REPUBLIC OF KENYA

LAKE BASIN DEVELOPMENT AUTHORITY

# SONDU RIVER MULTIPURPOSE DEVELOPMENT PROJECT

## VOLUME IV (PART 2)

## SUPPORTING STUDY REPORT FOR HYDROPOWER PLAN

DECEMBER 1987

JAPAN INTERNATIONAL COOPERATION AGENCY

NAIROBI OFFICE
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TOKYO, JAPAN

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1/ Sir Alexander Gibb & Partners, Kenya Nile Basin Water Resources Survey, 1954-6

2/ UNDP-Lotti/WLPU, Lake Basin River Catchment Development River Profile Studies, Draft Final Report Vol. II A, March 1985

# Chapter 1. OBJECTIVES

The Sondu River, one of six major rivers in the Lake Victoria basin, originates from the western slope of the Mau Escarpment and flows down westwards gathering major tributaries, Yurith and Kipsonoi rivers, draining the catchment of 3,470 $km^2$ at the river mouth. The Yurith River which passes Kericho areas with annual precipitation of more than 2,000 mm is characterized as the river with ample flow. Furthermore, after the Yurith and Kipsonoi river merges, the Sondu River comes into the narrow gorge penetrating the Nyakach Escarpment and falls in cascade with scenery waterfalls called Odino falls to the flood plains at Nyakwere. Elevation falls from Sondu village (El. 1,500 m) to the foot of escarpment (El. 1,200 m) are around 300 m for a distance of some 25 km. With such ample flow and great elevation falls, the Sondu River is marked as a river with high development potential of hydropower generation.

Vast tracts of more than 60,000 ha extend in the Kano Plain, an adjacent river basin of the Sondu on the north, where fertile soils promise high potentiality of agricultural development, provided that water necessary for agricultural production is sufficiently available.

In this circumstance, several development schemes to utilize ample flow and available head of the Sondu River have been identified and elaborated to enhance agricultural production in the Kano Plain and to generate hydropower. The primary objectives in this optimization study are to search the optimal development scale of the Sondu/Miriu hydropower project combining other identified schemes to utilize ample flow and available head of the Sondu River so that net gains yielded from power generation and irrigation can be maximized.

## Chapter 2. POTENTIAL SCHEMES

The schemes identified for hydropower generation in the Sondu River and the irrigation development in the Kano Plain are depicted in Figure 2.1, and brief explanation of each scheme is given by category; diversion, storage and irrigation schemes.

Diversion schemes are the inter-basin transfer of the Sondu River flow to the Kano Plain in order to generate hydropower using head created by trans-basin and to supply irrigation water.

The schemes contemplated are:

Scheme D-1: Sondu/Miriu diversion scheme

The diversion site is located about 18 km downstream from Sondu village. A 4 km long waterway heading Thurdibuoro village makes possible transfer of flow of the Sondu River and some 150 m head is to be created with this diversion.

Scheme D-2: Nyamarimba diversion scheme

Water diverted 1 km downstream from Miriu village is conveyed to Nyamarimba village with an open channel along El. 1,440 m contour, and then led with a 3 km long penstock down the escarpment towards 1 km east of Okanowach village. Created head is some 230 m.

Scheme D-3: Sondu-Maraboi diversion scheme

Sondu River flow is diverted 2 km upstream from the big bend of the Sondu near Sondu village and is conveyed to Kaplelatet village with an open channel along El. 1,520 m contour. A 3 km long penstock leads diverted water to the Asawo River near Onywongo village. The head created with this diversion is some 240 m.

Storage schemes are planned to increase firm discharge for power generation and to extend irrigation areas in the Kano Plain.

The impounding reservoir schemes contemplated are:

Scheme S-1: Magwagwa reservoir scheme

The site about 10 km upstream from Sondu village has a topographic favour to create a large scale impounding reservoir by building a 100 m high scale dam. The damsite proposed in the Interim Report was shifted to the downstream reach by some 1.5 km for the reduction of the construction cost, although the construction of a saddle dam is necessitated for keeping the active storage required.

Scheme S-2: Magwagwa reservoir scheme plus waterway

This is a plan with an 8 km long waterway from the Magwagwa reservoir to Pala village located 4 km downstream from Sondu village, and elevation falls of 100 m become available for power generation with this waterway in addition to the head created by dam. It is noted that this plan and Sondu-Maraboi diversion scheme (Scheme D-3) are mutually exclusive.

Scheme S-3: Sondu/Miriu reservoir with the diversion scheme

This plan is to build a reservoir at the Sondu/Miriu diversion site for increasing firm discharge to be diverted from the Sondu River flow. Moreover, construction of a dam makes it available for power generation additional head of nearly 80 m besides elevation falls by trans-basin(Scheme D-1).

Irrigation schemes which are to be combined with the abovementioned schemes are contemplated as follows.

Scheme I-1: Irrigation scheme for the left bank areas of the Nyando River in the Kano Plain (15,610 ha)

The development of this scheme relies on the Sondu River flow as a water source. It is confirmed in the subsequent Appendix VII, Extensible Irrigation Area in Kano Plain, that irrigation water requirements of this scheme are sufficed with the natural flow of the Sondu River. In other words, the diversion plan of the Sondu River flow (Scheme D-1 to 3) makes possible not only power generation, but also the full development of this irrigation scheme.

Scheme I-2: Irrigation scheme for the whole area of the Kano Plain (25,610 ha)

The Nyando River is the primal water source for the right bank areas of the Nyando River, but the availability of the Nyando River flow is not enough for the full development of the right bank areas of the Nyando, so that the Sondu River flow is supplementarily used to suffice water requirements.

The basic plans of the diversion and storage schemes were elaborated only for hydropower in this chapter, whilst the plans for the irrigation schemes in the Kano Plain are separately discussed in the subsequent Appendix VII, Extensible Irrigation Area in Kano Plain.

Figure 2.2, 2.3 and 2.4 show a general view of the Sondu/Miriu (Scheme D-1), Nyamarimba (Scheme D-2) and Sondu-Maraboi (Scheme D-3) diversion schemes. For the Sondu-Maraboi diversion scheme, a plan with a single powerhouse was studied instead of the plan with two powerhouses in a series previously conceived by Sir Alexander Gibb and Partners[1/] in order to reduce construction costs.

The plans of the Magwagwa reservoir scheme (Scheme S-1 & 2) are depicted in Figure 2.5 and 2.6, and its reservoir storage curve is shown in Figure 2.7, whilst the basic plan and reservoir storage curve for the Sondu/Miriu reservoir scheme (Scheme S-3) are in Figures 2.8 and 2.9.

## Chapter 3. DEVELOPMENT STRATEGIES

### 3.1 Combination Plans

Combination plans to seek the optimal development of power generation and irrigation are contemplated by combining the schemes by category as discussed below.

Combination-A , the basic idea of which is shown in Figure 3.1-A, is the plan to combine the best run-of-river scheme out of Scheme D-1 (Sondu/Miriu diversion) to Scheme D-3 (Sondu-Maraboi diversion) with the irrigation scheme (Scheme I-1) as shown in Figure 3.1-A.

Basic concepts of this combination plan are to maximize net benefits yielded from power generation and irrigation development only depending on the natural flow of the Sondu.

Combination-B is the plan to combine the Sondu/Miriu reservoir (Scheme S-3) with the irrigation development for the whole area of the Kano Plain (Scheme I-2) as shown in Figure 3.1-B.

Main discussions of this plan are not only to find out the optimal development scale of the reservoir for power generation, but also to search the possibility of extension of irrigation areas beyond the Nyando River.

Combination-C is the plan to combine the Magwagwa reservoir plus waterway as an impounding function (Scheme S-2) with the irrigation development for the whole area of the Kano Plain (Scheme I-2), and then either of the Sondu/Miriu (Scheme D-1) or Nyamarimba (Scheme D-2) schemes is selected as the function of trans-basin (refer to Figure 3.1-C).

This plan intends to efficiently use the available head in the Sondu River with the long waterway as well as to regulate the flow of the Sondu with the Magwagwa reservoir.

Combination-D is the plan to build reservoirs in a series at Magwagwa (Scheme S-2) and Sondu/Miriu (Scheme S-3), and to supply water to the irrigation areas extended in the whole Kano Plain (refer to Figure 3.1-D).

This plan aims at developing the Sondu River as much as possible in both of head and flow.

Combination-E is the plan to combine the Magwagwa reservoir (Scheme S-1) with the irrigation development for the whole area of the Kano Plain (Scheme I-2), and then the Sondu-Maraboi diversion (Scheme D-3) is selected as the trans-basin plan for utilizing the head of the Sondu efficiently (refer to Figure 3.1-E).

## 3.2 Simulation Models

Simulation models were built for calculating benefits and costs of each combination plan and for searching the optimal development scheme. The optimal development scale of the Sondu/Miriu hydropower plan and the most adequate combination plan are, first of all, defined as the oneto maximize the net benefit in present worth between costs necessary for power and irrigation development and benefits yielded by saling generated energy and agriculture products.

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

$$\frac{dS}{dt} = I - Q - E \qquad \ldots\ldots (1)$$

where S : storage in the reservoir
E : evaporation from the reservoir surface
t : time.

A constant release, Q, from the reservoir is, first of all, decided to warrant firm power generation through the year. However, if irrigation water requirement of a month is greater than the fixed constant release, water release is accorded to irrigation water requirements.

Once the release rate from the reservoir is selected, the active storage required is computed giving inflow data into Eq. (1), or the storage-draft curve, which shows the variation of active storage required by varying the release rate from the reservoir as discussed in Appendix III, Hydrology and Meteorology.

On the other hand, a flow duration curve, which is the rearrangement of the daily runoff recorded in a time period in a descending numerical order, is used for the determination of development scale of the run-of-river type plant.

In case that several schemes are contemplated in a series in a river course, outflow from the scheme located in the uppermost reach is treated as inflow for the second scheme; that is, a storage-draft curve or flow duration curve for the second scheme is re-constructed using the outflow from the uppermost scheme and inflow from the remaining catchment. Same procedures are used for the third scheme and so on.

Computer programs were elaborated to suit the models of Combination A to E. Figure 3.2 depicts the inter-relation among the programs.

## 3.3 Conditions and Assumptions for the Simulation Model

Numerous conditions and assumptions were set forth for the simulation model described above and are itemized as follows:

(1) It is confirmed in the pre-feasibility study of the Kano Plain irrigation project that water requirements of Scheme I-1 can be sufficed by the run-of-river of either of Scheme D-1 to 3. Thus,

the Sondu/Miriu and Magwagwa reservoir schemes are optimized with view of extending irrigation areas beyond the Nyando River.

In searching the possibilities to extend irrigation areas beyond the Nyando River, set up is a criteria that water required in the areas of the left bank of the Nyando is supplied from the Sondu, whilst the right bank areas of the Nyando are in principle furnished with water of the Nyando. In case that deficits occur, water to fulfill requirements is augmented from the Sondu.

(2) Irrigation areas beyond the Nyando River are extended by 5,000 ha upto the presumed maximum potential area in the right bank of the Nyando; 10,000 ha is presumed to be maximum gross area.

(3) Irrigation water requirements for the left bank areas of the Nyando are based on the estimates discussed in the subsequent Appendix VII, Extensible Irrigation Area in Kano Plain, whilst Lotti's estimates[2/] for the right bank areas.

(4) Several water supply projects are contemplated in the upper reaches of the Sondu and Nyando rivers as discussed in Appendix III on Hydrology and Meteorology, and demands are estimated at an order of 0.3 to 0.4 $m^3$/sec. For the simulation models, an amount of 0.5 $m^3$/sec is in advance deducted as future consumption from natural flow of the Sondu and Nyando rivers.

(5) Sediment formation is assumed to be horizontal in the reservoir for a 100-year project life of sediment.

(6) Runoff data at 1JG1 are converted to the reservoir sites by the ratio of catchment (Catchment at the Magwagwa and Sondu/Miriu sites is 3,160 and 3,360 $km^2$, respectively.), whilst runoff data at 1GD1 and 1GD4 are transferred to the irrigation intake site of the Nyando.

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

(8) Reservoir simulation is carried out for the period of June, 1946 to May, 1983. However, the simulation is commenced from June, 1948, when the Nyando River water is taken into account.

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

(10) Required active storage is defined as the storage which warrants a selected firm discharge for power generation and irrigation water requirements for selected command areas for a 10-year drought.

(11) The definition of firm power especially on the run-of-river type is accorded to the rule of the KP&L; that is, firm power is calculated based on firm discharge defined as discharge to warrant more than 90% of time on the period between January and March.

(12) The run-of-river type plant is operated as 8-hour peak and 16-hour off-peak plant for firm discharge, and then the rate on peak operation is estimated by dividing firm discharge by 0.6, a presumed load factor. A daily regulating pondage is designed for the regulation of firm flow as the 8-hour peak plant.

(13) Installed capacity of the reservoir type plant is rated at 8-hour peak operation, whilst the installed capacity of the run-of-river type plant is determined by selecting the optimum among the plant factors varied between the minimum one estimated from the plant discharge obtained by dividing firm discharge by 0.6 (a presumed load factor as mentioned above) and the maximum one assumed to be 0.5.

(14) Combined efficiency of the turbine and generator is assumed to be 0.84.

(15) Tailwater level of the power plant is set at El. 1,205 m to maximize the extension of irrigation areas in the Kano and Nyakach plains, whilst El. 1,280 m for the Sondu/Maraboi diversion plan.

The criteria and conditions used for the discounting technique which evaluates present worth of benefits and costs are itemized as follows:

(1) Construction costs are estimated based on the price level of December 1984 (Exchange rate: US$1.00=KShs 15.00).

(2) A list of unit costs for estimating construction costs is given in Table 3.1.

(3) A time period of project evaluation is taken as 50 years from date into service.

(4) A discount rate of 10% is adopted for the calculation of present worth.

(5) A long run marginal cost of US$0.0573/kWh is applied for the calculation of power benefits, and the value of secondary and dump energies is assumed to be 60% and 10% of firm energy, respectively.

(6) Dam and waterway (intake to tailrace) costs besides specific costs for power generation are fully allocated to the power sector for assessing viability of Sondu/Miriu hydropower generation plan itself.

(7) Costs necessary for engineering services are assumed to be 10% of direct construction cost.

(8) Physical contingency is taken as 15% of sum of direct and engineering services costs.

(9) Operating and maintenance costs for power generation are taken as 1% of total cost.

(10) Construction time periods of run-of-river and reservoir types are assumed to be 4 and 5 years, respectively. Disbursement of construction costs is assumed to be 0.15, 0.35, 0.30 & 0.20 and 0.15, 0.25, 0.30, 0.20 & 0.10 for the former and latter, respectively.

(11) Economic cost is assumed to be 94% of total cost. The value of 94% was estimated based on the assumption as follows:

(a) 70% of total cost is shared by foreign loan, whilst 30% by domestic finance.

(b) A full amount of foreign share is counted as economic cost.

(c) 80% of domestic share is counted as economic cost considering the opportunity cost and shadow price.

(d) Accordingly, economic cost assumed is

$$0.7 \times 1.0 + 0.3 \times 0.8 = 0.94.$$

# Chapter 4. PLAN OPTIMIZATION

First approach for the optimization of development plan is to look for the optimal development scale in each Combination A to E.

(1) In Combination-A, alternative development plans of each diversion scheme are contemplated by varying maximum plant discharge, since available flow is pre-determined by the flow duration curve. Plant discharge tested was ranged from 7.3 $m^3$/sec to 64.7 $m^3$/sec as shown in Table 4.1. Economic benefits and costs for each alternative plan are computed based on the simulation results and criteria mentioned in the preceding Chapter 3.

A plan with plant discharge of 29.6 $m^3$/sec on the Sondu-Maraboi diversion scheme was selected as an optimum from Combination-A as shown in Figure 4.1. A cost breakdown on the optimal development scale of each diversion scheme is shown in Table 4.2 as a reference. It is noted that irrigation areas in this plan are 15,610 ha extended in the left bank of the Nyando.

(2) Major tasks in Combination-B (Sondu/Miriu reservoir plan) are to search possibilities to extend irrigation areas beyond the Nyando as well as the scale of power generation. Figure 4.2 shows the results of simulation; inter-relation among firm discharge for power generation, dam height (full supply level or required active storage) and extensible irrigation area.

This figure tells that if firm discharge for power generation is optimized over point I (15.0 $m^3$/sec), irrigation area is no more related as a function to determine an optimal reservoir scale; that is, irrigation area can be extended to the maximum (25,610 ha). Furthermore, this figure suggests that if firm discharge for power generation is optimized over point II (16.8 $m^3$/sec), maximum extension of irrigation area is possible even without supply from the Nyando River.

Based on the simulation results shown in Figure 4.2, optimization was carried out for Combination-B. A plan with firm discharge of 17.1 $m^3$/sec, even if net benefit is negative, was selected as optimal for power generation as given in Figure 4.3, so that maximum net benefit of Combination-B is obtained in full extension of irrigation area. A cost breakdown of the optimal development scale on Combination-B is shown in Table 4.2 as a reference.

(3) Combination-C is conceived as a competitive combination plan against Combination-B, although detailed geological and topographic investigations have not been carried out for the Magwagwa reservoir site. Plan formulation of Magwagwa scheme is worked out based on the topographic map of 1/50,000 scale. A rockfill type dam was chosen for the estimate of construction costs of the Magwagwa plan due to insufficient information on geology, notwithstanding topography at the damsite attracts to build a concrete gravity type dam.

With the above premise, carried out was simulation of Combination-C, in which the Sondu/Miriu diversion scheme was selected as the trans-basin plan due to that the comparative study of Combination-A disclosed that the net benefit of the Sondu/Miriu diversion is greater than that of the Nyamarimba diversion and that the Sondu-Maraboi diversion is mutually exclusive against Combination-C.

In the procedure of simulation, an optimal development scale of the reservoir was, first of all, searched for a single purpose of hydropower development, because it was clarified in the simulation of Combination-B that maximum extension of irrigation area is possible, if firm discharge for power generation is optimized over point I (15.0 $m^3$/sec in Figure 4.2.).

Figure 4.4 shows the relationship between firm discharge and reservoir scale of the Magwagwa based on the results of simulation for a single purpose of hydropower development. On the other hand, alternative development plans for the Sondu/Miriu run-of-river scheme were studied by re-constructing the flow duration curve based on the release rates from the Magwagwa reservoir. Table 4.3 shows the simulation results for the selected release rates. Based on these information, benefits and costs on alternative plans of Combination-C were estimated as shown in Figure 4.5, and consequently,maximum net benefit was gained at the combination of firm discharge of 24.1 $m^3$/sec of the Magwagwa reservoir and plant discharge of 39.9 $m^3$/sec of the Sondu/Miriu run-of-river. As a reference, a cost breakdown of the optimal development scale on Combination-C is given in Table 4.2.

(4) Combination-D which is the plan with both Magwagwa and Sondu/Miriu reservoirs in a series seeks possibilities to develop the Sondu River water as much as possible. The simulation procedure for the Magwagwa reservoir was same as that used in Combination-C, but the storage draft curve for the Sondu/Miriu reservoir was re-constructed by treating the outflow from the Magwagwa reservoir as the inflow to the Sondu/Miriu reservoir. It is, furthermore, assumed that the Magwagwa reservoir traps all the sediment into the reservoir; that is, the sediment to the Sondu/Miriu reservoir comes only from the remaining catchment.

The results of the optimization of Combination-D in Figure 4.6 disclose that the development of 25 to 26 $m^3$/sec in terms of firm discharge is deemed to be maximum development degree of the Sondu River. This may imply that additional investment for building the Sondu/Miriu dam yields less increment of benefits compared with Combination-C.

(5) Combination-E, being mutually exclusive for Combination-B and C, was simulated with the same procedure applied for Combination-C; that is, alternative development plans for the Sondu-Maraboi run-of-river were studied by re-constructing the flow duration curve based on the release rates from the Magwagwa reservoir.

Based on the simulation results, a relationship between benefits and costs for the alternative plans of Combination-E was given in Figure

4.7, and consequently maximum net benefit was obtained at the combination of firm discharge of 24.1 $m^3$/sec of the Magwagwa reservoir and plant discharge of 39.9 $m^3$/sec of the Sondu-Maraboi run-of-river.

The optimal development plans of each combination alternative are depicted in Table 4.4 with benefits and costs from the irrigation plan discussed separately in the subsequent Appendix VII, Extensible Irrigation Area in Kano Plain. Combination-C, the Magwagwa reservoir with a waterway plus the Sondu/Miriu run-of-river, was proposed as an optimal combination because of highest net benefit. The development features of it are:

<u>Magwagwa reservoir plus waterway plan</u>

| | | |
|---|---|---|
| Firm discharge | : | 24.1 $m^3$/sec |
| Plant discharge (8-hour peak operation) | : | 72.3 $m^3$/sec |
| Full supply level | : | El. 1,662.9 m |
| Minimum operating level | : | El. 1,606.3 m |
| Dam crest elevation | : | El. 1,667.9 m |
| Dam height | : | 100.9 m |
| Active storage | : | 590.7 million $m^3$ |
| Installed capacity | : | 94.6 MW |
| Firm energy | : | 276.2 GWh/yr |
| Secondary energy | : | 57.9 GWh/yr |

<u>Sondu/Miriu run-of-river plan</u>

| | | | |
|---|---|---|---|
| Firm discharge | : | 24.1 $m^3$/sec | (3.3 $m^3$/sec) |
| Plant discharge | : | 39.9 $m^3$/sec | (29.6 $m^3$/sec) |
| Installed capacity | : | 48.6 MW | (32.8 MW) |
| Firm energy | : | 237.5 GWh/yr | (32.0 GWh/yr) |
| Secondary energy | : | 14.9 GWh/yr | (155.6 GWh/yr) |

Note: Figures in parentheses are the scale of the Sondu/Miriu diversion scheme only (Scheme D-1).

Outputs from both plants

| | | |
|---|---|---|
| Installed capacity | : | 143.2 MW |
| Firm energy | : | 513.7 GWh/yr |
| Secondary energy | : | 72.8 GWh/yr |

Irrigation area

| | | |
|---|---|---|
| In the left bank of the Nyando | : | 15,610 ha |
| In the right bank of the Nyando | : | 10,000 ha |

The development of Combination-C is recommended not only with the highest net benefit among the combinations, but also with the merits that the Sondu/Miriu site has been investigated and the Sondu/Miriu run-of-river power plan itself is viable with the economic internal rate of return of 10.95% (figure from Combination-A). Namely, stage development can be conceived on Combination-C and the possibility of stage development on Combination-C will be discussed in the subsequent planting-up study of the KP&L power system.

The unit energy production cost of the hydropower generation schemes of Combination-C was calculated to be 5.49 US¢/KWh. Furthermore, it is noted, as merits of Combination-C, that the Magwagwa reservoir development makes possible not only irrigation schemes for the whole area in the Kano Plain, but also bears great energy of more than 500 GWh/yr in firm basis.

On the other hand, the development of 24.1 $m^3$/sec in terms of firm discharge, around 60% of average flow (41.6 $m^3$/sec), may not be so large as to cause influence to river conservation in the downstream reaches of the Sondu. Furthermore, water supply to the permit holders of water abstraction in the lower reaches from the Nyakwere village is warranted by taking from the irrigation canal.

# *TABLES*

Table 3.1 Unit Price for Major Civil Works

| Work Item | Unit | Foreign Currency (US$) | Local Currency (KShs.) |
|---|---|---|---|
| Excavation, common (l=1,000m) | $m^3$ | 3.30 | 11.00 |
| - do - (l=2,000m) | $m^3$ | 3.80 | 12.20 |
| - do - (l=3,000m) | $m^3$ | 4.10 | 13.60 |
| Excavation, weathered rock (l=1,000m) | $m^3$ | 4.80 | 16.50 |
| - do - (l=2,000m) | $m^3$ | 5.30 | 18.00 |
| - do - (l=3,000m) | $m^3$ | 5.80 | 19.50 |
| Excavation, rock (l=1,000m) | $m^3$ | 10.10 | 55.60 |
| - do - (l=2,000m) | $m^3$ | 10.60 | 57.60 |
| - do - (l=3,000m) | $m^3$ | 11.20 | 59.90 |
| Embankment (l=500m) | $m^3$ | 3.80 | 13.80 |
| Fill & backfill (l=1,000m) | $m^3$ | 4.40 | 15.80 |
| - do - (l=2,000m) | $m^3$ | 4.80 | 17.00 |
| - do - (l=3,000m) | $m^3$ | 5.20 | 18.20 |
| Excavation, tunnel | $m^3$ | 44.10 | 369.00 |
| - do - , shaft | $m^3$ | 33.20 | 201.00 |
| Concrete, weir, slab | $m^3$ | 42.50 | 342.00 |
| - do - , structure (l=6,000m) | $m^3$ | 50.40 | 402.00 |
| - do - , structure (l= 500m) | $m^3$ | 44.20 | 376.00 |
| - do - , superstructure | $m^3$ | 45.40 | 409.00 |
| - do - , tunnel | $m^3$ | 54.60 | 478.00 |
| - do - , shaft | $m^3$ | 60.50 | 482.00 |
| Formwork, weir | $m^2$ | 2.00 | 49.80 |
| - do - , structure | $m^2$ | 2.50 | 55.50 |
| - do - , tunnel | $m^2$ | 7.40 | 36.40 |
| - do - , shaft | $m^2$ | 16.00 | 81.30 |
| Reinforcing bar | ton | 504.00 | 4,190.00 |
| Steel support | ton | 700.00 | 4,500.00 |
| Steel structure | ton | 1,050.00 | 5,250.00 |
| Consolidation grout, open | m | 46.30 | 246.00 |
| - do - , tunnel | m | 32.90 | 238.00 |
| Curtain grout | m | 81.00 | 536.00 |
| Backfill grout | $m^3$ | 38.00 | 385.00 |
| Gravel surface | $m^3$ | 10.90 | 46.60 |
| Slope protection, concrete | $m^2$ | 8.80 | 75.20 |
| - do - , gunite | $m^2$ | 13.00 | 138.00 |
| Asphalt pavement | $m^2$ | 10.30 | 6.30 |
| Fence | m | 10.00 | 96.00 |
| U-drain ditch | m | 4.40 | 100.00 |

Table 4.1 Study by Run-of-River Type (1/3)
(Sondu/Miriu Diversion Scheme, D-1)

| Case No. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Plant Factor | 0.94 | 0.90 | 0.80 | 0.70 | 0.60 | 0.50 |
| Firm Discharge, $m^3/s$ | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 |
| Plant Discharge, $m^3/s$ | 7.3 | 10.1 | 18.4 | 29.6 | 45.1 | 64.7 |
| Net Head, m | 119.6 | 116.7 | 128.2 | 134.5 | 138.7 | 141.4 |
| Firm Power, KW | 3249 | 3171 | 3482 | 3654 | 3767 | 3841 |
| Installed Capacity, KW | 7230 | 9713 | 19452 | 32828 | 51511 | 75268 |
| Firm Eergy, GWh/Yr | 28.46 | 27.78 | 30.51 | 32.01 | 33.00 | 33.65 |
| Secondary Energy, GWh/Yr | 31.44 | 49.42 | 106.61 | 155.55 | 160.36 | 163.50 |
| Dump Energy, GWh/Yr | 0. | 0. | 0. | 14.45 | 27.95 | 133.74 |
| Total Energy, GWh/Yr | 59.90 | 77.20 | 137.11 | 202.01 | 271.29 | 330.89 |

Table 4.1 Study by Run-of-River Type (2/3)
(Nyamarimba Diversion Scheme, D-2)

| Case No. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Plant Factor | 0.94 | 0.90 | 0.80 | 0.70 | 0.60 | 0.50 |
| Firm Discharge, $m^3/s$ | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 |
| Plant Discharge, $m^3/s$ | 7.3 | 10.1 | 18.4 | 29.6 | 45.1 | 64.7 |
| Net Head, m | 185.9 | 198.4 | 215.9 | 225.6 | 231.9 | 236.1 |
| Firm Power, KW | 5049 | 5391 | 5866 | 6128 | 6300 | 6413 |
| Installed Capacity, KW | 11235 | 16512 | 32766 | 55053 | 86153 | 125673 |
| Firm Eergy, GWh/Yr | 44.23 | 47.22 | 51.39 | 53.68 | 55.19 | 56.18 |
| Secondary Energy, GWh/Yr | 48.87 | 84.02 | 179.57 | 260.86 | 268.17 | 272.99 |
| Dump Energy, GWh/Yr | 0. | 0. | 0. | 24.23 | 130.37 | 223.31 |
| Total Energy, GWh/Yr | 93.09 | 131.24 | 230.96 | 338.77 | 453.73 | 552.47 |

Table 4.1 Study by Run-of-River Type (3/3)
(Sondu-Maraboi Diversion Scheme, D-3)

| Case No. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Plant Factor | 0.94 | 0.90 | 0.80 | 0.70 | 0.60 | 0.50 |
| Firm Discharge, $m^3/s$ | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 |
| Plant Discharge, $m^3/s$ | 7.3 | 10.1 | 18.4 | 29.6 | 45.1 | 64.7 |
| Net Head, m | 172.6 | 183.5 | 198.5 | 206.9 | 212.3 | 215.9 |
| Firm Power, KW | 4689 | 4984 | 5394 | 5620 | 5768 | 5865 |
| Installed Capacity, KW | 10434 | 15265 | 30127 | 50486 | 78877 | 114942 |
| Firm Eergy, GWh/Yr | 41.07 | 43.66 | 47.25 | 49.23 | 50.52 | 51.38 |
| Secondary Energy, GWh/Yr | 45.38 | 77.68 | 165.11 | 239.21 | 245.52 | 249.68 |
| Dump Energy, GWh/Yr | 0. | 0. | 0. | 22.22 | 119.36 | 204.24 |
| Total Energy, GWh/Yr | 86.46 | 121.33 | 212.36 | 310.66 | 415.41 | 505.30 |

Table 4.2 Economic Cost for Construction

( Unit : million US$ )

| Work Item | Combination-A | | | Combination-B | Combination-C | | Combination-D | | Combination-E | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sondu /Miriu R-O-R | Maraboi R-O-R | Nyamari-mba R-O-R | Sondu /Miriu Reservoir | Sondu /Miriu R-O-R | Magwagwa Reservoir | Magwagwa Reservoir | Sondu /Miriu Reservoir | Maraboi R-O-R | Magwagwa Reservoir |
| I. Preparatory Works | 4.00 | 6.31 | 7.95 | 10.53 | 4.69 | 11.52 | 8.33 | 15.14 | 7.28 | 8.84 |
| II. Civil Works | | | | | | | | | | |
| 2.1 River Diversion Works | 0.43 | 1.17 | 3.06 | 5.09 | 0.43 | 5.38 | 5.38 | 5.09 | 1.17 | 5.38 |
| 2.2 Dam and Spillway | - | - | - | 60.45 | - | 39.34 | 19.84 | 97.00 | - | 39.34 |
| 2.3 Waterway | 13.93 | 20.42 | 31.37 | 9.67 | 16.77 | 26.98 | 22.71 | 12.50 | 21.75 | 14.36 |
| 2.4 Power Station | 2.75 | 2.78 | 2.82 | 2.98 | 2.84 | 2.31 | 2.20 | 3.04 | 2.87 | 1.92 |
| 2.5 Outlet Channel & Road | 0.94 | 0.83 | 0.88 | 0.94 | 0.97 | 0.84 | 0.84 | 0.97 | 0.85 | 0.84 |
| III. Metal Works | 8.46 | 19.94 | 23.06 | 8.83 | 9.13 | 14.90 | 13.53 | 9.90 | 22.82 | 10.69 |
| IV. Generating & Substation Equipment | 11.71 | 16.98 | 17.00 | 15.56 | 14.98 | 25.08 | 18.36 | 21.10 | 22.39 | 15.27 |
| V. Transmission Line | 1.82 | 0.99 | 1.32 | 1.82 | 1.82 | 0.41 | 0.41 | 1.82 | 0.99 | 0.58 |
| Total of I to V | 44.04 | 69.42 | 87.46 | 115.87 | 51.63 | 126.76 | 91.60 | 166.56 | 80.12 | 97.22 |
| VI. Engineering Service | 4.40 | 6.94 | 8.75 | 11.56 | 5.16 | 12.68 | 9.16 | 16.66 | 8.01 | 9.72 |
| VII. Physical Contingency | 7.27 | 11.45 | 14.43 | 19.12 | 8.52 | 20.92 | 15.11 | 27.48 | 13.22 | 16.04 |
| Total | 55.71 | 87.81 | 110.64 | 146.58 | 65.31 | 160.36 | 115.87 | 210.70 | 101.35 | 122.98 |
| Economic Cost (Total x 0.94) | 52.37 | 82.54 | 104.00 | 137.79 | 61.39 | 150.74 | 108.92 | 198.06 | 95.27 | 115.60 |

Table 4.3 Sondu/Miriu Run-of-River Plan in Combination-C (1/6)
(Firm release from the Magnagwa : 8 $m^3$/sec)

| Case No. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Plant Factor | 0.91 | 0.90 | 0.80 | 0.70 | 0.60 | 0.50 |
| Firm Discharge, $m^3$/s | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| Plant Discharge, $m^3$/s | 13.4 | 13.9 | 22.1 | 33.7 | 49.5 | 69.6 |
| Net Head, m | 122.6 | 123.4 | 130.9 | 135.9 | 139.4 | 141.9 |
| Firm Power, KW | 8065 | 8117 | 8608 | 8939 | 9169 | 9331 |
| Installed Capacity, KW | 13479 | 14150 | 23860 | 37745 | 56762 | 81309 |
| Firm Eergy, GWh/Yr | 70.65 | 71.11 | 75.40 | 78.31 | 80.32 | 81.74 |
| Secondary Energy, GWh/Yr | 36.89 | 40.68 | 92.02 | 129.71 | 133.05 | 135.40 |
| Dump Energy, GWh/Yr | 0. | 0. | 0. | 23.85 | 85.49 | 139.59 |
| Total Energy, GWh/Yr | 107.54 | 111.79 | 167.42 | 231.87 | 298.87 | 356.73 |

Table 4.3 Sondu/Miriu Run-of-River Plan in Combination-C (2/6)
(Firm release from the Magwagwa : 12 $m^3$/sec)

| Case No. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Plant Factor | 0.86 | 0.80 | 0.70 | 0.60 | 0.50 |
| Firm Discharge, $m^3$/s | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 |
| Plant Discharge, $m^3$/s | 19.8 | 24.8 | 35.4 | 49.7 | 69.0 |
| Net Head, m | 129.3 | 132.4 | 136.4 | 139.5 | 141.8 |
| Firm Power, KW | 12679 | 12981 | 13376 | 13675 | 13905 |
| Installed Capacity, KW | 21122 | 27065 | 39790 | 57109 | 80543 |
| Firm Eergy, GWh/Yr | 111.07 | 113.71 | 117.17 | 119.79 | 121.81 |
| Secondary Energy, GWh/Yr | 48.80 | 76.17 | 89.57 | 91.58 | 93.12 |
| Dump Energy, GWh/Yr | 0. | 0. | 37.55 | 89.35 | 138.20 |
| Total Energy, GWh/Yr | 159.87 | 189.89 | 244.30 | 300.72 | 353.13 |

Table 4.3 Sondu/Miriu Run-of-River Plan in Combination-C (3/6)
(Firm release from the Magwagwa : 16 $m^3$/sec)

| Case No. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Plant Factor | 0.83 | 0.80 | 0.70 | 0.60 | 0.50 |
| Firm Discharge, $m^3$/s | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| Plant Discharge, $m^3$/s | 26.5 | 28.7 | 38.4 | 51.8 | 70.4 |
| Net Head, m | 133.2 | 134.2 | 137.2 | 139.8 | 141.9 |
| Firm Power, KW | 17459 | 17582 | 17981 | 18321 | 18603 |
| Installed Capacity, KW | 29095 | 31722 | 43342 | 59644 | 82237 |
| Firm Eergy, GWh/Yr | 152.94 | 154.02 | 157.51 | 160.49 | 162.96 |
| Secondary Energy, GWh/Yr | 44.94 | 45.26 | 46.28 | 47.16 | 47.88 |
| Dump Energy, GWh/Yr | 13.16 | 23.02 | 62.19 | 106.34 | 149.18 |
| Total Energy, GWh/Yr | 211.04 | 222.30 | 265.99 | 313.98 | 360.03 |

Table 4.3 Sondu/Miriu Run-of-River Plan in Combination-C (4/6)
(Firm release from the Magwagwa : 20.1 $m^3$/sec)

| Case No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Plant Factor | 0.79 | 0.70 | 0.60 | 0.50 |
| Firm Discharge, $m^3$/s | 20.1 | 20.1 | 20.1 | 20.1 |
| Plant Discharge, $m^3$/s | 33.3 | 41.8 | 54.2 | 71.8 |
| Net Head, m | 135.8 | 138.0 | 140.1 | 142.1 |
| Firm Power, KW | 22276 | 22640 | 22992 | 23309 |
| Installed Capacity, KW | 37183 | 47501 | 62574 | 83945 |
| Firm Eergy, GWh/Yr | 195.14 | 198.33 | 201.41 | 204.19 |
| Secondary Energy, GWh/Yr | 21.82 | 22.18 | 22.52 | 22.83 |
| Dump Energy, GWh/Yr | 40.94 | 70.52 | 105.45 | 140.98 |
| Total Energy, GWh/Yr | 257.90 | 291.03 | 329.39 | 368.00 |

Table 4.3 Sondu/Miriu Run-of-River Plan in Combination-C (5/6)
(Firm release from the Magwagwa : 24.1 $m^3$/sec)

| Case No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Plant Factor | 0.75 | 0.70 | 0.60 | 0.50 |
| Firm Discharge, $m^3$/s | 24.1 | 24.1 | 24.1 | 24.1 |
| Plant Discharge, $m^3$/s | 39.9 | 44.9 | 56.5 | 73.0 |
| Net Head, m | 137.6 | 138.6 | 140.4 | 142.2 |
| Firm Power, KW | 27110 | 27317 | 27678 | 28019 |
| Installed Capacity, KW | 48556 | 51204 | 65296 | 85440 |
| Firm Eergy, GWh/Yr | 237.48 | 239.30 | 242.46 | 245.45 |
| Secondary Energy, GWh/Yr | 14.91 | 15.03 | 15.22 | 15.41 |
| Dump Energy, GWh/Yr | 46.08 | 59.52 | 85.83 | 113.36 |
| Total Energy, GWh/Yr | 298.47 | 313.84 | 343.51 | 374.22 |

Table 4.3 Sondu/Miriu Run-of-River Plan in Combination-C (6/6)
(Firm release from the Magwagwa : 28.1 $m^3$/sec)

| Case No. | 1 | 2 | 3 |
|---|---|---|---|
| Plant Factor | 0.72 | 0.70 | 0.60 |
| Firm Discharge, $m^3$/s | 28.1 | 28.1 | 28.1 |
| Plant Discharge, $m^3$/s | 46.6 | 48.7 | 59.8 |
| Net Head, m | 138.9 | 139.3 | 140.9 |
| Firm Power, KW | 31966 | 32048 | 32409 |
| Installed Capacity, KW | 53297 | 55788 | 69382 |
| Firm Eergy, GWh/Yr | 280.02 | 280.74 | 283.90 |
| Secondary Energy, GWh/Yr | 11.69 | 11.72 | 11.85 |
| Dump Energy, GWh/Yr | 45.58 | 49.60 | 69.11 |
| Total Energy, GWh/Yr | 337.29 | 342.07 | 364.87 |

## Table 4.4 Plan Optimization

| Work Item | Combination-A | | | Combination-B | Combination-C | | Combination-D | | Combination-E | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sondu /Miriu R-O-R | Maraboi R-O-R | Nyamari-mba R-O-R | Sondu /Miriu Reservoir | Magwagwa Reservoir | Sondu /Miriu R-O-R | Magwagwa Reservoir | Sondu /Miriu Reservoir | Magwagwa Reservoir | Maraboi R-O-R |
| 1. Firm Discharge ($m^3$/sec) | 3.30 | 3.30 | 3.30 | 17.10 | 24.10 | 24.10 | 16.00 | 25.60 | 24.10 | 24.10 |
| 2. Plant Discharge ($m^3$/sec) | 29.60 | 29.60 | 29.60 | 28.40 | 72.30 | 39.90 | 48.00 | 42.70 | 72.30 | 39.90 |
| 3. Optimum Power Scale | | | | | | | | | | |
| Installed Capacity (MW) | 32.83 | 50.49 | 55.05 | 46.90 | 94.60 | 48.60 | 54.90 | 72.90 | 50.70 | 69.22 |
| Firm Energy (GWh/yr) | 32.01 | 49.23 | 53.68 | 246.30 | 276.20 | 237.48 | 160.20 | 383.30 | 147.90 | 364.05 |
| Secondary (GWh/yr) | 155.55 | 239.21 | 260.86 | 54.60 | 57.90 | 14.91 | 87.50 | 36.20 | 32.70 | 22.86 |
| Dump Energy (GWh/yr) | 14.45 | 22.22 | 24.23 | - | - | 46.08 | - | - | - | 70.63 |
| 4. Economic Scale on Power Sector | | | | | | | | | | |
| Benefit (mil. US$) * | 79.23 | 121.85 | 132.87 | 174.40 | 351.19 | | 386.00 | | 345.18 | |
| Cost (mil. US$) * | 72.14 | 113.70 | 143.26 | 202.30 | 305.85 | | 450.60 | | 300.93 | |
| B -C (mil.US$) * | 7.09 | 8.15 | -10.39 | -27.90 | 45.34 | | -64.60 | | 44.25 | |
| EIRR | 10.95 | 10.70 | 9.28 | 8.69 | 11.36 | | 8.63 | | 11.36 | |
| Cost per Energy (US¢/KWh) | 5.74 | 5.88 | 6.80 | 7.31 | 5.49 | | 7.36 | | 5.49 | |
| 5. Economic Scale on Irrigation Sector | | | | | | | | | | |
| Irrigation Area (ha) | 15,610 | 15,610 | 15,610 | 25,610 | 25,610 | | 25,610 | | 25,610 | |
| Benefit (mil. US$) * | 94.16 | 94.16 | 94.16 | 121.88 | 121.88 | | 121.88 | | 121.88 | |
| Cost (mil. US$) * | 52.08 | 52.08 | 52.08 | 78.64 | 78.64 | | 78.64 | | 78.64 | |
| B - C (mil. US$) * | 42.08 | 42.08 | 42.08 | 43.24 | 43.24 | | 43.24 | | 43.24 | |
| 6. Total Economic Scale | | | | | | | | | | |
| Benefit (mil. US$) * | 173.39 | 216.01 | 227.03 | 296.28 | 473.07 | | 507.88 | | 467.06 | |
| Cost (mil. US$) * | 124.22 | 165.78 | 195.34 | 280.94 | 384.49 | | 529.24 | | 379.57 | |
| B - C (mil. US$) * | 49.17 | 50.23 | 31.69 | 15.34 | 88.58 | | -21.36 | | 87.49 | |

* Discounted value at 10 %