FIGURES

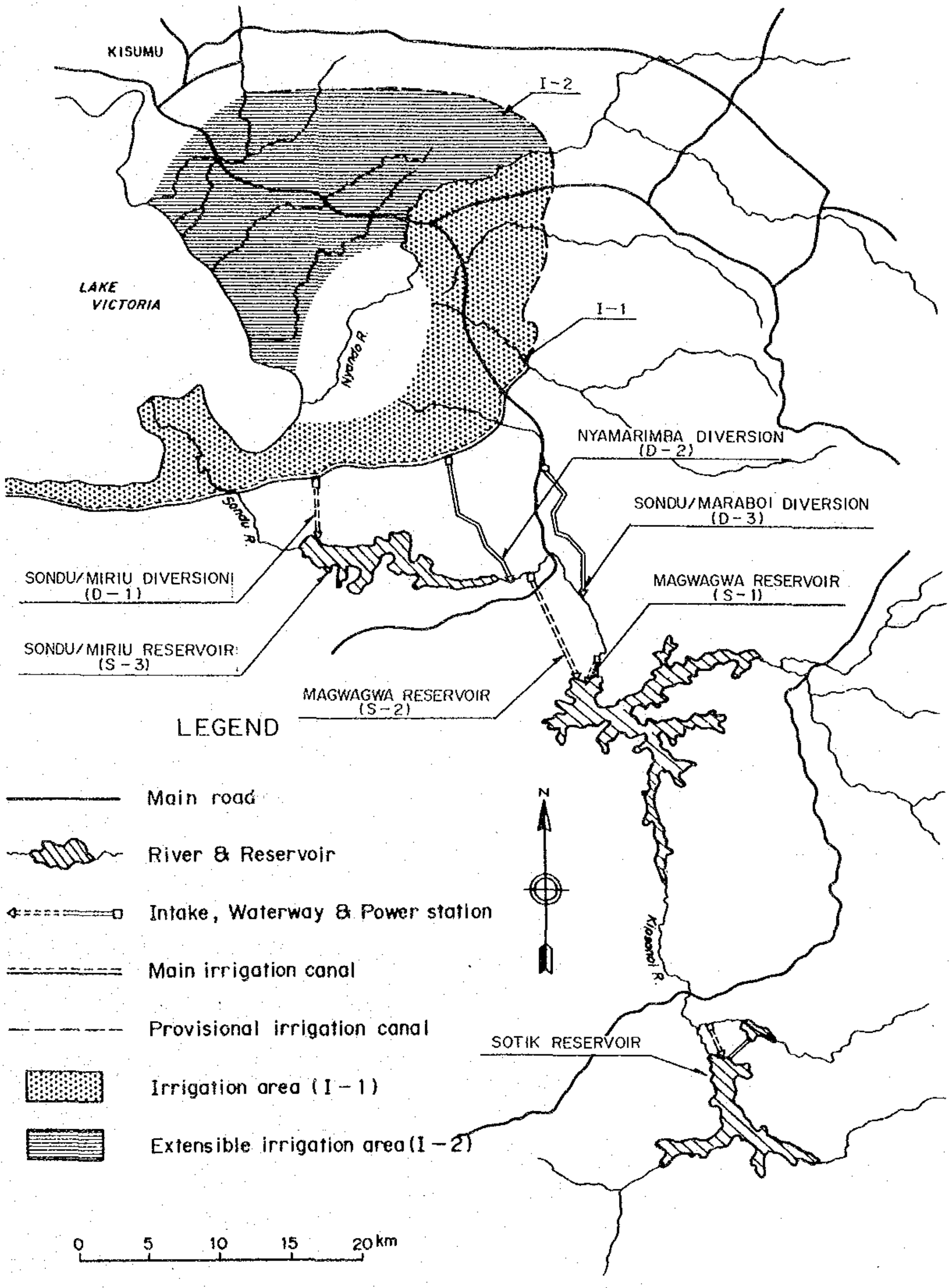
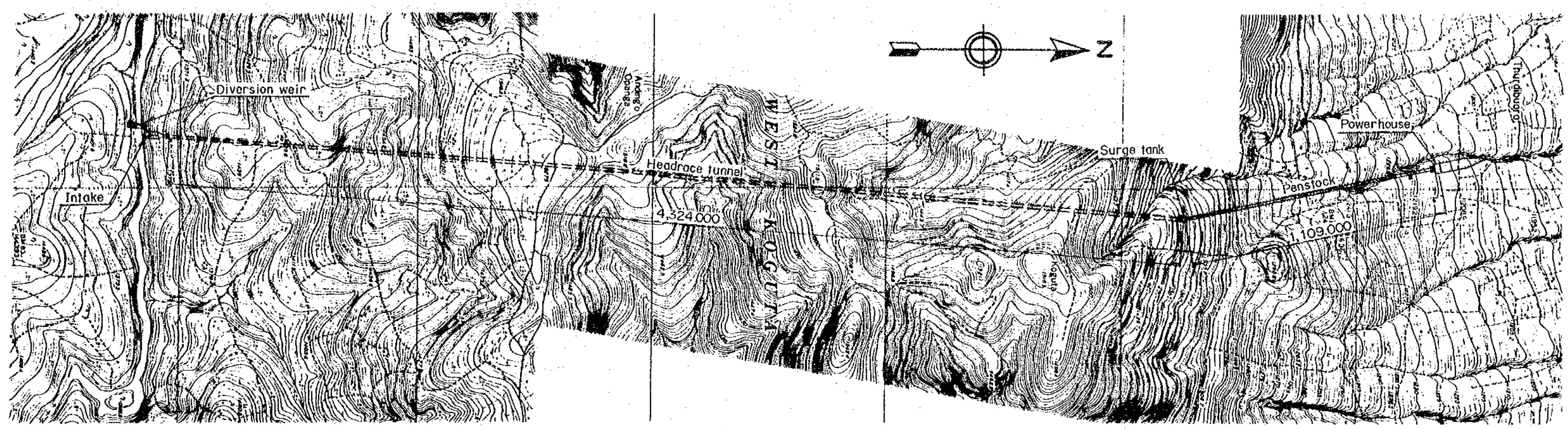
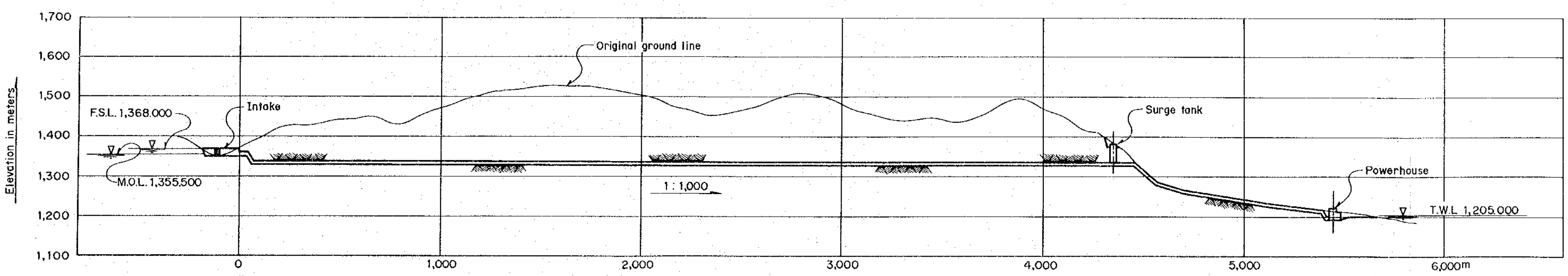


Figure 2.1
Location of Proposed Schemes

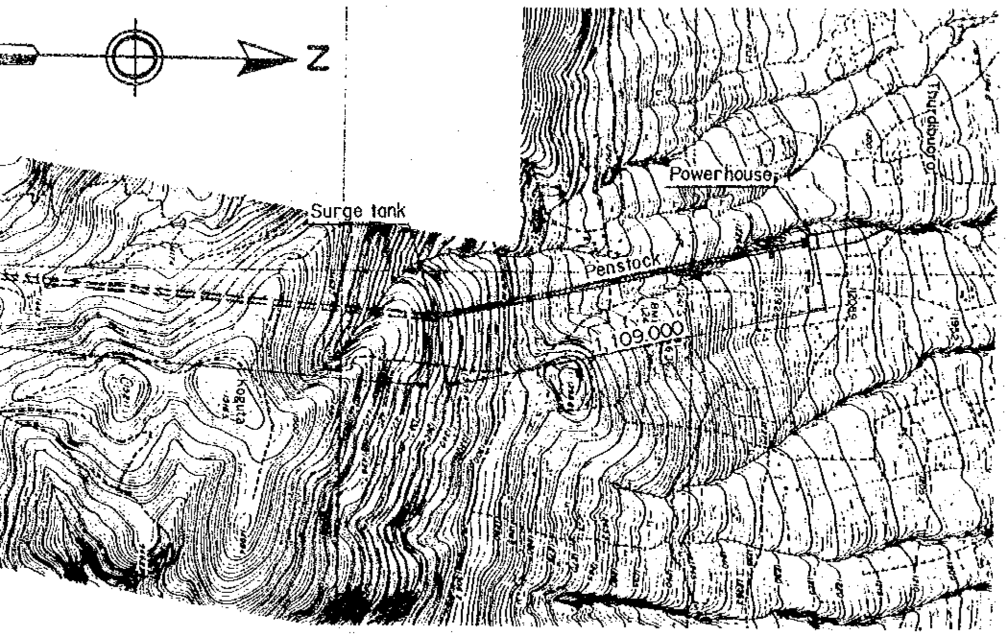
REPUBLIC OF KENYA
SONDU RIVER
MULTIPURPOSE DEVELOPMENT PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY

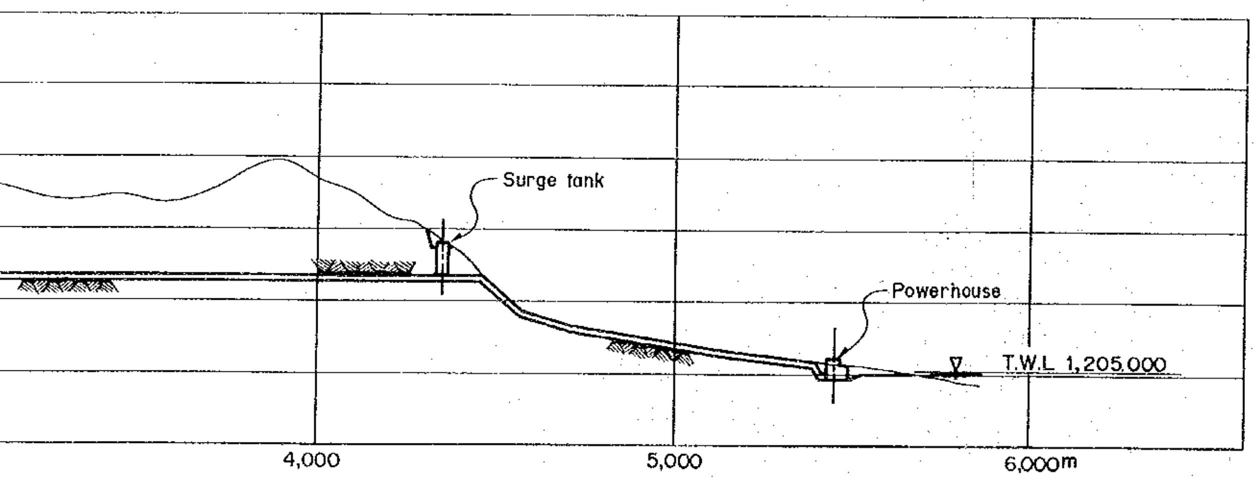


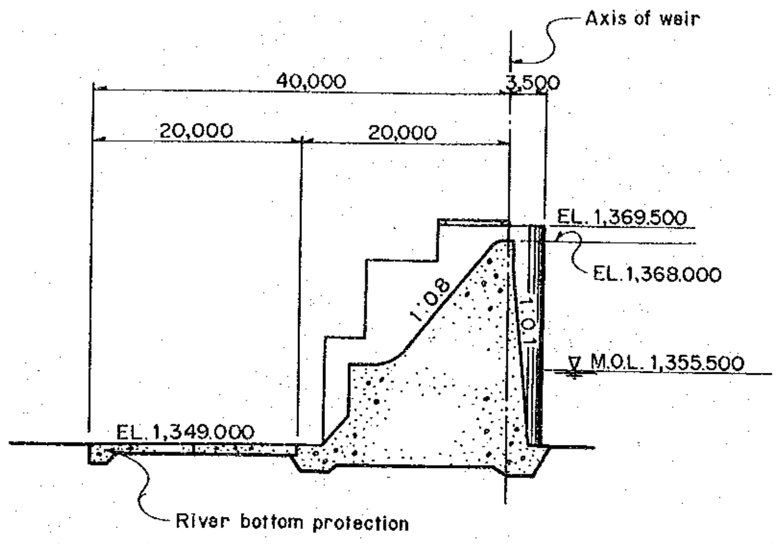
PLAN



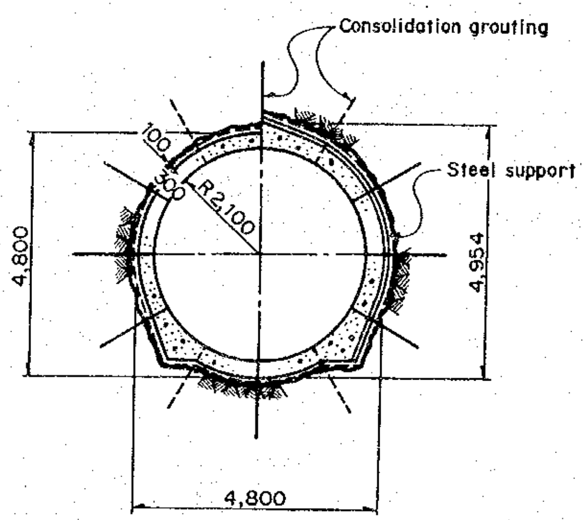
PROFILE



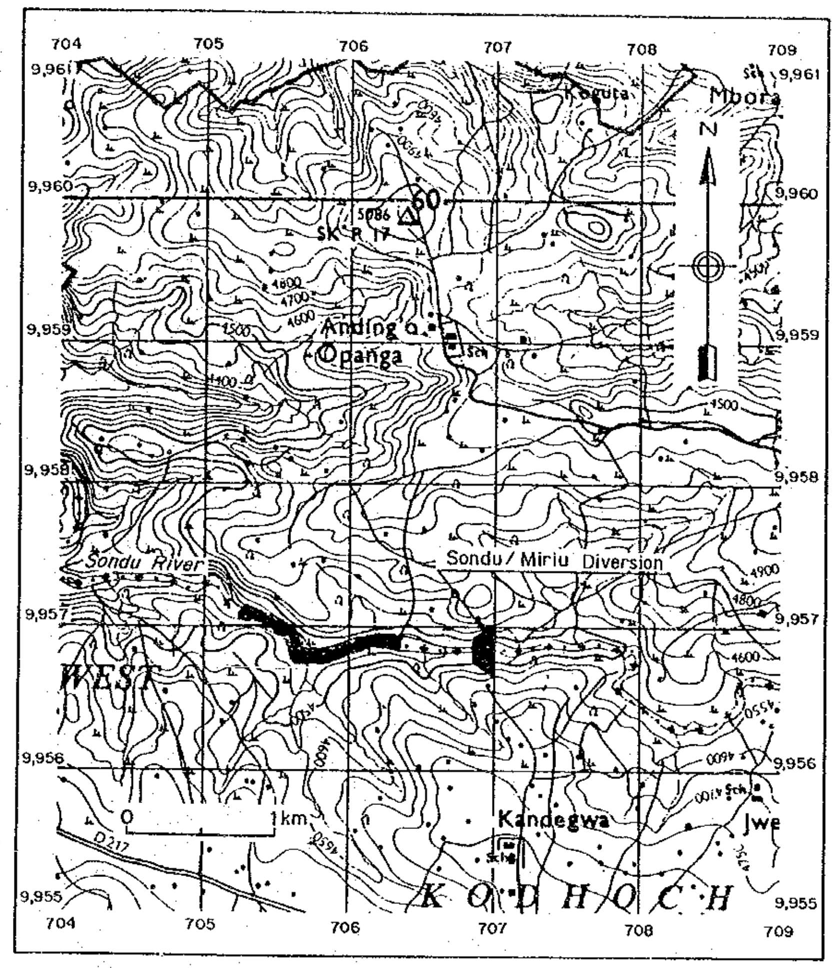




DIVERSION WEIR



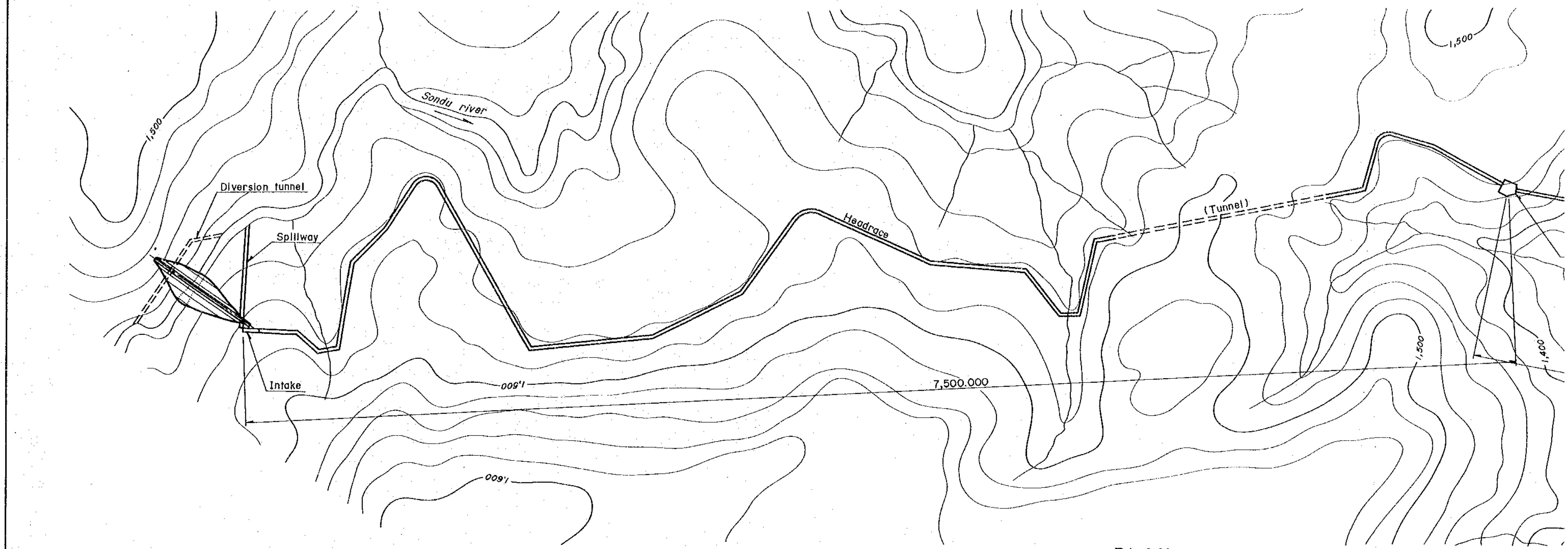
TYPICAL SECTION OF HEADRACE TUNNEL



KEY MAP

Figure 2.2 Sondu/Miriu Run-of-river Plan

REPUBLIC OF KENYA
SONDU RIVER
MULTIPURPOSE DEVELOPMENT PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY



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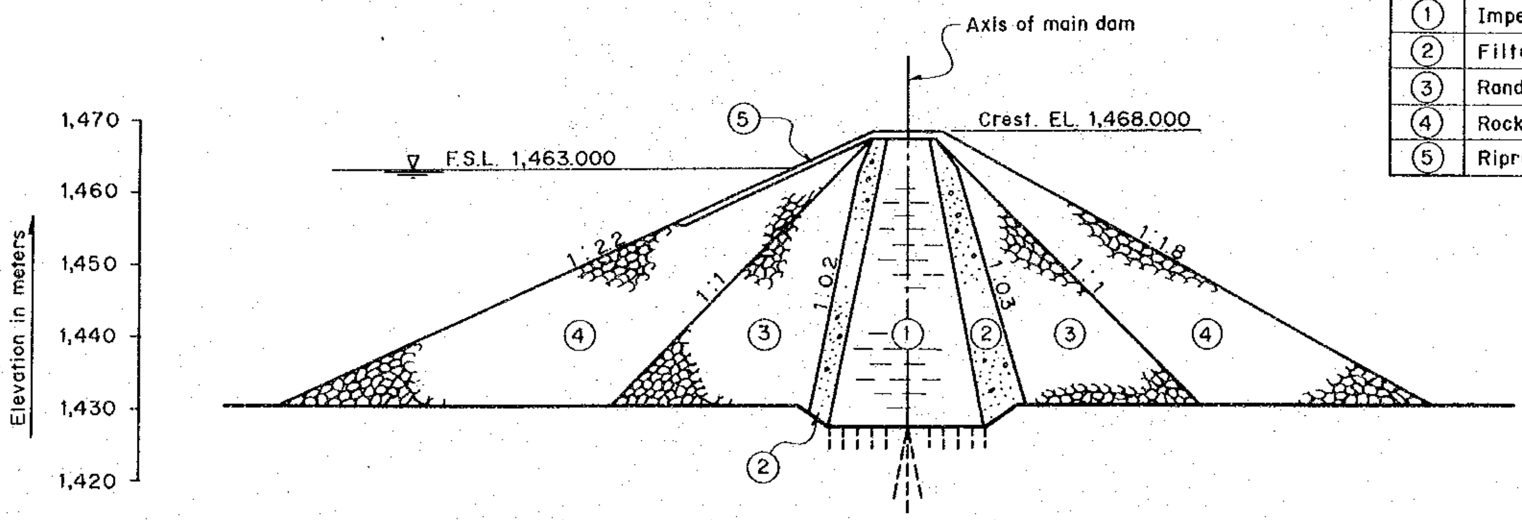
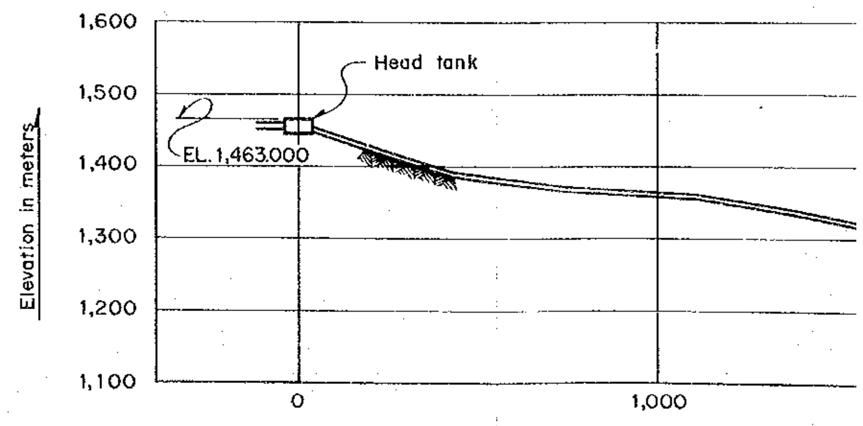


TYPICAL SECTION OF NYAMARIMBA DIVERSION DAM

Zone	Material
①	Impervious core
②	Filter
③	Random material
④	Rock
⑤	Riprap



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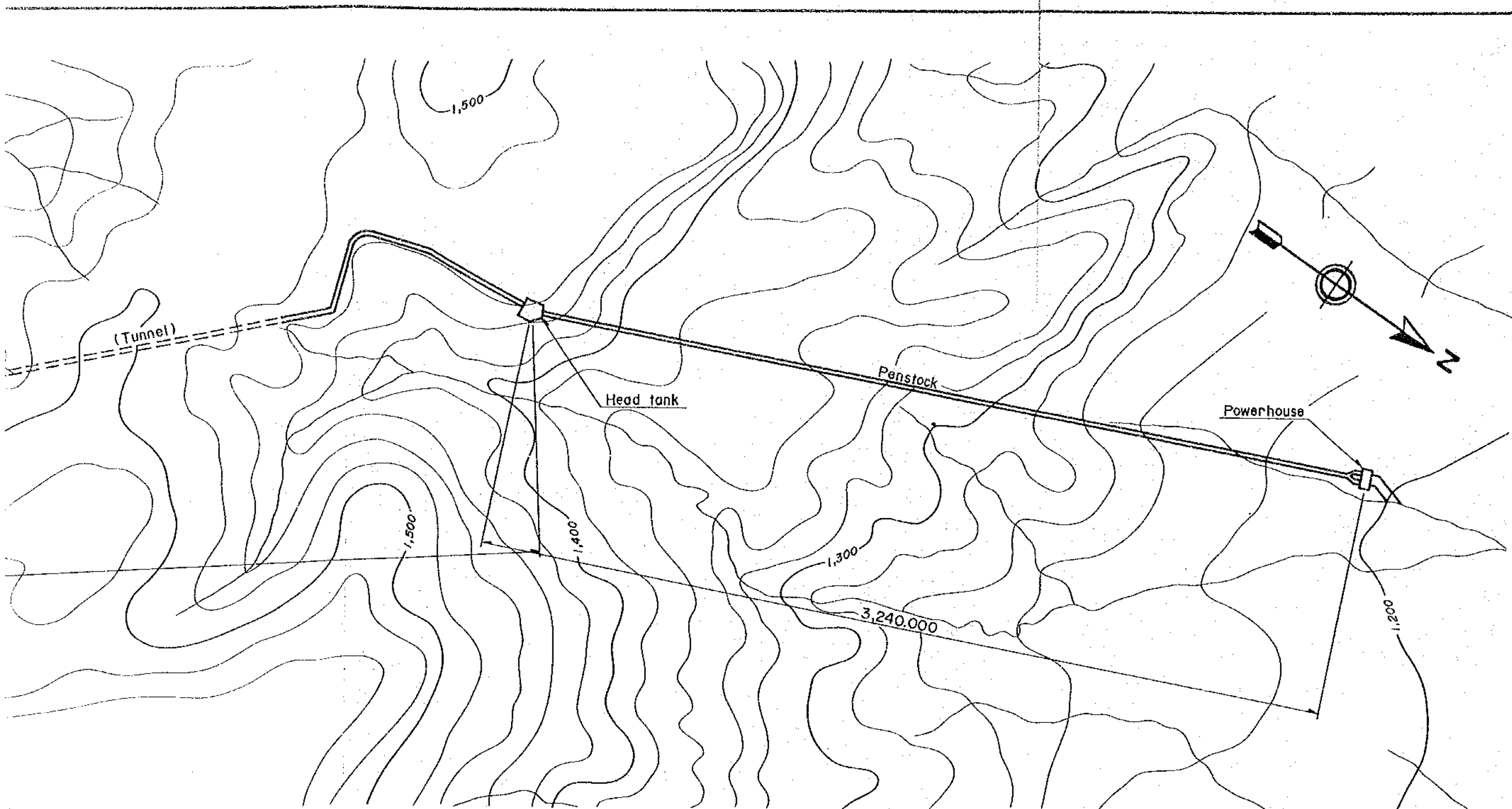

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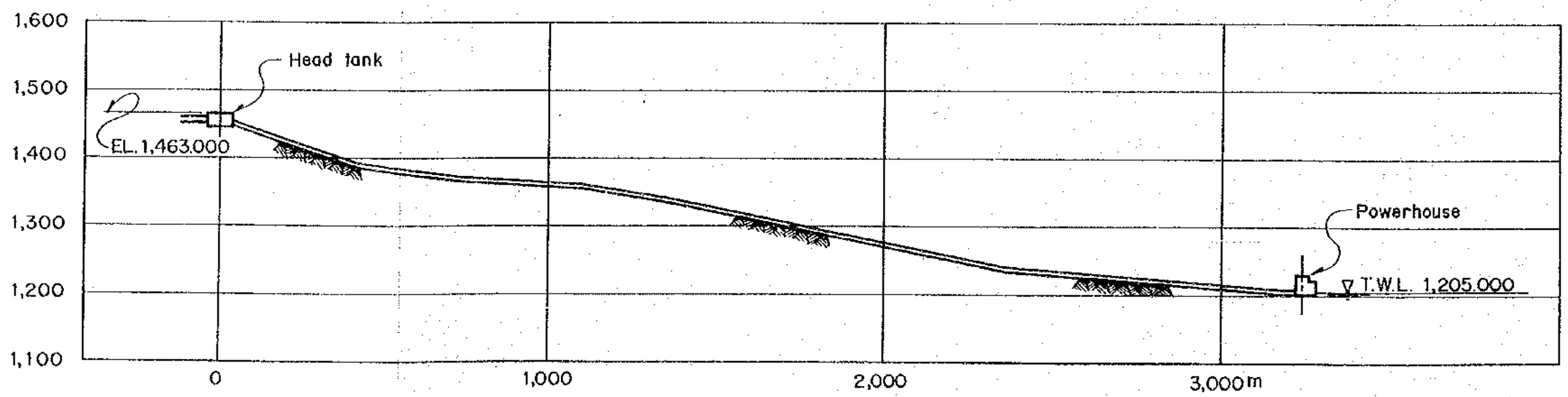

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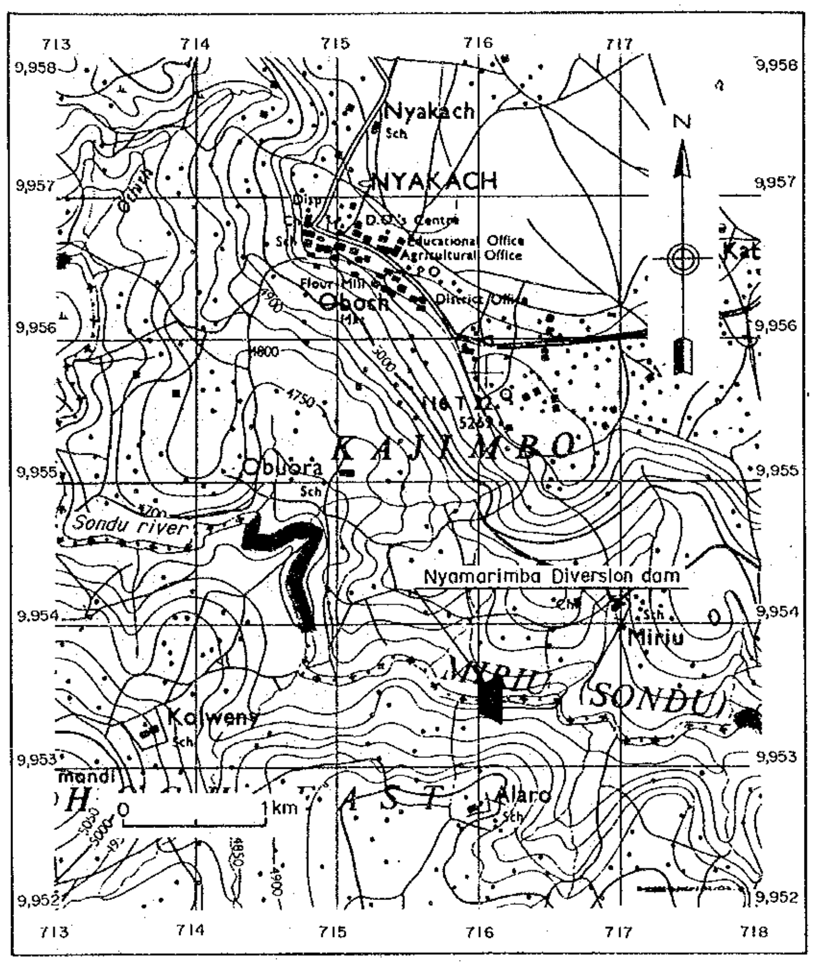
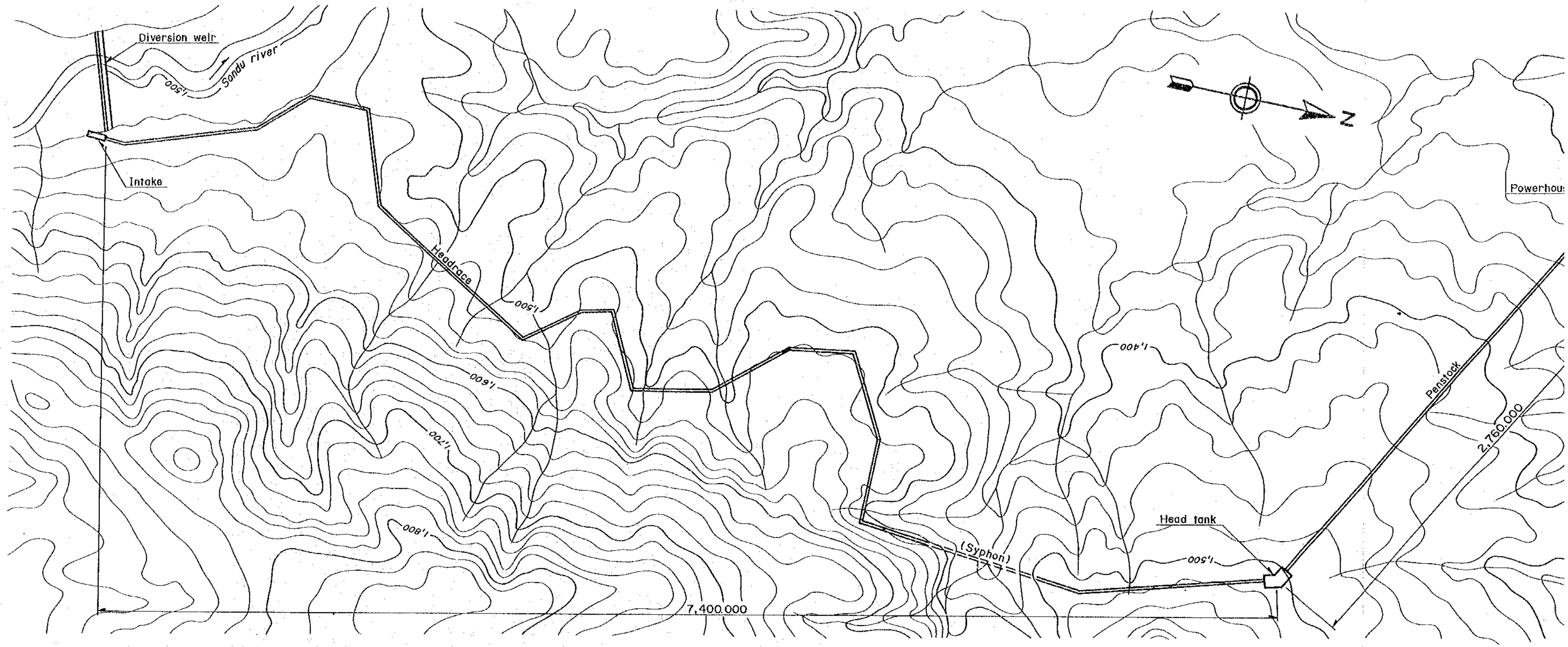


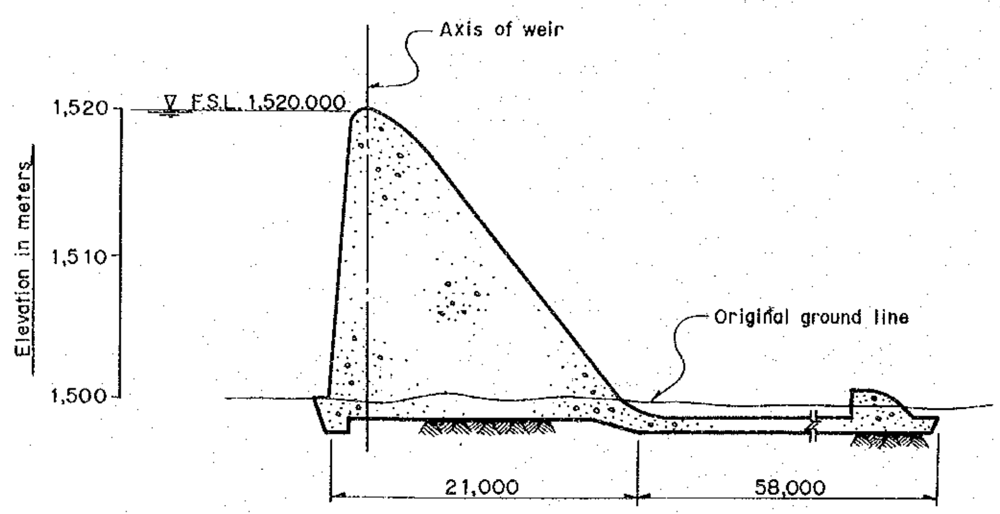
KEY MAP

Figure 2.3 Nyamarimba Run-of-river Plan

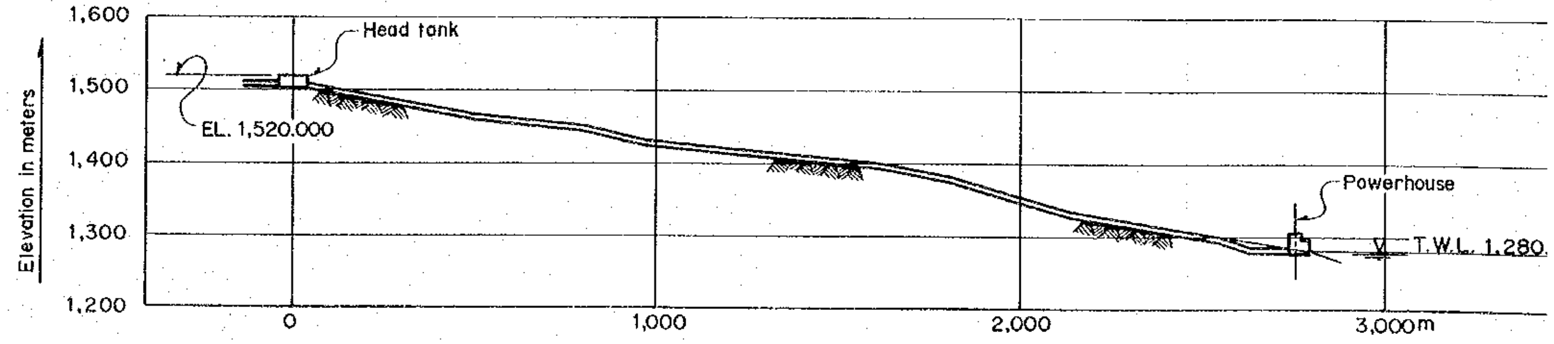
REPUBLIC OF KENYA
SONDU RIVER
MULTIPURPOSE DEVELOPMENT PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY



PLAN



DIVERSION WEIR



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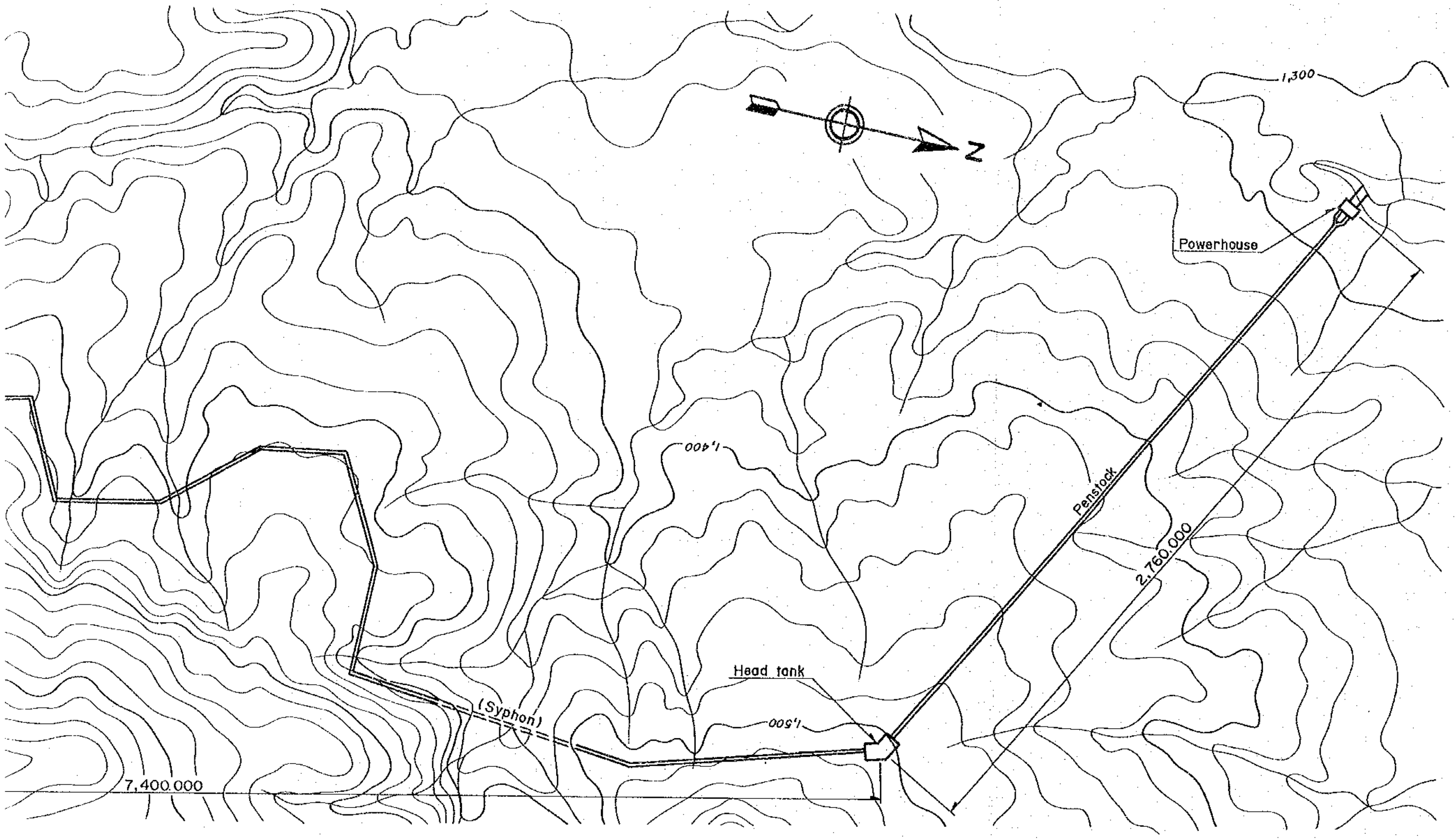
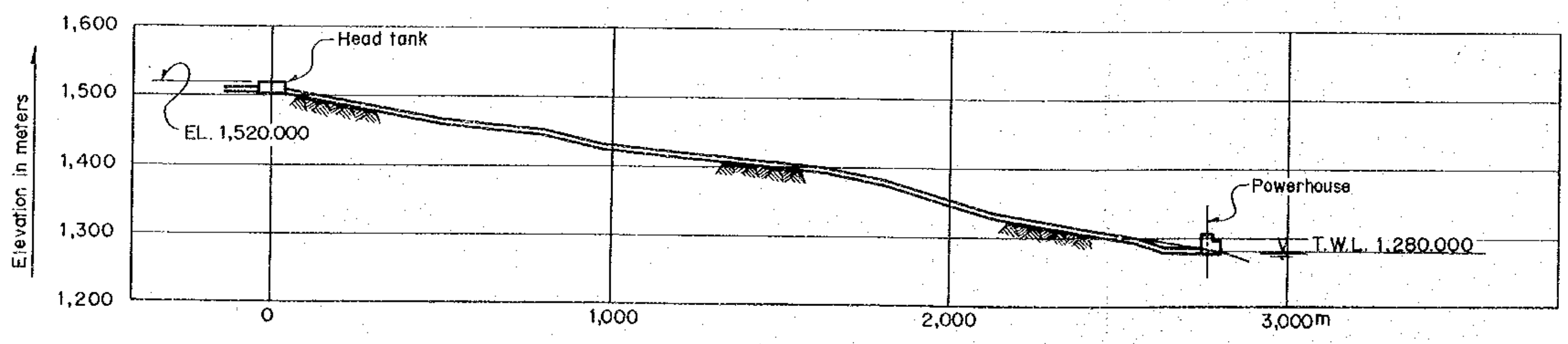
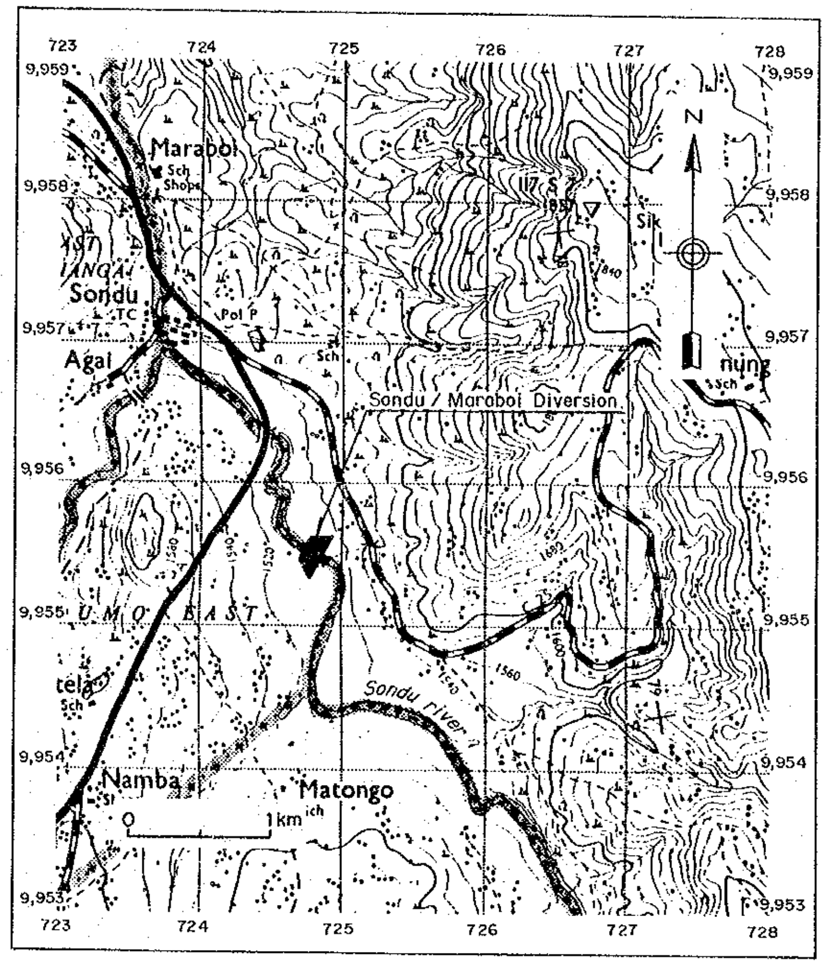


PLAN



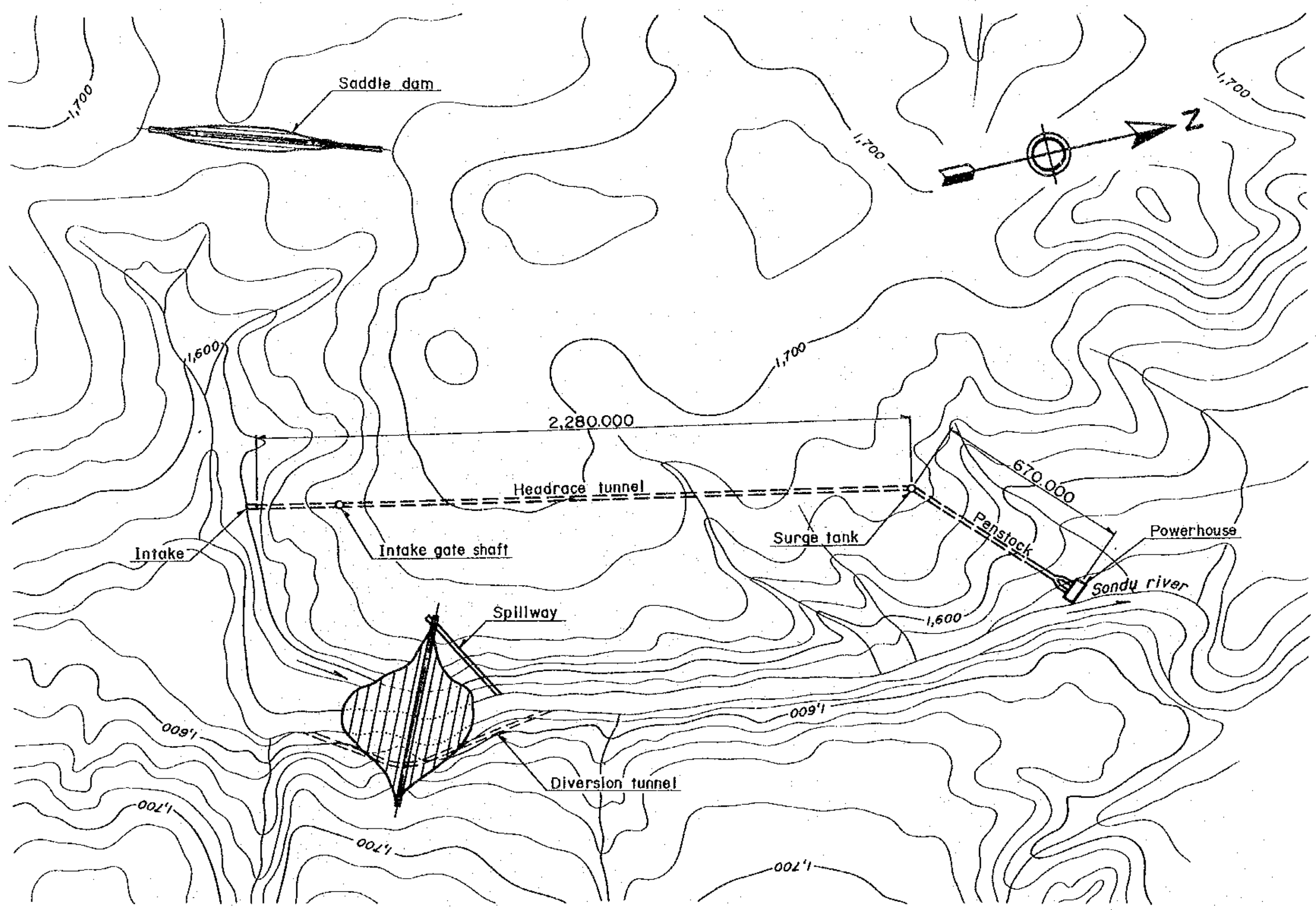
PROFILE



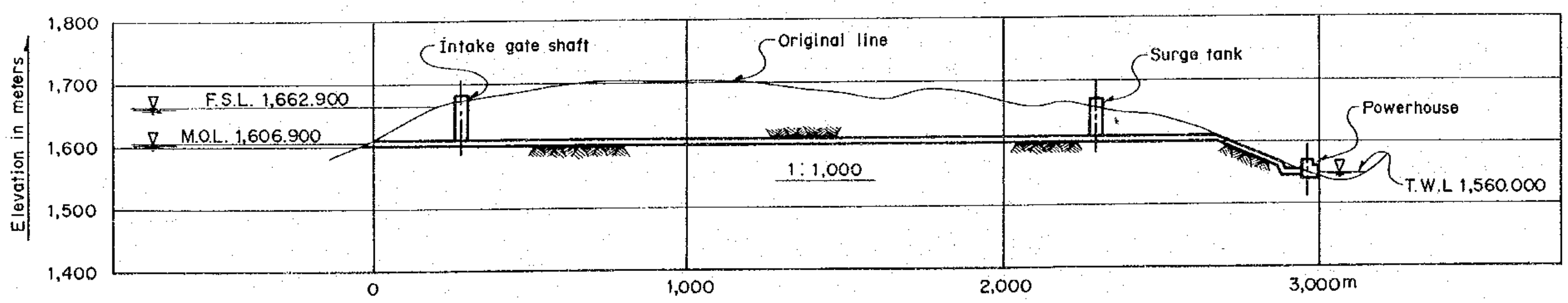
KEY MAP

Figure 2.4 Sondu/Maraboi Run-of-river Plan

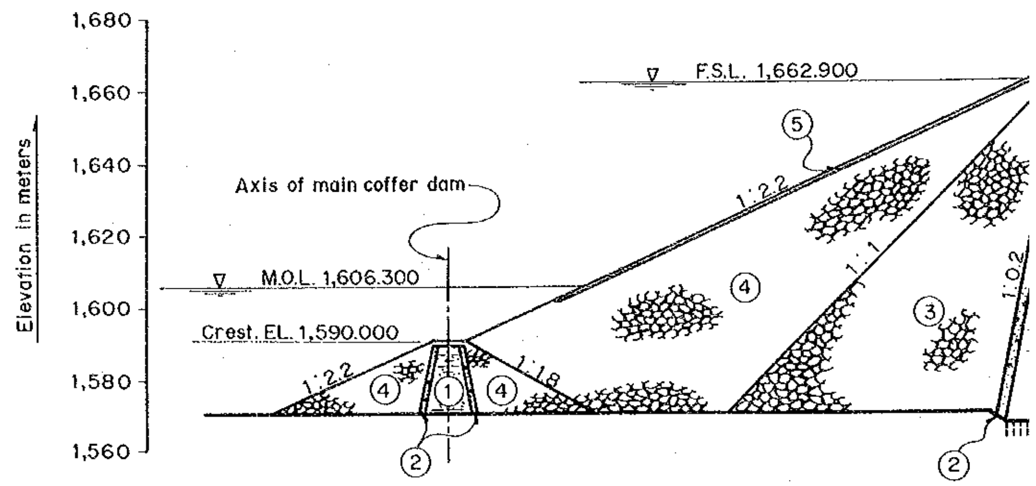
REPUBLIC OF KENYA
SONDU RIVER
MULTIPURPOSE DEVELOPMENT PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY



PLAN

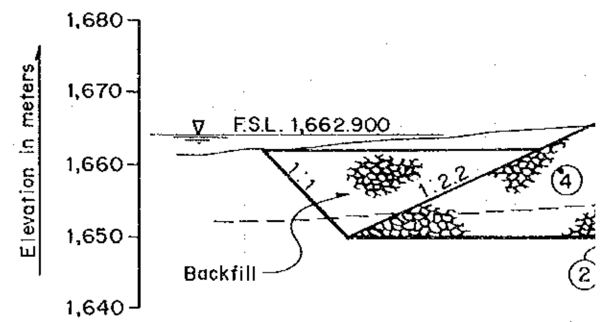


PROFILE

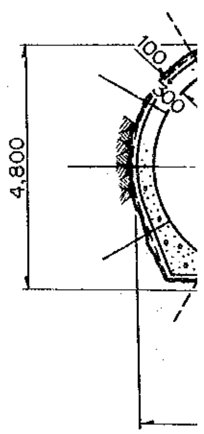


TYPICAL SECTION OF

Zone	Material
(1)	Impervious core
(2)	Filter
(3)	Random material
(4)	Rock
(5)	Riprap

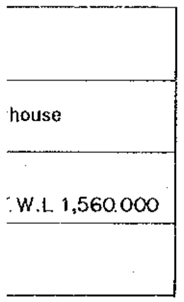


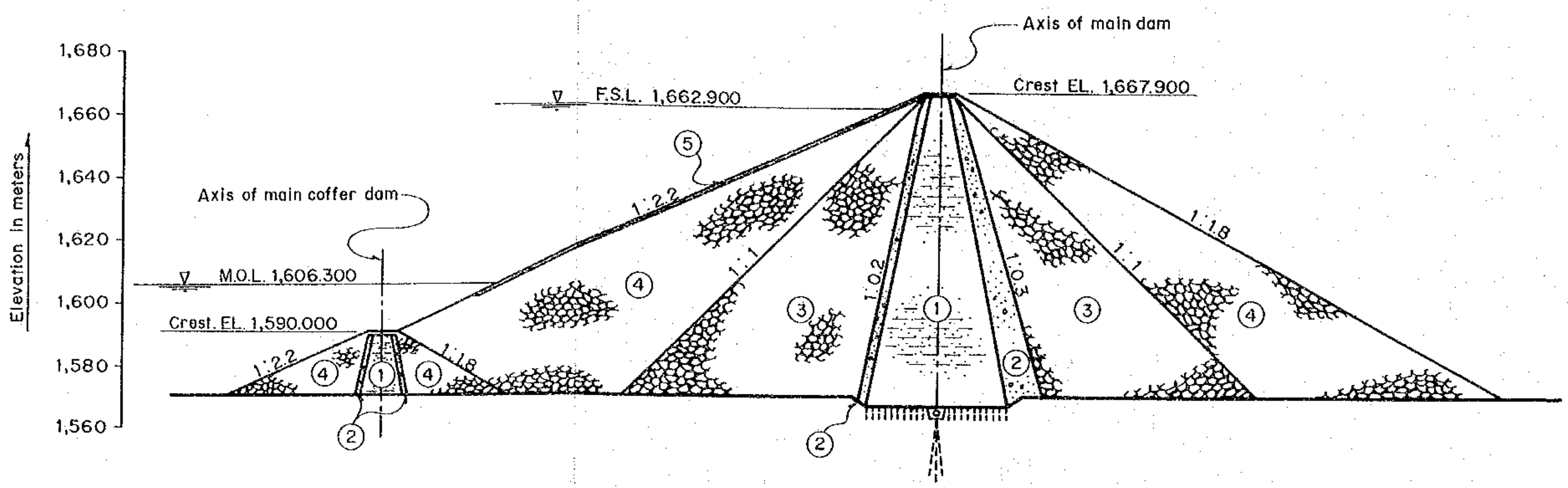
TYPICAL SECT



TYPE

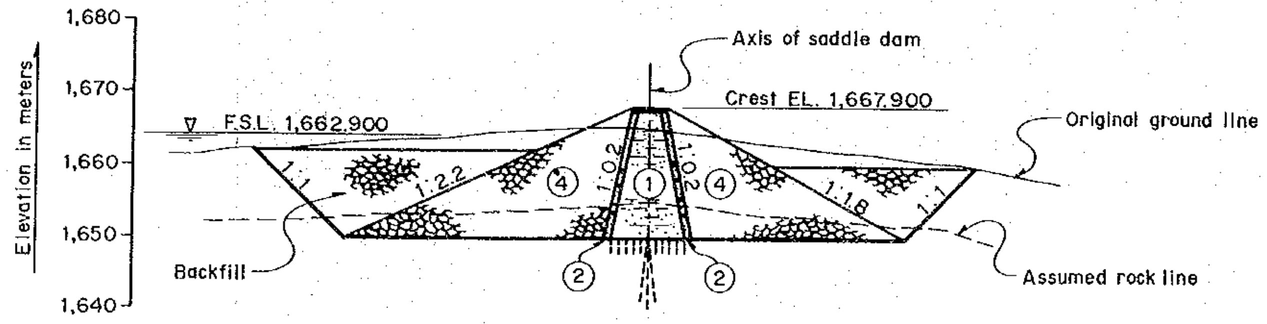
TYPIC
HEA



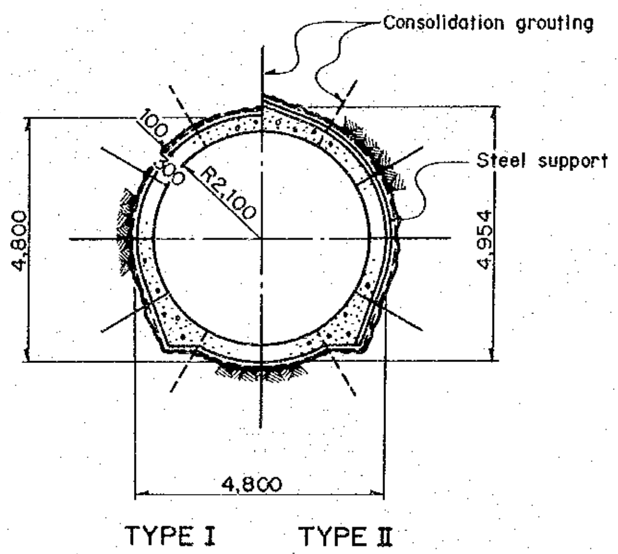


TYPICAL SECTION OF MAGWAGWA DAM

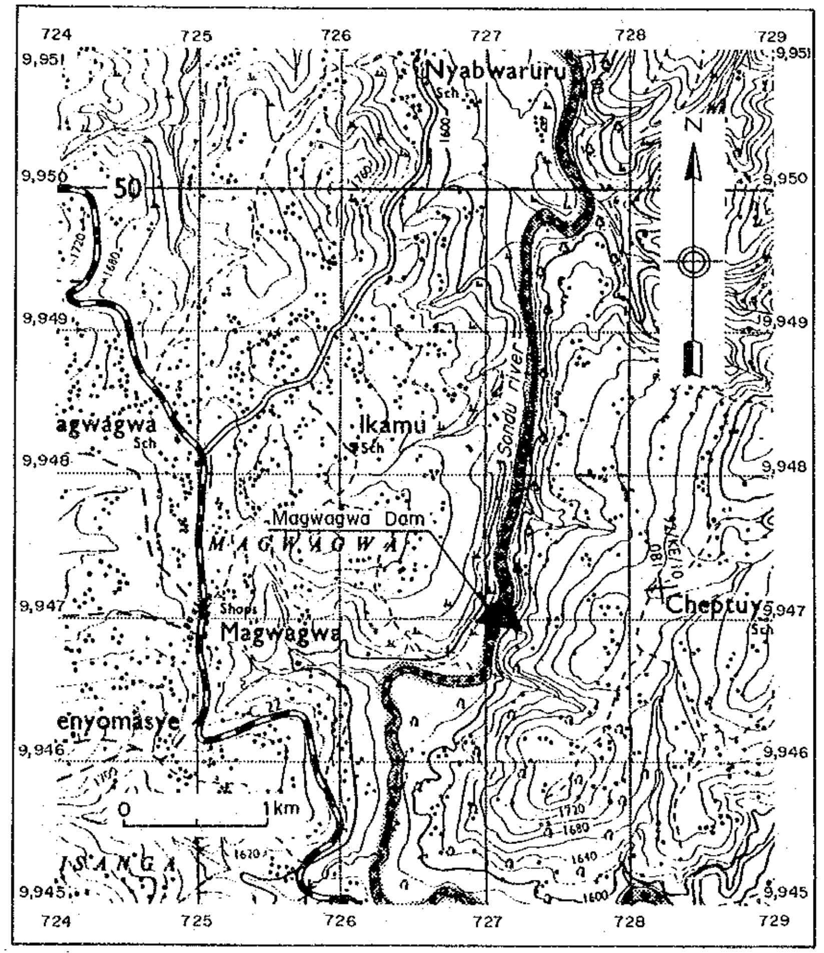
Zone	Material
1	Impervious core
2	Filter
3	Random material
4	Rock
5	Riprap



TYPICAL SECTION OF SADDLE DAM



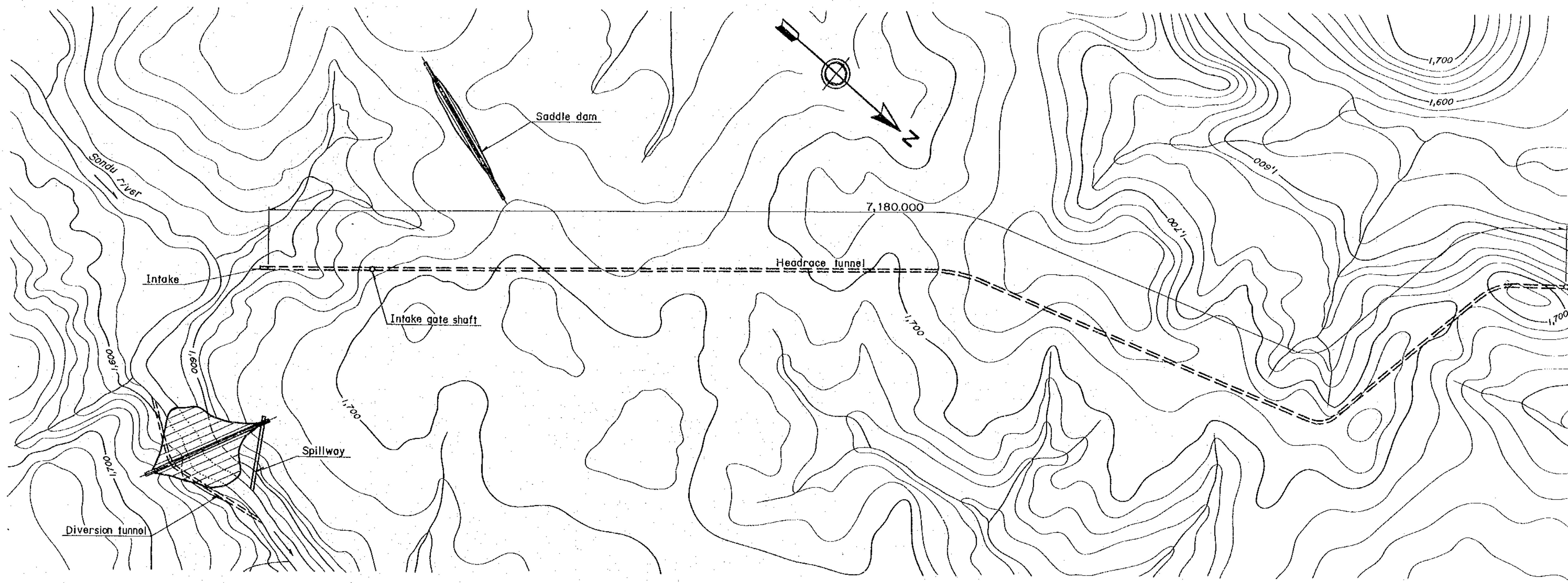
TYPICAL SECTION OF HEADRACE TUNNEL



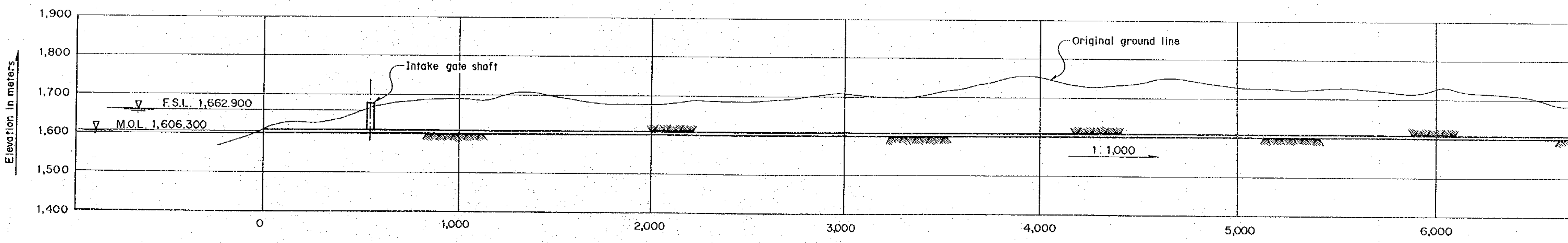
KEY MAP

Figure 2.5 Magwagwa Reservoir Plan

REPUBLIC OF KENYA
SONDU RIVER
MULTIPURPOSE DEVELOPMENT PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY



PLAN



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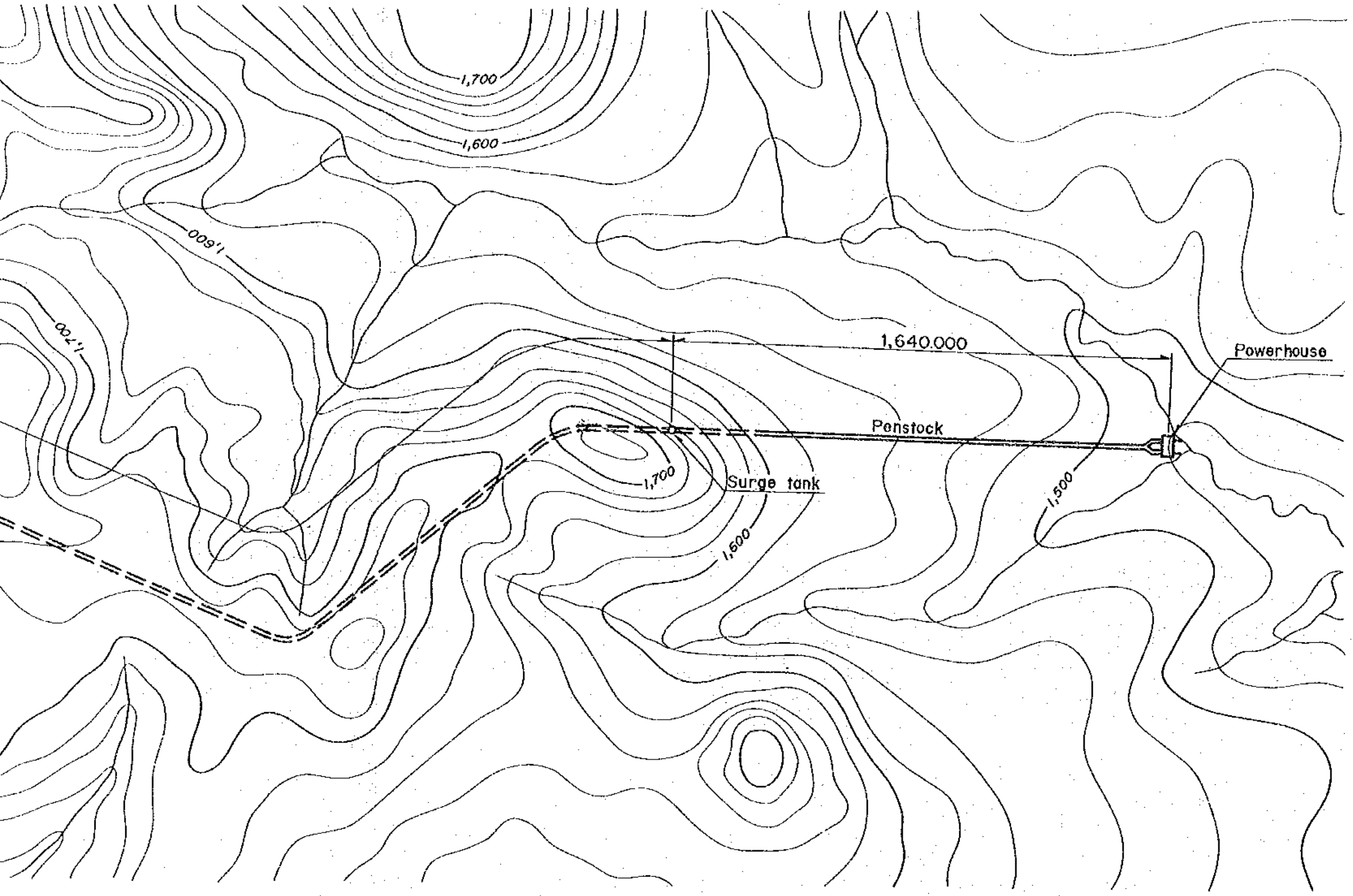
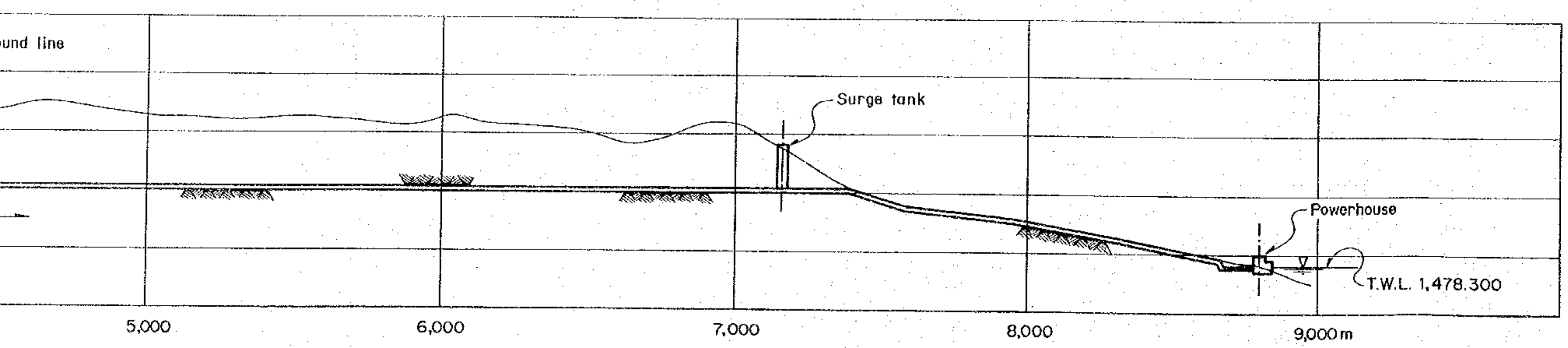
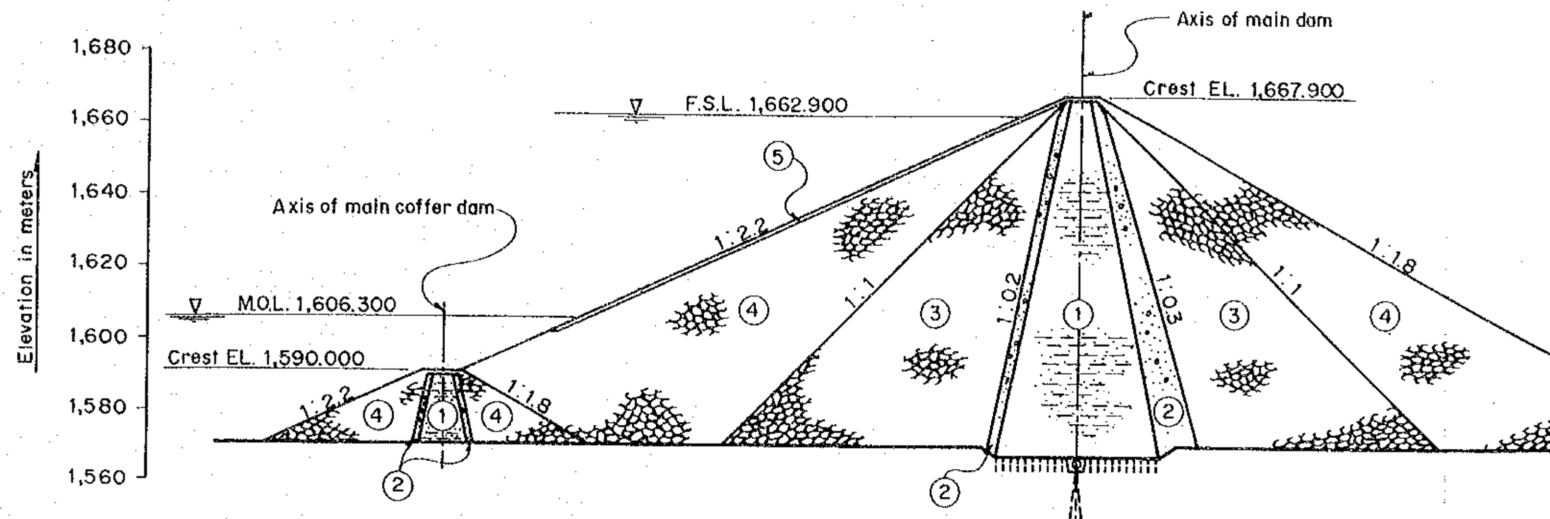
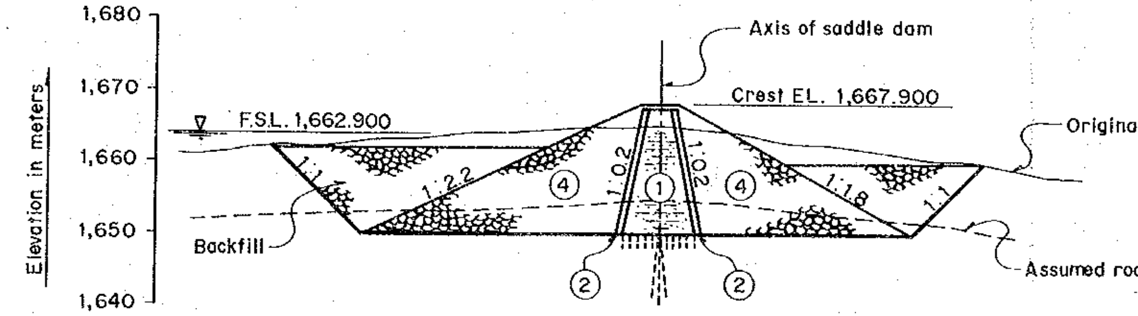




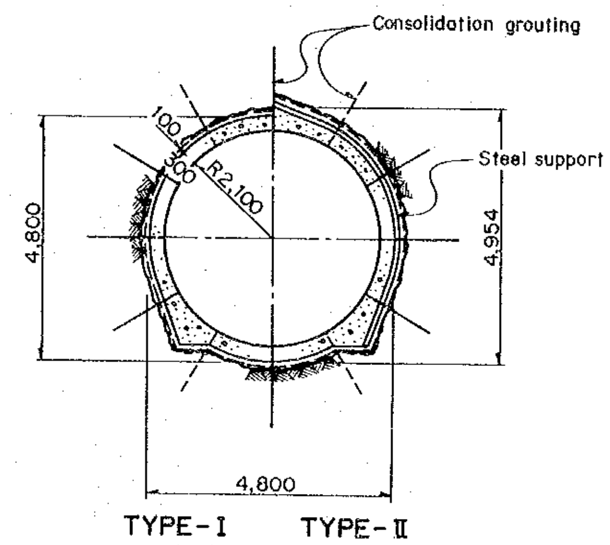


TYPICAL SECTION OF MAGWAGWA DAM

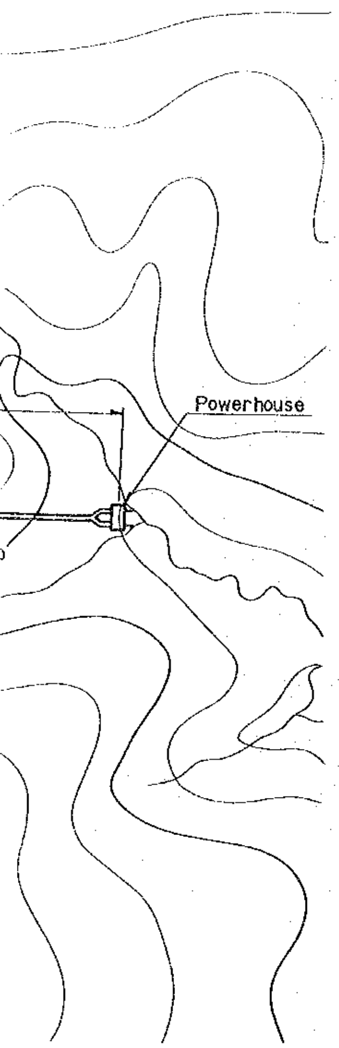
Zone	Material
①	Impervious core
②	Filter
③	Random material
④	Rock
⑤	Riprap

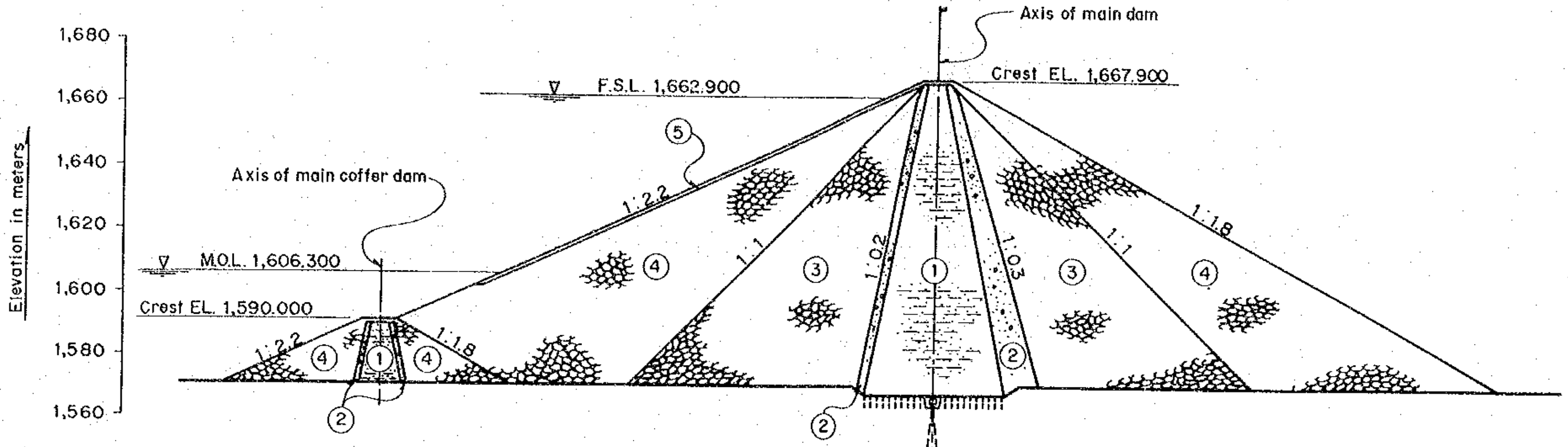


TYPICAL SECTION OF SADDLE DAM



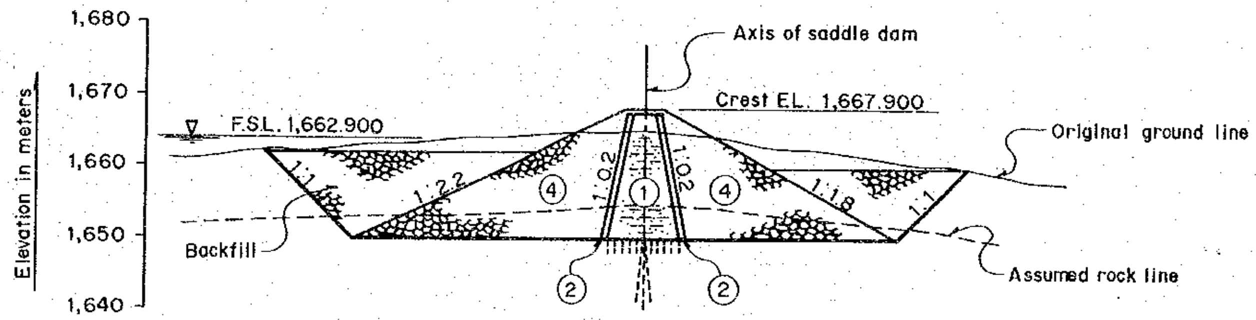
TYPICAL SECTION OF HEADRACE TUNNEL



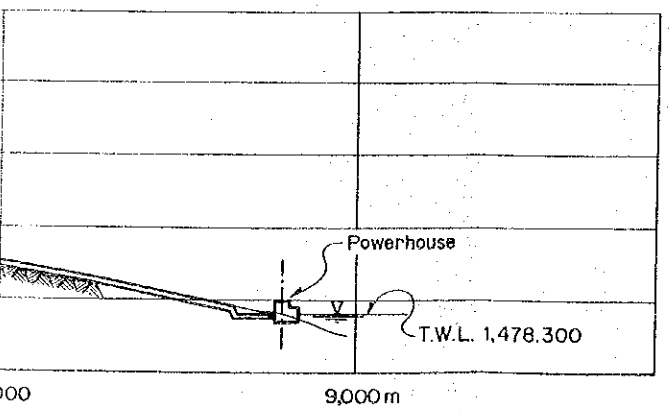


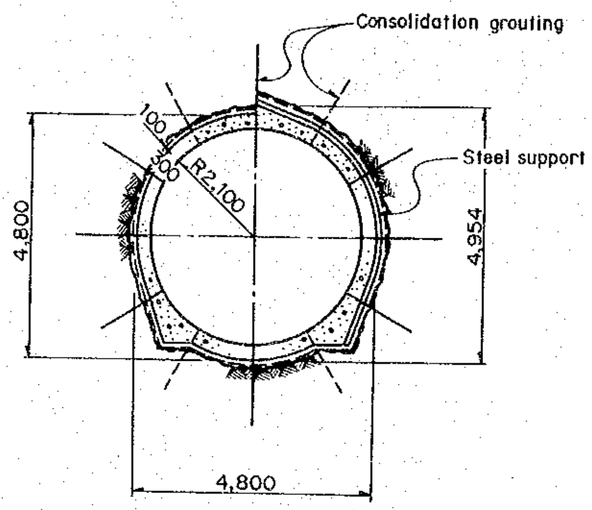
TYPICAL SECTION OF MAGWAGWA DAM

Zone	Material
①	Impervious core
②	Filter
③	Random material
④	Rock
⑤	Riprap

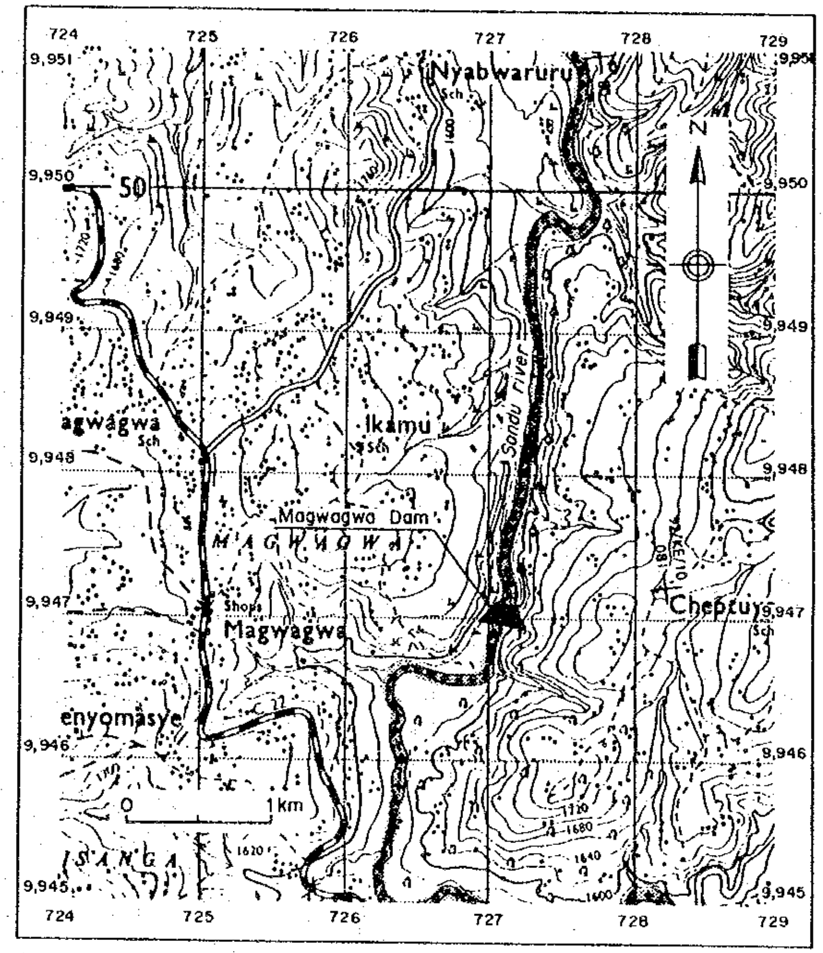


TYPICAL SECTION OF SADDLE DAM





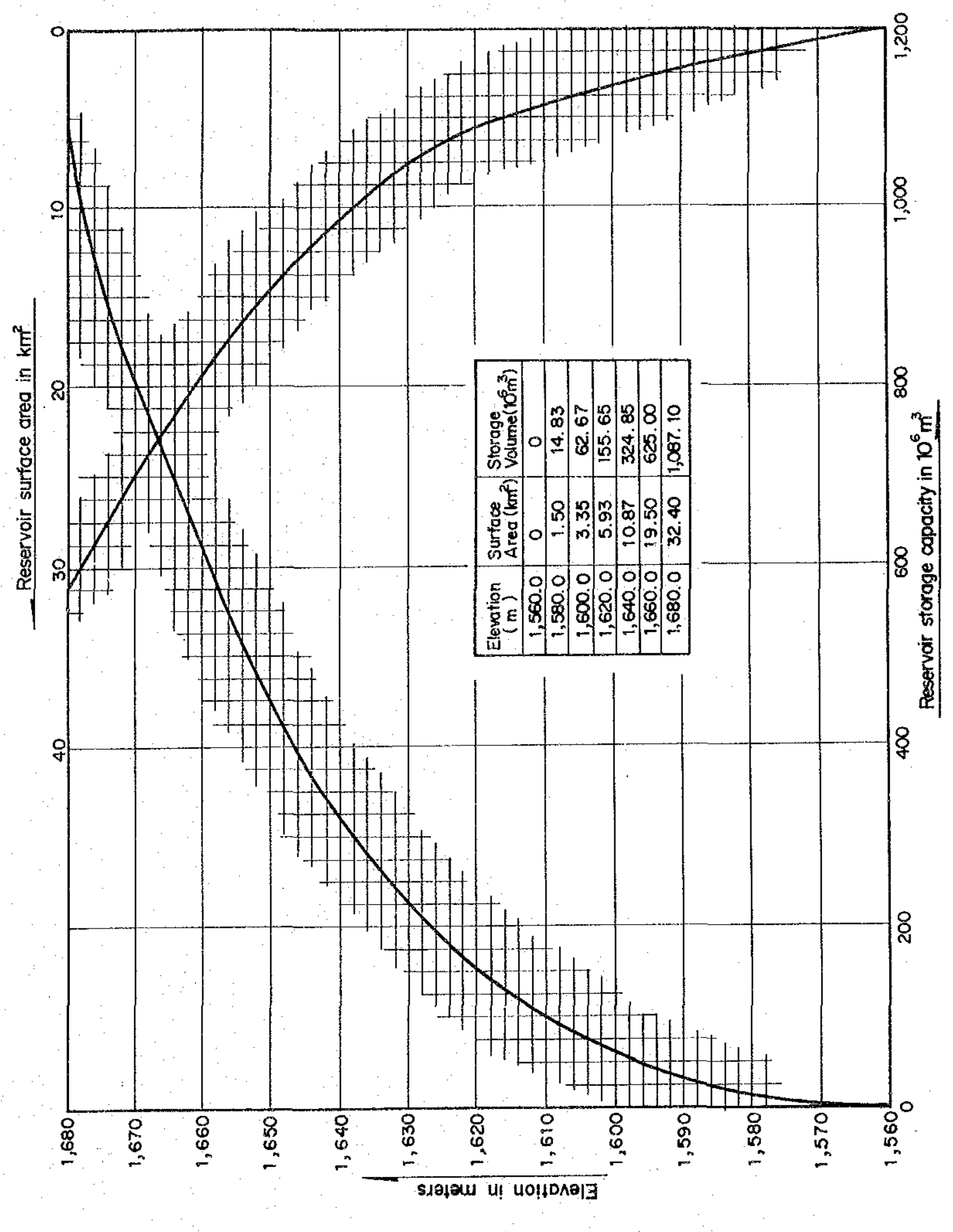
TYPICAL SECTION OF HEADRACE TUNNEL



KEY MAP

Figure 2.6 Magwagwa Reservoir plus Waterway Plan

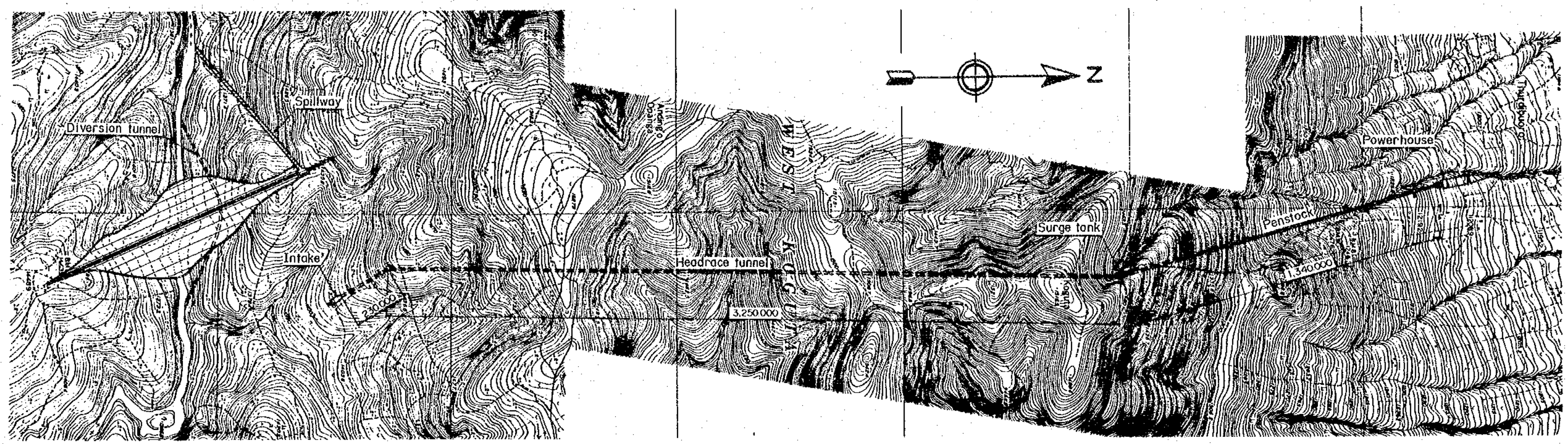
REPUBLIC OF KENYA
SONDU RIVER
MULTIPURPOSE DEVELOPMENT PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY



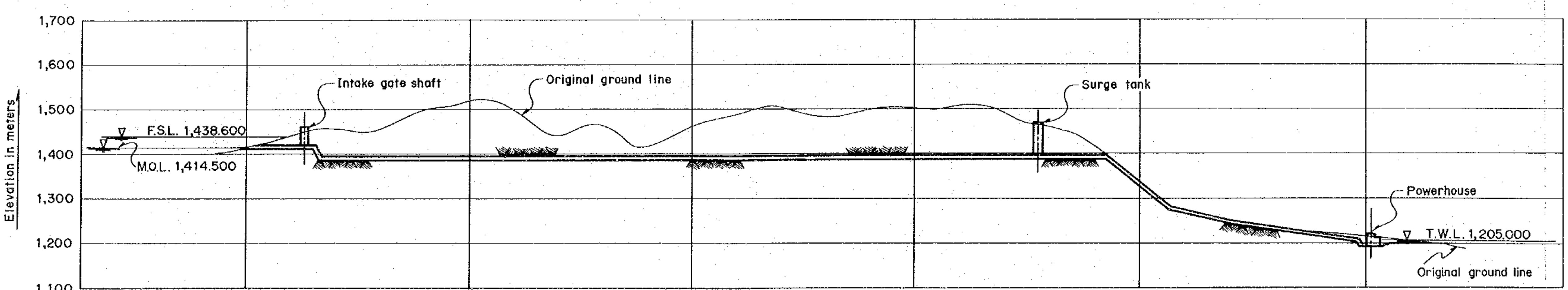
Elevation (m)	Surface Area (km²)	Storage Volume ($10^6 m^3$)
1,560.0	0	0
1,580.0	1.50	14.83
1,600.0	3.35	62.67
1,620.0	5.93	155.65
1,640.0	10.87	324.85
1,660.0	19.50	625.00
1,680.0	32.40	1,087.10

Figure 2.7 Area-Storage Curves of Magwagwa Reservoir

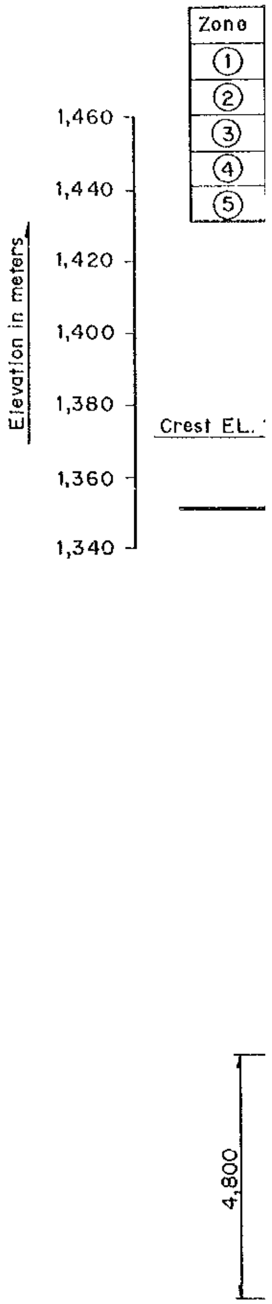
REPUBLIC OF KENYA
SONDU RIVER
MULTIPURPOSE DEVELOPMENT PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY

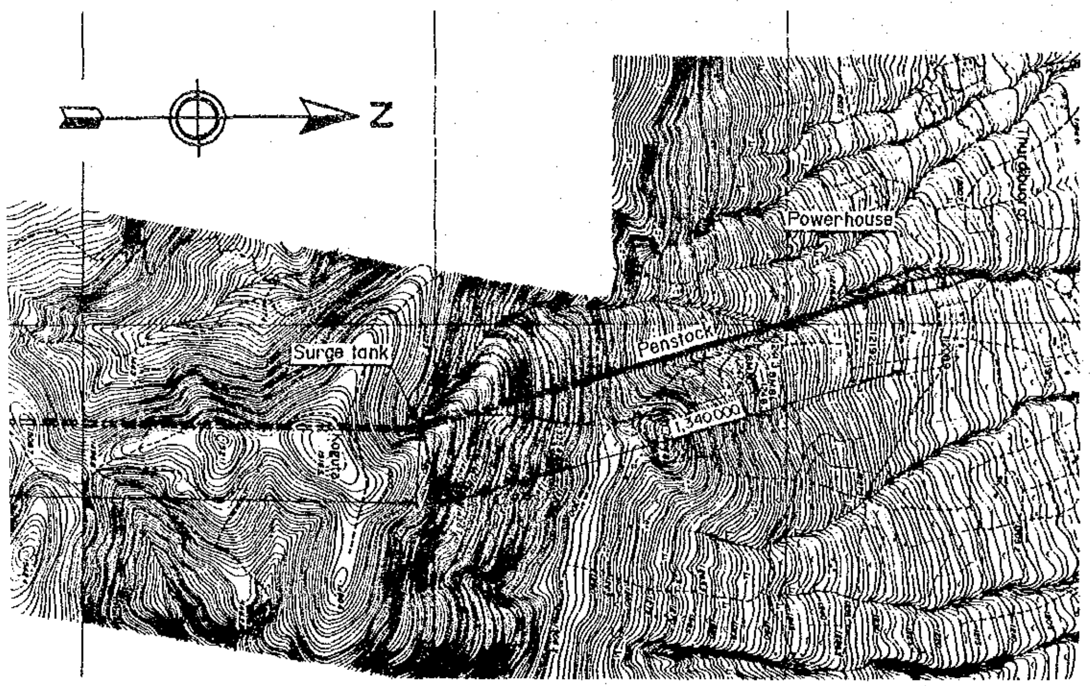


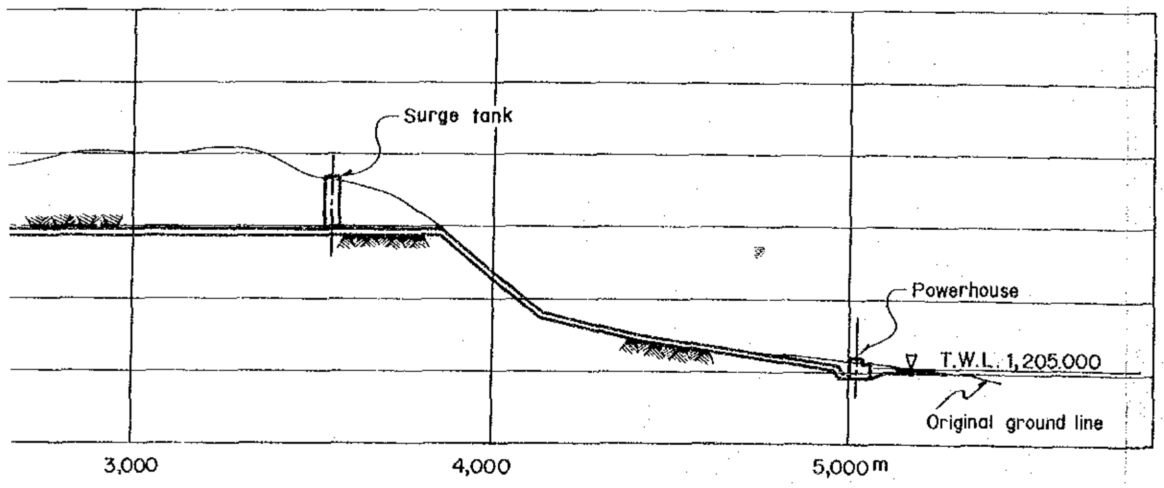
PLAN

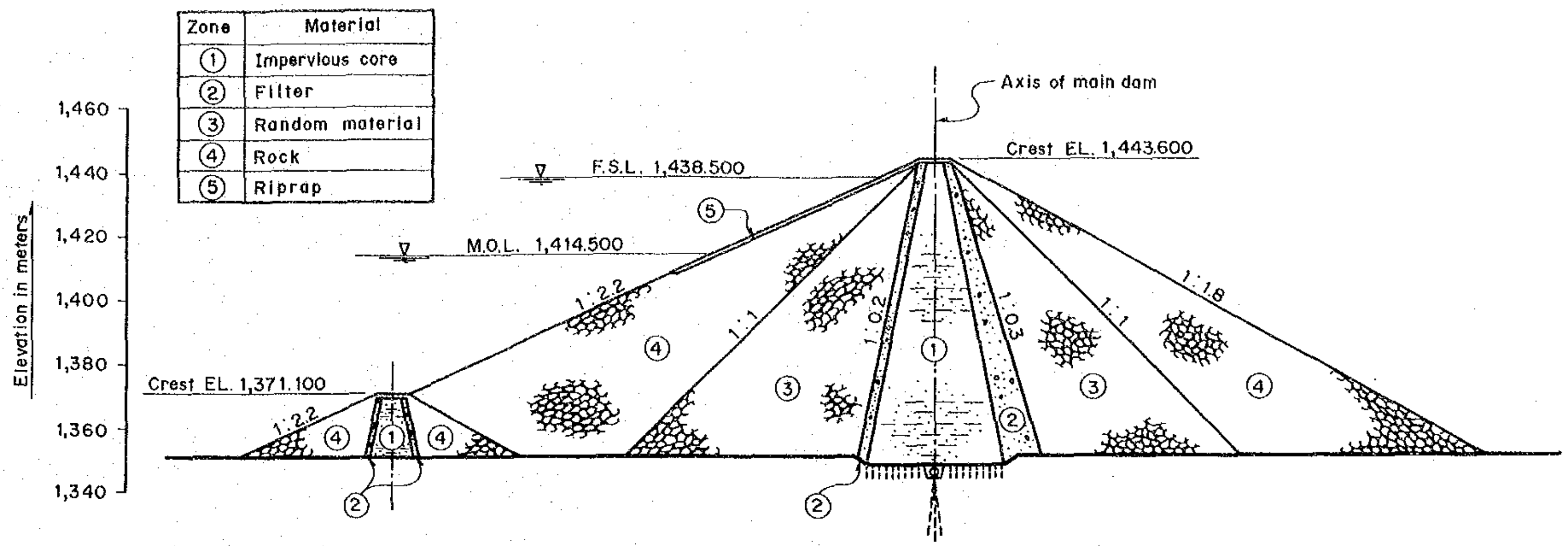


PROFILE

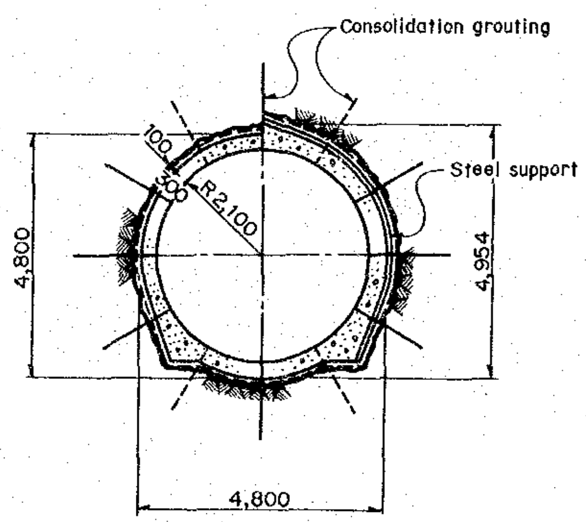






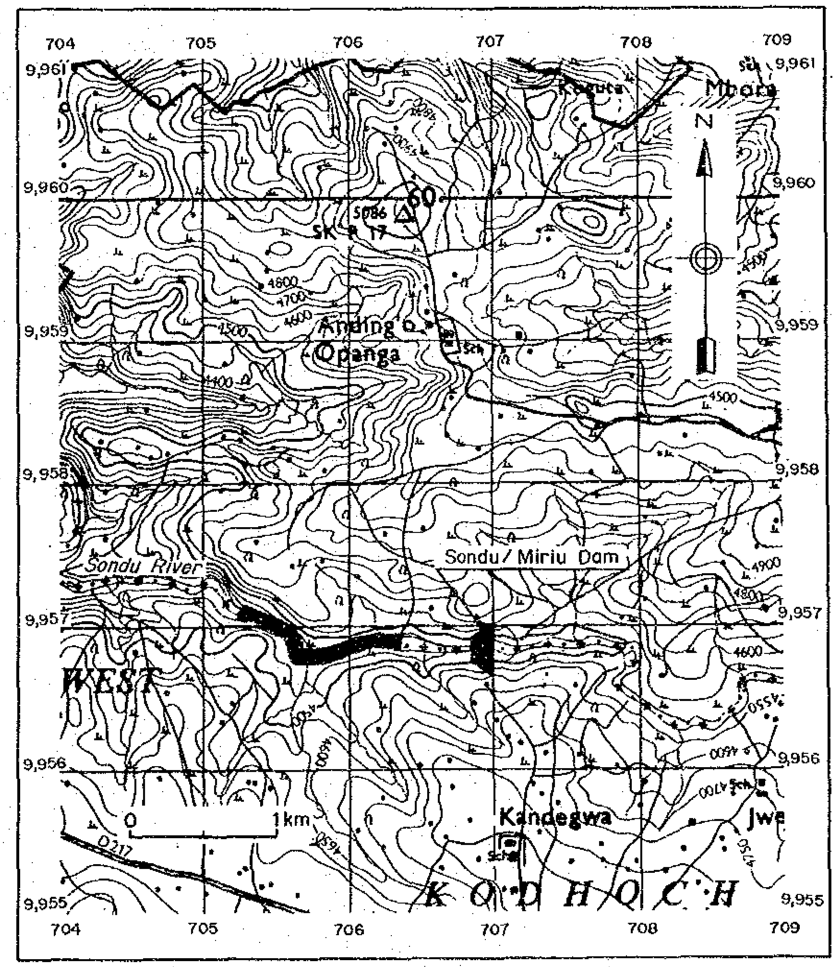


TYPICAL SECTION OF SONDU / MIRIU DAM



TYPE I TYPE II

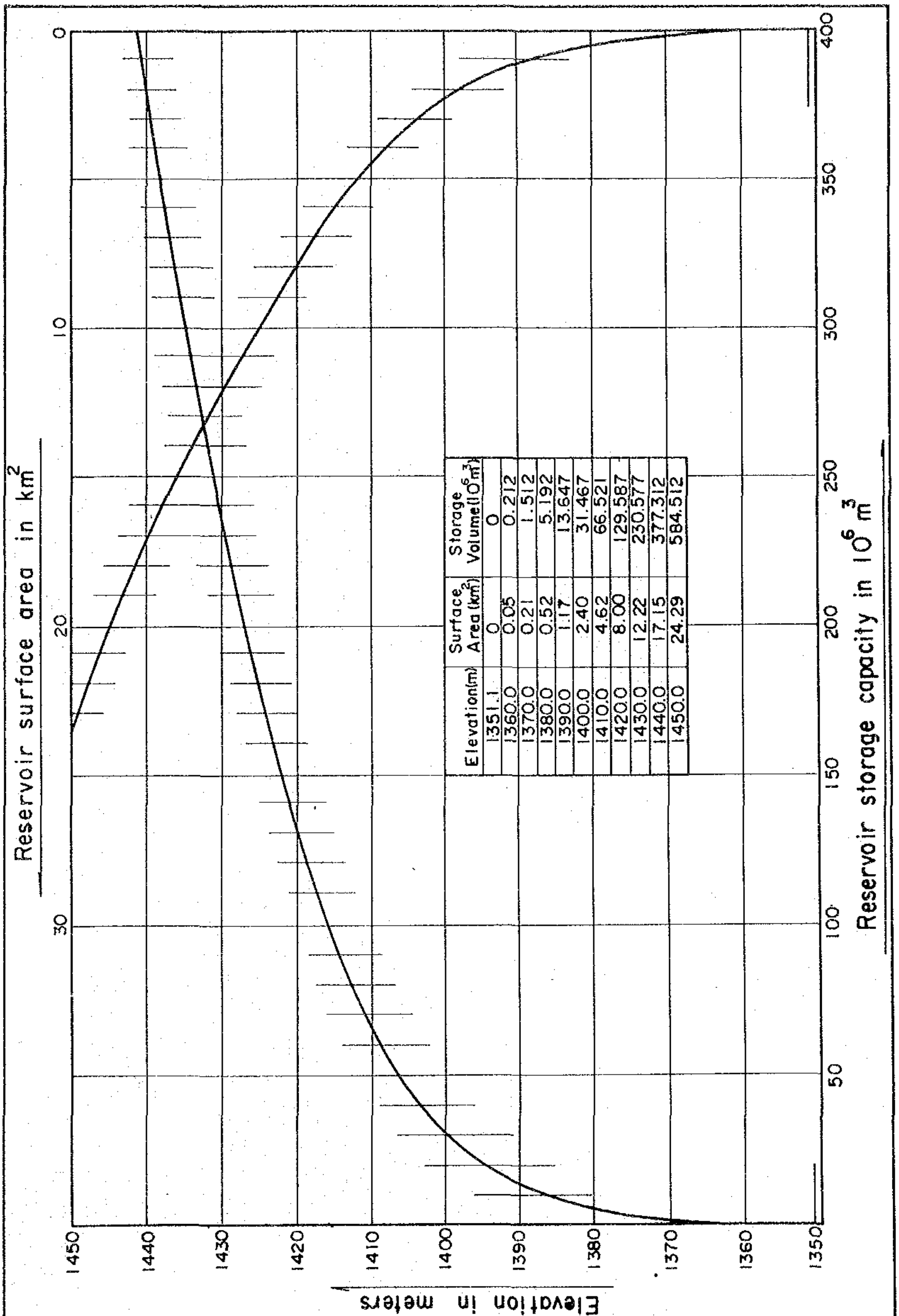
TYPICAL SECTION OF HEADRACE TUNNEL



KEY MAP

Figure 2.8
Sondu/Miriu
Reservoir Plan

REPUBLIC OF KENYA
SONDU RIVER
MULTIPURPOSE DEVELOPMENT PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY



Elevation(m)	Surface Area (km2)	Storage Volume (10^6 m3)
1351.1	0	0
1360.0	0.05	0.212
1370.0	0.21	1.512
1380.0	0.52	5.192
1390.0	1.17	13.647
1400.0	2.40	31.467
1410.0	4.62	66.521
1420.0	8.00	129.587
1430.0	12.22	230.577
1440.0	17.15	377.312
1450.0	24.29	584.512

Figure 2.9
Area-storage Curves of Sondu/Miriu Reservoir

REPUBLIC OF KENYA
SONDU RIVER
MULTIPURPOSE DEVELOPMENT PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY

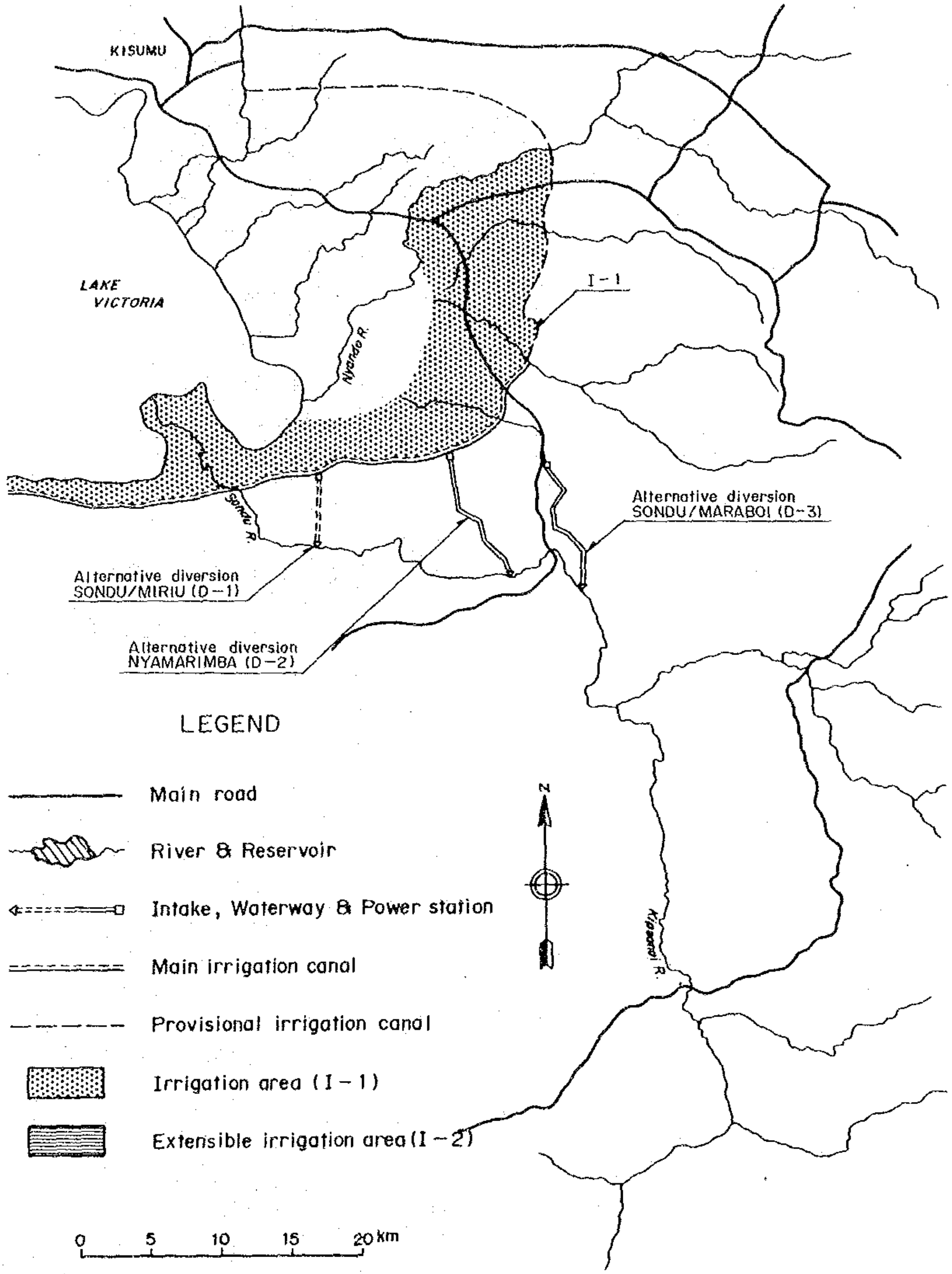


Figure 3.1-A.
Combination Plans for the Development of the Sondu River (Combination-A)

REPUBLIC OF KENYA
SONDU RIVER
MULTIPURPOSE DEVELOPMENT PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY

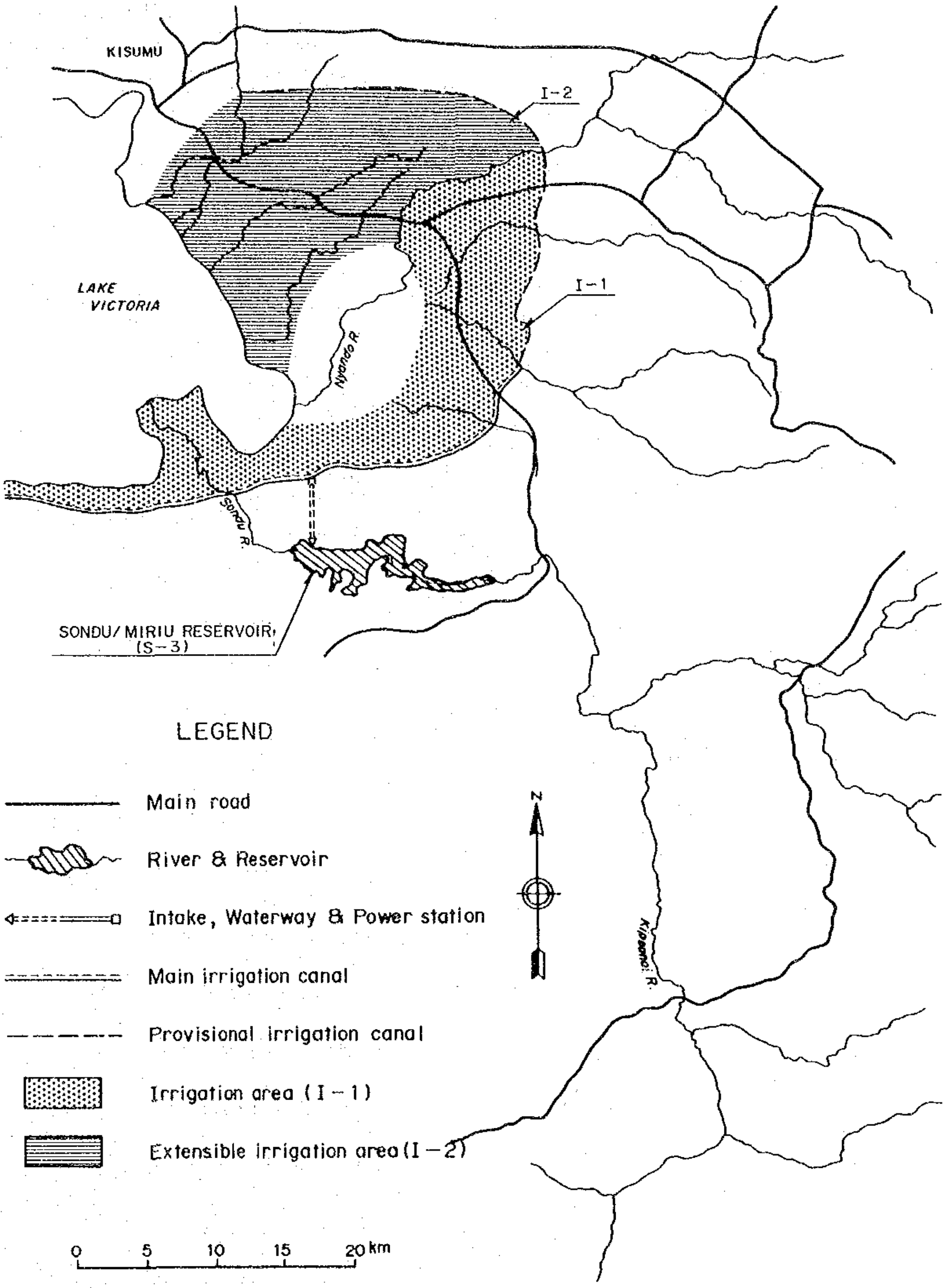


Figure 3.1-B
Combination Plans for the Development of the Sondu River (Combination-B)

REPUBLIC OF KENYA
SONDU RIVER
MULTIPURPOSE DEVELOPMENT PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY

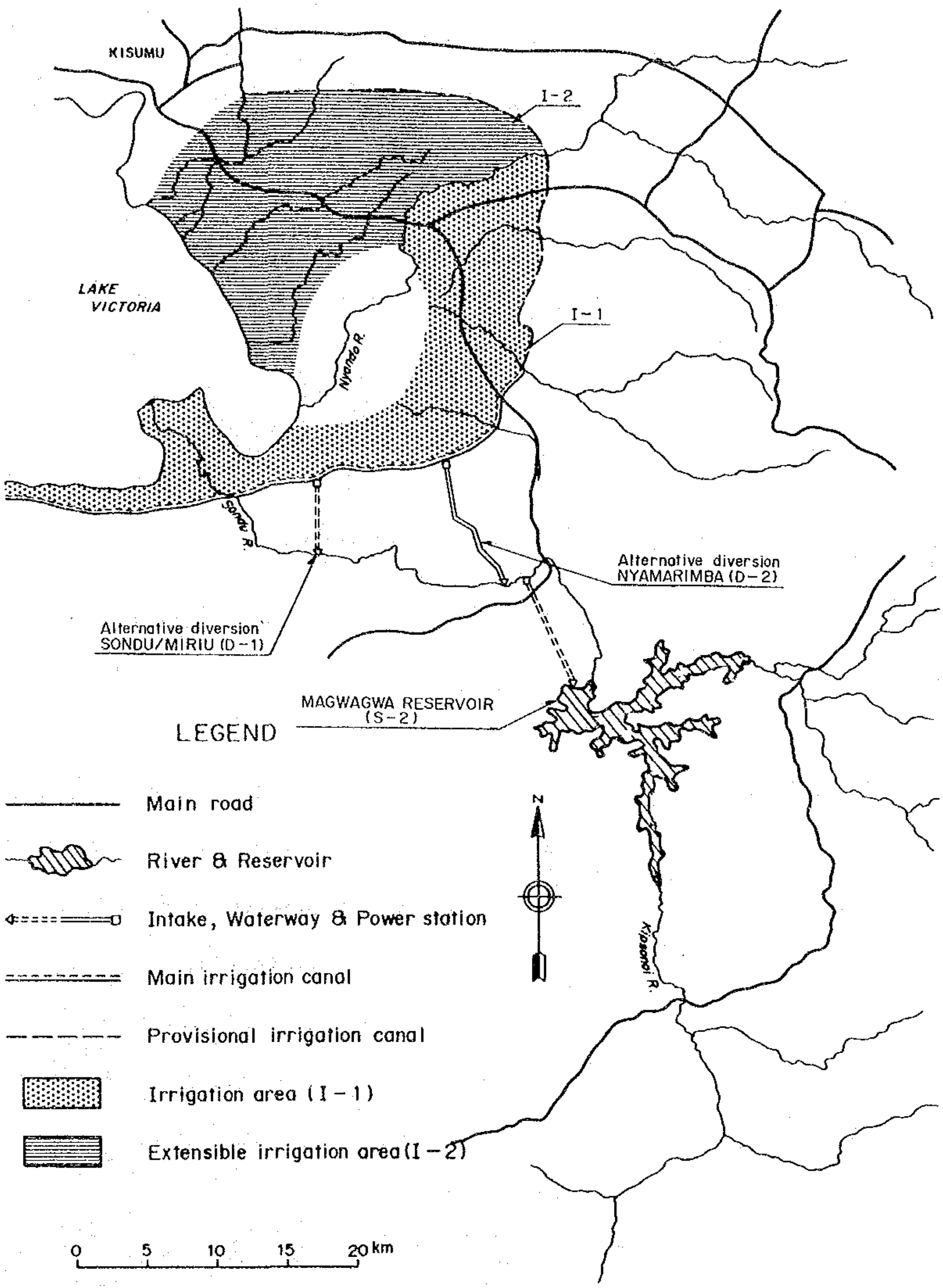


Figure 3.1-C
Combination Plans for the Development of the Sondu River (Combination-C)

REPUBLIC OF KENYA
SONDU RIVER
MULTIPURPOSE DEVELOPMENT PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY

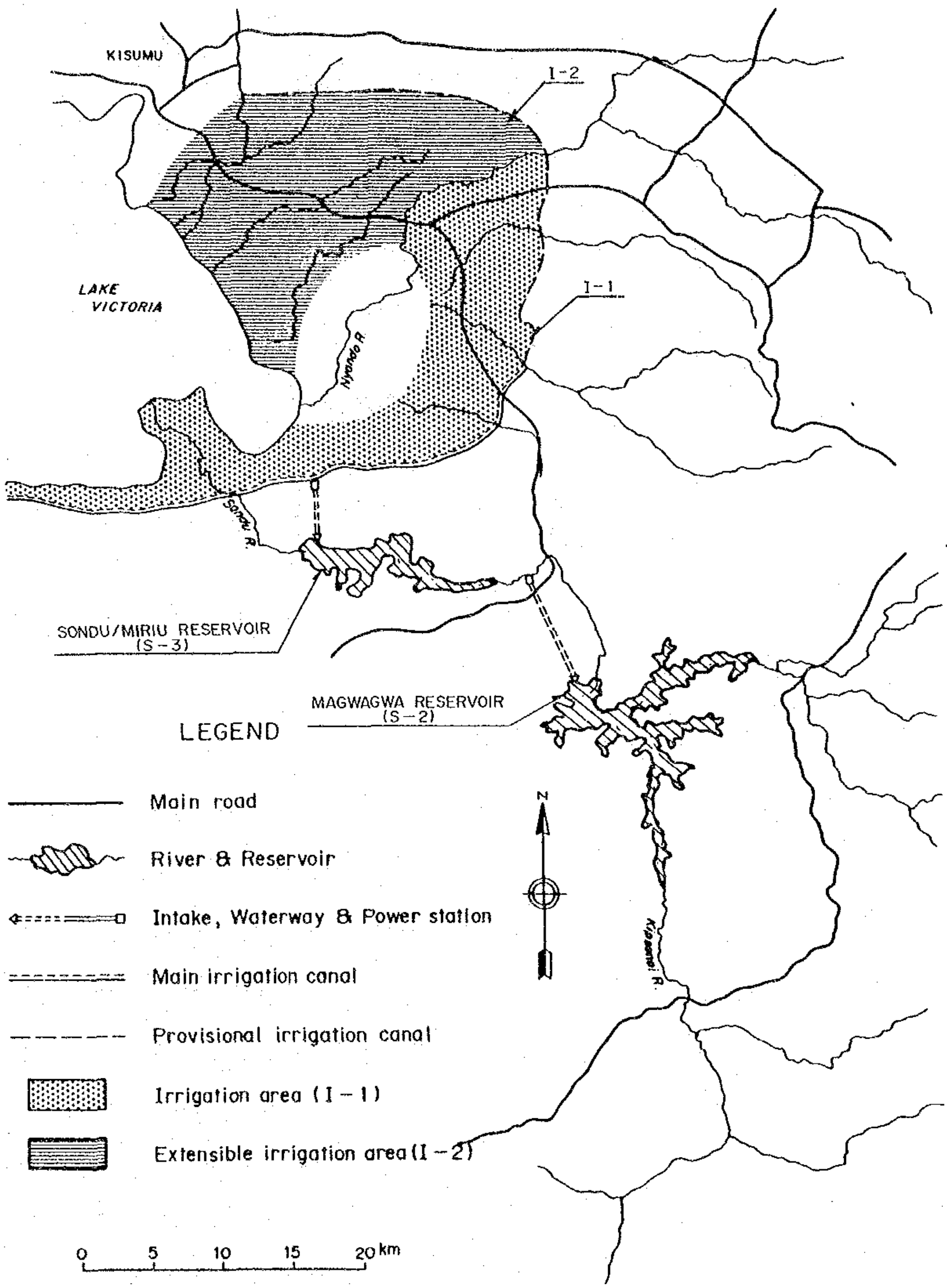


Figure 3.1-D
Combination Plans for the Development of the Sondu River (Combination-D)

REPUBLIC OF KENYA
SONDU RIVER
MULTIPURPOSE DEVELOPMENT PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY

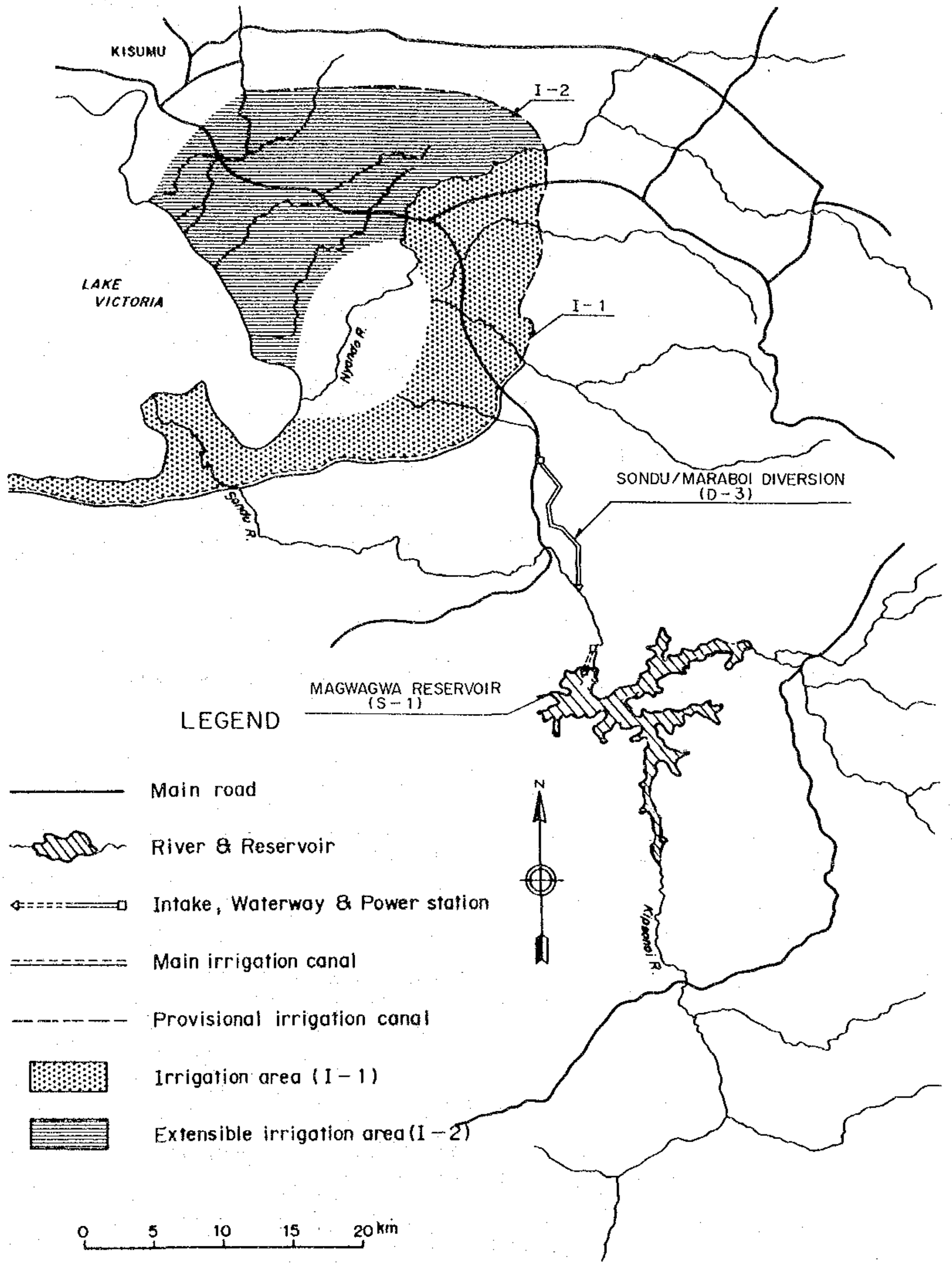
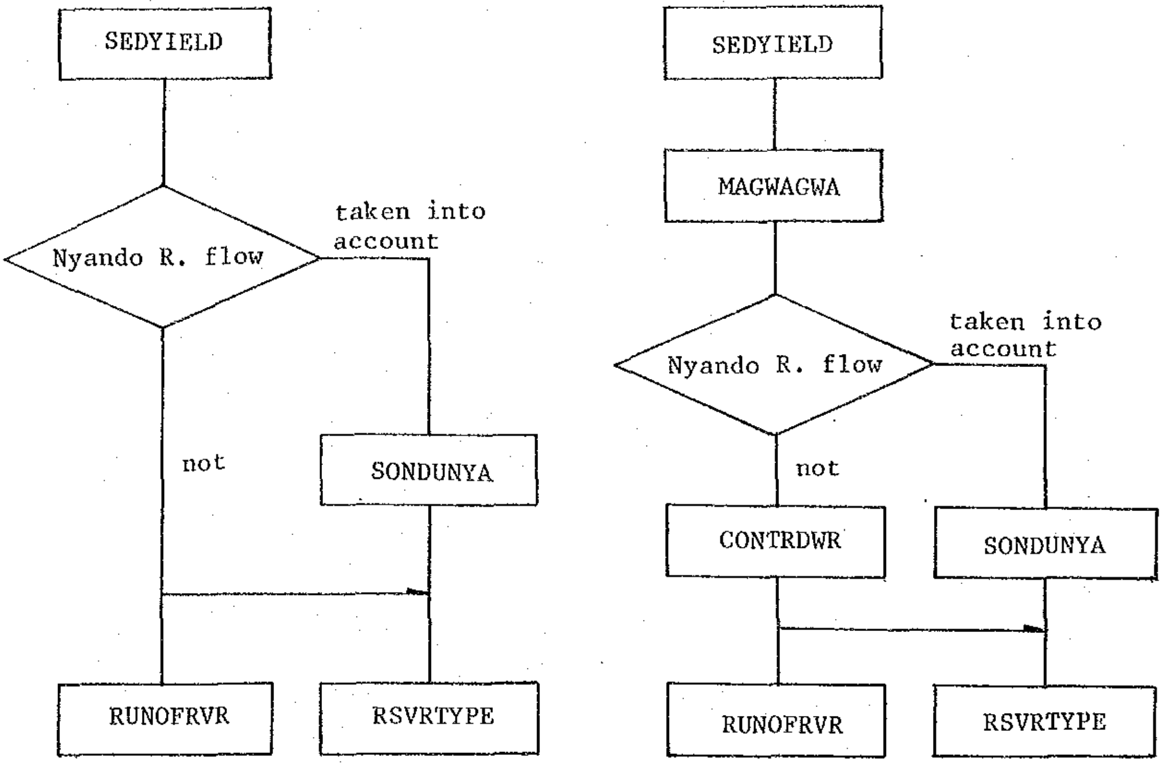


Figure 3.1-E
Combination Plans for the Development of the Sondu River (Combination-E)

REPUBLIC OF KENYA
SONDU RIVER
MULTIPURPOSE DEVELOPMENT PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY



Sondu/Miriu Scheme

Magwagwa and Sondu/Miriu Scheme

Notes: SEDYIELD is the program to prepare the storage-draft, and flow duration curves, sediment yield, etc.

MAGWAGWA is the program to evaluate the development scale of the Magwagwa reservoir scheme.

CONTRDWR is the program to prepare the storage-draft and flow duration curves of the flow regulated by the Magwagwa reservoir.

SONDUNYA is the program to compute the mass balance taking into account the Nyando flow.

RUNOFRVR is the program to evaluate the development scale of the run-of-river plan.

RSVRTYPE is the program to evaluate the development scale of the reservoir plan.

Figure 3.2
System Programs of Power Development

REPUBLIC OF KENYA
SONDU RIVER
MULTIPURPOSE DEVELOPMENT PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY

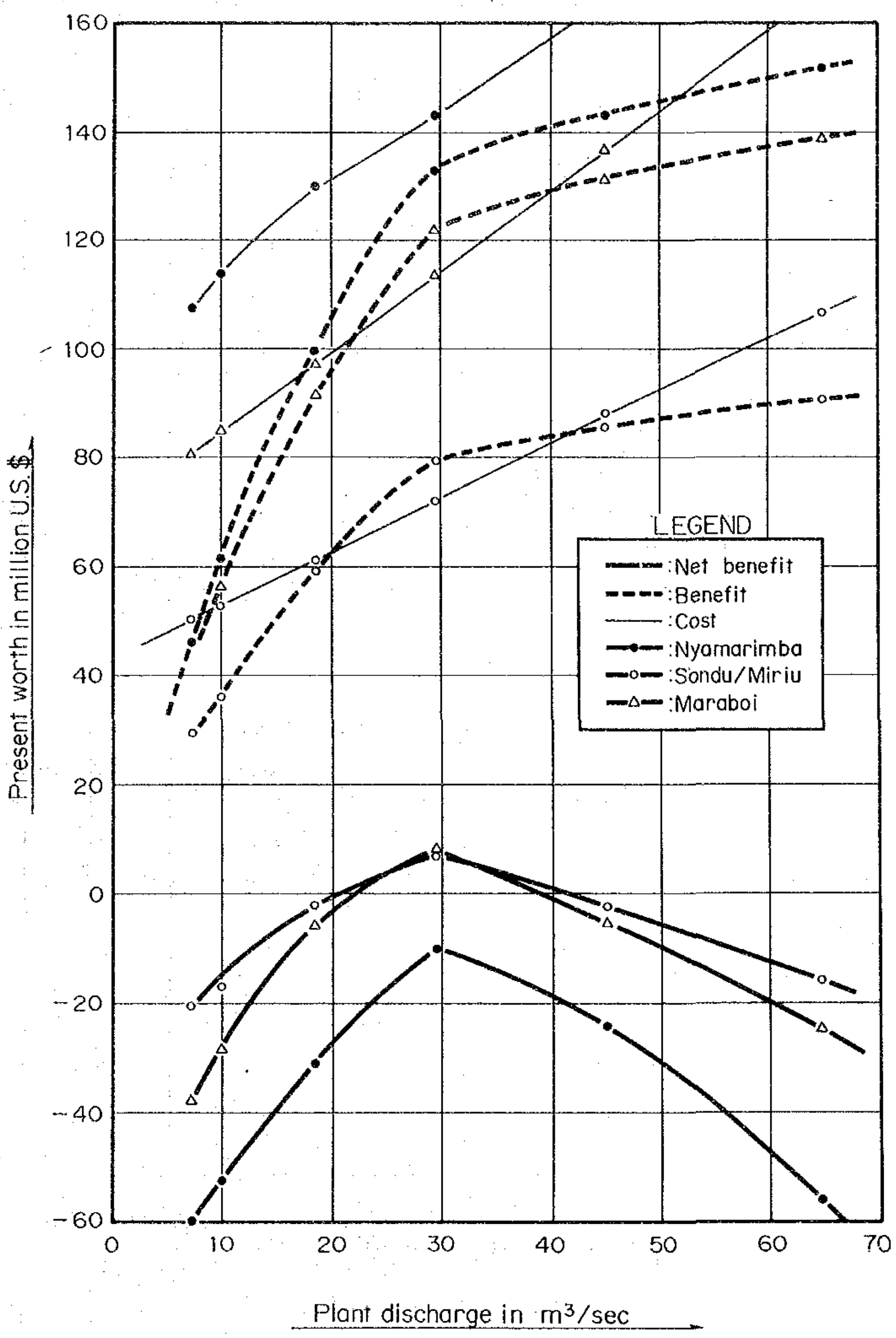


Figure 4.1
Optimization of Combination-A

REPUBLIC OF KENYA
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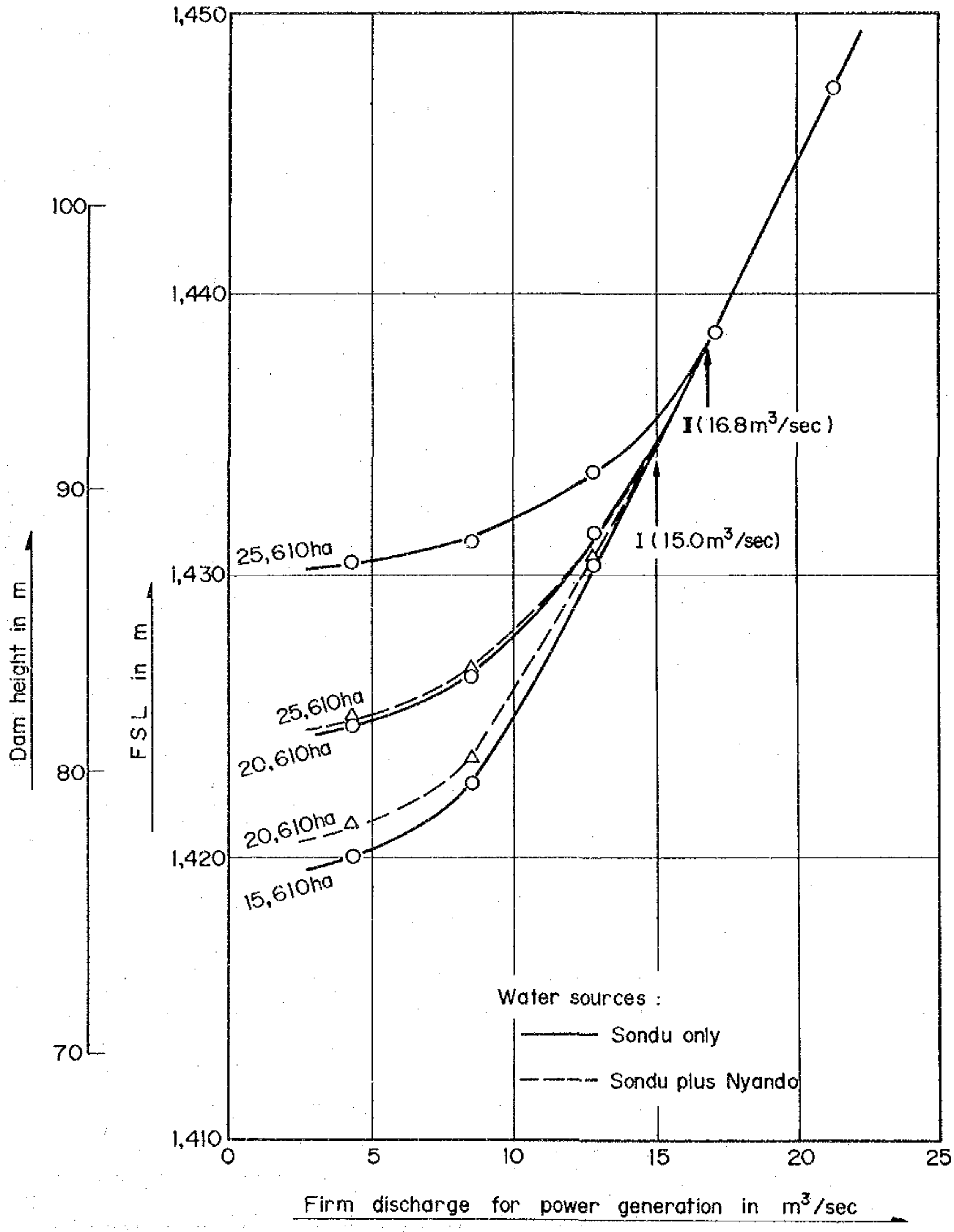

Figure 4.2 Required Dam Height versus Firm Discharge for Power Generation (Sondu/Miriu Reservoir)

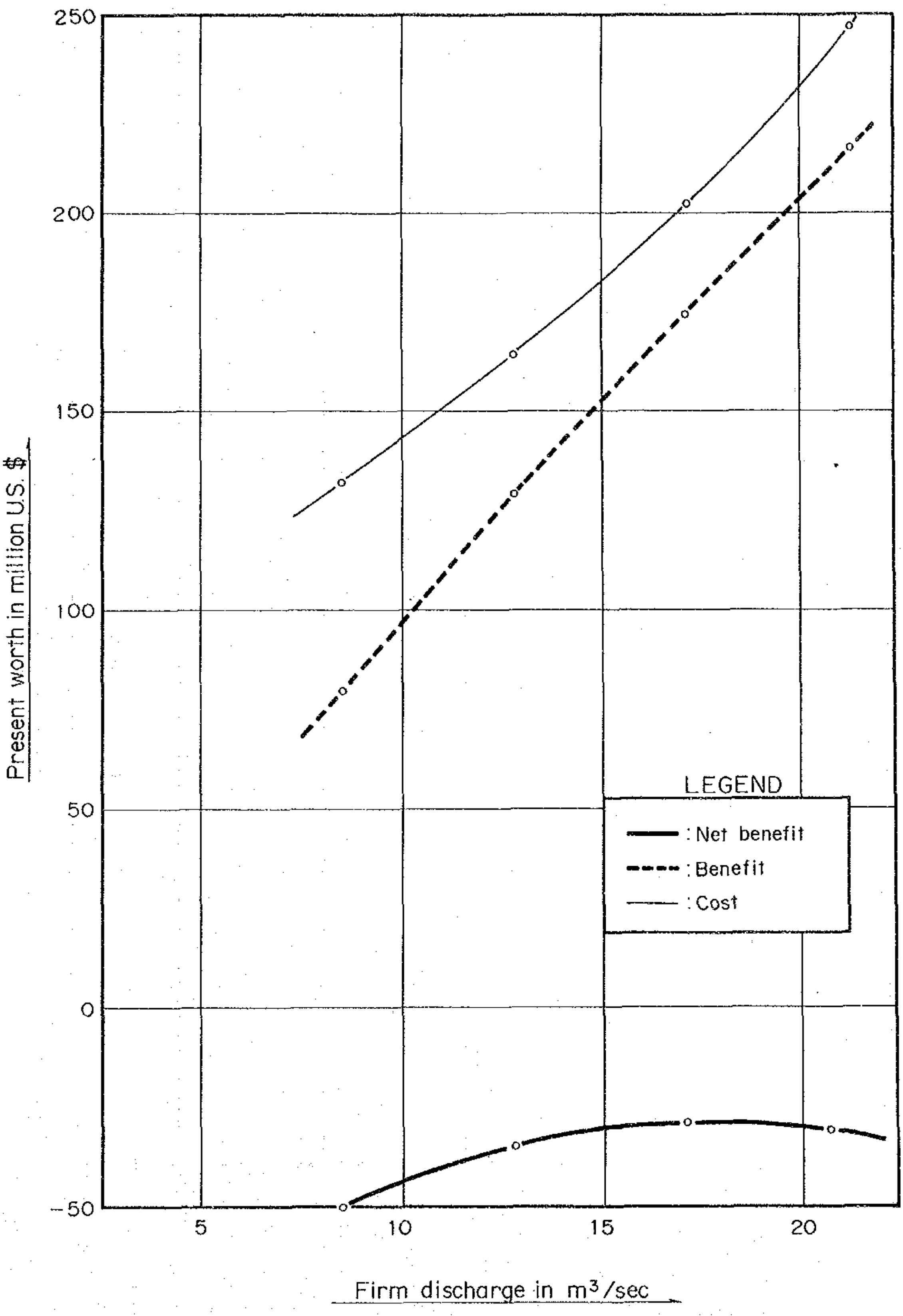

Figure 4.3
Optimization of Combination-B

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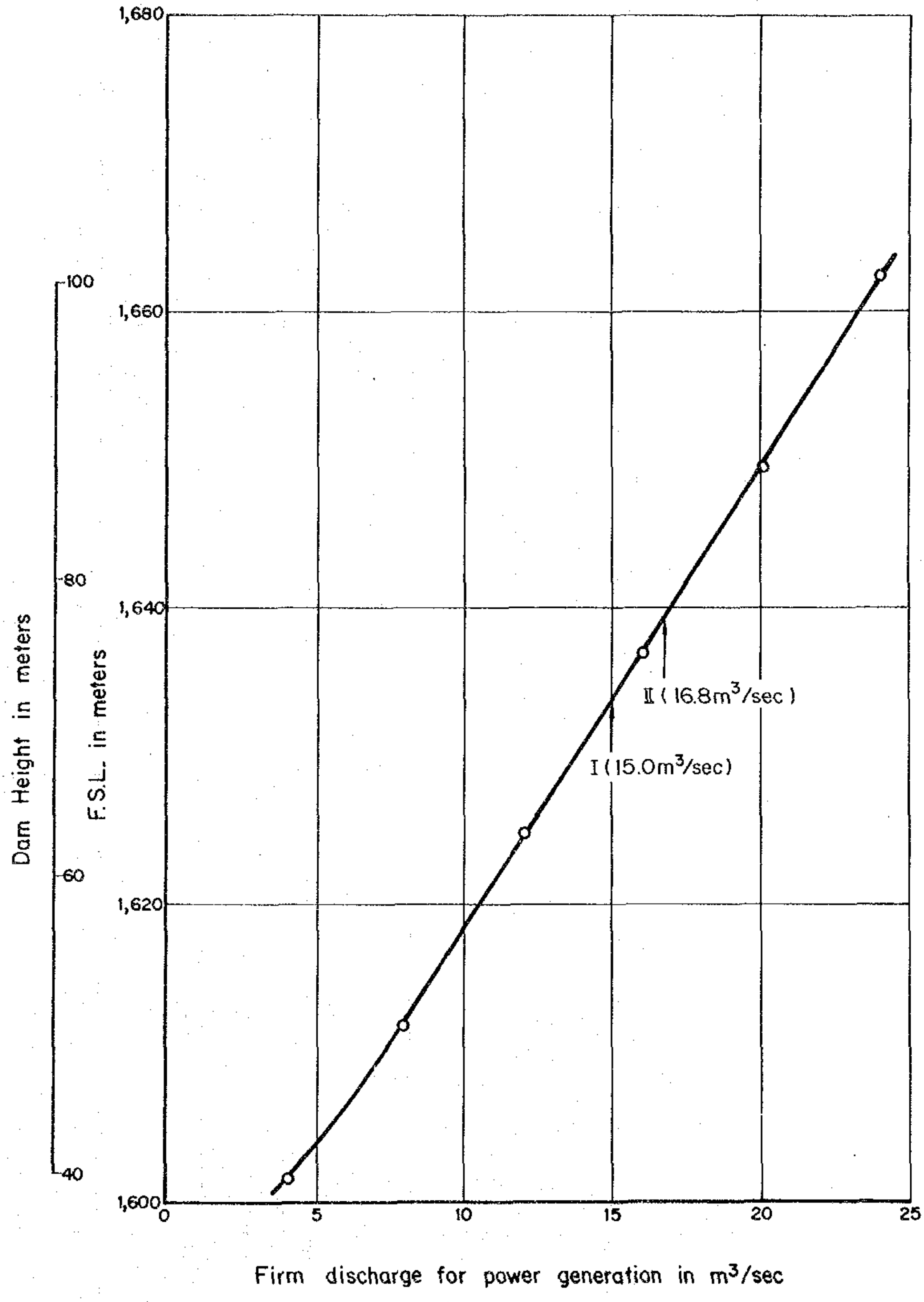

Figure 4.4 Required Dam Height versus Firm Discharge for Power Generation (Magwagwa Reservoir)

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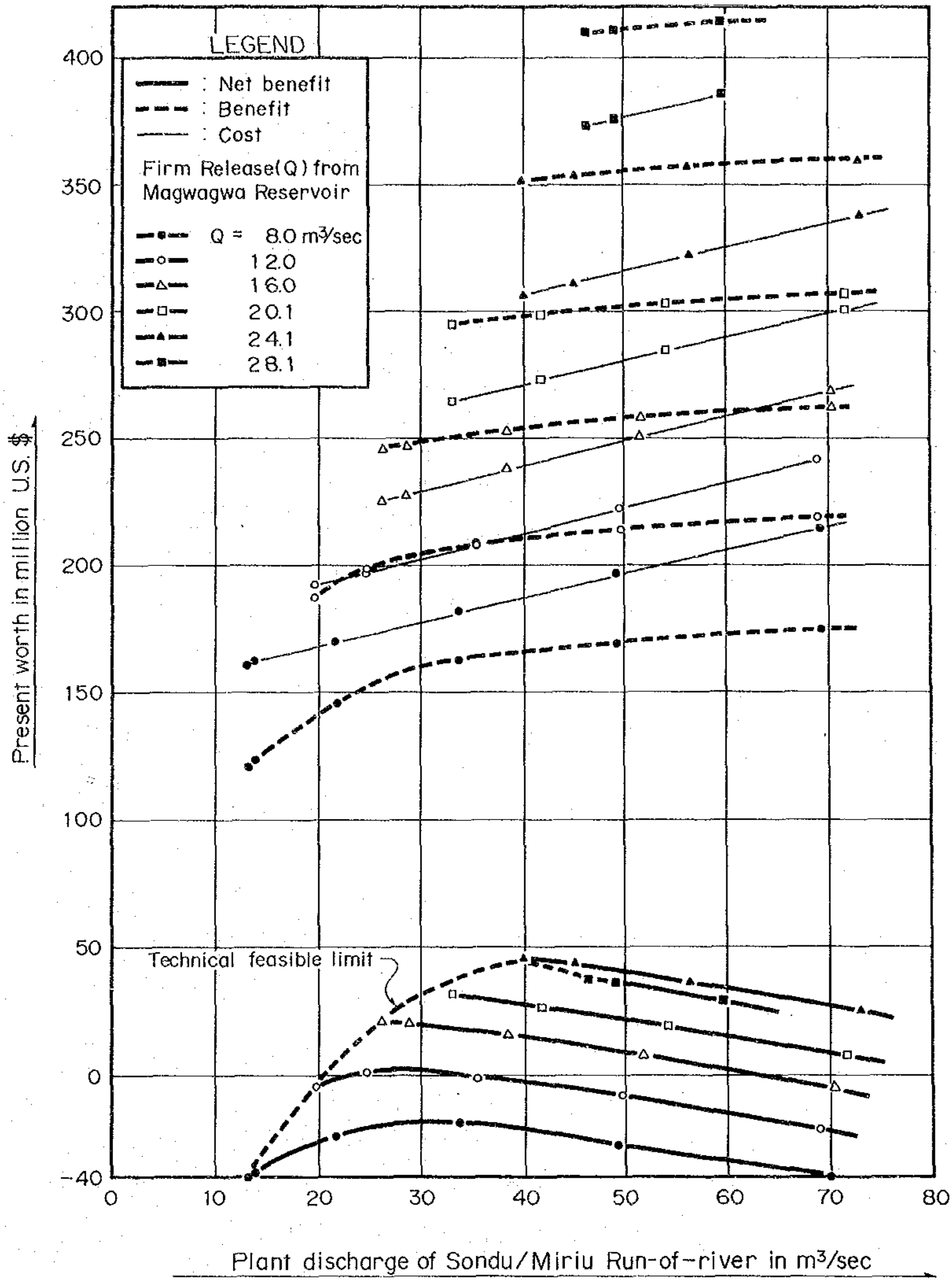

Figure 4.5
Optimization of Combination-C

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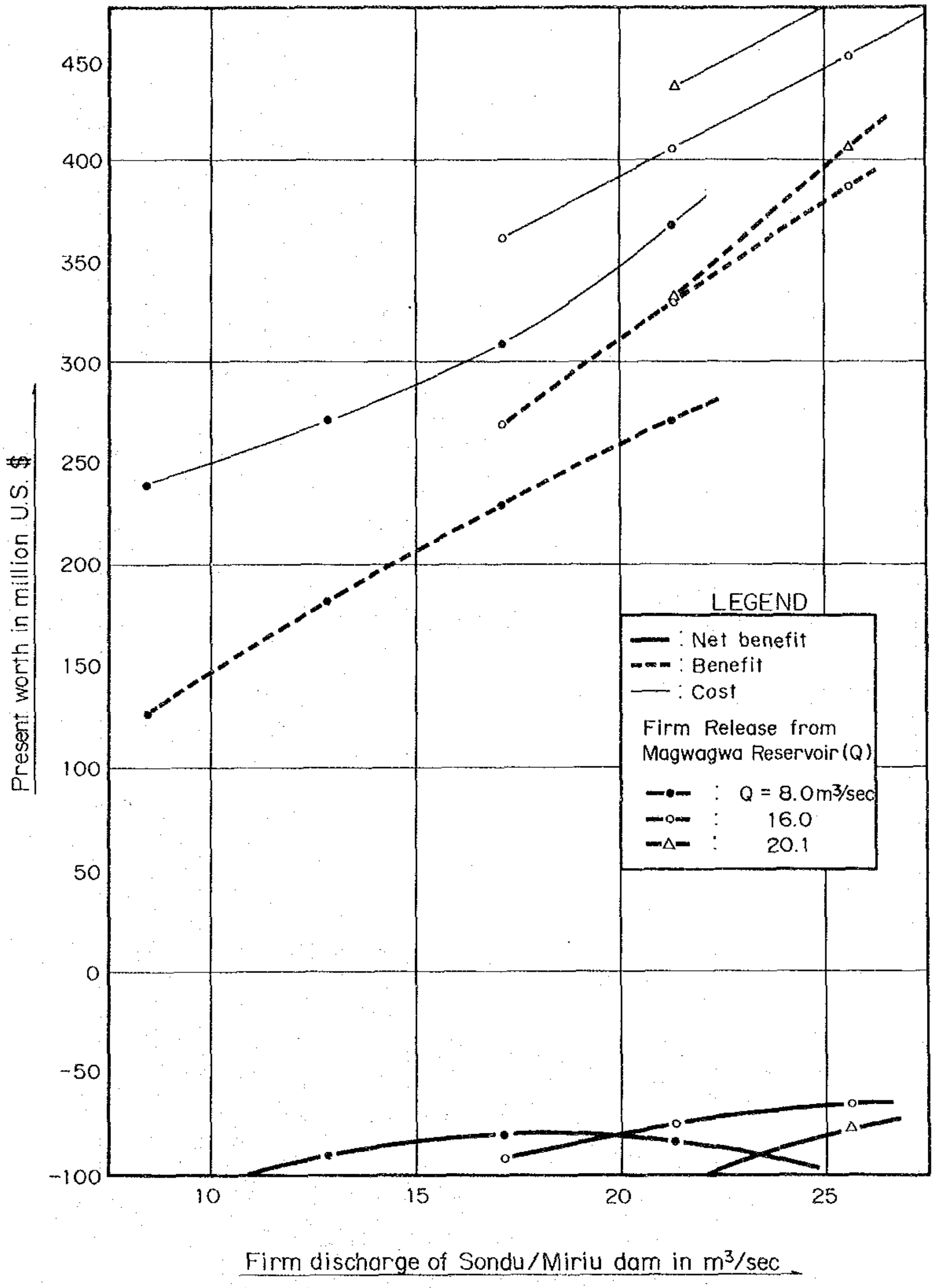

Figure 4.6
Optimization of Combination-D

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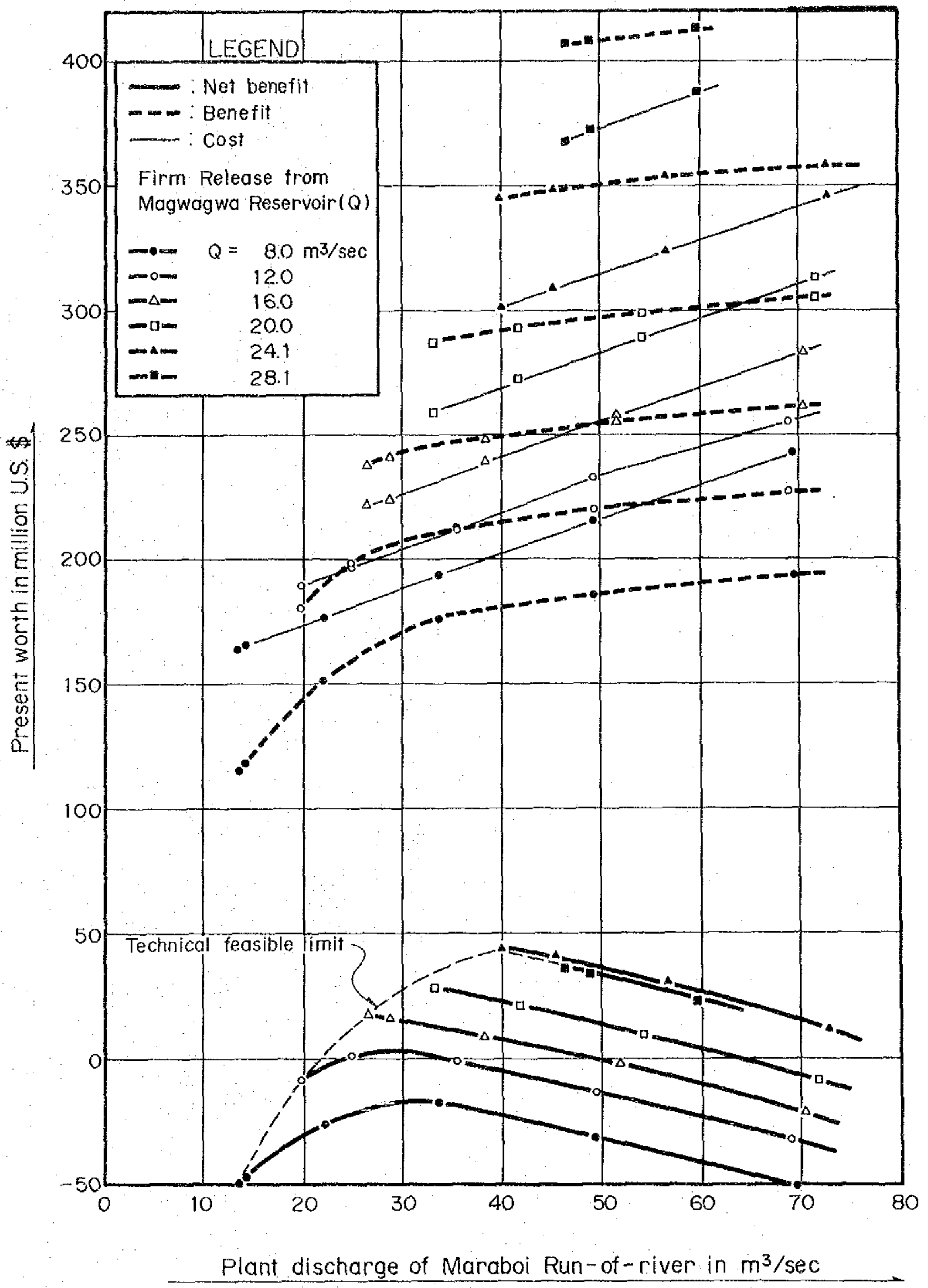

Figure 4.7
Optimization of Combination-E

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APPENDIX V POWER DEVELOPMENT PROGRAMME

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1/ R.E. Bellman and Dreyfus S.E., Applied Dynamic Programming, pp 15, Princeton University Press, 1962

2/ Watermeyer, Legge, Piesold and Ullman, Kiambere Hydroelectric Power Project, 1982

3/ Preece, Cardew and Rider, Generation and Economic Study for the Turkwell Gorge Project, July 1984

Chapter 1. APPROACH

In the preceding Appendix IV, Optimization Study, the development plan of the Sondu River was discussed in view of power generation and irrigation in the Kano Plain, and consequently a combination development plan with the Magwagwa reservoir in the middle reach and Sondu/Miriu diversion scheme in the lower reach was proposed as the optimal development plan of the Sondu River. This development plan makes possible the irrigation of 25,610 ha in the Kano Plain and power generation of 514 GWh a year (an installation capacity : 143.2 MW) in the firm basis.

A next study is to find the optimal installation timing of the Sondu hydropower project in the long-term installation programme of power plants newly added to the KP&L power grid (planting-up) so that increasing power and energy requirements can be met. This appendix deals to search the optimal installation programme of power plants newly added to the system as well as to find the installation timing of the Sondu project, applying Dynamic Programming, a method of operations research, as the analytical technique.

Chapter 2. METHODOLOGY AND BASIC CONDITIONS

2.1 Objective and Its Function

The optimal development programme of the planting-up study is defined as the least cost sequence necessary to develop power plants to meet power and energy requirements. In economic analysis, the optimal development programme is normally defined to maximize the net benefit between production costs and resulting benefits. In the power study, the revenue received from sales of power and energy is counted as benefits, which are the only function of applied tariff structure, provided that power and energy demands are given. Thus, the term of benefits is independent from that of costs necessary to develop power plants. Consequently, the least cost sequence for the investment programme of the power plants newly added to the system gives the same conclusions to the maximization of net benefit.

The capital costs and operating and maintenance costs of power plants constructed in a series for the projected period are counted as the cost, so that the objective of this planting-up study is found out a sequence to minimize the present worth of capital and operating and maintenance costs of power plants added to the system. The objective set up above is mathematically expressed as follows:

$$\text{Min} \left\{ \sum_{j=1}^{j=t} \sum_{x=1}^{x=8} f_{xj}(s_{xj}) + \sum_{k=1}^{k=T^*} \sum_{j=o}^{j=k} \sum_{x=1}^{x=8} g_{xjk}\ (t_{xjk}) \right\} \quad \ldots\ldots (1)$$

where,

s_{xj} : power scale of type-x plant added to the system on j year

t_{xjk} : annual energy outputs from type-x plant on j year

f_{xj} : present worth of capital costs

g_{xj} : present worth of operation and maintenance costs

j : time, $j = 1, 2, 3, \ldots\ldots, T$

k : time, $k = 1, 2, 3, \ldots\ldots, T^*$

x : type of power plant; oil-fired, coal-fired, gas turbine, diesel, geothermal and three types of hydro plant (run-of-river A and B, and reservoir types), namely eight different types of plant

T : investing horizon, and

T* : planning horizon.

In the above equation, j=0 implies the time before the investing and planning horizons; that is, the plants added to the system on j=0 are the existing ones. Moreover, the plants under construction and committed are categolized as the existing ones and only the difference between existing and constructing (committed) ones is that the plants under construction and committed are added to the system on the appointed commission date. Namely, the second term of Eq.(1), related to the operating and maintenance costs, is tried to optimize with not only the plants newly added to the system, but also the existing, constructing, and committed plants.

2.2 Constraints for Objective Function

In searching the optimal investment programme of hydropower schemes, the objective function is subject to the constraints on power and energy requirements as follows :

$$\sum_{x=1}^{x=x} \sum_{j=0}^{j=j} s_{xj} \geq X_j \qquad \text{............ (2)}$$

$$\sum_{x=1}^{x=x} \sum_{J=0}^{j=j} U_{xjp} \geq Y_{jp} \quad \text{for } p=0 \text{ to } 24 \qquad \text{..... (3)}$$

where, X_j is the peaking power requirement on j year, and Y_{jp} and U_{xjp} are the instantaneous power demand and supply capacity on time p in a day on j year, respectively.

2.3 Calculation Conditions Set Up

A number of conditions are set up for this planting-up study considering the reality of construction on each power plant, the financial problem for constructing power plants, the extension policy of power plants and so forth as follows:

(1) The projects under construction and committed are added to the KP&L power supply system on the appointed commission date with priority; Olkaria-3 (15 MW) in 1985, Kiambere (144 MW) in 1988 and Turkwell (100 MW) at the beginning of 1993.

(2) Should power and energy demands of the power supply system be not met with an installation of the committed project, an installation of one more project is allowed to the power supply system on that year to meet the required demands.

(3) On the year with no committed project, an addition of one project is allowed, as a principle, to meet the power and energy requirements. However, if an installation of the hydropower or geothermal scheme cannot meet the power and energy requirements on that year, an addition of thermal plant is allowed as a back-up plant of the hydropower or geothermal scheme.

(4) A newly installed project has to meet the power and energy requirements for years considering the reality of construction and financial problems as follows:

$$s_{xj} \geq X_{j+i} - X_j \quad \cdots\cdots\cdots\cdots (4)$$
$$U_{xjp} \geq Y_{j+i,p} - Y_{jp} \quad \cdots\cdots\cdots\cdots (5)$$

where, i is the years to meet power and energy requirements with a newly added plant.

(5) An economically feasible range of the type-x plant is set up as follows:

$$D_{min,x} \leq s_{xj} \leq D_{max,x} \cdots\cdots\cdots (6)$$

where, $D_{min,x}$ and $D_{max,x}$ are the economically feasible minimum and maximum capacities of the type-x plant, respectively. Moreover, calculation steps on power scales between the economically minimum and maximum capacities are changed depending on the type of power plants.

(6) The conditions set up in (4) and (5) are summarized in Table 2.1, in which the types of plant are arranged in the stacking order of the plants from base to peak which is subject to the merit-order of the plants. The run-of-river type is divided into two depending on whether or not the plant can be operated as a daily peaking plant.

(7) The construction and O&M costs for thermal candidates except for geothermal plants are estimated as the function of scale as shown in Table 2.2, whilst Table 2.3 for hydro and geothermal candidates, of which construction cost is estimated based on the site identification. Moreover, outlay of construction cost is subject to the presumed disbursement schedule.

(8) The installation of a power plant is not allowed, unless the time period necessary for the construction period plus lead time is sufficed. The construction period as well as lead time required for the feasibility study, finance and tendering, and detailed design is estimated by plant type as shown in Tables 2.2 and 2.3.

(9) Each thermal plant listed in Table 2.2 is assumed to be a candidate which will iteratively come to the system.

(10) The retirement of existing plants is considered, if the retirement of those plants comes during the investing horizon, whilst the replacement by newly added plants is taken into account. The life time of plants is also depicted in Table 2.2 and 2.3.

(11) The load curve, which shows the pattern of energy requirement, is estimated based on the daily load records and the projection of power and energy demands. Figure 2.1 shows the load curve applied for the investing horizon, and stacking of plants to assess whether or not energy requirements are sufficed with the plants conceived is based on this load curve.

(12) The stage development of a hydropower scheme is allowed, if desired. However, the second stage of the plant cannot come into the system without installation of the first stage.

(13) A decline rate of diesel plants is assumed to be 2% a year.

2.4 Applied Method and System Computer Program

Applied Method: Amongst such methods as calculus, linear programming, trial and error, and dynamic programming normally applied to the optimization problems, dynamic programming is selected as the method to solve the problem for the following reasons.

It is not easy to solve the multi-variate function expressed in Eq.(1) with calculus. If the trial and error method is applied, it is necessary to scan all the possibilities which would be practically impossible. On the other hand, if linear programming is applied, all the functions of the objective and constraints must be expressed in a linear form. But, the expression of Eq.(1) allows a non-linear form. Thus, it is considered to be adequate to apply dynamic programming to solve the non-linear multi-variate problem shown in Eq.(1).

Dynamic programming has the characteristics, as the merit of it, that the computer processing time to solve the problem contrarily decreases with the increase of constraints and conditions as well as dynamic programming can apply to non-linear multi-variate problems. Since the objective function given in Eq.(1) has many constraints and calculation conditions as mentioned in the previous section, dynamic programming, therefore, is the most adequate method even on the computer processing time.

It is, first of all, assumed for applying dynamic programming to the given problem to be able to apply "the principle of optimization"1/ which is the base of dynamic programming : An optimal policy has the property that whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision . The problem given is then written in the recurrsive form of dynamic programming. The electronic computer is used for the transaction of calculation.

System Computer Program, PRIORITY, consisting of several subprogrammes, is prepared for searching the optimal development order of attractive candidates; hydro, geothermal, oil-fired and coal-fired, gas turbine and diesel plants. As can be seen in the program flow of PRIORITY depicted in Figure 2.2, the system program consists of six subprogrammes; DEMDFILE, PLANTFL, HYDRFL, PLTOLD, CANDIDAT and HIERARCH.

DEMDFILE, PLANTFL and HYDRFL are the programs to preserve the projected power and energy demand curves and the information on the existing to committed thermal and hydro plants in the system into the permanent data files, DEMAND, FLPLTH and FLPLTA, respectively. PLTOLD retrieves all the information on the existing to committed thermal and hydro plants from the permanent data files (FLPLTT and FLPLTH), and transfers it to the program HIERARCH. The program, CANDIDAT, has also the function to transfer the information of candidates of hydro and geothermal projects given as the input data to HIERARCH.

The program, HIERARCH, searches the least cost combination out of numerous combinations consisting of power plants which have possibility to be added to the KP&L power supply system.

2.5 Input Data

Following are the input data to be prepared for the planting-up study.

(1) Existing, under-construction and committed plants

- Type and scale
- Installation data
- Annual firm energy

Table 2.4 gives the information on the existing to committed hydro plants. As of December 1984, total effective capacity stays at the level of 369 MW including electricity imported from the UEB. Two big plants, Kiambere and Turkwell, will come into the system in 1988 and 1993, and consequently effective capacity will be levelled up to 613 MW. On the other hand, since the KP&L has a plan to treat energy imported from UEB as non-firm after 1988, this plan is also studied as one of sensitivity tests.

Table 2.5 shows the information on the existing to committed thermal plants. Effective capacity stays at the level of 149 MW, 29% of total effective capacity of the KP&L system, as of December 1984. Another 15 MW of the Olkaria geothermal plant will join to the system in mid 1985. Plant retirement is subject to the KP&L schedule. If the retirement schedule is not designated, the existing to committed plant is retired according to the presumed life time, i.e. 30 years for coal-fired, oil-fired and geothermal, 25 years for gas turbine and 20 years for diesel.

(2) A catalogue of oil-fired, coal-fired, gas turbine and diesel candidates (refer to Table 2.2) with information on

- Capital cost with disbursement
- Life time and replacement cost (90% of initial cost)
- Fossil fuel consumption rate
- Station operation and maintenance costs.

The maximum unit capacity of oil and coal-fired plants is set at 60 MW considering the system reliability as recommended by the WLPU[2/], and it is confirmed by the PCR reconnaissance[3/] that the sites to build coal-fired plants areavailable including coal handling facilities at port Reitz, Mombasa. Meanwhile, the maximum unit capacity of diesel plant is set at 10 MW.

(3) A catalogue of hydro and geothermal candidates (refer to Table 2.3) with the information on

- Annual firm energy
- Capital costs with disbursement
- O&M costs
- Annual secondary energy

Five projects are listed up as the candidates of hydro plants including the Sondu/Miriu project, of which total construction cost is, in principle, allocated to the power sector. However, the optimal installation timing of the Sondu project based on the allocated cost will be searched in the sensitivity test. It is furthermore noted that construction cost estimate except for the Sondu/Miriu project is less reliable due to the project maturity; namely the investigation for the projects except for the Sondu/Miriu stays at reconnaissance or pre-feasibility study level.

On hydro plants, firm energy is only counted as the energy source to meet the energy requirements in searching the least cost sequence. It is true that secondary energy generated from the hydro plants bears the value in view of fuel saving. Thus, secondary energy generated from the hydro plants is taken into account in calculating the second term of Eq. (1).

(4) Projected power and energy demand curves

Power and energy demands projected in Chapter 5, Power Supply and Demand, of Volume II, are used for this planting-up study. However, since the demands are projected by year 2000, the demands beyond 2000 are estimated by an exponential extrapolation. Considering the system reliability, the reserve capacity of 17% is added to the power demand and expressed as the maximum power requirement.

(5) Parameters to be applied to the discounting technique:

- Discount rate : 0.10
- Investing horizon : 20 years between 1985 and 2005
- Planning horizon : 50 years between 1985 and 2035

The discount rate of 10% is selected as the prime test discount rate, and the tests by changing the discount rate are discussed in the sensitivity analysis.

Chapter 3. LEAST COST INSTALLATION PROGRAMME

The planting-up study to search the least cost sequence was carried out for the KP&L power supply system. The least cost sequence so obtained is shown in Table 3.1, whilst the power and energy balance in the least cost sequence is illustrated in Figure 3.1.

The optimal installation timing of the Sondu/Miriu project is reckoned to be 1992 (commissioning at the beginning of 1993) for the first stage (Sondu/Miriu run-of-river plan, 48.6 MW) and 1996 for the second stage (Magwagwa reservoir plus waterway plan, 94.6 MW). Olkaria IV geothermal (30 MW) and a coal-fired (60 MW) plant emerged in 1993 follow the first stage, whilst Eburru geothermal (15 MW in 1998) and coal-fired plants (120 MW in 1998, 60 MW in 2001, 60 MW in 2002, 120 MW in 2003 and 60 MW in 2004) come after the second stage.

In case that a run-of-river project is developed as a first stage in a basin and followed by a reservoir type project of upper reaches, it is normal that firm energy generated from the first stage is tremendously increased with the installation of the second stage. In such a case, simultaneous installation of both stages may be revealed in the study to search a least cost sequence due to that firm energy is only counted as available energy to meet energy demand.

Hydropower development in the Sondu River basin by the Sondu/Miriu run-of-river and Magwagwa reservoir projects is not exempted from the case mentioned above (both in 1996). The earlier installation (1992) of the Sondu/Miriu run-of-river as the first stage was, however, reckoned in the least cost sequence by fuel saving effects of secondary energy with 155.6 GWh/year; that is, fuel saving effects are greater than incremental discounted costs by shifting the installation year from 1996 (commission year of the second stage) to 1992.

A time schedule to implement both the first and second stages of the Sondu project was prepared according to the lead time necessary for finance and detailed design and construction period assumed in the planting-up study as shown in Figure 3.2, although a detailed implementation schedule for the first stage is discussed based on the construction plan and schedule in the subsequent Appendix VI. In order to fix the commission date of the first stage at the beginning of 1993, the arrangement of finance should be taken immediately after this feasibility study.

Furthermore, the planting-up study indicates that geothermal, as one of promising indigenous energy sources, shall be developed with priority; 45 MW by 1998. However, it is likely due to the small plant scale compared with the growing power and energy demands that the installation of Lake Bogoria was not emerged to the system in 2000's. Current earnest exploitation of geothermal at Olkaria, Eburru and Lake Bogoria shall be continued with the consideration of making plant scale larger.

For keeping the power and energy balance, the development of 480 MW is required on coal-fired plants by year 2005 besides the Sondu/Miriu and geothermal plants. Although oil-fired plants are competitive against coal-fired plants, the installation of coal-fired plants is more attractive than that of oil-fired plants, provided that the oil price stays at the present level.

None of hydro project than the Sondu/Miriu was emerged in the planting-up study. This may be due to uncertainties involved in the cost estimate of the project. Finally, total discounted cost obtained in the least cost sequence is US$846.209 million (refer to Table 4.1).

Chapter 4. SENSITIVITY TESTS

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

(1) Variation of discount rates; 5%, 8%, 12% and 15% besides the prime test discount rate of 10%

(2) Low and high demand forecasts

(3) Non-firm for the energy imported from the UEB after 1988

(4) Application of cost allocation for the Sondu/Miriu project

(5) Thermal candidates only for the planting-up study; coal-fired, oil-fired, diesel and gas turbine except geothermal and hydro plants

(6) 10% capital cost up for the Sondu/Miriu project

(7) 10% fuel cost up and down for the coal-fired plant, and

(8) 10% capital cost down for the thermal plant except geothermal.

The optimal installation timing of the Sondu/Miriu project indicated to be 1992 for the first stage and 1996 for the second stage in the least cost sequence was not changed even varying the discount rate from 5 to 15%. Figure 4.1 shows the peak power and energy balance based on the least cost sequence in case of the discount rate of 15%, in which Eburru geothermal is not revealed and is replaced by coal-fired plants likely due to small initial cost of coal-fired plant.

The variation of least cost sequence based on uncertainties involved in the demand forecasts is shown in Figures 4.2 and 4.3; low and high demand forecasts, respectively. In the low demand forecast, the installation of the Sondu/Miriu is delayed by 1998 for the second stage, whilst 1996 for the high demand forecast. It is, furthermore, noted in the high demand forecast that geothermal plants are not revealed in the least cost sequence likely due to the small plant scale. Thus, the geothermal plant scale of 15 to 30 MW shall be required to increase in case that high demand growth is expected in electricity.

In case that the energy imported from the UEB is treated as non-firm after 1988, there was no large change in the least cost sequence as shown in Figure 4.4. However, the installation of Eburru geothermal is revealed with 30 MW in 1998 for making up decreased firm energy.

The sensitivity on cost allocation of the Sondu/Miriu project was tested on the drastic assumption that nonseparable costs between power and irrigation sectors are shared by the ratio of use: Nonseparable costs after subtracting the specific costs of power sector such as power station, penstock, generating equipment, transmission line and substation were allocated by the cited ratio of average irrigation water requirement ($\doteqdot$ 12.5 m^3/sec for 25,610 ha development cited from Appendix VII) and firm discharge on power generation ($\doteqdot$ 24.1 m^3/sec), and consequently allocated costs for the first and second stages of the Sondu project were estimated to be US$49.0 and 120.1 million, respectively. Figure 4.5 shows the least cost sequence based on the cost allocation, in which the implementation of the first and second stages was revealed to be 1992 and 1996, respectively.

Least cost sequence based on the thermal candidates only requires to install eight coal-fired plants (capacity : 660 MW) and three diesel plants (capacity : 22 MW) by year 2005 as shown in Figure 4.6, and then total cost required for the installation of plant in the investing horizon and for the O & M in the planning horizon was counted to be US$959.6 million (refer to Table 4.1) in the present worth against US$846.2 million which is the cost required in the least cost sequence shown in Figure 3.1; that is, US$113.4 million can be saved by the development of indigeneous energy resources by year 2005.

Furthermore, sensitivity was tested by 10% capital cost up for the Sondu/Miriu project, 10% fuel cost up and down for the coal-fired plant and 10% capital cost down for the thermal plant except geothermal. The optimal installation timing of the Sondu/Miriu project was revealed to be 1992 for the first stage and 1996 for the second stage in these cases as indicated in Figure 3.1. Thus, the Sondu/Miriu project can be said to be a promising project to be developed, even if uncertainties are involved in the future costs and assumptions. Finally, total discounted costs in the sensitivity tests are summarized in Table 4.1.

TABLES

Table 2.1 Calculation Conditions on Planting-up Study

No.	Merit Order of Plants from Base to Peak Load	Economically Feasible Range, MW		Calculation Steps MW	Minimum Years to Meet the Power & Energy Requirements
		$D_{min,x}$	$D_{max,x}$		
1	Run-of-river A 1/	- 2/	-	-	1 3/
2	Geothermal	- 2/	-	-	1 3/
3	Run-of-river B 1/	- 2/	-	-	1 3/
4	Coal-fired	60	180	60 4/, 120, 180	1
5	Oil-fired	60	120	60 4/, 120	1
6	Reservoir	- 3/	-	-	1 3/
7	Diesel	2	30	2, 5, 10 4/, 20, 30	1
8	Gas Turbine	20	40	20, 40	1

Note : 1/ Run-of-river B is operated as daily peaking plant, while run-of-river A as base load plant. Energy imported from the UEB is treated as the run-of-river A.

2/ The development scale of hydro and geothermal plants is based on site identification.

3/ A supplementary installation of thermal plant is allowed, if a hydropower or geothermal plant cannot clear the minimum year to meet the power and energy requirements.

4/ Maximum unit capacity is set at 60 MW for coal and oil-fired plants and 10 MW for diesel plants considering the system reliability.

Table 2.2 Construction and O&M Costs of Thermal Candidates for KP&L System Planting-up

Type	Installed Capacity MW	Annual Max. Operation Rate %	Lead Time Year	Construction Time Period Year	Construction Disbursement	Life Time Year	Construction Cost US$/kW	O&M Cost %	Fuel Price US$/t	Calorific Value Kcal/kg	Fuel Cost US¢/kwh
Oil-fired	60 1/	70	2	5	0.05/0.25/0.40/0.20/0.10	30	1,055	2	220	10,300	6.80
	120	"	"	"	"	"	"	"	"	"	"
Coal-fired	60 1/	70	2	5	0.05/0.25/0.40/0.20/0.10	30	1,815	2	52	6,200	2.67
	120	"	"	"	"	"	"	"	"	"	"
	180	"	"	"	"	"	"	"	"	"	"
Gas-turbine	20	50	0	2	0.40/0.60	25	565	2.5	340	10,800	11.27
	40	"	"	"	"	"	460	"	"	"	"
Diesel	2	60	0	1	1.0	20	1,300	3	340	10,800	7.96
	5	"	"	"	"	"	990	"	"	"	"
	10 2/	"	"	"	"	"	800	"	"	"	"
	20	"	"	"	"	"	"	"	"	"	"
	30	"	"	"	"	"	"	"	"	"	"

Notes : 1/ Maximum unit capacity is set at 60 MW considering the system reliability as recommended by WLPU, and it is confirmed by the PCR reconnaissance that plant construction sites are available including coal handling facilities at Port Reitz, Mombasa.

2/ Maximum unit capacity is set at 10 MW.

Table 2.3 Construction O&M Costs of Hydro and Geothermal Candidates for KP&L System Planting-up

Project	Installed Capacity MW	Firm Energy GWh/year	Lead 1/ Time Year	Construction Time Period Year	Construction Disbursement	Life Time Year	Construction 2/ Cost Million US$	O&M 3/ Cost %	Fuel Cost US¢/kwh
Hydro									
Sondu/Miriu-1 4/	48.6	32	3	4	0.20/0.30/0.30/0.20	50	61.4	1	-
Sondu/Miriu-2	94.6	482 5/	5	5	0.15/0.25/0.30/0.20/0.10	"	150.7	"	-
Mutonga	70.0	153	"	"	"	"	173.7	"	-
Grand Falls	120.0	321	"	"	"	"	450.0	"	-
Adamson's Falls	50.0	200	"	6	0.15/0.20/0.25/0.20/0.15/0.05	"	520.0	"	-
Munyu	38.0	133	"	5	0.15/0.25/0.30/0.20/0.10	"	223.9	"	-
Geothermal									
Olkaria IV	15.0	105	3	4	0.10/0.45/0.35/0.10	30	33.1 6/	2	0.5
" IV	30.0	210	"	"	"	"	66.3	"	"
Eburru	15.0	105	5	"	"	"	33.1	"	"
"	30.0	210	5	"	"	"	66.3	"	"
Lake Bogoria	15.0	105	5	"	"	"	40.6 7/	"	"
	30.0	210	5	"	"	"	72.7	"	"

Notes : 1/ Presumable lead time before construction is set forth as follows; 2 years for feasibility study, 1 year for finance and tendering, and 2 years for detailed design. Lead time is reduced based on the project maturity.

2/ Price level is set at December 1984.

3/ Annual O&M costs are expressed with percentage for construction cost.

4/ Sondu/Miriu-1 is the first stage of Combination-C, Sondu/Miriu run-of-river, whilst Sondu/Miriu-2 corresponds to the second stage of Combination-C, Magwagwa reservoir plan.

5/ Incremental firm energy from Sondu/Miriu-1 by the installation of Sondu/Miriu-2 is counted in the second stage.

6/ Construction Cost is estimated at US$2,209/kw, in which a half of drilling cost (US$427/kw ÷ 2 = US$214/kw) is included, namely a remaining half of drilling cost is assumed to have been invested and is treated as sunk cost.

7/ Full drilling cost (US$427/kw) and transmission line cost (US$4.25 million for 85 km long) are included in the construction cost.

Table 2.4 Existing to Committed Hydro Plants in the KP&L System

Plant	Installed Capacity MW	Effective Capacity MW	Average/ Firm Energy GWh/year	Installation Year	Remarks
Existing					
Tana	14.4	12.4	69.8	1935/50/53	Average
Wanjii	7.4	7.4	43.6	1952	"
Masinga	40.0	40.0	59.7	1981	"
Kamburu	91.5	84.0	324.2	1974/76	"
Gitaru	145.0	145.0	638.8	1978	"
Kindaruma	44.0	44.0	170.4	1968	"
Others	6.2	6.2	22.4		Ndula, Mesco, Sagana, Selby Falls
Under-construction					
Kiambere	144.0	144.0	683	1988	Firm
Committed					
Turkwell	106.0	106.0	321	1993*	Firm
Electricity imported from the UEB					
	-	30.0			

Note : * PCR proposed the in-service date of Jan. 1st, 1993.

Table 2.5 Existing to Committed Thermal Plants in the KP&L System

Plant	Type	Plate Capacity MW	Effective Capacity MW	Installation Year	Remarks
Existing					
Kipevu-2	Oil-fired	5.0	4.0	1958	**
-3	"	5.0	4.0	1958	**
-4	"	12.5	10.0*	1961	
-5	"	12.5	10.0	1962	
-6	"	30.0	27.0	1973	
-7	"	33.0	30.0	1976	
Mombasa	Gas-turbine	12.2	8.0*	1972	
Nairobi	"	17.9	14.0	1973	
Nairobi	Diesel	-	8.0	-	***
Ruiru	"	-	2.0	-	***
Mbaraki	"	-	2.0	-	***
Olkaria 1	Geothermal	15.0	15.0	1981	
" 2	"	15.0	15.0	1982	
Committed					
Olkaria 3	"	15.0	15.0	1985	

Notes : * Based on the proposed rehabilitation works.

** Two 5 MW units will be retired in 1992.

*** These plants will be retired in 1988.

Table 3.1 Optimal Planting-up Sequence in the KP&L System (1986 to 2005)

Plant	Type	Capacity MW	Installation Year	Notes
Kiambere	Hydro	144	1988	Under Construction
Turkwell	Hydro	100	1992	Committed (the first date of 1993)
Sondu/Miru 1	Hydro	48.6	1992	
Olkaria IV	Geothermal	30	1993	
Coal-1	Coal	60	1993	
Sondu/Miriu 2	Hydro	94.6	1996	
Eburru	Geothermal	15	1998	
Coal-2	Coal	120	1998	
Coal-3	Coal	60	2001	
Coal-4	Coal	60	2002	
Coal-5	Coal	120	2003	
Coal-6	Coal	60	2004	

Table 4.1 Discounted Cost of Least Cost Sequence in Sensitivity Tests

Case			Discounted Cost, million US$
(1)	Tst discount rate of	5%	2,045.200
	"	8%	1.166.654
	"	10%*	846.209
	"	12%	639.998
	"	15%	440.613
(2)	High demand forecast		1,242.316
	Low "		623.101
(3)	Non-firm for the energy imported from the UEB after 1988		1,055.336
(4)	Application of cost allocation for the Sondu/Miriu project		823.133
(5)	Thermal candidates only		959.625
(6)	10% capital cost up for the Sondu/Miriu project		857.585
(7)	10% fuel cost up		869.377
	" down		823.042
(8)	10% capital cost down for the thermal plant except geothermal		796.043

Note: * shows the prime test discount rate

FIGURES

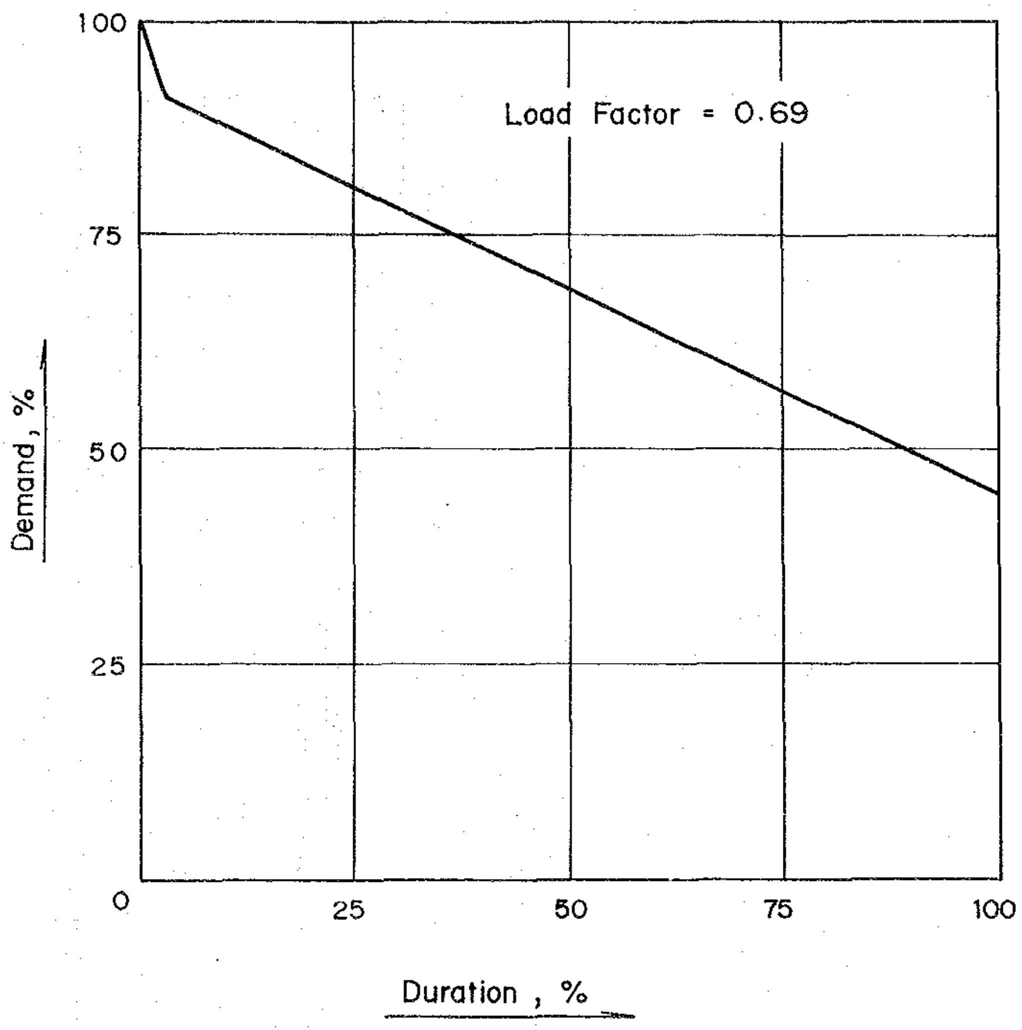

Figure 2.1
Presumed Load Duration Curve

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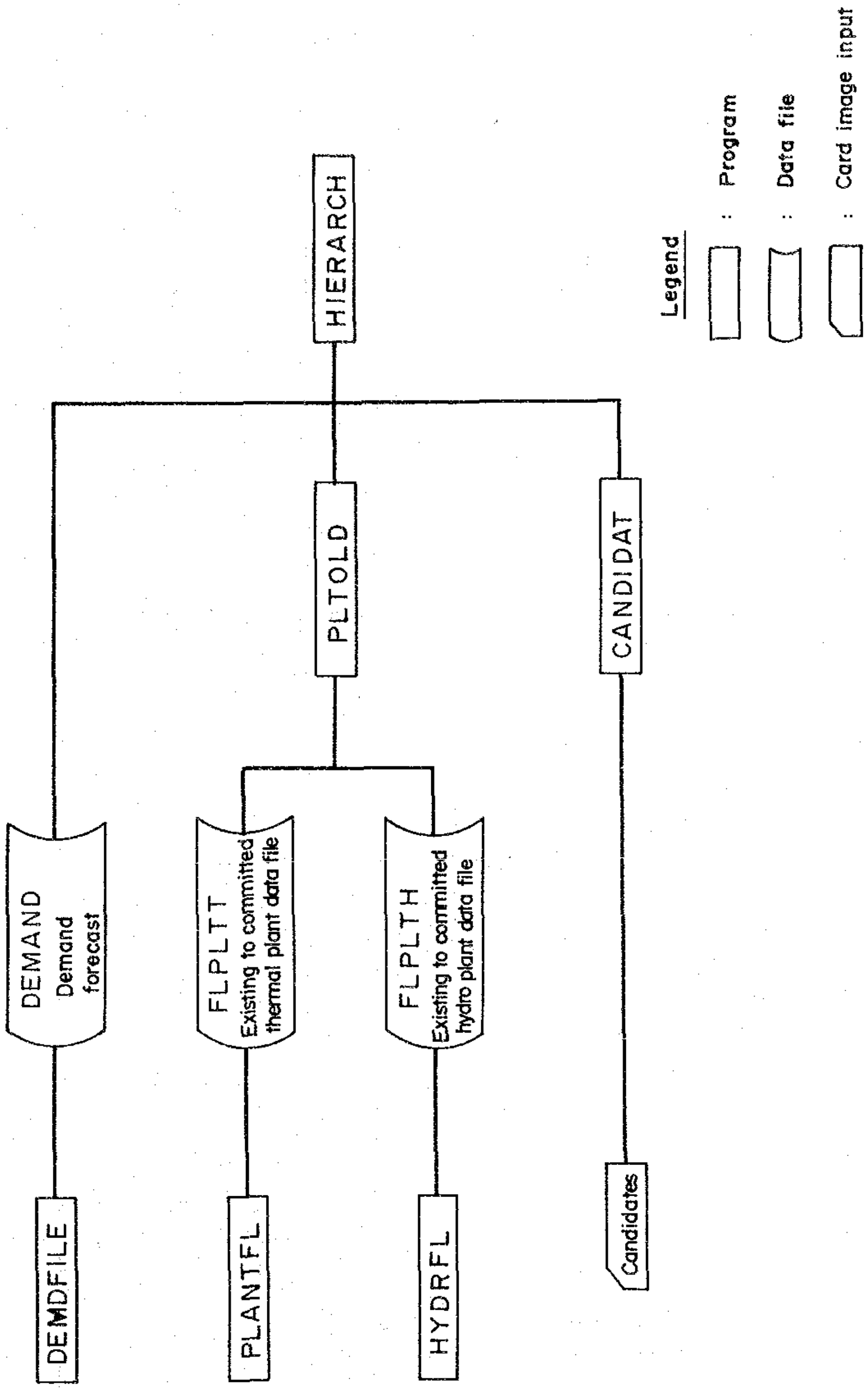

Figure 2.2
Program Flow of PRIORITY

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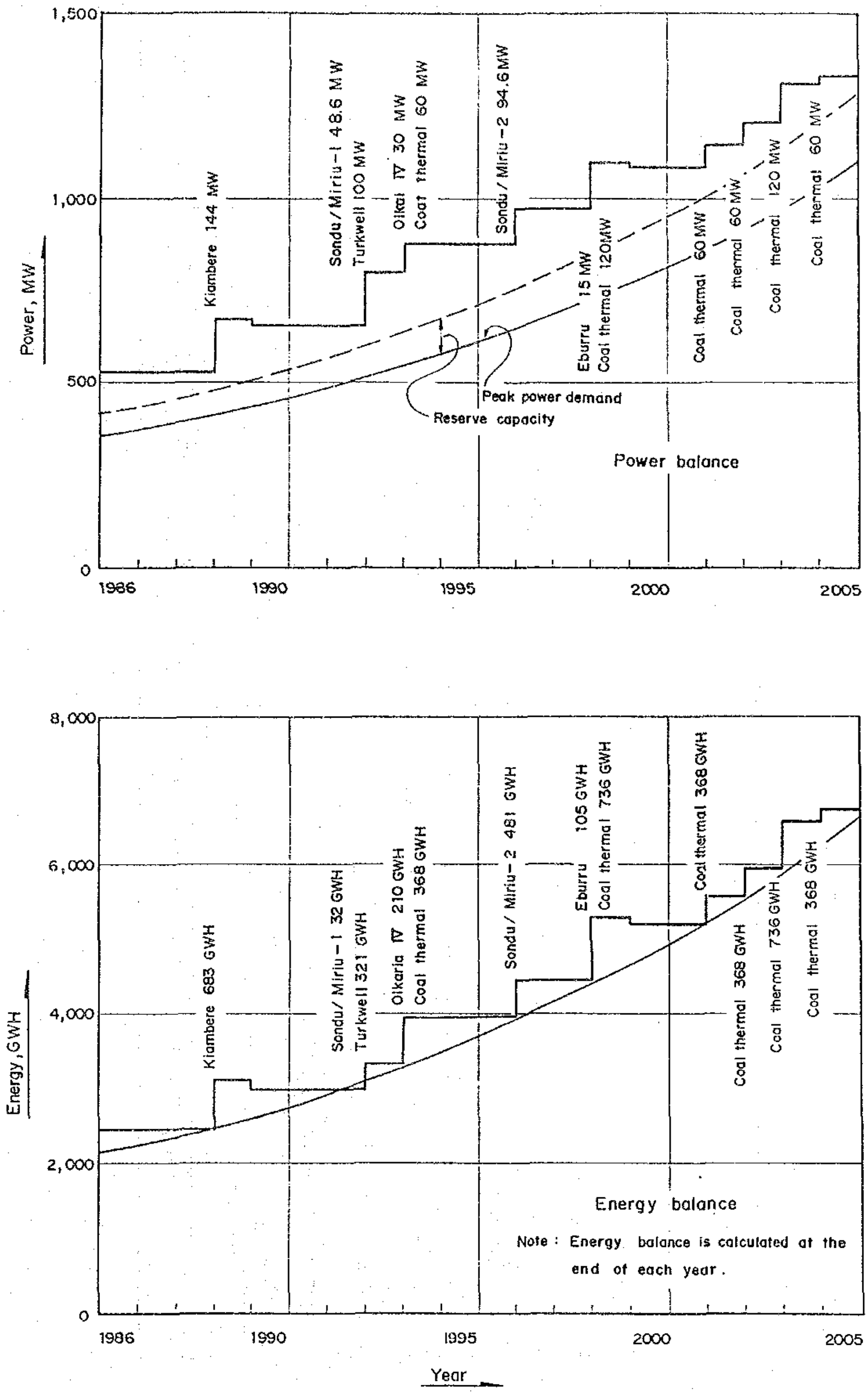

Figure 3.1
Peak Power and Energy Balance in KP&L Power Supply System

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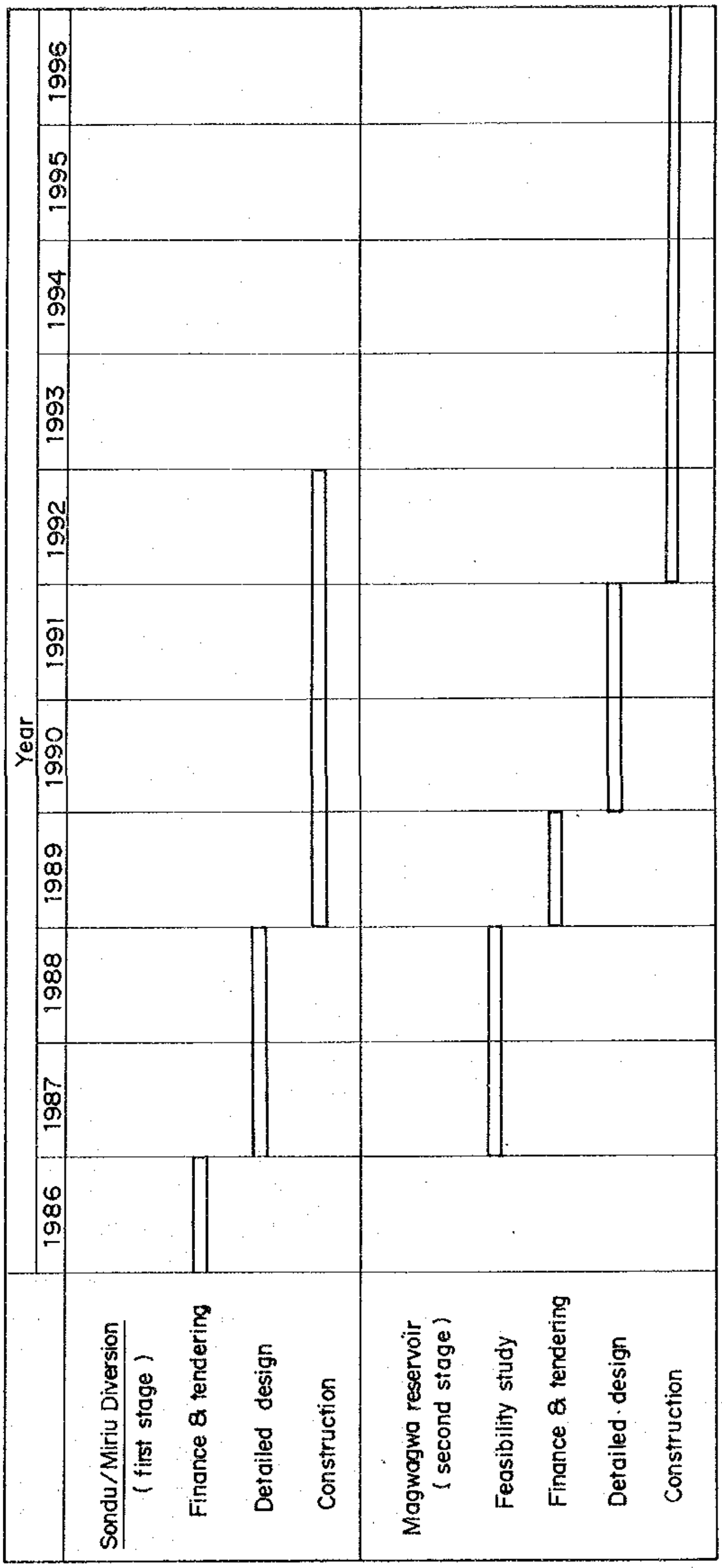

Figure 3.2
Implementation Time
Schedule of the Sondu/Miriu Project

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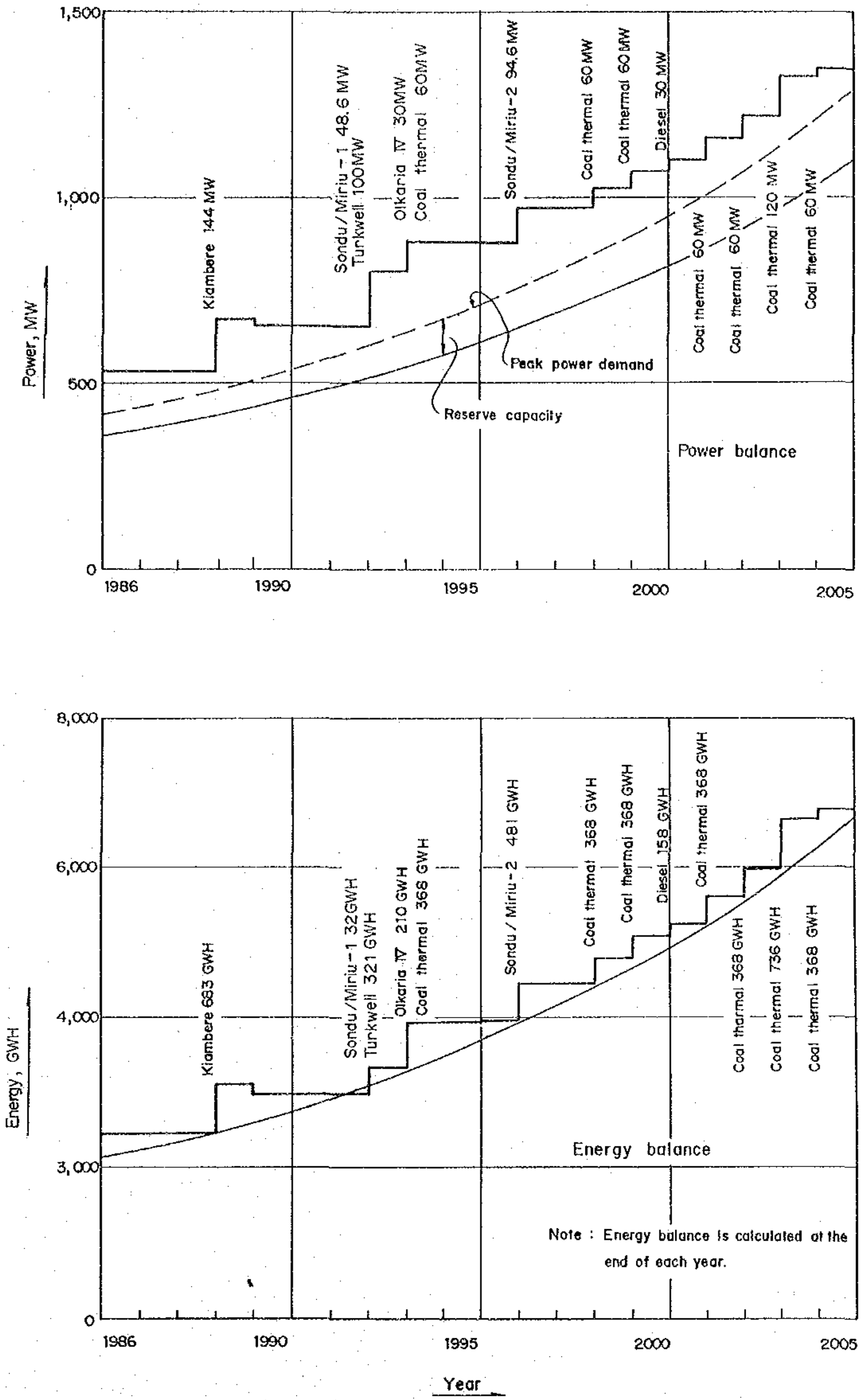

Figure 4.1
Peak Power and Energy Balance
in KP&L Power Supply System
(Sensitivity test: 15% discount rate)

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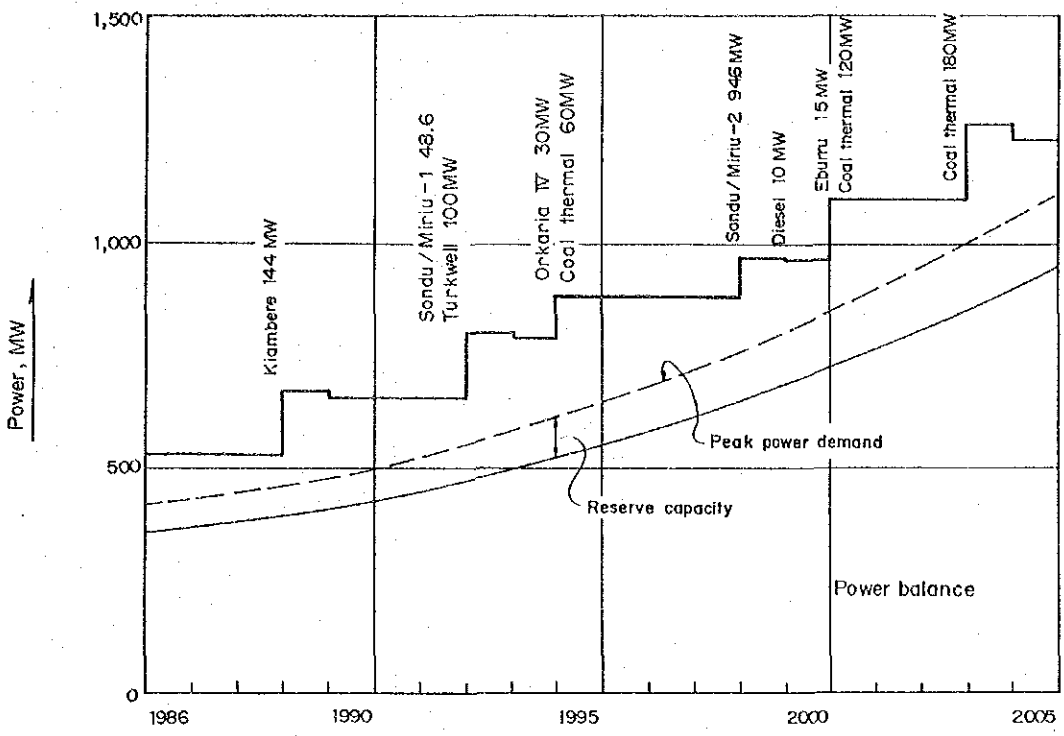

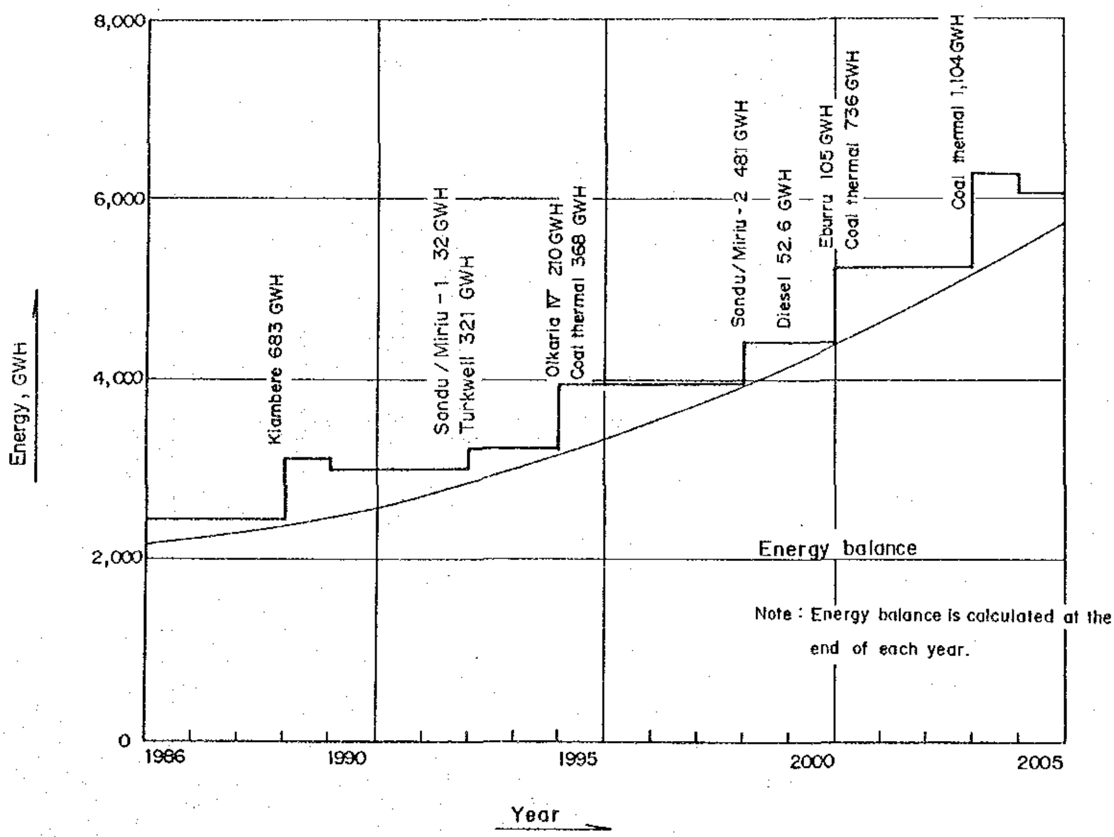

Figure 4.2
Peak Power and Energy Blance in KP&L Power Supply System (Low demand forecest)

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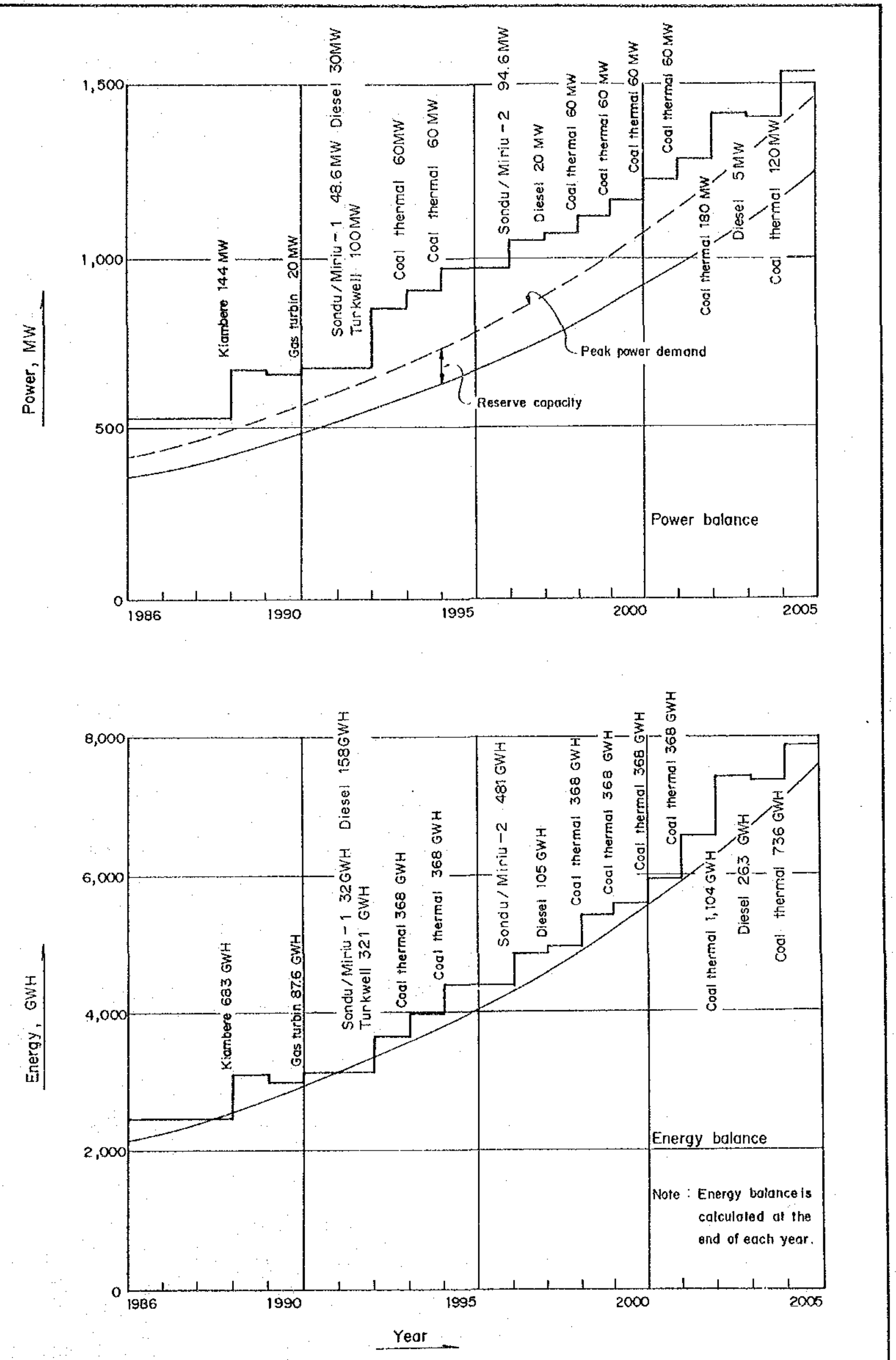

Figure 4.3
Peak Power and Energy Balance in KP&L Power Supply System (High demand forecest)

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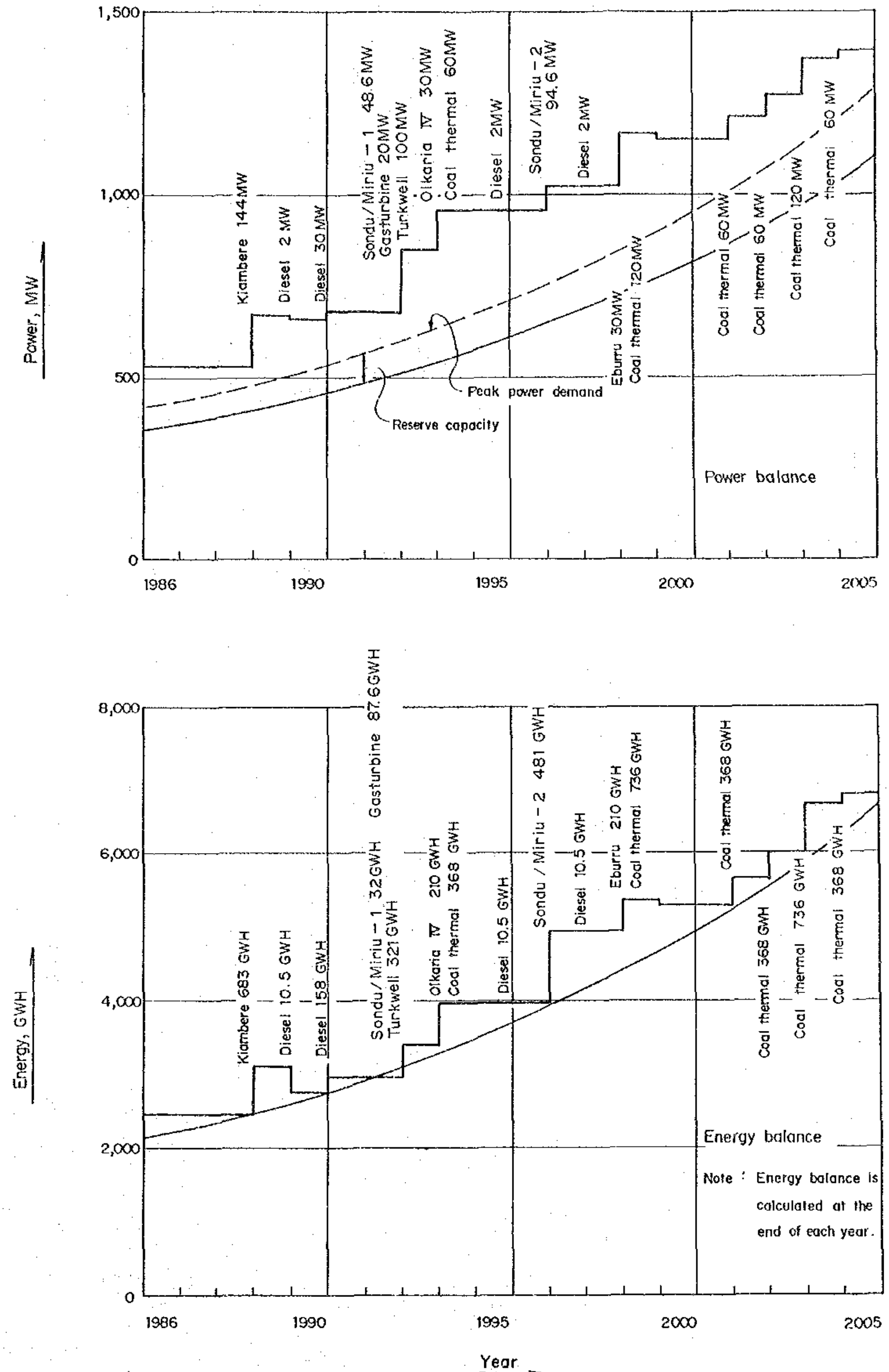

Figure 4.4
Peak Power and Energy Balance in KP&L Power Supply System (Non-form for the energy imported from the UFB after 1988)

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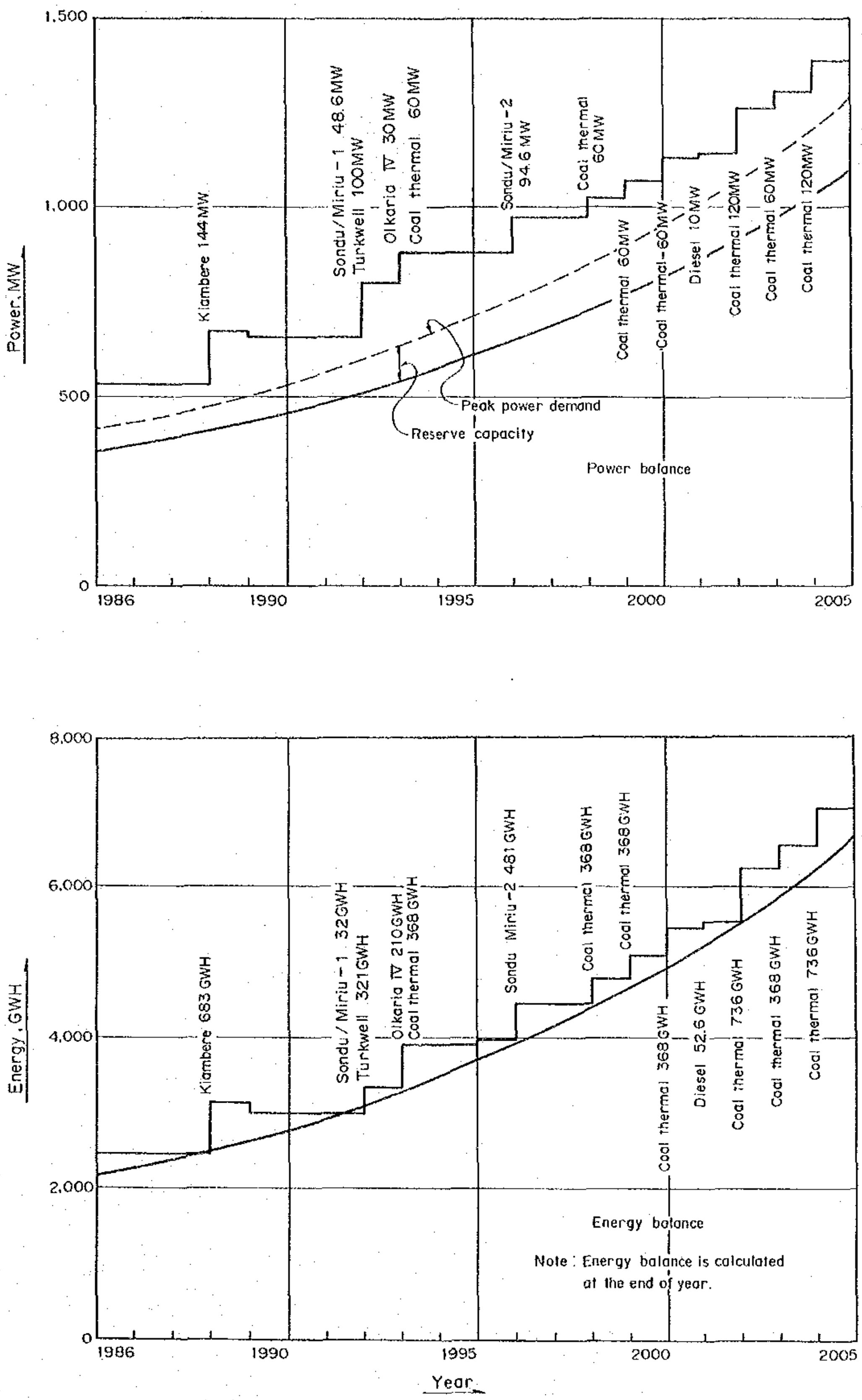

Figure 4.5
Peak Power and Energy Balance in KP&L Power Supply System (Cost allocation)

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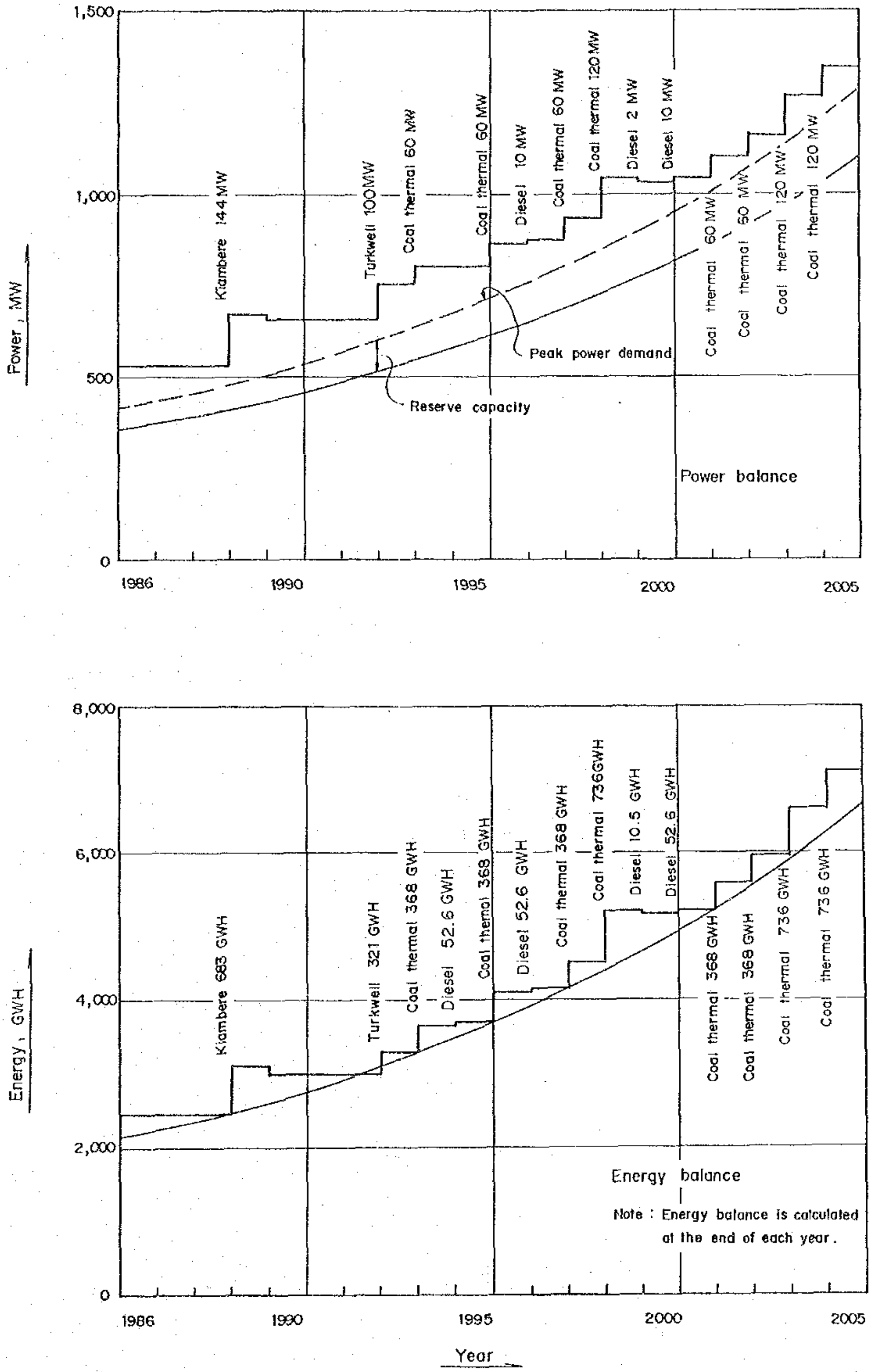

Figure 4.6
Peak Power and Energy Balance in KP&L Power Supply System (Thermal candidates only)

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APPENDIX VI CONSTRUCTION PLAN AND COST ESTIMATE

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Chapter 1. CONSTRUCTION PLAN AND SCHEDULE

1.1 General

On the basis of the preliminary design, the construction plan for the Sondu River Multipurpose Development Project gives an outline of possible procedures, construction sequences, construction methods and types of plant and equipment for the smooth execution of the project. The construction methods and equipment described herein are developed by assuming that the construction works will be performed by an international contract basis.

All the project works will be fundamentally executed by contractors selected by means of international competitive tender including prequalification except the engineering services. The following are modes of construction for the project works.

- Main civil works (River diversion, waterway, power station including building works, outlet channel and road construction)	:	International competitive tender
- Metal works (Weir metal work, intake metal work and penstock metal work)	:	International competitive tender
- Generating equipment & transmission line (Generating equipment, substation equipment and transmission line)	:	International competitive tender
- Engineering services (Detailed design and construction supervision)	:	Direct order