3.5.5 Involuntary resettlement

(1) Understandings of involuntary resettlement

a) Some features of involuntary resettlement

Involuntary resettlement is significantly different from voluntary resettlement such as settlement schemes in Kenya. Those displaced are indiscriminately evicted against their desire without their plans in future, whereas migrating people are self-selected and voluntary-moving segment of the population. In dam projects, the displaced people cannot return to their original home forever. Therefore, such differences call for different designs, approaches, institutional responsibilities and financing sources.

The displaced people encounter extraordinary difficulties mainly due to the setback of their living standards caused by the loss of principal productive assets and of communities. They lose not only visible assets, but invisible property or rights such as employment, business, rights vested in members of community, etc. of which recovery is not guaranteed. Also, involuntary resettlement is a traumatic process for the affected people, since they are compelled to leave behind their beloved land, relatives, neighbours, etc. and not necessarily welcomed by the host population in new sites. The impacts of compulsory resettlement are more serious on vulnerable groups such as the poor, the aged, women and children.

b) Land-based and non-land-based strategies

Compensation is usually rewarded in the form either of land or of cash in national projects. Apparently, however, the form of compensation in recent projects in the world has shifted from "cash for land" to "land for land", especially in the case that the displaced people largely depend on land, typically farmers.

This change in the way of compensation reflects the lessons learned from the experiences in past projects with non-land-based strategy, and is attributable not only to disastrous impacts on the people evacuated, but to seriously negative effects on the projects, the regional and national development. The negative impacts become more substantial as the number of affected people increases. The causes of the negative impacts can be summarized in Table 3.12.

Taking into the above discussion, the Project should choose "land for land" approach because there are not a few conditions indicating a high possibility that the negative impacts would take place: A large scale of displacement; almost all the local people prefer the "land for land"; most of the displaced people are traditional farmers who are less educated; high population pressure on land and diminishing available land and kinship systems and other socio-cultural factors still play important roles.

c) Review of involuntary resettlements in other projects

In Kenya, there have been no projects which relocate considerable numbers of people like the Project. Therefore, it is worthwhile referring to the experiences in other projects in the world.

Problems and impacts resulting from failure of resettlements

The process of involuntary resettlement may be divided into four phases:

i) Preparation of resettlement,
ii) Transfer (uprooting) of the displaced people,
iii) Transition for resettlement, and
iv) Self-sustenance (rerooting) of resettlers.

There have been various problems during the stages from the preparation to the self-sustenance, so that it took longer time to reach the final stage. Such problems may be summarized as shown in Table 3.13.

Failures of resettlements caused by the above problems have had negative impacts on the projects, regional and national development, as well as serious damages to the displaced people. Figure 3.20 schematizes the process of occurrence of such effects, together with the impacts resulting from unsuccessful restoration around the reservoir area.

Resettlement components were often left out of major project design and concern principally due to underestimate of its economic, socio-cultural and political consequences and less awareness of its complexity. As a result, this approach brought about incomplete design, underestimate of cost and underfinancing and institutional problems of implementation.

(2) Framework of resettlement plans

a) Objectives and principles of resettlement

Based on the aforementioned discussions, objectives and principles of resettlements are summarized as shown below:

i) To maintain, at a minimum, the displaced people's current standard of living and to provide opportunities for them to achieve a higher standard of living, after resettlement, whether they have land or not;
ii) To minimize the socio-cultural and mental damages on the displaced people;
iii) To involve the affected population and the officials concerned in planning and implementation of resettlement;
iv) To minimize the transition period of resettlement with adequate provision and assistance of both a social and economic natures;
v) To avoid the drastic changes in the environment and bases of livelihood that hamper the smooth resettlement, and hence to minimize the distance between their homeland and the new sites as much as possible;
vi) To make the financial/human resources and development proposal available when and where required;
vii) To have adequate institutional arrangements to ensure effective and timely implementation and adequate monitoring/evaluation arrangements;
viii) To ensure that there would be no adverse impacts of the resettlement, especially on the host populations and their environment; and
ix) To allow for the "second generation" or predictable growth of affected households.

b) Approach to resettlement

<u>Legal framework</u>

Resettlement is allowable in situations of compulsory land acquisition of national projects in context of the land-based compensation strategies under the Land Acquisition Act and its amendment of 1990.

Government responsibility

Figure 3.21 presents the process of resettlement. Taking into account the principles and legal framework of the involuntary resettlement, and the nature of the Project as a national project, the Government of Kenya has the responsibility for the provisions and assistances to the displaced people from the preparation of resettlement to the transition period of resettlement.

Involvement of the affected people

A main reason for the failures in resettlement can be attributable to less attention to the the displaced people's as well as of the host populations' ideas and preferences, and the ignorance of their socio-cultural and economic characteristics from the formulation of plans through implementation.

Development-oriented resettlement

Resettlement is not just a compensation, but a process of re-establishment and regional development. The government should give the affected people a set of provisions and assistances including housing, infrastructures, facilities, training and agricultural extension programme etc. so that they can get sufficient opportunities and resources for their social and economic re-establishment in the shortest possible period, taking into account their population growth in future. Among them, provision of land in sufficient quantity and quality is of significant importance for farmers. The efforts made for the development would be in vain if the land alienated is not suitable for them.

(3) Components of resettlement plans

Resettlement plans may be divided into i) compensation, ii) resettlement preparation, iii) development and iv) management components. Key issues of each component are described in Appendix VI, 5.2.3.

(4) Result of preliminary investigation on resettlement sites

A preliminary survey was conducted for possible resettlement sites. The survey was carried out on ad-hoc basis based on the information derived from officials and local people. Therefore, what will be described below is intended only to provide some information on possible resettlement sites.

Sites investigated are i) settlement schemes, ii) swamp/marsh areas, iii) Ngoina tea estate and other adjoining estates, iv) ADC farms in Trans Nzoia district, v) Simbauti farm and vi) government land in Kericho district. The characteristics of each site are described in Appendix VI, 5.3.1. Table 3.14 summarizes a result of preliminary investigation on possible resettlement sites. This is mostly based on impressions without detailed survey, so that the assessment should be used just for reference.

### 3.5.6 Conclusion and recommendations

#### (1) Conclusion

It cannot be conclusive that the Project is socially acceptable and sound since resettlement plans including compensation, restoration plans and associated regional development plans in the affected areas have not been completely formulated yet. In other words, it can be when such plans or countermeasures are judged feasible from social, economic, financial, environmental and technical points of view.

However, it is expected that the results of this Study will be able to substantially contribute to getting the plans and countermeasures feasible.

#### (2) Recommendations

Further studies mainly comprise i) Resettlement Plan including compensation, ii) Restoration Plan around the reservoir area and iii) Area or Regional Development Plans, as countermeasures, around the reservoir area.

Among others, the following are recommended, in particular, for further studies:

a) Appropriate understandings of involuntary resettlements and other socio-economic impacts of the Project

It is quite indispensable to recognize the substantial impacts of the Project especially due to the inundation of the reservoir area, the necessity of " land for land " approach as well as the impacts of failure in resettlement and restoration not only on the affected people but on the Project, the regional development and national development. This component is an integral part of the Project and not taken as the secondary status.

b) Institutional set-up for formulating the required plans and countermeasures as early as possible

The institutional set-up is a prerequisite to carry out the further studies to formulate the required plans. The KPC is expected to establish such special unit or function, of which tasks include public relations with the affected people to smoothly carry out the studies and coordination with the required line agencies/ministries.

c) Involvement of the affected people and the officials concerned

To get the plans feasible, it is essential to involve the affected people, as well as the officials concerned, in formulating those plans and countermeasures. Many resettlements in the past projects in the world have failed mainly due to less involvement of them and institutional/organizational incapability.

d) Full costing of all the components of the plans and countermeasures

As underestimate of the costs of the required plans leads to underfinancing, all the costs required for implementing those plans and countermeasures should be estimated based on detailed surveys.

e) Commencement of the further studies as early as possible with adequate resources and experts

It will take time to carry out the further studies, especially the identification of resettlement sites, which will come the first among others in the resettlement plan and be the most important component, which will require qualified and sufficient number of experts. Also, comprehensive and detailed base-line information will have to be collected in both the reservoir and its vicinity and the resettlement sites. Thus, unlike other components of the Project, the further studies will need comprehensive fields of experts and details.

# IV. POWER SURVEY

## 4.1 Outline of the Power Sector in Kenya

Electric industry of the country is composed of six entities as below:

- The Kenya Power Co. Ltd. (KPC)
- The Kenya Power & Lighting Co. Ltd. (KPLC),
- The Tana River Development Co., Ltd. (TRDC)
- The Kerio Valley Development Authority (KVDA)
- The Tana and Athi Rivers Development Authority (TARDA), and
- The Lake Basin Development Authority (LBDA).

It is noted that the LBDA belongs to the Ministry of Regional Development (MRD) and the other five entities to the Ministry of Energy.

The KPC, counterpart agency of the Feasibility Study for the Magwagwa hydropower project, and other entities retain a part of generating facilities in the national power system, but actual operation and maintenance of the facilities are carried out by the KPLC under the management agreement.

The KPLC, which is a 60% government-owned entity, coordinates the national power network, purchases power in bulk from the KPC, TRDC and TARDA, and distributes to consumers. Besides, the KPLC imports energy from Uganda through the Lessos substation in the Western region.

The country is divided into five regions in terms of power supply as follows:

(1) Nairobi region,
(2) Coast region,
(3) Rift Valley region,
(4) Western region, and
(5) Mt. Kenya region.

Note: The regions are currently divided into six; Nairobi, Coast, Central Rift, West Kenya, Mount Kenya and North Rift.

Energy sales in the whole of the KPLC's network were 2,434 GWh in 1987/88, of which the sales in the Nairobi region shared 1,303 GWh, followed by the Coast region of

544 GWh, the Western region of 346 GWh, the Rift Valley region of 137 GWh and the Mt. Kenya region of 104 GWh. This implies that more than 75% of KPLC's sold energy was consumed in the Nairobi and Coast regions.

On the other hand, hydroelectric power potential of the country is mainly identified in the Tana River, Lake Victoria, Ewaso Ngiro River (South), Rift and Kerio valleys and Athi River basins, whilst geothermal potential concentrates in the Rift Valley.

Some of indigenous power potential has been developed and interconnected to the national power network with the 132 kV and 220 kV transmission lines for supplying power to such major load centres as Nairobi and Mombasa.

The locations of existing power plants as well as potential sites are shown in Figure 4.1.

## 4.2 Existing and Committed Generating Plants

As given in Table 4.1, a total of installed capacity of the generating facilities was 702 MW as of June 1990 in the interconnected power system. In addition, there are such energy sources as isolated power plants with a total of installed capacity of about 4 MW and energy imports from Uganda.

By type, hydropower plant shares 70% of the installed capacity, 79% of the effective capacity and 85% of the 1989/90 annual energy production. Imports from Uganda are equivalent to about 6% of energy production. Following are a summary of installed capacity, effective capacity and average annual energy production in the country in 1989/90 by generating type (refer to Table 4.1):

| Sources | Installed Capacity (MW) | Effective Capacity (MW) | Annual Production (GWh) |
|---|---|---|---|
| Hydro | 492.5 | 479.0 | 2,517.0 |
| Conventional Thermal | 145.9 | 69.8 | 107.0 |
| Geothermal | 45.0 | 43.0 | 336.0 |
| Diesel (incl. Isolated Diesel) | 22.2 | 11.9 | 14.0 |
| Imports from Uganda (agreed max. power) | — | (30.0) | (174.0) |
| Total | 705.6 | 633.7 | 3,148.0 |

The Turkwel hydropower project currently under construction will be completed in 1990/91 with an installed capacity of 107 MW, which contributes to the increase of 13% in the installed capacity of the system.

The promising schemes which will follow the Turkwel are as follows:

- Sondu/Miriu hydropower scheme in the Sondu River with an anticipated installed capacity of 60 MW,
- North-east Olkaria geothermal plant with an installed capacity of 60 MW.

The feasibility or pre-feasibility study for the above schemes has been finished.

## 4.3 Existing Transmission and Distribution Systems

There exist 20 main substations to connect the 132 kV and 220 kV transmission lines in the national power system including Juja Road (Nairobi region), Kipevu (Coast region) and Lessos (Western region) substations located near the load centres of respective regions as seen in Figures 4.1 and 4.2. The information for the system substations is detailed in Table 4.2 with the substation facilities as of 30 June, 1989.

In 1983, a 220 kV transmission line system was introduced to the country, and since then the system in terms of transformer capacity station (step-up and distribution substations) has been expanded with an average annual growth rate of 12.5% (1982 to 1989) against the lower rate before the introduction.

Distribution transformers for the voltages of 33 kV/415 - 230 V and 11 kV/415 - 230 V were recorded at 1,376 MVA in the system as of 30th June, 1989, which shows an annual average increase rate of 8.23% since 1979 with 649 MVA.

Electric power in the nation is supplied by the transmission line with voltages of 220 kV, 132 kV, 66 kV, 40 kV and 33 kV. The length of 220 kV line is 647 cct-km as of June, 1989, whilst 1,786 cct-km for 132 kV, 389 cct-km for 66 kV, 121 cct-km for 40 kV and 2,955 cct-km for 33 kV. Further details are given in Table 4.3.

Voltages of 66 kV and 40 kV are applied only in the Nairobi region, and 132 kV lines occupy the majority of the existing transmission line in the country. New 220 kV transmission lines have been completed recently in the Nairobi region (Embakasi - Dandora with double circuit over 12 km) and in the Western region (Turkwel - Lessos single circuit over 225 km).

In order to supply energy to rural areas, 33 kV lines have widely been developed in the Western region. With the progress of the rural electrification programme in the country, both 132 kV and 33 kV lines will be more constructed.

Distribution lines in the country consist of 11 kV on the high voltage and 415/230 V on the low voltage. Table 4.4 details the feature of existing distribution network including the SWER (Single Wire Earth Return) system, which had been used in the rural area, but all of which has been converted to a 3-wire system.

Following are a summary of Table 4.4:

| Region | 11 kV System (cct-km) | | | | 415/230 V System (cct-km) | | | |
|---|---|---|---|---|---|---|---|---|
| | 1976 | 1983 | 1988 | Growth (76 - 88) | 1976 | 1983 | 1988 | Growth (76 - 88) |
| Nairobi | 2,220 | 2,783 | 3,158 | 3.11% | 1,003 | 1,370 | 1,639 | 4.36% |
| Rift Valley | 519 | 683 | 810 | 3.95% | 153 | 226 | 376 | 8,16% |
| Western | 914 | 1,164 | 1,329 | 3.31% | 295 | 427 | 723 | 8.12% |
| Coast | 472 | 593 | 655 | 2.90% | 335 | 413 | 482 | 3.20% |
| Mt. Kenya & KLP | 627 | 1,075 | 1,228 | 5.76% | 196 | 373 | 599 | 10.18% |
| Total | 4,752 | 6,298 | 7,180 | 3.64% | 1,982 | 2,809 | 3,819 | 5.87% |

As seen in the Table, the average growth rates of Rift Valley, Western and Mt. Kenya regions are higher than those of the others, which implies that rural electrification is steadily implemented.

## 4.4 Electric Power Market

### 4.4.1 Generation in the country

As discussed in the preceding Section 4.2, major sources of electric energy supply are hydro and geothermal followed by conventional thermal and diesel. Historical records of energy supply by these plants are summarized as given below, showing that the average annual growth rates for net generation, total sales and maximum demand were 5.3%, 5.5% and 6.0% respectively in the past 10 years, say 1979 to 1989, but 7.3%, 7.1% and 7.8%

in a period of 1972 to 1985. Further details are given in Table 4.5, whilst Table 4.6 shows the historical records of energy generation by plant after 1978 onward.

| | | 1972 | 1975 | 1979 | 1985 | 1989 | Growth (1979 - 89) |
|---|---|---|---|---|---|---|---|
| Supply (GWh) | | | | | | | |
| Hydro | | 376 | 634 | 1,288 | 1,660 | 2,254 | 5.76% |
| Oil Thermal | | 256 | 242 | 205 | 83 | 14 | — |
| Geothermal | | — | — | — | 336 | 316 | — |
| Diesel & G.T. | | 27 | 12 | 2 | 6 | 1 | — |
| Imports | | 283 | 261 | 160 | 215 | 163 | — |
| Total Supply | | 942 | 1,149 | 1,655 | 2,300 | 2,748 | 5.20% |
| Station-Use | | 33 | 20 | 22 | 27 | | — |
| Net Supply | | 909 | 1,129 | 1,633 | 2,273 | 2,748 | 5.34% |
| T&D Losses | (GWh) | 104 | 135 | 220 | 317 | | |
| Total KPLC Sales | (GWh) | 795 | 1,001 | 1,409 | 1,944 | 2,412 | 5.50% |
| REF Sales | (GWh) | - | - | 2 | 19 | 49 | |
| Total Sales | (GWh) | 795 | 1,001 | 1,411 | 1,963 | 2,461 | 5.71% |
| Max. Demand | (MW) | 146 | 184 | 269 | 387 | 480 | 6.00% |
| Load Factor | | (%) | 72.7 | 71.7 | 70.2 | 67.8 | |

### 4.4.2 Energy consumption

(1) Consumer's category

According to the "Methods of Charge (KPLC) Byelaws 1991", electricity consumers are classified into the following 11 categories:

(i) Method Ao : Ordinary domestic consumers whose consumption does not exceed 7,000 kWh per month,

(ii) Method A1 : Ordinary small non-domestic consumers whose consumption does not exceed 7,000 kWh/month,

Method B : Ordinary consumers whose consumption exceeds 7,000 kWh per month but does not exceed 100,000 kWh/month:

(iii) Method Bo : Irrigation pumping loads at 240 V single phase 2 wires or 415 V, 3 phase - 4 wires,

| | | |
|---|---|---|
| (iv) | Method B1 | : Consumers at 240 V single phase 2-wire or 415 V 3 phase 4 wires, |
| (v) | Method B2 | : Consumers at 11 kV or 33 kV, |
| (vi) | Method B3 | : Consumers at 66 kV or 132 kV, |
| | Method C | : Ordinary consumers whose consumption exceeds 100,000 kWh per month: |
| (vii) | Method C1 | : Consumers at 415 V 3 phase 4 wires, |
| (viii) | Method C2 | : Consumers at 11 kV or 33 kV, |
| (ix) | Method C3 | : Consumers at 66 kV or 132 kV, |
| (x) | Method Do | : Interruptible off-peak supplies of electric energy to ordinary consumers, and |
| (xi) | Method E | : Public and local authorities to supply electric energy with public lamps. |

In addition to the above, a category "F" will be defined for energy consumption by KPLC's staff.

Previous consumer's category was amended by KPLC in 1979 as discussed above. In order to analyse the historical tendency of energy consumption and the demand forecast, the above consumer's categories are grouped into following three as examined in the country since then:

| | | | |
|---|---|---|---|
| (a) | Group-1 | : | Domestic use, small lighting power, lighting and power of less than 7,000 kWh/month, street lighting and KPLC's staff consumption in the category before 1978, or Methods Ao, A1, E and F in the present category. |
| (b) | Group-2 | : | Lighting and power of more than 7,000 kWh/month, industries of more than 21,000 kWh/month and special contracts in the category before 1978, or Methods Bo, B1, B2, B3, C1, C2 and C3 at present. |
| (c) | Group-3 | : | Off peak load in the category before 1978 or present Method Do. |

Besides, KPLC altered its accounting year from 1st January - 31st December to 1st July - 30th June since 1986. Demand analysis and forecast are examined in consideration of those amendment as well.

(2) Historical energy demand

Historical demand records in each region by group are summarized as follows and further details are given in Table 4.7:

Unit : GWh

| Region | 1973 | 1975 | 1979 | 1985 | 1987/88 | Annual Growth (%) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 72-85 | 79-85 | 79-88 |
| Nairobi | | | | | | | | |
| Group-1 | 169 | 208 | 253 | 340 | 480 | 5.65 | 5.06 | 8.06 |
| Group-2 | 230 | 300 | 428 | 614 | 720 | 7.83 | 6.18 | 6.31 |
| Group-3 | 106 | 119 | 110 | 96 | 95 | — | — | — |
| Sub-total | 505 | 627 | 790 | 1050 | 1303 | 5.78 | 4.82 | 6.05 |
| Coast | | | | | | | | |
| Group-1 | 41 | 53 | 69 | 99 | 135 | 6.09 | 6.04 | 8.22 |
| Group-2 | 144 | 180 | 270 | 337 | 405 | 6.75 | 3.78 | 4.89 |
| Group-3 | 5 | 5 | 5 | 4 | 3 | — | — | — |
| Sub-total | 190 | 238 | 344 | 440 | 544 | 6.65 | 4.18 | 5.54 |
| Rift Valley | | | | | | | | |
| Group-1 | 14 | 18 | 24 | 36 | 48 | 7.54 | 7.67 | 8.50 |
| Group-2 | 21 | 27 | 45 | 62 | 87 | 8.87 | 6.56 | 8.06 |
| Group-3 | 4 | 6 | 2 | 1 | 2 | — | — | — |
| Sub-total | 39 | 51 | 71 | 99 | 137 | 7.60 | 5.81 | 8.04 |
| Western | | | | | | | | |
| Group-1 | 18 | 25 | 36 | 51 | 75 | 8.07 | 5.60 | 9.02 |
| Group-2 | 39 | 56 | 127 | 215 | 267 | 14.07 | 9.11 | 9.14 |
| Group-3 | 4 | 4 | 4 | 3 | 3 | — | — | — |
| Sub-total | 61 | 85 | 168 | 269 | 346 | 12.12 | 8.18 | 8.87 |
| Mt. Kenya | | | | | | | | |
| Group-1 | included in | | 17 | 29 | 41 | — | 9.46 | 10.91 |
| Group-2 | Nairobi | | 18 | 56 | 62 | — | 21.40 | 15.66 |
| Group-3 | Region | | 2 | 2 | 2 | — | — | — |
| Sub-total | | | 37 | 87 | 104 | — | 15.77 | 12.93 |
| National Total | | | | | | | | |
| Group-1 | 242 | 304 | 399 | 555 | 788 | 6.40 | 5.32 | 8.34 |
| Group-2 | 434 | 563 | 888 | 1284 | 1541 | 8.70 | 6.43 | 6.70 |
| Group-3 | 119 | 134 | 123 | 106 | 104 | — | — | — |
| Total | 795 | 1001 | 1410 | 1945 | 2433 | 7.12 | 5.51 | 6.63 |

An average annual growth rate of energy consumption in the country was 7.12% over a period of 1972 to 1985 and 6.63% over a period of 1979 to 1987/88, whilst the rates in each year are given in Figure 4.3 with elasticity. Total demand of group-2, which mainly consists of large irrigation, industries and commerces, was higher than that of others. The tendency deems to continue for a some time in the future.

The demand of group-3 categorized for off-peak load was not growing but keeping the same level in all the regions.

The Nairobi region, the largest load centre in the country, has ever consumed 54 to 60% of the total energy in the country. Demand of group-2, large scale industries and commerces, in the region shares 55% of total consumption of the region in 1987/88, being the biggest consumers' category in the region.

The Coast region is the second biggest load centre in the country, sharing 23% of the total national energy consumption. While, group-1 of this region showed a high growth rate with more than 8% over a period of 1979 to 1987/88.

The Rift Valley, Western and Mt. Kenya regions are developing areas in terms of energy consumption, showing high growth rates compared with those of the Nairobi and Coast regions. Energy consumption in those developing regions will keep growing in light of the government policy to promote rural electrification.

Per capita consumption was 91.95 kWh/year in 1979, 90.48 kWh/year in 1984 and 96.41 kWh/year in 1985. The population for the above estimate is based on the 1979 census and the figures projected for 1984 and 1985. The 96 kWh per capita consumption of the country in 1985 is rather high compared with other east African countries such as 15 kWh of Ethiopia, 46 kWh of Sudan, 35 kWh of Tanzania and 55 kWh of Malawi in the same year, although those consumptions were much lower than those in other African countries.

### 4.4.3 Electrification

The electrification rate for the entire households of the country was 4.1% in 1983, consisting of 6.8% in the Nairobi, 11.3% in the Coast, 1.5% in the Western, 6.0% in the Rift Valley and 1.3% in the Mt. Kenya according to the estimate in the JICA's Feasibility Study Report of Sondu River Multipurpose Development Project.

### 4.4.4 Load patterns

The load patterns in the country are illustrated in Figure 4.4, showing following characteristics:

(a) No remarkable seasonal variation of energy demand is recognised nationwise and also regionwise.

(b) Daily peak load appears around 8:00 pm to 9:00 pm both in the country and in the area covered by the Lessos substation.

(c) Difference of daily load pattern between Sunday and weekdays is obvious in the whole area of the system, however, such tendency in the Lessos area is less distinct in spite that demand share of Group-2 in the area is more than 75%.

(d) The annual load factor is computed at 68.4%.

4.4.5 Number of consumers

Growth of consumers in number is shown in Table 4.8 and summarized below:

| Region | Group | 1980 | 1985 | 1989 | Ave. Annual Growth Rate (%) |
|---|---|---|---|---|---|
| Nairobi : | Group-1 | 61,148 | 82,541 | 129,507 | 9.23 |
| | Group-2 | 687 | 922 | 1,156 | 6.31 |
| | Group-3 | 717 | 797 | 1,023 | 4.27 |
| | Total | 62,552 | 84,260 | 131,686 | 9.15 |
| Coast : | Group-1 | 31,935 | 38,405 | 44,559 | 4.00 |
| | Group-2 | 244 | 288 | 345 | 4.16 |
| | Group-3 | 91 | 53 | 54 | — |
| | Total | 32,270 | 38,746 | 44,958 | 3.98 |
| Rift Valley : | Group-1 | 9,398 | 12,150 | 15,411 | 5.99 |
| | Group-2 | 116 | 169 | 251 | 9.51 |
| | Group-3 | 50 | 48 | 41 | — |
| | Total | 9,564 | 12,367 | 15,703 | 6.01 |
| Western : | Group-1 | 15,957 | 20,781 | 25,397 | 5.62 |
| | Group-2 | 149 | 209 | 246 | 6.08 |
| | Group-3 | 21 | 25 | 19 | — |
| | Total | 16,127 | 21,015 | 25,662 | 5.62 |
| Mt. Kenya : | Group-1 | 3,191 | 11,925 | 16,335 | 21.18 |
| | Group-2 | 65 | 95 | 124 | 7.89 |
| | Group-3 | 28 | 27 | 29 | — |
| | Total | 3,284 | 12,047 | 16,488 | 20.90 |
| R.E.F. : | Group-1 | 1,427 | 6,045 | 15,046 | 31.95 |
| | Group-2 | 7 | 26 | 65 | 29.98 |
| | Group-3 | 0 | 1 | 3 | — |
| | Total | 1,434 | 6,072 | 15,132 | 31.95 |
| Total : | Group-1 | 123,056 | 171,847 | 246,273 | 8.50 |
| | Group-2 | 1,268 | 1,709 | 2,187 | 6.62 |
| | Group-3 | 907 | 951 | 1,169 | 3.03 |
| | Total | 125,231 | 174,504 | 249,629 | 8.45 |

Group-1 consumers share 99% of the total number of consumers. The Nairobi region has more than 50% of consumers in sum of all categories.

The number of consumers has grown at an annual rate of 8.45% nationwise since 1980, while the growth rate of Mt. Kenya region was as high as 20.9%. Rapid growth of REF (Rural Electrification Fund) is also marked, showing rural electrification in the country has progressed with a steady pace.

4.4.6. Present power tariff

The present power tariff of monthly basis was introduced in year 1991, and the outline of the tariff is as follows:

| | | | |
|---|---|---|---|
| (a) | Method Ao : | (i) | A fixed charge of KShs. 30.00 |
| | | (ii) | * 69 cents/kWh for the first 50 kWh consumption<br>* 119 cents/kWh for another 50 kWh consumption<br>* 151 cents/kWh for another 200 kWh consumption<br>* 200 cents/kWh for the consumption over 200 kWh up to 7,000 kWh |
| (b) | Method A1 : | (i) | A fixed charge of KShs. 45.00 |
| | | (ii) | 179 cents/kWh for consumption |
| (c) | Method Bo : | (i) | A fixed charge of KShs. 120.00 |
| | | (ii) | 144 cents/kWh for consumption |
| (d) | Method B1 : | (i) | A fixed charge of KShs. 120.00 |
| | | (ii) | 161 cents/kWh for consumption |
| | | (iii) | KShs. 50.00/kVA for demand |
| (e) | Method B2 : | (i) | A fixed charge of KShs. 720.00 |
| | | (ii) | 157 cents/kWh for consumption |
| | | (iii) | KShs. 45.00/kVA for demand |
| (f) | Method B3 : | (i) | A fixed charge of KShs. 3,280.00 |
| | | (ii) | 150 cents/kWh for consumption |
| | | (iii) | KShs. 40.00/kVA for demand |
| (g) | Method C1 : | (i) | A fixed charge of KShs. 120.00 |
| | | (ii) | 148 cents/kWh for consumption |
| | | (iii) | KShs. 50.00/kVA for demand |
| (h) | Method C2 : | (i) | A fixed charge of KShs. 720.00 |
| | | (ii) | 143 cents/kWh for consumption |
| | | (iii) | KShs. 45.00/kVA for demand |
| (i) | Method C3 : | (i) | A fixed charge of KShs. 3,280.00 |
| | | (ii) | 137 cents/kWh for consumption |
| | | (iii) | KShs. 40.00/kVA for demand |

| | | | |
|---|---|---|---|
| (j) | Method Do : | (i) | A fixed charge of KShs. 50.00 |
| | | (ii) | 143 cents/kWh for consumption |
| (k) | Method E : | (i) | A fixed charge of KShs. 65.00 per supply terminal |
| | | (ii) | 178 cents/kWh for consumption. |

## 4.5 Demand Forecast

### 4.5.1 Introduction

Electric power and energy demands for the country were forecast up to the year 2005 by Acres International Limited (Acres) in their "Kenya National Power Development Plan, 1986-2006" prepared in 1987. The forecast was reviewed by Ewbank Preece Limited (EPL) in December 1989 in their Feasibility Study for "A Geothermal Power Station at North East Olkaria".

The demand forecast in this study reviewed and updated the above mentioned forecasts using the latest power data. The review and updating were made regionwise and nationwise in each consumer category as mentioned in Subsection 4.4.2, i.e. group-1, group-2 and group-3. In addition, total energy required in the system was also forecast including not only energy losses in the transmission and distribution lines but also energy consumption in the power stations required for their operation and maintenance.

### 4.5.2 Basis of demand forecast

(a) Methodology of forecast

Acres' forecast methodology was based on a combination of detailed regional disaggregate forecasts in the short-term and on econometric models of total power sales.

Review in this study was conducted on the basis of the Acres' forecast methodology. A tendency of demand growth in the country was discussed by region and consumer's category as mentioned in the preceding Subsection 4.4.2. Forecasts of each category in respective power supply regions were reviewed and updated based on the actual records experienced until the year 1987/88.

(b) Growth scenarios

The review was made for three scenarios; median, low and high growths.

The median growth forecast was based on anticipation that improvements in the performance of the Kenya economy will be realised with greater efficiency of new capital investments and higher growth rates in the agricultural and industrial sectors than experienced. The forecast is slightly optimistic, but it will be appropriate for planning the system development.

The low growth scenario is based on continuation of historic growth rates in Kenya since 1979 with some marginal improvement. The low growth scenario so prepared shows a conservative estimate of electricity sales and will be used for financial analyses and tariff studies of power market.

The high growth forecast is based on the assumption that the Kenya's official target of economic development plan will fully be materialised. Although the scenario is optimistic, the forecast values will be considered as a high side limit of the load growth under the present situation.

(c) Regional and national forecasts

Regional forecasts were conducted over energy requirement by each consumer's category. Regional peak demand was then forecast by applying the regional load factor, which was assumed to be common for three growth scenarios.

National total forecast was made by summing up the values of each regional forecast. While, gross generation requirement in the country was estimated by adding energy losses in transmission/distribution network and energy consumed in power stations for their operation and maintenance to the national total energy sales so forecast.

The transmission and distribution network losses and station-use energy were respectively assumed at 16.2% of the total energy sales in the system and 1.4% of the sum of energy sales and network losses from the experienced records.

4.5.3 Results of forecasts

Results of forecasts for three scenarios were summarized in Tables 4.9 to 4.11, and Figures 4.5 to 4.7. Following are excerpts from those Tables:

(a) Median forecast:

| Region | 1987/88 | 1989/90 | 1995/96 | 2000/01 | 2005/06 | 2014/15 | Ave. Growth a Year (%) (1987/88-2014/15) |
|---|---|---|---|---|---|---|---|
| Energy (GWh) | | | | | | | |
| Nairobi | 1,303.1 | 1,423.5 | 1,845.9 | 2,312.2 | 2,879.9 | 4,263.9 | 4.49 |
| Coast | 543.8 | 610.5 | 785.8 | 964.4 | 1,178.2 | 1,673.3 | 4.25 |
| Rift Valley | 136.7 | 160.3 | 214.3 | 276.1 | 355.4 | 558.8 | 5.35 |
| Western | 345.5 | 394.1 | 593.7 | 846.7 | 1,199.4 | 2,205.7 | 7.11 |
| Mt. Kenya | 104.3 | 111.8 | 188.5 | 298.9 | 472.9 | 1,066.1 | 8.99 |
| Total | 2,433.4 | 2,700.4 | 3,628.2 | 4,698.3 | 6,085.7 | 9,767.8 | 5.28 |
| Peak Load (MW) | | | | | | | |
| Nairobi | 231.0 | 270.8 | 351.2 | 439.9 | 547.9 | 811.2 | 4.76 |
| Coast | 107.0 | 108.9 | 140.2 | 172.0 | 210.2 | 298.5 | 3.87 |
| Rift Valley | 30.0 | 36.6 | 48.9 | 63.0 | 81.1 | 127.6 | 5.51 |
| Western | 79.0 | 86.5 | 130.3 | 185.9 | 263.3 | 484.2 | 6.95 |
| Mt. Kenya | 22.0 | 28.4 | 47.8 | 75.8 | 120.0 | 270.5 | 9.74 |
| Total | 469.0 | 531.2 | 718.4 | 936.7 | 1,222.5 | 1,992.0 | 5.50 |
| National Energy Requirement (GWh) | | | | | | | |
| Network Losses | — | 437.5 | 587.8 | 761.1 | 985.9 | 1,582.4 | — |
| Station-use | — | 43.9 | 59.0 | 76.4 | 99.0 | 158.9 | — |
| Gross Generation | — | 3,181.8 | 4,275.0 | 5,535.8 | 7,170.6 | 11,509.1 | 5.28 |

(b) Low forecast:

| Region | 1987/88 | 1989/90 | 1995/96 | 2000/01 | 2005/06 | 2014/15 | Ave. Growth a Year (%) (1987/88-2014/15) |
|---|---|---|---|---|---|---|---|
| Energy (GWh) | | | | | | | |
| Nairobi | 1,303.1 | 1,414.0 | 1,774.8 | 2,163.3 | 2,626.8 | 3,693.8 | 3.93 |
| Coast | 543.8 | 606.9 | 746.4 | 893.0 | 1,066.8 | 1,459.4 | 3.72 |
| Rift Valley | 136.7 | 159.3 | 206.0 | 258.1 | 324.5 | 490.2 | 4.84 |
| Western | 345.5 | 389.8 | 553.2 | 750.4 | 1,014.2 | 1,718.2 | 6.12 |
| Mt. Kenya | 104.3 | 110.3 | 174.1 | 260.4 | 389.3 | 787.7 | 7.78 |
| Total | 2,433.4 | 2,680.3 | 3,454.5 | 4,325.3 | 5,421.6 | 8,149.3 | 4.60 |
| Peak Load (MW) | | | | | | | |
| Nairobi | 231.0 | 269.0 | 337.7 | 411.6 | 499.8 | 702.8 | 4.21 |
| Coast | 107.0 | 108.3 | 133.1 | 159.3 | 190.3 | 260.3 | 3.34 |
| Rift Valley | 30.0 | 36.4 | 47.0 | 58.9 | 74.1 | 111.9 | 5.00 |
| Western | 79.0 | 85.6 | 121.4 | 164.7 | 222.7 | 377.2 | 5.96 |
| Mt. Kenya | 22.0 | 28.0 | 44.2 | 66.1 | 98.8 | 199.8 | 8.51 |
| Total | 469.0 | 527.2 | 683.5 | 860.6 | 1,085.5 | 1,652.0 | 4.77 |
| National Energy Requirement (GWh) | | | | | | | |
| Network Losses | — | 434.2 | 559.6 | 700.7 | 878.3 | 1,320.2 | — |
| Station-use | — | 43.6 | 56.2 | 70.4 | 88.3 | 132.6 | — |
| Gross Generation | — | 3,158.1 | 4,070.4 | 5,096.3 | 6,388.1 | 9,602.0 | 4.56 |

(c) High forecast:

| Region | 1987/88 | 1989/90 | 1995/96 | 2000/01 | 2005/06 | 2014/15 | Ave. Growth a Year (%) (1987/88-2014/15) |
|---|---|---|---|---|---|---|---|
| Energy (GWh) | | | | | | | |
| Nairobi | 1,303.1 | 1,426.9 | 1,913.0 | 2,463.5 | 3,148.0 | 4,863.3 | 5.00 |
| Coast | 543.8 | 618.4 | 848.1 | 1,094.9 | 1,399.2 | 2,144.3 | 5.21 |
| Rift Valley | 136.7 | 162.3 | 232.0 | 315.2 | 425.7 | 723.5 | 6.37 |
| Western | 345.5 | 403.1 | 682.4 | 1,072.7 | 1,674.9 | 3,655.7 | 9.13 |
| Mt. Kenya | 104.3 | 114.7 | 220.8 | 395.0 | 707.0 | 2,005.9 | 11.57 |
| Total | 2,433.4 | 2,725.3 | 3,896.3 | 5,341.3 | 7,354.7 | 13,392.7 | 6.52 |
| Peak Load (MW) | | | | | | | |
| Nairobi | 231.0 | 271.5 | 364.0 | 468.7 | 598.9 | 925.3 | 5.27 |
| Coast | 107.0 | 110.3 | 151.3 | 195.3 | 249.6 | 382.5 | 4.83 |
| Rift Valley | 30.0 | 37.1 | 53.0 | 72.0 | 97.2 | 165.2 | 6.52 |
| Western | 79.0 | 88.5 | 149.8 | 235.5 | 367.7 | 802.5 | 8.97 |
| Mt. Kenya | 22.0 | 29.1 | 56.0 | 100.2 | 179.4 | 508.8 | 12.34 |
| Total | 469.0 | 536.4 | 774.0 | 1,071.6 | 1,492.7 | 2,784.3 | 6.82 |
| National Energy Requirement (GWh) | | | | | | | |
| Network Losses | — | 441.5 | 631.2 | 865.3 | 1,191.5 | 2,169.6 | — |
| Station-use | — | 44.3 | 63.4 | 86.9 | 119.6 | 217.9 | — |
| Gross Generation | — | 3,211.2 | 4,590.9 | 6,293.4 | 8,665.9 | 15,780.2 | 6.55 |

The forecast for the median growth scenario results in:

(1) Requirements of energy and peak power demand will continuously and steadily increase in the nation at annual growth rates of 5.3% and 5.5% respectively over a period of 1987/88 to 2014/15 (the experienced rate at 6.63% in the years 1979 - 1988).

(2) Gross generation should be increased at a rate of 5.3% to meet the national energy requirement.

(3) Consumption of group-2 (big consumers) in the entire power system will grow at a high rate compared with that of group-1, which was in the reverse order in the past.

(4) Consumption of group-3 will stagnate in the future as same as previous tendency.

(5) High growth of demands in the Western and Mt. Kenya regions will be maintained because of the rural electrification programme, and the energy demand of the Western region will surpass that of the Coast region after the year 2005/2006.

(6) Gross generation required will be 4,275.0 GWh in 1995/96, 5,535.8 GWh in 2000/01, 7,170.6 GWh in 2005/06 and 11,509.1 GWh in 2014/15.

Average annual growth rates of energy until year 2014/15 are nationwise forecast to be 5.28%, 4.60% and 6.52% for median, low and high respectively excluding network losses and station-use, whilst 5.50%, 4.77% and 6.82% in peak demand for respective demand scenarios; median, low and high. Compared with the forecast done by Ewbank, median and high forecasts to year 2005/06 show almost the same tendency, whilst low forecast in this study predicts a higher value by 3%. Graphical tendency of each forecast is shown in Figures 4.5 to 4.7.

## 4.6 Transmission Line System for the Project

### 4.6.1 Introduction

A total maximum output of the precedently commissioned Sondu/Miriu plant and the Magwagwa hydropower plant will be 180 MW. The peak demand in the project area, which is the areas received power supply through the Lessos - Muhoroni transmission line, is anticipated to reach 180 MW around year 2013/14, resulting in the full consumption of generated power in the project area. Before the full consumption of generated power in the project area, surplus will be supplied to other areas through the national power grid joining at the existing Lessos substation via the existing Muhoroni switching station (refer to Figure 4.1).

The transmission line system in the project area should be designed so that power outputs from the Sondu/Miriu and Magwagwa power plants can contribute to the stable power supply in the project area; that is, a ring supply system is recommended to connect such substations and power stations as Kisumu - Muhoroni - Chemosit - Magwagwa-Sondu/Miriu - Kisumu.

The existing 132 kV Muhoroni-Lessos line with a single circuit of Wolf conductor would not be efficient in transmitting surplus power to the Lessos or future reverse transmission of bulk power from the Lessos to the project area, so that a new line would be required in the section.

Furthermore, an additional line may be constructed between the Magwagwa power plant and the Muhoroni substation for more efficient transmission of surplus power from the Magwagwa power plant to the Lessos substation and for assurance of power supply to the project area even in such a case as fault occurrence on the Sondu/Miriu - Kisumu, Sondu/Miriu - Magwagwa or Magwagwa - Chemosit line.

### 4.6.2 Transmission line voltage

On the basis of the maximum power demand of 34 MW recorded on the Lessos-Muhoroni line in 1989 and an average annual growth rate of the Western region as forecast in the Section 4.5, power demand in the project area is expected to grow as given below, and furthermore power balance between the supply capacity from the Sondu/Miriu (60 MW) and Magwagwa (120 MW) and the power demand so estimated is also reckoned:

| Year | Max. Demand (Median) in Project Area (MW) | | | Total Output of Both Power Stations (MW) | Power Flow in Lessos-Muhoroni Section (MW) | |
|---|---|---|---|---|---|---|
| | Kisumu | Chemosit | Total | | LS-MHRN | MHRN-LS |
| 1989/90 | 18.5 | 15.2 | 33.7 | — | 33.7 | — |
| 90/91 | 19.8 | 16.2 | 36.0 | — | 36.0 | — |
| 91/92 | 21.1 | 17.4 | 38.5 | — | 38.5 | — |
| 92/93 | 22.6 | 18.6 | 41.2 | — | 41.2 | — |
| 93/94 | 24.2 | 19.9 | 44.1 | — | 44.1 | — |
| 94/95 | 26.0 | 21.4 | 47.4 | — | 47.4 | — |
| 95/96 | 27.9 | 22.9 | 50.8 | — | 50.8 | — |
| 96/97 | 29.9 | 24.6 | 54.5 | 60.0 | — | 5.5 |
| 97/98 | 32.1 | 26.4 | 58.5 | 60.0 | — | 1.5 |
| 98/99 | 34.4 | 28.3 | 62.7 | 60.0 | 2.7 | — |
| 99/2000 | 37.0 | 30.4 | 67.4 | 60.0 | 7.4 | — |
| 2000/01 | 39.7 | 32.7 | 72.4 | 60.0 | 12.4 | — |
| 01/02 | 42.7 | 35.1 | 77.8 | 60.0 | 17.8 | — |
| 02/03 | 45.9 | 37.7 | 83.6 | 180.0 | — | 96.4 |
| 03/04 | 49.2 | 40.4 | 89.6 | 180.0 | — | 90.4 |
| 04/05 | 52.6 | 43.2 | 95.8 | 180.0 | — | 84.2 |
| 05/06 | 56.3 | 46.3 | 102.6 | 180.0 | — | 77.4 |
| 06/07 | 60.2 | 49.5 | 109.7 | 180.0 | — | 70.3 |
| 07/08 | 64.5 | 53.0 | 117.5 | 180.0 | — | 62.5 |
| 08/09 | 69.0 | 56.7 | 125.7 | 180.0 | — | 54.3 |
| 09/10 | 73.8 | 60.6 | 134.4 | 180.0 | — | 45.6 |
| 10/11 | 79.0 | 64.9 | 143.9 | 180.0 | — | 36.1 |
| 11/12 | 84.5 | 69.4 | 153.9 | 180.0 | — | 26.1 |
| 12/13 | 90.4 | 74.3 | 164.7 | 180.0 | — | 15.3 |
| 13/14 | 96.7 | 79.5 | 176.2 | 180.0 | — | 3.8 |
| 14/15 | 103.5 | 85.1 | 188.6 | 180.0 | 8.6 | — |

There would be surplus in the consumption of power generated from both power stations in the project area until the year 2013/14 and the surplus will be sent to the national power grid through the Lessos substation. After the year 2014/15, power shortage in the project area will be supplemented from the national power grid through the Lessos substation.

The present standard system voltage is 220 kV, 132 kV and 66 kV for the trunk lines of the country. The voltage of 66 kV is mainly used in the Nairobi region. In the Western region, the highest voltage was 132 kV until the operation of 220 kV in 1990/91 for the Turkwel. Therefore, the system voltage employed for the Magwagwa project will be selected from either 220 kV or 132 kV.

The new Sondu/Miriu - Kisumu line will be constructed with a 132 kV single circuit as results of technical and economic comparison under the Sondu/Miriu hydro-power project. Considering the effective utilization of existing electrical facilities and the combination with the precedent Sondu/Miriu project, the new lines to be constructed under this Project will also be 132 kV.

4.6.3 Recommended route of transmission line

The plan of transmission lines under the project discussed in Progress Report No. (1) was altered because of the introduced Sondu/Miriu transmission system plan. As mentioned above, the new transmission line under the Sondu/Miriu project is to be constructed between the power station and the existing Kisumu substation.

The new power transmission system under this project is planned as follows:

(a) A new 132 kV line between the Sondu/Miriu and Magwagwa power stations in order to accommodate power interchange and to supply power to Kisumu through the precedent Sondu/Miriu - Kisumu line.

(b) A new 132 kV line between the power station and the existing Chemosit substation for direct power supply.

Thanks to the above two transmission lines, the project area is to be provided with a ring supply system of Magwagwa-Sondu/Miriu-Kisumu-Muhoroni-Chemosit-Magwagwa, making the operation of power supply flexible.

(c) A new 132 kV line between the power station and the existing Muhoroni switching station for transmitting surplus power from the project to the Lessos system, which will also function as an alternative line in such an emergency case as serious line fault on the Magwagwa-Sondu/Miriu section or the Magwagwa-Chemosit section.

(d) Another new 132 kV line between the Muhoroni station and the Lessos station for transmission of surplus power in the project area and for supplementary power supply from the Lessos substation to the project area in future when power demand in the area grows far beyond the total output from both the power stations, 180 MW. Necessity of this line will be re-examined at the detailed design stage of the Magwagwa project by reviewing actual loads required for the Kisumu and the Chemosit as well as load forecast for the project area at that time.

The recommended routes of those transmission lines are shown in Figure 4.8 and outlined as follows:

(1) Magwagwa - Sondu/Miriu line

The recommended route is almost the shortest distance of 22 km in this section. The line extended from the Magwagwa power station is directed to Nyakach village after going across the Sondu River. There are several access roads in this area, and therefore construction and maintenance works will not find any difficulty.

The line after passing over Nyakach village is aligned along the existing motorable road to the Sondu/Miriu power station. There are only a few residential houses in the right of way of the transmission line.

Foundation along the transmission line route seems to have enough bearing capacity for towering, and there is no place subject to seasonal flood.

(2) Magwagwa - Chemosit line

The new line for this section is aligned to avoid the Magwagwa reservoir area and steep slopes of hills, being close to the existing access roads and short as much as possible.

The line extended from the Magwagwa power station would go across over the reservoir on the way, where the line is selected at the shortest route passing near the existing bridge situated south of Mindililwet village. The crossing span will be around 700 m or twice of the standard span length. The position of towers erected for the transmission line spanning over the reservoir should be located at the highest points of the both banks to reduce tower height.

The route of this section, the length of which is around 23 km, is under-laid with sound foundation so that no special foundation treatment would be required in this section.

(3) Magwagwa - Muhoroni line

Following three alternative routes were examined:

(a) A straight line route between the power station and the switching station giving the shortest distance (30 km) as Alternative-1; there is no motorable road along the route.

(b) A 32 km long line route along the dry weather motorable road over approximately 15 km to the Muhoroni station. Remaining 17 km of the route runs on the slightly undulating terrain avoiding a swamp, but there exists a semi-motorable road in the section (Alternative-2).

(c) A line route entirely along the all-weather motorable road and the dry weather road over a total length of 35 km as Alternative-3; the route, however, passes through densely populated villages and runs along the existing overhead telephone lines.

After the examination, Alternative-2 is recommended as the Magwagwa-Muhoroni line in consideration of environmental impact, interference to the existing telephone lines, compensation to residential houses and lands, easiness of construction and maintenance works and so forth.

(4) Muhoroni - Lessos line:

The line will be constructed in parallel with the existing 132 kV line for convenience of construction and maintenance works as well as easy wayleaves for the line. Total route length between both stations will be about 60 km.

4.6.4 Substations

(1) Chemosit substation

The Chemosit substation will be extended for an incoming line from the Magwagwa. Installation of an additional transformer will be required, depending on the actually installed capacity of transformers at the time of development of the Magwagwa project.

Land space of the existing substation and room of the existing control building are sufficient for the installation of new equipment.

(2) Muhoroni switching station

The station widely modified under the Sondu/Miriu project will be added with a 132 kV incoming feeder from the Magwagwa power station and a 132 kV outgoing feeder to the Lessos substation (refer to Figure 4.9).

(3) Lessos substation

There is a spare bay in the switchyard of the substation at present. Utilising the bay, additional 132 kV switchgears will be installed for the new line from the Muhoroni switching station. Since the existing control building is fully occupied by panels and cubicles of the lines, the building should be extended when built.

## 4.7 Power Flow Study

Power in the area between the Kisumu and Chemosit substations is at present supplied with the 132 kV transmission line T-branched at the Muhoroni switching station, which is linked to the Lessos substation where power system in the Western region is controlled.

The Magwagwa power station is planned to connect to the Sondu power station and the Chemosit and Muhoroni substations with 132 kV transmission lines, and furthermore another 132 kV transmission line to the Lessos substation will be constructed to reinforce the transmission line capacity as discussed in the preceding Section 4.6, Transmission Line System for the Project.

The following conductors will be applied for the new 132 kV transmission lines:

- Lynx .............. Magwagwa - Muhoroni - Lessos lines
- Wolf .............. Sondu/Miriu - Magwagwa - Chemosit lines.

A power flow study was carried out by limiting to the Western region. A target year for the calculation is 2002/03 when the Magwagwa hydropower plant is added to the national power grid as discussed in the subsequent Chapter 5, Plan Formulation. On the other hand, the median forecast is selected as the power requirement to meet; 215 MW in year 2002/03.

Power demand of 215 MW in year 2002/03 of the Western region is monitored as that of the respective substations as follows:

- Power demand at the substations

| Substation | Load |
|---|---|
| Kisumu | 46 MW |
| Chemosit | 38 MW |
| Eldoret | 47 MW |
| Webuye P.P.M. | 24 MW |
| Lessos | 17 MW |
| Musaga | 43 MW |
| | 215 MW |

Outputs from the power plants in year 2002/03 of the Western region are as follows:

- Power plants

| Plant | Power output |
|---|---|
| Magwagwa | 120 MW |
| Sondu/Miriu | 60 MW |
| Turkwel | 100 MW |
| Owen's Falls (Uganda) | 30 MW |
| | 310 MW |

Assuming the power factor of load at 0.95 and machine constants at the standard value and referring to Figure 4.2 for line impedance, power flow was computed. After the completion of the Magwagwa power station, surplus power in the Western region will flow to the Rift Valley region as shown in Figure 4.10. Power flow from the Lessos substation to the Lanet substation is about 70 MVA in the normal system operation in the year 2002/03. The transmission line connecting these substations has enough capacity to carry the surplus power.

# V. PLAN FORMULATION

## 5.1 Introduction

As explained in the preceding Section 1.2, The Project and the Study Objectives, three schemes, i.e. Magwagwa, Sondu/Miriu and Kano schemes, are substantially considered as one project in the sense to develop the Sondu River and the Kano plain in an integrated manner. Two development elements of hydropower and irrigation are thus taken into consideration in seeking the optimal development scale of the Magwagwa scheme.

The optimal development scale of the Magwagwa scheme is in principle defined to maximize the net benefit gained from the Magwagwa and Sondu/Miriu hydropower schemes and the irrigated agriculture scheme in the Kano plain, even if studies to weigh on hydropower development or irrigated agriculture development are examined.

This Chapter 5, Plan Formulation, furthermore deals with the studies to search for the optimal installation scale and timing of the Magwagwa hydropower plant added to the Kenya Power system, considering the growing power and energy demands, other alternative power sources such as geothermal, oil-fired and gas turbine besides other promising hydro candidates, and power output of existing hydro plants.

The studies of this Plan Formulation mainly to search for the optimal development scale of the Magwagwa reservoir and the optimal installation scale and timing of the Magwagwa hydropower plant are carried out in three steps.

The first step is to find out the optimal layout plan of the Magwagwa scheme by comparing several development alternatives of damsite and waterway taking into account the topographic and geological conditions at the site.

The second step seeks the optimal development scale of the Magwagwa reservoir by building a simulation model consisting of three components of the Magwagwa, Sondu/Miriu and Kano schemes. Water requirements determined on basis of extent of command area and cropping pattern of the Kano irrigation scheme are among decisive inputs as well as the operation mode of power generation in the simulation model to find out the optimal development scale of the Magwagwa reservoir. The criteria applied for the reservoir optimization are to maximize the net benefit as discussed above. It is noted that since the creation of Magwagwa reservoir causes the displacement issue of more or less 700 households, this impact is also taken into account in determining the reservoir scale.

The third step searches for the optimal installation capacity and timing of the Magwagwa hydropower scheme by taking into consideration the power and energy demand growth, the operation of existing hydro plants and other promising power candidates to be added to the system. The optimal installed capacity and timing of the Magwagwa hydropower scheme are sought as the installation capacity and year of the Magwagwa scheme listed in the least cost sequence of the long term planting-up programme.

## 5.2 Development Alternatives

### 5.2.1 Dam alternatives

The Magwagwa dam is proposed to be built at the river stretch about 10 km upstream of the Sondu Township in the Sondu River Multipurpose Project as given in Figure 5.1.

Two major tributaries, the Yurith and Kipsonoi rivers, gather 4 km upstream of the damsite, forming a rather wide valley suitable for creating a reservoir. The Sondu River changes its flow direction from the west to the north at right angles some 2 km downstream of the confluences of the Yurith and Kipsonoi rivers. After 2 km further flow-down, the Sondu River enters the gorge where the construction of Magwagwa dam is proposed, and thereafter travels the river course with a rather steep slope of 1 to 150, finally draining into Lake Victoria (refer to Figure 5.2).

The topographic features of the Sondu River around the proposed Magwagwa damsite are as a summary characterized by a wide valley in the upstream reaches and rather steep river slope after entering the gorge. This implies that the damsite should be selected just after entering the gorge in view of saving construction costs and not losing head available for the power generation.

Figure 5.3 shows the location of the proposed damsite. The studies to select the most suitable dam axis in the limited reaches just after entering the gorge will be discussed in the subsequent Section 6.2.2, Main Dam, taking into consideration the topography and geology at the site.

5.2.2 Waterway alternatives

As discussed above, the Sondu River flows down the steep river course downstream from the proposed Magwagwa damsite. Seven alternatives for the waterway are prepared by taking into consideration the big bend of the Sondu River at Sondu Township besides the steep river course as shown in Figure 5.4; that is, the selection of optimal waterway alternative is in the most efficient use of available head between the Magwagwa dam and Sondu/Miriu intake sites.

Alternative-1 is the scheme to develop hydropower with a 3,500 m long waterway along the river course. The powerhouse can be built with a surface type taking advantage of favourable topography at the site as shown in Figure 5.5.

Alternative-2 is the scheme to extend the waterway along the river course, a total length of which is 6,600 m. The powerhouse will be built with an underground type as depicted in Figure 5.6.

Alternative-3 is the scheme to take advantage of the big bend at Sondu Township, i.e. to increase head by shortcut of the river course (refer to Figure 5.4). The proposed plan has an 8,800 m long waterway and a surface type powerhouse as given in Figure 5.7.

The Rigari River, which has a wide and deep valley, merges into the Sondu River just downstream of the proposed powerhouse site of Alternative-3 (refer to Figure 5.4). In case of extending the waterway further downstream of the Rigari River, this topographic characteristics favour the construction of the underground type powerhouse. Alternatives 4 to 7 given in Figures 5.8 to 5.12 correspond to this case. Alternative-7 is a plan to fully utilize available head between the Magwagwa dam and Sondu/Miriu intake sites.

As the principal features of Alternative 1 to 7 are given in Table 5.1, the installed capacity for respective alternatives ranges from 55 MW to 135 MW. In these estimates, an 8-hour peaking operation is assumed for power generation, taking into consideration the relatively high load factor of 68% with a peak at night and the high generation share of hydro plants in the power system, resulting in requiring long time operation for hydropower plants. However, the detailed discussion to determine the installed capacity is given way to the subsequent Section 5.4, Installation Scale and Timing, and an indicative figure is only given to assess the relative merits among the alternatives in this section.

A comparison to select the optimal development alternative of waterway was carried out under the following conditions:

(1) The alternative which gains the net benefit maximum is optimal. Other indexes such as economic internal rate of return, EIRR, and unit energy value, US$/kWh, are also calculated as reference.

(2) Although the Magwagwa dam scheme has the functions to boost firm power and energy of the Sondu/Miriu scheme and to supply irrigation water to the Kano plain, the selection of the optimal development alternative for the waterway is based on the maximization of net benefit accrued directly from the Magwagwa hydropower scheme.

(3) Full Supply Level of the Magwagwa dam is set at El. 1,662.9 m, which is the scale optimized in Sondu River Multipurpose Development Project.

(4) A concrete facing rockfill type is selected as the type of Magwagwa dam, taking into account scarce availability of impervious core materials (refer to the subsequent Section 6.2.2, Main Dam, for further discussions).

(5) Firm discharge is 24.1 $m^3$/sec for the above development scale.

(6) The criteria and conditions to evaluate present worth of benefits and costs are itemized as follows:

- A time horizon of 50 years from the in-service date
- A time period of 5 years for the construction of Magwagwa dam scheme, in which cost disbursement is 0.10, 0.25, 0.30, 0.25 and 0.10.
- A discount rate of 10% to evaluate the present values of benefits and costs,
- A long run marginal cost of US$0.092/kWh for the calculation of power benefits, and
- A factor of 0.83 for the conversion from the construction cost of Magwagwa project to the economic cost. Discussions to estimate the long run marginal cost and the conversion factor are in detail given in Appendix VII.

The result of economic comparison for seven development alternatives of waterway is summarized as given in Table 5.2, showing the maximum net benefit of

US$ 30 million for Alternative-3. Furthermore, Alternative-3 demonstrates a high viability of 12.8% in EIRR. The study on development alternatives reveals that the Magwagwa hydropower project be developed with the Alternative-3 for the waterway alternative plan.

## 5.3 Plan Optimization

### 5.3.1 Simulation model

A simulation model composed of three components, Magwagwa, Sondu/Miriu and Kano schemes (refer to Figure 5.1), was built to find out the optimal reservoir scale of Alternative-3 selected to be optimal among seven development alternatives. The criteria applied for seeking the optimal development scale of the Magwagwa reservoir are to maximize the net benefit gained from power generation of Magwagwa itself and Sondu/Miriu and irrigated agriculture development in the Kano plain

Simulation of the Magwagwa reservoir is based on the continuity equation that the difference between inflow I into the Magwagwa reservoir and outflow Q from the reservoir is the rate of change of storage. The continuity equation is expressed as follows:

$$dS/dt = I - Q - E - M \quad \text{......(1)}$$

where S : Storage in the reservoir
E : Evaporation from the reservoir surface
M : Mandatory release for river maintenance and water supply projects
t : Time.

A selected constant release, Q, from the reservoir, although Q is slightly adjusted by the change of reservoir water level, is selected for power generation. In case that development priority is placed on irrigation rather than power and that irrigation water requirement of a month is greater than the selected constant release for power generation, water release from the reservoir is accorded to the irrigation water requirement.

Once a release rate from the reservoir is selected, the required active storage is computed by giving inflow data into Eq. (1). Since the Sondu/Miriu scheme located downstream of the Magwagwa reservoir is essentially a run-of-river type even with a daily regulating pondage, the inflow to the scheme, which is equivalent to the outflow from the

Magwagwa reservoir, is released as outflow without any regulation for power generation in terms of monthly basis.

5.3.2 Conditions and assumptions for the simulation model

The conditions and assumptions applied for the simulation model described above are itemized as follows:

(1) Simulation is tried to carry out for two cases taking into consideration development objectives; one is the case to place the development priority on power generation (Case One) and the other on irrigation (Case Two).

In case of giving the development priority to power, the irrigation command areas to be exploitable are restricted to the extent gained by coinciding the maximum water requirement of irrigation with firm discharge for power generation. On the other hand, the development priority to irrigation commands the maximum extension of irrigable area in the Kano plain as long as water supply to the entire irrigation area is possible with a certain selected development scale of the Magwagwa reservoir. If not, extension of the irrigation area is naturally limited to the area exploitable with available water.

(2) The potential irrigable area in the Kano plain is delineated at 25,640 ha in net by the JICA Kano irrigation team (Interim Report, March 1991), subdividing into three zones by river as follows (refer to Figure 5.13):

Zone A : 7,260 ha of the Kendu Bay to the Awach Kano River
Zone B : 7,670 ha of the Awach Kano River to the Nyando River
Zone C : 10,710 ha of the right bank of the Nyando River.

The proposed cropping patterns in the respective zones (refer to Figure 5.14) are the base to estimate the water requirements for irrigation.

(3) Water requirements for 25,640 ha based on the cropping patterns proposed above are:

Unit: $m^3/sec$

| Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14.6 | 23.9 | 24.7 | 18.8 | 21.9 | 20.5 | 12.4 | 18.1 | 24.8 | 24.6 | 22.7 | 16.8 |

(4) Water sources for the irrigation development in the Kano plain are the Sondu and Nyando rivers: Diverted water from the Sondu River is the primary source and Nyando River water is expected as the supplementary water source with non-regulated flow.

(5) Economic prices of crops are based on the prevailing prices of 1990 in Kenya.

(6) Economic benefits of the irrigation scheme are based on the assumed cropping pattern, yield of crops and economic prices of crops applying the criteria of with-and-without the project (refer to Appendix VII for further discussions). On the other hand, the costs for the development of irrigation facilities are estimated by the Kano irrigation team as follows:

| | Zone | | |
|---|---|---|---|
| | A (7,260 ha) | A+B (14,930 ha) | A+B+C (25,640 ha) |
| Economic cost (mil. US$) | 50.8 | 104.8 | 191.7 |

Full development of the Kano irrigation scheme is assumed to coincide with the in-service date of the Magwagwa hydropower scheme.

(7) The reservoir simulation of Magwagwa is carried out using runoff data available at 1JG1 over a period of 1947 to 1990. The shift of runoff data from 1JG1 to the damsite is based on the catchment area ratio of 0.97 (3,260 km$^2$ at 1JG1 and 3,160 km$^2$ at the damsite).

(8) Mandatory release of 0.5 m$^3$/sec from the reservoir is assumed taking into consideration the river maintenance flow and the water supply projects in the downstream reaches in the simulation model.

(9) A sediment formation is assumed to be horizontal in the reservoir taking into account a 100-year project life for sediment (53.1 million m$^3$ or El. 1,599 m from the reservoir storage curve shown below), resulting in Minimum Operating Level to El. 1,609 m.

(10) Evaporation from the reservoir surface is counted as losses in the mass balance and the evaporation rate is based on the estimates discussed in Appendix IV, Hydrology and Meteorology.

(11) The storage and area curves of the reservoir are drawn on basis of the 1 to 5,000 scale topographic maps prepared in this study as given in Figure 5.15.

(12) Initial storage in the reservoir is assumed to be full for the simulation.

(13) Active storage of the reservoir is defined as the required storage to warrant a selected firm discharge for power generation with 100% assurance in the simulation over a period of 1947 to 1990.

Actual release of the selected firm discharge ,Q, is adjusted following the change of reservoir water level as follows:

$$Q = Qr\,(H / Hr)^{1/2} \quad \text{.......} \quad (2)$$

| | | | |
|---|---|---|---|
| where | Qr | : | Rated discharge obtained by coinciding with the selected firm discharge |
| | Hr | : | Rated head |
| | H | : | Head. |

Firm power is calculated based on discharge and head at the Minimum Operating Level (MOL), whilst firm energy is the annual accumulation of monthly energy generated in the year when water level reaches MOL.

Meanwhile, the area which can be irrigated with water supply from the Magwagwa reservoir is found out by allowing deficits for the drought once in five years.

(14) Dam crest elevation is assumed to have 5 m freeboard above Full Supply Level (FSL), whilst the tailrace water level necessary for the calculation of power generation is set at El. 1,458 m.

(15) The installed capacity of the Magwagwa hydropower plant is rated at 8-hour peak operation, whilst a plant factor of 0.6 is assumed for the Sondu/Miriu.

(16) Combined efficiency of the turbines and generators is varied in a range of 78 to 88% (e.g. 0.87 = 0.975 x 0.895 for the Sondu/Miriu).

(17) The basic design of the Magwagwa hydropower scheme selected as the concrete facing rockfill type is based on the topographic maps newly prepared on a scale of 1 -

to 1,000 (refer to subsequent Chapter 6), whilst the Sondu/Miriu development plan depends on the idea mentioned in the Preliminary Design Report of the Sondu/Miriu Hydropower Project (January 1991).

(18) The criteria and conditions used for the discounting technique which evaluates the present worth of economic benefits and costs are the same as those discussed in the preceding sub-section 5.2.2, Waterway alternatives.

### 5.3.3 Optimal development plan

Simulation results for Cases 1 and 2, placing development priority on power generation and irrigation development respectively, based on the criteria and assumptions described in the preceding Sub-section are compared in terms of net benefit as shown in Figure 5.16, showing the maximum net benefit at the dam crest elevation of El.1,670 m (FSL at El. 1,665 m) when benefits are counted from three components of Magwagwa, Sondu/Miriu and Kano schemes and when the development priority is given to irrigation.

Table 5.3 shows the further detailed comparison of Cases 1 and 2 on the case that the dam crest elevation is set at El. 1,670.0 m, revealing that full irrigation development in the Kano plain can be attained by minimal sacrifice of power development; that is, substantial energy output will not reduce even if the development priority is given to irrigation. Minimal sacrifice of power development furthermore implies that development for power and irrigation can be compatible with little intervention to each other, provided that a regulating pondage is provided at the tailrace of the Sondu/Miriu.

Table 5.3 furthermore shows high viability of integrated development of the Sondu River and the Kano plain by the economic internal rate of return, EIRR, of 12.6%. Table 5.4 shows an example of cash flows to obtain the results given in Figure 5.16. The construction cost to develop the Magwagwa dam is given in Table 5.5. It is noted that benefits accrued from the multi-reservoir operation as discussed in the subsequent Section 5.4 are not counted in this optimization study of the reservoir, since the development scale of the reservoir has yet to be determined.

## 5.4. Installation Scale and Timing

### 5.4.1 Introduction

The reservoir scale of the Magwagwa scheme was assessed to be optimal by setting the dam crest elevation at El.1,670 m as discussed in the preceding Section 5.3, Plan Optimization. Next discussions will be to look for the optimal installation scale and timing of the Magwagwa hydropower plant.

The optimal installation scale and timing of the Magwagwa hydropower plant are defined to be the scale and year of the Magwagwa hydropower plant appeared in the least cost sequence on the long-term installation programme of power plants newly added to the national power grid so as to meet growing power and energy requirements.

A computer program was prepared to find out the least cost sequence of power plants newly added to the power system by dividing into two parts; scheduling model and simulation model. The scheduling model tries to find out the least cost sequence to meet growing power and energy requirements with firm power and energy of existing and newly added power plants, and furthermore the reliability of power supply is confirmed on loss of load probability, LOLP. The simulation model intends to gauge fuel savings of thermal plants by simulating energy of hydropower plants actually produced following the change of climate. A technique used for this study is Dynamic programming.

### 5.4.2 Conditions and assumptions

The studies to search for the optimal installation scale and timing of the Magwagwa hydropower plant were carried out on the following conditions and assumptions:

(1) A time period of 20 years between the year 1991 and 2010 is set at the investing horizon, in which plants to be newly added to the system are studied. On the other hand, 50 years between the year 1991 and 2040 are set as the evaluation horizon for the economic assessment. A discount rate of 10% is applied to estimate the present value of capital costs and operation and maintenance costs accrued in the evaluation horizons.

(2) Power and energy requirements as a constraint to search for the least cost sequence of plants to be newly added to the system are based on the median forecast in the preceding Chapter 4, Power Survey.

(3) Table 5.6 shows a list of existing and committed hydropower plants. The Turkwel hydropower plant is assumed to commit in January, 1991, whilst the Sondu/Miriu is presumed to commit at the beginning of year 1997 with an installed capacity of 60 MW as concluded in the Preliminary Design Report of the Sondu/Miriu project.

(4) The existing thermal plants are composed of geothermal at Olkaria, steam plants at Kipevu and simple combustion turbines at Nairobi and Kipevu as given in Table 5.7. A diesel plant of 75 MW and geothermal plants of 64 MW are considered to be committed in 1992 and 1993, respectively.

(5) Promising thermal candidates to be added to the national grid system are listed in Table 5.8, in which suitable capacity of thermal plants, i.e. geothermal, coal-fired, oil-fired and open cycle combustion turbine, is assumed to be 30 and 60 MW.

(6) The Low Grand Falls and the Mutonga are listed besides the Magwagwa as promising hydro candidates as given in Table 5.9. The construction costs and the energy outputs for the former two hydro plants are referred to 1991 Interim Update of National Power Development Plan 1991 to 2010 (Draft), April 1991, by Acres International.

(7) Average annual energy and annual firm energy generated from the Magwagwa (refer to Table 5.9) are estimated by carrying out the multi-reservoir operation of the reservoirs in Kenya. The objective function of the study is to maximize energy outputs in the system generated from five reservoir type power stations (Masinga, Kamburu and Kiambere in the Tana River system, Magwagwa in the Sondu River system and Turkwel in the Turkwel River system) and three run-of-river type power stations (Gitaru and Kindaruma in the Tana River system and Sondu/Miriu in the Sondu River system). Among constraints in the study is the penalty for insufficiency to water requirement of the irrigation projects developed in the downstream reaches of those three river systems. The applied technique to maximize energy outputs based on the multi-reservoir operation is Stochastic dynamic programming.

(8) In seeking the optimal installed capacity of the Magwagwa hydropower plant, plant capacities of 67, 100, 120, 133, 140 and 200 MW are listed as promising candidates. The preliminary studies discussed in the Progress Report (3) revealed that the optimal installed capacity would fall in the range of 100 to 130 MW, so that the plant capacities of 100, 120 and 140 MW are retained as the candidates to seek

the optimal installed capacity taking into account the increment of every 20 MW from 100 MW. Maximum plant discharges for the plant capacities of 100, 120 and 140 MW are 65.7, 82.0 and 90.6 $m^3$/sec, respectively. It is noted that firm-up effects of the Sondu/Miriu by building the Magwagwa reservoir are assumed to arise in the year of the Magwagwa's completion onward.

(9) The Magwagwa project has dual development objectives of hydropower and irrigation. The cost of the Magwagwa hydropower project used for the planting-up study is based on the allocated cost for power development. Table 5.10 shows the allocation ratio of costs for respective power outputs between the hydropower and irrigation components obtained by applying the separable costs-remaining benefits method. Table 5.11 gives the economic cost of power component for the respective power outputs of the Magwagwa project. It is noted that the economic cost of the Magwagwa is estimated by multiplying the conversion factor of 0.83 by the total construction cost or the allocated construction cost.

(10) The earliest in-service date of the Magwagwa hydropower project is assumed to be 1st January, 2003 (refer to Chapter 7 in further discussions). Although the other hydro candidates, the Low Grand Falls and the Mutonga, would require the lead time longer than the Magwagwa project, their earliest commission is presumed to be the same as that of the Magwagwa.

(11) Fuel prices are estimated to be US$ 19/bbl for crude oil and US$ 44/MT for coal at the level of year 1990 based on the world market prices of commodities forecast by the World Bank, Fourth Quarter 1989.

### 5.4.3 Optimal installation scale and timing of the Magwagwa power plant

The planting-up study to seek the optimal installation capacity and year of the Magwagwa hydropower project was carried out by two steps; the first step looks for the optimal installation capacity and year of the Magwagwa hydropower project without the other hydro candidates and the second step is to see the competitiveness of the optimized Magwagwa hydropower project for the Low Grand Falls and the Mutonga.

The results of the planting-up study for the first step, which are obtained by changing the installation capacity and year of the Magwagwa hydropower plant, are given by comparing the present worth of respective cases as follows:

Unit: Million US$

| Commissioning Year | Magwagwa Hydropower Plant | | | | | |
|---|---|---|---|---|---|---|
| | 100 MW | | 120 MW | | 140 MW | |
| | Fuel | Total | Fuel | Total | Fuel | Total |
| 2003 | 294.04 | 894.69 | 289.50 | 891.47 | 288.48 | 895.84 |
| 2004 | 298.52 | 893.57 | 294.17 | 889.98 | 293.01 | 900.93 |
| 2005 | 302.28 | 897.67 | 298.16 | 889.86 | 296.13 | 897.88 |
| 2006 | 306.24 | 896.28 | 303.13 | 889.77 | 302.35 | 893.28 |
| 2007 | 313.91 | 896.73 | 307.04 | 890.42 | 306.60 | 895.33 |
| 2008 | 318.78 | 898.35 | 315.44 | 895.80 | 314.00 | 908.11 |

The above Table suggests the optimal installed capacity be 120 MW due to the fact that total present worth of 120 MW is minimum in each installation year, even if the difference is marginal. It is noted that the column of fuel shows the present worth of expenditures required for fuel.

On the other hand, the Magwagwa plant is recommended to be added to the system on the earliest commission year, i.e. 2003, although the least present worth of 120 MW appears in year 2006, based on the following reasons:

(1) The Sondu/Miriu and Kano irrigation projects located downstream would seek the earliest implementation of the Magwagwa project to increase firm discharge of the Sondu/Miriu and to supply irrigation water to the Kano project according to its water requirements.

(2) The variation of total present worth is blunt for the change of installation year; that is, the difference of present worth is only US$1.70 million between the earliest installation year (2003) and the optimal installation year (2006).

(3) Development sequence of power plants added to the system as given in Figure 5.17, in which the installation year of the Magwagwa power plant is 2003, tells that the power system requires to develop 240 MW of geothermal besides 64 MW in 1993 (refer to Table 5.7). Since geothermal involves uncertainties in its development, the earliest implementation of the Magwagwa plant is desired to make up the power and energy deficits which would be expected to cause when the implementation schedule of geothermal is delayed.

(4) Power development sequence only with thermal candidates requires the present worth of US$1,001.10 million with the conditions of 240 MW development of

geothermal and US$19/bbl for crude oil, showing relative attractiveness to develop the Magwagwa plant.

The studies of the second step to see the competitiveness of the optimized Magwagwa plant (120 MW) for the Low Grand Falls and the Mutonga revealed as follows:

Unit: Million US$

| Commissioning Year | Hydropower Plant | | | | | |
|---|---|---|---|---|---|---|
| | Magwagwa (120 MW) | | Low Grand Falls (120 MW) | | Mutonga (60 MW) | |
| | Fuel | Total | Fuel | Total | Fuel | Total |
| 2003 | 289.50 | 891.47 | 338.29 | 939.09 | 362.06 | 934.23 |
| 2004 | 294.17 | 889.98 | 342.42 | 937.39 | 363.92 | 933.14 |
| 2005 | 298.16 | 889.86 | 344.18 | 934.34 | 364.82 | 932.45 |
| 2006 | 303.13 | 889.77 | 345.98 | 932.26 | 365.14 | 930.34 |
| 2007 | 307.04 | 890.42 | 349.86 | 934.65 | 366.25 | 929.23 |
| 2008 | 315.44 | 895.80 | 356.59 | 936.62 | 367.07 | 929.28 |

The above Table reveals the relative attractiveness to develop the Magwagwa plant compared with the Low Grand Falls and the Mutonga in terms of the present worth. It is recommended from the study results of the above two steps that the Magwagwa hydropower plant be developed in year 2003 with a capacity of 120 MW. Tables 5.12 and 5.13 give the power and energy balance of the planting-up programme with the Magwagwa of 120 MW in 2003, showing acceptable power and energy balance, even if there exist energy deficits to require urgent power development in 1990, 1991 and 1992.

### 5.4.4 Sensitivity tests

Sensitivity tests were carried out for assessing uncertainties involved in the future costs and assumptions applied for the planting-up study, and then following were selected as the cases to be performed:

(1) Variation of discount rates; 8% and 12% besides the prime test discount rate of 10%
(2) Variation of fuel prices
(3) 10% capital cost up for the Magwagwa project
(4) Low and high demand forecasts.

The results of sensitivity test with a discount rate of 8% and 12% showed that the installation of 120 MW is viable in comparison with the planting-up sequence only with thermal candidates after the installation of the Sondu/Miriu in 1997; that is, the difference of present worth for the with and without Magwagwa is US$196.24 million for 8% and US$49.22 million for 12%.

The sensitivity test by changing fuel prices, which involve high uncertainties reflecting the current political and economic situations in the world, revealed that when the crude oil price stays at the present level (US$19/barrel), the planting-up sequence with the Magwagwa and the Low Grand Falls is more attractive than that of thermal only with the Sondu/Miriu, and furthermore that the Low Grand Falls shall be developed following the Magwagwa if the crude oil price is over US$23.50/barrel as shown in Figure 5.18.

The planting-up sequence with 10% capital cost up for the Magwagwa project gained US$92 million surplus compared with that only with thermal candidates after the installation of the Sondu/Miriu in 1997, so that the installation of 120 MW is viable for the Magwagwa.

The change of demand forecasts, high and low demands, was less effective to the planting-up sequence; that is, the installation of the Magwagwa with a capacity of 120 MW is required.

# VI. BASIC DESIGN

## 6.1 Introduction

This Chapter describes the basic design concepts and principal features of the main structures of the Magwagwa Project (refer to Plate No. 1). The design made here is, however, of a feasibility study level mainly to achieve a realistic estimate of construction cost for the project.

Through and based on the comparison and optimization study to determine the development scale of the project described in the preceding Chapter 5, Plan Formulation, the following basic dimensions have been worked out for the project:

| | | | |
|---|---|---|---|
| (1) | Full Supply Level (FSL) | : | El. 1,665.00 m |
| (2) | Minimum Operating Level (MOL) | : | El. 1,609.00 m |
| (3) | Total installed capacity | : | 120 MW (60 MW x 2 units) |
| (4) | Maximum plant discharge | : | 82.0 $m^3$/sec |
| (5) | Tailrace water level for the maximum plant discharge | : | El. 1,458.00 m. |

Through the design work, the 3-dimensional CAD (Computer-Aided Design) system was fully utilized to estimate such work quantities as excavation, embankment and concrete. For reference, bird's-eye views of damsite created by the CAD system are attached in the front pages of the Report.

## 6.2 Main Civil Structures

### 6.2.1 River diversion

(1) Design conditions

Diversion tunnels and cofferdams are provided for the purpose of diverting riverflow during the period of the construction works of the main dam. The diversion tunnels are provided on the left abutment (refer to Plate No. 2), considering the topographic conditions at the site.

Two lines of diversion tunnels will be provided, and a river outlet facility will be installed in the No. 2 tunnel for discharging river maintenance flow and controlling the reservoir water level during initial impounding as well as drawing the reservoir water level down in the emergency case of a dam (refer to Plate No. 9).

A 25-year probable flood with a peak discharge of 641 $m^3$/sec was adopted as the design flood discharge for the diversion scheme without the effect of the flood routing in the reservoir. At that time, the downstream outlet water level was estimated at El. 1,561.00 m from the rating curve given in Figure 6.1. In designing the diversion tunnel, the maximum velocity is restricted to less than 15 m/sec for the tunnels lined with reinforced concrete.

(2) River diversion scheme

Since the upstream cofferdam is designed apart from the main dam in case of a concrete facing rockfill dam, the optimum diversion scheme was elaborated by minimizing the sum of construction costs required for the upstream cofferdam and the diversion tunnels. The alternative diameter of the diversion tunnels was determined taking into consideration the upstream reservoir water level and flow velocity in the tunnel.

The outlet water level was estimated at El. 1,561.00 m for the design discharge of 641 $m^3$/sec from the rating curve shown in Figure 6.1. The crest elevation of the cofferdam was set by adding a freeboard of 1.0 m to the surcharge water level for the 25-year probable flood.

Based on the above assumption, construction costs for various combinations of the diversion tunnels and the cofferdams were estimated to obtain the optimum diversion scheme as given in Figure 6.2. The optimal diversion scheme so obtained is as follows:

- Diameter of the diversion tunnel : D = 6.20 m (circular section)
- Total length of the diversion tunnel : 1,291 m (No. 1 : 628 m, No. 2 : 663 m)
- Crest elevation of the U/S cofferdam : El. 1,580.00 m.

In this diameter, the maximum velocity in the diversion tunnel was estimated at 10.6 m/sec.

### 6.2.2 Main dam

(1) Dam axis

Taking the geological conditions and the topographic conditions into consideration, three dam axes were proposed as given in Figure 6.3. Figures 6.4 and 6.5 depict a plan and a profile of the dam at the upper site (Axis-A) by selecting the concrete facing rockfill type, which is conceived to be one of promising dam types, whilst Figures 6.6 and 6.7 for the lower site (Axis-B), and Figures 6.8 and 6.9 for the further down site (Axis-C).

Construction costs at three sites were compared by the concrete facing rockfill type to select the optimal damsite, showing the smallest construction cost at Axis-B as given in Table 6.1. Therefore, the middle dam axis (Axis-B) was selected as the damsite of the Magwagwa dam.

(2) Dam type

The topography and geology at the proposed damsite will allow the construction of either concrete gravity dam or fill type dam. The following 4 dam types were thus assessed technically and economically :

(a) Concrete gravity dam
(b) Roller compacted concrete dam
(c) Centre core rockfill dam
(d) Concrete facing rockfill dam.

During the field investigation, borrow areas for the impervious core materials were not found in terms of quantity within 10 to 20 km from the damsite, resulting in the expensive construction cost of the centre core rockfill dam. Although an asphalt facing rockfill type dam would be selected as one of dam type alternatives, this type is not included in dam type alternatives due to the height of the Magwagwa dam, more or less 110 m, and the requirement of the flatter upstream slope for construction compared with the concrete facing rockfill dam, resulting in embankment volume larger than that of the concrete facing rockfill dam. This dam type shall however be included in the study of dam type selection which will be carried out in the Detailed Design of this project.

General plans for the above four dam types proposed as alternatives are shown in Figures 6.6, 6.10 to 6.11, in which the dam crest elevation is set at El. 1,670 m for fill type dams and at El. 1,669 m for concrete dams, whilst the typical cross sections for them are depicted in Figure 6.12. The following show the results of cost comparison to select the optimal dam type, and further details are given in Table 6.2:

| Dam type alternative | Estimated cost (million US$) | |
|---|---|---|
| Concrete gravity dam | 147.1 | (139.7 %) |
| Roller compacted concrete dam | 141.1 | (134.0 %) |
| Centre core rockfill dam | 144.1 | (136.9 %) |
| Concrete facing rockfill dam | 105.3 | (100.0 %) |

The concrete facing rockfill dam is selected as the most suitable type of the Magwagwa dam due to the following reasons:

(i) Construction cost is least among 4 alternatives.

(ii) Construction will be less affected by wet weather, resulting in the shortest construction time period among all alternatives, because the rock zones can be embanked in any seasons.

(iii) Site preparation is less than the other alternatives.

(iv) Requirements of the foundation treatment are less intensive.

(3) Dam crest elevation

As demonstrated in Chapter 5, the proposed reservoir has FSL at El. 1,665.00 m and MOL at El. 1,609.00 m. In accordance with the ICOLD criterion the crest elevation of the dam should be designed to be safe against the flood discharge, water waves by wind or earthquake and other allowances. Hence, the dam crest elevation is determined at El.1,670.00 m by adding a freeboard of 5.00 m to FSL 1,665.00 m as calculated below:

| | | |
|---|---|---|
| - Surcharge by design flood above FSL | : | 2.97 m |
| - Wind wave runup | : | 1.00 m |
| - Allowance for fill dam | : | 1.00 m |
| Total (Freeboard) | : | 4.97 m ≒ 5.00 m. |

It is noted that the surcharge water level was estimated by assuming no retention effect of the reservoir, namely inflow into the spillway equals outflow from it for the 1,000-year probable flood, and that wind wave runup of 1.00 m was computed based on the storm wind velocity of 30 m/sec and the fetch of 1.6 km, the distance to the other side of the reservoir.

(4) Zoning

The final output for the design of the main dam is shown in Plate Nos. 2 and 3. The height of the proposed dam will be 110 m at the maximum section above the bottom of the facing toe foundation, and the crest is 620 m long and 10 m wide. While, both the upstream and downstream slopes are 1 : 1.40. The dam cross section is classified into four zones with four different embankment materials, the features of which are detailed below :

(a) Concrete face slab

The thickness of the face slab varies with water head and is based on the following empirical formula:

$$t = 0.3 + 0.003\ H$$

where, t : slab thickness (m)
H : water head when the water level stays at FSL (m).

Reinforcement will be required in the face slab to prevent it from cracking which would otherwise result from the thermal and drying shrinkage that occurs before reservoir impounding. The vertical slab joints provided with an interval of 15 m in the face slab will be sealed by copper waterstop.

(b) Rock zone

The rock zone is divided into two, i.e. the upstream and downstream rock zones, from the viewpoint of economy and availability of rock materials. The upstream rock zone is embanked with selected excavated rock materials from the spillway, the availability of which is limited to 300,000 $m^3$ for the total requirement, 3,911,000 $m^3$, of both zones.

The downstream shell zone will be constructed with quarried rocks to be obtained from the quarry located downstream of the dam, which show sufficient strength as rock embankment materials. An amount of quarried rocks to be hauled will be 3,611,000 $m^3$.

(c) Filter zone

Between the concrete facing slab and the upstream rock zone, a filter zone will be provided to restrict flow in the event of leakage through the face slab after completion. In addition, this zone acts as a bedding layer of the face slab, and materials for the filter zone will require a small size for accurate placing and trimming of the upstream face slope. Using materials produced by crushing and processing of quarried rocks, the filter zone will have 2 m in thickness at the foundation level of a parapet wall and will increase linearly up to 7.325 m at El. 1,560.0 m, which is the foundation level of the plinth at the riverbed.

The surface of the upstream slope will specially be treated with asphaltic emulation and coarse sand, and compacted upward and parallel to the slope with a vibrating roller.

(d) Parapet wall

A parapet wall with a height of 4.5 m will be provided at the portion above FSL of the upstream slope to reduce the volume of rockfill and to prevent the dam from the overtopping caused by wave run-up on the relatively smooth face slab.

(e) Upstream earthfill

Compacted earthfill will be provided upstream of the slab up to El. 1,580.00 m with the upstream side slope of 1:2.0 as an additional sealing element. The dam embankment volumes of respective zones and portions are based on the design mentioned above, and are summarized below:

| Zone | Volume ($m^3$) | Materials |
|---|---|---|
| (1) Main dam | | |
| - Concrete face | 37,400 | Reinforced concrete |
| - Filter | 143,600 | Crushed and processed rocks |
| - Rock | 3,611,000 | Quarried rock materials |
| - Rock | 300,000 | Selected excavated rock materials |
| - Parapet wall | 2,700 | Reinforced concrete |
| - Upstream earthfill | 68,600 | Lateritic soils |
| Subtotal | 4,163,300 | |
| (2) Cofferdam | | |
| - Core | 22,900 | Lateritic soils |
| - Filter | 7,600 | Crushed and processed rocks |
| - Rock | 178,600 | Quarried rock materials |
| - Riprap | 15,500 | Quarried rock materials |
| Subtotal | 224,600 | |
| Total | 4,387,900 | |

(5) Foundation treatment

Grouting works will be carried out through the upstream toe slab (plinth), which also serves as the grout cap. Two rows of curtain grouting adopt 0.5 m spacing, and a hole interval in a row is 3.0 m. Rim grouting will be carried out under the side spillway and both the abutments connecting with curtain grouting.

Consolidation grouting of one line each will be provided upstream and downstream of curtain grout to reinforce water tightness with 3 m intervals. The grouting length will be 5 m. These grout arrangement discussed above is shown in Plate No. 3.

(6) Instrumentation for dam

Various kinds of observation instruments will be placed in the dam body or its surroundings not only for proper control of the construction process, but also for monitoring safety of the dam as a useful reference. The instruments to be installed will include the following:

(a) Hydraulic settlement gauges in the rockfill
(b) Survey monuments along the dam crest
(c) Inclinometers on the concrete surface slab
(d) Joint meters on the concrete surface slab
(e) Stress meters on the concrete surface slab

(f) Inclinometers in both the abutments

(g) Piezometers in the dam foundation

(h) Observation holes drilled in both the abutments

(i) A leakage measuring weir at the downstream toe of the dam.

This instrument installation plan should duly be studied at the detailed design stage before the commencement of construction works.

### 6.2.3 Spillway

(1) Design conditions

The spillway is designed to discharge a 1,000-year probable flood with a peak discharge of 1,634 $m^3$/sec not counting the retention effect of the reservoir as discussed in the preceding Section 6.2.2. Considering free operation and maintenance, an ungated type is proposed for the spillway, the location of which is on the left abutment to suit the topography as shown in Plate No. 2. The spillway consists of the portions of ungated weir, open chuteway, flip bucket and plunge pool.

(2) Optimum layout

(a) Length of weir

The ungated spillway has the characteristics that the higher the dam crest elevation is, the shorter the length of the ungated weir becomes, and vice versa. Cost comparison by changing weir length was therefore made to select the optimal length of the ungated weir. The total cost of the dam and spillway, which is a parameter to determine the weir length of spillway, was estimated for the following four cases:

| | Length of Ungated Weir (m) | | | |
|---|---|---|---|---|
| | 105.0 | 125.0 | 160.0 | 210.0 |
| Dam crest elevation (El. m) | 1,671.00 | 1,670.50 | 1,670.00 | 1,669.50 |
| Construction cost ($10^6$ US$) | | | | |
| Dam | 84.5 | 83.0 | 79.1 | 78.6 |
| Spillway | 11.5 | 12.3 | 13.7 | 15.6 |
| Total | 96.0 | 95.3 | 92.8 | 94.2 |

The least cost plan appears in the case to set the dam crest at El. 1,670.00 m, for which the length of ungated weir length is 160.0 m and the resultant flood water level reaches El. 1,667.97 m.

(b) Type of energy dissipator

A flip bucket type is adopted as the energy dissipator due to the fact that the construction cost is generally cheaper than a stilling basin type, and that there are not important structures to be damaged with flood waves.

(3) Hydraulic and structural design

A 1,000-year probable flood with an instantaneous peak inflow of 1,634 $m^3$/sec was adopted as the design flood of the spillway as mentioned earlier.

The probable maximum flood (PMF) in the basin where the project lies would have characteristics of the long lasting duration, say a month, and enormous flood volume, whilst the reservoir has a relatively small flood space compared with the flood volume of PMF. Thus, the flood routing studies for the PMF were carried out to confirm the safety of main dam as given in Figure 6.13, showing that the PMF can be discharged through the spillway safely within the freeboard.

In addition, a 10,000-year probable flood with an instantaneous peak inflow of 2,535 $m^3$/sec was also studied to confirm the safety of the main dam. The proposed spillway can discharge the said flood by the water level of EL. 1,668.97, which is 1.03 m lower than the dam crest level. Further rise of water level by wind wave runup will be within the freeboard of 1.03 m, relying on the fact that the recorded maximum wind velocity is 7.2 m/sec in the area (Kisumu Meteorological Station), which is compared with the wind velocity of 30 m/sec used for the estimate of 1 m runup.

The chuteway was designed by dividing into two parts on slope to save the excavation cost taking into account the topographic conditions; 1: 5.5 for the upstream part and 1: 2.5 for the downstream part. The width of chuteway is 20 m based on the nonuniform flow calculation. The water profile for the design flood is shown in Figure 6.14. The maximum velocity in the chuteway is estimated at 38.2 m/sec for the 1,000-year probable flood.

A 100-year probable flood with a peak discharge of 958 $m^3$/sec was applied for the design of energy dissipator, for which a flip bucket type with a 100 m long plunge pool was adopted from the economic viewpoint.

### 6.2.4 Waterway

(1) General

The waterway for power generation will be composed of an intake, an intake gate shaft, a headrace tunnel, a headrace surge tank, a penstock line, a tailrace surge tank, a tailrace tunnel and an outlet channel, since the underground type is selected for the powerhouse as discussed in the subsequent Section 6.2.5.

The waterway is arranged in the left bank to connect the intake with the tailrace outlet through the underground type powerhouse. The route is selected so as to minimize its length and to ensure adequate earth cover over the headrace tunnel. A profile of the waterway is shown in Plate No.4.

(2) Intake

The intake is located at the left bank about 300 m upstream of the spillway, taking into consideration avoiding a probable area of land slide and minimizing the total length of the headrace tunnel. The elevation of intake invert is set at El. 1,598.00 m considering the formation of the 100-year sediment level.

The intake has two inlets, the dimensions of which are 7.5 m wide and 7.5 m high. The flow velocity at the inlets is 0.73 m/sec for the maximum plant discharge of 82.0 $m^3$/sec. Trashracks are installed in front of the intake to prevent from entrainment of flowing logs into the headrace tunnel.

(3) Intake gate shaft

A 65.8 m high intake gate shaft for the gate is provided to close the waterway 500 m downstream of the intake. The selection of the shaft type to mount the gate relies on easy approach; that is, the proposed shaft site is located on the access road between the damsite and Magwagwa village.

Inspection of the headrace tunnel will be carried out through the air entrance hole located just downstream of the intake gate slot. Structural details of the intake and the intake gate shaft are shown in Plate No.5.

(4) Headrace tunnel

Route of the headrace tunnel

A comparative study to select the optimal headrace tunnel route was carried out for three alternatives as shown in Figure 6.15. The Route-B was selected as the optimum one of headrace tunnel based on the following reasons:

(i) The construction cost including not only the headrace tunnel itself but also work adits was the lowest among these three alternatives.
(ii) An intake of the alternative Route-A is located near the fault zone, which would result in land slide in future.

Diameter of the headrace tunnel

The optimal diameter of the headrace tunnel was obtained by minimizing the sum of negative benefit accrued from energy losses due to friction losses in the tunnel and the annual equivalent construction cost of the headrace tunnel. The result tells the optimum diameter of the headrace tunnel is 5.4 m.

Basic design

The headrace tunnel with a circular section of 5.4 m in inside diameter is 7,190 m long for the distance between the intake and the headrace surge tank. The tunnel will be concrete-lined for the whole length to get a small roughness coefficient. A rock-supporting system for tunnel excavation was planned by the combination of NATM (the New Austrian Tunneling Method) and steel supports depending on rock conditions:

| Type | Support type | Lining thickness (cm) | Assumed length (m) |
|---|---|---|---|
| I | NATM | 30 cm | 4,490 m |
| II | Steel support | 30 cm | 1,000 m |
| III | Steel support | 40 cm | 500 m |
| IV | Steel support | 50 cm | 1,200 m |

The extra excavation of 10 cm outside the design lining line is taken into account in estimating excavation and concrete volumes. It is assumed in cost estimates that 30% of the total tunnel length does not require any support. Cross sections for the above 4 types are shown in Plate No. 6.

For the construction of the headrace tunnel, two work adits (refer to Plate No. 1) will be provided, the location of which is determined not so as that the tunnel length between both the entrances exceeds 4.0 km at maximum from the construction time schedule. The No. 2 adit located near the surge tank will be used as the drain tunnel of the headrace tunnel after plugging. For this purpose, the high-pressure gate with a guard valve and a steel conduit pipe of 0.75 m diameter will be placed in the plug portion.

(5) Headrace surge tank

The headrace surge tank is of restricted orifice type. The maximum up-surging water level was estimated under the condition that full load is rejected when the reservoir water level stays at FSL, while the maximum down-surging water level for half load increase when the reservoir water level stays at MOL.

The principal features of the surge tank (refer to Plate No. 6) are summarized below:

| | | |
|---|---|---|
| Shaft | : | 18.0 m diameter x 93.6 m high |
| Port diameter | : | 3.0 m |
| Maximum up-surging water level | : | El. 1,682.23 m |
| Maximum down-surging water level | : | El. 1,591.34 m. |

The surging waves to give the maximum and minimum surging water levels are depicted in Figure 6.16.

(6) Penstock lines

The penstock line consists of a vertical shaft of which the centre line coincides with that of the headrace surge tank and the lower horizontal tunnel part. The vertical shaft is 134 m long and the lower horizontal tunnel part is 40 m long. The steel penstock pipe is bifurcated 20 m upstream of the powerhouse.

From the economic and geotechnical viewpoints, the penstock was designed to bear half of internal water pressure including dynamic pressure due to water hammer and up-surging by the surrounding rocks. Water hammer in the penstock was analysed by the Jaeger's formula. The closing time was determined at 4 seconds as a result of economic study by combining with the cost of generating equipment. The results of the study are summarized below :

(i) Diameter

| Part | Length (m) | Diameter (m) |
|---|---|---|
| Vertical shaft part | 134 | 4.4 to 3.2 |
| Lower horizontal part before branch | 20 | 3.0 |
| Horizontal part after branch | 20 | 2.1 |

(ii) Water hammer

| | | |
|---|---|---|
| Total static head | : | 214.0 m |
| Pressure rise including static head | : | 279.4 m (30.6 % by water hammer) |

(iii) Total weight of steel pipe : 380 ton including the spherical branch and the bifurcated portion.

(7) Tailrace surge tank

Since the tailrace tunnel is designed to be a 1,850 m long pressure tunnel (refer to Plate No. 4), a surge tank will be provided 80 m downstream of the turbines. The surge tank was designed to be of restricted orifice type which is the same type as the headrace surge tank.

The maximum up-surging water level was estimated under half load increase while the maximum down-surging water level was under full load rejection at the normal tailrace water level (TWL). The down-surging was limited to be higher than El. 1,451.40 m in order not to entrain air into the tailrace tunnel for avoiding air hammer phenomena.

The principal features of the surge tank (refer to Plate No. 6) are summarized below:

| | | |
|---|---|---|
| Shaft | : | 23.0 m diameter x 27.1 m high |
| Port diameter | : | 3.0 m |
| Maximum up-surging water level | : | El. 1,463.34 m |
| Maximum down-surging water level | : | El. 1,452.68 m. |

The surging waves to give the maximum and minimum surging water levels are depicted in Figure 6.17.

(8) Tailrace tunnel

The tailrace tunnel was designed as a circular-shape concrete-lined pressure tunnel. The diameter and the length of the tunnel are 5.4 m and 1,850 m, respectively. General layout of the tailrace tunnel is shown in Plate No. 7.

The alignment of the tunnel was determined from the topograghic point of view, while the diameter was determined in economic comparison as the headrace tunnel did. The longitudinal alignment of tunnel was decided to slope up to the tailrace outlet with a gradient of 1 : 154, since the underground powerhouse is located to be at El. 1,451.00 m for the turbine centre level.

(9) Outlet channel

A tailrace outlet channel will be provided downstream of the tailrace tunnel to smoothly lead the plant discharge to the Sondu River. The channel will be 730 m long with the bottom width of 20 m. Adjacent to the outlet of the tailrace tunnel, a 20 m long weir will be provided to control the tail water level, the crest of which is set at El. 1,456.20 m.

6.2.5 Power station

(1) General

The selected power station lies underground and about 2,500 m inside of the left abutment of the Sondu River from the tailrace channel outlet located about 17.5 km downstream of the Magwagwa dam along the river course. The power station consists of a powerhouse, an access tunnel, cable tunnels and an outdoor switchyard located at the right bank of the powerhouse. The powerhouse will house two units of vertical synchronous generators and Francis type hydraulic turbines. Main transformers will be installed in the same cavern and will be connected with the outdoor switchyard through the access tunnel and the cable tunnel.

(2) Type of powerhouse

A comparison study was carried out to select either an open air type powerhouse or an underground type powerhouse from the economic and technical viewpoints. For the economic comparison, water hammer and surging calculations were made for both types. The results of the economic comparison are as follows :

(Unit : 1,000 US$)

| Work items | Open air type | Underground type |
|---|---|---|
| Headrace surge tank | 4,507 | 4,839 |
| Penstock (Civil works) | 4,882 | 808 |
| Penstock (Metal works) | 18,430 | 1,628 |
| Powerhouse | 3,972 | 4,591 |
| Tailrace surge tank and gate chamber | - | 1,340 |
| Access tunnel and cable tunnels | - | 4,811 |
| Tailrace | 5,797 | 9,484 |
| Outlet channel | 1,772 | 1,772 |
| Outdoor switchyard | 786 | 473 |
| Access road | 103 | 17 |
| Generating equipment | 23,543 | 20,174 |
| Total | 63,792<br>(100 %) | 49,937<br>(78.2 %) |

Finally the underground type powerhouse was selected by the following reasons :

(i) The construction cost of the underground type powerhouse is cheaper than that of the open air type powerhouse.

(ii) The underground type powerhouse is much advantageous in the viewpoint of security during operation and maintenance.

(3) Powerhouse

The underground type powerhouse was designed to house two 60 MW generating units. Dimensions of the cavern, 22 m wide, 38 m high and 60 m long, are determined essentially from the size of turbines and generators and from the area and the height required for erecting and installing the generating equipment. The basic arrangement for the equipment and appurtenant structures in the powerhouse is shown in Plate No. 8.

The powerhouse consists of a machine room, an erection bay and a main transformer room. The machine room is 17 m wide and 30.5 m long, while 17 m wide and 15.5 m long for the erection bay and 17 m wide and 10 m long for the main transformer.

The main units have a space of 15.0 m between centres to provide an area for installation and arrangement of turbines, its auxiliaries and other electrical equipment. The turbine centre is set at El. 1,451.00 m, 7 m lower than TWL El. 1,458.00 m, to secure draft head required.

(4) Related underground structures surrounding powerhouse

The tunnels and chambers located underground around the powerhouse are shown in Plate No. 7.

A 900 m long access tunnel is provided between the outside access road and the erection bay in the powerhouse with a 10% gradient for transportation of generating equipment as well as construction materials during construction. The tunnel functions also as an air supply tunnel to the underground cavern and a part of cable tunnel. The tunnel is a 7.0 m wide and 6.0 m high 'D'-shaped cross section sized to meet the requirement of equipment transportation.

Two draft gates are provided 30 m downstream of the units centre. For these gates, a chamber is provided with 3.0 m in width, 3.5 m in height and 25 m in length. The chamber is connected to the access tunnel with a 'D'-shaped tunnel, the dimensions of which are 4.0 m wide, 4.0 m high and 150 m long.

Two 'D'-shaped cable tunnels are provided for the cables between the main transformer room and the outdoor switchyard as well as for the air supply. One is 2.5 m wide, 2.5 m high and 120 m long, connecting the outdoor switchyard with the access tunnel. The other is 4.0 m wide, 4.0 m high and 80 m long, branching off the access tunnel to the arch crown of the underground powerhouse. This tunnel will be utilized for the work adit to the powerhouse during construction.

Ventilation of the underground powerhouse will be made through air ducts hung down in the two cable tunnels and the access tunnel. For this purpose, a ventilation house will be provided in the outlet portal of the cable tunnel.

(5) Outdoor switchyard

The outdoor switchyard is located in the left bank of the National Highway Route A1 considering easier access with the dimensions of 60 m wide and 150 m long at the ground elevation of El. 1,566.00 m to accommodate main switchgear equipment and a control house. The underground powerhouse is basically remote-controlled from this control house.

### 6.2.6 River outlet

A river outlet will be provided for the purpose of :

(a) controlling the reservoir water level during initial impounding,
(b) releasing maintenance flow required in the downstream reaches, and
(c) emergency draw-down of the reservoir water level when the safety of the dam is threatened for any reason.

The river outlet facilities are provided in the No. 2 diversion tunnel, consisting of an intake tower with trashracks, a steel pipe in the plug portion, a valve chamber and a connecting tunnel between two diversion tunnels. Details are shown in Plate No.9.

The floor elevation of the inlet is set at El. 1,592.00 m corresponding to the sediment level after 50 years. The capacity of the outlet valve was determined to keep the reservoir water level constant at El. 1,592.00 m in releasing some 30 $m^3$/sec in dry seasons.

The valve chamber houses a 2.0 m diameter hollow jet valve and a 2.0 m diameter ring-follower gate as a guard valve.

A shaft type entrance will be provided at the downstream end of the No. 1 diversion tunnel. The access to the valve chamber will be made through this entrance and the connecting tunnel after the No. 1 tunnel is plugged.

### 6.2.7 Saddle dam

A saddle dam will be constructed near Magwagwa village. The dam alignment was determined so as to minimize the number of houses to be relocated from the village.

The dam was designed as a homogeneous earthfill type with the upstream and downstream slopes of 1:3.00 and 1:2.00, respectively, considering the dam height of about 20 m. The dam crest is 710 m long and will be used as a relocation road. Details are shown in Plate No.10.

### 6.2.8 Permanent access road

The project will require construction of access roads, relocation roads and haul roads. The access roads and the relocation roads will be permanent with tarmac finishing, while the haul roads are for temporary use.

Permanent access roads to the Magwagwa damsite are comprised of the National Highway Route A1, the local road C22 to Magwagwa village to be improved and the newly constructed access road between Magwagwa village and the damsite. The road C22 requires minor upgrading works for some portions prior to commencement of the construction works. The distance between the branch point at Magwagwa village and the damsite is approximately 3.0 km.

The following permanent access roads will be required for the Project:

| From | To | Length (km) | Width (m) |
|---|---|---|---|
| Magwagwa village | Damsite | 3.0 | 6.0 |
| A1 Highway | Access tunnel | 0.2 | 6.0 |
| A1 Highway | Drain tunnel | 0.8 | 6.0 |

## 6.3 Hydro-mechanical Works

Major items of metal works to be supplied and installed in the project will be gates, trashracks, valves, and steel penstock pipes. The following are main features of the structures required for the project :

(1) Diversion gate

| | | |
|---|---|---|
| Type | : | Roller gate |
| Number | : | 1 set |
| Dimensions | : | 6.2 m wide x 6.2 m high |

(2) River outlet valve

| | | |
|---|---|---|
| Type | : | Hollow jet valve and ring follower gate |
| Number | : | 1 set each |
| Dimensions | : | 2.0 m in diameter |

(3) River outlet trashracks

| | | |
|---|---|---|
| Type | : | Fixed screen |
| Number | : | 4 sets |
| Dimensions | : | 4.0 m wide x 4.0 m high |

(4) Intake trashracks

| | | |
|---|---|---|
| Type | : | Fixed screen |
| Number | : | 2 sets |
| Dimensions | : | 7.5 m wide x 9.0 m high |

(5) Intake gate

| | | |
|---|---|---|
| Type | : | Caterpillar gate |
| Number | : | 1 set |
| Dimensions | : | 5.4 m square |

(6) Drain valve in the headrace tunnel

| | | |
|---|---|---|
| Type | : | High-pressure slide valve with a guard valve |
| Number | : | 1 set |
| Dimensions | : | 0.75 m in diameter |

(7) Draft tube gate

| | | |
|---|---|---|
| Type | : | Slide gate |
| Number | : | 2 sets |
| Dimensions | : | 3.1 m wide x 3.5 m high |

(8) Penstock pipe

The penstock line will be bifurcated 20 m upstream of the powerhouse. A total length of the penstock pipe is 198 m between the downstream end of the headrace surge tank and the inlet valve in the powerhouse, and the total weight is estimated at 380 ton.

The following are the summary of the steel materials assumed for the design of the penstock pipe and the thickness of steel liners obtained in this study :

| Materials | Allowable tensile strength (kg/cm$^2$) | Max. thickness (mm) |
|---|---|---|
| JIS SM41B | 1,300 | 18 |

The thickness of the steel liners changes at respective sections subject to varying water pressure including water hammer.

## 6.4 Generating Equipment

Basic design conditions of the generating equipment are summarized below:

- Full supply level of reservoir : El. 1,665.0 m
- Minimum operating level : El. 1,609.0 m
- Maximum plant discharge : 82 m$^3$/sec
- Tailwater level for maximum plant discharge : El. 1,458.0 m
- Rated head : 170.4 m.

The layout of two units was selected taking into account the effects to give power system operation at the time when the unit is forced to be out of service due to trouble or repair in case of one unit selection for the plant.

A Francis type was selected as the turbine type based on head and discharge available for each unit of turbines connected to the penstock through a hollow-through type inlet valve with a diameter of 2.4 m.

Vertical-shaft semi-umbrella type synchronous generators were selected as the type of generators.

A single line diagram with a low voltage synchronization system was tentatively laid out as shown in Plate No. 11. Generator voltage is to be stepped up with a unit transformer with $1\frac{1}{3}$ circuit breaker arrangement of 132 kV switchgear in the outdoor switchyard. One 3,000 kVA local transformer is also provided for 33 kV local service supply.

The principal features of the generating equipment of the Magwagwa hydropower station are outlined as follows:

a) Water turbine

- Number of units : 2
- Type : Vertical shaft Francis
- Rated net head : 170.4 m
- Maximum plant discharge for each unit : 41.0 $m^3$/sec
- Rated output : 61,500 kW
- Rated speed : 333 rpm

b) Generator

- Number of units : 2
- Type : Three-phase, semi-umbrella, synchronous generator of vertical shaft with static type exciter
- Rated capacity : 66,800 kA
- Rated voltage : 11 kV
- Rated frequency : 50 Hz
- Rated power factor : 0.9
- Electrical output : 60,100 kW

c) Main transformer

- Number of transformers : 2
- Type : indoor use with natural cooled/forced air cooled (ONAN/ONFA)
- Capacity : 66,800 kVA
- Voltage ratio : 11/145.2-132-118.8 KV

d) 132 kV SF6 circuit breaker

- Rated voltage : 145 kV
- Rated continuous current : 1,250 A
- Rated rupturing current : 31.5 kA.

Major auxiliary equipment of the power station includes the following:

- One (1) 150-ton overhead travelling crane with an auxiliary hoist for handling miscellaneous equipment,
- One (1) set of diesel engine generator for emergency power supply to the auxiliary equipment.

The general layout of the powerhouse is shown in Plate No. 8.

## 6.5 Transmission Line and Substation

### 6.5.1 Conductors and overhead earthwires

(1) Conductor sizes

The minimum ACSR conductor applicable for the 132 kV is "Hyena" in the BS code having its outside diameter of 14.5 mm for corona critical voltage. ACSR conductors used for 132 kV lines in the country are Wolf, Lynx, Goat and Canary whose diameters are bigger than the minimum 14.5 mm.

Conductors applied for the project will be selected from those kinds in the economic comparison in consideration of the power flow on recommended lines and the load forecast to be reviewed at the detailed design stage of the project.

(2) Overhead earthwires

An overhead earthwire is installed over the power conductors to protect them from direct strokes of lightning. The earthwire will also be effective for reducing induction interference from fault current of the line to telephone lines.

The wire will be selected from its mechanical strength for keeping its sufficient shielding effect to power conductors so that sags of the wire should be less than 80% of those of power conductors at midspans in still air under the minimum temperature.

(3) Design of sag

The sags will be designed under the following conditions:

| | | | |
|---|---|---|---|
| (a) | Most severe design condition | | |
| | - to design maximum conductor tension | : | maximum wind under minimum temperature |
| | - to design maximum conductor sag | : | maximum temperature with still wind |
| (b) | Max. wind pressure on conductor | : | 385 N/sq.m |
| (c) | Max. air temperature | : | 36.7°C |
| (d) | Min. air temperature | : | 6.0°C |
| (e) | Max. conductor temperature | : | 75.0°C |
| (f) | Min. conductor temperature | : | 0.0°C |
| (g) | Average conductor temperature | : | 25.0°C |
| (h) | Factor of safety | | |
| | - max. working tension to UTS | : | more than 2.5 |
| | - everyday stress to UTS | : | more than 5.0 |
| (i) | Young's modulus of aluminium | : | 6,300 kg/sq.mm |
| | Young's modulus of steel | : | 21,000 kg/sq.mm |
| (j) | Linear expansion coefficient | : | 23 x $10^{-6}$/°C for alum.<br>1.5 x $10^{-6}$/°C for st. |

(4) Accessories of conductors and earthwires

In order to prevent conductors and wires from damage due to repeated vibrations caused by breeze, Stockbridge type vibration dampers will be applied for both the conductors and wires. Aluminium-made preformed armour rods will also be used for the conductors at every suspension clamping point for the same purpose.

### 6.5.2 Insulation

(1) Insulator units

Characteristics of the insulator unit are as follows:

| | | | | | |
|---|---|---|---|---|---|
| (a) | Dimension | : | 254 mm x 146 mm cap and pin type with ball and socket coupling recommended by IEC | | |
| (b) | Withstand voltage | : | 50 Hz and wet | : | 40 kV |
| | | | 50 Hz and dry | : | 70 kV |
| (c) | Puncture voltage | : | 110 kV | | |
| (d) | Min. failing load | : | 12,000 kg | | |
| (e) | Color of surface | : | brown. | | |

(2) Insulator sets

All the insulator sets will be designed with minimum mechanical factor of safety of 3.0 to their ultimate strength under the most severe loading condition to the sets.

Electrical characteristics of the sets will be as follows:

| | | | Suspension set | Tension set |
|---|---|---|---|---|
| (a) | Number of units per set | : | 10 | 11 |
| (b) | Power frequency withstand voltage, wet | : | 345 kV | 365 kV |
| (c) | impulse withstand voltage, wet | : | 375 kV | 625 kV |

(3) Minimum electrical clearance

Minimum electrical clearance of live parts (suspension insulator sets and jumper conductors) to earthed structures on supports is determined in insulation coordination as follows:

| | | | |
|---|---|---|---|
| (a) | In still air | : | 1,350 mm |
| (b) | Under assumed 20 deg. swing | : | 1,350 mm |
| (c) | Under assumed 40 deg. swing | : | 1,100 mm |
| (d) | Under assumed 60 deg. swing | : | 830 mm. |

6.5.3 Supports

(1) Type of supports

The supports will be of self-supporting and broad-base galvanized steel lattice type towers with body and hillside extensions.

Tower foundations will generally be of concrete pad and chimney type, rock anchor, pile or raft type, depending on soil condition at the tower site. Following tower types will be designed for the project in order to suitably meet various tower loadings at tower positions selected:

(a) Type-S : This is the type to be used at tangential positions or angle points up to 2 degrees of horizontal deviation, provided with suspension type insulator sets.

(b) Type-L : This is the type to be used at positions of light angle up to 15 degrees of horizontal angle deviation with tension type insulator sets.

(c) Type-M : This is the type to be used at positions of medium angle up to 30 degrees of horizontal angle deviation with tension type insulator sets.

(d) Type-H : This is the type to be used at positions of heavy angle up to 60 degrees of horizontal angle deviation with tension type insulator sets.

(e) Type-T : This is the type to be used at positions of line termination or 60 degrees of horizontal angle deviation with tension type insulator sets.

Following minimum clearance of power conductors will be kept above ground or other crossing objects:

| | | | |
|---|---|---|---|
| (a) | above general terrain | : | 6.7 m |
| (b) | above main roads | : | 7.5 m |
| (c) | above other power lines | : | 3.2 m |
| (d) | above telephone lines | : | 3.2 m |
| (e) | above railways | : | 8.5 m. |

(2) Design conditions

Towers will be designed under the following conditions:

(a) Wind pressure in the projected area of tower structures will be 690 N/sq.m.
(b) Basic design span length will be 350 m.
(c) Broken-wire condition will be assumed at breakage of either any one power conductor or an overhead earthwire under the maximum wind pressure and maximum working tension of a conductor or earthwire.
(d) Following safety factors for the tower structures will be adopted in design:
   - more than 2.5 for the synthetic maximum load under the normal loading conditions,
   - more than 1.25 for the synthetic maximum load under the broken-wire loading condition.

6.5.4 Substations

(1) Chemosit substation

Additional 132 kV switchgears for the transmission line from the Magwagwa power station will be constructed in the spare bay of the existing substation premises. Re-arrangement between the new 132 kV coming line and the existing 132 kV Muhoroni line will be required, since the existing Muhoroni line is connected with the switchgears on the side of the Magwagwa station and therefore both the lines will cross each other unless arrangement is done. Arrangement of 132 kV bus is also recommended to modify 1.5 CB from the single bus so as to increase the reliability of power supply and to facilitate the maintenance of the equipment without outage of the substation.

The existing substation building will be used for the new switchgears without expansion.

(2) Muhoroni switching station

The existing station is to be largely modified under the Sondu/Miriu project, which is to provide with bays for the new 132 kV transmission lines from the Magwagwa power station and an additional 132 kV line to the Lessos substation.

A 132/33 kV stepdown transformer has been provided under the Sondu/Miriu Project.

Under the Magwagwa project, additional switchgears for the lines will be constructed in the spare bays.

(3) Lessos substation

In case that a new 132 kV transmission line will be required between this substation and the Muhoroni switching station as mentioned in the preceding Section 4.6.3, an additional transmission line bay will be constructed in the Lessos substation. A spare 132 kV bay in the existing switchyard will be used, and no expansion of the substation premises will be required, accordingly.

The control room will be extended to allow for extended SCADA system.

(4) Design of stations

Insulation levels of switchgears installed under the project will be at 650 kV of rated lightning impulse voltage and at 275 kV of rated 1-minute power frequency withstand voltage in accordance with the IEC standard and the present system design in the country.

On the other hand, the rated breaking current of circuit breakers, rated short-time withstand current of disconnecting switches and their rated normal current will be selected from the standard values specified in the relevant IEC standards. Those currents to be specified will be determined based on the analysis results of the power system at the time when the project is implemented.

High speed single pole reclosers will be provided for the Muhoroni-Lessos line so that power flow of the sound transmission line will not exceed the rated capacity when faults occur. Three-phase slow speed autoreclosers will be applied for the Sondu-Magwagwa, Magwagwa-Muhoroni and Magwagwa-Chemosit lines, since the said three lines will consist of a linked line including the Sondu-Kisumu and Kisumu-Muhoroni lines, and therefore the linked line will have capacity to flow power safely even when faults occur.

# VII. CONSTRUCTION PLAN AND COST ESTIMATE

## 7.1 Construction Plan and Schedule

### 7.1.1 Introduction

A construction plan of the Project is prepared on the basis of the preliminary design discussed in the preceding Chapter 6, giving an outline of possible procedures, construction sequences, methods and types of plant and equipment to implement the construction works. The construction works will be divided into four packages shown below and will be executed by the contractor selected by international competitive tenders for respective packages including prequalification. As for the engineering services, a consultant will be required for the execution of the Project on the detailed design stage and the construction supervision stage, respectively.

(a) Civil works including preparatory works

Civil works include the construction of diversion tunnel, cofferdam, main dam, saddle dam, spillway, river outlet, waterway, power station, outlet channel, architectural building, access road and base camp as well as preparatory works.

(b) Metal works

Metal works are composed of the installation of diversion gate, river outlet valve, river outlet trashracks, intake trashracks, intake gate, drain valve, steel penstock, draft tube gate and tailrace gate.

(c) Generating equipment

The works for generating equipment are for the installation of turbines, generators, transformers, switchgear and control equipment, supervisory equipment, ancillary equipment, miscellaneous equipment, transmission line protective relays and PLC communication.

(d) Transmission lines and substation equipment

Transmission lines are built for the routes of Magwagwa to Sondu/Miriu, Magwagwa to Chemosit, Magwagwa to Muhoroni and Muhoroni to Lessos.