APPENDIX – II

WATER RESOURCES DEVELOPMENT

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1 KUDU DAM IRRIGATION AGRICULTURAL PROJECT

1.1 General

It is expected to secure water not only for irrigation but also for industry and urban demand in and around the study area, and in the Project, the large-scale Kudu Dam is proposed to be constructed on the Munyati river as mentioned in the previous section. Based on the review of the previous study and the latest data of river discharges, water rights, water demands for irrigation and urban requirements collected during field survey period, the study on water resources development is conducted through the water balance study to optimize dam capacity and the size of irrigation command area.

1.2 Water Resources of Munyati River Basin

(1) Hydrological Zone

Zimbabwe is classified into six(6) hydrological zones namely Zone A to Zone F ; Zone A has 102,557 km^2 of Zambezi River basin covering upstream Kariba City, Zone B covers 62,541 km^2 of Limpopo River basin, Zone C has 90,523 km^2 of Zambeze River basin covering downstream Kariba City, Zone D covers 36,711 km^2 of Luia River basin, the tributary of the Zambezi River, Zone E covers 84,550 km^2 of Save River basin, and Zone F covers 7,296 km^2 of Buzi River basin on the east plateau. The study area is located in Zone C in this classification. In Zone C, the river systems drain in the northerly direction and there is unexploited potential in the zone. Zone C consists of 23 sub-zones as shown below.

Sub-Hydrological Zones in Hydrological Zone C

Name of Sub-Zone	Number of Sub-Zone	Area (km^2)	Major River in the Sub-Zone
CA1-CA2	2	9,479	Angwa
CH1-CH5	5	14,339	Munyati
CS	1	9,657	Sanyati
CUF1-CUF4	4	11,866	Umfuli
CUG1-CUG2	2	6,925	Musengesi
CUN1-CUN6	6	21,771	Munyati
CUS	1	3,215	Umsweswe
CZ1-CZ2	2	13,271	-
TOTAL	23	90,523	

Proposed Kudu Dam is located in CUN1 in the classification, and the dam can receive natural flow from its catchment area, CUN2-CUN6 and CUS. Sub-hydrological zones in the Kudu Dam catchment area are summarized below and shown in Fig. 1.

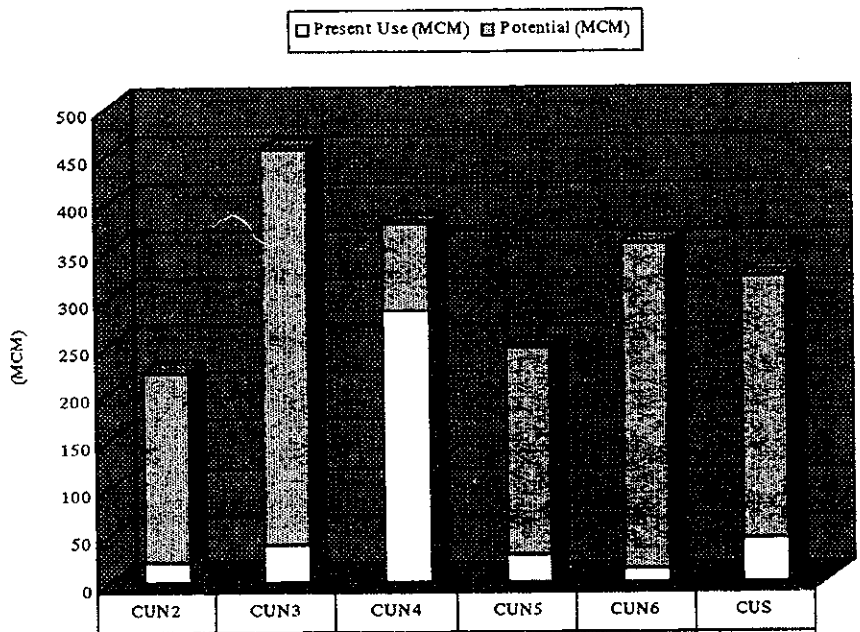
Sub-Hydrological Zones in the Kudu Dam Catchment Area

Name of Sub-Zone	Name of Catchment	Area (km^2)	Mean Annual Runoff (mm)	Major River
CUN2	Munyati	3,179	35	Munyati
CUN3	Lower Sebakwe	4,161	55	Sebakwe
CUN4	Upper Sebakwe	2,705	70	Sebakwe
CUN5	Ngesi	1,775	70	Ngesi
CUN6	Upper Munyati	2,748	65	Munyati
CUS	Umsweswe	3,215	50	Umsweswe
TOTAL		17,783		

(2) Potential Water Resources

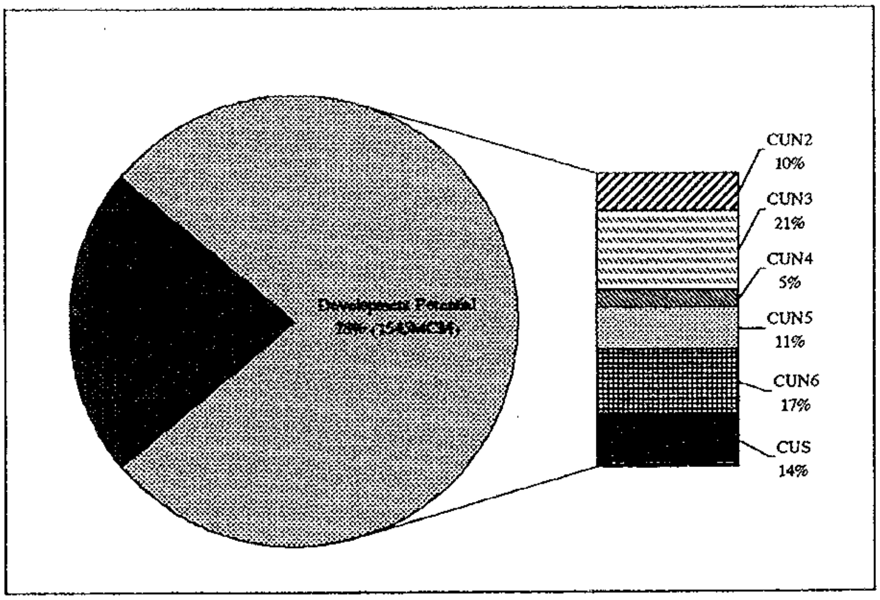
Present water utilization and water resources development potential of the catchment sub-zones are estimated by Zimbabwean Government, which is summarized below. Among the catchment sub-zones, water utilization of CUN4 is higher than other sub-zones. The catchment area has about 1,550MCM of water resource development potential in total, which can be fully developed by Kudu Dam construction.

Present Water Utilization and Water Resource Development Potential of Kudu Dam Catchment Areas



	CUN2	CUN3	CUN4	CUN5	CUN6	CUS
Potential (MCM)	200.080	418.472	89.533	218.851	342.331	276.247
Present Use (MCM)	21.92	39.528	288.467	29.149	15.669	45.753

Water Development Potential of Kudu Dam Catchemnt Areas



Source : Irrigation Manual, AGRITEX

1.3 Water Balance Study

(1) Dam Yield at 10 % Risk

Dam yield at 10% risk means available water amount from the dam in 90% dependability. The required data to calculate dam yield at 10% risk are:

(a) Mean annual inflow into the dam (MAR in 10^3m^3)
(b) Coefficient of variation of annual inflow (CV in %)
(c) Evaporation Factor (EF)

According to the Detailed Design Report of Kudu Dam prepared by DWD in 1992, yield at 10% risk for Kudu Dam is estimated as 380MCM/year. Since the yield shows general information for water development potential without any consideration for water use, the detailed water balance study is necessary to confirm the available water for irrigation command area. In water balance study, some important parameters which are not considered in dam yield estimation such as fluctuation of water demand (peak demand for irrigation), seepage loss, river maintenance flow, etc. should be taken into account.

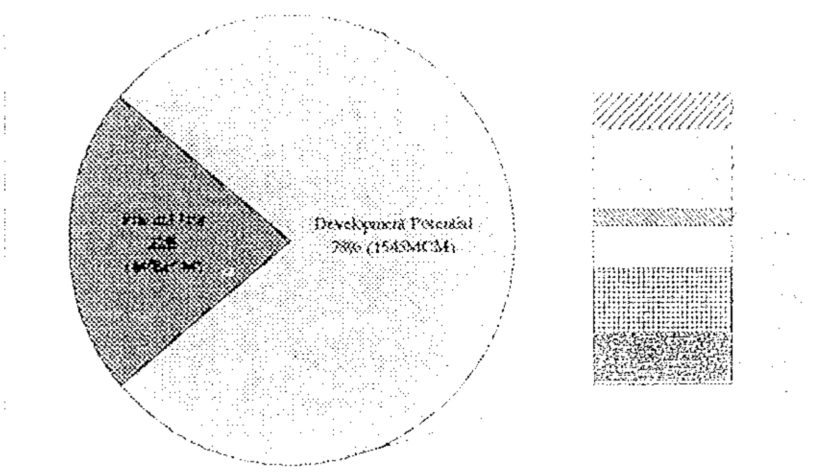
(2) Water Balance Study Model

Water balance study model consists of three sub-models:

(a) Inflow sub-model to the dam reservoir (upstream of the dam)
(b) Water supply sub-model from the reservoir (downstream of the dam)
(c) Dam reservoir water balance sub-model

Relationship between above three models and procedure of the water balance study is

Water Development Potential of [illegible]



Source: Irrigation Manual, AGRITEX

1.3 Water Balance Study

(1) Dam Yield at 10 % Risk

Dam yield at 10% risk means available water amount from the dam in [illegible] dependability. The required data to calculate dam yield at 10% risk are

(a) Mean annual inflow into the dam (MAR in 10^6m^3)
(b) Coefficient of variation of annual inflow (CV in %)
(c) Evaporation Factor (EF)

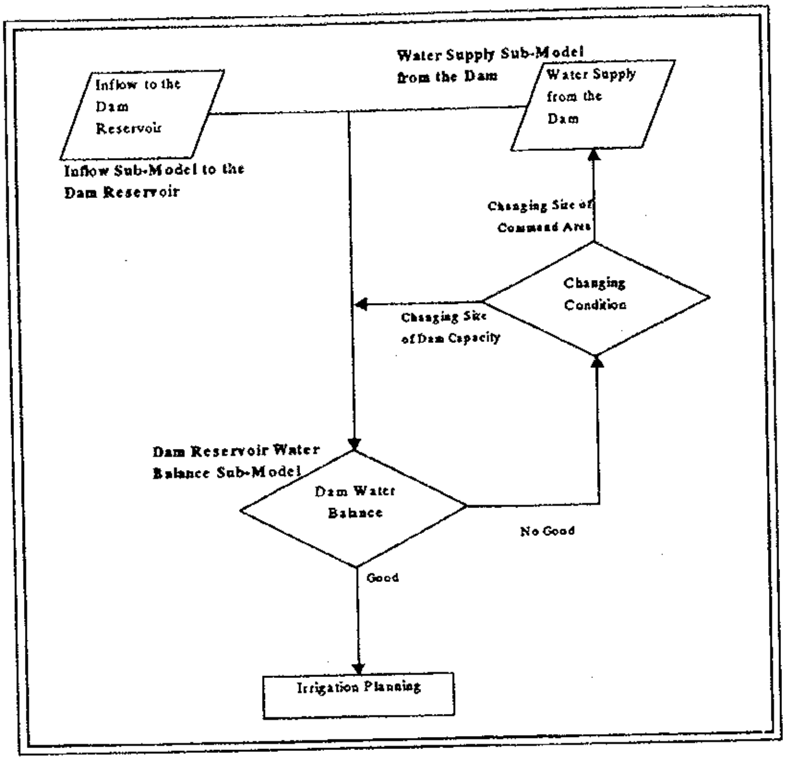
According to the Detailed Design Report of Kudu Dam prepared by DWD in [illegible] yield at 10% risk for Kudu Dam is estimated as 380MCM/year. Since the [illegible] shows general information for water development potential without any consideration for water use, the detailed water balance study is necessary to confirm the [illegible] water for irrigation command area. In water balance study, some important parameters which are not considered in dam yield estimation such as fluctuation of water demand (peak demand for irrigation), seepage loss, river maintenance [illegible] should be taken into account.

(2) Water Balance Study Model

Water balance study model consists of three sub-models:

(a) Inflow sub-model to the dam reservoir (upstream of the dam)
(b) Water supply sub-model from the reservoir (downstream of the dam)
(c) Dam reservoir water balance sub-model

Relationship between above three models and procedure of the water balance [illegible] summarized in the following flow chart and total water balance model is shown in Fig.2.



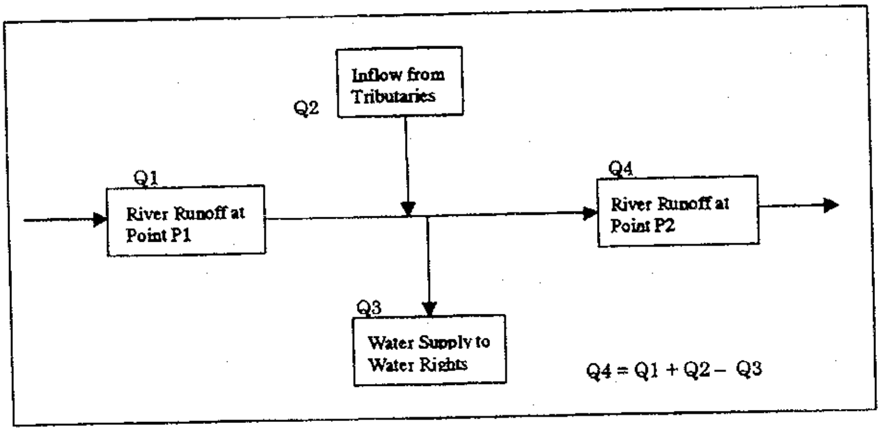
Flow Chart of Water Balance Study

(a) Inflow Sub-Model to the Dam Reservoir

Inflow sub-model is established to estimate the volume of inflow to Kudu dam reservoir. Inflow sub-model consists of three parts:

(i) measured river runoff at river runoff gauging station
(ii) water rights in downstream of river runoff gauging station
(iii) inflow from the tributaries

The relationship of above three parts is conceptualized as shown below.



Conceptualized Inflow Sub-Model

(i) Daily measured river runoff data in Munyati river basin are collected from DWD hydrological section. Among them, data of Station C8 at Munyati river, C9 at KweKwe river, C36 at Sebakwe river and C48 at Umsweswe river are used for the study. Insufficient data are supplemented by using specific river runoff of the most highly correlative river runoff gauging station as shown below.

Data Supplementation

River Runoff Gauging Station	1st Priority Station (The highest correlative station)		2nd Priority Station (The second highest correlative station)	
	Station No.	Correlation Factor	Station No.	Correlation Factor
C8	C18	0.9330	C30	0.9046
C9	C8	0.7965	C18	0.7206
C36	C8	0.8594	C18	0.7658
C48	C87	0.8910	C18	0.8310

Note : Correlation factor was estimated by using 10days river runoff data

(ii) In the inflow sub-model, water rights in the river basin must be considered because it may take certain amount of water from the natural river runoff. As water rights at the upstream of river runoff gauging stations are already abstracted in the measured river runoffs at the gauging stations, only downstream water rights of gauging stations are considered in the sub-model. The list of water rights in the river basin is collected at the DWD water rights section.

(iii) Inflow from the tributaries are estimated by using specific runoff of the most nearest upstream runoff in the sub-model. Catchment area of the river basin used for the study is shown in Fig. 3.

The result of Inflow Sub-Model calculation is shown in Fig. 4.

(b) Water Supply Sub-Model from the Dam Reservoir

Water supply sub-model has four components, which are:

(i) irrigation water requirement for the command area,

(ii) urban water demand for the surrounding town area,

(iii) river maintenance flow to the downstream of the dam, and

(iv) primary water requirements

Each component is described as below.

(i) Irrigation water requirement of the command area is estimated based on the proposed cropping pattern in the study area.

(ii) Urban water demand in year 2025 for the surrounding towns is estimated based on the collected water demand data of Gokwe, Kadoma, KweKwe

Gweru, Sanyati and Nembudziya. Data of present water use and future demand are obtained from respective provincial offices of DWD, Local Authorities of the respective Urban Centres and Rural District Councils. To estimate future water demand for urban water use, the following equation used by DWD is applied :

$$D = P \times (1 + r)^n$$

where, D : future urban water demand
P : present urban water use
r : expected growth rate
n : design period

Expected urban water demand of respective areas are estimated as shown below.

Expected Urban Water Demand of Surrounding Town Areas

	Gweru Shurugwi	KweKwe Redcliff	Kadoma Mines	Gokwe	Sanyati	Nembudziya
Present Use (MCM/year)	19.2	20.4	14.04	7.2	1.68	0.165
Growth Rate (%)	4	4	4	5	4	5
Demand in 2025 (MCM/year)	53.23	56.52	38.88	25.56	4.68	0.60

There are several water development plans in the areas, which can supply urban water to the respective towns. Consequently, net urban water demand of Kudu dam is estimated taking account of these plans. The result of estimation shows that net urban water demand of Kudu dam will be about 60MCM/year in year 2025 as shown below.

Urban Water Demand of Kudu Dam

	Gweru Shurugwi	KweKwe Redcliff	Kadoma Mines	Gokwe	Sanyati	Nembudziya	TOTAL
Demand in 2025 (MCM/year)	53.230	56.520	38.880	25.560	4.680	0.600	179.470
Current Supply (MCM/year)	19.200	20.400	14.040	7.200	1.680	0.165	62.685
Current Source	Gwenoro + Other dams	Sebakwe Dam	Claw Dam	Boreholes	Sanyati Weir	Boreholes	
Supply from Other Plans (MCM/year)	40.000	26.000	0.000	0.000	0.000	0.000	66.000
Future Source	Raising Gwenoro Dam, Lubango Dam	Reduce Irrigation from Sebakwe	–	–	–	–	–
Supply from Kudu Dam (MCM/year)	0.000	10.120	24.840	18.360	3.000	0.435	56.755

(iii) River maintenance flow will be released from the dam for several purpose, such as water rights in the downstream, environment conservation, fishery and so on. In case of Munyati river, there is little natural flow in the dry season and water demand after confluence point of Munyati river and Mupfure river is very small since there are no major irrigation schemes. Accordingly, for the water supply sub-model, only water rights from downstream of Kudu dam up to the confluence point of Munyati river and Mupfure river is taken into consideration as the river maintenance flow.

(iv) Primary water requirements consist of domestic water use for households and drinking water for cattle, etc in the downstream of dam. Since those water requirements are negligible small comparing with irrigation water requirement and urban water requirement, they are considered to be included in the balance of other water requirements.

(c) Dam Reservoir Water Balance Sub-Model

The procedure of dam reservoir water balance calculation is shown in Fig. 5. Dam reservoir water balance sub-model has four components as shown below.

(i) Inflow from Munyati river is given from Inflow Sub-Model.

(ii) Water supply to the downstream is given from Water Supply Sub-Model.

(iii) Direct rainfall to the dam reservoir is estimated by the following formula :

$$DR = R_{(K)} \times A \times 10$$

where, DR : Direct rainfall to dam reservoir (m^3/day)

$R_{(K)}$: Rainfall at Kadoma meteorological station (mm/day)

A : Reservoir surface area (ha)

(iv) Losses from the dam reservoir consists of two parts which are:

<u>Evaporation loss from the dam reservoir</u>

Evaporation loss from the dam reservoir is estimated by using the following formula:

$EL = E \times A \times 10$

where, EL : Evaporation loss from the dam reservoir (m^3/day)

E : 80% of A-Pan (mm/day)

A : Reservoir surface area (ha)

<u>Seepage loss from the dam reservoir</u>

Seepage loss from the dam reservoir is estimated by using the following formula:

$SL = 0.0002 \times Q$

where, SL : Seepage loss from the dam reservoir (MCM/day)

Q : Storage of the dam reservoir for the calculation da (MCM)

Considering the above four components, the following formula is used for the dam reservoir water balance sub-model.

$Q_{(i+1)} = Q_{(i)} + Fin + DR - Wi - Wu - Wm - EL - SL$

where, $Q_{(i+1)}$: Storage at time (i+1)

$Q_{(i)}$: Storage at time (i)

Fin : Inflow to dam reservoir

DR : Direct rainfall to dam reservoir

Wi : Irrigation water supply

Wu : Urban water supply

Wm : River maintenance flow

EL : Evaporation loss

SL : Seepage loss

(3) Result of Water Balance Study

H - A (Water surface elevation – Water surface area) and H – Q (Water surface elevation – Storage capacity) curves of the Kudu Dam reservoir are obtained from the detail design report of Kudu Dam prepared by DWD as shown in Fig. 6. In the sub-model, water balance calculation is made on the ten-days basis and started from March (end of the rainy season) to February. Initial storage (March 1st period of ten-days, 1967) of the calculation is set up as same volume as end storage (February 3rd period of ten-days, 1997).

In the water balance study, water deficit risks for urban water and irrigation water are defined as follows :

(a) Urban Water

$WDR_{(U)}$ (%)= $NWD_{(U)}$ / (36 x 30) x 100

where, $WDR_{(U)}$: Water deficit risk for urban water (%), less than 4 %

$NWD_{(U)}$: Number of water deficit period of ten-days in 30 years

(b) Irrigation Water

$WDR_{(I)}$ (%)= $NWD_{(I)}$ / 30 x 100

where, $WDR_{(I)}$: Water deficit risk for irrigation water (%) , less than 20%

$NWD_{(I)}$: Number of water deficit year in 30 years

Since water shortage risks for urban water and irrigation water are different as shown above, certain amount of water should be stored in the reservoir, so that urban water shortage risk can be less than 4%. In other words, when the storage is less than required storage for urban water, irrigation supply shall be cut off to maintain urban water shortage risk of less than 4 %. In the dam reservoir water balance sub-model, the minimum storage for urban water to clear its water shortage risk is calculated.

Water balance calculation is done to optimize dam scale and irrigation area, using the above mentioned model for several cases of different dam heights as shown in the following table:

Dam Height (Full supply Level)	Storage Capacity (MCM)	Irrigable Area (ha)	Storage for Urban Water (MCM)
72.70 m(EL.947.00m)	1,551.4	25,000	60.0
67.70 m(EL.942.00m)	1,266.6	20,000	60.0
62.70 m(EL.937.00m)	972.6	16,000	60.0
57.70 m(EL.932.00m)	732.6	11,000	60.0
52.70 m(EL.927.00m)	542.6	7,500	60.0
47.70 m(EL.922.00m)	393.6	3,700	60.0

Fig. 7 shows the results of water balance study in the case of the maximum dam height of 72.7m. In this figure, required storage for urban water is shown by water surface level with light line, and it means when the water surface level is below this level, irrigation supply should be cut off to keep urban water with less than 4% of water deficit risk.

1.4 Optimum Scale of Kudu Dam

For determining the optimum scale of Kudu Dam, environmental impact and project economy should be considered. The environmental impact is mentioned at next section 4.8 in detail. Accompanied with the construction of Kudu Dam, 3,100 persons (about 500 households) at maximum will be forced to remove from their own lands and houses. Judging from the result of villagers' intention survey in the proposed submerged area and public consultation meetings held two times during the first field survey, the local inhabitants are not enforced to oppose the dam construction. However, as about 10% inhabitants are positively against the resettlement due to dam construction and about 35% inhabitants agree with conditions, the Government of Zimbabwe should have discussions with the inhabitants about this matter including their compensation hereafter. In case of resettlement, the local inhabitants want to remove on a village or a ward level than on a personal level. The result of inventory survey in and around the submerged area shows that there is neither animals/plants to be conserved strictly nor cultural or historical heritages, and therefore it can be judged that both natural environment and social environment would not be affected greatly by the dam scale.

Regarding economic aspect of the Project, water demand should be taken into account. In the study area, the extensive farmlands spread out over the communal and resettlement areas, small scale commercial farms, and large scale commercial farms. About 23,000 ha of irrigable areas are found in the communal and resettlement area, however, these irrigable areas are scattered consisting small blocks and are located from El. 850m to El.950m. The areas are divided into two categories depend on whether gravity irrigation is practicable or not. This classification is judged from the relation between water level of the main canal and elevation of the farmland. Therefore, economical evaluation of irrigation water distribution among the gravity irrigation area and pumping irrigation area in the communal and resettlement areas, small scale commercial farm and large scale commercial farm shall be made in relation with the Kudu dam scale.

The urban/industry water supply to urban areas around the study area, i.e., Kadoma, Gokwe, and Kwekwe, etc., is given to a high priority because its shortage be depend on the Kudu dam reservoir accounting future water demand after consideration of other independent water sources. Therefore, the Kudu dam will play an important roll even in this aspect.

Considering the above, following case study was made for examining the project economy. It is noted that the urban water requirement of 60 MCM per annum is assured in every cases.

(1) Case 1 : Dam scale is the maximum and irrigation water allocation is 58% for communal & resettlement area, 24% for small scale commercial farm and 18% for large scale commercial farm following the allocation rate as in the Master Plan Study.

    (a) Dam height : 72.7m
    (b) Storage capacity : 1,551.4 MCM
    (c) Dam embankment volume : 9,557,000 m^3
    (d) Irrigation area : 25,000 ha
        − Communal & resettlement area: 14,500ha

(Gravity irrigation area : 8,992ha)
(Pump irrigation area : 5,508ha)
- Large scale commercial farm : 4,500ha
- Small scale commercial farm : 6,000ha

(e) Main irrigation canal : Right bank canal :74.1 km
Left bank canal :103.8 km

(2) Case 2 : Dam scale is the maximum and irrigation water is supplied to commercial & resettlement area and large scale commercial farm without allocation for small scale commercial farm to reduce the length of main irrigation canal.

(a) Dam height : 72.7m
(b) Storage capacity : 1,551.4 MCM
(c) Dam embankment volume : 9,557,000 m^3
(d) Irrigation area : 25,000 ha
- Communal & resettlement area: 18,207ha
(Gravity irrigation area : 8,992ha)
(Pump irrigation area : 9,215ha)
- Large scale commercial farm : 6,793ha
- Small scale commercial farm : 0ha

(e) Main irrigation canal : Right bank canal : 74.1 km
Left bank canal : 98.8 km

(3) Case 3 : Dam height is 10m lower than the maximum and irrigation water allocation is 58% for communal & resettlement area, 24% for small scale commercial farm and 18% for large scale commercial farm following the allocation rate as in the Master Plan Study.

(a) Dam height : 62.7m
(b) Storage capacity : 972.6 MCM
(c) Dam embankment volume : 6,068,000 m^3
(d) Irrigation area : 16,000 ha
- Communal & resettlement area : 9,280ha
(Gravity irrigation area : 8,992ha)
(Pump irrigation area : 288ha)
- Large scale commercial farm : 2,880ha
- Small scale commercial farm : 3,840ha

(e) Main irrigation canal : Right bank canal : 74.1 km
Left bank canal : 103.8 km

(4) Case 4 : Dam height is 10m lower than the maximum and irrigation water is supplied to only communal & resettlement area including high head pumping irrigation area.

(a) Dam height : 62.7m

(b) Storage capacity : 972.6 MCM
(c) Dam embankment volume: 6,068,000 m³
(d) Irrigation area : 16,000 ha
- Communal & resettlement area: 16,000ha
(Gravity irrigation area : 8,992ha)
(Pump irrigation area : 7,008ha)
- Large scale commercial farm : 0ha
- Small scale commercial farm : 0ha
(e) Main irrigation canal : Right bank canal : 74.1 km
Left bank canal : 98.8 km

(5) Case 5 : Irrigation water is supplied to gravity irrigation area and low head pumping irrigation area in communal & resettlement area only.

(a) Dam height : 59.7m
(b) Storage capacity : 828.6 MCM
(c) Dam embankment volume: 5,237,000 m³
(d) Irrigation area : 13,230 ha
- Communal & resettlement area: 13,230ha
(Gravity irrigation area : 8,992ha)
(Pump irrigation area : 4,238ha)
- Large scale commercial farm : 0ha
- Small scale commercial farm : 0ha
(e) Main irrigation canal : Right bank canal : 74.1 km
Left bank canal : 98.8 km

(6) Case 6 : Irrigation water is supplied to only gravity irrigation area in communal & resettlement area.

(a) Dam height : 53.7m
(b) Storage capacity : 580.6 MCM
(c) Dam embankment volume: 3,842,000 m³
(d) Irrigation area : 8,992 ha
- Communal & resettlement area : 8,992ha
(Gravity irrigation area : 8,992ha)
(Pump irrigation area : 0ha)
- Large scale commercial farm : 0ha
- Small scale commercial farm : 0ha
(e) Main irrigation canal : Right bank canal : 74.1 km
Left bank canal : 98.8 km

For the above six cases, the economic evaluation was roughly made based on the estimated cost and benefit. Construction cost of main irrigation canal and on-farm development cost in the communal & resettlement area was estimated using the new orthophoto maps which were prepared in May 1999. The Kudu dam construction cost and irrigation development costs in small and large scale commercial farms were estimated referring to the Master Plan Study. The benefit was calculated based on the crop budgets in the proposed cropping pattern shown in the next chapter 4.3. The unit prices in June 1999 was used for estimation the costs and benefits. The result of economic evaluation in six cases is shown in Table 1 and summarized as follows :

Result of Comparative Study

Case	Economic Cost (1,000Z$)	Economic Benefit (1,000Z$)	EIRR (%)
1	7,487,603	1,393,711	10.1
2	7,550,910	1,393,711	10.0
3	5,489,150	891,975	9.0
4	5,290,612	891,975	9.3
5	4,845,261	737,552	8.5
6	3,970,703	501,290	7.2

As shown in the above table, it can be said that Case-1 and Case-2 have advantage of the project economy providing the largest irrigation area of 25,000ha with the maximum dam scale. The difference between C-1 and C-2 is the different allocation of irrigation water to irrigation areas and there is little difference between their project economics. Case-1 is followed by the allocation rate adopted in the Master Plan Study, where the irrigation water will be distributed to the small scale commercial farms and the large scale commercial farms besides the communal and resettlement areas. At the meeting with the Government of Zimbabwe on Progress Report (1) of Phase-I First Field Survey, both of the Government of Zimbabwe and the JICA Study Team agreed, "The irrigation development plan will be made following the water allocation as in the Master Plan Study. Re-allocation of irrigation water shall be considered when the economic analysis is made available." Taking into account the above, C-1 is adopted, in which the Kudu dam is designed as the maximum scale (dam height: 72.7 m, reservoir capacity: 1,551.4 MCM) supplying irrigation water to 14,500 ha in the communal and resettlement areas, 6,000 ha in the small scale commercial farms, and 4,500 ha in large scale commercial farms, moreover, urban/industrial water to the urban areas around the study area.

1.5 Review of Kudu Dam Design prepared by DWD

Under the Zimbabwean governmental policy to develop the limited water resources in the country, the construction of the Kudu Dam on the Munyati River has been planned since the 1960's. Following this, design of dam has been completed by the Zimbabwean budget and resources in 1993. To examine the validity of the dam design, the review works were carried out based on the available data and supplemental field investigation during the first field work in November 1998 to February 1999. The results of review works are described shown below.

1.5.1 Previous Surveys done by DWD

The following topographic and geological surveys have been conducted by DWD for dam design :

(1) Topographic Survey

Dam site	S = 1/1,000	Topographic map (2 sheets)
Reservoir area	S = 1/5,000	Topographic map (17 sheets)

(2) Geological Survey

Location	Boring (holes)	Seismic Exploration (lines)	Test Pitting	Laboratory Test
Main Dam	16	○	○	
Saddle Dam	8	○	○	
Spillway	6	○		
Intake Facilities	6			
Borrow Area			○	○

1.5.2 Main Features of Kudu Dam designed by DWD

General features of dam and its appurtenances designed by DWD are shown below.

Hydrological Data		Dam body	
River	Munyati	Main dam	
Major tributaries	Nyamatani, Mazde Umsweswe, Zhombe Sesombi, Sebakwe	Dam type	Zoned fill dam
		Height of dam	72.70 m
		Crest level	EL. 955.20 m
Catchment area	17,520 km²	Crest length	860.00 m
Mean annual rainfall	700 mm	Crest width	8.00 m
Mean annual runoff	56.7 mm	Slope upstream	1:2.4 – 1:2.6
	993 x 10⁶ m³	downstream	1:2.0 – 1:2.3
Yield at 10% risk	380 x 10⁶ m³	Embankment volume	6.2 x 10⁶ m³
Reservoir		Saddle dam	
Surface area at FSL	7,800 ha	Dam type	Zoned fill dam
Full supply capacity	1,551.40 x 10⁶ m³	Height of dam	30.00 m
Live storage	1,426.85 x 10⁶ m³	Crest length	875.00 m
Dead storage	60.00 x 10⁶ m³	Crest width	8.00 m
Sediment volume	64.55 x 10⁶ m³	Slope upstream	1:2.5
High flood level	EL. 963.12 m	downstream	1:2.0 – 1:2.1
Full supply level	EL. 947.00 m	Embankment volume	1.3 x 10⁶ m³
Minimum level	EL. 905.00 m		
River bed level	EL. 882.50 m		
Spillway		Outlet works	
Type	Ungated ogee type	Type	Intake tower
Crest length	300 m	Tunnel Diameter	2.5 m
Design flood discharge	12,122 m³/s (2000 year flood)	Length	650 m
		Outlet capacity	31.49 m³/s
Overflow depth	6.12 m	(at level of 10% full capacity)	

1.5.3 Geo-technical Assessment

The bedrock of damsite consists of basaltic rocks on the riverbed and the right bank, and sedimentary rocks such as argillite, arenite and conglomerate on the left bank. The bedrock is very stiff with an assumed unconfined compressive strength more than 58.9 N/mm^2 at the intact portions, and weathered and/or deteriorated on the shallow portions and along minor sheared zones. Faults on the riverbed that described in the previous investigation report are not in serious condition. The sheared zones are closely jointed and seem to be weathered to a considerable depth, but few clayey materials have been seen in the sheared zones.

In terms of strength, suitable foundations seem to appear 1m to 5 m below the rock surface on the left bank, 5m to 10 m below the rock surface on the right bank. No rock excavation, except trimming, is required on the riverbed and below the terrace deposits. Although no permeability test was done, it is foreseeable that bedrock on the left bank shows high permeability and requires huge grout injection to secure water tightness. In addition, rim grouting line seems to extend for considerably long distance to make a reliable water-stop along the ridge on the left bank, because the higher portion of the bank forms relatively narrow ridge with short seepage path, and seems to consist of high permeable rocks. To avoid a large amount of rock excavation on the right bank and huge grout injection on the left bank, it is suggested to shift the dam axis upstream for 100 m to 200 m after confirmation of the rock condition and permeability of the upstream portion.

Surficial deposits consist of top soil, residual soil, talus deposits, terrace deposits, and recent river deposit. It is assumed that the talus deposits are 5 m thick on the higher portion of both banks. Terrace deposits are 15 m to 20 m thick on the middle portion of the left bank, and 8 m to 12 m thick on the middle to lower portion of the right bank. Other surficial deposits are partial and thin. These deposits will be excavated and could be used for dam embankment depending on the respective quality that will be clarified through addition investigation at this stage.

1.5.4 Embankment Materials

Kudu Dam was designed as the zoned fill dam with a height of about 73 m, by DWD in 1993. Through the site investigation in 1998 by the JICA study team, the additional investigation was proposed to study the possibility of the rock fill dam construction and to get the detail characteristics of embankment material (especially at the depth of more than 2m of the borrow-pit).

The contents of the additional surveys are shown in Tables 2 & 3 and Figs. 8 & 9. The results of the laboratory soil test and rock test carried out in the additional surveys are summarized in Table 4 "Summary of Laboratory Test (Earth Material)", Table 5 "Summary of Laboratory Test (Sand/Gravel)" and Table 6 "Summary of Laboratory Test (Rock Material)".

The survey results are described below.

(1) Earth Material

The particle size distribution of the earth material which was obtained in the original investigation (1992) and the additional investigation (1999) are shown in Fig. 10. Fig. 11. shows the procter compaction characteristics of both materials. In the original dam design, zoned fill dam was adopted. The impervious zone (core zone) was located at the center portion of dam cross section and shell zone (semi-impervious zone) was located at upstream and downstream sides of core zone. However, judging from the above both figures, it is difficult to collect and select those core materials and shell zone materials, because there is almost no difference between them except for the one which the particle size distribution differs clearly. Accordingly, the following arrangement of core and shell zones is recommended :

Core zone : main function shall be put to the impervious characteristics
Shell zone : main function shall be put to the shear strength

The impervious material with the permeability coefficient of less than $k = 1 \times 10^{-5}$ cm/s should be used for the core zone and the semi-pervious material with the permeability coefficient of more than $k = 1 \times 10^{-4}$ cm/s be used for the shell zone. Shear strength of those materials shows wide range values, and the material with an average shear strength of ϕ'=25 degree shall be used for core zone and ϕ'=30 degree for shell zone. Furthermore, most of these materials will be obtained in the dry side condition of field moisture content, consequently moisture content adjustment will be necessary, for example by the sprinkling, when construction.

(2) Sand/Gravel

The river deposit locate about 1～3 km downstream of the dam site, was investigated as the sand/gravel material. The particle size distribution is shown in Fig. 12. The sand/ gravel material will be expected to be used as not only filter material but also concrete aggregate.

Generally, the filter material should satisfy following conditions :

(a) $F_{15} / B_{15} > 5$
$F_{15} / B_{85} < 5$
where,

F_{15}: 15% grain diameter of the filter material
B_{15}: 15% grain diameter of the material to be protected with the filter

(b) It is desirable that the grading curve of the filter material is approximately parallel to the grading curve for material to be protected by the filter.

(c) The filter material should be non-cohesive and the content of finer than 0.074 mm should be 5% or less.

(d) The maximum grain diameter of the filter material should be about 75 mm or less.

Grading condition of the filter is shown in Fig. 12, some of the sand/gravel materials satisfy the filter condition. And also, these gravel materials are available to be used for the fine aggregate of the concrete.

(3) Rock Material

In general, required characteristics for the rock material is shown below.

- Compression strength qu≧29.5～39.3 N/mm^2
- Specific gravity Gs≧2.5
- Water absorption Q≦3%
- Abrasion loss by the Los Angeles testing machine : 40% or less in weight

The test result of the additional investigation satisfy above conditions and all of these rock material are available for rock zone and rip-rap material.

(4) Design Value

The design values of dam embankment materials were decided as shown below based on the result of the additional investigation mentioned above.

Design Values

Item			Earth Material		Rock Material		Sand / Gravel
			Core Zone	Fill Zone	Rock Zone	Transition Zone	Filter Zone
Density	ρ_t	tf/m^3	1.98	1.98	2.00	2.00	1.90
	ρ_{sat}	tf/m^3	2.06	2.06	2.10	2.10	2.04
Shear	C'	tf/m^2	1.5	1.5	0	0	0
Strength	ϕ'	deg.	25	30	40	35	30

1.5.5 Dam Body

(1) Dam type/Dam axis

(a) Dam type

In the Kudu Dam Design Report prepared by DWD(1993), the zoned fill dam type was adopted, because it was judged that high quality and large amount of rock materials could not be found around dam site. However, through the site investigation during the first field work in November and December 1998, the possible quarry site was found at the upstream area of 4～5 km distance from dam site. In order to confirm the quality of rock, the rock tests such as compression strength, water absorption ratio and specific gravity, etc. were made by using existing boring core located in the left / right bank of the dam site. It was judged from these tests that these rock materials be able to be used as the rock embankment material.

Considering the above situation, the comparative study was made for selection of dam type. Two dam types of zoned fill dam and rock fill dam were studied. Rough quantity calculation were made for both dams based on the typical standard cross sections shown in Fig. 13 and Fig. 14. The result of the quantity calculation is shown in Table 7. In this calculation, only earthwork quantity of the main dam was summarized in this table, because the other works (saddle dam, spillway, inlet/outlet works and grouting etc.) have approximately same dimensions in both cases. The study result shows that the zoned fill dam has economic advantage although there is a few differences of construction costs between zoned fill dam and rock-fill dam. From this study, the dam type of Kudu Dam can be decided as zoned fill dam. However, as the Kudu Dam is a large scale dam with the dam height of 72 m, it is recommended to examine the possibility of rock fill dam, which has more advantage of the stability for the pore pressure and deformation of the dam body, through the detailed investigation of the location of quarry site, available quantity and quality of rock materials.

(b) Dam axis

The appropriate dam axis shall be selected in consideration of (i) examinations in terms of deformation and shear strength as the dam foundation and examination of maximum storage with minimum excavation/filling volume. The designed dam axis by DWD satisfies the above conditions, however, from the topographic map, there is a steep branch on the left bank side of the designed dam axis. Furthermore, the conglomerate strata can be observed at the left bank of more than EL.930 m. From observation of the boring core, it seems that the permeability at/near the conglomerate strata are relatively higher than other portions. Therefore, seepage flow through the abutment shall be examined carefully so as to keep safety for determination of dam axis.

There is a method using the creep ratio to evaluate the safety to the seepage failure (piping phenomenon) of the foundation. The examination to the piping phenomenon of the dam foundation was made by Bligh's method. Fig. 15 shows the comparison between two dam axis, one is the original dam axis and the other is the proposed dam axis which is shifted about 100 m to upstream direction of the original dam axis.

The creep ratio to two streamlines shown in figure are obtained as follows :

- For the original dam axis : $C_B = 370/(947-915) = 11.5$
- For the proposed dam axis : $C_B = 470/(947-915) = 14.7$

On the other hand, assuming that the permeable strata of conglomerate consists of the sand/grave to coarse sand, required creep ratio in this case is 9~12. Therefore it is recommended that the original dam axis shall be shifted about 100 m to upstream direction from the original position so as to keep required creep ratio. In this case, the reservoir storage capacity will decrease but its volume is estimated only 0.26% of total storage(1,551.4 million m^3) as shown below. It is noted that geological investigations at the proposed damsite should be done to confirm the geological conditions of dam foundation. When the dam axis will be kept as the original design, special treatment should be considered for protecting seepage failure.

Regarding the arch-shaped dam axis, there is no technical evidence to adopt it for the fill-type dam. Although the arch-shaped dam axis has disadvantage of increase of work quantity and difficulty of construction, many fill-type dams with the arch-shaped has been constructed in Zimbabwe. It seems that the arch-shaped axis presents a beautiful sight after completion of dam construction. Therefore, the arch-shaped dam axis can be adopted as same as original design in this study.

(2) Verification of Dam Crest Elevation and Freeboard

Dam Crest Elevation and Freeboard are verified here in accordance with Japanese standard (Ministry of Construction, River Bureau). Required dam crest elevation is calculated by the following equation :

$Hh + hw + 1.0 = 953.12 + 1.1 + 1.0 = 955.22$

where,

Hh : Design flood level (m)
hw : Wind induced wave height from reservoir surface (m)

In original design, dam crest elevation is EL. 955.2 m, which is almost same with the above calculation.

(3) Design Seismic Force

The seismic force is not considered for dam design in Zimbabwe, because it is generally said that Zimbabwe is located out of earthquake area. In this study, the following basic policy regarding seismic force is proposed :

(a) Seismic force is not taken as a rule but safety of dam body is checked considering the scale of dam.
(b) The maximum acceleration which will be occurred in the future is calculated by statistics analysis based on the earthquake records in and around Zimbabwe.
(c) The safety factor (Fs) to the slope stability analysis is taken as follow :
In the case non seismic force : $Fs \geqq 1.2$
In the case the seismic force by the statistics calculation : $Fs \geqq 1.1$

Kudu dam is a large scale and damages caused by catastrophic failure of dam will be serious in the downstream area. From this viewpoint, at least $Fs \geqq 1.1$ shall be kept during earthquake with a probability of 200-year return period. Fig. 16 shows the statistics calculation result of earthquake records for 26 years from 1973 to 1998. Total number of earthquake records is 140 (out of them, 52 are minute earthquakes like as non description of magnitude). From this figure, maximum acceleration of 200-year period is estimated about 45gal. Therefore, the seismic coefficient (Kh) is shown below.

Kh = 45 / 980 = 0.046 g, say 0.05g

where,

g ; gravitational acceleration

(4) Stability Analysis of Dam Body

Stability analysis by slip circle slice method was made for four (4) cases of reservoir water level shown in the following table :

Cases for Examination of Sliding Failure

Case	Reservoir water level	Seepage (Pore pressure) condition	Seismic force (%)	Application of circular slice method	
				Stress indication	Examined slope
1	Design Flood Level (DFL)	Seepage flows in steady state	-	Effective stress	Upstream and downstream slopes
2	Full Supply Level (FSL)	Seepage flows in steady state	-	Effective stress	Upstream and downstream slopes
3	Intermediate Water Level (IWL)	Seepage flows in steady state	-	Effective stress	Upstream slopes
4	Just After Completion (JAC)	Pore pressure during construction remains	-	Effective stress or Total stress	Upstream and downstream slopes

Results of stability analysis are shown in below

Result of Stability Analysis

Reservoir water level	WL (EL)	Seismic force (Kh)	u/s slope	d/s slope
DFL	953.12	--	1.824	1.374
FSL	947.00	--	1.693	1.371
IWL	925.00	--	1.441	1.371
JAC	--	--	1.605	1.238
FSL	947.00	0.05	1.323	1.193
IWL	925.00	0.05	1.185	1.193

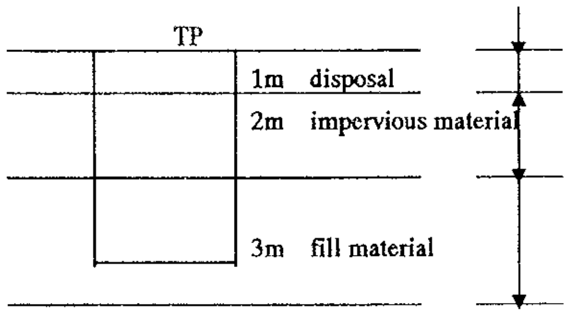
The results of safety analysis show that all cases satisfy the following safety factors which were mentioned above as the basic policy of safety factor for Kudu Dam.

- In the case non seismic force :$Fs \geqq 1.2$
- In the case the seismic force by the statistics calculation :$Fs \geqq 1.1$

(5) Collection Plan of Embankment Materials

Kudu dam is the earth-fill type dam, so more than 95% of total embankment volume of about 9.6 MCM are earth materials. In the material investigation report prepared by DWD in 1992, test pitting and laboratory tests were carried out for selected 29 places of borrow area near the dam site. The depth of each test pit was 2 m at that time, and soil property at the deep portion were not well known. In the additional investigation in 1999, soil property up to the depth of 5 m was checked and it was confirmed that these materials have suitable property as the impervious material and can be used to the core zone and fill zone.

The material distribution of borrow area is typically shown in the following rough sketch and as shown in Fig. 17, the 8 borrow areas of named A, H, K, L, P, T, ZD and ZH can be got the required volume of embankment materials.



1.5.6 Foundation Treatment

(1) Excavation Criteria of Dam Foundation

Excavation criteria for dam foundation was determined by the rock classification mentioned in the Table 8 and 9 which prepared based on the geological investigation by the JICA study team.

The dam foundation is classified into two categories, one is cut-off trench and the other is dam body foundation except cut-off trench. Grouting will be executed from cut-off trench, therefore the cut-off trench shall be provided with the following conditions; (i) to reduce differential settlement and (ii) to select suitable foundation which target Lugeon value can be achieved easily.

On the other hand, dam body foundation except cut-off trench shall be chosen as to prevent occurrence of sliding and deformation during/after construction. Consequently, talus deposit (dt), terrace deposit (tr) and highly weathered rock (D) shall be removed out of dam foundation because of loose condition, insufficient shear strength and poor modulus of deformation.

Proposed excavation criteria of dam foundation are as follow :

- Cut-off trench : at least CM class rock
- Dam foundation except cut-off trench : at least CL class rock

Furthermore, it is desirable that the longitudinal gradient of cut-off trench shall be finished in smooth shape.

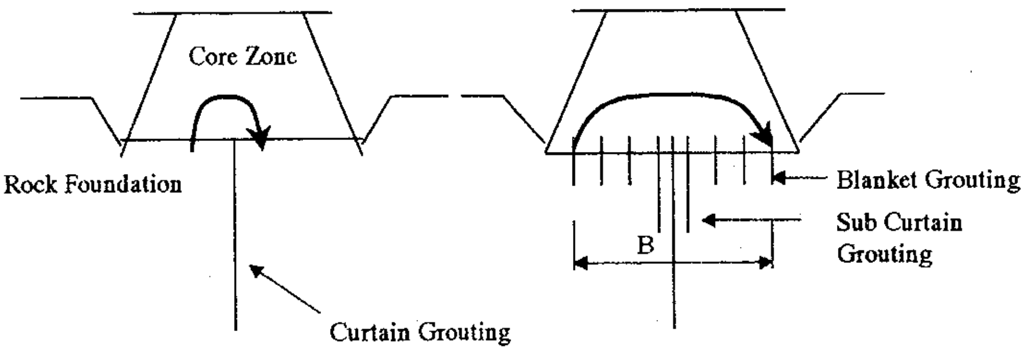
(2) Grouting

(a) Classification and purpose of Grouting

The grouting of fill-type dam is categorized into the curtain grouting and blanket grouting, and purpose of the grouting is shown below.

- Curtain grouting : To reduce seepage quantity through the dam foundation and to reduce uplift acting on the downstream side ofthe dam body.
- Blanket grouting : To make higher uniformity and water tightness alongthe boundary between core zone and foundation.

The following rough sketch shows the seepage flow along the boundary between core zone and foundation in the two cases of which blanket grouting is executed or not.



(Without Blanket Grouting) (With Blanket Grouting)

As shown above, the seepage path along the boundary becomes longer and the safety to the seepage failure becomes high when the blanket grouting is executed. It is, therefore, recommended that blanket grouting shall be executed in addition to the curtain grouting and width of execution area (B) of blanket grouting shall be about 50% of water depth.

(b) Curtain Grouting

(i) Spacing of injection hole

As it seems that sound bed rock will lie at deep portion of the foundation, single line of curtain grouting is planed. However, each one line of sub curtain grouting to the upstream and downstream sides of the central curtain grouting shall be executed, because it is judged that the permeability near the surface of the foundation have to be improved.

- Raw spacing : 1.5 m
- Hole spacing : 2.0 m

(ii) Injection depth

- Curtain grouting : $d = (1/3) \cdot H + C$

where, H : water depth (m)
C : constant, usually 5 - 25 m (the average 15 m)

- Sub curtain grouting : half (1/2) of central curtain grouting

(iii) Injection stage depth : 6m in consideration of the achievements of Zimbabwe

(iv) Target Lugeon value : 5 Lu

(c) Blanket Grouting

(i) Width of execution area : about 50% of water depth at both sides of curtain grouting

(ii) Spacing of injection hole

- Raw spacing : 3.0 m
- Hole spacing : 4.0 m

(iii) Injection depth : 6 m of one stage

(iv) Target Lugeon value : 10 Lu

1.5.7 Spillway

(1) Basic Plan

In the original design (DWD, 1993), the only part of overflow weir section of spillway was designed as the concrete structure with the design flood discharge of 2000-year return period. The flood discharge after overflow portion will be running through the natural ground and then flow into the river. From the result of the geological investigation, highly weathered basaltic rock and talus deposit seem to be distributed with the thickness of more than 5 m at the downstream area of the overflow weir. Therefore, the overflow flood will erode and devastate the natural ground gradually.

On the other hand, Zimbabwe has an alternative standard regarding the design flood discharge of spillway. That is, emergency spillway has to be installed with the flood discharge of 2000-year return period, and 250-year flood can be taken for the service spillway in consideration of the various situations such as topographic or economic constraints.

The basic concept regarding the design of spillway in this study is summarized below.

(a) The emergency spillway and service spillway should be installed in consideration of the frequency of use.

(b) The service spillway is designed to be able to release the flood discharge of 250-year return period, and is designed as a concrete structure so as to protect the ensure the stable flow condition of the flood discharge. But at the portion in where sound rock can be observed at the bottom and side of the spillway channel by excavation like as riverbed, concrete protection will not be necessary.

(c) The emergency spillway is designed to be able to release the flood discharge of 2000-year return period and the channel is not lined with concrete except the inflow section. The guide channel to connect with the downstream river is designed with natural ground without the structure.

(2) Design Condition

(a) Design flood discharge

- for service spillway : Qd = 6,000 m^3/s (250-year return period)
- for emergency spillway : Qd = 12,122 m^3/s (2000-year return period)

(b) Dimensions

- Design flood level : EL.953.12 (2,000-year return period)
- Full supply level : EL.947.00
- Overflow depth : 6.12m
- Length of overflow weir : 300m

(3) Type and alignment of spillway

The spillway for Kudu dam is located on the hill between the main dam and saddle dam at the right bank of the main dam in consideration of topographic conditions and the relation of other structures. The service spillway is composed of inflow portion, upstream channel, chute portion and dissipater. Type of each portion is determined as shown below.

- Inflow portion : Side spillway type
- Upstream channel : Channel type
- Chute portion : Chute type
- Dissipater : Endsill dissipater type

1.5.8 Apparatus Facilities

(1) Intake Facilities/Outlet Works

As the result of modification to shift the dam axis to upstream direction, distance of about 100m, intake facilities and outlet works have also to be shifted. In the original design, end portion of intake tunnel and location of outlet works are located in terrace deposit (tr) or talus deposit (dt). Intake facilities, intake tunnel and outlet works should be constructed in/on the hard rock so as to keep the stability and safety during/after construction.

After re-examination of each facilities in consideration of above, dimension of main facilities is planed as follows :

- Type of inlet : Intake tower
- Intake tunnel : Internal diameter 2.5 m
- Length : 560 m
- Tunnel gradient : 1/200

- Entrance : EL. 898 m
- Outlet : EL. 895 m

(2) Temporary Diversion Works

Generally, a fill-type dam has less resistance to overflow, and overtopping from dam crest should be avoided even if during construction. In the small and medium rivers in Zimbabwe, width of the river is relatively wide and river stream disappears into underground in the dry season. From these characteristics, the construction method without diversion channel is often applied in Zimbabwe. This method is to provide a weir section cutting a part of dam body filled in the dry season and to discharge river stream through this weir section in the rainy season.

In the original design by DWD, the above construction method was applied, because DWD has many experiences in construction of fill-type dams with this construction method. However, the Kudu dam is a large scale dam with about 9.5 MCM of embankment volume and construction period will be about 5 years. Also, the Munyati river is a big river and the catchment area at the proposed damsite is very wide at about 17,000 km^2. It means considerable big floods will be expected during construction period. Therefore, careful attention should be paid to the adjacent zone between previous embankment and new embankment because previous embankment may be damaged by floods in the rainy season.

From the viewpoint of safety construction, it is recommended that the originally designed intake tunnel be re-studied so as to have the function as the diversion channel such as elevation and section of tunnel, etc.

2. NYARUPAKWE PILOT PROJECT

2.1 General

The Lower Munyati River Basin Agricultural Development Project is a large-scale irrigation project including large-scale water sources development and would be a pioneering irrigation project for smallholder farmers in Zimbabwe. However, smallholder farmers have had almost no experience in irrigation cultivation, furthermore the implementation of this large-scale project will take a long time until the completion of the on-farm irrigation facilities. Therefore, in order to promote national agricultural production, step-by-step implementation of the project should be considered, and it is important to establish a pilot project serving as a place of technical training and trial-and–error learning for farmers in the area.

A pilot area has been selected in the western extremity of the main project zone, near Nyarupakwe in Gokwe South Rural District through the Phase I Study conducted in 1998-1999. For formulation of the agricultural development plan in the Pilot Project Area, a survey on the socio-economic structure of the area was carried out based on the active participation of the local population to the Pilot Project. The survey including public hearing meeting and individual household interview survey was conducted by a NGO "Intermediate Technology Development Group(ITDG)" under supervision of the JICA Study Team in order to clarify the needs and demands of the population of the local communities related to the Pilot Project Area and to assess anticipated positive and negative effects and obligations committed by the beneficiaries of the Pilot Project. Through the survey, the it was identified that local population in the area strongly want to obtain water for livestock, domestic use and irrigation.

It is, therefore, proposed to construct a medium scale dam at the middle reach of Nyarupakwe River in order to exploit water resources to the maximum extent for the Pilot Project Area, and also to construct a small scale dam at about 5 km upstream of the proposed Nyarupakwe dam to provide water for livestock for the upstream community.

2.2 Nyarupakwe Dam

2.2.1 Water Resources Development Potential

The proposed dam site is located at about 400 m downstream of the existing main rural road running between Nyarupakwe and Njelele/Gokwe/Empress Mine. A catchment area of the proposed damsite is estimated at 80 km^2. H – A (Water surface elevation – Water surface area) and H – Q (Water surface elevation – Storage capacity) at the proposed damsite are shown in Fig. 18 based on the topographic map with a scale of 1 to 5,000. From this figure, the gross capacity of the proposed reservoir is expected to be 1.65 x 10^6 m^3 with the full water level of El.898 m.

Since there is no hydrological data in the catchment area of the Nyarupakwe River, water resources development potential of the catchment is estimated use of data described in "An Assessment of the Surface Water Resources of Zimbabwe and Guideline for Development Planning, Ministry of Water Resources and Development". Zimbabwe is classified into six hydrological zones namely, Zone A to Zone F. The Pilot Project Area is located in Zone C in this classification. Zone C consists of 23 sub-hydrological zones and the proposed Nyarupakwe Dam is located in UN1 sub-zone. Based on the data obtained from the above hydrological zone, the yield of the proposed Nyarupakwe Dam is calculated as follows :

<u>Given</u> :

(a)	Catchment area	:	80.0 km^2
(b)	Mean annual runoff (MAR)	:	40 mm
(c)	Coefficient of varietion (CV)	:	1.20
(d)	Full water level (FWL)	:	El. 898.0 m
(e)	Reservoir surface area at FWL	:	47.5 ha
(f)	Gross storage capacity	:	1,650,000 m^3

Calculation :

(a) Gross MAR : $80 \times 10^6 \times 0.04 = 3,200,000$ m^3

(b) Gross storage ratio : 1,650,000/3,200,000 = 0.52

(c) Sediment allowance : $3,200,000 \times 0.065 = 200,000$ m^3

(d) Live capacity (U) : $1,650,000 - 200,000 = 1,450,000$ m^3

(e) U/MAR : 1,450,000/3,200,000 = 0.45

(f) Evaporation index (EI) :

$EI = E \times A / U = 1.1 \times 237,500 / 1,450,000 = 0.2$

Where, E : 80 % of pan-evaporation over 9 dry months
A : 50 % of reservoir surface area at FWL
U : Live capacity

(g) Yield /Live storage ratio at 10 % risk :

EI = 0.2. U/MAR = 0.45, CV = 1.2 $\Rightarrow$ 0.43

(h) Yield at 10 % risk

$0.44 \times U = 0.43 \times 1,450,000 = 638,000$ m^3

(i) Yield at 20 % risk

10 % Yield x 1.03 + 0.06 x 3,200,000 $\fallingdotseq$ 850,000 m^3

Available water of storage reservoir is estimated at 850,000 m^3 per annum at 20 % risk level. For water allocation of this amount, first priority is given to livestock and domestic water supply, and the remaining amount is used for irrigation depending on result of local population during the participatory social environmental survey.

(a) For livestock :
5,000 livestock unit x 40 liter x 8 months = 48,000 m^3

(b) For domestic water supply :
2,500 person x 40 liter x 365 day = 37,000 m^3

(c) For irrigation :
$850,000 - (48,000 + 37,000) = 765,000$ m^3

2.2.2 Design of Nyarupakwe Dam

The design of dam was made based on the result of geological and soil mechanical investigation at the proposed damsite conducted by a local contractor on sub-contract in May and June 2000. "A Guide to Design and Construction of Medium Sized Earth Dams in Zimbabwe" was used for the design.

(1) Geology

Foundation rock in and around the dam site is composed of silt stone, sand stone and conglomerate originating Mesozoic sedimentary rock. Overburden such as more highly weathered rock and top soil are present at surface layer with 1 to 2 m thickness. Quaternary deposits, such as talus, terrace, river bed deposit are found in and around the dam site. Talus and terrace deposits are very thin. River bed deposit is composed of sand and gravel. This material is good quality for filter material, because having conditions for filter such as gradation, hardness, grain shape, durability.

According to drilling log and test pit profile, foundation rock is classified into three zones such as highly weathered rock, moderately weathered rock and slightly weathered rock.

(a) Highly weathered rock

Highly weathered rock exists at less than about 7 m depth in hill area, and composed of mainly silty sand. N value of this layer is 20 to 50, and coefficient of permeability is 4×10^{-4}cm/s. Therefore this layer shall be excavated at foundation of core on fill type dam or foundation of on gravity type dam. According to results of laboratory test, fine content (75 microns) of highly weathered rock is 10 to 70%. This material is suitable as the semi-pervious to impervious material.

(b) Moderately weathered rock

Moderately weathered rock exists at about 7 m to 10 m depth in hill area and less than about 5 m at river bed. This layer is estimated to be satisfactory bearing strength and permeability for foundation of core of fill type dam or foundation of gravity type dam, due to N value is more than 50 and coefficient of permeability is about 1×10^{-5}cm/s. This material is crushed very easy, and turn into silty sand and sand with gravel. Therefore this material is semi-pervious material.

(c) Slightly weathered rock

Slightly weathered rock exists at about 15m or more depth in hill area and or more about 5 m at river bed. This material is estimated that can be used for rip rap material. But, if this material is used for concrete aggregate, compressive strength and durability shall be checked by physical properties test.

(2) Design of Spillway

(a) Design flood discharge

The design flood discharge of spillway was estimated at 400 m^3/s with 250 year return period referring to "A Guide to Design and Construction of Medium Sized Earth Dams in Zimbabwe".

(b) Overflow depth

Type of inlet was decided to be straight overflow type without crest gate. Overflow depth including approach velocity head was determined to be 1.0 m in due consideration of the required reservoir capacity.

(c) Crest length of overflow weir

The following formula is applied for calculation of crest length.

$L = Q/CH^{3/2} = 400/(2 \times 1.0^{3/2}) = 200$ m

Where, L : Effective crest length of overflow weir

Q : Design flood discharge = 400m^3/s

C : Coefficient of discharge = 2.0

H : Overflow depth include approach velocity head =1.0m

(d) Selection of spillway type

Two alternatives are conceivable to determine spillway type ; (i) gravity dam type and (ii) side spillway type because the scale of spillway becomes relatively big comparing to the dam scale.

The estimated construction costs of both alternative types are as follows;

① Gravity dam type

Works	Quantity	Unit price (Z$)	Amount (1,000 Z$)
Concrete	29,500m^3	2,550	75,225
Form	5,900m^2	550	3,245
Steel bar	200t	20,000	4,000
Excavation	145,700m^3	170	24,769
Embankment	87,500m^3	92	8,050
Total cost			115,289

② Side spillway type

Works	Quantity	Unit price (Z$)	Amount (1,000 Z$)
Concrete	15,200m^3	2,550	38,760
Form	15,200m^2	550	8,360
Steel bar	610t	20,000	12,200
Excavation	275,800m^3	170	46,886
Embankment	180,300m^3	92	16,588
Intake Pipe	70 m	1,000	70
Total cost			122,864

From the above, spillway type was determined to be gravity dam type, therefore the dam body was decided to be combined type of fill dam and concrete gravity dam.

(3) Design of Dam

(a) Free board and elevation of dam crest

Free board was determined to be 2.2 m by adding wet free board and dry free board.

Wet free board is overflow depth include approach velocity head to equal 1.0 m, and the total dry free board wave allowance by wind can be taken as 1.5 times. The following formula is applied for calculation of wave height by wind .

$$Wh = 0.032\sqrt{VF} + 0.76 - 0.27 \times \sqrt[4]{F}$$

Where, Wh : Wave height by wind (m)

V : Wind speed V=55km/hr

F : Fetch F=1.8km

$$\therefore Wh = 0.032\sqrt{55 \times 1.8} + 0.76 - 0.27 \times \sqrt[4]{1.8} = 0.766 \text{ m} \doteqdot 0.8 \text{ m}$$

Therefore,

Dry free board = 0.8 x 1.5 = 1.2m

Free board = 1.0 + 1.2 = 2.2 m

Elevation of dam crest = EL.898.0 + 2.2 = EL.900.20 m

(b) Type of fill dam

Generally, the fill dam is classified into two typical types in cross section, i.e homogeneous type and zone type. For getting the same value of safety factor on stability analysis, cross section of zone type becomes smaller than that of homogeneous type, since residual pore pressure in the zone type is usually lower than in homogeneous type in case of rapid draw down. But in case of small to medium size dam, construction cost of homogeneous type is less than zone type, due to construction method of homogeneous type is simpler than zone type. Available volume of soil material is satisfied, because highly weathered rock exists with 5 m thickness in and around the proposed dam site and it can be used for soil material. Therefore, dam type of fill dam was determined to be homogeneous type.

Embankment materials are as follows;

- Soil material : Highly weathered rock (Silt to Sandy silt)
- Filter : River bed deposit (Sand and gravel)

(c) Cross section of fill dam

(i) Crest width of dam : 8.0 m for use as the main rural road

(ii) Embankment slope : 1:2.5 for upstream slope and 1:2.0 for downstream slope

(iii) Core trench : According to insitu-permeability test, it is judged that highly weathered rock is pervious or semi-pervious layer, because coefficient of permeability is or more 1 x 10^{-4} cm/s, and moderately weathered rock is impervious foundation because coefficient of permeability is or less 1 x 10^{-5} cm/s. Therefore core trench and cutoff trench shall be made to reaches until moderately weathered rock. Bottom width of core trench and cutoff was decided to 3 m, according to Design Criteria on Zimbabwe

(iv) Filter : In order that the phreatic surface avoids appearing in the surface of down slope, blanket drain would be planned. Thickness of blanket drain would be determined to be 1.0 m.

(v) Slope protection : Up stream slope – rip rap and down stream slope - grass, Slightly weathered rock can be used for rip rap.

(d) Portion of Concrete gravity dam

The moderately weathered rock can be used as the foundation of small size concrete gravity dam because N value is or more 50 and coefficient of permeability is or less 1 x 10^{-5} cm/s at this layer. Therefore, base rock of concrete gravity dam portion was determined to be moderately weathered rock.

2.3 Small Scale Dam at Upstream of Nyarupakwe Dam

In order to provide water for livestock for the upstream community, a small scale dam is proposed to be constructed at about 5 km upstream of the proposed Nyarupakwe Dam. This dam will be expected to have a function as a sand trap for the Nyarupakwe dam, where local peoples shall be required to remove sediment periodically.

At the proposed damsite, hard rocks are exposed at both river bed and side slopes. The width of river bed is about 15 m and the height of both banks is about 5 m. In consideration of topography, geology and scale of dam, a concrete gravity dam is proposed. The main features of the proposed dam are summarized below.

(a)	Catchment area	:	58 km^2
(b)	Dam type	:	Concrete gravity dam
(c)	Dam height	:	7.2 m from base rock to the dam crest
(d)	Dam crest length	:	61.0 m
(e)	Overflow section	:	W 20 m x H 1.0 m at the center of the dam wall

TABLES

Table 1 Case Study on Kudu Dam Scale and Irrigation Development Area

項目	Case 1	2	3	4	5	6
(1) Scale of Kudu Dam						
a) Dam Height (m)	72.7	72.7	62.7	62.7	59.7	53.7
b) Storage Capacity (MCM)	1,551.4	1,551.4	972.6	972.6	828.6	580.6
c) Embankment Volume (m3)	9,557,000	9,557,000	6,068,000	6,068,000	5,237,000	3,842,000
(2) Irrigation Area						
a) Communal & Resettlement Area						
Gravity Irrigation Area(ha)	8,992	8,992	8,992	8,992	8,992	8,992
Pump Irrigation Area(ha)	5,508	9,215	288	7,008	4,238	0
b) Small Scale Commercial Farm(ha)	6,000	0	3,840	0	0	0
c) Large Scale Commercial Farm(ha)	4,500	6,793	2,880	0	0	0
Total(ha)	25,000	25,000	16,000	16,000	13,230	8,992
(3) Construction Cost						
a) Finabcial Cost(1,000Z$)						
i) Kudu Dam	3,640,574	3,640,574	2,632,135	2,632,135	2,493,793	2,020,519
ii) Main & Secondary Irrigation Canal	3,519,230	3,812,076	2,577,769	3,284,115	2,865,769	2,245,846
iii) On-farm Development						
- Communal & Resettlement Area	697,015	697,015	697,015	697,015	697,015	697,015
- Small Scale Commercial Farm	637,560	0	408,038	0	0	0
- Large Scale Commercial Farm	853,875	1,288,972	546,480	0	0	0
Total	9,348,254	9,438,637	6,861,437	6,613,265	6,056,577	4,963,379
(Z$/ha)	373,930	377,545	428,840	413,329	457,791	551,977
(US$/ha)	9,840	9,935	11,285	10,877	12,047	14,526
b) Economic Cost(1,000Z$)	7,478,603	7,550,910	5,489,150	5,290,612	4,845,261	3,970,703
(Z$/ha)	299,144	302,036	343,072	330,663	366,233	441,582
(US$/ha)	7,872	7,948	9,028	8,702	9,638	11,621
(4) Benefit						
a) Finabcial Benefit(1,000Z$)	1,028,026	1,028,026	657,937	657,937	544,031	369,760
(Z$/ha)	41,121	41,121	41,121	41,121	41,121	41,121
(US$/ha)	1,082	1,082	1,082	1,082	1,082	1,082
b) Economic Benefit(1,000Z$)	1,393,711	1,393,711	891,975	891,975	737,552	501,290
(Z$/ha)	55,748	55,748	55,748	55,748	55,748	55,748
(US$/ha)	1,467	1,467	1,467	1,467	1,467	1,467
(5) IRR(%)	10.1	10.0	9.0	9.3	8.5	7.2
B/C(Discount Rate = 10%)	1.01	1.00	0.88	0.92	0.83	0.69

Table 2 Quantity of Test Pitting

Marerial	Spot	Depth (m)	Nos. of Sample
Borrow Area			
A	4	5	8
K	2	5	4
ZD	2	5	4
H	2	5	4
Sub-total	10	50	20
Sand/Gravel			
	5	1	10
Rock Material			
Block sample from the proposed quarry site			3
Existing boring core sample			9

Table 3 Item and Quantity of Laboratory Test

Test Item	Earth Material	Sand/Gravel		Rock Material
		Fine	Coarse	
Grain size analysis	20	10		
Liquid limit and Plastic limit test	20			
Specific gravity test	20	10	10	12
Water absorption test		10	10	12
Water content test	20			
Procter compaction test	20	10		
Triaxial compression test (CU)	10			
Permeability test	10	10		
Dispersive characteristics	10			
Absorption test				12
Soundness test by sodium sulfate				12
Alkali-silica reactive test				12
Compression test				12

Table 4 Summary of Laboratory Test (Earth Material)

Pit NO.	Depth	Gradation					Gs	Liquid Limit	Plastic Index	Classifi-cation	FMC	Proctor Test			Triaxial Test		Permeability Test	Emerson Crumb		Remarks
		Gravel	Coarse Sand	Medium Sand	Fine Sand	Silt Clay						ρd_{max}	OMC	FMC-OMC	C'	φ'	k	NaOH	Dist Water	
	(m)	(%)	(%)	(%)	(%)	(%)					(%)	(tf/m³)	(%)	(%)	(tf/m²)	(deg)	(cm/s)			
P1	2.5	0	7	13	19	61	2.66	24	11	CL	8.0	1.868	13.4	-5.4	0.06	29.2	1.60E-06	H	ND	
P1	5.0	0	4	13	16	67	2.63	23	12	CL	8.1	1.771	16.9	-8.8				SL-M	ND	
P2	2.5	9	2	7	8	74	2.73	39	18	CI	18.6	1.824	15.6	3.0	2.14	27.5	7.40E-06	ND	ND	
P2A	2.5	34	6	4	5	51	2.65	39	19	CI	14.6	1.913	16.0	-1.4				SL-M	SL	
P3	2.5	0	0	2	6	92	2.63	38	19	CI	14.6	1.673	20.0	-5.4	1.26	22.9	6.58E-07	SL-M	ND	
P3	4.6	14	4	6	8	68	2.62	41	22	CI	7.0	1.727	20.4	-13.4				SL	ND	
P4	2.5	1	2	4	9	84	2.62	32	16	CL	10.4	1.765	15.6	-5.2	2.55	27.6	2.80E-06	ND	ND	
P4	4.0	64	8	5	2	21	2.62	36	18	GC	8.1	1.829	13.7	-5.6				SL	SL	
P5	2.5	0	2	18	25	55	2.60	25	12	CL	7.2	1.752	15.6	-8.4	0.68	34.9	2.84E-06	SL	ND	
P5	5.0	2	9	24	16	49	2.58	22	11	SC	5.3	1.875	10.7	-5.4				SL	SL	
P6	2.5	0	3	19	21	57	2.64	20	10	CL	5.4	1.789	11.8	-6.4	13.60 *	54.3 *	5.99E-06	M	SL-M	
P6	5.0	0	3	19	32	46	2.59	24	12	SC	7.1	1.853	9.1	-2.0				SL	SL	
P7	2.5	0	1	14	32	53	2.64	24	12	CL	5.9	1.838	10.5	-4.6	1.64	30.0	1.13E-05	H	ND	
P7	5.0	47	39	7	2	5	2.59	27	13	SC	5.4	2.006	10.0	-4.6				SL	SL	
P8	2.5	35	5	5	4	51	2.62	43	21	CI	7.8	1.689	19.4	-11.6	0.39	31.1	1.70E-06	SL-M	SL	
P8A	2.5	4	5	5	9	77	2.65	37	18	CI	11.8	1.739	18.2	-6.4				H	H	
P8A	5.0	37	4	3	2	53	2.65	45	20	CI	8.7	1.825	14.4	-5.7				SL	SL	
P9	2.5	13	3	3	2	79	2.61	47	23	CI	16.2	1.712	17.5	-1.3	4.31	13.6	6.05E-07	ND	ND	
P10	1.5	63	5	3	3	26	2.62	38	16	GC	8.6	1.872	13.3	-4.7			2.91E-05	SL	SL	
P10B	2.0	35	9	4	3	49	2.60	40	18	GC	7.1	1.875	16.7	-9.6	4.62	18.0	1.20E-07	TRACE	ND	
Average							2.63	33	16		9.3	1.810	14.9	-5.6	1.96	26.1	5.83E-06			

0.95ρd 1.72 tf/m³
e 0.53

* : exclusion (too large)

Design Value						
ρt	1.98 tf/m³	C'	1.5 tf/m²	kv	6.0E-06 cm/s
ρsat	2.06 tf/m³	φ'	25 deg	kh	3.0E-05 cm/s
Sr	74.3 %			kave	1.3E-05 cm/s

Table 5 Summary of Laboratory Test (Sand Gravel)

Pit NO.	Depth	Gradation: Gravel	Coarse Sand	Medium Sand	Fine Sand	Silt Clay	Gs	Liquid Limit	Plastic Index	Classifi-cation	Proctor Test: ρd_{max}	OMC	Permeability Test: k	Remarks
	(m)	(%)	(%)	(%)	(%)	(%)					(ton/m^3)	(%)	(cm/s)	
P11	0.5	1	38	53	6	2	2.65	NP		SM	1.613	7.9	3.55E-01	
P11	1.0	0	21	53	10	16	2.58	NP		SM	1.642	17.0	6.43E-03	
P12	0.5	17	57	19	5	2	2.57	NP		SM	1.771	10.8	3.03E-02	
P12	1.0	22	55	16	5	2	2.54	NP		SM	1.759	11.7	3.12E-02	
P13	0.5	29	10	18	15	28	2.59	NP		SM	1.804	12.7	2.28E-04	↑
P13	1.0	21	14	19	16	30	2.59	NP		SM	1.873	12.1	2.20E-04	
P14	0.5	0	1	1	3	95	2.65	52	25	CH	1.475	24.8	2.21E-04	Unsuitable
P14	1.0	0	1	1	2	96	2.66	54	28	CH	1.475	23.4	2.71E-05	for Filter
P15	0.5	0	0	6	18	76	2.67	32	16	CL	1.676	16.5	1.26E-05	
P15	1.0	0	3	42	20	35	2.68	NP		SM	1.724	16.1	1.26E-05	↓
Average[*1]							2.59				1.696	11.85	1.06E-01	

*1: except for unsuitable material

Design Value						
	ρt	1.90 tf/m^3	C' *2	0 tf/m^2	k	1.0E-01 cm/s
	ρsat	2.04 tf/m^3	ϕ' *2	30 deg		

*2: assumed value

Table 6 Summary of Laboratory Test (Rock Material)

Sample NO.	Depth (m)	Type of Rocks	Classification of Bedrocks	Specific Gravity Gs	Absorbed Moisture FMC (%)	Unconfined Compressive Strength (kgf/cm^2)	Los-Angeles Test (%)	Remarks
LB 5	26.8	Ba	CH	2.68	0.7	450.7		
LB 7	22.8-23.2	Ag	CH	2.67	1.3	378.3		
LB 7	28.45-29.75	Ag	CH	2.62	0.8	829.0		
LB 8	14.15-14.4	Cg	CM	2.68	0.3	1496.9		
OT/2	15.0-15.2	Ar	CH	2.66	0.9	739.3		
OT/4	20.4-20.6	Cg	CH	2.67	0.6	415.0		
OT/4	23.65-23.85	Ag	B	2.66	0.7	685.2		
SP 10	26.6	Ba	B	2.65	0.2	1605.0		
SP 11	28.1	Ba	B	2.64	0.3	1225.7		
US EX RB1 1				2.65	0.3	535.3		
US EX RB1 2				2.63	0.4	580.2	12	
US EX RB1 3				2.64	0.5	393.6		
at RB 1							13	
Halfway Down Hill to Rest Camp							17	
L/B Top of Hill to Rest Camp							13	
Average			CM-CH	2.66	0.8	718.2	14	
			B	2.65	0.4	1172.0		

Proposed Design value

Transition Zone	ρt	2.00 tf/m^3	C' *2	0 tf/m^2	CL-CM
	ρsat	2.10 tf/m^3	φ' *2	35 deg	$qu \geqq 300 kgf/cm^2$
Rock Zone	ρt	2.00 tf/m^3	C' *2	0 tf/m^2	CM, CH-B
	ρsat	2.10 tf/m^3	φ' *2	40 deg	$qu \geqq 500 kgf/cm^2$

Table 7 Comparison of Earthfill Dam and Rockfill Dam

Earthfill Dam

Filling Item		Volume m^3	TTL.Vol. m^3
Earth material	Coffer D.	360,400	6,641,485
	u/s zone	1,883,936	
	Core	2,761,660	
	d/s zone	1,635,489	
Rock material	Rock toe	361,380	361,380
Excavation Item	**Class**	**Volume m^3**	**TTL.Vol. m^3**
Hard rock	CH	0	13,482
	CM	13,482	
Soft rock	CL	31,959	31,959
Siol	D	198,917	2,050,078
	dt	1,851,161	
Construction Cost		Z$ 780 x 10^3	

Rockfill Dam

Filling Item		Volume m^3	TTL.Vol. m^3
Earth material	Core	785,176	949,138
	Filter	163,962	
Transition material	Tr.zone	1,900,263	1,900,263
Rock material	Ro.zone	1,840,493	2,129,283
	Coffer D.	288,790	
Excavation Item	**Class**	**Volume m^3**	**TTL.Vol. m^3**
Hard rock	CH	712	11,702
	CM	10,990	
Soft rock	CL	32,079	32,079
Siol	D	142,245	1,462,234
	dt	1,319,989	
Construction Cost		Z$ 880 x 10^3	

Note : The above estimation was made based on the prices of June 1999.

Table 8 Factors for Rock Classification

Grade	Hardness	Assumed unconfined compression strength (kgf/cm^2)
A	Very hard	$600 \leqq Qu$ (hardly broken with clear sound by hammer blow)
B	Hard	$200 \leqq Qu < 600$ (difficult to break with clear sound by hammer blow)
C	Fairly hard	$100 \leqq Qu < 200$ (broken with dim sound by hammer blow)
D	Moderate	$50 \leqq Qu < 100$ (easily broken with dull sound by hammer blow)
E	Soft	$Qu < 50$ (easily broken into small pieces by hammer blow)

Grade	Joint Interval (cm)
1	$30 \leqq I$
2	$10 \leqq I < 30$
3	$5 \leqq I < 10$
4	$2 \leqq I < 5$
5	$I < 2$

Grade	Joint Condition
a	Fresh, closely adhered
b	Stained and slightly deteriorated along joints
c	Stained and deteriorated or intercalated with soft materials
d	Un-distinguishable (Fragments, sandy - silty, or clayey)

Table 9 Combination of Factors for Rock Classification

	A					B					C				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
a	B	B	CH	CM	-	B	CH	CH	CM	CL	CH	CH	CM	CM	CL
b	B	CH	CH	CM	-	CH	CH	CH	CM	CL	CH	CH	CM	CL	D
c	CH	CH	CM	CL	-	CH	CH	CM	CL	D	CM	CL	CL	CL	D
d	-	-	-	-	-	-	-	CL	D	D	CL	CL	D	D	D

	D					E				
	1	2	3	4	5	1	2	3	4	5
a	CM	CM	CL	CL	D	CM	CL	D	D	D
b	CM	CL	CL	CL	D	CL	D	D	D	D
c	CL	CL	CL	D	D	D	D	D	D	D
d	D	D	D	D	D	D	D	D	D	D

FIGURES

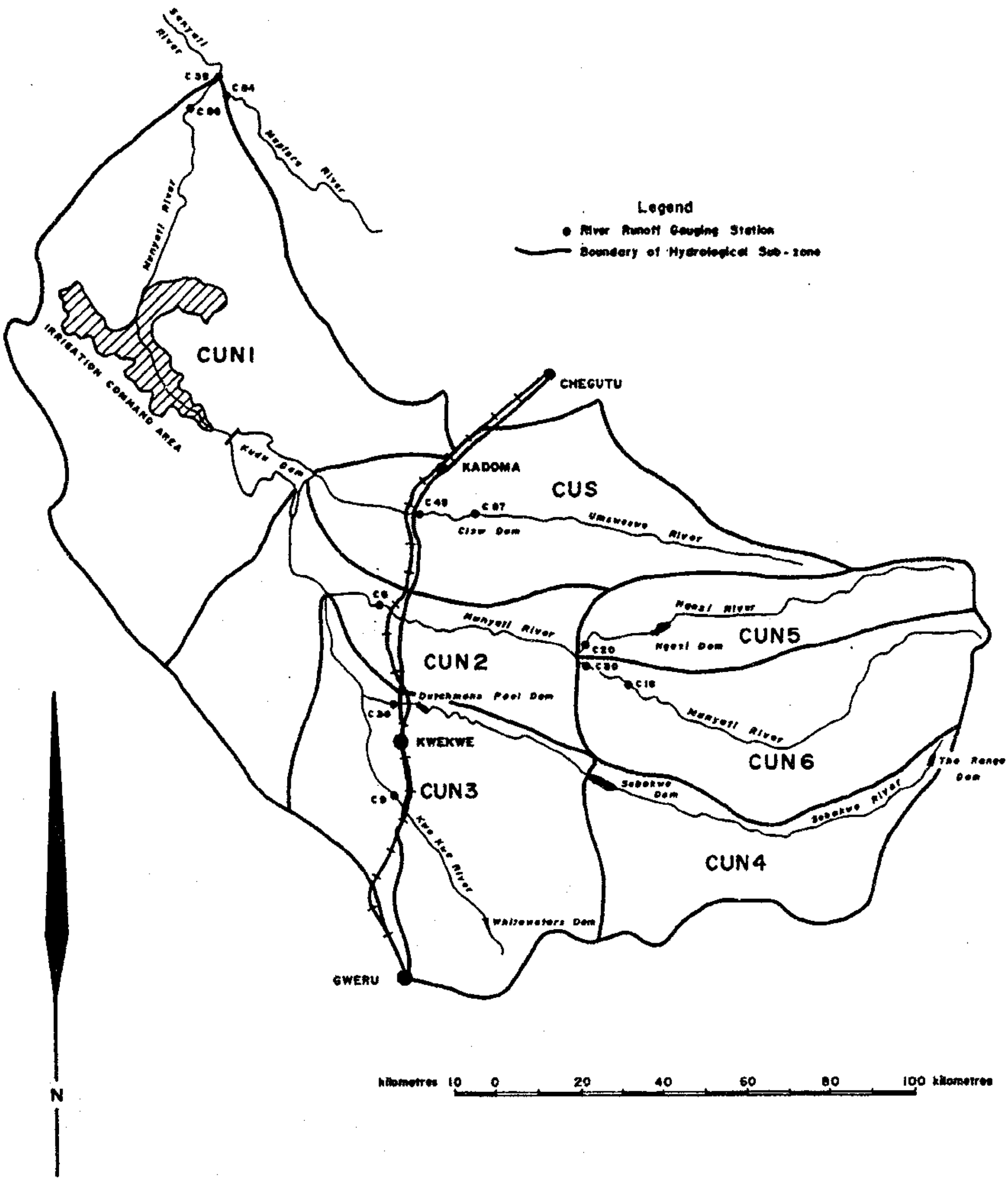


Fig. 1 Sub-Hydrological Zones in the Kudu Dam Catchment Area

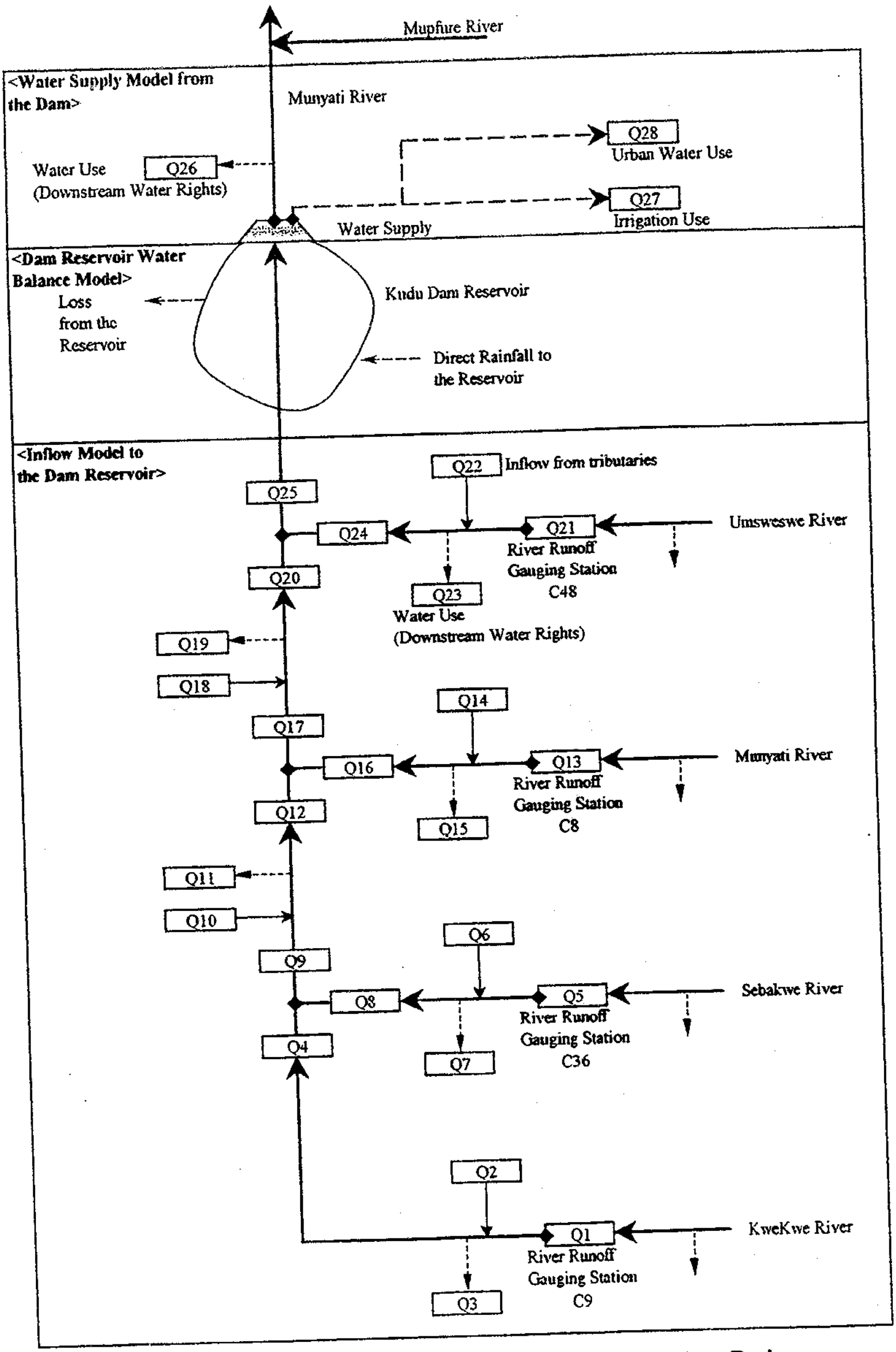


Fig. 2 Water Balance Model of Munyati River Basin

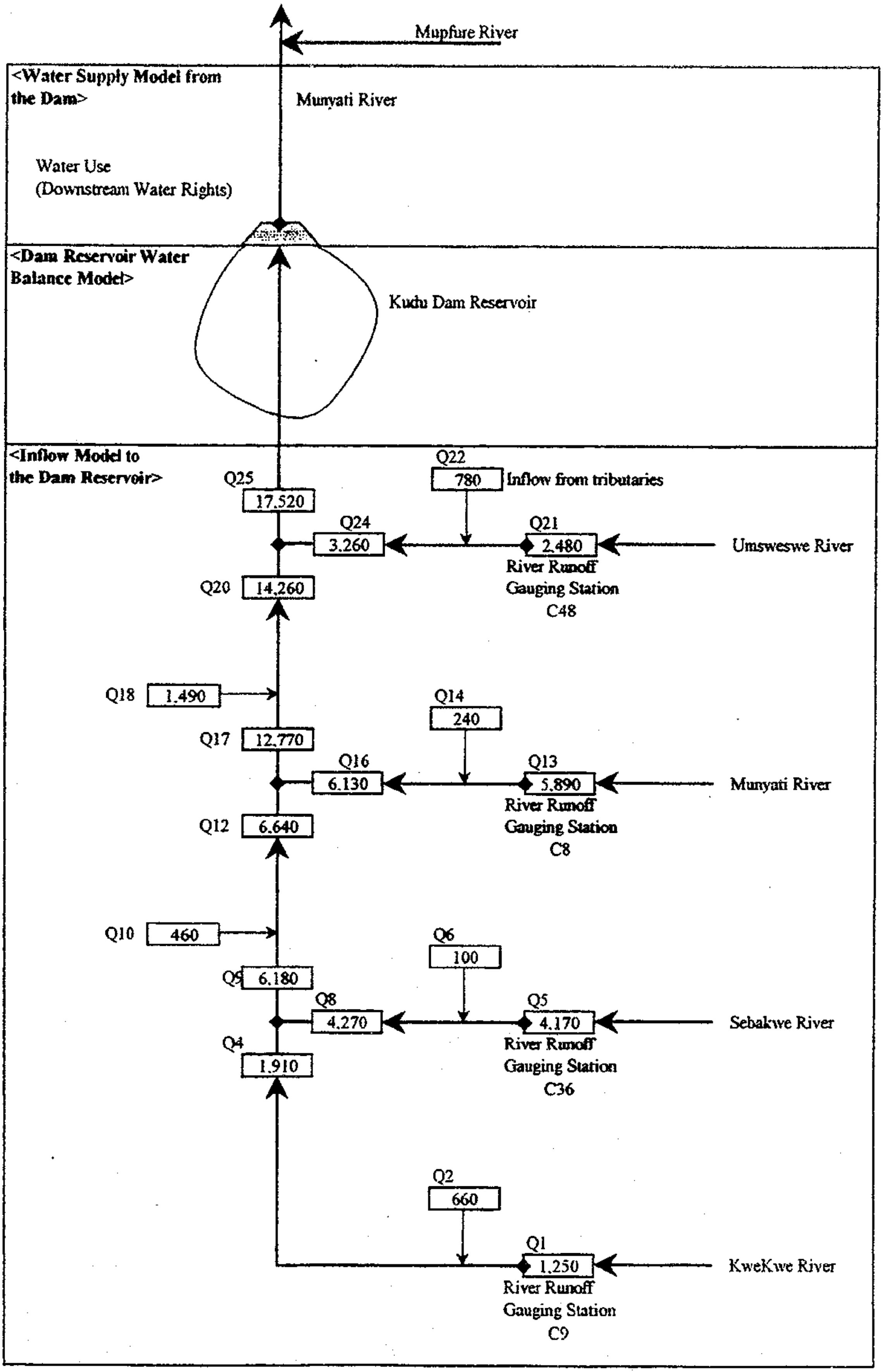


Fig. 3 Catchment Area of Kudu Dam

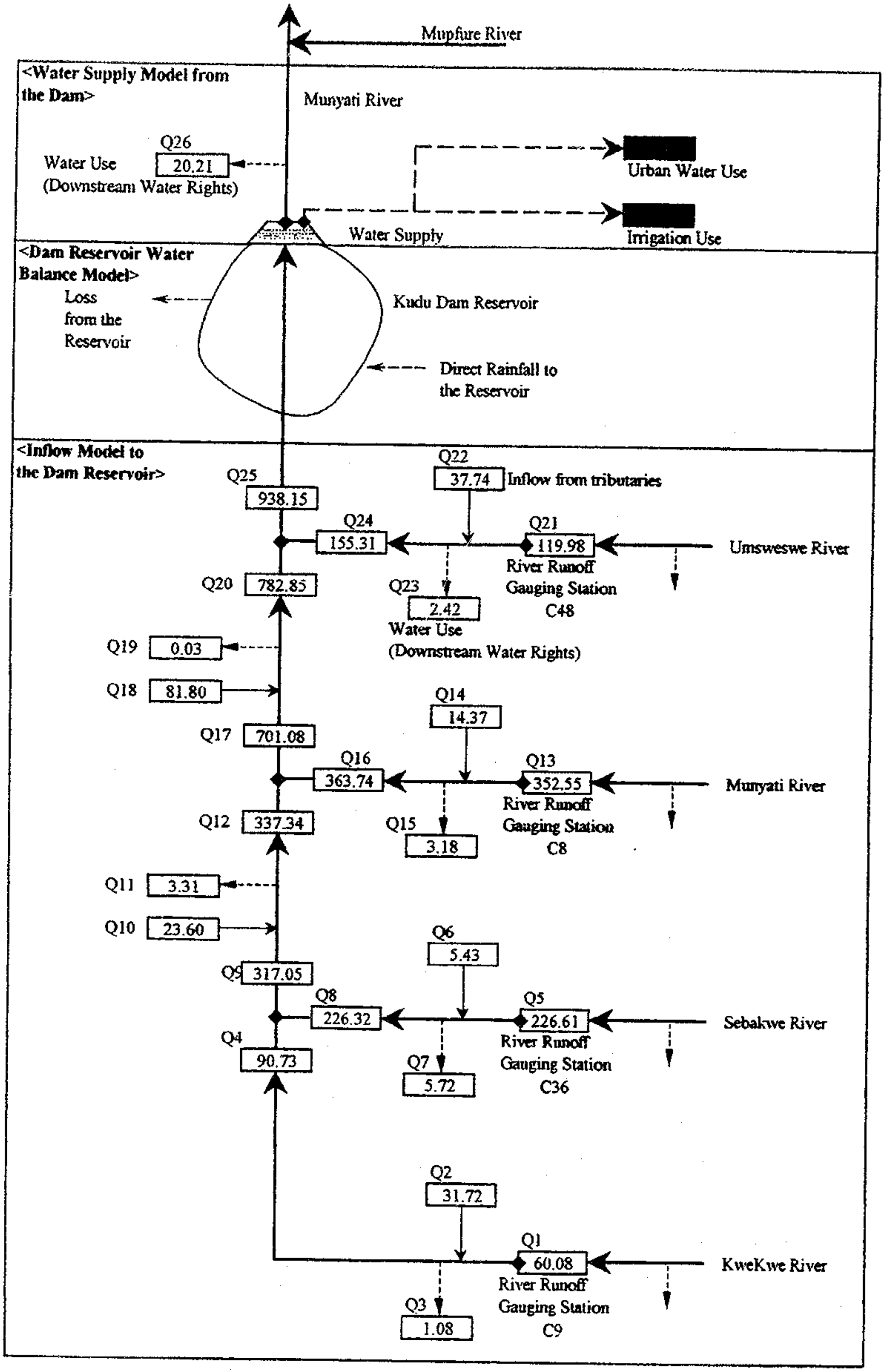
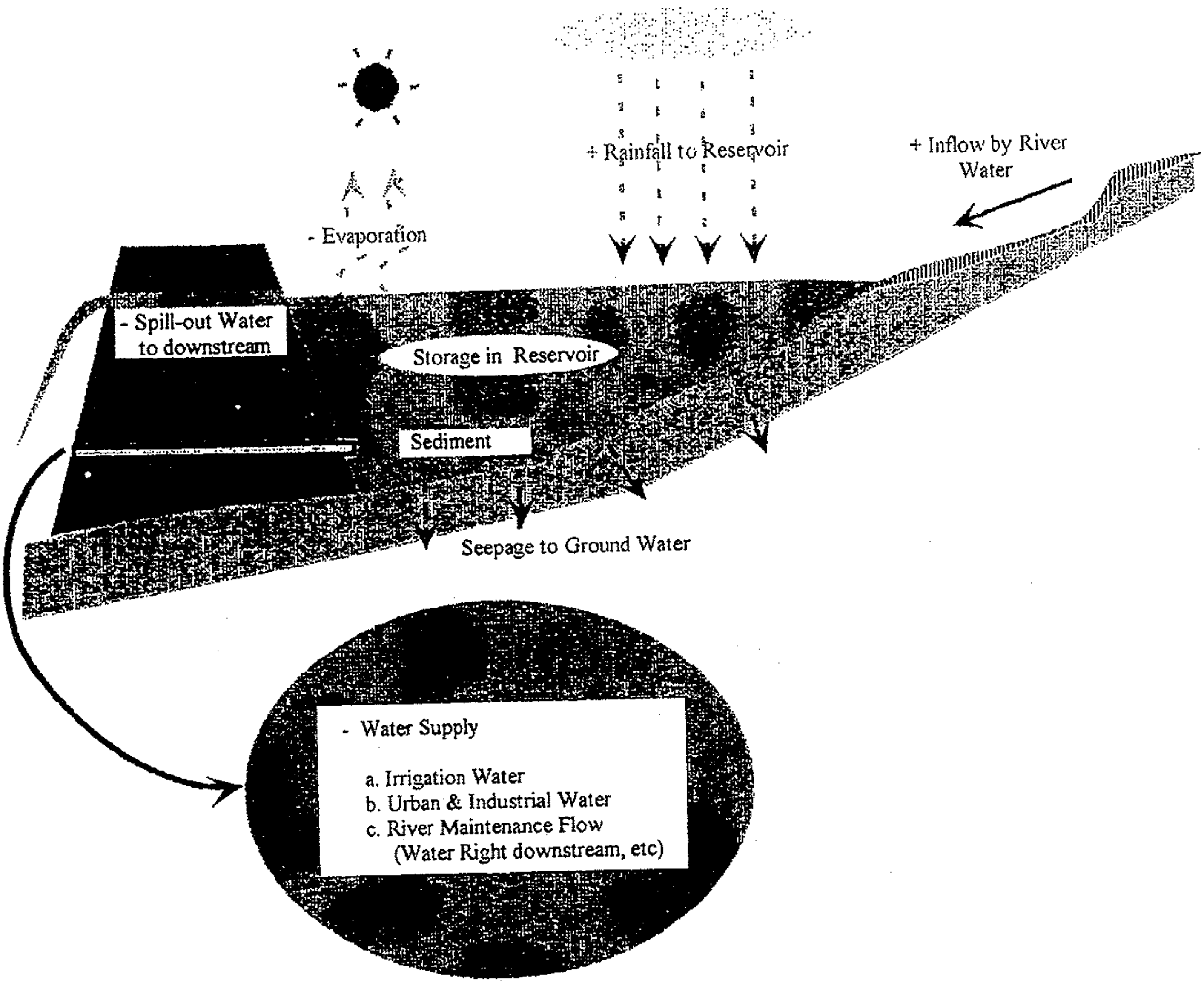


Fig. 4 Average Annual Runoff to Kudu Dam

Fig. 5 Procedure of Water Balance & Reservoir Operation Study

Image of Water Balance in a Reservoir



Water Balance & Reservoir Operation Study for the proposed Kudu Dam has been carried out, applying the following equation, on the basis of the above factors in the schematic reservoir.

Storage*present = Storage*previous + Inflow + Rainfall

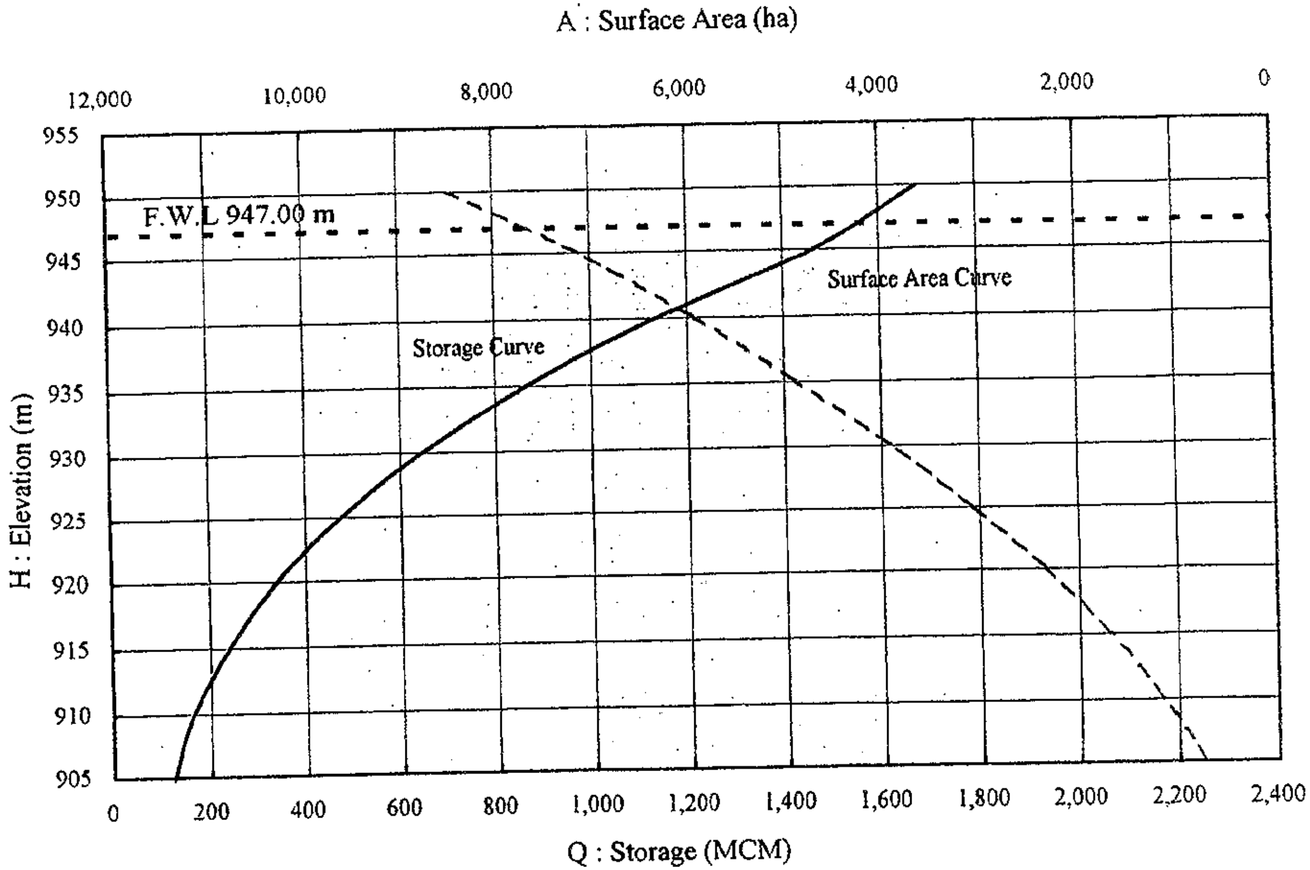
- Irrigation Water Release - Urban Water Release - River Maintenance Flow

- Evaporation Loss - Seepage Loss

- Spill-out Water when Water level is more than Full Storage Level

However, <u>When calculated Storage*present < 0, then Storage*present = 0</u>

Fig. 6 H-A and H-Q Curves of Kudu Dam Reservoir



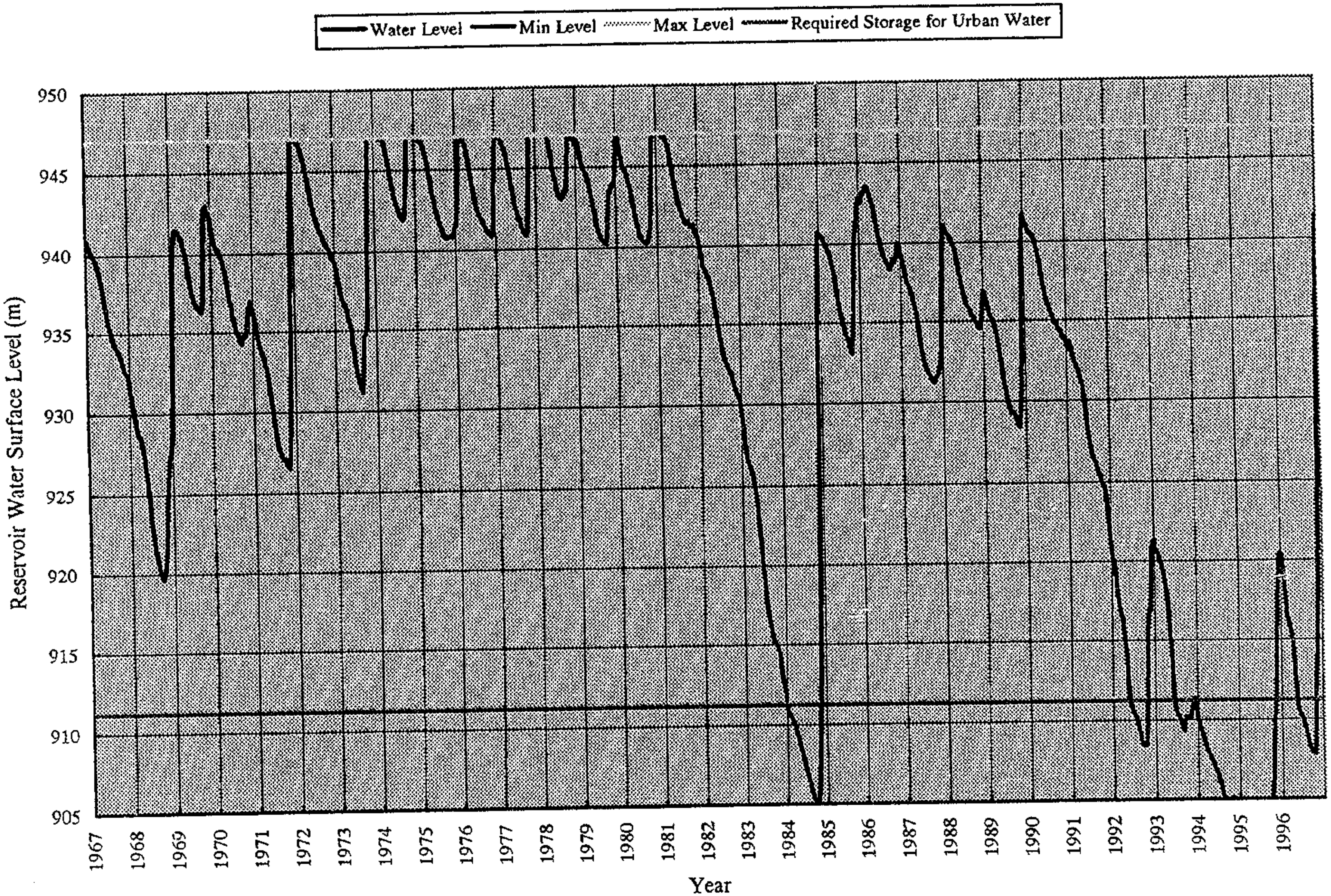
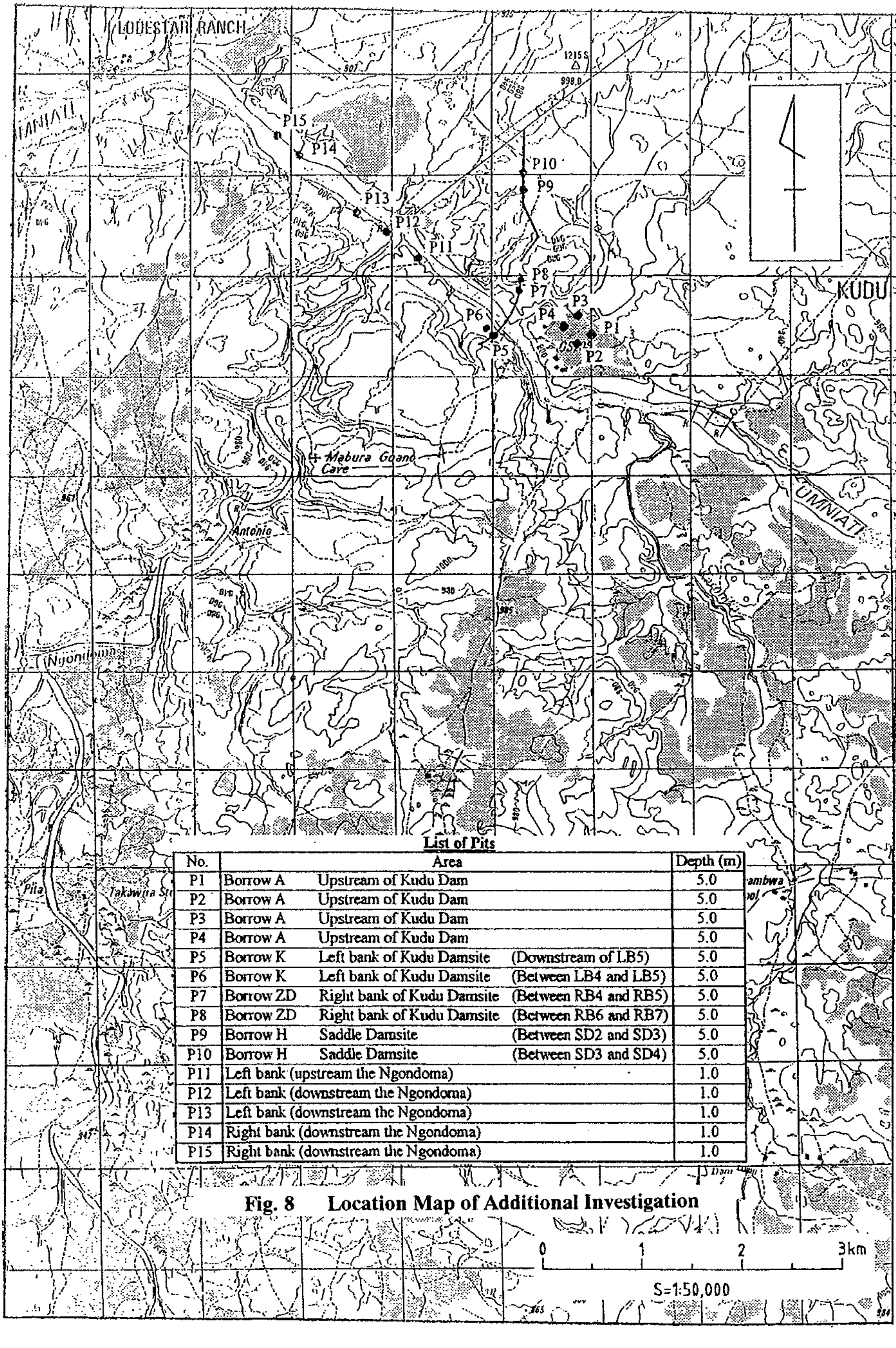


Fig. 7 Result of Kudu Dam Water Balance Study

(Irrigation Area: 25,000ha, Full Water Surface Level: 947.00m)



List of Pits

No.	Area			Depth (m)
P1	Borrow A	Upstream of Kudu Dam		5.0
P2	Borrow A	Upstream of Kudu Dam		5.0
P3	Borrow A	Upstream of Kudu Dam		5.0
P4	Borrow A	Upstream of Kudu Dam		5.0
P5	Borrow K	Left bank of Kudu Damsite	(Downstream of LB5)	5.0
P6	Borrow K	Left bank of Kudu Damsite	(Between LB4 and LB5)	5.0
P7	Borrow ZD	Right bank of Kudu Damsite	(Between RB4 and RB5)	5.0
P8	Borrow ZD	Right bank of Kudu Damsite	(Between RB6 and RB7)	5.0
P9	Borrow H	Saddle Damsite	(Between SD2 and SD3)	5.0
P10	Borrow H	Saddle Damsite	(Between SD3 and SD4)	5.0
P11	Left bank (upstream the Ngondoma)			1.0
P12	Left bank (downstream the Ngondoma)			1.0
P13	Left bank (downstream the Ngondoma)			1.0
P14	Right bank (downstream the Ngondoma)			1.0
P15	Right bank (downstream the Ngondoma)			1.0

Fig. 8 Location Map of Additional Investigation

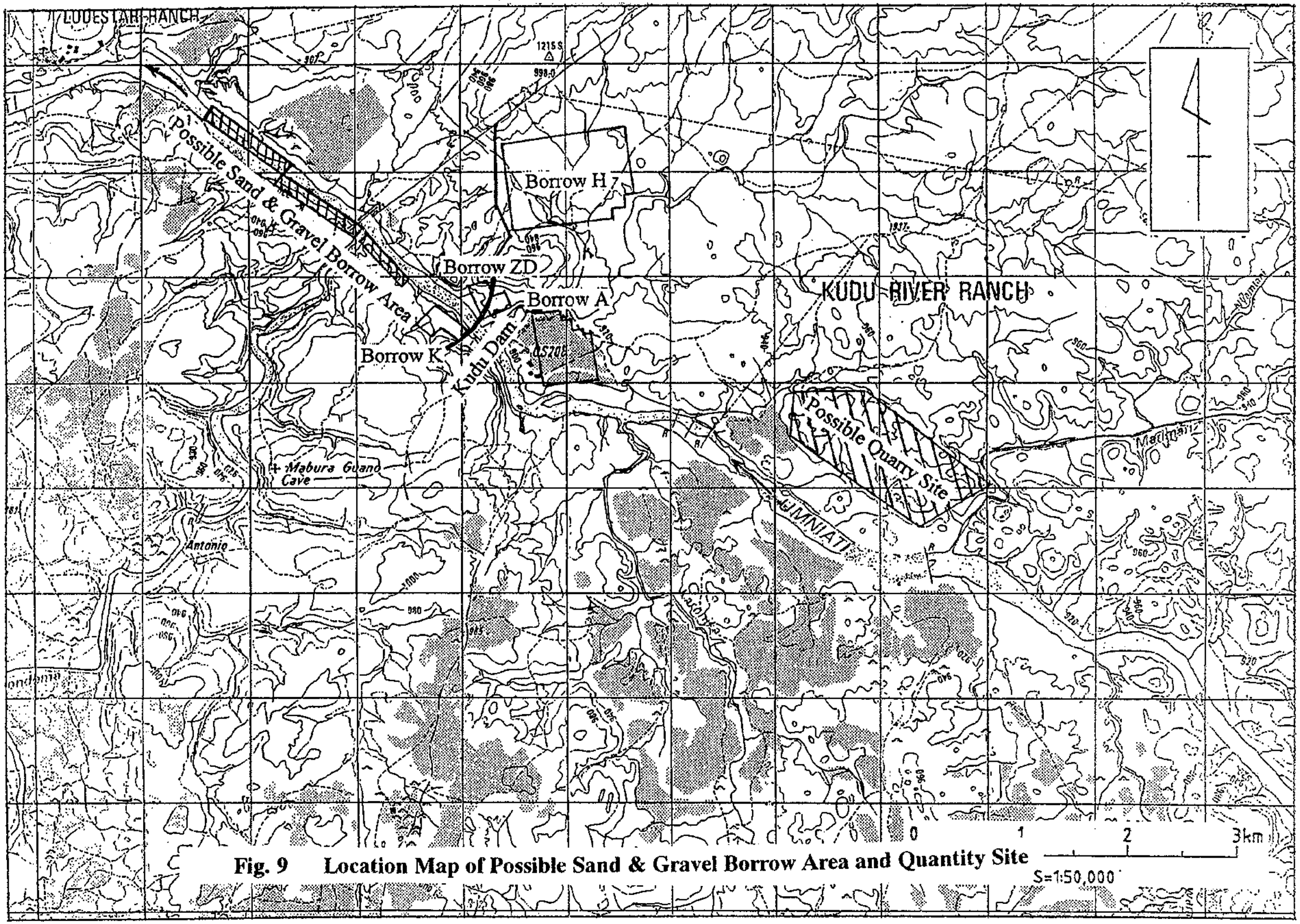
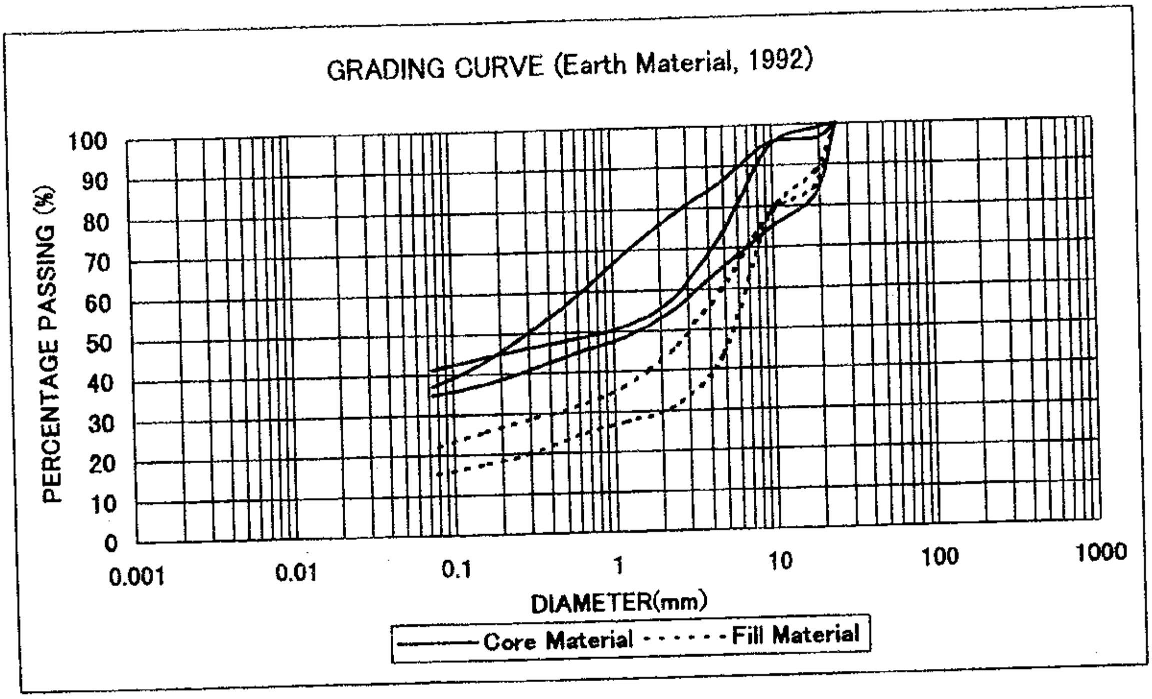


Fig. 9 Location Map of Possible Sand & Gravel Borrow Area and Quantity Site

Fig. 10 Grading Curves of Dam Body Materials (Earth Material)



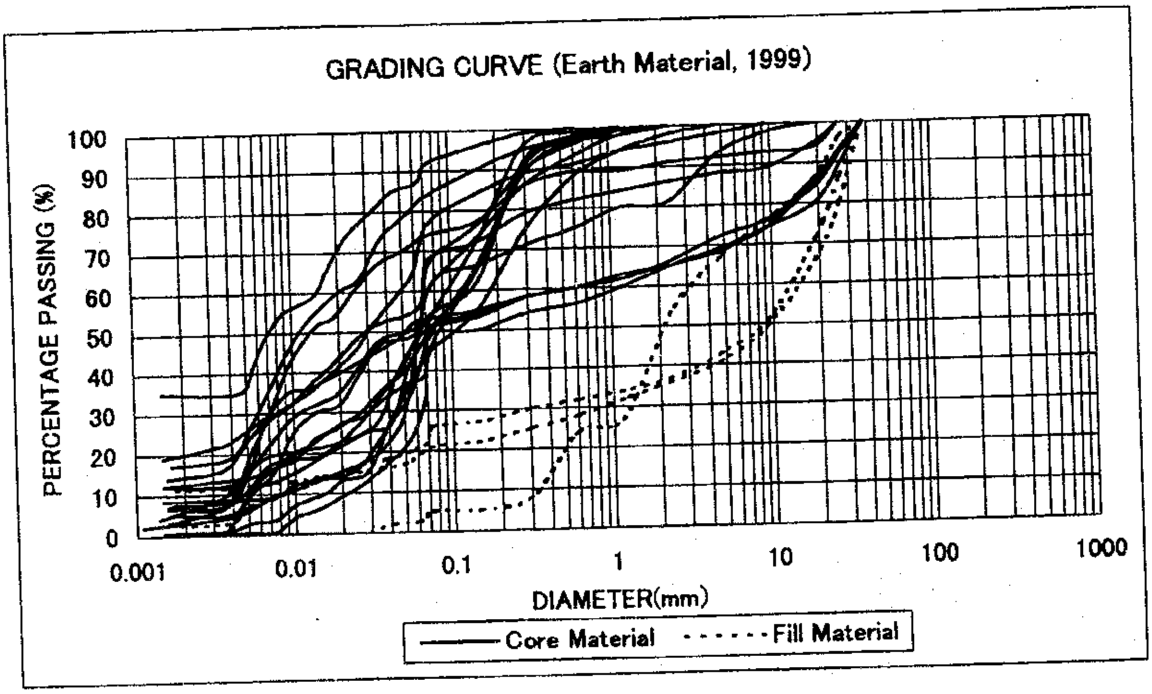
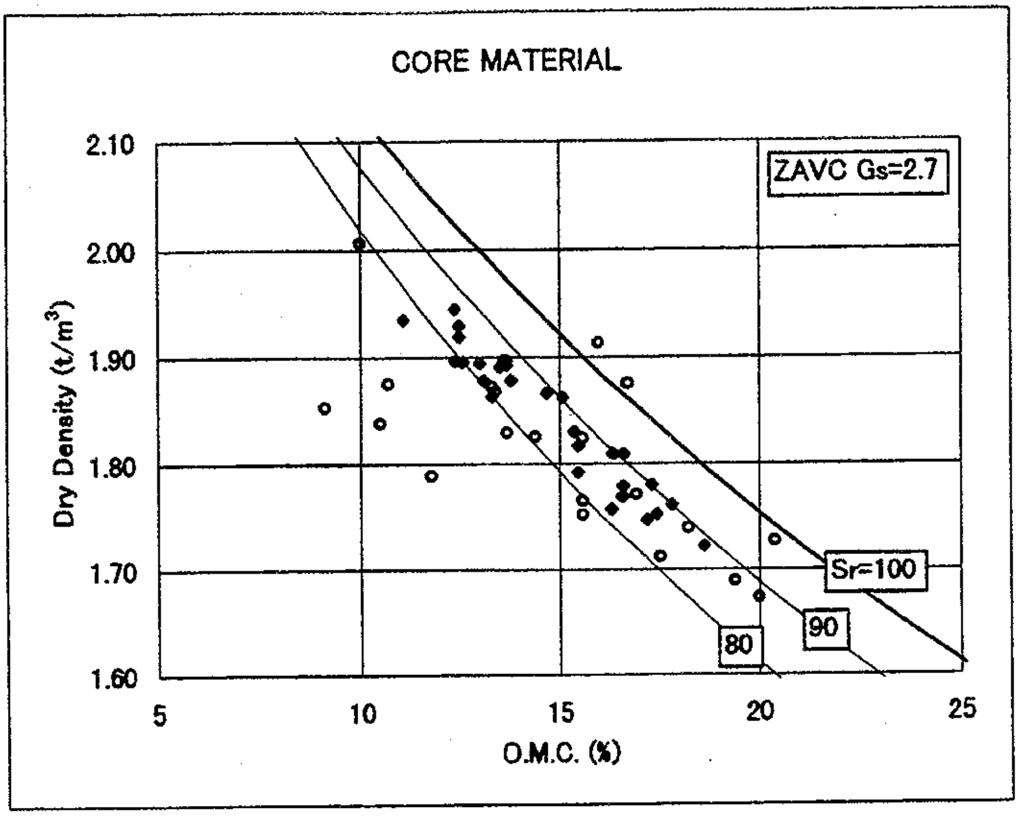


Fig. 11 Optimum Water Contents (OWC) and Dry Density

◆: 1992
○: 1998



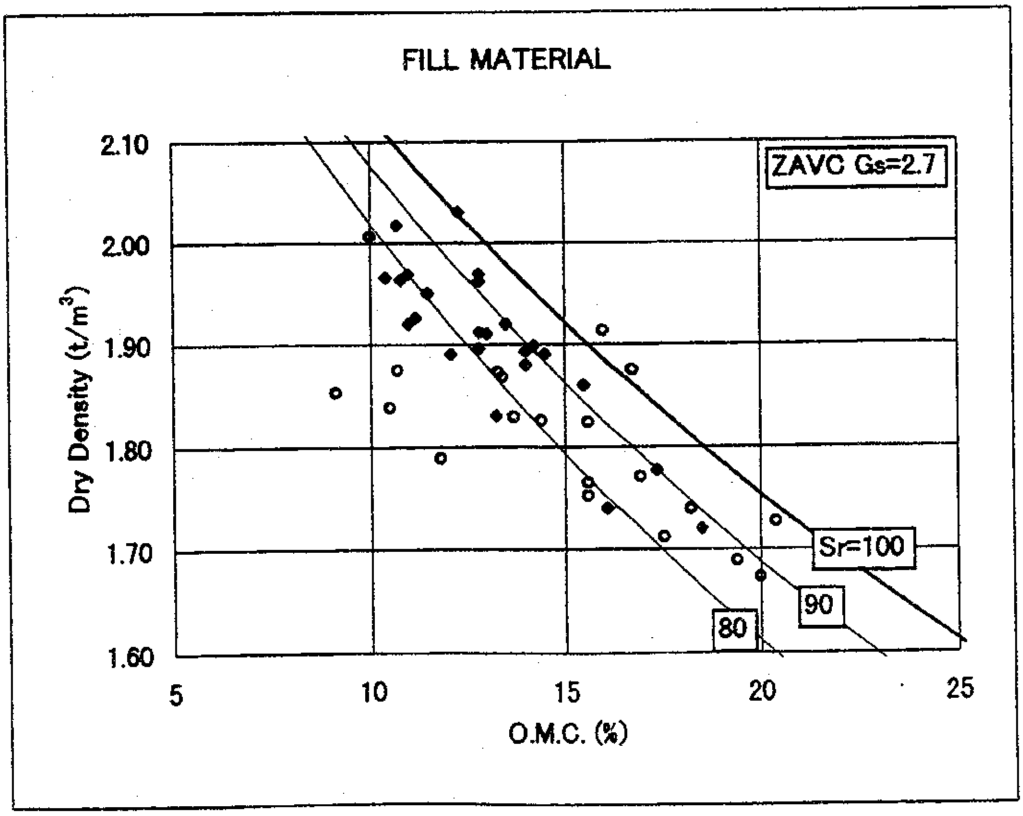
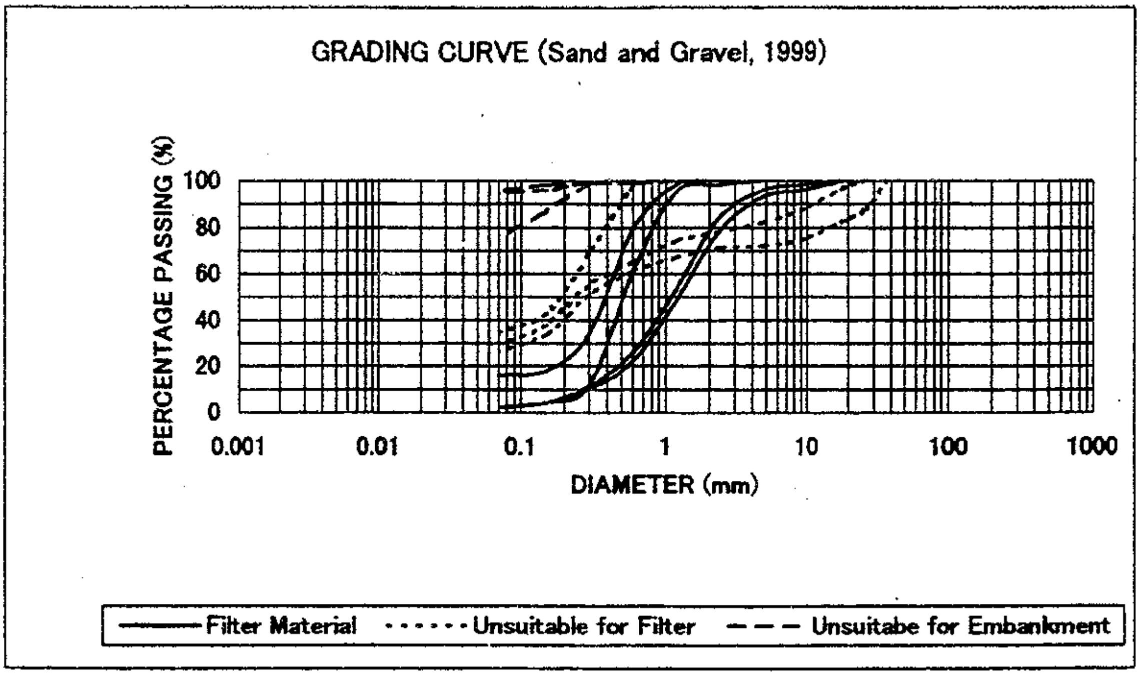


Fig. 12 Grading Curves of Dam Body Materials (Sand/Gravel, Filter)



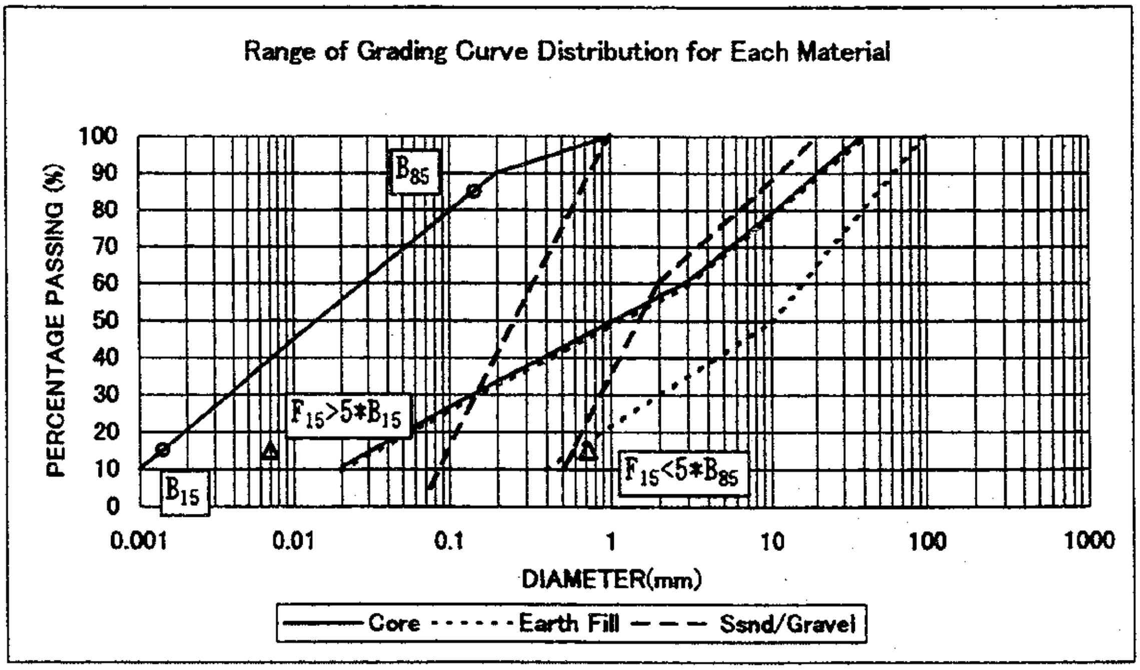


Fig. 13 Standard Cross Section of Earthfill Dam

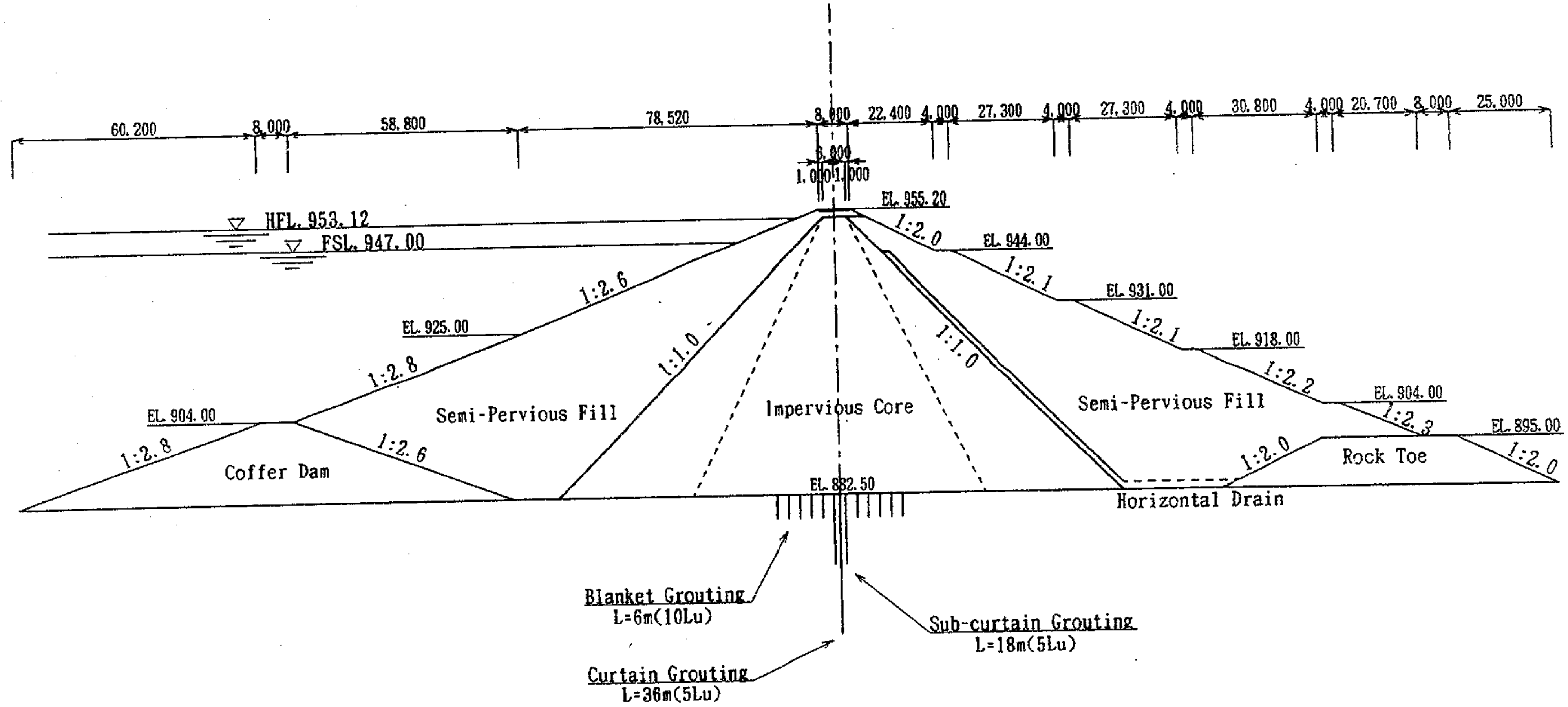


Fig. 14 Standard Cross Section of Rockfill Dam

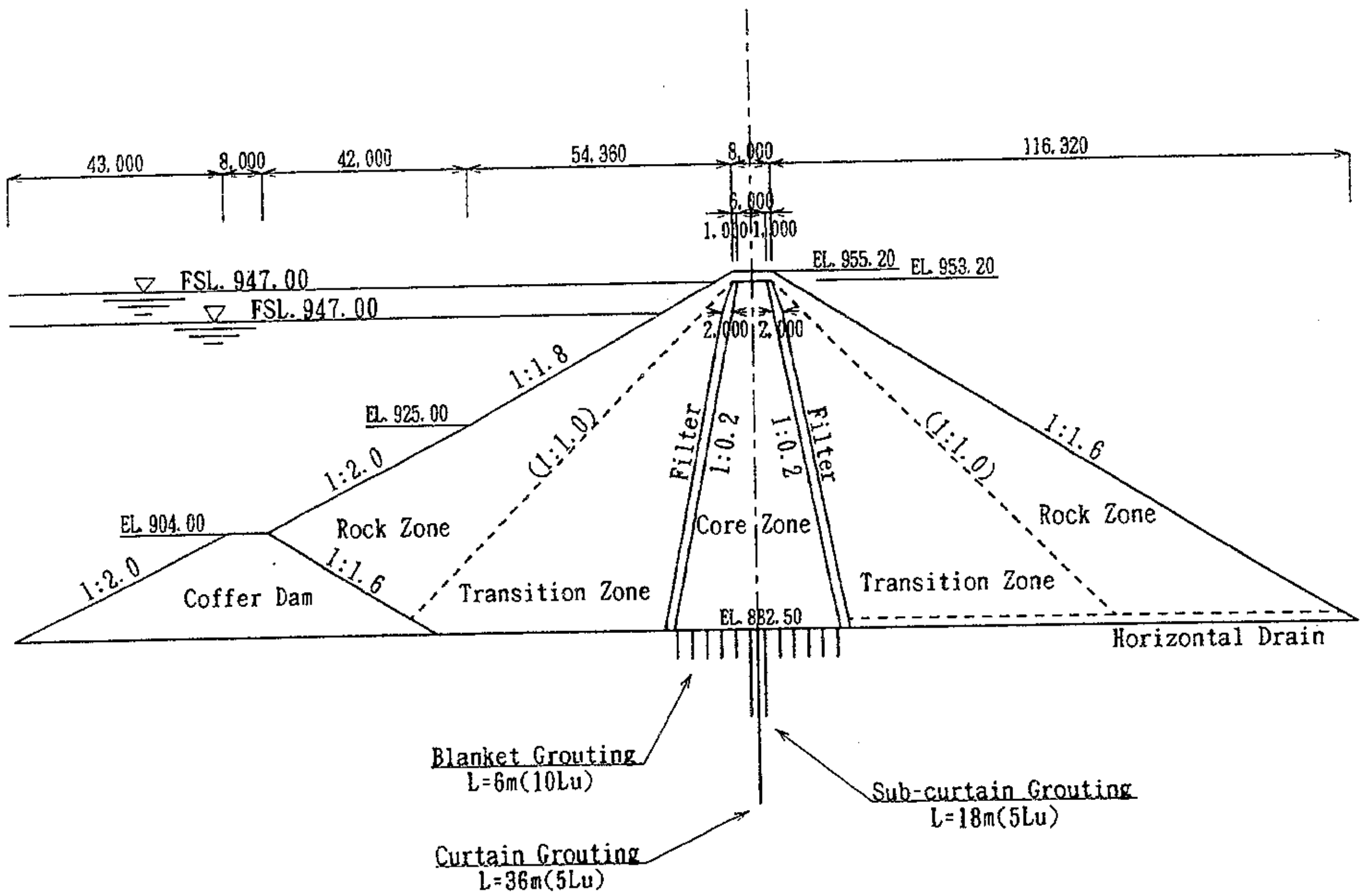


Fig. 15 Comparison of Creep Ratio between Original Dam Axis and Proposed Dam Axis

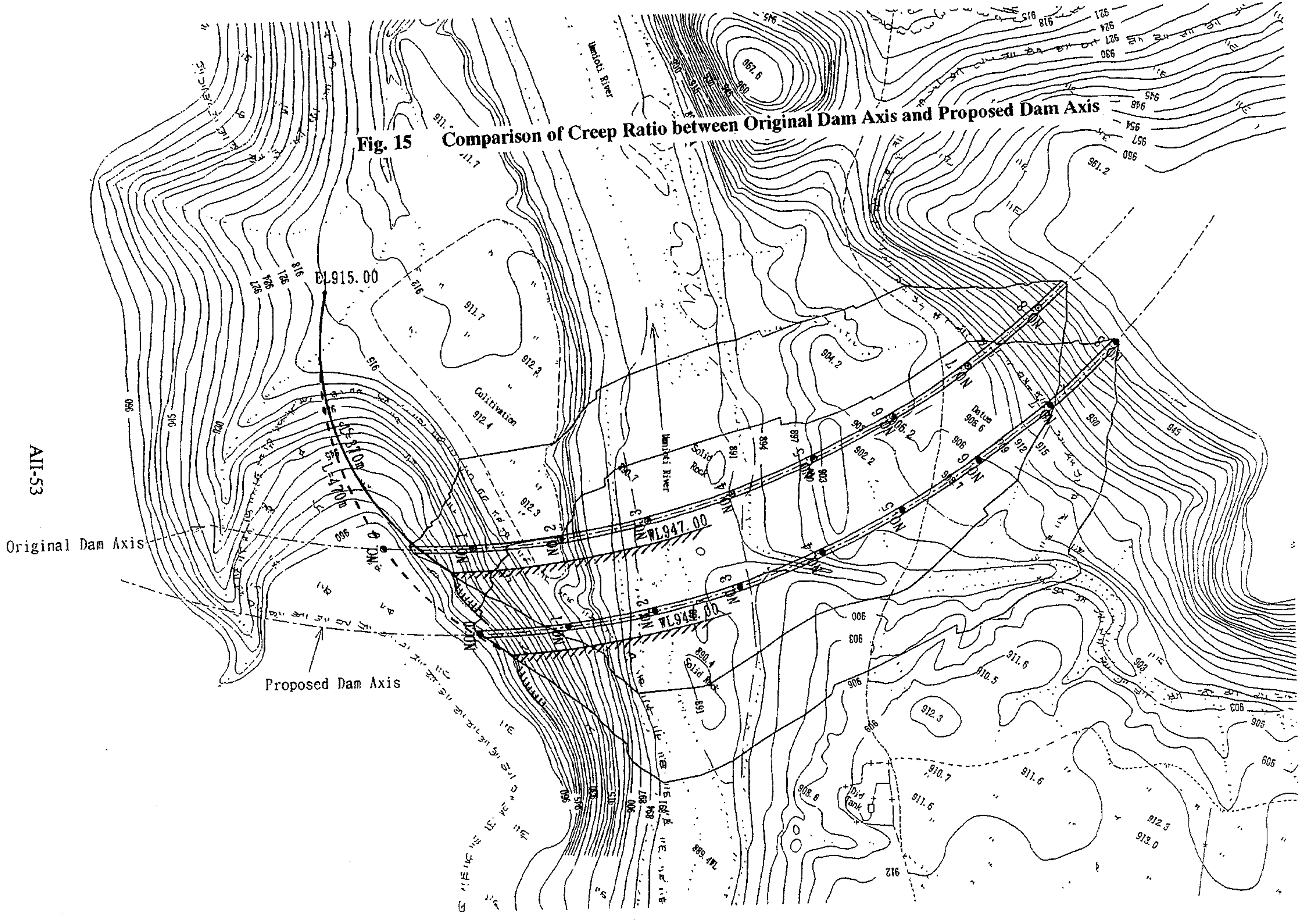
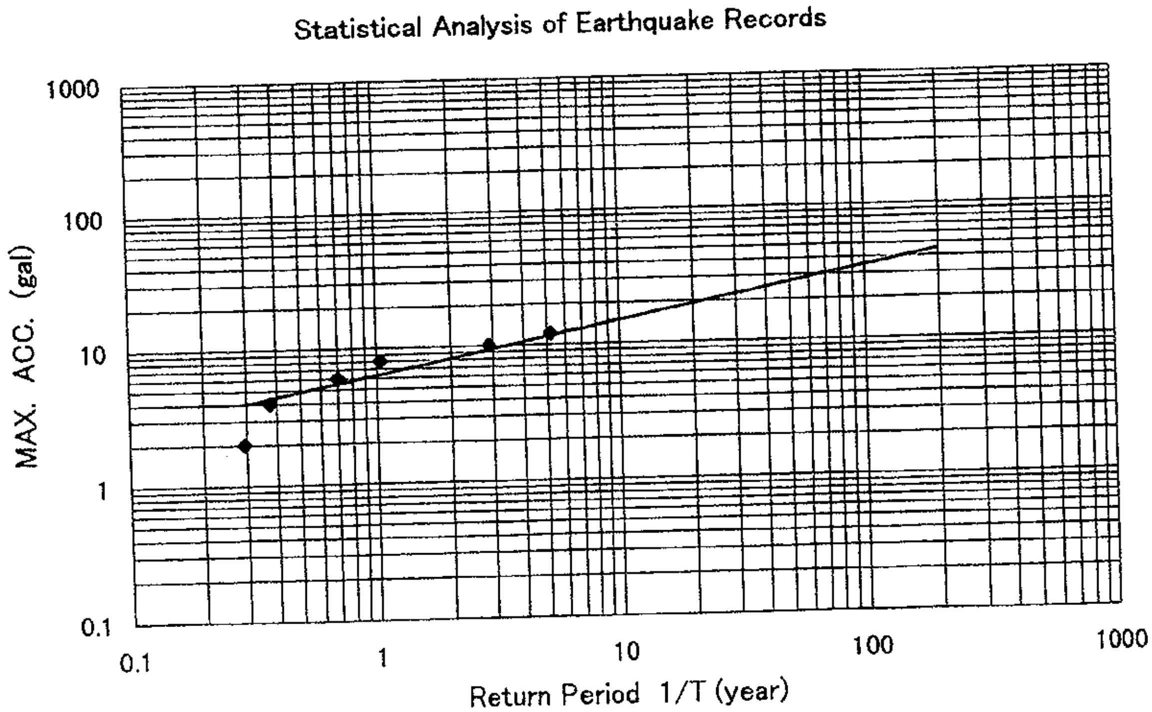


Fig. 16 Statistical Analysis of Earthquake Records

M.O.C. (Class 1)

Range (gal)	NOS	Total Nos	Return Period (1/T)
0			
	0	88	0.295
2			
	19	88	0.295
4			
	32	69	0.377
6			
	12	37	0.703
8			
	16	25	1.040
10			
	4	9	2.889
12			
	5	5	5.200
14			
	0	0	
16			
Sum	88		



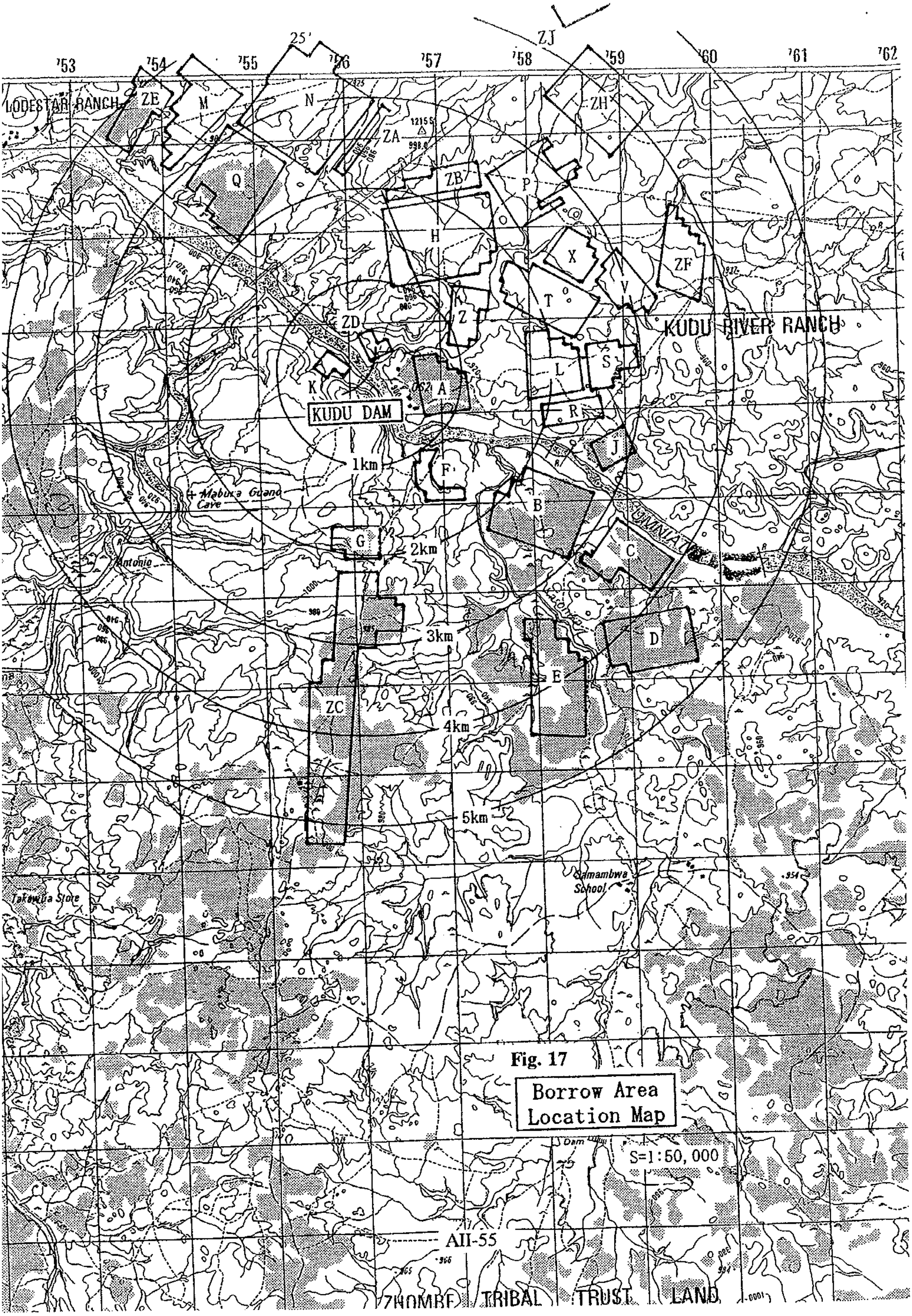
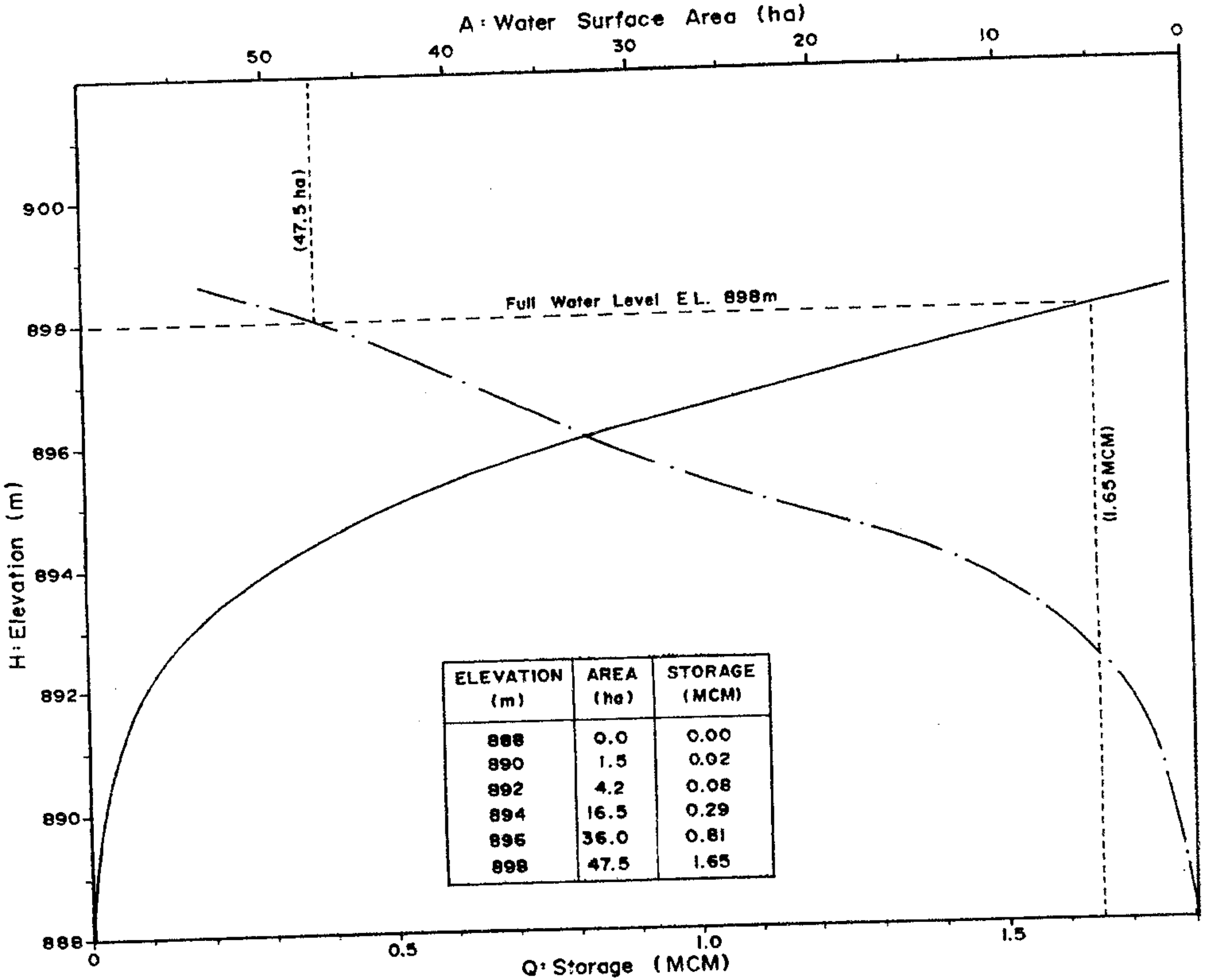


Fig. 17

Borrow Area Location Map



ELEVATION (m)	AREA (ha)	STORAGE (MCM)
888	0.0	0.00
890	1.5	0.02
892	4.2	0.08
894	16.5	0.29
896	36.0	0.81
898	47.5	1.65

Fig. 18 H-A and H-Q Curves of Nyarupakwe Dam Reservoir