Table 4.1 Quality Classification of Rock

| Classification | Characteristics |
|---|---|
| A | Rock-forming minerals(1) are fresh and not weathered or altered. Joints and cracks are very closely adhered with no weathering along their planes. A clear sound is emitted when hammered. |
| B | Rock-forming minerals are weathered slightly or partially altered, the rock being hard. Joints and cracks are closely adhered. A clear sound is emitted when hammered. |
| CH | Rock-forming minerals are weathered but the rock is fairly hard. The bond between rock blocks is slightly reduced and each block is apt to be exfoliated along joints and cracks by strong hammering. Joints and cracks sometimes contain clay and other material which may be coloured by limonite. A slightly dull sound is emitted when hammered. |
| CM | Rock-forming minerals are weathered and the rock is slightly soft. Exfoliation of the rock occurs along joints and cracks by normal hammering. Joints and cracks sometimes contain clay and other material. A somewhat dull sound is emitted when hammered. |
| CL | Rock-forming minerals are weathered and the rock is soft. Exfoliation of the rock occurs along joints and cracks by light hammering. Joints and cracks contain clay. A dull sound is emitted when hammered. |
| D | Rock-forming minerals are weathered, and rock is very soft. There is virtually no bond between rock blocks, and collapse occurs at the slightest hammering. Joints and cracks contain clay. A very dull sound is emitted when hammered. |

(1): Except quartz

Table 4.2 Relationship between Seismic Velocity and its Corresponding Geology

| Damsite<br>Velocity<br>Layer | Velocity<br>(km/sec) | Assumed Geology |
|---|---|---|
| 1ST layer | 0.3 to 0.8 | Top soil, residual soil, talus and river sand/gravel |
| 2ND layer | 1.3 to 1.5 | Talus and river sand/gravel, Heavily weathered rock (CL) |
| 3RD layer | 2.8 to 3.0 | Slightly weathered rock (CM) |
| 4TH layer | 5.4 to 5.5 | Fresh rock (CH) |
| Saddle damsite | | |
| 1ST layer | 0.3 to 0.4 | Top soil |
| 2ND layer | 0.9 to 1.1 | Compacted laterite soil |
| 3RD layer | 2.0 to 3.0 | Weathered rock of andesite and sandstone (CM - CL) |
| 4TH layer | 4.0 to 4.7 | Slightly weathered andesite and sandstone (CM) |
| Waterway | | |
| 1ST layer | 0.3 to 0.8 | Top soil, residual soil, and talus deposits |
| 2ND layer | 1.3 to 1.5 | Heavily weathered rocks (CL-D) (andesite, sandstone, tuff breccia, granodiorite) |
| 3RD layer | 2.8 to 3.2 | Weathered rocks (CM) |
| 4TH layer | 4.4 to 5.5 | Fresh rocks (CH - B) |

# Figures

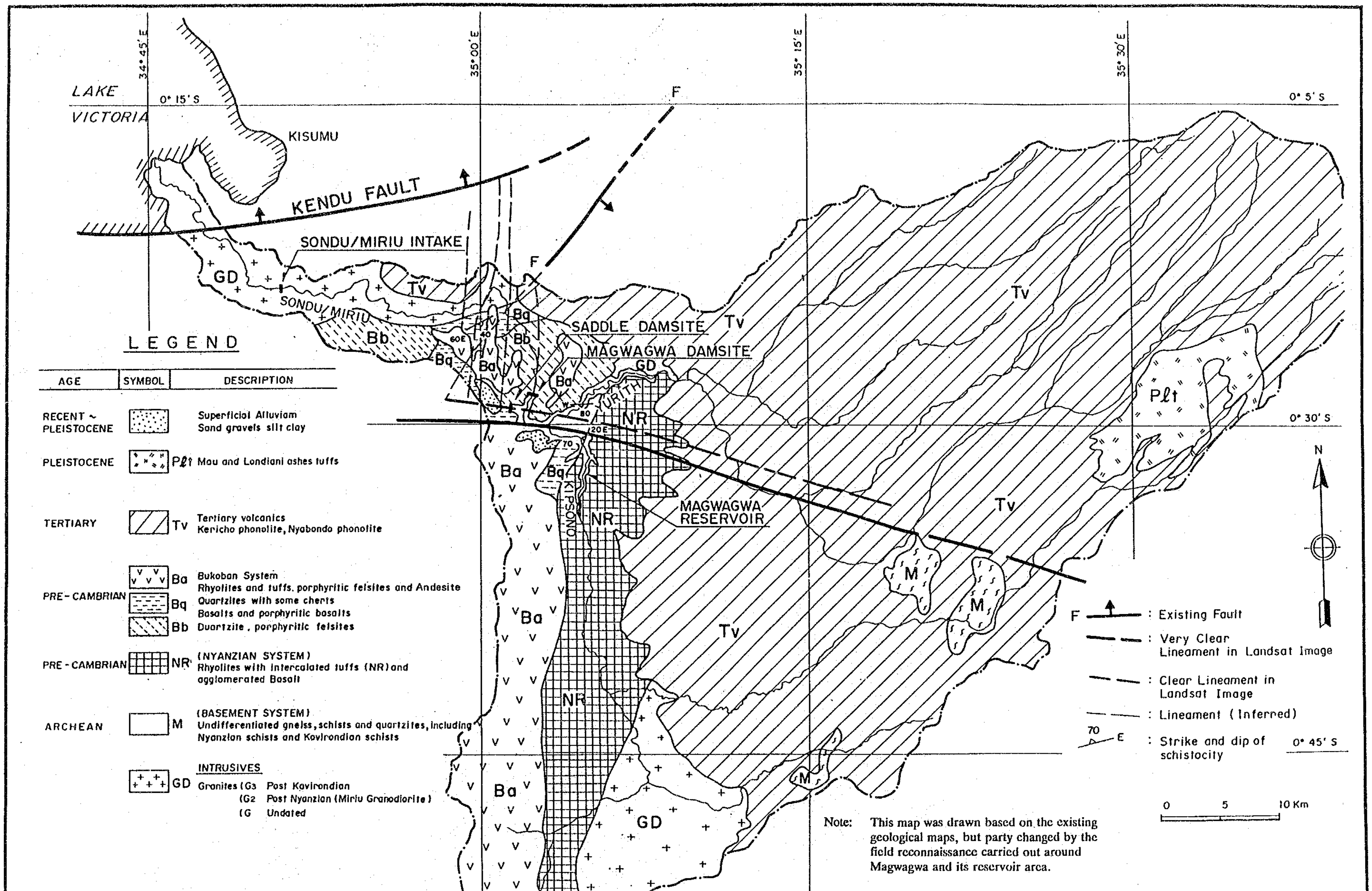


Figure 2.1 Regional Geological Map of the Sondu/Miriu Catchment Area

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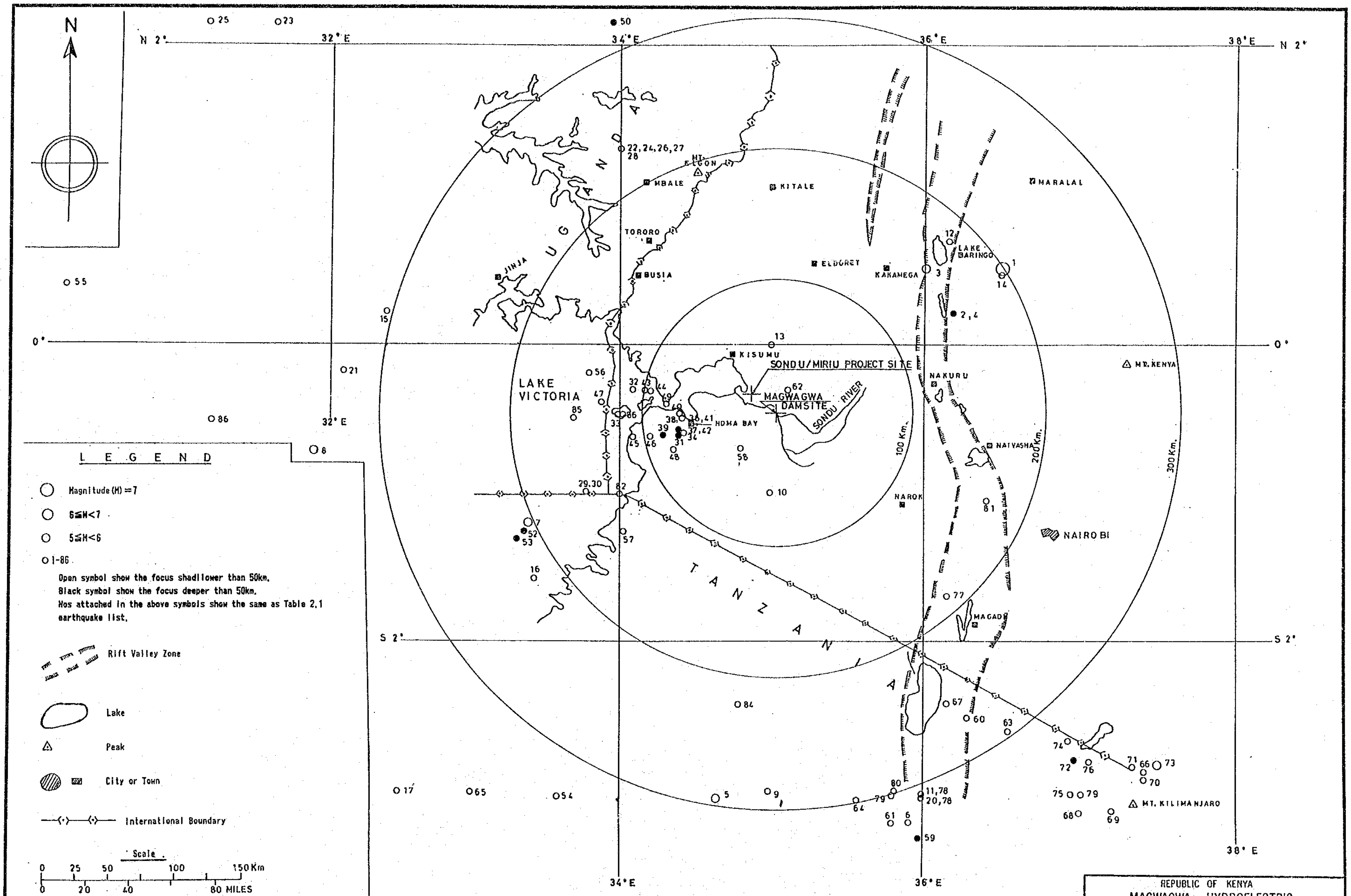


Figure 3.1 Epicentral Map of Earthquakes Occurred over a Period of 1904 to 1990

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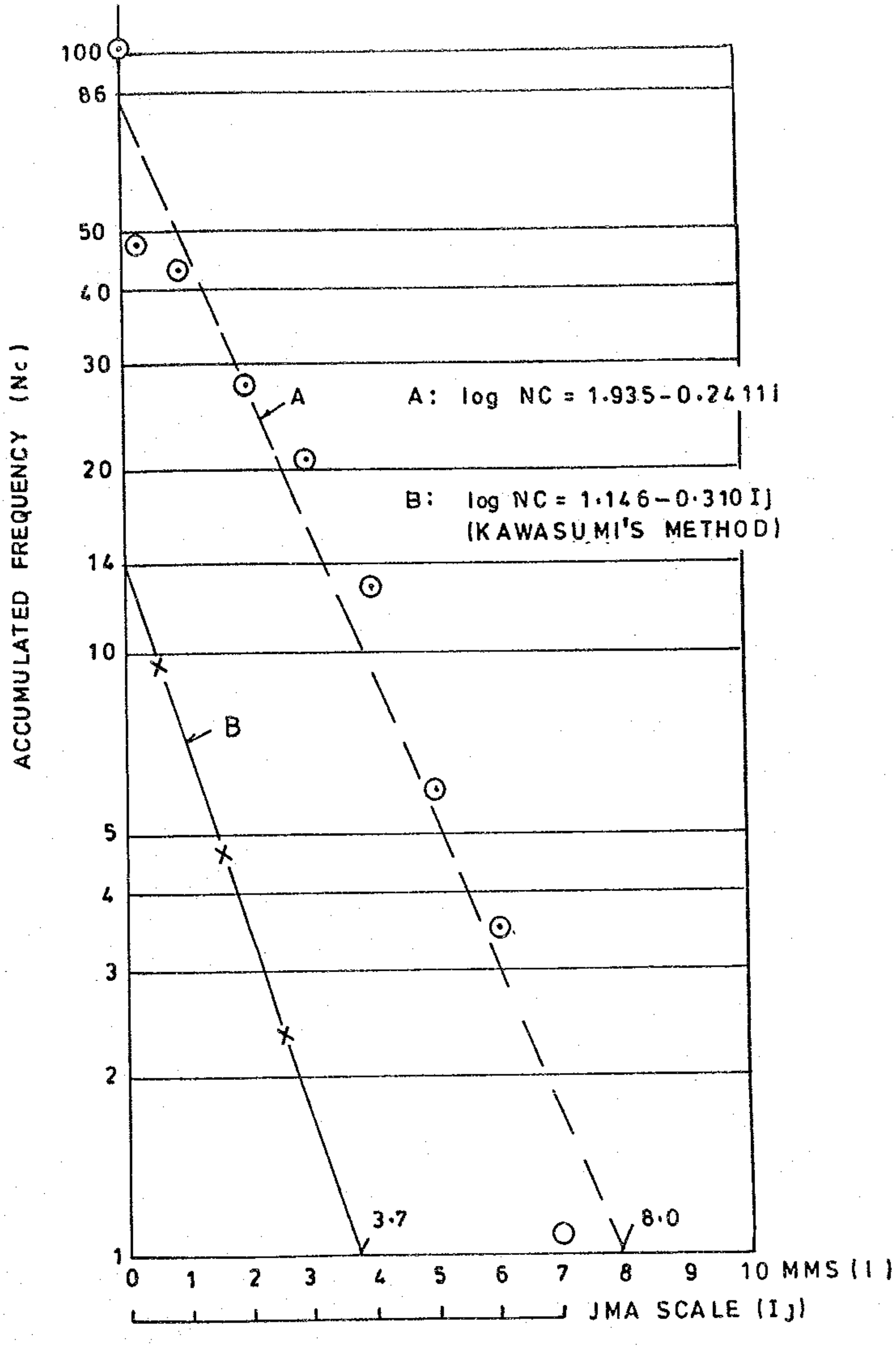


Figure 3.2 Analysis of Earthquake Intensity and Frequency

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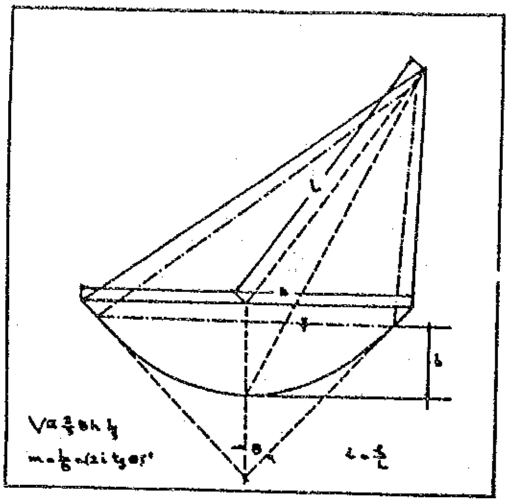
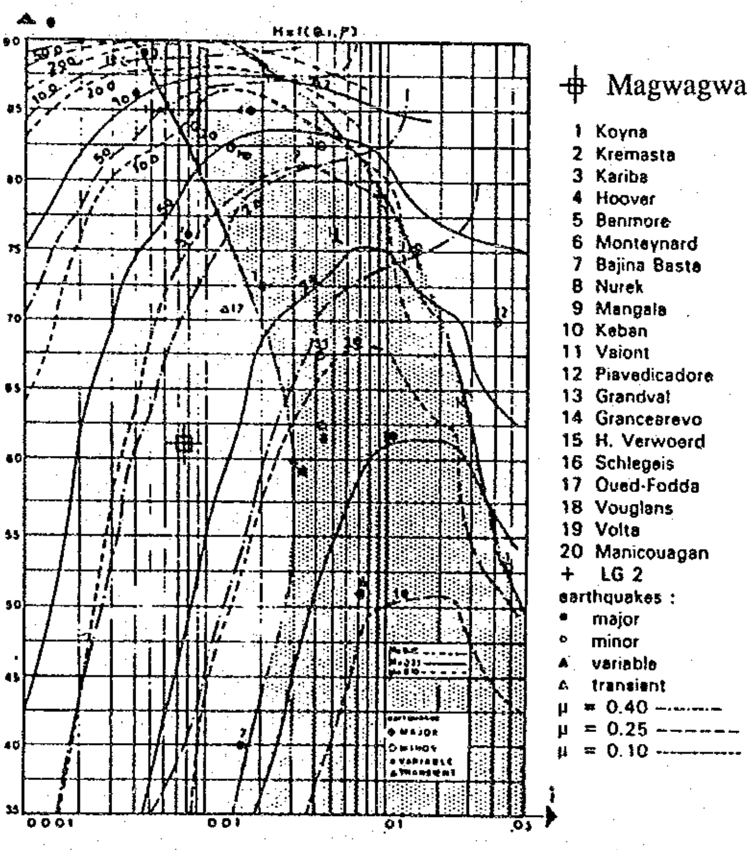


At Magwagwa Reservoir

q = 62° on average
h = 110m at maximum
L = 15,000m
i = h/L ≒ 0.0073

(A)




*The relationship between the volume of water storage, and a dimensional number of the depth of underground storage. The following symbols are used: Ø = dimensionless number; θ = aperture angle of the parabola which describes the average morphological type of reservoir; and i the average slope of the river along the water storage. The shadowed area idicates the occurrence of induced phonomena for 20 reservoirs. The numbers indicate the reservoir involved (see list).*

(B)

Figure 3.3 Identification of a Risk of RIS Occurrence by Impounding (by T. VLADUT)

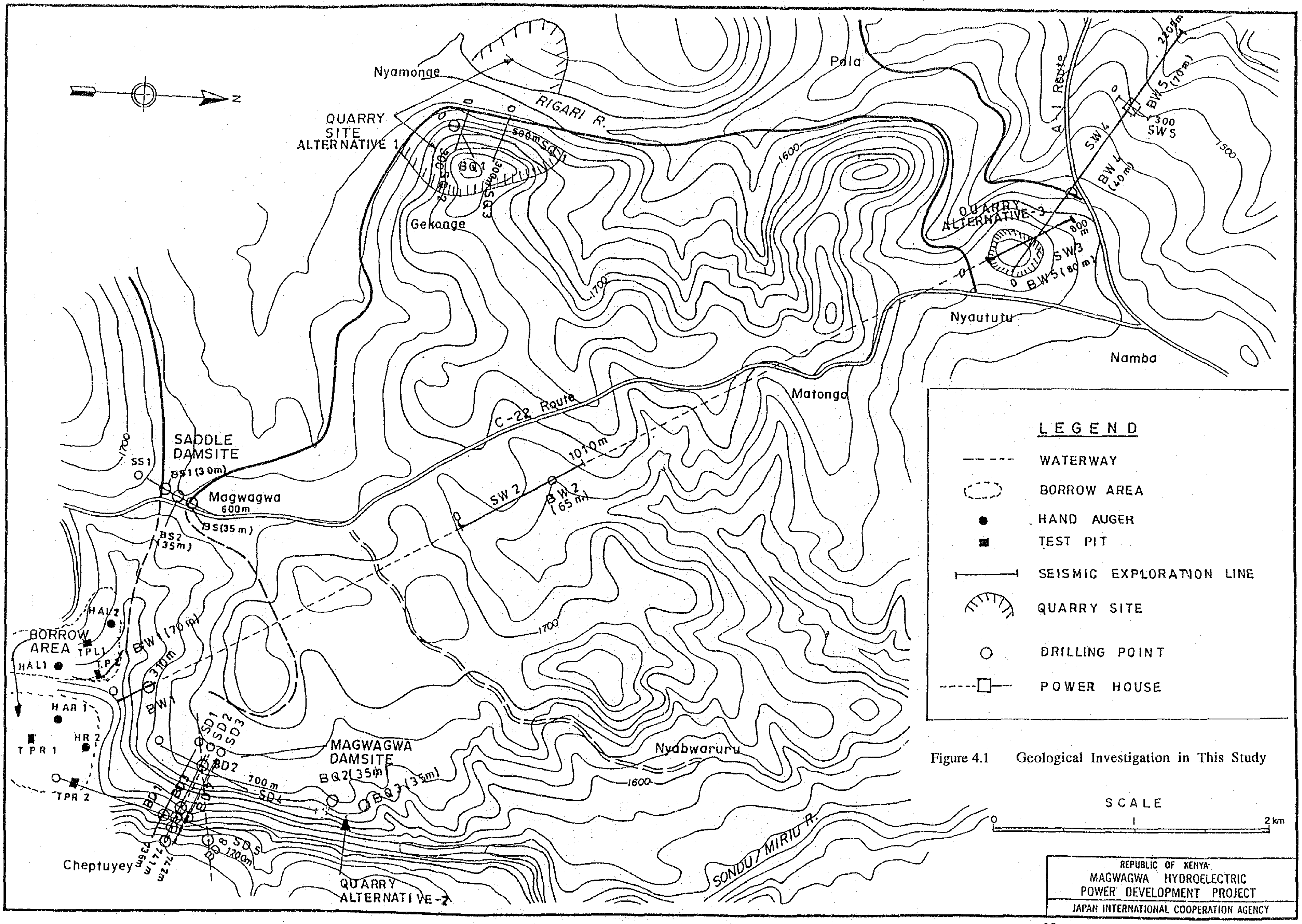
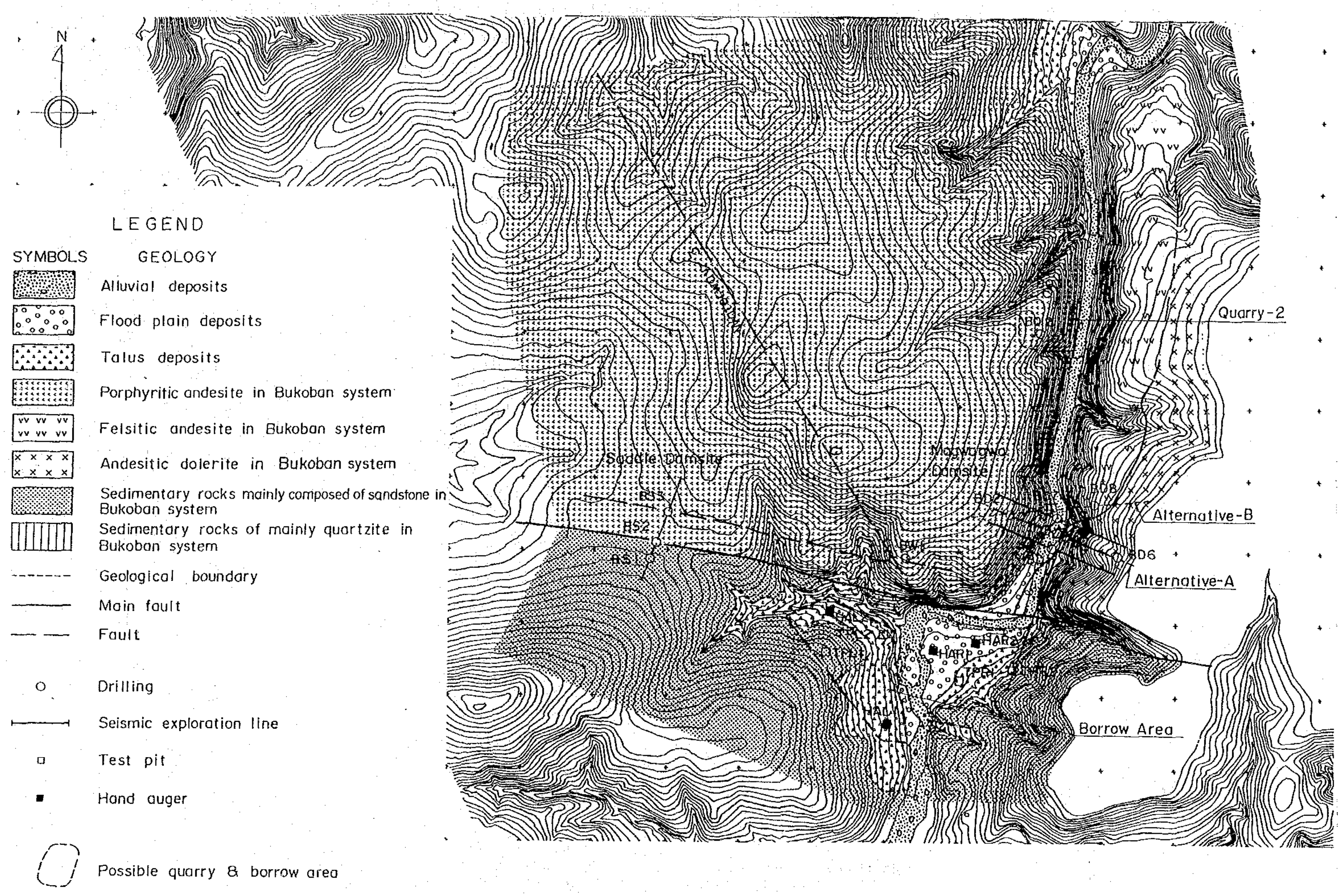



Figure 4.1 Geological Investigation in This Study




SCALE
0 400 800 1200m

**Figure 4.2 Geological Map around the Magwagwa Damsite**

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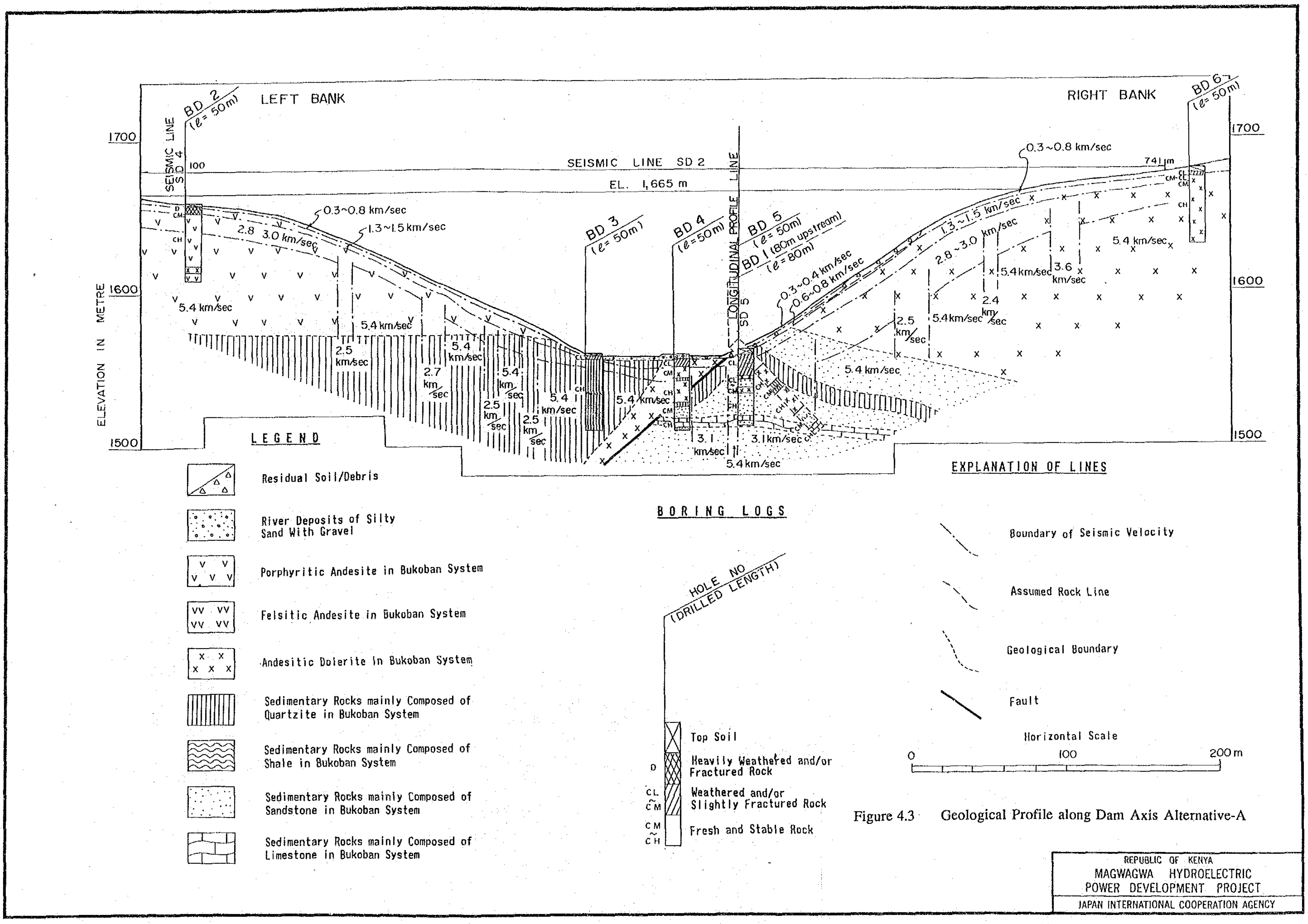


Figure 4.3 Geological Profile along Dam Axis Alternative-A

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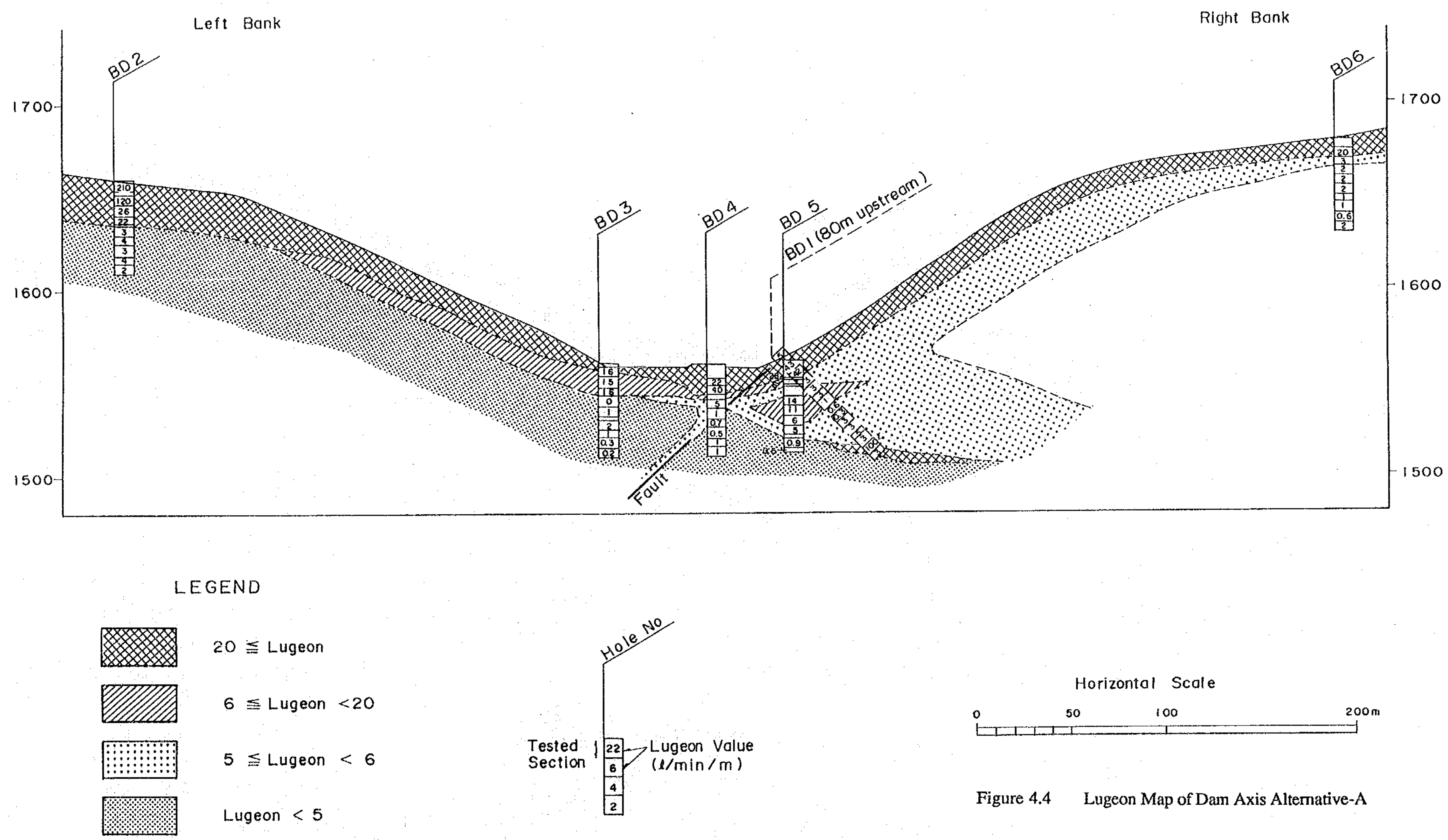


Figure 4.4 Lugeon Map of Dam Axis Alternative-A

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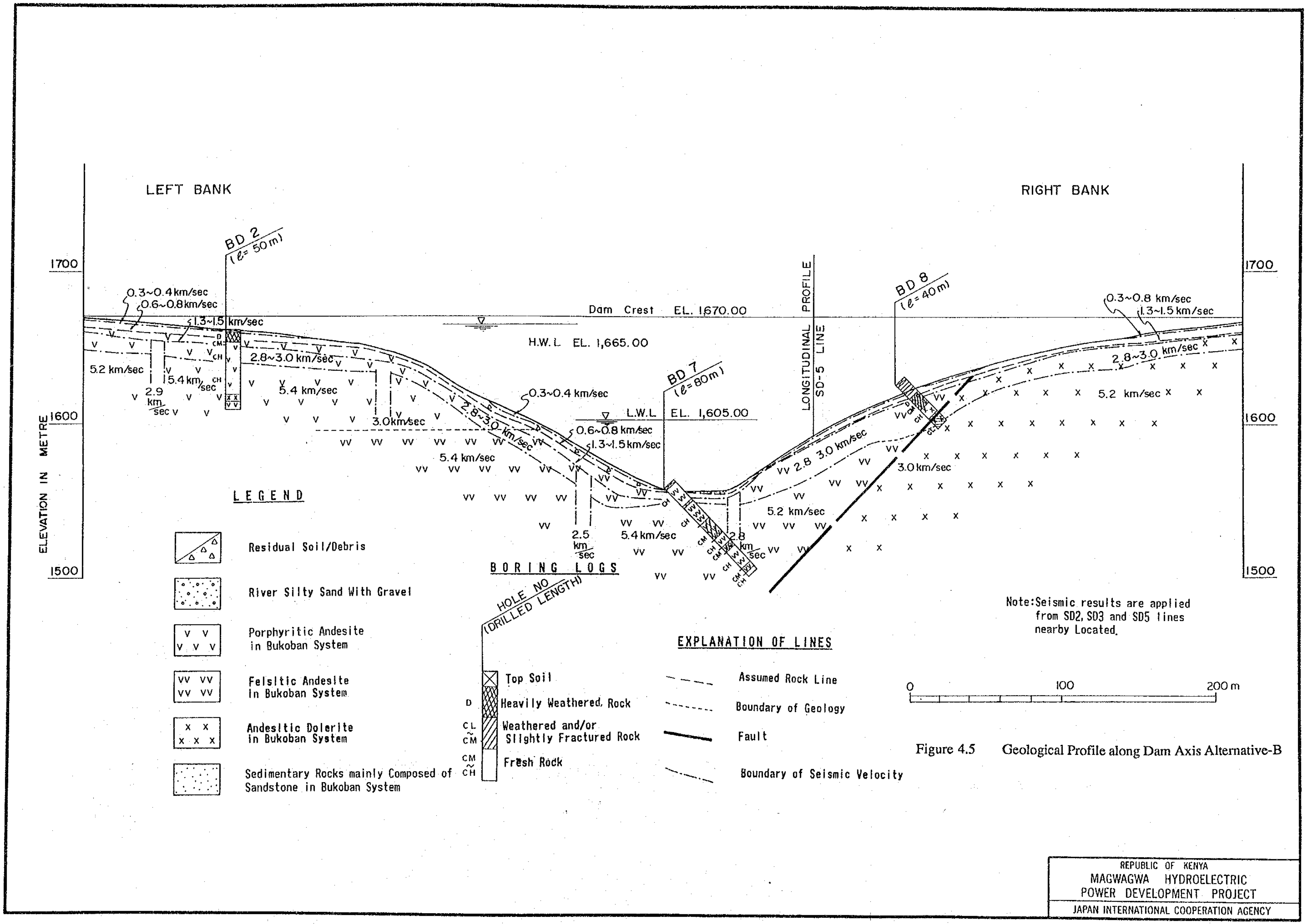


Figure 4.5 Geological Profile along Dam Axis Alternative-B

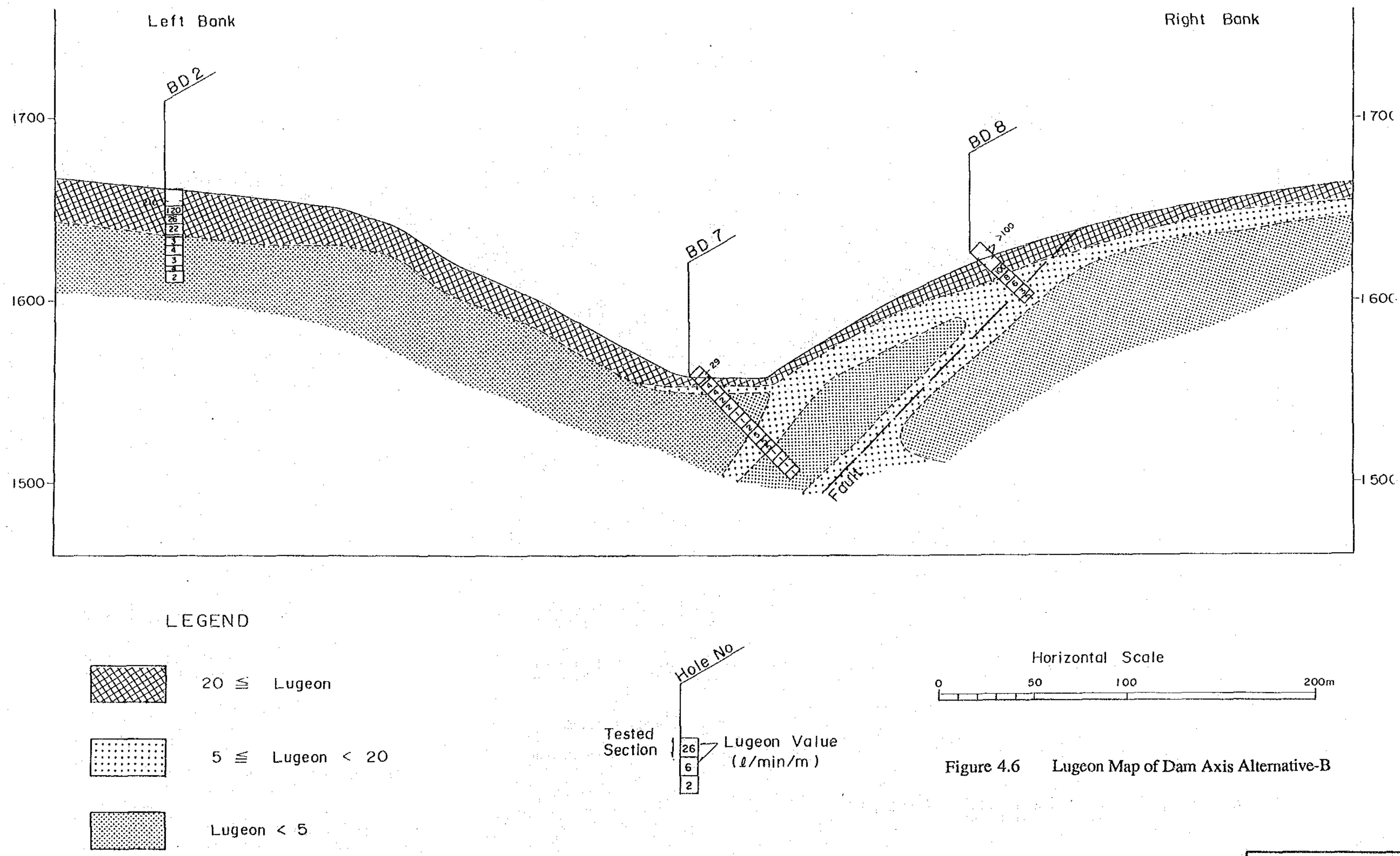


Figure 4.6 Lugeon Map of Dam Axis Alternative-B

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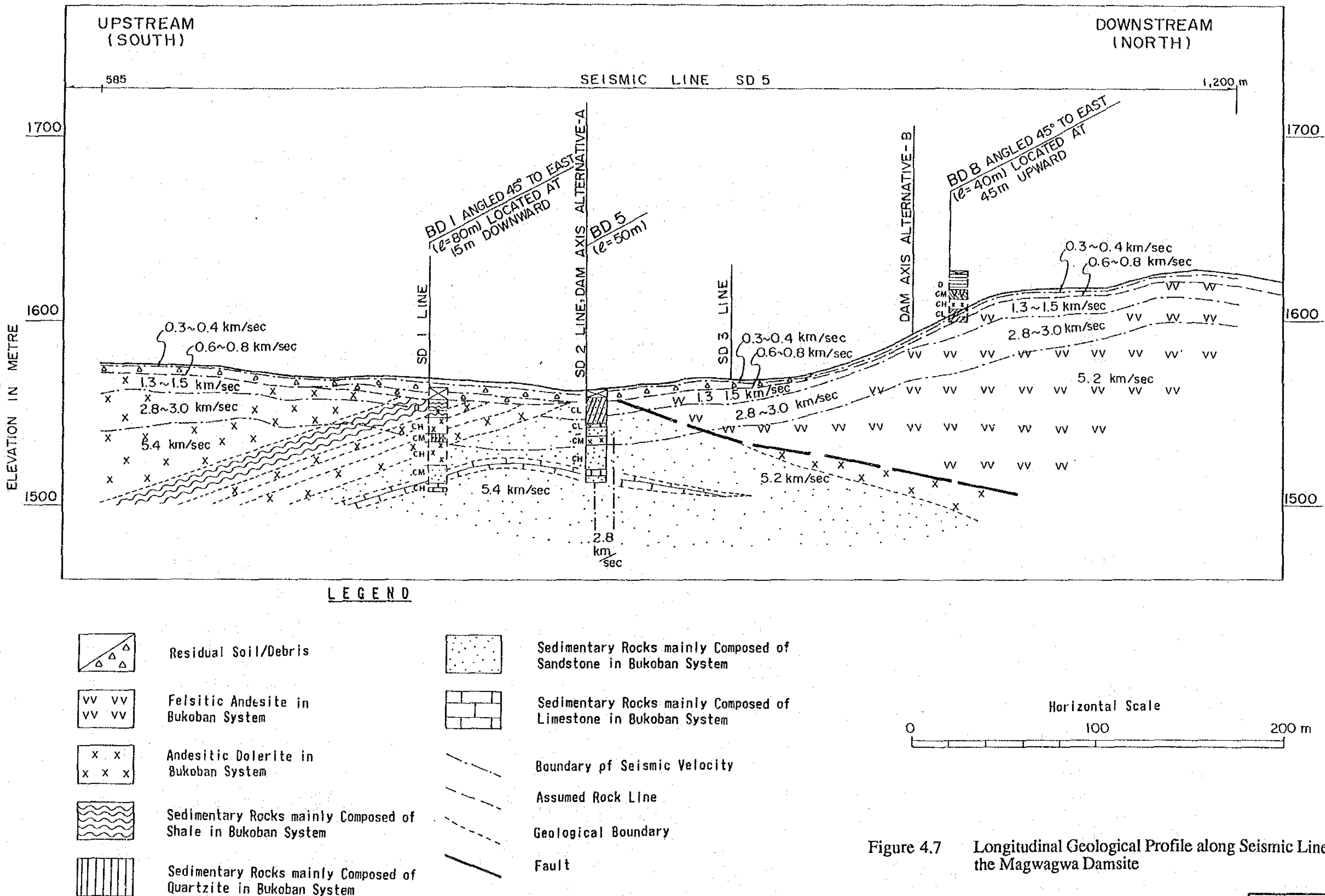


LEGEND



Figure 4.7 Longitudinal Geological Profile along Seismic Line SD-5 at the Magwagwa Damsite

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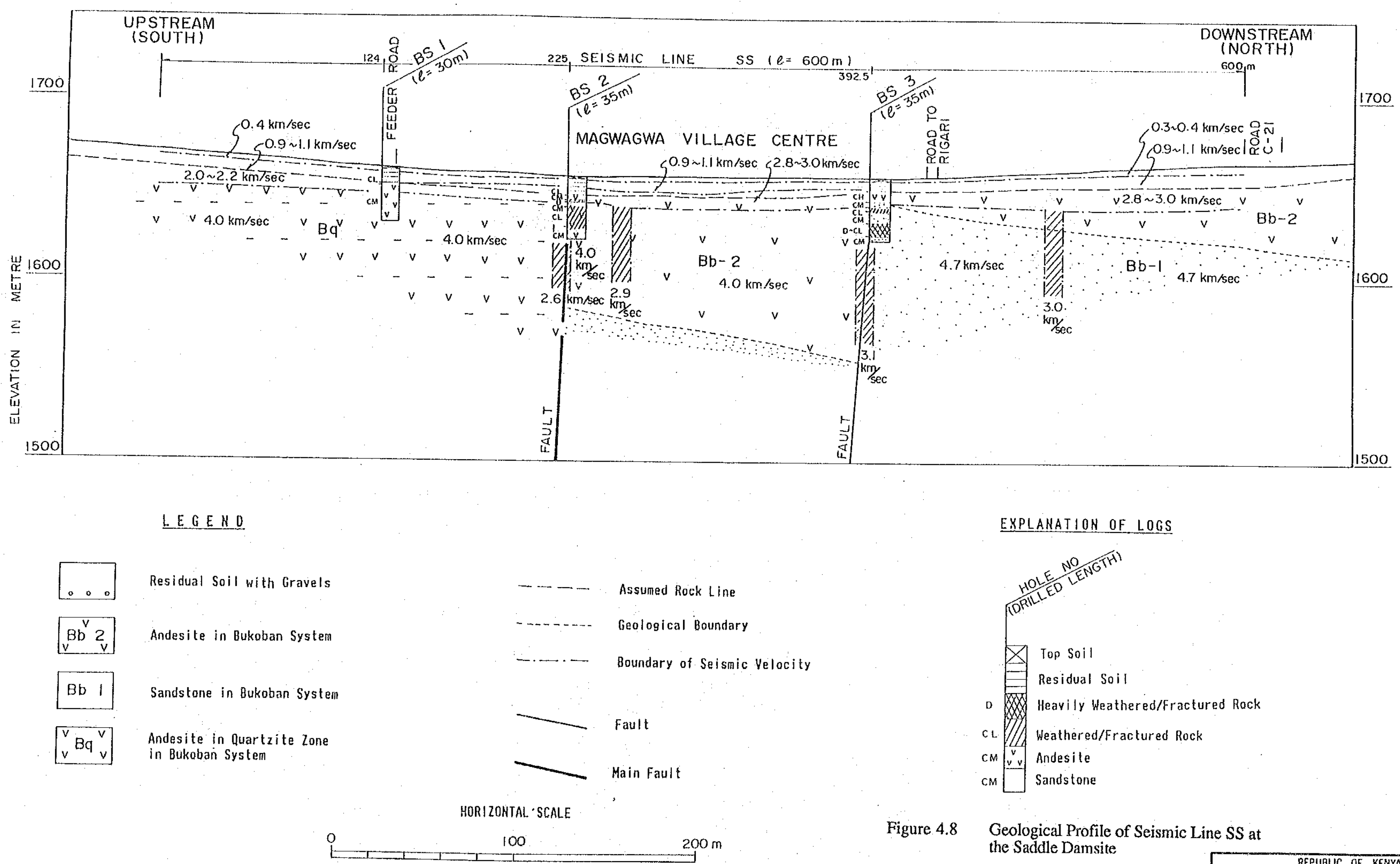


Figure 4.8 Geological Profile of Seismic Line SS at the Saddle Damsite

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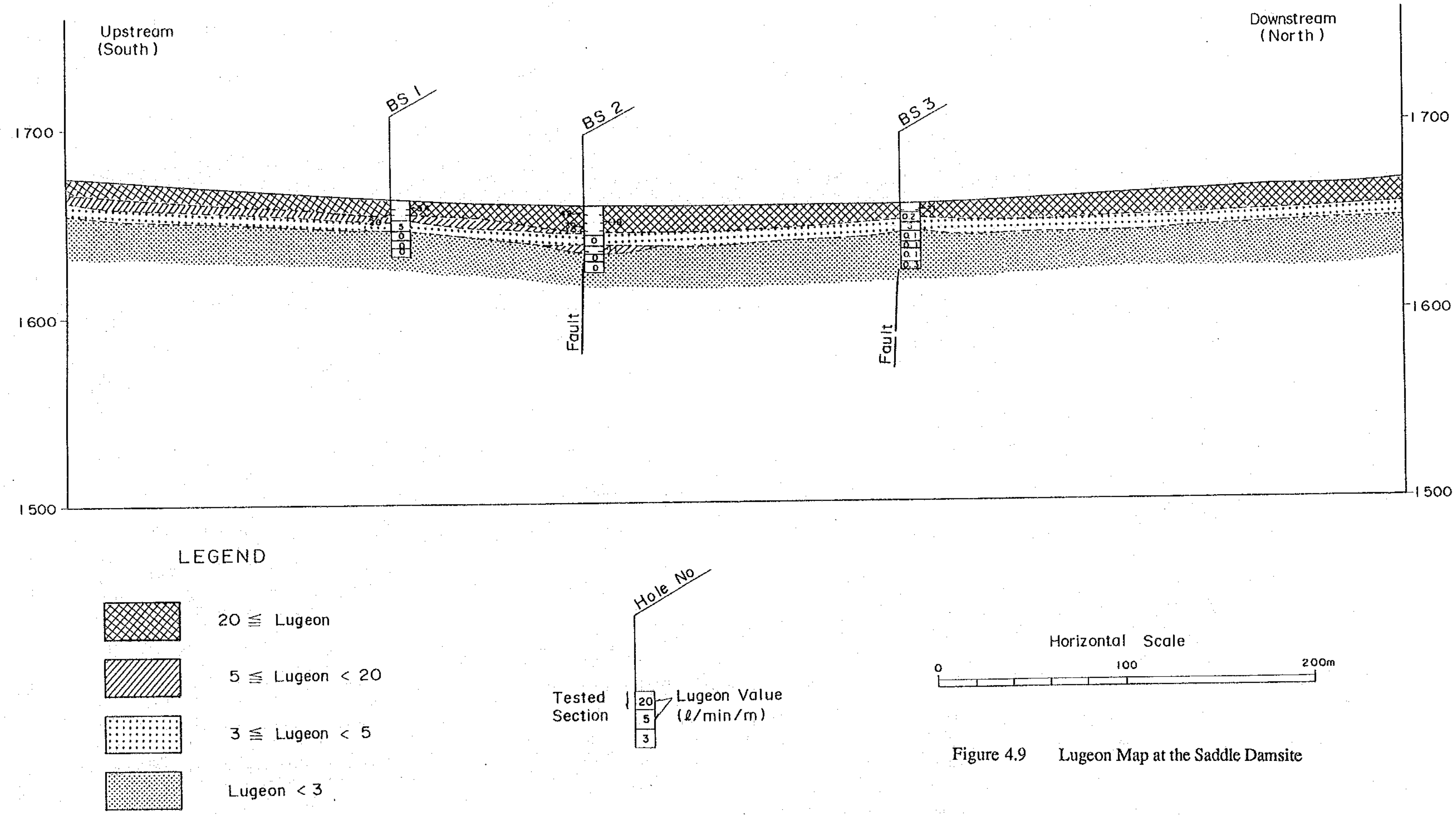


Figure 4.9 Lugeon Map at the Saddle Damsite

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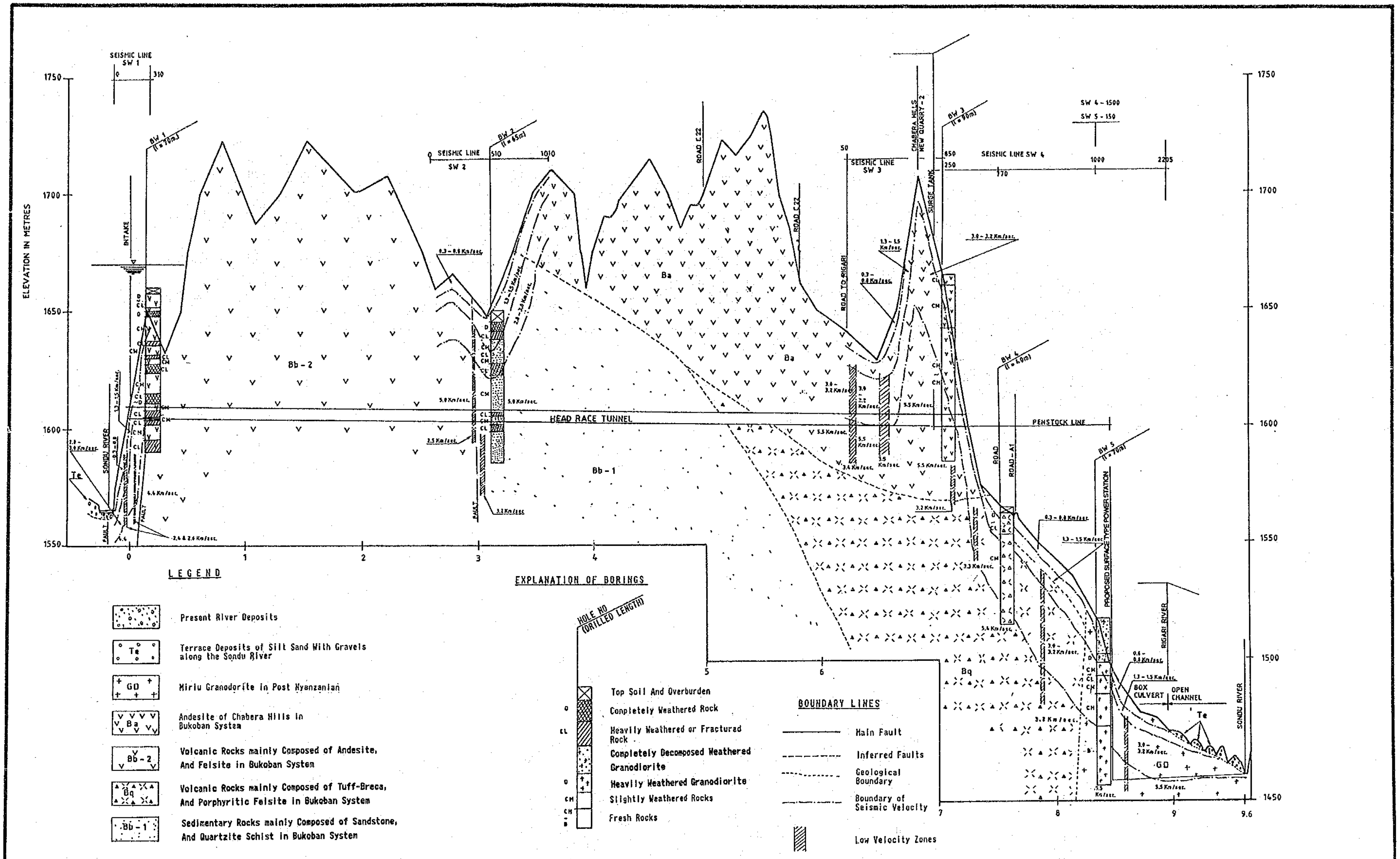


Figure 4.10 Geological Profile along the Waterway Route of Alternative-3

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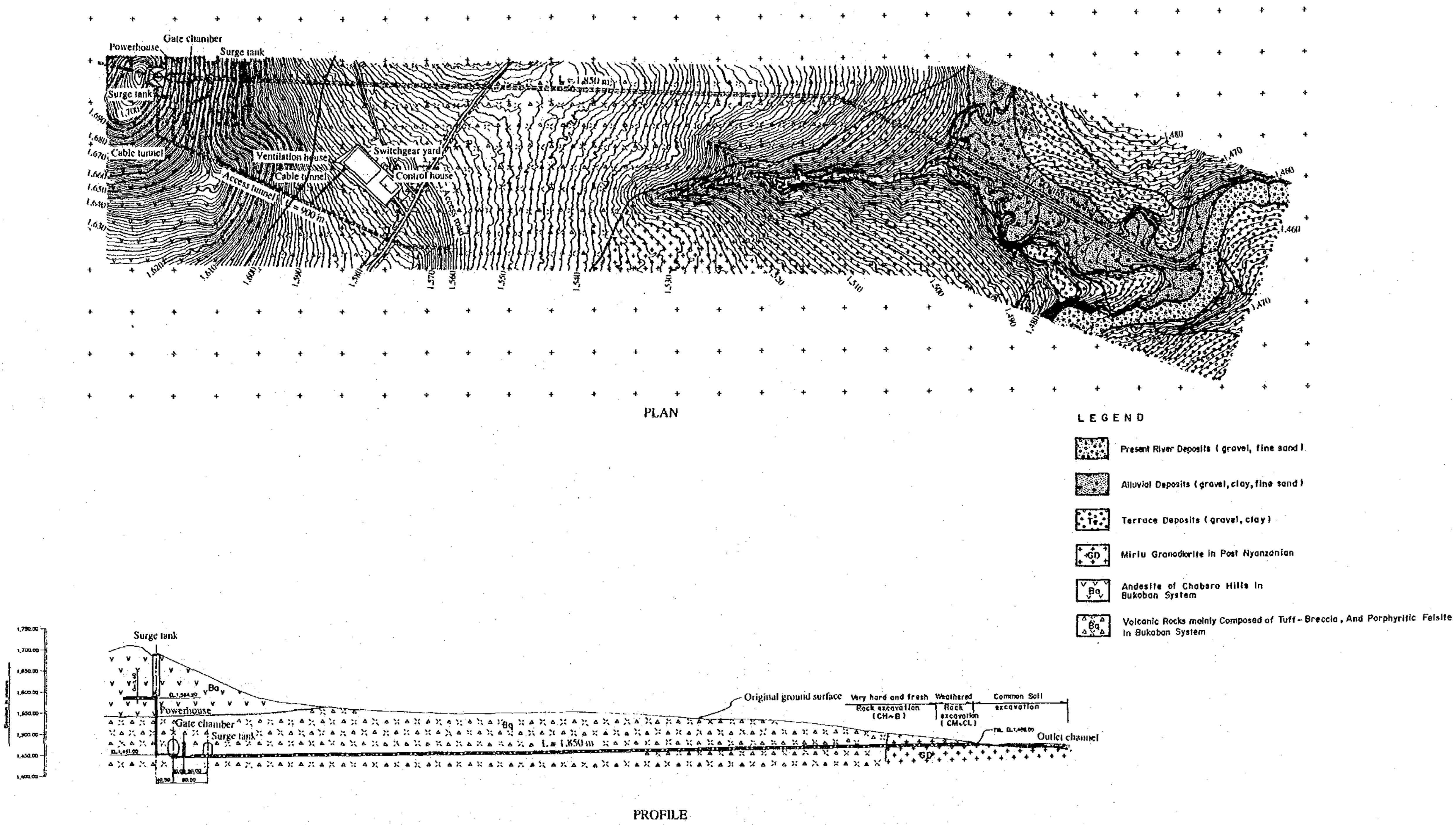


Figure 4.11 Geological Plan and Profile along the Tailrace Tunnel

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|---|
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# APPENDIX III.

# CONSTRUCTION MATERIAL SURVEY

## APPENDIX III. CONSTRUCTION MATERIAL SURVEY

## TABLE OF CONTENTS

## LIST OF TABLE



## LIST OF FIGURE

# I. INTRODUCTION

Construction material survey was carried out over a period of January to November 1990 driving into two study stages. The survey work of those two stages is as follows:

1) Identification Stage (January to February, 1990)

- Preliminary site reconnaissance to the potential borrow and rock quarry sites to look for suitable impervious core materials of the rock-fill type dam and construction materials of the rock-fill and concrete gravity types such as rocks and concrete aggregates respectively in terms of quality and quantity.

- Preparation of the technical specifications for such survey as hand augering, test pitting (for borrow sites), core drilling (for rock quarry site) and laboratory tests to subcontract to a subcontractor.

2) Field Investigation Stage (June to November, 1990)

- Substantial work of the above survey was carried out by the subcontractor selected by tendering, and has duly been completed within the period stipulated in the specifications. The work quantity of the construction material survey is given in Table 1.1.

## II. RESULTS OF THE FIELD INVESTIGATION WORK

### 2.1 Borrow Site

The possible borrow sites located at the both banks just upstream of the Magwagwa damsite (refer to Figure 2.1) were investigated by the test pitting (TPL1, 2, and TPR1, 2) and hand augering (HAL1, 2, and HAR1, 2). The survey results reveal thin deposit soil of less than 4 m, resulting in a far small amount compared with the embankment volume required for the impervious core of the rock-fill type dam. However, the borrow site located at the left bank near the saddle damsite can readily be exploited as a source of embankment materials for the saddle dam due to short haul distance and easy access. Further detailed discussions are given as below:

1) Test Pits at TPR1, 2 (Right bank) and TPL1, 2 (Left bank)

<u>TPR1 (5 m Deep)</u>

| | | |
|---|---|---|
| 0 - 0.2 m | : | Dark reddish brown sandy soil |
| 0.2 - 0.8 m | : | Brown sandy clay |
| 0.8 - 5.0 m | : | Yellow, completely decomposed, weathered soft rock with clay of sandstone. The layer below 4 m is hard and consolidated. |

<u>TPR2 (5 m Deep)</u>

| | | |
|---|---|---|
| 0 - 0.3 m | : | Dark reddish brown clayey soil |
| 0.3 - 1.2 m | : | Large and hard rolling stones of quartzite |
| 1.2 - 5.0 m | : | Yellow, completely decomposed, weathered soft rock of sandstone. The layer below 4 m is hard. |

<u>TPL1 (5 m Deep)</u>

| | | |
|---|---|---|
| 0 - 0.5 m | : | Dark brown, clayey soil |
| 0.5 - 0.8 m | : | Brown clay |
| 0.8 - 2.2 m | : | Brown, completely weathered and decomposed sandstone |
| 2.2 - 5.0 m | : | Brown, heavily weathered and loosen sandstone |

(The groundwater seeped at 4.1 m from the ground surface).

TPL2 (5 m Deep)

| | | | | |
|---|---|---|---|---|
| 0 | - | 0.5 m | : | Dark brown, clayey soil |
| 0.5 | - | 1.1 m | : | Yellow, very soft rock of completely weathered sandstone |
| 1.1 | - | 1.5 m | : | Yellow, very soft rock of completely weathered sandstone |
| 1.5 | - | 2.6 m | : | Light yellow, completely decomposed sandstone with quartzite. |
| 2.6 | - | 5.0 m | : | Light yellow, completely decomposed sandstone with quartzite. The layer below 4 m is hard and consolidated. |

2) Hand Auger at HAR 1, 2 (Right bank) and HAL 1, 2 (Left bank)

HAR 1(5 m Deep)

| | | | | |
|---|---|---|---|---|
| 0 | - | 1.0 m | : | Dark brown, clayey soil |
| 1.0 | - | 2.0 m | : | Dark brown, silty clay |
| 2.0 | - | 4.0 m | : | Dark brown, silty clay |
| 4.0 | - | 5.0 m | : | Brown, sandy clay of heavily weathered sandstone. |

HAR 2 (5 m Deep)

| | | | | |
|---|---|---|---|---|
| 0 | - | 1.0 m | : | Dark brown, clayey soil |
| 1.0 | - | 2.0 m | : | Dark brown, silty clay |
| 2.0 | - | 4.0 m | : | Dark brown, sandy clay |
| 4.0 | - | 5.0 m | : | Brown, sandy clay of heavily weathered sandstone. |

HAL 1 (5 m Deep)

| | | | | |
|---|---|---|---|---|
| 0 | - | 1.0 m | : | Light brown to red, clayey soil |
| 1.0 | - | 2.0 m | : | Light brown to yellow clay |
| 2.0 | - | 4.0 m | : | Light brown to yellow clay |
| 4.0 | - | 5.0 m | : | Yellow, completely decomposed sandstone. |

HAL 2 (5 m Deep)

| | | | | |
|---|---|---|---|---|
| 0 | - | 1.0 m | : | Dark brown, clayey soil |
| 1.0 | - | 3.0 m | : | Brown to yellow, sandy clay |
| 3.0 | - | 4.0 m | : | Brown to yellow, sandy clay of heavily weathered sandstone |
| 4.0 | - | 5.0 m | : | Yellow, weathered sandstone. |

When the dam crest elevation of Magwagwa dam is set at El. 1,670 m, a saddle dam is required to build at the ground depression located at the left bank upstream of the main Magwagwa dam. The survey results of BS-1, 2 and 3 drilled at the saddle damsite, showing overburden of 7 to 8 m thick, would suggest the possibility of building a homogeneous earth-fill type dam for the saddle dam, if the land acquisition is possible for a borrow area around the saddle dam. The required volume is some 300,000 and could be hauled from that borrow area. The required scale of the borrow area is 300 m x 300 m x 3 m (thickness). However, further discussions will be given place to the detailed design stage.

## 2.2. Rock Quarry Site

The reconnaissance in the Identification Stage identified the Rigari rock quarry site.

The bore hole BQ1 drilled at the slope of the right bank of the Rigari valley showed the most constricted conditions due to covering overburden, resulting in the suspension of drilling by 30 m deep for the original target of 50 m deep, and another 50 m drill planned at BQ2 was reserved for a new quarry site. The new quarry site, located at the left bank of some 1 km downstream of the main dam axis, was identified using the 1 to 5,000 scale topographic maps newly prepared in this study. The site was investigated by two bore holes (BQ2 and BQ3) of 35 m deep each as given in Figure 2.1, revealing thin residual soil of 1.5 m to 3.5 m and hard porphyritic andesite without heavy weathering.

Furthermore, the area around the surge tank (Chabera Hills) could be expected as another quarry to supply concrete aggregates and sand to the powerhouse, penstock, surgetank and a part of the headrace tunnel, judging from the drilling result at BW-3. Exploitable volume to be obtained from the quarry sites is estimated as follows:

| Site | Quantity | | Area (Length, Width, Height) |
|---|---|---|---|
| Site 1 km downstream of dam | 7,000,000 $m^3$ | = | 500 (L) x 200 (W) x 70 (H) |
| Chabera Hills | 1,700,000 $m^3$ | = | 400 (L) x 400 (W) x 40/3 (H). |

## III. LABORATORY TESTS

### 3.1 Physical Properties of Soils at the Borrow Sites

Soil in the borrow area located at the right bank is of silty to sandy clay derived from weathering of sandstone, which will be suitable as impervious materials of the homogeneous earthfill type dam required moderate plasticity. River crossing makes less favourable in using this borrow area as a material source of the saddle dam construction.

The in-site moisture contents in the range of 20% to 30% at the TPR 1 and 2 are nearly the same as the optimum, while 37% to 45% at the HAR 1 and 2 located at the flood plain of the right bank is in an over-saturated condition compared with the optimum. These soils are classified as ML for TPR 1 and 2, and MH for HAR 1 and 2 under the Unified Classification System (refer to Figures 3.1 and 3.2).

Soil in the borrow area located at the left bank is of sandy clay, which will be suitable as impervious materials of the saddle dam as well without any further operations for moisture control required. With in-site natural moisture content in the range of 20% to 30%, which is within the optimum, the soil may require a further processing of slightly wetting in dry seasons, and gravels larger than 75 mm in diameter will be required to screen out before embankment of the saddle dam. Soil is classified as CL to CH under the Unified Classification System.

### 3.2 Mechanical Properties of Soils at the Borrow Sites

The maximum dry density of soils in the borrow areas ranges from 1.51 to 1.85 $t/m^3$. The laboratory permeability of the samples compacted under the optimum moisture condition was smaller than $1x10^{-6}$ cm/sec as shown below:

| Sample | Depth (m) | Permeability (cm/sec) |
|---|---|---|
| TPL 1 | 0.5 - 0.8 | $6.8 \times 10^{-7}$ |
| TPL 1 | 0.8 - 2.2 | $8.7 \times 10^{-7}$ |
| TPL 2 | 1.1 - 1.5 | $2.8 \times 10^{-7}$ |
| TPL 2 | 1.5 - 2.6 | $10.6 \times 10^{-7}$ |
| TPR 1 | 0.2 - 0.8 | $1.6 \times 10^{-7}$ |
| TPR 1 | 0.8 - 5.0 | $1.2 \times 10^{-7}$ |
| TPR 2 | 0.3 - 1.2 | $1.3 \times 10^{-7}$ |
| TPR 2 | 1.2 - 4.5 | $5.7 \times 10^{-7}$ |

Triaxial tests and direct shear tests of the samples showed a wide variation in cohesion strength and internal friction angle as shown below:

Triaxial Tests (UU)

| Sample No. (Depth) | Cohesion Strength ($kg/cm^2$) | Internal Friction Angle (ø) |
|---|---|---|
| TPL 1 (0.5 - 0.8 m) | 0.105 | 12.1° |
| TPL 1 (0.8 - 2.2 m) | 0.087 | 14.0° |
| TPL 2 (1.1 - 1.5 m) | 0.064 | 16.0° |
| TPL 2 (1.5 - 2.6 m) | 0.196 | 17.0° |
| Design Value | 0.06 | 12° |
| TPR 1 (0.2 - 0.8 m) | 0.045 | 11.9° |
| TPR 1 (0.8 - 5.0 m) | 0.096 | 19.6° |
| TPR 2 (0.3 - 1.2 m) | 0.240 | 28.7° |
| TPR 2 (1.2 - 4.6 m) | 0.074 | 23.0° |
| Design Value | 0.05 | 12° |

Direct Shear Tests (UU)

| Sample No. (Depth) | Cohesion Strength ($kg/cm^2$) | Internal Friction Angle (ø) |
|---|---|---|
| TPL 1 (1.0 - 5.0 m) | 0.22 | 16.1° |
| TPL 1 (0.5 - 0.8 m) | 0.255 | 23° |
| TPL 1 (0.8 - 2.2 m) | 0.262 | 20° |
| TPL 2 (1.1 - 1.5 m) | 0.270 | 18° |
| TPL 2 (1.5 - 2.6 m) | 0.32 | 16° |
| Design Value | 0.22 | 16° |
| TPR 1 (0.2 - 0.8 m) | 0.191 | 15° |
| TPR 1 (0.8 - 5.0 m) | 0.268 | 23° |
| TPR 2 (0.3 - 1.2 m) | 0.403 | 28° |
| TPR 2 (1.2 - 4.6 m) | 0.268 | 17° |
| Design Value | 0.19 | 15° |

The smallest value obtained in the respective tests is adopted as the design value of cohesion strength and internal friction angle for the the soils of respective borrow areas.

## 3.3 Results of Rock Test in the Quarry and Damsite

The most promising quarry site in quality and quantity was found out at the left bank some 1 km downstream of the main damsite (Alternative-2). Laboratory tests were mainly carried out for the samples taken from the Alternative-2 site and the left bank of the damsite where rock conditions of porphyritic andesite are similar to those of the Alternative-2.

The unconfined compressive strength of the sample in the depth of 26.3 m to 26.5 m of BQ2 hole is 3409.6 $kgf/cm^2$, which demonstrates an excellent condition in hardness. The tensile strength of the sample in the depth of 49.8 m to 50.0 m of BD2 hole drilled at the left bank of the damsite is 177.8 kgf/cm, resulting in nearly 1/20 of the compressive strength, because the rock tested has no schistosity.

An ultra sonic velocity value of Vp and Vs for the above samples is obtained as follows:

| Sample (Depth) | VP (km/sec) | VS (km/sec) | ED ($kgf/cm^3$) | μD | $\sigma'$ ( $= \sigma c \times \upsilon p^2/Vp^2$) ($kgf/cm^2$) |
|---|---|---|---|---|---|
| BQ2 (26.3-26.5) | 6.54 | 3.78 | $9.62 \times 10^5$ | 0.249 | 600-2,300 |
| BD2 (49.8-50.0) | 6.78 | 4.50 | $1.21 \times 10^6$ | 0.106 | 580-2,100 |

where,

| | | |
|---|---|---|
| VP | : | Ultra sonic velocity of the primary wave of the samples |
| VS | : | Ultra sonic velocity of the secondary wave of the samples |
| ED | : | Dynamic modulus of elasticity of the samples |
| μD | : | Dynamic Poisson's ratio of the samples |
| $\sigma'$ | : | Assumed strength of the in-situ basement rock ($kgf/cm^2$) |
| $\upsilon p$ | : | ( = 5.4 km/sec, 28 km/sec) : Seismic velocity value of the primary wave detected by the field exploration work (SD-1, 2, 3, 4 and 5) |
| $\sigma_c$ | : | Uniaxial compressive strength of the samples (= 3409-$kgf/cm^2$). |

From the seismic velocity values of the in-situ and laboratory test, the assumed strength of the most fresh basement rock (Vp = 5.4-km/sec) and the dam foundation rock (2.8 km/sec) is inferred more than 2,000 $kgf/cm^2$ (Vp = 5.4 km/sec) and 580 $kgf/cm^2$ (Vp = 2.8 km/sec) respectively. The static modulus of elasticity of the basement rock ($E_S$) is inferred to be $1 \times 10^3$ $kgf/cm^2$, taking $E_S = (0.1 - 0.01) \times E_D$ on the safety side.

Mechanical properties of these rocks proved to be applicable for any kind of dam types. In case of the concrete facing dam type with rockfill, the internal friction angle of $\phi = 55°$ or more and cohesion of $c = 0$ kgf/cm$^2$ for rockfill material can be expected for the design value of rockfill zone in the feasibility stage, although the design values in the detailed design stage shall be carefully examined after checking compaction method and conditions.

## IV. DESIGN VALUE

Based on the results of the field data, laboratory tests and so on, the design values adopted for the dam construction plan are summarized as follows:

| ITEM | DESIGN VALUE | REMARKS |
|---|---|---|
| - Seismic coefficient | 0.10 G | Magwagwa and Saddle Dam |
| - Strength of basement | σ'=125 $kgf/cm^2$ (Rockfill zone) | Magwagwa Dam Foundation |
| | σ'=580 $kgf/cm^2$ (Concrete zone) | " |
| - Static modulus (Modulus of Deformation) | Es= $1x10^3$ $kgf/cm^3$ | " |
| - Angle of internal friction | ø = 55 degree | Rockfill material |
| - Cohesion strength | C = 0 $kgf/cm^2$ | " |
| - Angle of internal friction of soil | ø = 12 degree | Saddle dam, earthfill material |
| - Cohesion strength | C = 0.05 $kgf/cm^2$ | " |
| - Permeability of compacted soil | k = $1x10^{-6}$ cm/sec | " |

# Tables

Table 1.1 Work Quantity of Construction Material Survey

1) Test Pitting & Hand Augering in Borrow Site

| | | |
|---|---|---|
| TPR1 | Right bank | Depth 5 m |
| TPR2 | Right bank | Depth 5 m |
| TPL1 | Left bank | Depth 5 m |
| TPL2 | Left bank | Depth 5 m |
| HAR1 | Right bank | Depth 5 m |
| HAR2 | Right bank | Depth 5 m |
| HAL1 | Left bank | Depth 5 m |
| HAL2 | Left bank | Depth 5 m |

2) Laboratory test

ITEM A

- Unit Weight test
- Uni-axial compression test
- Tensile strength test
- Ultra sonic velocity test

ITEM B

- Specific gravity of soils
- Natural moisture content
- Particle size analysis
- Liquid limit
- Plastic limit and plasticity index
- Moisture - density relations of soil and soil-aggregate, mixtures, using 5.5.-lb (2.4 kg) rammer and 12 in (305 mm) drop
- Permeability of solid (at Optimum moisture condition)
- Triaxial shear (CU) in optimum moisture condition
- Consolidation test
- Direct shear (CU) in optimum moisture condition
- Shrinkage test in optimum moisture condition
- Measurement of solubc salt and Na, K, Mg, Ca, Fe, SO4, CO3 ions

ITEM C

- Natural moisture content
- Particle size analysis
- Specific gravity
- Liquid limit
- Plastic limit and plasticity index

ITEM D

- Abrasion test (Los Angels Test)
- Chemical durability

# Figures

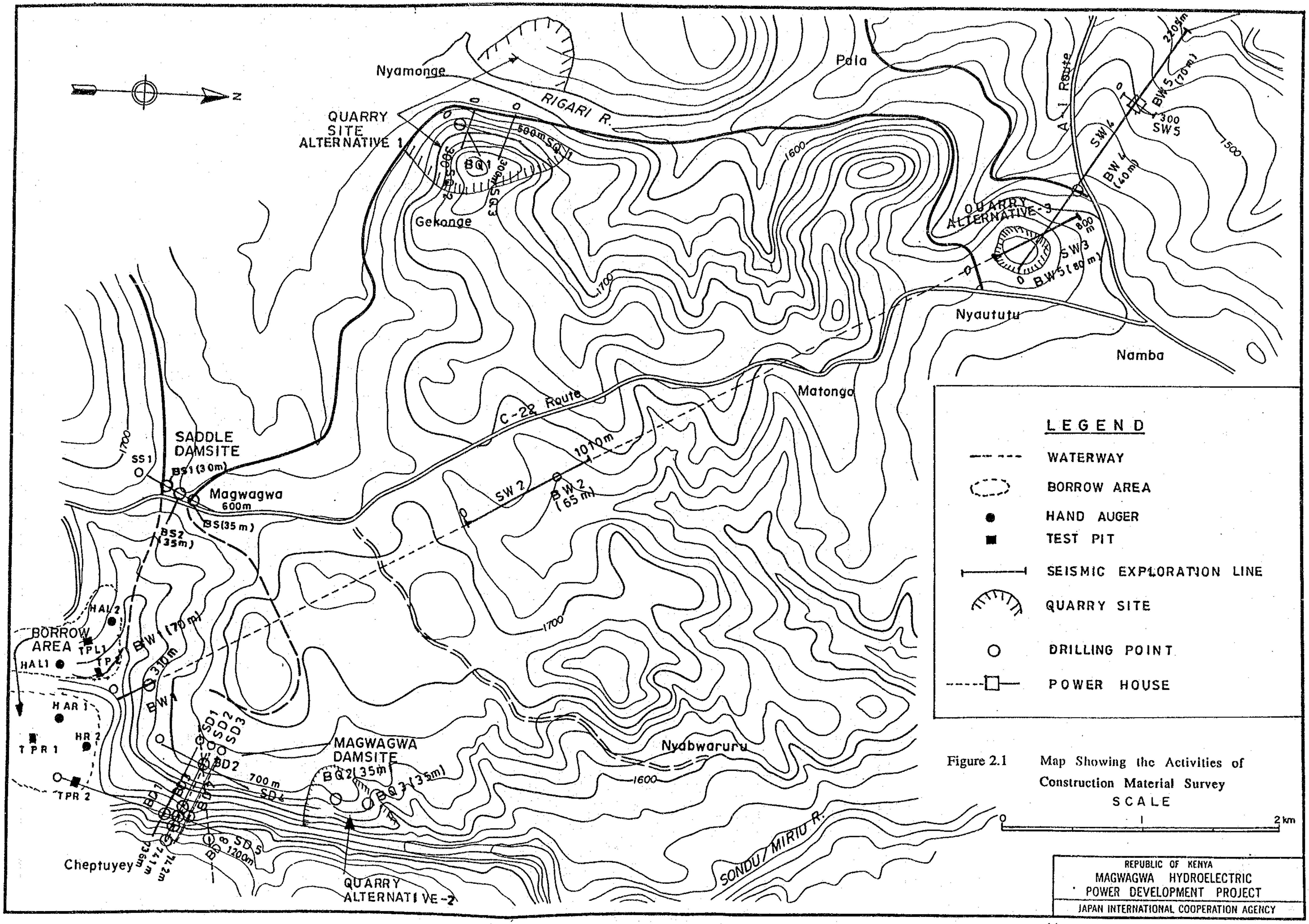


Figure 2.1 Map Showing the Activities of Construction Material Survey

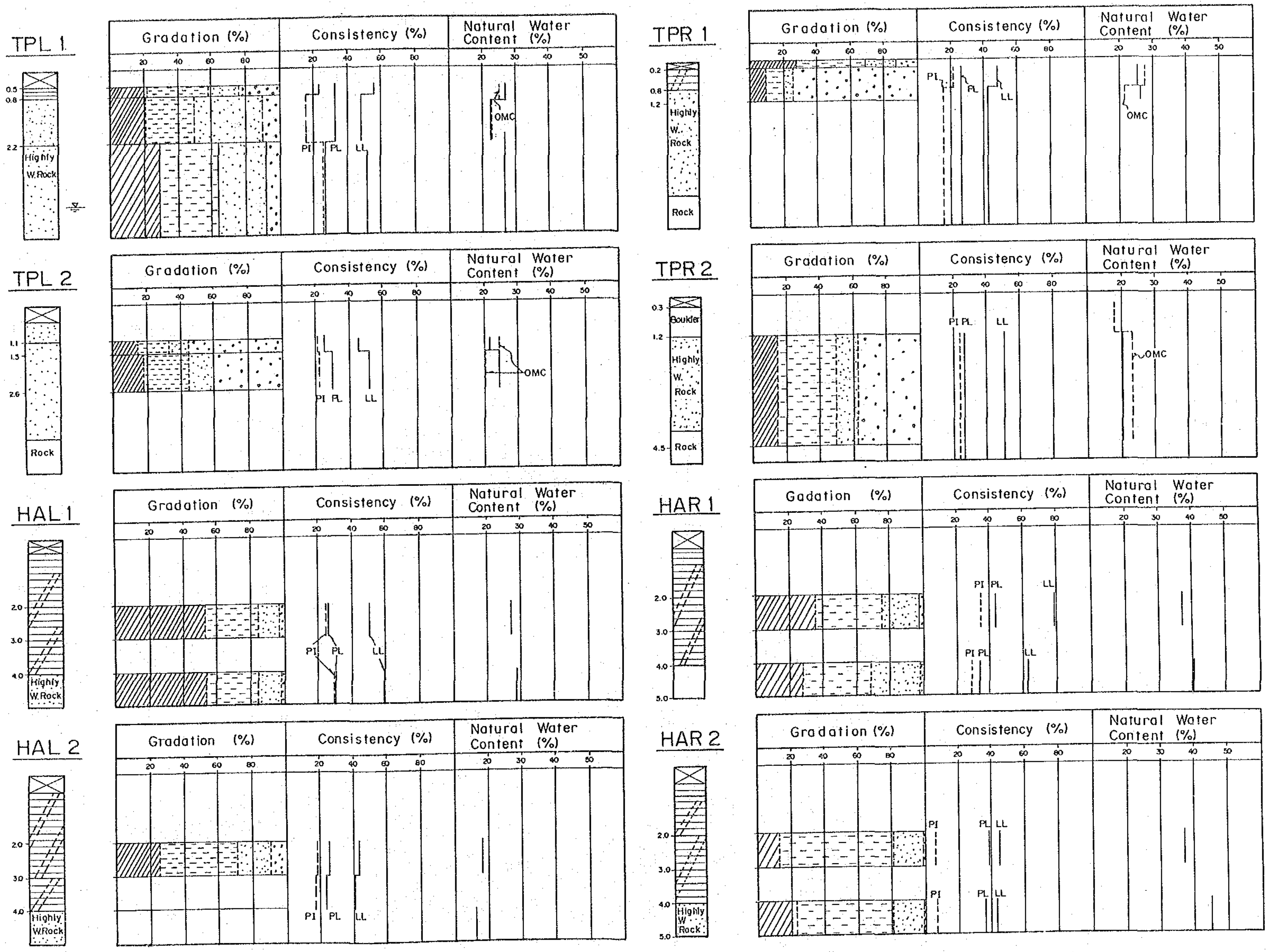


Figure 3.1 Physical Properties of Soil in the Borrow Areas

REPUBLIC OF KENYA
MAGWAGWA HYDROELECTRIC POWER DEVELOPMENT PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY

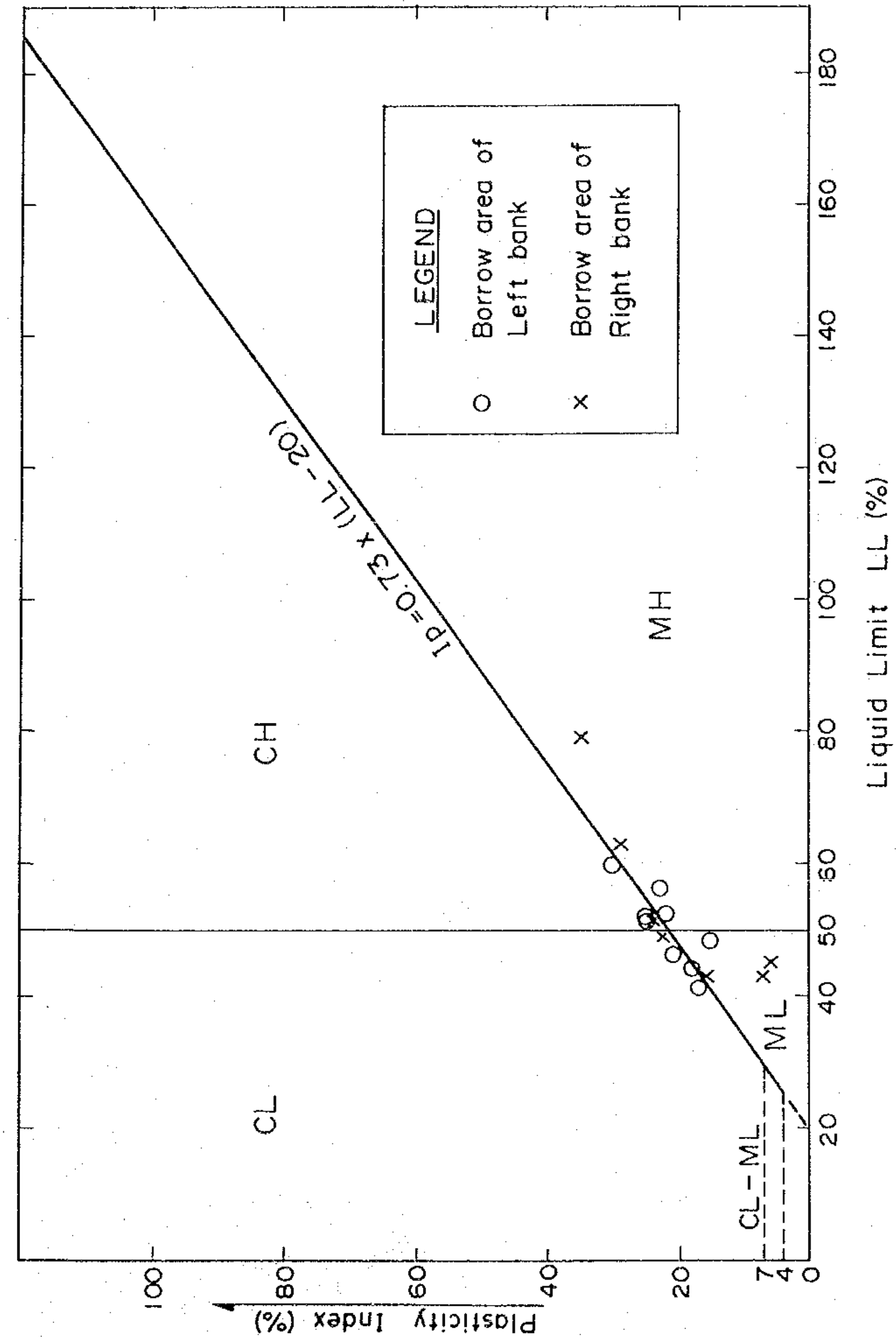


Figure 3.2 Plasticity Range of Soil

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POWER DEVELOPMENT PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

# APPENDIX IV.

# HYDROLOGY AND METEOROLOGY

## APPENDIX IV HYDROLOGY AND METEOROLOGY

### Table of Contents

## List of Tables

## List of Figures

# I. INTRODUCTION

## 1.1 Scope of Work

Hydrological studies aim at grasping meteo-hydrological conditions in the Sondu River basin to assess the viability of Magwagwa Hydro-electric Power Development Project. This project is a component of the integrated development of the Sondu River and the Kano plain with the Sondu/Miriu Hydro-electric Power Project and the Kano Plain Irrigation Development Project.

Both the projects, the Sondu/Miriu and the Kano, are located downstream of the Magwagwa power outlet. Thus, the role of the Magwagwa dam and reservoir is not only to generate power at the Magwagwa power station, but also to regulate discharge for the Sondu/Miriu power station and to supply irrigation water to the Kano plain.

Considering the above, the contents of the study are composed of data collection, low flow analysis, flood analysis, sediment yield analysis and estimate of water abstract in future.

Description of study activities in each chapter are is given below:

Chapter II shows the results of basin reconnaissance and the progress of such field work as installation of stream gauges and discharge measurements.

Chapter III discusses meteorological studies on temperature, wind speed, dew point and evaporation in the Sondu River basin.

Chapter IV deals with basin rainfall, mean monthly rainfall pattern, point rainfall intensity and rainfall depth-area-duration analysis.

Chapter V discusses river runoff estimated based on the daily gauge heights recorded at 1JG1, the observation period of which is 45 years between 1946 and 1990. The result so estimated is applied to determine the optimum development scale of the reservoir.

Chapter VI provides probable flood hydrographs and a probable maximum flood for determining the scale of spillway and diversion tunnel and the dam crest elevation.

Chapter VII estimates sediment deposit volume in the reservoir for assessing the dead storage volume and the minimum operating level, MOL, based on suspended load observed at 1JG1.

Chapter VIII contains a list of existing water abstract permits in the Sondu River, which are used for assessing the quantity of river maintenance flow. Water Act in Kenya is also referred to formulate the water regulation and diversion plan.

## 1.2 Sondu River Basin

The Sondu River which originates from the western frank of the Mau Forest meanders the vast highlands with gentle slopes westward, finally draining into Lake Victoria with a catchment area of 3,470 $km^2$ at the estuary. The Southwestern Mau Forest extended in the upstream reaches with an area of 1,000 $km^2$ is protected as a gazetted forest from developing. Middle and lower reaches of the basin are well developed as agricultural lands, especially, large scale tea plantations lie in the north-central part of the basin, Kericho region, with an area of 250 $km^2$.

There are two main tributaries in the basin, the Kipsonoi and Yurith rivers, which meet 60 km upstream of the river mouth, and the downstream stretches after the confluence of two rivers are called the Sondu/Miriu River. The proposed Magwagwa damsite, with a catchment area of 3,160 $km^2$, is located 5 km downstream of the confluence.

## 1.3 Previous Study

A meteo-hydrological study focussed on the Sondu River basin was carried out in the Sondu Multipurpose Development Project executed by JICA in 1986. Considerable parts of the study are applicable for the Magwagwa Hydropower Development Project due to the over-lapping of the project areas. Thus, the previous meteo-hydrological study was reviewed by adding the data observed thereafter.

## 1.4 Agencies Related to Meteo-hydrological Study

(1) Ministry of Water Development (MOWD)

The MOWD is responsible for the management of surface water including installation of water level gauging stations, runoff observation, discharge measurement, sediment measurement, water quality management and issuance of water abstract permits.

The stream gauges installed in Kenya are managed by the MOWD. The observation records measured in daily base are stored in the MOWD headquarters. The flood records are not arranged, but the recorded charts are available.

Monthly rainfall records observed in Kenya are transferred from the Meteorological Department and are compiled in the MOWD headquarters.

A list of the existing water abstract permits is stored in the data base system of the headquarters.

(2) Meteorological Department

The Meteorological Department is a government agency under the Ministry of Transport and Communications (MOTC), being responsible for such meteorological observation and forecast as climate, air temperature, wind speed, dew point, evaporation and so on.

The agency installs and manages all the meteorological stations and rain gauge stations in Kenya. A data base system of rainfall and meteorological records is available in daily base over a period between 1926 and 1988.

Rainfall data of hourly base is not arranged but the recorded charts are kept in the Rainfall Section of the agency.

(3) Lake Basin Development Authority (LBDA)

Lake Basin Development Authority under the Ministry of Regional Development is responsible for the development planning and implementation in the Lake basin area including the Sondu River basin.

The meteo-hydrological data of the Lake basin area is transferred from the MOWD and the Meteorological Department. Rainfall and runoff records on daily base are stored in the computer data base system, through which the LBDA examines such work as in-filling of missing data and correction of unreliable data, although the records observed in recent 5 years have not been processed yet.

## II. FIELD INVESTIGATION

### 2.1 Field Reconnaissance

Field reconnaissance was made twice at the beginning of February and at the end of November in 1990, through which the following characteristics were identified:

(1) The Sondu River basin is well developed by agriculture, especially, tea plantations with an area of 250 $km^2$, are developed in and around Kericho Township located in the middle reaches of the river.

(2) The upstream basin is covered with the Mau Forest, which is protected from developing with respect to environmental aspects. The area is estimated at 1,000 $km^2$.

(3) Large scale swamps exist upstream of the proposed Magwagwa damsite.

(4) Water is drawn from the Sondu River for the domestic use of Sondu Township which lies between the proposed damsite and the power outlet site.

(5) River width of the Sondu River is relatively narrow, between 50 m and 100 m in the downstream reaches of the proposed Magwagwa damsite.

### 2.2 Installation of New Stream Gauges

The installation of staff gauges was made at the proposed damsite and the power outlet site, the purposes of which are as follows:

(1) Staff gauge at the damsite:

This gauge was installed to reveal the river stage during flood periods for designing the height of cofferdam.

(2) Staff gauge at the power outlet site:

This gauge was installed to establish a discharge-river stage relationship for designing the tailrace water level. Discharge measurements are currently carried out at these two staff gauges by MOWD.

## III. METEOROLOGICAL STUDY

Meteorological observation in Kenya is carried out by the Meteorological Department. Meteorological data including temperature, relative humidity, wind speed, dew point, sunshine hours and evaporation was collected at three meteorological stations, Kisumu, Kericho and Kisii, located in and around the Sondu River basin.

### 3.1 Temperature

Monthly temperature records in and around the Sondu River basin are shown in Table 3.1. Mid-day temperatures (observation at noon) in the Sondu River basin are generally stable throughout the year, ranging from 17.6°C in August to 22.2°C in February at the Kericho meteorological station located in the north-central part of the basin. On the other hand, average annual daily temperature fluctuates in the range of 2.8°C from 16.8°C at 6:00 a.m. to 19.6°C at noon at Kericho, showing rather small fluctuation compared with that of Kisumu, 6°C.

### 3.2 Evaporation

Evaporation is observed at three meteorological stations, Ahero Market, Kericho and Sotik, using the class-A pan. Those monthly observation records of evaporation at these three stations are listed in Table 3.2.

Mean monthly pan evaporation of the Sondu River basin was estimated by computing arithmetic mean of records of three stations as shown below:

Unit: mm/day

| | Pan Evaporation | Reservoir Evaporation |
|---|---|---|
| Jan. | 4.46 | 3.12 |
| Feb. | 5.40 | 3.78 |
| Mar. | 5.18 | 3.63 |
| Apr. | 4.20 | 2.94 |
| May | 3.69 | 2.58 |
| Jun. | 3.89 | 2.70 |
| Jul. | 3.65 | 2.56 |
| Aug. | 4.05 | 2.84 |
| Sep. | 4.43 | 3.10 |
| Oct. | 4.36 | 3.05 |
| Nov. | 4.25 | 2.98 |
| Dec. | 4.50 | 3.15 |
| Mean | 4.34 | 3.04 |

The evaporation from the open surface of the Magwagwa reservoir was estimated as given above by multiplying 70% by mean monthly pan evaporation of the Sondu River basin so obtained.

Past experimental researches show that the pan coefficient, which is a conversion factor from the evaporation rate observed with the class-A pan to the rate for reservoirs, is recommended to be 70%, even varying from 60% to 80% (Handbook of Applied Hydrology, Ven Te Chow, McGrow-Hill). This is due to the fact that water temperature in the small area with shallow water depth, i.e. 4 feet in diameter and 10 inches deep for the class-A pan, tends to go up greater than that in reservoirs with an area of square kilometer order by sun heat, resulting in the higher evaporation rate in the class-A pan compared with that in the reservoirs.

## IV. RAINFALL STUDY

### 4.1 Available Rainfall Data

Reflecting high potential of the Sondu River basin in terms of agricultural development, a large number of rain gauges have been established and are well operated in the basin, although some were abandoned with a short observation period. All of rain gauges are owned and maintained by the Meteorological Department.

Figure 4.1 shows the information of 57 rain gauges located in the Sondu River basin including the coordinates, altitude and observation period. Monthly rainfall data has been collected from these 57 gauges, of which 26 stations are currently operated. The location of 57 rain gauges is shown in Figure 4.2.

Daily rainfall records were collected from following eleven stations out of 57, considering the observation period and the distribution of rain gauges in the basin:

| Station ID. NO. | Data Observation Period |
|---|---|
| 9035001 | 1947-1988 |
| 9035003 | 1947-1986 |
| 9035013 | 1947-1988 |
| 9035067 | 1947-1977 |
| 9035075 | 1957-1988 |
| 9035079 | 1947-1988 |
| 9035129 | 1961-1988 |
| 9035233 | 1961-1988 |
| 9035253 | 1963-1988 |
| 9035260 | 1971-1988 |
| 9035292 | 1975-1988. |

### 4.2 Mean Annual Rainfall

Mean annual rainfall of recent 50 years between 1940 and 1988 was obtained to be 1,505 mm by computing arithmetic mean of the 13 gauges listed in Table 4.1. Annual basin rainfall on the other hand fluctuates between 1,152 mm in 1984 and 1,892 mm in 1978.

These rain gauges are well distributed in the north and south-western part of the basin, however, the rain gauges are sparse in the central and south central part of the basin.

Unbalanced rain gauge distribution and missing the observation records in some stations limit the accuracy of estimated mean basin rainfall.

An isohyetal map of mean annual rainfall was prepared using all the available data of 57 rain gauges as shown in Figure 4.3, indicating that the central part of the basin lying in and around Kericho district is abundant between 1,800 mm and 2,000 mm per annum. The other place with ample rainfall spreads at the west-central part of the basin located in Kisii district, whilst the upstream area extended in the eastern part of the basin and the downstream area of the Sondu/Miriu River have a small amount of rainfall between 1,000 mm and 1,400 mm a year. Monthly rainfall records of 13 rain gauges listed in Table 4.1 are given in Tables 4.2 to 4.14.

## 4.3 Monthly Rainfall Distribution Pattern

The distribution patterns of monthly rainfall were prepared for the selected 13 stations as presented in Figure 4.4 and Table 4.15, showing three distinct types depending on the location of rain gauges; the central, eastern and western part of the basin. The characteristics of respective rainfall patterns are depicted in Figure 4.5, and described below:

Central part of the basin

Rainfall is abundant between March and November, especially ample rainfall in April and May, sharing 40% of annual rainfall. A dry season on the other hand exists between December and February.

The rain gauges which belong to this type are St. No 9035001, 9035003, 9035075, 9035260 and 9035079.

Eastern part of the basin

This part of the basin shows a bi-modal rainfall pattern with the rainy seasons in a period of April to May, and July to August, respectively; the second peak represents the major rainy season with 25% of annual rainfall. A remarkable dry season exists in December to February.

The rain gauges which belong to this type are St.No. 9035067, 9035129, 9035233 and 9035292.

Western part of the basin

There is no typical dry season. Abundant rainfall is recorded in March to May with a peak of rainfall in April, 50% of annual rainfall. However monthly fluctuation of rainfall is small compared with the above two patterns. The driest month appears in October.

The rain gauges which belong to this type are St.No. 9034024, 9035013, 9035253 and 9035261.

## 4.4 Frequency Analysis of Annual Maximum Daily Rainfall

Frequency analysis of annual maximum daily rainfall was conducted applying the Gumbel method at eight stations at which the available samples are more than twenty as given in Table 4.16, indicating the stations located in the eastern part of the basin have small probable rainfall rather than those in the other parts as shown below:

Unit: mm/day

| ID.No. | 9035001 | 9035013 | 9035067 | 9035129 | 9035233 |
|---|---|---|---|---|---|
| Location | Central | Western | Eastern | Eastern | Eastern |
| Sample No. | 64 | 65 | 36 | 28 | 26 |
| Return Period | | | | | |
| 1.01 yr | 34 | 27 | 20 | 29 | 26 |
| 2 yr | 56 | 54 | 41 | 45 | 46 |
| 5 yr | 69 | 70 | 53 | 55 | 58 |
| 10 yr | 78 | 81 | 62 | 62 | 66 |
| 20 yr | 86 | 92 | 70 | 68 | 73 |
| 50 yr | 97 | 105 | 80 | 76 | 83 |
| 100 yr | 105 | 115 | 88 | 82 | 91 |
| 200 yr | 113 | 125 | 95 | 88 | 98 |

## 4.5 Depth-duration Analysis

Basin rainfall depth-duration analysis is required to carry out flood study, especially for derivation of the Probable Maximum Precipitation over the catchment area of the proposed Magwagwa Dam.

Daily basin rainfall, which is the first step to obtain the depth-duration relationship, was computed over a period of 1947 to 1988 by taking arithmetic mean of the records listed in Table 4.17.

Annual maximum rainfalls for respective durations were calculated for each year based on the daily basin rainfall so obtained as given in Table 4.18. The selection of the maximum values from the annual maximum rainfalls for the respective durations shows the relationship between basin rainfall depth and duration as given in Figure 4.6 and as summarized below:

| Duration (day) | Rainfall depth (mm) |
|---|---|
| 1-day | 56.6 |
| 2-day | 85.4 |
| 3-day | 107.9 |
| 4-day | 126.7 |
| 5-day | 136.2 |
| 6-day | 160.8 |
| 7-day | 195.4 |
| 10-day | 233.6 |
| 15-day | 269.0 |
| 20-day | 328.7 |
| 30-day | 455.3 |

Figure 4.6 shows the relationship between basin rainfall depth and duration for P.M.P. as well by multiplying 1.6 by the relationship obtained above, which will be discussed in the subsequent Section 6.4.7.

# V. RUNOFF STUDY

## 5.1 Available Runoff Data

Many stream gauges have been installed in the Sondu River basin as well as rain gauges, counting 46 in total as shown in Figure 5.1. Of 46 stations, 18 gauges are currently under operation, the location of which is depicted in Figure 5.2.

All the stream gauges in the Sondu River basin are owned and maintained by the MOWD. Observed records are collected by the Kisumu branch of MOWD, and transferred to the MOWD head office and LBDA. However, hourly flood hydrographs are available only in the MOWD head office.

Daily runoff records of stream gauges collected and examined in this study are 1JG1 in the Sondu River, 1JD3 in the Yurith River and 1JF1, 1JF7 and 1JF8 in the Kipsonoi River. In addition, daily runoff of 1GD4, which is the key stream gauge in the Nyando River, is also collected taking into consideration the Kano Plain Irrigation Development Project.

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

## 5.2 Mean Annual Runoff

Flow of the Sondu River is ample with an average annual value of 42.0 $m^3$ at the 1JG1 stream gauge site with a catchment area of 3,260 $km^2$, reflecting abundant rainfall of the basin.

The Sondu River is composed of two main tributaries, Yurith and Kipsonoi rivers. The Yurith River basin located in the northern precipitious area of the Sondu River basin records mean annual runoff of 30.5 $m^3/s$ at 1JD3 stream gauge site with a catchment area of 1,570 $km^2$, sharing 74% of the Sondu River flow.

The Kipsonoi River basin covers 47 % of the Sondu River basin, 1,540 $km^2$ at the 1JF8 stream gauge site, but mean annual runoff is estimated to be 11.3 $m^3/s$ at the gauge reflecting small rainfall in the basin.

Monthly runoff records at the above three stations as well as 1GD4 in the Nyando River are shown in Tables 5.1 to 5.4, and summarized below.

| Station No. | River | CA ($km^2$) | Period | Mean Annual Runoff ($m^3/s$) | (mm) |
|---|---|---|---|---|---|
| 1JG1 | Sondu | 3,260 | 1946-1990 | 42.0 | 406 |
| 1JD3 | Yurith | 1,570 | 1969-1989 | 30.5 | 613 |
| 1JF1/8 | Kipsonoi | 1,523/1,540 | 1951-1989 | 10.3 | 211 |
| 1GD4 | Nyando | 2,520 | 1956-1988 | 11.3 | 141 |
| | | | (1951-1962) | | |

A rating curve was developed at 1JG1 using 93 discharge measurement records carried out between 1946 and 1984 as given in Figure 5.3, whilst Table 5.5 shows a list of 93 records with the highest record of 349.69 $m^3/s$ and the lowest of 1.47 $m^3/s$. Although there is no discharge measurement record after 1984, the rating curve is judged to be well developed. However, intensive discharge measurements shall be carried out to enhance its reliability.

Discharge measurement records at 1JD3 and 1JF8 are listed in Tables 5.6 and 5.7. The rating curves at these stations were established as given in Figures 5.4 and 5.5 based on those discharge measurement records.

## 5.3 Monthly Runoff Pattern

Monthly runoff patterns at the four stream gauge stations, 1JG1, 1JD3, 1JF1/8 and 1GD4, were prepared using monthly runoff data at the respective stations as given in Figure 5.6, showing the characteristics of the respective river basins as described below:

Sondu River at 1JG1 (CA = 3,260 $km^2$)

Mean monthly runoff varies between 82.9 $m^3/s$ in May and 13.5 $m^3/s$ in February. Bi-modal high water seasons are found in April to June and in August to September.

A dry season lasts for three months over a period of January to March. The estimated mean runoff in this period is around 16.9 $m^3/s$, which is 40% of mean annual runoff, 42.0 $m^3/s$.

Yurith River at 1JD3 (CA = 1,570 km$^2$)

Small fluctuation of runoff was observed throughout the year; the highest runoff of 43.0 m$^3$/s in August and the lowest runoff of 10.6 m$^3$/s in January for mean annual runoff of 30.5 m$^3$/s.

Runoff with the small variation in the Yurith River can be explained by the fact that the Mau forest and large scale tea fields occupying the upper basin and swamps existing in the Kericho highlands areas contribute to retaining rainfall in the basin for a long time and retarding runoff to the downstream reaches. This is furthermore endorsed by the fact that the high flow season lasts for five months of May to September and that there is no extremely high flow season.

Kipsonoi River at 1JF1/8 (CA = 1,523/1,540 km$^2$)

Despite almost the same scale between the Yurith River and the Kipsonoi River in terms of catchment area, the Kipsonoi River is observed to be one-third of mean annual runoff of the Yurith River; mean annual runoff of 10.3 m$^3$/s at 1JF1/8 with the highest in May and the lowest of 4.0 m$^3$/s in February and March.

The basin occupying the south-western part of the Sondu River basin has small rainfall.

Nyando River at 1GD4 (CA = 2,520 km$^2$)

The basin neighbours the Sondu River in the south. Compared with the Sondu River basin, river flow is remarkably small, observing mean annual runoff of 11.3 m$^3$/s with a catchment area of 2,520 km$^2$.

Runoff fluctuation is small between 18.8 m$^3$/s in May and 5.1 m$^3$/s in January. The monthly runoff pattern is similar to that of 1JD3 in the Yurith River. Runoff in the high flow season of April to September was found to be 15.0 m$^3$/s on an average.

## 5.4 Runoff Coefficient

Runoff coefficients of mean annual discharge were examined at three stream gauges, 1JG1, 1JD3 and 1JF8 (1JF1) by obtaining arithmetic mean rainfall of the following rain gauges (asterisks show the gauges used to obtain the arithmetic mean):

| Rain Gauge Station No. | 1JG1 | 1JD3 | 1JF1/8 |
|---|---|---|---|
| 9035024 | * | | * |
| 9035001 | * | * | |
| 9035003 | * | * | |
| 9035013 | * | | * |
| 9035067 | * | | * |
| 9035075 | * | * | |
| 9035079 | * | | * |
| 9035129 | * | * | * |
| 9035233 | * | | * |
| 9035253 | * | | * |
| 9035260 | * | * | * |
| 9035261 | * | | * |
| 9035292 | * | * | * |
| Total | 13 | 6 | 10 |

Mean runoff coefficients of the respective rivers are shown below and detailed in Table 5.8:

| St. No. | River | CA ($km^2$) | Runoff (mm) | Rainfall (mm) | Coefficient (%) | Applied Period |
|---|---|---|---|---|---|---|
| 1JG1 | Sondu | 3,260 | 396 | 1,511 | 26.2 | 1947-88 |
| 1JD3 | Yurith | 1,570 | 610 | 1,695 | 36.0 | 1970-88 |
| 1JF1/8 | Kipsonoi | 1,540 | 211 | 1,324 | 15.9 | 1952-1961,1986-88 |

## 5.5 Duration Curve at the Proposed Magwagwa Damsite

A duration curve of daily runoff at the Proposed Magwagwa damsite with a catchment area of 3,160 $km^2$ was prepared using 1JG1 records between 1946 and 1990 as shown below and applying the series and parallel methods. Further details are given in Figures 5.7 and 5.8 and Tables 5.9 and 5.10. Runoff at the Magwagwa damsite for the preparation of the duration curve was estimated by multiplying the catchment area ratio of 0.969 (= 3,160/3,260) by that observed at 1JG1.

Series method

| Excess in % | Runoff in $m^3/s$ |
|---|---|
| 1 | 234.4 |
| 10 | 89.9 |
| 20 | 62.6 |
| 30 | 48.0 |
| 40 | 36.1 |
| 50 | 25.9 |
| 60 | 18.5 |
| 70 | 13.2 |
| 80 | 9.3 |
| 90 | 5.9 |
| 95 | 4.3 |
| 98 | 2.9 |
| 99 | 2.3 |

Parallel method

| Excess in days | Runoff in $m^3/s$ |
|---|---|
| 1 | 186.8 |
| 36 | 92.0 |
| 72 | 60.7 |
| 108 | 48.3 |
| 144 | 39.0 |
| 180 | 30.2 |
| 216 | 23.1 |
| 252 | 16.2 |
| 288 | 11.3 |
| 324 | 8.0 |
| 342 | 6.7 |
| 355 | 5.8 |
| 365 | 4.8 |

## VI. FLOOD STUDY

### 6.1 Available Data

Flood study includes probability analysis on annual maximum flood, provision of the design flood hydrograph based on the recorded hydrographs, and estimate of probable maximum flood based on the storm rainfall records in and around the Sondu River basin.

Data required for the above study is rainstorm records, hourly flood runoff records and various meteorological records especially during the flood period.

In this study, hourly flood data recorded at 1JG1 for 44 years and the following daily rainfall records are available for the` flood analysis:

Available Rainfall Data for Flood Analysis

| Station No. | Data Period | Type of Data |
|---|---|---|
| 9035001 | 1947 - 1988 | Daily |
| 9035003 | 1947 - 1986 | Daily |
| 9035013 | 1947 - 1988 | Daily |
| 9035067 | 1957 - 1976 | Daily |
| 9035075 | 1963 - 1988 | Daily |
| 9035079 | 1955 - 1987 | Daily |

Hourly rainstorm data could not be collected due to no observation in the Sondu River basin.

### 6.2 Frequency Analysis on Annual Maximum Flood

Frequency analysis has made using annual maximum flood records observed at 1JG1 for 44 years of 1947 to 1990. Flood records of annual instantaneous flood peak discharges are collected as shown in Table 6.1.

Recorded maximum peak flood is 639 $m^3/s$ on April 6, 1990. Specific peak flood discharge is calculated to be 0.195 $m^3/s/km^2$. It is judged that the specific flow of the recorded maximum flood in the Sondu River is relatively high compared with other rivers in the Lake basin as shown below:

| River | Gauge ID | Recorded Maximum Flood ($m^3/s$) | Catchment Area ($km^2$) | Recording Period | Specific Discharge ($m^3/s/km^2$) |
|---|---|---|---|---|---|
| Sondu | 1JG1 | 639 | 3,260 | 1947 - 1990 | 0.195 |
| Nyando | 1GD4 | 363 | 2,600 | 1955 - 1983 | 0.139 |
| Yala | 1FG1 | 139 | 2,388 | 1948 - 1985 | 0.058 |
| Nzoia | 1DA2 | 528 | 8,417 | 1948 - 1985 | 0.062 |

Frequency analysis on flood peak flow was carried out applying two approaches, Gumbel and Log Pearson Type-III methods as given in Table 6.2.

The results obtained with the Log Pearson Type-III method were adopted as those of the frequency analysis because the results indicate values higher than those of the other approach to use the second order moment and because the difference between the observed records and the calculated values is within an allowable range. The frequency curve so obtained is shown in Figure 6.1.

Specific discharges for peak flood in the Lake basin with a return period of 100 years are listed below:

| River | Gauge ID | 100-year Probable Flood ($m^3/s$) | Catchment Area ($km^2$) | Specific Discharge ($m^3/s/km^2$) |
|---|---|---|---|---|
| Sondu | 1JG1 | 958 | 3,260 | 0.294 |
| Sio | 1AH1 | 85 | 1,450 | 0.059 |
| Nzoia | 1DA2 | 512 | 8,417 | 0.061 |
| Yala | 1FG1 | 185 | 2,388 | 0.077 |
| Nyando | 1GD4 | 459 | 2,600 | 0.177 |
| Kuja | 1KB5 | 1,055 | 6,600 | 0.160 |

It is revealed that the Sondu River basin has a high flood peak in the Lake basin, because of the following reasons:

(1) There is a rich rainfall area in the south-eastern pat of the Lake basin, where the Sondu and Kuja river basins are located.

(2) The Sondu River basin is well developed in the middle and lower reaches, whilst the upper reaches are covered with the Mau Forest with a catchment area of 1,000 $km^2$.

Peak discharge of a 10,000-year probable flood was furthermore computed to be 2,535 $m^3/s$ at the damsite applying the Log Pearson Type-III method, even if the small number of samples, 44 as seen in Figure 6.1, shows the low reliability in prediction. This computed peak discharge was used for the endorsement of the predicted P.M.F. discussed in the subsequent Section 6.4 and for ensuring the security of the designed spillway from overtopping.

## 6.3 Flood Hydrograph Characteristics

In order to predict a unit hydrograph in the Sondu River, nine recorded flood hydrographs were collected as shown in Figures 6.2 to 6.10. Further details are presented in Tables 6.3 to 6.11 as reference.

Characteristics of those nine flood hydrographs are summarised below:

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

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

It is found that floods occurred in the Sondu River last almost for one month, and dull peak runoff is observed. The time lag between the rainstorm and the corresponding peak flood runoff is observed to be 2 to 3 days. The flood runoff ratio is estimated to be as low as the values of 30% to 60% depending on the precedent condition of the basin.

It is judged that the flood in the Sondu River is characterized as the one with a dull peak and a long time lag, because of the natural retarding effect due to the swamps spread around Kericho Township and Mau Forest in the upper basin of the Sondu River. In addition, the long lasting rainstorm also contributes to such a dull peak flood.

A note is given to the 1990-flood observed in the Sondu River in the course of this study as follows:

(1) Instantaneous peak discharge of 639 $m^3$/sec observed at 1JG1 on April 10, 1990 is the recorded maximum since the observation was started in 1947.

(2) The observed hydrograph as referred to Figure 6.10 shows conspicuous triple peaks with a long lasting recession rim as same as past floods.

(3) A rainstorm with an intensity of 30 to 50 mm a day occurred in the middle and lower reaches of the basin with time advance of longer than 28 hours from the time when the first flood peak appears. Another rainstorm of 40 mm a day is recorded in the upper reaches of the basin a day earlier from the above rainstorm. The flood with the recorded maximum peak discharge is estimated to be caused by simultaneity of flood runoff from the above two rainstorms.

(4) A comparison of flood frequency analysis on the condition of the with-and-without 1990-flood is given below:

| Recurrence interval, year | Without 1990-flood | With 1990-flood |
|---|---|---|
| 5 | 320 | 339 |
| 25 | 600 | 641 |
| 100 | 890 | 958 |
| 200 | 1,060 | 1,140 |
| 1,000 | 1,500 | 1,634 |

## 6.4 Derivation of Probable Maximum Flood

### 6.4.1 Procedures

The Unit Hydrograph Method was applied to estimate probable maximum flood (hereinafter as P.M.F.) for the design of Magwagwa dam. Following are the procedures to estimate P.M.F.:

(1) Preparation of dimensionless graph at 1JG1,
(2) Prediction of the unitgraph at the Magwagwa damsite based on the dimensionless graph at 1JG1 and topographic condition of the basin,
(3) Estimation of Probable Maximum Precipitation (hereinafter P.M.P.) based on the results of rainfall depth-duration analysis and the consideration of the storm maximization factor in the basin, and
(4) Derivation of P.M.F. at the Magwagwa damsite applying the convolution integral for the unitgraph and P.M.P. so obtained.

### 6.4.2 Dimensionless graph

In order to establish a unitgraph at the Magwagwa damsite, the dimensionless graph at 1JG1 was at first derived from the recorded floods described in the preceding Section 6.3.

The floods which have conspicuous causality between storm rainfall and peak discharge were tried to select for providing the dimensionless graph. However, most of floods recorded at 1JG1 are composed of bulk of rainfall with a long duration and dull peak of flood, resulting in difficulty in selecting an appropriate flood.

1964-flood, which has peak discharge of 530 $m^3/s$, could be selected as a typical flood for providing the dimensionless graph, however, its rainfall pattern has dual peaks and longer time lag of 6 - 7 days compared with others.

On the other hand, 1978-flood having the peak discharge of 413 $m^3/s$ shows a clear shape and relationship between the peak flood and the bulk of rainfall with time lag of 2 - 3 days. Accordingly, 1978-flood was selected as a typical flood to provide the dimensionless graph as given in Figure 6.11 with that of 1964-flood.

It is noted that the 1990-flood, which has the recorded maximum peak flood of 640 $m^3/sec$, is not suitable as the typical flood to provide the dimensionless graph due to the fact that the flood has triple peaks (refer to Figure 6.10).

### 6.4.3 Unitgraph

A unitgraph is developed for unit rainfall of 10 mm over the Sondu River basin considering the unit duration determined from the dimensionless graph and time lag, Tcv, defined as the time between the beginning of the rising rim and the centroid of the net hydrograph. According to the instruction of USBR given in "Design of Small Dams", a unit duration should be selected to be less than 25% of Tcv. Time lag of 2 days is observed in 1978-flood, which is the shortest time lag among the collected floods. Therefore, 12 hours of unit duration, equivalent to 25% of time lag, Tcv, was selected.

Basin time lag, Lg, defined as the time difference between the centroids of rainfall excess and hydrograph, is required to develop a unitgraph. The time lag, Lg, is estimated for all the collected floods as dealt with in Section 6.3.

On 1978-flood, Lg is computed to be 61 hours, which is the shortest time lag due to the precedent condition of the basin with the highest base flow.

To estimate the time lag, Lg, at the Magwagwa damsite, the Synider's formula was applied as given below:

$$Lg = Ct \times (LxLc)^{0.3}$$

where, Lg : Basin time lag (hr.)

L : Length of the longest watercourse from the point of interest to the basin boundary (mile)

Lc : Length of watercourse from the point of interest to the centroid of the basin (mile)

Ct : Synider's coefficient.

A Synider's coefficient for the Sondu River basin, Ct, was computed to be 4.9936 from the data of 1JG1; Lg = 61 hours, L = 86.06 mile and Lc = 48.78 mile, applying the above formula.

Applying the value of Ct of 4.9936 obtained from the data of 1JG1, L = 55.92 mile and Lc = 17.09 mile, the value of Lg was obtained to be 39.13 hours. It is noted that the values of L and Lc were measured not from the damsite, but from the reservoir upstream end.

A unitgraph at the Magwagwa damsite was developed as shown in Figure 6.12 and Table 6.12, applying Lg + D/2 of 51.13 hours, where "D" means the rainfall duration in hour (12 hours for the unit hydrograph).