31%	146,347 x 10^3 US$	1.76

As indicated by indices of B-C and B/C of the combined project, the costs of construction and operation of the project is much smaller than those of an alternative thermal power plant which can provide equivalent service, and it can be also concluded that the project can continue to maintain its superiority as long as the discount rate which reflects the capital opportunity cost does not exceed 39.31%.

- Financial Analysis

For the financial analysis of the project, "Financial Evaluation from Viewpoint of Total Investment-Calculation of the Financial Internal Rate of Return" is analyzed and judgement is made for evaluation.

FIRRs of the Upper Kihansi Project and the Lower Kihansi Project are 6.49% and 12.74% respectively and that of the combined project is 12.07% as shown in Table 13-5.

Judging from the FIRR of the combined project, the project is sound from the financial point of view, even though the Upper Kihansi Project itself is not sound based on the unit electric price adopted for the evaluation.

Summary of Upper Kihansi Hydroelectric Power Development Project

Item	Unit	Description
Location		Kihansi River
Catchment Area	km^2	583
Annual Inflow	10^6 m^3	494.48
Design Flood	m^3/sec	400
Reservoir		
Normal High Water Level	m	1,360
Low Water Level	m	1,330
Available Drawdown	m	30
Sedimentation Level	m	1,300
Gross Storage Capacity	10^6 m^3	94.90
Effective Storage Capacity	10^6 m^3	75.10
Reservoir Area	km^2	3.86
Sub-diversion Tunnel		
Design flood discharge	m^3/sec	10
Type		Semi-circle
Number		1
Dimension	m	Width 2.00
	m	Height 2.00
Length	m	300.00

Item	Unit	Description
Main Diversion Tunnel		
Design flood discharge	m^3/sec	90
Type		Semi-circle
Number		1
Dimension	m	Width 3.00
	m	Height 3.00
Length	m	425.00
Dam		
Type		Rockfill with center core
Crest elevation	m	1,365.00
Crest length	m	583.00
Crest width	m	10.00
Dam height	m	95.00
Dam volume	m^3	5,350,000
Spillway		
Design flood discharge	m^3/sec	400
Spillway capacity	m^3/sec	400
Type		Free overflow type
Crest elevation	m	1,360.00
Crest length	m	100

Item	Unit	Description
Intake		
Type		Inclined type made of reinforced concrete
Number		1
Maximum discharge	m^3/sec	25.7
Inlet level	m	1,320.00
Dimension	m	Width 6.00
	m	Height 50.00
Headrace Tunnel		
Number		1
Maximum discharge	m^3/sec	25.7
Diameter	m	3.30
Length	m	653.00
Penstock		
Number		1
Maximum discharge	m^3/sec	25.7
Diameter	m	3.30 ~ 1.85
Length	m	510.24

Item	Unit	Description
Powerhouse		
Type		Semi-underground of reinforced concrete
Dimension	m	Width 20.00
	m	Length 22.50
	m	Height 35.00
Turbine center level	m	1,135.00
Installed capacity	MW	47
Tailrace Tunnel		
Type		Horseshoe
Maximum discharge	m^3/sec	25.7
Diameter	m	4.00
Length	m	641.00
Tailrace Outlet		
Type		Box culvert made of reinforced concrete
Maximum discharge	m^3/sec	25.7
Dimension	m	Width 4.00
	m	Length 10.00
	m	Height 7.50
Outlet level	m	1,135.35

Item	Unit	Description
Turbine		
Type		Vertical Shaft Francis Turbine
Number of unit		1
Rated effective head	m	214.50
Water discharge	m^3/sec	25.7
Rated output	MW	48
Revolving speed	rpm	429
Generator		
Type		3-phase, AC, synchronous generator
Number of unit		1
Capacity	MVA	53 (with 0.9 lagging power factor)
Revolving speed	rpm	429
Frequency	Hz	50
Voltage	kV	11.0
Main Transformer		
Type		Outdoor, single-phase transformer
Number of units		4 (including 1 spare transformer)
Capacity	MVA	53
Voltage	kV	11.0

Item	Unit	Description
Switchyard		
Bus type		Single bus
Bus		Aluminum cable
Number of lines		2 circuits
Voltage	kV	220
Conductor type		ACSR, 400 mm^2
Annual Energy Production		
Total Energy	GWh	275.1
Firm Energy	GWh	335.7
Construction Period	years	4.5
Project Cost	10^3 US$	261,000
Unit Construction Cost at Sending End	US$/kWh	0.78
Financial Internal Rate of Return (FIRR)	%	6.49
Economic Internal Rate of Return (EIRR)	%	11.26
Net Present Value (B-C)	10^3 US$	9,221.46
Benefit Cost Ratio (B/C)		1.07

Summary of Lower Kihansi Hydroelectric Power Development Project

Item	Unit	Description
Location		Kihansi River
Catchment Area	km^2	590
Annual Inflow	10^6 m^3	500.48
Design Flood	m^3/sec	400
Regulating Reservoir		
Normal High Water Level	m	1,140
Low Water Level	m	1,137
Available Drawdown	m	3
Sedimentation Level	m	1,125
Gross Storage Capacity	10^6 m^3	1.39
Effective Storage Capacity	10^6 m^3	0.48
Reservoir Area	km^2	0.19
Diversion		
Design flood discharge	m^3/sec	80
Type		Box culvert inside the dam
Number	m	1
Dimension	m	Width 3.00
	m	Height 4.00
Invert level		1,115.00

Item	Unit	Description
Dam		
Type		Concrete gravity
Crest elevation	m	1,143.00
Crest length	m	177.00
Crest width	m	5.00
Dam height	m	35.00
Dam volume	m^3	54,000
Spillway		
Design flood discharge	m^3/sec	400
Spillway capacity	m^3/sec	160
Type		Free overflow type
Crest elevation	m	1,140.00
Crest length	m	13.00 x 4 spans = 52.00
Sand Flushing		
Capacity	m^3/sec	240
Type		Controlled type with gate inside the dam
Dimension	m	Width 4.00
	m	Height 4.00
Invert level	m	1,123.00

Item	Unit	Description
Intake		
Type		Vertical type made of reinforced concrete
Number		1
Maximum discharge	m^3/sec	22.2
Inlet level	m	1,125.00
Dimension	m	Width 6.00
	m	Height 25.50
Headrace Tunnel		
Number		1
Maximum discharge	m^3/sec	22.2
Diameter	m	3.00
Length	m	1,258.69
Penstock		
Number		Main 1
		Branches 3
Maximum discharge	m^3/sec	Main 22.2
	m^3/sec	Branches 7.4
Diameter	m	Main 3.00 ~ 2.20
	m	Branches 1.80 ~ 0.90
Length	m	Main 2,858.31
	m	Branches No.1 80.00
		No.2 82.05
		No.3 64.00

Item	Unit	Description
Powerhouse		
Type		Semi-underground made of reinforced concrete
Dimension	m	Width 25.50
	m	Length 59.00
	m	Height 34.60
Turbine center level	m	296.50
Installed capacity	MW	153
Tailrace Tunnel		
Type		Main Horseshoe
		Branches Semi-circle
Maximum discharge	m^3/sec	Main 22.2
	m^3/sec	Branches 7.4
Diameter	m	Main 3.50
	m	Branches 3.00
Length	m	Main 580.00
	m	Branches 35.00 x 3 units = 105.00
Tailrace Outlet		
Type		Open channel made of reinforced concrete
Maximum discharge	m^3/sec	22.2
Dimension	m	Width 7.00 ~ 15.00
	m	Length 47.00
	m	Height 9.70
Outlet level	m	293.00

Item	Unit	Description
Turbine		
Type		Vertical Shaft Pelton Turbine (6-nozzle)
Number of unit		3
Rated effective head	m	813.00
Water discharge	m^3/sec	7.4 (22.2 with 3 units)
Rated output	MW	52
Revolving speed	rpm	750
Generator		
Type		3-phase, AC, synchronous generator
Number of units		3
Capacity	MVA	57 (with 0.9 lagging power factor)
Revolving speed	rpm	750
Frequency	Hz	50
Voltage	kV	11.0
Main Transformer		
Type		Outdoor, single-phase transformer
Number of units		10 (including 1 spare transformer)
Capacity	MVA	19
Voltage	kV	11.0

Item	Unit	Description
Switchyard		
Bus type		Double bus
Bus		Aluminum cable
Number of lines		2 circuits
Voltage	kV	220
Conductor type		AAC 400 mm^2
Transmisison Lines		
Number of circuits		2
Voltage	kV	220
Conductor type		ACSR 380 mm^2
Section		Lower switchyard to Iringa Substation
Length	km	113
Annual Energy Production		
Total Energy	GWh	868.9
Firm Energy	GWh	551.0
Construction Period	years	3.5
Project Cost	10^3 US$	206,000
Unit Construction Cost at Sending End	US$/kWh	0.37

Item	Unit	Description
Economic Internal Rate of Return (EIRR)	%	45.94
Financial Internal Rate of Return (FIRR)	%	12.74
Net Present Value (B-C)	10^3 US$	129,236.15
Benefit Cost Ratio (B/C)	-	2.32