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REPUBLIC OF KENYA

KENYA POWER COMPANY LIMITED

FEASIBILITY STUDY ON MAGWAGWA HYDROELECTRIC POWER DEVELOPMENT PROJECT

FINAL REPORT

MAIN REPORT

OCTOBER 1991

JAPAN INTERNATIONAL COOPERATION AGENCY

NAIROBI OFFICE
P.O.BOX 50572
NAIROBI KENYA

TOKYO HEAD OFFICE
P.O.BOX 216 SHINJUKU
TOKYO JAPAN

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This Report consists of

Volume I	*Executive Summary*
Volume II	*Main Report*
Volume III	*Supporting Report (1)*
Volume IV	*Supporting Report (2)*
Volume V	*Data Book (1)*
Volume VI	*Data Book (2)*

PREFACE

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

JICA sent a survey team to Kenya headed by Mr. Keisuke Sumikawa of Nippon Koei Co., Ltd. over four periods of January to March 1990, June to November 1990, March 1991 and August 1991.

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

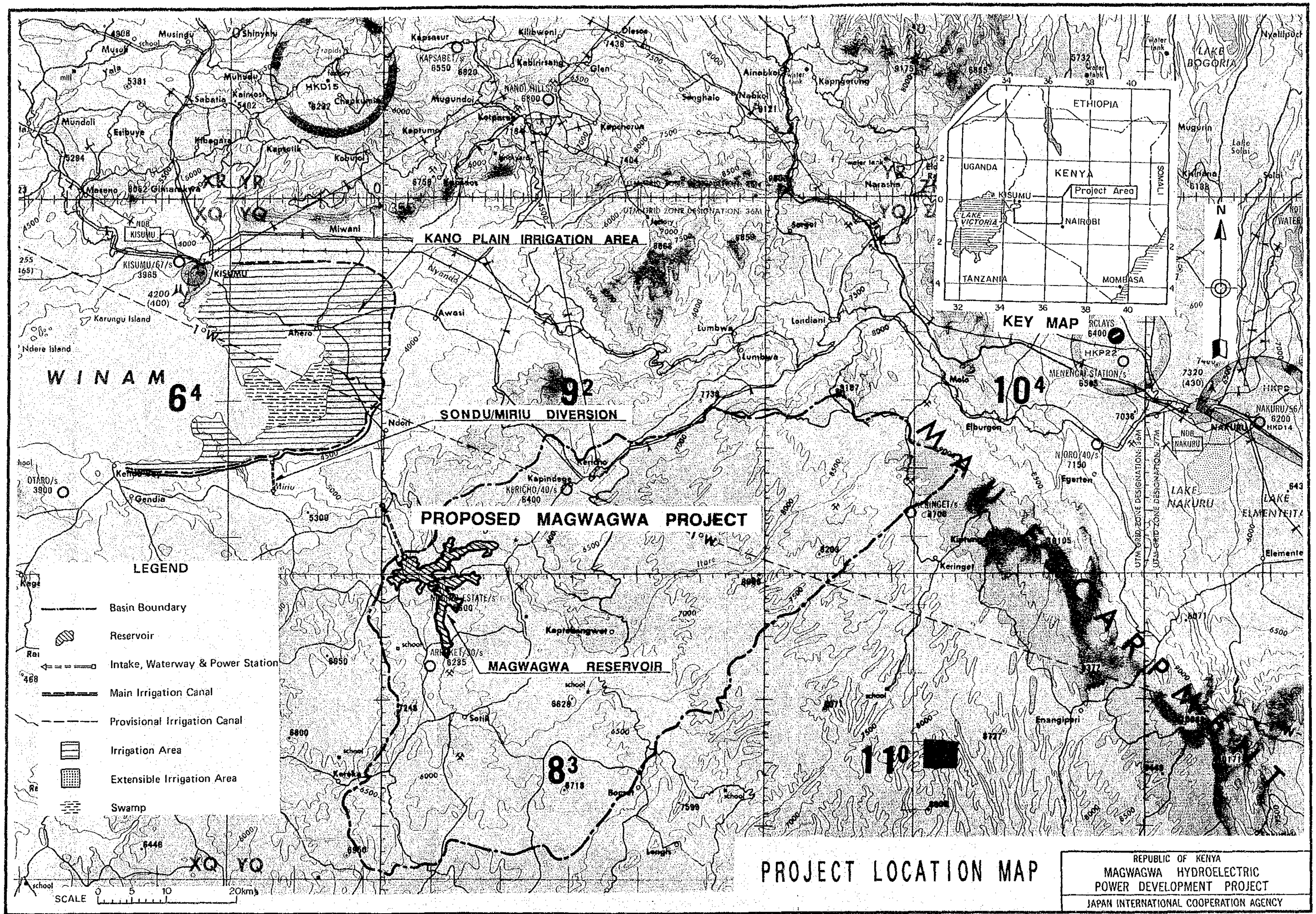
I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

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

October, 1991

Kensuke Yanagiya

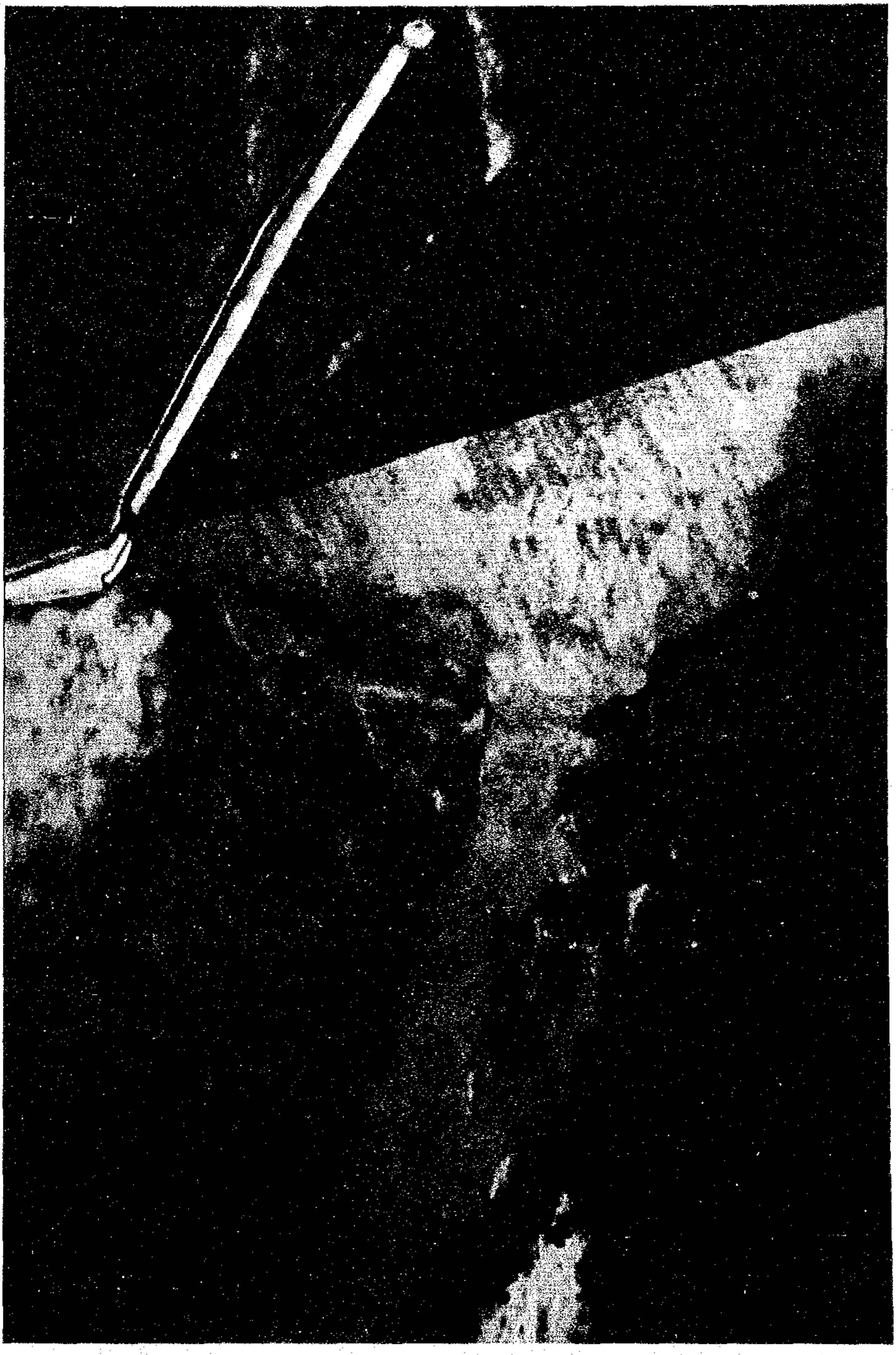
Kensuke Yanagiya
President
Japan International Cooperation Agency



PROJECT LOCATION MAP

REPUBLIC OF KENYA
MAGWAGWA HYDROELECTRIC
POWER DEVELOPMENT PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY



Perspective View of the Proposed Dam

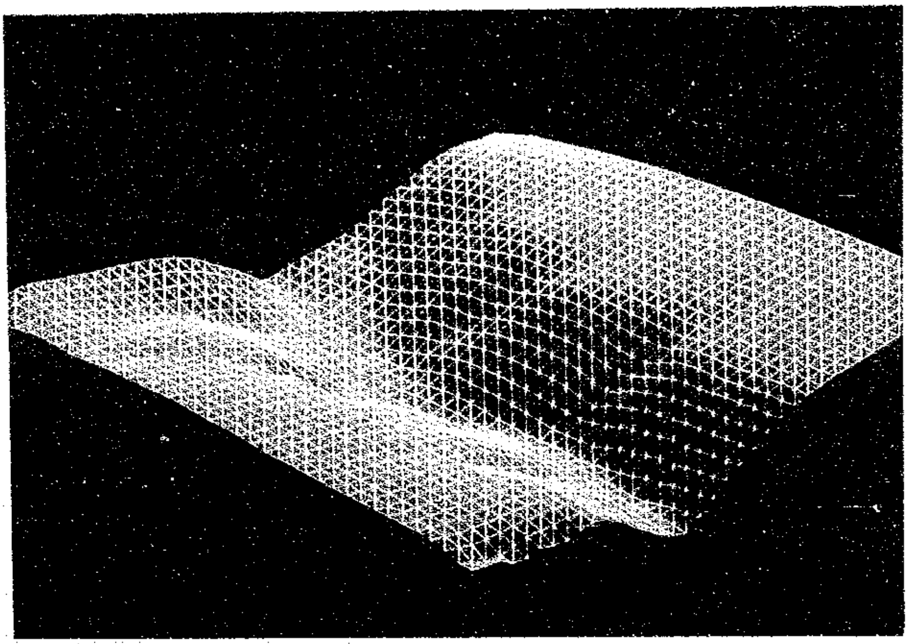


Photo 1 Downstream View of Topography at Proposed Damsite

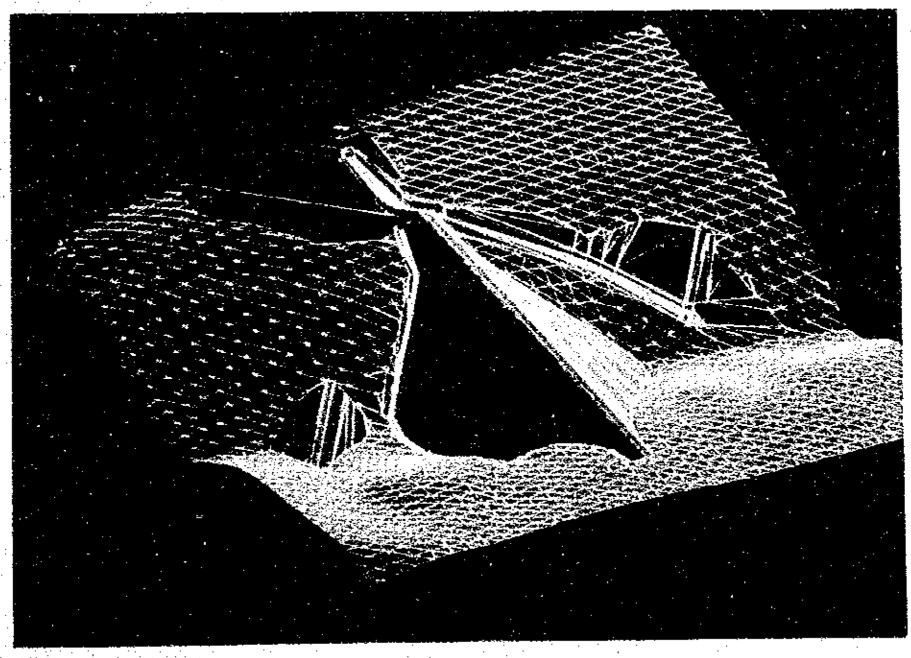


Photo 2 Overall View of Proposed Dam before Reservoir Impounding

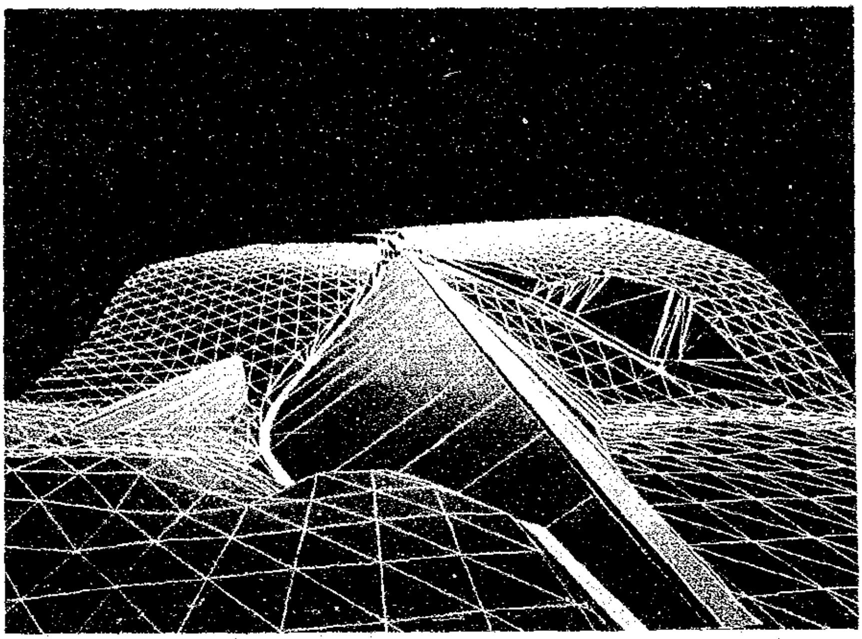


Photo 3 Perspective from Right Abutment

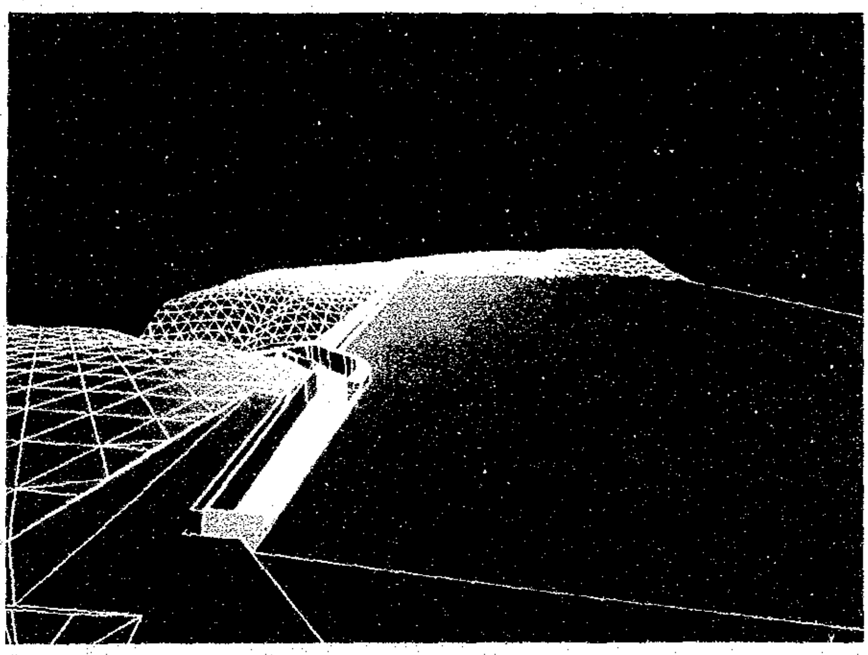


Photo 4 Perspective from Left Abutment with Reservoir Impounding

FEASIBILITY STUDY
ON
MAGWAGWA HYDROELECTRIC POWER
DEVELOPMENT PROJECT

FINAL REPORT

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II. Geological Study

III. Construction Material Survey

IV. Hydrology and Meteorology

V. Natural Environmental Aspect

VI. Social Environmental Aspect

VII. Parameters for the Economic Evaluation

I. INTRODUCTION

1.1 Background

1.1.1 Electric power development

Electric power in Kenya is supplied with 2,610 km long power transmission systems and 10,960 km long power distribution systems throughout the country. The installed capacity in the systems is 702 MW (effective capacity of 509 MW), consisting of 493 MW of hydropower, 45 MW of geothermal and 164 MW of oil thermal.

Recent completion of Kiambere hydro plant with an installed capacity of 144 MW and an addition of Turkwel hydro plant with an installed capacity of 106 MW in 1991 will raise the total effective capacity to a level of 750 MW, in which power supply of 30 MW from Uganda is included. But, recent power supply shortage in Uganda makes hard expect the imported power as firm.

On the other hand, power demand in Kenya increased with a high rate of 6.8% per annum for a period of 1976 to present, varying annual increase rates of 1.7% in 1982 to 1983 and 10.8% in 1985 to 1986. Moreover, power demand in recent five years (1983 to 1988) recorded an annual increase rate of 7.5%, reaching 480 MW and 2,931 GWh a year in power and energy demands respectively at the level of 1988/89.

According to the recent power demand forecast by Kenya Power and Lighting Limited (KPLC), power demand in Kenya is expected to reach 718 MW (3,529 GWh a year) in 1995 and 938 MW (4,578 GWh a year) in 2000. To meet the growing power demand, such new power plants as Sondu/Miriu hydro of 60 MW and geothermal of 115 MW are planned to be developed in the latter half of 1990's.

Even with such new additions of power plants, the power system in Kenya would require the development of some 200 MW by year 2000 to meet the power demand, taking into consideration the reserve capacity of some 20% and power generation decrease of hydro plants in dry seasons.

Since Kenya is a non-oil producing country and her oil import shares more than 30% of total imports, the Government of Kenya places a high priority to develop the indigenous energy resources such as hydro and geothermal and to reduce oil consumption as much as possible in view of saving foreign currency.

1.1.2 Agricultural development

Agriculture in Kenya mainly practises in a rainfed condition, much relying on rainfall. Insufficient and unevenly distributed rainfall limits the land used for agricultural practice to 19% of a total land area of 564,000 km^2.

Maize, staple food in Kenya, is vulnerable to the change of climate, and its production largely fluctuates year by year following the climate condition, causing food shortage in dry years. This could result in the import of staple food. In addition, recent shift of consumer's taste from maize to rice on staple food spurs the increase of food import, which is another reason to aggravate the national financial balance.

Under the above condition, the Government of Kenya launched a programme weighing on two points; to achieve the self-sufficiency of maize and rice and to promote agriculture-based industry for increasing the added value of traditional cash crops such as tea and coffee toward year 2000 as part of a long-term economic development strategy.

1.2 The Project and the Study Objectives

1.2.1 The Project

The Sondu River, one of six major rivers in the Lake Victoria basin, which originates from the western flank of the Mau Escarpment and flows down in the precipitous highlands such as Kericho area, is well known as a river with ample flow. River water at present in vain drains in Lake Victoria after only using for local water supply and so on due to the topographic characteristics with the deep river valley and the small plain at the river mouth.

The vast Kano plain neighbours the Sondu River basin in the north. The agricultural practice in the plain is carried out under the rainfed condition, resulting in low productivity due to erratic and limited rainfall.

Under such a condition, a study with dual objectives of hydropower development in the Sondu River and irrigated agriculture development in the Kano plain was carried out by JICA in 1985, proposing a plan consisting of three components; Magwagwa dam scheme, Sondu/Miriu diversion scheme and irrigation scheme in the Kano plain as depicted in Figure 1.1.

The Magwagwa dam scheme has the functions to regulate river flow with its reservoir capacity of some 800 million m^3 for power generation and irrigation water supply and to generate power availing head created by dam itself and 8 km long waterway. The Sondu/Miriu diversion scheme has dual functions of inter-basin water transfer from the Sondu River to the Kano plain and hydropower generation taking advantage of head existing between the intake and outlet sites of the diversion tunnel. The Kano plain irrigation scheme, commanding an area of some 26,000 ha, aims to enhance agricultural productivity by introducing the Sondu River water.

Since the Magwagwa scheme has the nature of multi-purpose development as discussed above, its optimal development scale will be searched for by taking into consideration hydropower development in the Sondu River and irrigated agricultural development in the Kano plain.

1.2.2 Study objectives

The Government of Kenya envisaged to develop the Magwagwa hydroelectric power development project in light of her energy and agricultural development policies, i.e. exploration of indigenous energy resources and achievement of self-sufficiency on staple food, and requested to the Government of Japan technical cooperation in carrying out its feasibility study.

In response to the request of the Government of Kenya, the Government of Japan dispatched a mission consisting of officials of Japan International Cooperation Agency (JICA), the official agency responsible for the implementation of technical cooperation programmes of the Japanese Government, to Kenya for discussing the scope of work of the Study with its counterpart agency, the Kenya Power Company Limited (KPC), in August, 1989.

According to the scope of work so prepared under the discussions of two agencies, the objective of the Study is to formulate an optimum plan for the Magwagwa Hydroelectric Power Development Project and to assess its technical, economic and financial feasibility.

Another implicit objective of the Study is transfer of technology, which will be accomplished mainly through the on-job-training in the course of work. In view of technical cooperation policies of Japan, this is in fact an essential objective of the Study.

1.3 Work Progress

The Study was commenced by dispatching a study team to Kenya for a period of January to March, 1990. Main activities in the period were the discussion of the Inception Report which showed the plan of operation of the Study, reconnaissance to the site, power survey, socio-economic survey and selection of development alternatives, the results of which were briefed in the Progress Report (1).

The work of the Field Investigation Stage following the Identification Stage in the period of January to March, 1990 was resumed in June, 1990 and was continued until November, 1990. Main activities in this Field Investigation Stage were placed on the field work for topography, geology including construction materials and hydrology as well as natural and social environmental impact surveys.

Two Progress Reports were prepared in this Field Investigation Stage; Progress Report (2) and (3). Progress Report (2) prepared in August, 1990 dealt with the progress of field work, and Progress Report (3) summarized the results and analyses of field surveys achieved in the Field Investigation Stage.

As mentioned in the preceding Sub-section 1.2.1, The Project, the integrated development of the Sondu River and the Kano plain is composed of three components; Magwagwa dam, Sondu/Miriu diversion and Kano plain irrigation schemes. The studies for the Sondu/Miriu and Kano schemes which are under the detailed design and feasibility study stages respectively are being carried out simultaneously with those of the Magwagwa scheme.

A joint meeting consisting of three teams in charge of respective studies and the counterpart agencies, KPC, LBDA and the Ministry of Energy, was held in October, 1990 to seek the optimal development of potential in the Sondu River and the Kano plain. Chapter 5, Plan Formulation, reflects the results discussed in the joint meeting.

The study team, returned to Japan with the completion of the work of the Field Investigation Stage at the end of November, immediately started the work of the Preliminary Design Stage, i.e. selection of optimal development alternative and scale, preliminary design at the feasibility study level and preparation of construction plan and cost estimates.

Interim Report was prepared in March, 1991 by incorporating the results achieved by that time for the work of the Preliminary Design Stage as well as the summarization of outcomes obtained in the Field Investigation Stage.

The work of the Preliminary Design Stage was continued by July, 1991 for elaborating basic design at the feasibility study level and preparation of construction plan and cost estimates and for assessing economic and financial viability. An overall evaluation of the project was finally made including the assessment for the natural and social impact studies. Draft Final Report was submitted in August, 1991 by dealing with all the results achieved in this study.

The study team came back to Kenya in late August and discussed Draft Final Report with KPC, its counterpart agency. By incorporating comments raised from KPC to the report, Final Report was submitted to the government of Kenya in October, 1991.

II. SOCIO-ECONOMIC SCENES

2.1 People and Population

The population of Kenya is estimated to have reached 23 million at the end of 1988 with a growth rate of 3.8% a year. The south-western quadrant in Kenya, mainly Nyanza and Western Provinces (refer to Figure 2.1) where the project lies, contains over 30% of total population for less than 5% of total land area, 564,000 km^2.

Acute population pressures and over population in the region may be endorsed by the fact that the average population density in Kisumu District was 359 persons/km^2 compared with that of 35 persons/km^2 in the nation in 1984. The average number of a household was 6.6 persons in Nyanza Province and 6.4 persons in Kisumu District in 1983, whilst 4.7 persons on the national average. About 40% of farmers had two acres of land or less at the national level in 1988, however the figure was over 47% in South Nyanza District, 58% in Kisii District and 59% in Kisumu District.

According to the 1979 census, the indigenous African population in Kenya was classified into forty-two tribes based on ethnic, linguistic and geographical considerations (refer to Figure 2.2). Three major tribes among them are the Kikuyu, Luhya and Luo in number, whilst the Gosha, Sakuye, Hawiyah and El Molo who migrate in north-eastern Kenya only count the number of less than two thousand.

In the project area, the district boundaries almost coincide with those of tribes; that is, the stretches of the Sondu River where the Magwagwa dam is built are not only the district boundary between Kericho and Nyamira districts, but also the tribal boundary between the Kipsigis and Kisii. The district boundary between Nyamira and South Nyanza districts running south of the Kisumu - Kisii road in parallel also demarcates spatial distribution of the Kisii from that of Luo.

The waterway starting from the intake proposed near Magwagwa Village in Nyamira District goes across the district boundary between Nyamira and South Nyanza districts at almost right angles, leading water to the powerhouse located in South Nyanza district a few kilometres downstream of Sondu Township along the Sondu River. That is to say, the project spreads over the homelands of the Kipsigis, Kisii and Luo tribes.

2.2 National Economy

Kenya attained an impressive growth performance over the period of her independence in December 1963 to year 1971 as recorded an annual average growth rate of 6.5% in terms of GDP. Agriculture was a leading sector by sharing 33 to 38% of total GDP, followed by the manufacturing sector with a share of 9 to 10% of total GDP.

The smooth economic growth of Kenya achieved in the first nine years after her independence was frustrated by the 1973/74 oil crisis and bad weather prevailing in 1974, as seen in sharp drop of GDP from a high rate of 6.7% in 1964 to 1972 to only 3.1% in 1975. In fact, the 1973/74 oil crisis brought the price of crude oil trebled in a period of before and after-crisis, resulting in the expenditure of K£ 87 million for fuel imports from K£ 16 million in 1973.

The so-called coffee boom over the period of 1976 to 1978 recovered the Kenya's economy, attaining an annual average growth rate of 8.2 and 7.9% in 1977 and 1978, respectively. The second oil crisis aggravated Kenya's economy again with a decline of GDP growth rate from 7.9% in 1978 to 5.0% in 1979 and 3.9% in 1980.

Recent Kenya economy (1982 to 1988) has gained the growth rate of 4.5% per annum in terms of total gross domestic product, GDP, as illustrated in Table 2.1. Agriculture is a leading sector by sharing 29% of total GDP, followed by the manufacturing sector only sharing 13% of total GDP. However, its growth rate is highest with a value of 5.5% per annum.

On the other hand, the population of Kenya is estimated to have reached 23 million at the end of 1988 with a growth rate of 3.8% a year, resulting in a marginal increase of 1% in GDP per capita.

2.3 Development Policies and Target

The current development plan (1989 to 93), which is the sixth five-year development plan since the independence of Kenya, raises a theme of Participation for Progress, which is translated into mobilizing individual capacities for the improvement of the quality of life for all.

The development target in the current development plan is set to achieve the growth rate of 5.4% per annum for absorbing labour force swelling the current estimated number of 8.6 million to 10.6 million.

Agriculture is the key sector to keep the target growth rate, the central goal of which is to make the country self-sufficient in food production. Coffee, tea and horticultural products will remain as the major foreign exchange earners. Another key sector is manufacturing, which will have capacities to absorb increasing labour force. Table 2.2 depicts the target growth rates by sector, in which the manufacturing sector has a highest rate of 7.5%.

The Gulf Crisis outbroken in mid 1990 showed symptoms of fuel price increase, which would force hardship to achieve the target growth rate of 5.4% as experienced in the past oil crisis. However, endeavours to achieve self-sufficiency on staple food and high reliance to indigenous energy will enhance the defiance against external pressures such as fluctuation of oil price, making the target growth rate possible.

2.4 Development Potential and Constraints in the Region

The project lies in the Western region consisting of Nyanza and Western provinces in terms of electric power supply, where natural resources are well endowed as represented by fertile soils and favourable climatic conditions. Supported with these well endowed natural resources, a wide variety of crops is grown in the region including maize and rice as staple foods to tea, coffee, cotton, surgarcane and so on as cash crops.

The population of Nyanza and Western provinces is estimated at more than seven million compared with the population of 24 million for the entire Kenya in year 1990, sharing 30% of total population. On the other hand, Nyanza and Western provinces cover an administrative area of 24,500 km^2, corresponding to 4.3% of the total land area of Kenya, 564,000 km^2. This fact implies the region is well endowed with human resources.

The five-year development plan of LBDA (1989 to 1993) mentions that the gross regional domestic product, GRDP, of the region, which includes not only Nyanza and Western provinces but also Kericho, Nandi, Uasin Gishu and Trans Nzoia districts, and part of Nakuru district in Rift Valley Province, is assumed to share some 23.5% of the nation's GDP varying year by year; that is, the GRDP share of the Western region in terms of electric power supply to the nation's GDP can be inferred to be further smaller than

23.5%, resulting in smaller contribution to national economy compared with its population share of 30%.

Although it is true that GDP share is not a sole factor to represent the region's contribution to the national development, it cannot be denied that the region is considerably behind compared with other regions in Kenya in terms of development.

Main constraints for the development of the region, as many a district development plan mentions, are explained by lack of proper infrastructures, and electricity supply in which the region is now under the peripheral condition cannot be excluded from the above constraints. It is thus desired to have electric power sources in the region as a pivot of development for mobilizing well endowed natural and human resources.

III. GENERAL CONDITION OF THE PROJECT AREA

3.1 Location and Topography

The Sondu River, one of six major rivers in the Lake Victoria basin, originates from the western slope of Mau Escarpment, neighbouring the Nyando River in the north and the Kuja River in the south. Meandering high lands with gentle undulation and collecting tributaries, the Sondu River generally flows down westwardly.

After two major tributaries, the Yurith and Kipsonoi rivers, merge, the Sondu River enters the narrow gorge penetrating the Nyakach Escarpment and falls in cascade with scenic waterfalls called Odino falls to the flood plains at Nyakwere. Elevation falls of some 300 m for a distance of 25 km, Sondu Township (El.1,500 m) located 12 km downstream of the Yurith and Kipsonoi confluence to the foot of escarpment (El.1,200 m), Nyakwere, are contrasted with gentle undulation in the highlands. The Sondu River finally drains in the Winam Gulf of Lake Victoria with a catchment area of 3,470 km^2 at the estuary.

The proposed Magwagwa dam lies in the narrow gorge just after two major tributaries, the Yurith and Kipsonoi, merge; that is, topography at the site shows a favour to create a large impounding reservoir of 800 million m^3 scale by building a 100 m class high dam. Ample rainfall in the highlands with more than 1,800 mm a year furthermore attracts the construction of the Magwagwa dam.

Administratively speaking, the reservoir created by the Magwagwa dam extends in Kericho District of Rift Valley Province and Nyamira District of Nyanza Province, which is a district newly born by dividing Kisii District into two. On the other hand, the proposed powerhouse lies in South Nyanza District.

Topographic maps on a scale of 1 to 1,000 and 1 to 5,000 were newly prepared by means of photogrammetry to obtain topographic information in detail at the proposed structure sites and in the reservoir area. The 1 to 5,000 scale maps furthermore identify the households to be submerged in the reservoir and to be affected by the project.

3.2 Meteorology and Hydrology

3.2.1 Meteorology

The climate of the Sondu River basin is mild with small variation of 19°C to 25°C on average monthly air temperature throughout the year due to the high elevation of El. 1,600 m to El. 2,700 m. Daily air temperature fluctuates largely, ranging from 15°C to 30°C.

Mean annual rainfall over a period of 49 years between 1940 and 1988 was obtained to be 1,505 mm by computing arithmetic mean of the 13 gauges listed in Table 3.1. Annual basin rainfall on the other hand fluctuates between 1,152 mm in 1984 and 1,892 mm in 1978.

An isohyetal map of mean annual rainfall was prepared using all the available data of 57 rain gauges as shown in Figure 3.1, indicating that the central part of the basin lying in and around Kericho district is abundant between 1,800 mm and 2,000 mm per annum. Another place with ample rainfall spreads at the west-central part of the basin located in Kisii district, whilst the upstream areas of the basin extended in its eastern part and the downstream part of the Sondu River have a small amount of rainfall between 1,000 mm and 1,400 mm a year.

The distribution patterns of monthly rainfall were prepared for the three regions of the basin based on the data of the selected 13 stations as presented in Figure 3.2, showing a peak over a period of April to May in the central part of the basin, bimodal peaks of April to May and July to August in the eastern part and a peak, even not conspicuous, in April in the western part.

Frequency analysis of annual maximum daily rainfall was conducted applying the Gumbel method as given in Table 3.2, finding that the rain gauges located in the eastern part of the basin (Reginget, Marindas and Teret) have probable rainfall smaller than those in other parts.

3.2.2 Hydrology

The catchment area of the proposed Magwagwa dam is mainly covered with forests of 1,000 km^2, tea plantations of 200 km^2, scattered tree areas of 250 km^2 and swamp areas of 70 km^2 as shown in Figure 3.3. Those areas will contribute to increasing low-flow and to retarding and decreasing flood peak discharge.

1JG1, a stream gauge standing near Sondu Township, acts as a key station in determining the optimal development scale of the Magwagwa Hydropower Project due to the fact that the station currently well operated not only lies near the project site, but also has the longest record in the basin. Thus, special attention was drawn to the records observed at 1JG1.

Monthly runoff recorded at 1JG1 is shown in Table 3.3, estimating mean annual runoff of 42.0 m^3/sec. A flow duration curve was drawn by the Series method at the Magwagwa damsite based on the daily runoff recorded at 1JG1 as given in Figure 3.4, obtaining 4.3 m^3/sec as the 95% guarantee flow over a period of 1946 to 1990.

The Sondu River is composed of two main tributaries, The Yurith and Kipsonoi rivers. Mean runoff coefficients for both rivers were computed as shown in Table 3.4 and summarized below:

St. No	River	Catchment Area (km^2)	Runoff Depth (mm)	Basin Rainfall (mm)	Runoff Coefficient (%)	Period
1JG1	Sondu	3,260	406	1,511	26.9	1946-90
1JD3	Yurith	1,570	610	1,690	34.8	1970-88
1JF1/8	Kipsonoi	1,540	211	1,338	15.5	1952-61, 1986-88

Monthly runoff patterns for the above three rivers are described in Figure 3.5. The pattern for the Nyando River is also presented as reference.

Despite almost the same catchment area between the Yurith and Kipsonoi rivers, runoff of the Yurith River much contributes to the one of the Sondu River as endorsed by the difference of runoff depth and runoff coefficient.

Records of flood hydrographs and rainstorms have been collected for flood analysis including frequency analysis of peak flood and prediction of the design flood hydrographs. The characteristics of the recorded floods are summarized below:

Flood Period	Flood Duration (day)	Peak Discharge (m^3/sec)	Base Flow (m^3/sec)	Direct Flood Volume (mil. m^3)	Runoff Ratio (%)	Peak Time Lag (day)	Basin Time Lag (hr.)
Jun 1 - 20, 1957	20	230	100	116	50.0	2 - 3	100.0
May 1 - 24, 1962	24	325	70	253	44.8	2 - 3	125.5
Apr. 16 - May 6, 1964	21	523	50 - 100	415	57.9	6 - 7	122.0
Apr. 20 - May 13, 1968	24	346	90 - 150	224	40.0	2 - 3	132.1
Apr. 15 - May 26, 1977	42	253	80	281	35.9	2 - 3	131.3
Mar. 23 - Apr. 1, 1978	10	413	170 - 200	87	49.6	2 - 3	61.0
Apr. 6 - Apr. 23, 1981	18	272	50	105	34.2	2 - 3	83.6
Nov. 21 - Dec. 16, 1982	25	332	90	237	37.4	2 - 3	174.6
Apr. 4 - Apr. 23, 1990	20	640	200	271	35.4	28 hr - 48 hr	64.8
For P.M.F. Estimate	30	—	200	--	60.0	2 - 3	—

* Peak Time Lag means the time duration between peak rainfall and peak discharge.
* Basin Time Lag means the time duration between the centroids of the hydrograph and the corresponding hyetograph.

It was found that the flood in the Sondu River basin has a long duration from 10 days to 50 days due to the long duration of rainstorms and high retention and retardation effects of the basin.

Probability of annual maximum peak discharges observed at 1JG1 was estimated applying the Log Pearson Type III density function as shown in Figure 3.6 and summarized below:

Return Period (Yr.)	Peak Discharge (m^3/sec)
1,000	1,634
500	1,409
200	1,140
100	958
50	792
25	641
20	595
10	461
5	339

Probable Maximum Flood (P.M.F.) at the proposed Magwagwa damsite was developed based on a unit hydrograph (refer to Figure 3.7) predicted from the flood recorded at 1JG1 in April, 1978 and the probable maximum precipitation over the Sondu River basin as shown in Figure 3.8. The predicted P.M.F. has peak discharge of 1,920 m^3/sec which is equivalent to 1.18 times of the 1,000-year flood.

On the other hand, peak discharge of a 10,000-year probable flood was computed to be 2,535 m^3/sec at the damsite applying the Log Pearson Type III method, even if the small number of samples, 44, as seen in Figure 3.6, shows the low reliability in prediction. This computed peak discharge is used for the endorsement of the predicted P.M.F. and for ensuring the security of the designed spillway from overtopping.

Mean annual sediment yield at the damsite was estimated by simulating daily runoff data of 1947 to 1990 to the developed runoff-sediment yield curve, resulting in 531,000 m^3/year or 0.168 mm/km^2/year in terms of the denudation rate (refer to Table 3.5).

According to MOWD, the standard to determine the amount of river maintenance flow consists of the following three categories:

(a) To guarantee the amount of existing water abstraction rights of the downstream reaches,
(b) In addition to (a), to release water for the domestic use of riparians, the amount of which is equivalent to 95% dependability discharge in the duration curve of flow,
(c) In addition to (a) and (b), to release 30% of the amount of (b) for aquatic lives.

Applying the above criteria, recommended river maintenance flow was estimated to be 0.5 m^3/sec.

3.3 Geology

3.3.1 Geology in the region

The Sondu River flows down generally from the east to the west gathering such major tributaries as the Yurith and Kipsonoi rivers, despite the change of direction from the south to the north in the middle reaches, finally draining in Lake Victoria with a catchment of 3,470 km^2 at the estuary. The upstream areas of the river form rather gentle flat highlands reflecting the geology composed of comparatively younger strata than that of the downstream area, and are covered with Tertiary andesite lava called phonolite as shown in Figure 3.9.

The areas in the lower reaches on the other hand expose the basement of meta-sedimentary rocks, igneous rocks in Pre-Cambrian and granitic rocks in Post Cambrian. Predominant in the project area located at the middle to lower reaches are Pre-Cambrian andesite, felsite and sedimentary rocks. Table 3.6 gives a list of geology in the region consisting of sedimentary rocks (metamorphic rocks), igneous rocks in Pre-Cambrian, granitic rocks intruded in Post-Cambrian, tertiary volcanic rock, Pleistocene to recent river deposits along the present river course and talus on the rather gentle slopes in a descending order.

According to the seismic zoning map of Kenya and earthquake data collected from International Seismological Centre, the project site falls into the rather low seismicity zone of "VI" (21.0 to 44.0 gal, i.e. 0.05 G) in Modified Mercalli Intensity Scale. The results of seismic analysis revealed to be 0.10 G as the coefficient of dam design, in which the recurrence interval of earthquake is adopted at 100 years.

It is reported in the 1988 meeting of ICOLD (International Commission on Large Dams) and by T. Vladut (August, 1989 Water Power & Dam Construction) that Reservoir Induced Seismicity (RIS) is recognised as a significant environmental issue related to dam safety. The risk of RIS in this area was predicted by the approach proposed by T.Vladut, indicating rare occurrence of induced seismic phenomena as the result of RIS analysis shows a value of 0.05 G. The risk of RIS is within the range of safety for the dam designed with a value of $k = 0.10$ G.

3.3.2 Geology at the project site

Geological investigation was carried out by means of core drilling, seismic exploration and laboratory testing to confirm the suitability of rocks as the foundation of the proposed structures as shown in Figure 3.10. Construction material survey was at the same time performed to confirm the available quality and quantity of soils and rocks in the proposed quarry sites and borrow areas by boring, test pitting, hand augering and laboratory testing. Following summarize geological conditions at the proposed structure sites based on the results revealed by geological investigation and survey.

(1) Geology at the Magwagwa damsite

In the study of the Identification Stage conducted in a period of January to March, 1990, two alternatives on the dam axis, SD2 and SD3 (refer to Figure 3.10 and subsequent Section 6.2.2), were proposed. The upstream axis (Alternative-A) was assessed to be more preferable than downstream one in the sense of topography and geology, so that geological investigation by seismic exploration and drilling was concentrated at the Alternative-A site.

Another promising alternative on the dam axis called Alternative-B, which is located some 150 m downstream of Alternative-A, was found by availing the topographic maps newly prepared on a scale of 1 to 1,000 in this study, so that drilling work at BD8 was newly added along the axis of Alternative-B.

Drilled cores at BD2 and BD7 besides BD8 show the suitability of Alternative-B as the dam foundation more than that of Alternative-A due to a fault running along the river course slipped out from the riverbed as depicted in Figures 3.11, 3.12 and 3.13, despite residual soil developed on the left bank of Alternative-B thicker than that of Alternative-A.

River deposits are 2 m to 3 m thick and the average thickness of residual soil is 3 m in the area except for the foot portion of the right bank on Alternative-A and the upper slope of the right bank on Alternative B. Excavation depth will be 7 m on an average to rest the dam foundation on sound rocks.

The permeability of dam foundation is generally lower than 5 Lugeon in the area except for the weathered zone of 10 m to 40 m in thickness, a fault zone of 10 m wide running at the right corner of the riverbed on Alternative-A and the right bank of Alternative-B, and the upper boundary between sandstone and limestone located at the right corner of the riverbed on Alternative-A. The required length of curtain grout will be 40 m on an average.

The subsequent Section 6.2.2, Main Dam, deals with the study to look for the most promising dam axis by adding Alternative-C, located further downstream of Alternative-B. The site geology of Alternative-C is inferred from that of Alternative-B.

(2) Geology at the saddle damsite

A saddle dam will be built at a ground depression, the lowest elevation of which is El. 1,658 m to 1,670 m, located at the left bank upstream of the damsite (refer to Figure 3.14). Of the 3 drillings, the drilling at BS2 and BS3 was selected just on probable fault lines detected by seismic exploration. The results of drilling at these two spots revealed residual soil of 7 m to 8 m thick and partly fractured zones of andesite and sandstone, however, site geology shows the suitability as the foundation of saddle dam with relatively low height (more or less 10 m).

Considering the low permeability of less than 1×10^{-4} cm/sec (1×10^{-5} cm/sec on an average) in the residual soil layer and less than 1 Lugeon in the basement rock, it can hardly be expected that serious leakage occurs from the foundation of saddle dam and reservoir area. N-values of the residual soil layer below 3 m were greater than 10 blows, which have enough bearing capacity for the embankment of saddle dam with low height.

(3) Geology at the waterway route

Seismic exploration and drilling were carried out at the selected places of the waterway; the intake site, thin covering portions along the headrace tunnel, surge tank site, penstock line and power station site as shown in Figures 3.10 and 3.15. The investigation results revealed moderately good geological conditions, although BW1 and BW2 drilled at the intake and the portion with a thin coverage from the ground show an indication of fault existence and/or deep weathering. BW3 drilled at the Chabera Hills revealed the composition of andesite mass.

(4) Geology at the quarry and borrow sites

The Rigari rock quarry site was identified through the reconnaissance carried out in the Identification Stage. BQ1 was drilled at the proposed quarry site, revealing thick overburden which is unsuitable as a quarry site.

Unsuitability of the Rigari site as the quarry obliged to look for a new quarry site, which was found at the left bank 1 km downstream of the main dam. Two bore holes drilled at the new quarry site met hard and slightly weathered porphyritic andesite with residual soil of 1.5 m to 3.5 m thick, so that the new site is judged to be suitable as the quarry of the dam. The results of the laboratory tests for the rock samples taken from the new quarry site revealed uniaxial compression strength of

3,400 kgf/cm^2 and tensile strength of 180 kgf/cm^2, which demonstrate an excellent condition in quality. Furthermore, the Chabera Hills will be used as a quarry to obtain concrete aggregates for constructing the powerhouse, the penstock and a part of the waterway.

The possible borrow sites located at the both banks just upstream of the Magwagwa dam were investigated for seeking the possibility of building a rockfill type dam by test pitting, hand augering and laboratory testing (refer to Figure 3.10), showing the availability of far less amount compared with the volume required for the embankment of the impervious core due to top soils thinner than 4 m. Therefore, the type of the Magwagwa dam would be selected from either of concrete gravity and concrete facing types, even if the final selection relies on the cost comparison.

Figure 3.16 shows the soil properties of the possible two borrow sites. Preliminary tests tell these soil properties are suitable for embankment materials of the impervious zone. The borrow site located at the left bank can be used for earthfill materials of the saddle dam due to a short haul distance, although further investigations are required.

3.4 Natural Environment

3.4.1 Objectives

The objectives of the Natural Environmental Study for the Project are as follows:

- i) To identify impacts which are expected to cause negative effects for the natural environment by the Project,
- ii) To evaluate magnitude/significance of the impacts,
- iii) To propose countermeasures for the mitigation of the magnitude of impacts,
- iv) To evaluate the acceptability of the Project from the viewpoint of the natural environment, and to recommend further studies if any.

To attain the objectives mentioned above, the screening and scoping approaches were applied for the study. The screening approach was conducted to assess whether the Environmental Impact Assessment (EIA) should be studied based on the existing guidelines set by the Government of Kenya and the World Bank related to the environmental assessment in Kenya, judging that the EIA should be studied obviously due to a large reservoir scheme with an impounding volume of some 800 million m^3. The scoping approach intends to extract environmental items and to define the scope of study to examine the Environmental Impact Assessment (EIA) by carrying out the Initial Environmental Examination (IEE) for the Project prior to the EIA.

3.4.2 Results of IEE

The results of IEE were shown in Table 3.7 with preliminary evaluation of the expected effects. A total of 23 environmental items was examined based on the existing data and the field reconnaissance. Among those items, the change of water temperature, water contamination in the downstream area, eutrophication, vector borne diseases and disturbance of health facility utilization were identified as the impacts which would cause negative effects to the natural environment in and around the Project area. More detailed investigation and assessment for them were thus carried out in EIA to evaluate the magnitude and to recommend countermeasures more precisely. Meanwhile, reservoir fishery was expected to bring about positive effects for local people, so that further studies related to the fishery development was recommended in this study.

3.4.3 Environmental impact assessment (EIA)

(1) Change of water temperature

A formation of water temperature stratification would be considered in the proposed reservoir because its retention time (Annual inflow/Active storage volume) was about 2.1 times/year and the existing Jamji dam located about 20 km upstream of the Project site showed clear stratification. Therefore, temperature of water released from the Magwagwa reservoir would be around 18°C because the intake constructed below the Minimum Operating Level, MOL, could catch the layer of colder water. Water returned from the power plant to the Sondu River would flow down about 15 km to the intake of the Sondu/Miriu scheme, and the flow-down of water in the river channel would raise its temperature by about 1°C, resulting in water temperature of 18°C to 19°C at the intake site of irrigation canal.

Since no river fishery was conducted and no precious ecology was reported in the downstream area, it was not expected that serious effects would be caused by the change of water temperature by the Project though the aquatic ecosystem might be slightly changed. Therefore, no countermeasures would be needed for this impact.

(2) Water contamination in the downstream area

In the operation stage of the Project, water quality deterioration in the downstream area was expected due to the reduction of river flow. According to the existing water quality data, BOD concentrations at the dam site and 1JG1 were 1.0 mg/l and 2.7 mg/l, respectively. The concentration of BOD at 1JG1 after completion of the dam would be roughly estimated at 6.8 mg/l by using the complete mixture equation without any self-purification effect.

The expected BOD concentration at 1JG1, 6.8 mg/l, was considered to be in an acceptable level as a source of drinking water if it was treated by normal treatment facilities. Also no river fishery was conducted in the downstream area. Therefore, no serious effects were expected to the water contamination in the downstream area by the Project. However, the potential of water contamination by human and livestock fecal bacteria could increase considerably, so that it was recommended that the existing intake at Sondu village for the Nyakach water supply project should be shifted to the proposed reservoir or the power outlet for direct intake.

(3) Eutrophication

The potential of eutrophication normally depends on the inflow of nutrients and the characteristics of the reservoir. Therefore, preliminary assessment was conducted using the Vollenweider model. The concentration of the total phosphate in the inflow was considered to be less than 0.03 mg/l because the obtained concentration data of PO4 from the water quality analysis at the dam site was about 0.01 mg/l. In the case that the concentration range was assumed from 0.01 to 0.03 mg/l, the annual phosphate surface load was estimated in a range from 0.65 to 1.95 $gP/m^2.yr$. The estimated range plotted on the Vollenweider model revealed that the proposed reservoir would not be likely to be eutrophicated so long as the inflow of organic pollutants does not increase rapidly.

At present, no other large scale development projects which could bring about serious water pollution are planned in the catchment area. Moreover, the experiences of other dams in Kenya support that the reservoir would not be eutrophicated seriously. Consequently, it was expected that the potential of eutrophication would be very low and no significant effects would be caused by the Project.

(4) Vector borne diseases

Anopheles gambiae was confirmed during the field survey in slow moving streams in the area. A. gambiae breeds in any collection of water if exposed to the sun such as puddles, pits, wells and pools in river beds. The expected fluctuation pattern of the water level in the proposed reservoir and the reduction of the river flow in the downstream area would favour the proliferation of this mosquitoe. Therefore, the morbidity of malaria would be expected to increase and effective countermeasures are needed to reduce its magnitude to the local people.

Schistosomiasis would not seem to be a serious threat to the health of the local people in spite of the recovery of transmitter snails in the area. The cold climate in the area presumably slows down the development of the snail stages of the worm and eliminates the water stages rapidly. However, it was recommended that the improvement of a state of hygiene and sanitation in the area especially during the construction stage must be conducted because the vector, Schistosoma mansoni, could be spread through fecal contaminated water.

(5) Disturbance of health facility utilization

More than 70 % of the local people mainly receive medical services from the health centres and dispensaries. This fact implies that these facilities are important for the local people in and around the Project area to keep their health. Utilization of health facilities is closely related to accessibility to such services of the local people. The proposed alignment of relocation roads was considered acceptable because no serious inconvenience to the local people would be caused through the view point of the utilization of health services.

The population movement caused by the Project and the possible increase of vector borne diseases would overwhelm the already strained health facilities. The current dispensaries under insufficient staff and meagre equipment could not cope with the health problems of the area even at present. Therefore, setting up curative and preventive services exclusively used for workers should be considered to avoid the confusion on the existing health service system for the local people.

3.4.4 Conclusion of the natural environmental study

The EIA revealed that only the effect on the public health especially spread of vector borne diseases was considered significant, and the others were not. However, even the effect of the vector borne diseases could be reduced its magnitude by taking appropriate countermeasures. Therefore, it was concluded that the Project would not cause any unavoidable effects on the natural environment in and around the Project area. Consequently, the proposed Project was considered acceptable through the viewpoint of the natural environment.

3.5 Social Environment

3.5.1 Objectives

The study on social environment aims to assess the soundness of the Project mainly from the local people's point of view in terms of socio-cultural and economic aspects. The main objectives of the Study are i) to clarify the current conditions of the socio-economic characteristics in the affected areas, ii) to analyse socio-economic impacts of the Project, iii) to provide basic data and information concerning compensation and countermeasures including resettlement, and iv) to recommend further studies.

3.5.2 Existing conditions

The socio-economic characteristics in the reservoir and its vicinity areas can be summarized as shown in Table 3.8 and details are described in Chapter 2 of Appendix VI. The following are a gist of existing conditions in the areas:

(1) Population

The population in the reservoir area is estimated at nearly 4,300, multiplying 700 households estimated from household distribution by elevation in Figure 3.17 by the average number of household members of 6.1. It is noted that the population of Magwagwa village is excluded in the above count, since the axis of the saddle dam, which will be built at the topographic depression located in Magwagwa village (refer to subsequent Section 6.2.7, Saddle dam), is designed not to pass the most densely populated area of the village, i.e. the trading centre of the region.

With the reservoir area of 26 km^2 including river channels and uncultivated lands (refer to Figure 3.18), the population density is estimated at $162/km^2$ on an average. However, the population density is quite different between the Nyamira and Kericho sides: $295/km^2$ and $92/km^2$, respectively.

The population in the areas is characterized by its "youthfulness". Of the total population, over 50% fall in the group aged under 14-year old, whereas the working age group (15 - 59 year old) comprises 46% of total population. About 90% of household heads have lived in the current location since birth in the areas. On the other hand, those who once lived outside districts are few and have little experience with in-migrants. Similarly, they seem to have little experience of out-migration although a current out-migration trend has not been traced.

(2) Land use

The land which would be submerged in the proposed Magwagwa reservoir is well developed from the top of hills to the river side as agriculture lands, despite steep slopes along the river. About half a total holdings of households are used for agriculture, followed by pasture (38%), forestry including agroforestry (9%) and waste land (2%).

Although the Project belongs to the marginal zone in terms of tea growing, a vast tea plantation extends in the area occupying between the Yurith and Kipsonoi rivers. The tea plantation would be free from submergence with the proposed dam crest level, but a part of forest reserved as fuel sources for tea processing and grasslands located downslope of the tea plantation would be submerged in the reservoir.

(3) Social aspects

Ethnic groups in the reservoir and its vicinity areas are clearly separated into two groups. In the Nyamira side, the Gusii people occupies a share of 96.5%, whereas the Kipsigis shares 98.5% in the Kericho. Of the 724 heads of households, 85% are currently married, 10% widowed and 5% still single. There are still polygamous families, although declining nowadays.

Although a traditional religious system appears to still affect their lives to a lesser extent than before, the christianism is a dominant religion in the areas. However, there is a major contrast of sects between the Nyamira and Kericho.

Of the total household heads in the areas, 52% can read and write Vernacular language, followed by Swahili (44%) and English (34%). Social networks based on kinship systems are still the backbone of their socio-economic activities. In addition, they have recently developed some types of socio-economic groups, mainly for income generation. The women's group is the largest among others.

(4) Economic aspects

An overall sketch of economic activities in the areas can be seen from the employment structure as shown in Table 3.9. Those in schooling and infants occupy the largest share of 62% of the total population. Of the remaining 38% comprising the working age group, farmers whose majority is mixed farmers (crops and livestock) are dominant with a share of 70%, followed by wage employment (19%) and self-employed in household business (6%). Non-farm incomes play an important role in their household economy. Salary/wages, trade/business and others as secondary income sources contribute to the livelihood of 42% of total households.

Almost all the land has been adjudicated and registered. The average land holding size of households is 5.0 ha, broken down into 3.6 ha in the Nyamira side and over 5 ha in the Kericho side. Those with less than 2 ha occupy one fourth in the Kericho and 35% in the Nyamira. The figures on the average land holding size may be overestimated since land owners may not always report to the district land registration offices. Major land problems are diminution of land holding and fragmentation of land.

Most of the farmers cultivate their own land for themselves: 43% of farm households reported that they handle all the farm work with family labour alone. Most of those which need others' help hire casual labour during the peaking time period. The farmers have traditionally elaborated the production system in which the maximum yield and risk avoidance can be achieved with limited land, and at the same time conserved the environment against soil erosion and others as much as possible, enabling most of them to achieve self-sufficiency of food. Their efforts are typically reflected in crop mixtures, inter-cropping, and hence crop diversification such as maize, beans, tea, coffee, bananas, vegetables, etc. and mixed farming comprising crop and livestock.

There are five trading centres in and around the areas. Of 109 establishments enumerated in the trading centres, the most common type of business is retail shops (39%), followed by tea kiosks (15%), butcheries (11%) and water mills for grinding maize (11%). The residents in and around the centres enjoy not only the requirements for ordinary life and employment opportunities, but amenities and amusements.

3.5.3 Social and economic impact analysis

(1) Summary of initial screening

Table 3.10 summarizes an initial screening of socio-economic impacts of the Project. The causes of the most severe impacts are likely to be displacement of people and submergence of land, infrastructures and facilities. Some 95% of total households surveyed expressed their concerns about a negative impact of land loss, while 86% for the impact of resettlement.

(2) Evaluation of significant socio-economic impacts

a) Displacement of people

The displaced people would be at least some 4,300 people at the moment including some 80 households in other affected areas. In addition, some of those who live outside would be compelled to move together with them for any socio-economic reasons.

For the preferred form of compensation, 82% of total households chose land for land and about 17% were interested in the combination of land and cash, whereas only 0.4% preferred cash only. They are aware that it is getting difficult to buy alternative land due to the reduced available land for agriculture even if they obtain money. Indeed, the resettlement through their own arrangement is supported by 31%, while the resettlement that the Government takes initiatives by 83% (these percentages do not total to 100% since they were asked whether each form of arrangements was supported or not).

Taking into account the displaced people's current situations, sufficient land in terms of both quantity and quality should be provided to them so that they can continue their production system. This would be the best way to re-establish their economic base in the possible shortest period and hence least-cost solution in the long term even if the land acquisition of alternative land costs much.

The displacement of the people will bring about the disruption of communities, resulting in substantial impacts on them due to the communities' nature of social cohesiveness and no experiences in out-migration and living with a mass of different ethnic groups. These impacts would be alleviated if the displaced people continue to have close relations with their original communities, or live in the vicinity of them. Their social organizations should survive so as to re-establish their communities.

There must be sufficient social and economic infrastructures and facilities in the resettlement sites so that the displaced people will be able to rebuild their lives in the new environment. Above all, the educational and health services will be emphasized due to the larger share of children and infants.

b) Submergence of land, infrastructures and facilities

Roads

In the identification of the routes, not only engineering aspect, but socio-economic ones should be allowed for to avoid isolating some areas in terms of socio-economic aspects and to minimize the people to be displaced by the new construction of roads. As most of the people in the areas usually walk on roads, and the transport measures are scarce, their range of travel is limited. Some of them may not be able to reach within permissible time their destinations essential for their daily lives. Such situations should be avoided by selecting appropriate routes for recreation of the roads and building new roads as needed (refer to Figure 3.19, Relocation Roads in and around the Reservoir Area).

Misogwa village in the Nyamira side may be one of those sufferers. After the submergence of the routes between it and Magwagwa village, it would be difficult for the people in the village to reach the Magwagwa village and to get into trouble since the latter is the centre of Magwagwa sub-location.

Public facilities

There do not appear many facilities in the areas based on the newly prepared topographic maps and the study on Natural Environmental Aspect. It was revealed that a school at Ngoina would be submerged. For the recreation of the facilities, particular attention should be paid to i) number of users for each facility, ii) whether or not the users among the remaining people will be able to utilize other facilities which would remain, iii) whether or not the facilities will have to be recreated for the remaining people, and iv) whether the existing facilities can be moved into the vicinity area or new facilities should be constructed.

Cultural/historical sites

The existence of cultural and historical sites has yet to be confirmed for both the public in general and the local people, especially the latter. If there are, the transferability of the assets should carefully be examined, and the transfer implemented.

3.5.4 Compensation and proposed countermeasures

Compensation and resettlement are main countermeasures for the displacement, whereas the restoration and area development for the submergence. As resettlement is a big issue, it will be separately delineated in the next Sub-section. Some ideas on the mitigation of the impacts are described in the Section 3.2 of Appendix VI.

(1) Compensation

Compensation is subject to the Constitution of Kenya, the Land Acquisition Act cap. 295, the Land Acquisition (Amendment) Act of 1990 and the Trust Land Act, cap. 288. Table 3.11 presents a summary of rough estimate on compensation, which would be the base for acquiring alternative lands for the evacuees, but not necessarily be equal. The compensation would amount to some KShs. 635 million, but still would have to be revised due to its insufficient and relatively ambiguous base of data.

(2) Proposed countermeasures

a) Restoration around the reservoir

Public common areas, facilities and infrastructures may not normally be a subject of compensation in case of compulsory land acquisition in Kenya. The restoration of them, however, is a "must" for the remaining people around the reservoir to sustain their socio-economic activities.

In planning the restoration of them, with a careful inventory survey, not only engineering aspect, but socio-economic aspects should be taken into account as described in the Sub-section 3.5.3, (2), 2) and 4.5 of APPENDIX V NATURAL ENVIRONMENTAL ASPECT (health facilities). Consultation with the affected people is important in formulating an appropriate plan. The schedule of the restoration should be well coordinated with the construction schedule of the reservoir so as to avoid the discontinuity of the affected people's socio-economic activities.

b) Employment generation and regional development

Some measures should be taken to rescue those who are to be displaced but have to remain around the reservoir and those who live outside the reservoir but lose their jobs due to the impoundment. The most promising way would be to provide them with permanent employment opportunities created by the Project, for instance, the tasks of operation and maintenance of the reservoir, if they agree. However, there are constraints: One is that they have to wait for obtaining the jobs until the operation stage of the dam, and the other is that the number of employment opportunities may not be large enough to absorb all of them. They may survive as casual labourers for the construction of the dam, but most of them lose their jobs after its completion.

Thus, a long-range strategy from the regional development point of view is required for the generation of employment opportunities for them. Besides, the regional development is needed so as to provide the benefits of the Project for those remaining around the reservoir, who are facing increasing population pressure on land, partly for which the Project is responsible.

There would be some major components or bases of regional development provided by the Project, including i) fish industry or aquaculture using the reservoir, ii) provision of water supply and iii) provision of electricity. These benefits are highly expected by the local people and administration as mentioned in the Appendix VI, 3.2, (4). Some officials claimed that the guarantee of such provisions would be the prerequisite to accept the Project. The fishery development would require comprehensive and detailed studies from technical, financial and environmental points of view.