REPUBLIC OF KENYA

KENYA POWER COMPANY LIMITED

FEASIBILITY STUDY ON MAGWAGWA HYDROELECTRIC POWER DEVELOPMENT PROJECT

FINAL REPORT

SUPPORTING REPORT (1)

OCTOBER 1991

JAPAN INTERNATIONAL COOPERATION AGENCY

NAIROBI OFFICE
P.O BOX 50572
NAIROBI KENYA

TOKYO HEAD OFFICE
P.O BOX 216 SHINJUKU
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This Report consists of

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I. INTRODUCTION

Topographic survey work in this study was commenced with data collection and aerial photograph shooting carried out in a period between January and March, 1990, followed by ground control survey and field verification work between June and August, 1990.

Based on the newly shot aerial photographs and the data obtained from the ground control survey and so on, topographic maps on a scale of 1 to 1,000 and 1 to 5,000 were prepared taking advantage of photogrammetry in Tokyo by October 1990, and then the maps so prepared were used for the subsequent preliminary design work and the social environmental impact study.

The maps on a scale of 1 to 1,000 cover the areas where major structures will be built, whilst the 1 to 5,000 scale maps for the entire reservoir area as well as the major structure sites. It is noted that the 1 to 5,000 scale maps so prepared not only show permanent structures, geographical names and so forth, but also identify the location of households to be submerged in the reservoir and to be affected by the project.

The identification work of households in and around the reservoir area will not only clarify the magnitude of resettlement issue, but also make easy the handling of such issue.

II. DATA COLLECTION

Work of data collection started with the collection of 1 to 50,000 and 1 to 250,000 scale topographic maps covering the Sondu River basin prepared by Survey of Kenya, the index number of which is as given in Table 2.1. Furthermore, the 1 to 10,000 scale maps prepared for the area downstream of the proposed Magwagwa powerhouse site in Sondu River Multipurpose Development Project were also collected to coincide the 1 to 5,000 scale maps which would be prepared in this study with them in terms of contour lines.

District maps were collected for Kisii and Kericho districts where the proposed Magwagwa reservoir extends. It is noted that the district map for Nyamira divided from Kisii District in the current jurisdiction system has not been prepared yet. On the other hand, the district map for Trans Nzoia was gathered aiming at identifying potential resettlement areas.

Cadastral maps shown in sub-location basis, smallest jurisdiction unit, were also collected in Kericho and Kisii districts as given in Table 2.1 for identifying the ownership of lands, which will also provide basic information on land acquisition and compensation.

III. MAP PREPARATION

3.1 Aerial Photograph Shooting

To prepare topographic maps with photogrammetry, work started with the preparation of aerial photographs for the target areas, consisting of aerial signal setting and photograph shooting as described hereinafter.

(1) Aerial signal setting

Signals were placed in the target areas prior to aerial photograph shooting for indicating the control points required for aerial triangulation and mapping work on the aerial photographs. The signals placed on the target area were nine.

(2) Aerial photography

Black and white vertical photographs were taken using an aerial camera mounted in the airplane with side-angle lens of 9-inch focus distance. Figure 3.1 shows the flight courses flown for aerial photograph shooting.

Aerial photographs on a scale of 1 to 20,000 were taken in flight runs 1 to 5 for preparing the topographic maps of 1 to 5,000 scale, and flight line length for these five runs was approximately 87 km in total. The aerial photographs so taken have the specifications of 50% ± 5% on overlapping and 30% ± 5% on sidelapping.

Flight runs 6 to 9 show the courses for 1 to 4,000 scale aerial photographs, which were used for the preparation of 1 to 1,000 scale maps. Total flight length for these four runs was 7 km, and the specifications for these aerial photograph shooting were the same as those for the 1 to 20,000 scale aerial photographs.

The negative films of aerial photographs so taken were brought to Japan for mapping work and are kept by JICA Tokyo taking into account future uses. One set of contact prints of those aerial photographs is preserved by Survey of Kenya with an index map considering the convenience of future uses in Kenya.

3.2 Ground Control Survey and Field Investigation

(1) Control point survey

Control point survey was carried out to identify the absolute coordinates of the newly established control points in the target area by means of the Global Positioning System, GPS, taking advantage of the geodetic satellite. The number of the control points observed by GPS is seven for the 1 to 5,000 scale maps and nine for the 1 to 1,000 scale maps as given in Figure 3.2.

(2) Levelling work

Levelling work was carried out for marking the altitude of the newly established 16 control points. To make the levelling work easy, temporary bench marks were set up with an interval of 5 to 10 km, and furthermore vertical control points installed at distinct places with an interval of approximately 500 metre supplemented the levelling work.

There were three places in the levelling route where altitude difference between the vertical control points is great. Levelling work at these three places was carried out by relying on trigonometric levelling. The levelling work, as its routes are given in Figure 3.2, was carried out for a distance of 107 km in order to mark the altitude of the established 16 control points and temporary bench marks.

(3) *Field verification*

Field verification, which is the work to identify the name of places and jurisdictional boundaries that cannot be interpreted from aerial photographs, classification of vegetation and so forth, was carried out by referring to the relevant data and by accessing to the sites. The work to identify the households scattering in the proposed reservoir area was performed by visiting each household, which is expressed on the 1 to 5,000 scale maps together with the name of places, jurisdictional boundaries, classification of vegetation, public roads and so on to make easy the handling of resettlement issue.

3.3 Map Preparation

(1) Aerial triangulation

Aerial triangulation which is the adjustment computation to seek conformity among the aerial photographs in terms of scale by availing the results of control point survey and levelling work was carried out using the "PAT-M43" aerial triangulation block adjustment programme as the initial work of the map preparation. In fact, aerial triangulation was computed for 47 models to prepare 1 to 5,000 scale topographic maps, whilst 19 models for 1 to 1,000 scale topographic maps.

(2) Plotting and editing

The topographic maps on a scale of 1 to 1,000 and 1 to 5,000 were prepared with plotting machines based on the results of aerial triangulation and field survey. Principal contour lines were drawn with a 5 m interval for 1 to 5,000 scale topographic maps, whilst a 1 m interval for 1 to 1,000 scale topographic maps.

With cartographic work, final maps were prepared, and work volume was 117 km^2 for 1 to 5,000 scale maps and 3.2 km^2 for 1 to 1,000 scale map. Figures 3.3 and 3.4 show an index for the topographic maps so prepared. The topographic maps prepared in this study are separately compiled in the Data Book.

Tables

Table 2.1 Data Collected on Topography

Sort of maps	Index number	Source
1 to 50,000 scale topographic maps	116/4 (Nyakach), 117/3 (Belgut), 117/4 (Kericho), 118/3 (Keringet), 130/2 (Kisii), 130/4 (Keroka), 131/1 (Chemagel), 131/2 (Tenwek), 131/3 (Chepalungu), 131/4 (Bomet), 132/1 (Olenguruone)	Survey of Kenya
1 to 250,000 scale topographic map	SA-36-4 (Kisumu)	Survey of Kenya
District maps	Kisii, 1/ Kericho, Trans Nzoia	
Cadastral maps	<u>Kericho District</u> Roret 2/, Nyamanga, Kipsonoi, Tebesonik, Kapkatet, Kipsonoi, Chemoiben, Litein, Boito, Kabianga, Kapsuser, Kebenet, Kapkatet, Kiptere, Kebenet, Getarwet, Chemagel, Mogogosiek <u>Kisii District</u> Magwagwa 2/, Boisanga, West Bosamaro West Mugirango, Botabori I and III, Bonyamondo I, Ikonge, Bomanono, Bogichora, Mwabosire, Monyerero, Mwogeto, Siamani.	Survey of Kenya

Notes: 1/ Kisii District covers the area of Nyamira, which is now an independent district.

2/ The names given show the registration section (sub-location).

Figures

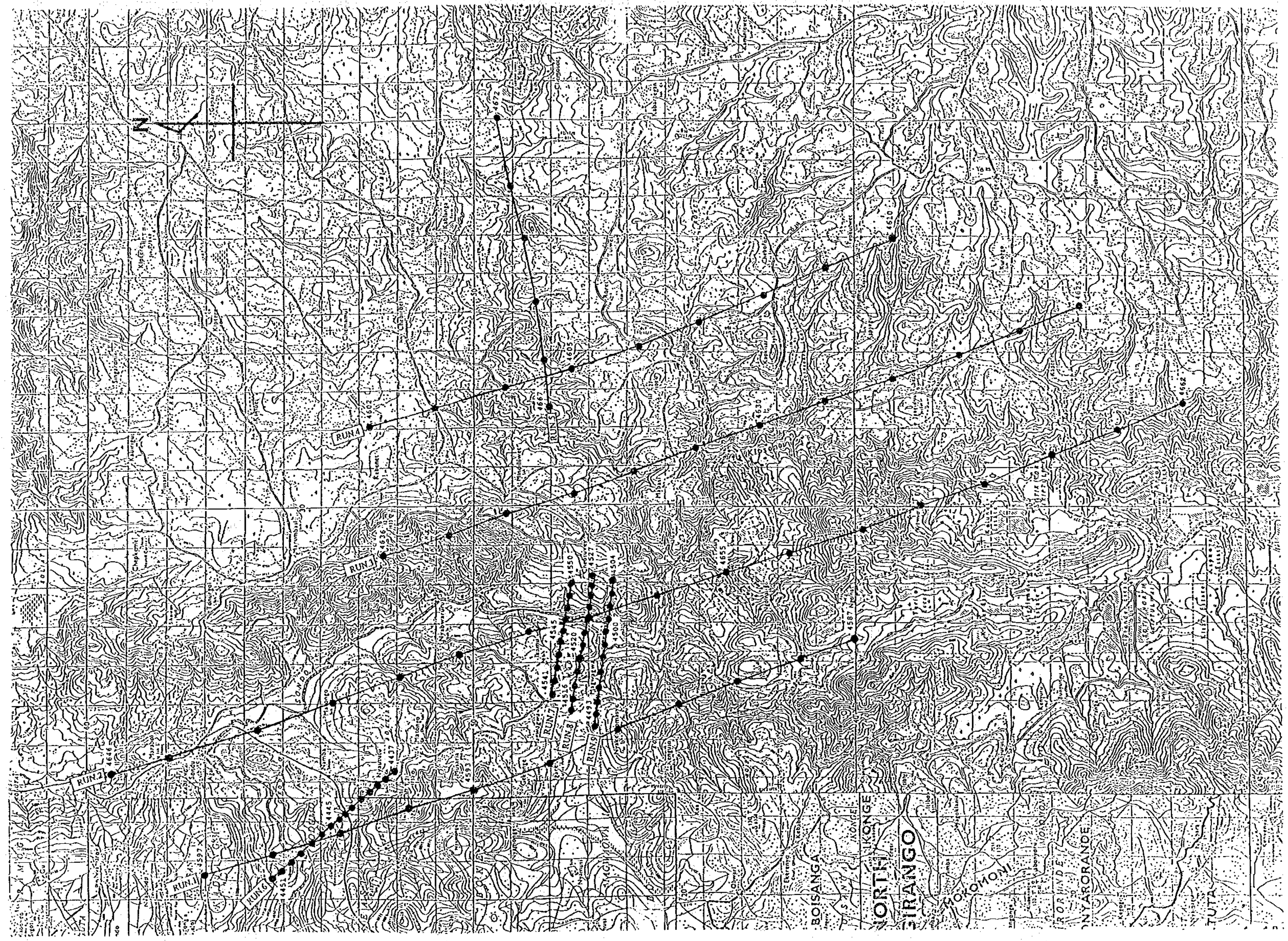

Figure 3.1 Aerial Photography Flight Index

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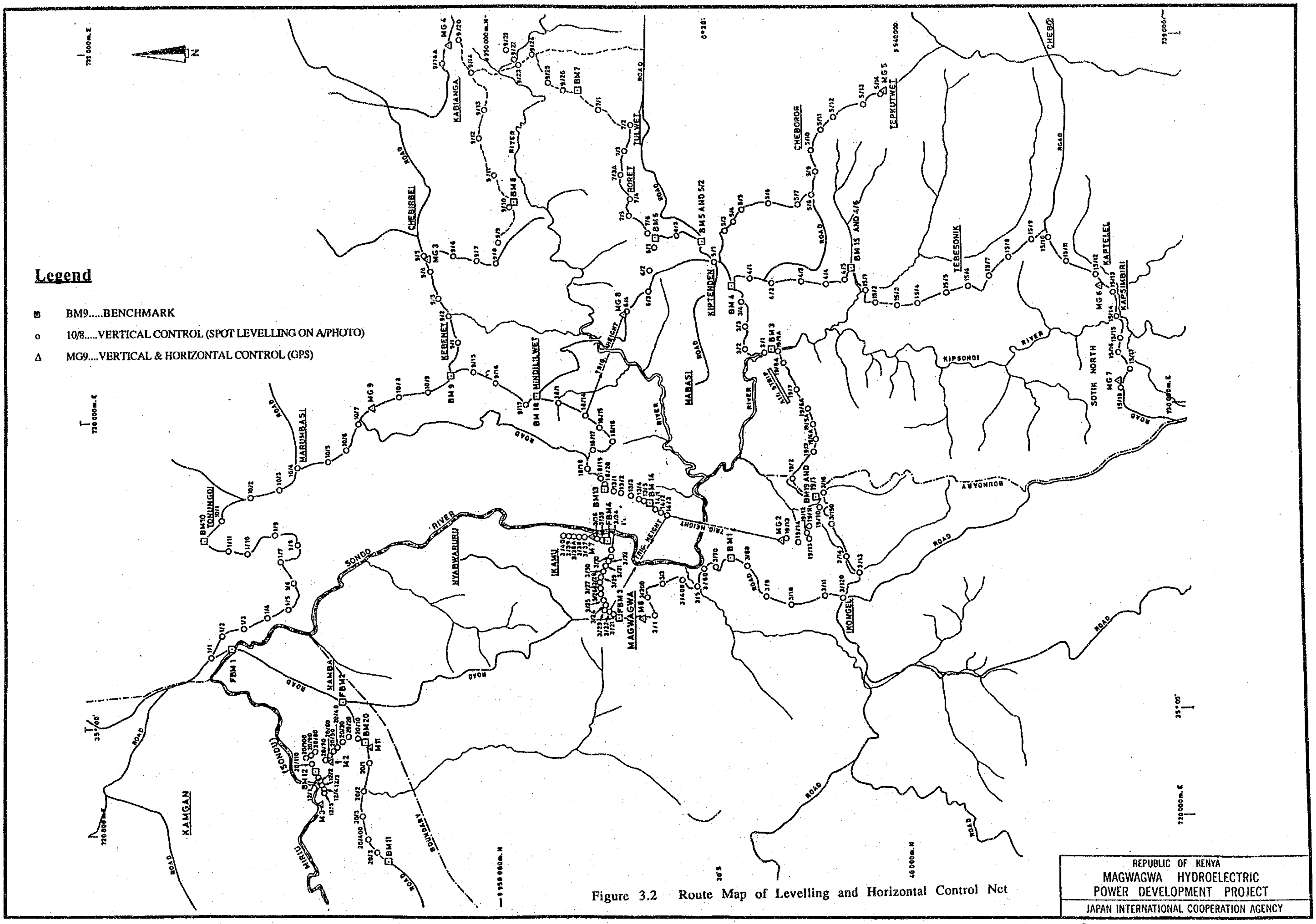

Figure 3.2 Route Map of Levelling and Horizontal Control Net

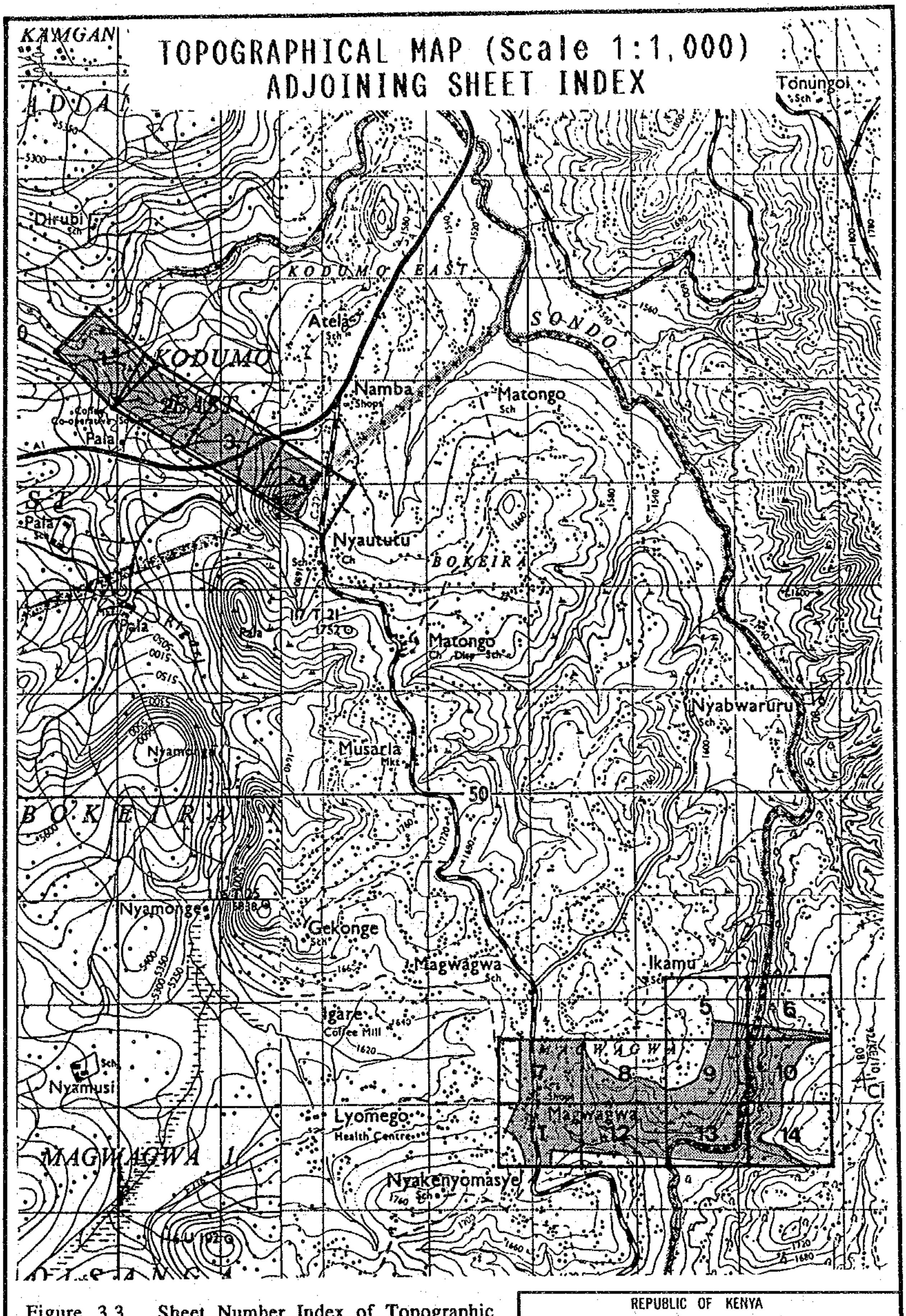

Figure 3.3 Sheet Number Index of Topographic Maps on a Scale of 1 to 1,000

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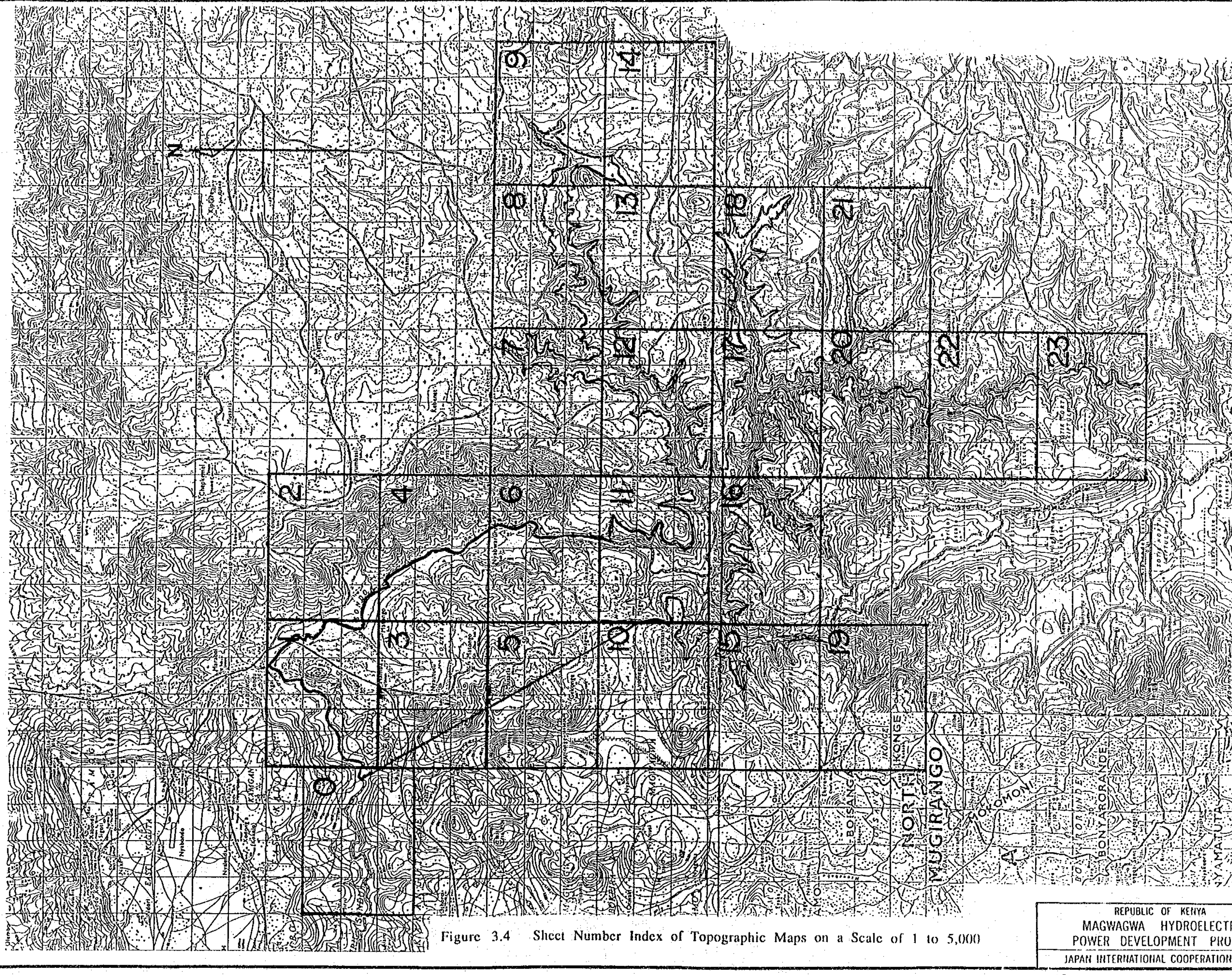

Figure 3.4 Sheet Number Index of Topographic Maps on a Scale of 1 to 5,000

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APPENDIX II.

GEOLOGICAL STUDY

APPENDIX II GEOLOGICAL STUDY

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I. INTRODUCTION

Geological investigation is composed of geological data collection, review and site reconnaissance in the Identification Stage (January to March, 1990) and survey by core drilling and seismic exploration in the Field Investigation Stage (June to November, 1990) to clarify the geology at the project site.

The main purposes of the study are of 1) providing the geological features of the project site and clarifying problems regarding geology at the project 2) executing of the geological investigation to solve geological problems constricted to the project and to obtain more detailed geological conditions to be clarified for the following design work.

The investigation results and the new findings by the site reconnaissance are described hereinafter.

II. GEOLOGY IN THE REGION

2.1 Topography

The Sondu River drains a catchment area of 3,470 square kilometres at the river mouth, flowing down generally from the east to the west gathering major tributaries such as the Yurith and Kipsonoi rivers, however, at the middle reaches, the river turns the direction from the south to the north.

The upstream areas of the river form rather gentle flat highlands reflecting the geology composed of comparatively younger strata than that of the downstream area of the Sondu River. The areas of the upper reaches are covered with Tertiary andesite lava called phonolite. On the other hand, the areas of the lower reaches expose the basement of meta-sedimentary rocks, igneous rocks in Pre-Cambrian and granitic rocks in Post-Cambrian.

The project site is located in the middle to lower reaches of the Sondu River after gathering of major tributaries. The river at the contemplated damsite flows down from the south to the north forming a rather steep gorge, and then turns its stream direction to the west approximately 9 km downstream of the project site or near Sondu Township.

2.2 Geology

Geology in the region as shown in Figure 2.1 consists of sedimentary rocks (metamorphic rocks), igneous rocks in Pre-Cambrian, Granitic rocks intruded in Post-Cambrian, Tertiary volcanic, Pleistocene to Recent river deposits along the present river course and Talus on the rather gentle slopes in a descending order (refer to Table 2.1). Details are as follows:

Intrusives (Granitic rocks)

The rocks, granodiorite and granite belonging to the Post-Cambrian, are developed mainly at the lower reaches of the Sondu River and the uppermost reaches of the Kipsonoi River, respectively.

Sedimentary rocks (Metamorphic rocks)

The rocks widely developed along the Kipsonoi River and in the middle to the lower reaches of the Sondu River are of quartzite and schist with some cherts in Pre-Cambrian called Basement System "M" in Archen and Bukoban System "Bq".

The rocks of Basement "M" are partly developed at the south-eastern margin of the catchment, whilst Bukoban System "Bq" is in the vicinity of the project site.

It is conceivable that these sedimentary rocks were received metamorphism in some degree by intrusion of granitic rocks.

Igneous rocks

The rocks mostly developed along the Kipsonoi River and in the western fringe of the catchment are of rhyolites with intercalated tuffs, agglomerate and basalt called Nyanzian System (NR) in Pre-Cambrian, which is exposed along the Kipsonoi River. Andesite and porphyritic felsites called Bukoban System (Ba, Bb) in Pre-Cambrian are exposed in the middle reaches of the Sondu River, i.e. the left bank of the Kipsonoi River(Ba) and in the vicinity of Magwagwa damsite(Bb).

Tertiary volcanics

The rocks called Kericho phonolite and/or Nyabondo phonolite are widely developed by overlying the above-mentioned Pre/Post-Cambrian rocks in the eastern half of the catchment and in Sondu/Nyakachi, the right bank of the downstream reaches of the river.

River deposits

River sand, silt, clay and gravel are sparsely developed along the present river course. Terrace deposits in Pleistocene are well developed in a small scale in the middle to the lower reaches of the Sondu River.

Talus deposits

Talus deposits composed of silt, clay and debris spread sporadically on the gentle slopes and their feet in the catchment.

2.3 Geological Structure

The geological structure in and around the study area is as follows:

a) Intrusives in Post-Cambrian, sedimentary rocks (metamorphic rocks) and igneous rocks in Pre-Cambrian are the main components of the formed basement,

b) Tertiary volcanics developed in the eastern half of the Sondu River catchment overlie the above-mentioned basement rocks,

c) A conspicuous fault is traced along the slope foot of the Kendu escarpment demarcated the highland areas (the project area) from the Kano plain. Near the project area, two probable faults trending the E-W direction can be traced 1 and 3 km upstream of the Magwagwa damsite by interpreting landsat images (see Figure 2.1). The saddle damsite would lie in the former fault zone.

d) Several lineaments are inferred at the project site by the interpretation of landsat images as given in Figure 2.1, running in the N-S direction parallel with the river course of the middle reaches of the Sondu.

III. SEISMICITY

3.1 Collected Data for Seismicity Analysis

Earthquake data around the project area was collected from the International Seismological Centre in the Identification Stage. According to it, earthquakes likely affecting to the Magwagwa project are 87 events over a period of 1904 to 1990 as listed in Table 3.1, whilst their epicentres are shown in Figure 3.1. The collected data of earthquakes covers an area falling in a range of 3°21'36"S to 2°13'06"N and 32°21'36"E to 37°42'33"E, or an area within a radius of 300 km of the site, even some are beyond the range.

The earthquake recorded the maximum magnitude is 7.0, which occurred on 6 January, 1928 at x=0.5N and y=36.5E with shallow depth; that is, 195 km away from the Magwagwa damsite.

Of earthquakes ever recorded, the nearest one occurred 22 km away from the site (x=0.299S and y=35.117E) with shallow depth on 10 September, 1972, the magnitude of which was 4.6.

According to the existing seismic zoning map of Kenya, the project site lies in the middle seismicity zone of "VI" (21.0 to 44.0 gal) in Modified Mercalli Intensity Scale (refer to Table 3.2).

3.2 Analysis of Seismic Coefficient

Probable ground acceleration with a 100-year recurrence interval was estimated to ensure the dam safety during earthquakes using the earthquake records given in Table 3.1 and the three formulae given below:

1) I.S.C. (International Seismological Centre)

Intensity on the Modified Mercalli scale is calculated at the specified position using the following formula:

$$i = 8.0 + 1.5\, m - 2.5 \ln (r)$$

where m = magnitude
r = focal distance in km
ln = natural logarithm.

Peak horizontal acceleration in cm/sec^2 (ah) is calculated using the following formula:

$$\log ah = 0.014 + 0.30\, i.$$

2) Estiva's method

The expected acceleration at the proposed damsite is given by the following equation:

a	=	$(5{,}000 \times \exp(0.8 \times M))/(HD + 40)^2$	(3)
HD	=	$(D^2+Z^2)^{1/2}$	(4)
D	=	$2 \times 3.14 \times R\ (d/360)$	(5)
d	=	$\cos^{-1}(\sin(yo) \times \sin(y) + \cos(yo) \times \cos(y) \times \cos(x-xo))$	(6)
R	=	$Ry^2 / (1-e^2 \times \cos^2 y)^{1/2}$	(7)
e	=	C/Rx	(8)
C	=	$(Rx^2 - Ry^2)^{1/2}$	(9)

where
- a : Peak ground acceleration in cm/sec^2
- M : Magnitude
- D : Distance between damsite (xo,yo) and epicentre (x,y)
- Z : Depth of earthquake in km
- R : Radius of the earth in km : Rx = 6,378 and Ry = 6,356
- e,exp : exponential
- d, C : Parameters.

3) Kawasumi's method

Intensity on the JMA (Japan Meteorological Agency) scale as referred in Table 3.2 is computed by the following formula:

$$S = 2M - 4.6052 \log R - 0.00183 R - 0.307 \qquad \text{(when } R > 100 \text{ km)}$$
$$S = 2(M - \log X) - 0.0166X - 3.9916 \qquad \text{(when } R < 100 \text{ km)}$$

where
- S : Intensity on the JMA (Japan Meteorological Agency) scale
- M : Magnitude in Richter scale
- R : Distance from the epicentre in km
- X : Distance from the focus in km.

The expected acceleration is given by the following formula:

A	=	0.45 x 10S/2	(when S < 5.5)
	=	20 x 10S/5	(when 5.5 < S< 7.0)

where A : Acceleration in cm/sec^2
S : Intensity in JMA.

Probable ground acceleration was revealed to be 50 to 60 gals as summarized in Table 3.3 at the proposed damsite using the above three equations and the maximum and nearest earthquakes recorded around the site (refer to Section 3.1).

4) Maximum acceleration to be expected in a probable return period of 100 years

Frequency of earthquakes (Mercalli Scale) recorded over the 86-year period of 1904 to 1990 was converted into frequency in 100 years as shown in Table 3.4. Plotting the relationship between the intensity (i) and the cumulative number of frequency (Nc) on a semi-log paper, the following formula was obtained by the least square method (refer to Figure 3.2):

$$\log Nc = 1.935 - 0.2411\ i.$$

For the case of Nc = 1, the expected maximum intensity in a probable return period of 100 years was estimated at i = 8.0. According to the method adopted by I.S.C., this intensity corresponds to the ground acceleration of 259 in gal. However, the Kawasumi's method using the J.M.A. scale shows a value of 32 in gal (i.e. Ij = 3.7 of J.M.A.) only. As well known, the Japanese archipelagoes lie in the most active seismic zone in the world and a seismatic value of 0.15 G (150 in gal) has been adopted at maximum. The estimated 250 gal for a probable return period of 100 years at this site has never been experienced in Japan. The seismic value obtained by the ISC's equation is extremely large judging from the fact that the area is in the middle seismicity zone. Furthermore, considering the design value adopted in other projects such as the Kiambere Project, a value of k = 0.10 G is adopted as a coefficient of earthquake to occur once in 100 years.

3.3 Analysis of Reservoir Induced Seismicity (RIS)

After impounding water in the large reservoirs, it is reported RIS phenomenon is occurred in several reservoirs in the world. When RIS is occurred in this low seismic zone, an issue to the dam safety would be induced.

A study for RIS was attempted by Thomas Vladut, Canada, 1988. The RIS in the Magwagwa reservoir was also analysed using the diagram developed by T.Vladut as shown in Figure 3.3. Plotting the values of $q = 62°$ (aperture angle of parabola which describes the average morphological type of reservoir) and $i = 0.0073$ (average slope of the river along the water storage) which were obtained from the topographic condition at the Magwagwa dam site on the diagram, conspicuous phenomenon of the RIS cannot be expected to occur in the reservoir with this impounding scale.

The recorded maximum of RIS is 5 in magnitude. Even if this maximum value of 5 in magnitude occurs in the middle of this reservoir of 15 km long, the expected acceleration may be in the range of 50 to 55 in gal., i.e. 0.05 G, using the Kawasumi's formula discussed in the preceding Section 3.2. Consequently, the risk of RIS is judged to be within the range of safety for the dam to be designed as $k = 0.10$ G.

IV. GEOLOGY AT THE PROJECT SITE

4.1 General

In the Identification Stage of the study conducted from January to March, 1990, two alternatives on dam axis, SD2 (Alternative-A dam axis as referred to Figure 6.3 of the Main Report) and SD3 (downstream of Alternative-A), were preliminary selected. Figure 4.1 shows the location of those axes as well as other sites where geological investigation was carried out, while Figure 4.2 presents a geological map around the damsite. The two alternatives are located at the riverbed of El. 1,558.0 m to El. 1,559.5 m, as a geological profile along the axis of Alternative-A is given in Figure 4.3, with a distance of 80 m to each other.

Another dam axis, Alternative-B (BD2-BD8), was found in the course of the Field Investigation Stage using the topographic maps newly prepared in this study. The riverbed of alternative-B lies at El. 1,557.0 m (refer to Figure 4.5). The geological investigation work by drilling and seismic exploration was carried out for these three alternatives.

As dealt with in Section 6.2 of the Main Report, studies to look for the most promising dam axis were examined by adding another Alternative-C, located further downstream of Alternative-B. Since the addition of Alternative-C seeks for the most appropriate dam axis in terms of costs, explanation in this Chapter on site geology is limited to the dam axes of Alternative-A, SD3 and Alternative-B.

A saddle dam will be built at a ground depression, the lowest elevation of which is El.1,653 m to El.1,670 m, located on the left bank upstream of the damsite (refer to Figure 4.1). In order to clarify the geological conditions of the site and the probable faults running across the saddle dam, seismic exploration and drilling were carried out for a distance of 600 m long and at three spots, respectively.

Seven alternatives on the waterway route were identified in the Identification Stage of January to March, 1990. Among them, the Alternative-3 route was nominated as a top priority from economic and technical viewpoints. The geological investigation by means of seismic exploration and drilling was concentrated on the intake point, thin covering portion of headrace tunnel, surge tank, penstock line, and powerhouse of the Alternative-3 waterway route. The work volume was 5 lines for seismic exploration and 5 holes for drilling.

Discussions for the results obtained at the above-mentioned sites are given hereinafter.

4.2 Magwagwa Damsite

The river is 80 m wide along the Alternative-A, 60 m along the SD3 axis, and 50 m along the Alternative-B. The dam crest length, when the crest level is set at El.1,670 m, is 670 m for Alternative-A and 700 m along the SD3 axis and 700 m for Alternative-B.

1) Geology along the dam axis of Alternative-A

Geology of the basement rocks along Alternative-A (refer to Figure 4.3) consists of sedimentary rocks of Bukoban System at the bottom of the gorge, dolerite of Bukoban System at the right bank and under the river deposits, and andesite of Bukoban System at the left bank. One fault with the fracture zone of 5 m wide is running along the flow direction. The fault strikes NNE-SSW and dips 45° to 50° E. The sedimentary rocks of Bukoban System at the bottom of the gorge can be subdivided into a sandstone layer, a limestone layer of 6.6 m thick, a shale layer of some 10 m thick and a quartzite layer.

A homogeneous thick quartzite layer occupies the left side of the bottom of gorge, while the other sedimentary rocks such as sandstone, limestone and shale layers at the right side of the bottom of gorge. The boundary of the both sedimentary rocks is separated by the above-mentioned fault and dolerite intruded into the sedimentary rocks.

Seismic velocity observed along the line SD2 of Alternative-A is also shown in Figure 4.3. The fastest velocity is 5.4 km/sec of the 4TH layer reflecting a fresh rock of CH in classification (refer to Tables 4.1 and 4.2). Several low velocity zones such as 2.4, 2.5, 2.7 and 3.1 km/sec are distributed in this 4TH layer. A conspicuous low velocity zone of 3.1 km/sec with some 60 m in total width was observed at the right corner of the bottom of gorge, where the said fault is running and various kinds of sedimentary rocks in Bukoban System underlie the overburden such as river sand/gravel and talus deposits.

The 3RD velocity layer of 2.8 - 3.0 km/sec overlies the 4TH layer. The 3RD layer has 10 m to 20 m thickness at the left bank and 20 m to 35 m thickness at the right bank. The velocity values of 2.8 - 3.0 km/sec in this layer suggest the conditions of a slightly weathered rock and/or cracks developed greater than the 4TH layer. The rock classification in the 3RD layer is CM to CH suitable for the dam foundation.

The 2ND layer of 1.3 - 1.5 km/sec velocity has 5 m to 10 m thickness in the right bank as well as the 3RD layer. The rock classification in the 2ND layer is mostly in CL demonstrating much weathered rocks and cracks developed more than the 3RD layer and partly D at the uppermost of this layer. It is recommended to excavate upper half of this layer for the dam foundation of rockfill zone.

The 1ST layer recorded with the velocity of 0.3 - 0.8 km/sec is composed of top soil, residual soil, talus deposits, river sand/gravel deposits, and completely weathered/decomposed rock of D in rock classification, the thickness of which has 5 m on an average, ranging from 2 m to 6 m.

Drilling results at BD2, BD3, BD4, BD5 and BD6 along Alternative-A are depicted in Figure 4.3 together with BD1 drilled nearby to make a geological profile and better understanding of the seismic exploration results as mentioned above.

The fault location is confirmed in the range of 18.0 m to 23.4 m from the ground level of BD1, while 3.0 m to 8.8 m for BD4 and 13.9 m to 20.4 m for BD5. The drilled core in this fault zone is composed of fragmented sandy shale (BD1 and BD5) and fractured dolerite (BD 4) without any intercalated clay.

No cave or its indication in the limestone is found in the hole BD1, BD4 and BD5. However, it is less advantageous to select the dam axis at this site due to the fault located at the riverbed and the developed soluble limestone besides riverbed wider than that of Alternative-B.

Figure 4.4 shows the distribution of Lugeon values along Alternative-A. Permeable zones over 5 Lugeon value are developed in the weathered zone of 25 m thick at the left bank, 40 m thick at the right bank and at the bottom of gorge. The high permeable zone at the bottom of gorge is caused by the existence of the fault and soluble limestone intercalated.

2) Geology along the dam axis of Alternative SD3

Geology along SD3 consists mainly of andesite of Bukoban System at the riverbed portion of the left bank , and dolerite of Bukoban System at the right bank.

Sedimentary rocks of Bukoban System widely developed along the Alternative-A dam axis might be thickly overlain by the said dolerite. A fault is located at the foot of the right bank covered by talus deposits of 5 m to 6 m thick.

Seismic exploration of SD3 shows the similar results to those of SD2 along the Alternative-A dam axis. However, the low velocity zone of 3.0 km/sec with 50 m wide slips in the foot portion of the right bank from the riverbed of Alternative-A. The velocity of the 4TH layer is 5.2 km/sec at the right bank, although the SD2 line of the alternative-A dam axis shows the velocity of 5.4 km/sec.

The bore hole BD7 was drilled at the riverbed along the SD3 with an inclined angle of 45 degree from the left bank toward the right bank. The results of BD7 reveal the purple to blue andesite is distributed below the riverbed. The andesite is classified into CM and CH in quality in all drilled sections. No fractured or fault zone is found within the drilled length of 80 m.

The results of permeability test carried out in the hole BD7 show the Lugeon value as small as 1 to 4 except for the tested section from 46.75 m to 61.45 m in depth with a Lugeon value of 5.

The dam axis of Alternative SD3 is judged to be slightly better than that of Alternative-A from the geological conditions explained above. However, since the fault is located at the foot portion of the right bank, Alternative-B mentioned hereunder will be much better than Alternative SD3.

3) Geology along the dam axis of Alternative-B

Geology along Alternative-B consists largely of andesite of Bukoban System. Dolerite of Bukoban System is distributed at the upper half of the right bank. The sedimentary rocks of Bukoban System developed at Alternative-A do not affect this dam axis as shown in Figures 4.5 and 4.7, because the fault slips in the upper portion of the right bank and the sedimentary rocks develop further below from ground surface along the dam axis of Alternative-B.

Top soil and residual soil on the upper half of the right bank cover with 5 m to 8 m thicker than those of Alternative-A and SD3. Seismic velocity along Alternative-B is projected from SD1, SD2, SD3 (left bank) and SD5 (right bank) located nearby as shown in Figure 4.5.

The low velocity zone of 3.0 km/sec suggests the fault running at the upper portion of the right bank, the elevation of El. 1,620 m or higher. The 4TH layer has the velocity of 5.4 km/sec at the riverbed portion of the left bank, and 5.2 km/sec at the right bank. The slightly weathered 3RD layer of 2.8 - 3.0 km/sec is thickly distributed at the right bank more than at the left bank, which might be resulted from the fault running.

The holes of BD2, BD7 and BD8 were drilled along and around the dam axis of Alternative-B. The results of BD2 and BD7 have already been explained above.

The purpose of BD8 drilling was to confirm the location and condition of the fault running at the upper portion of the right bank of Alternative-B. The hole was drilled with a 45 inclined angle and 40 m deep along the drilling direction to cross vertically the fault plane.

Top soil and residual soil are 9.5 m thick and rather permeable with a value of $1x10^{-4}$ cm/sec. The heavily weathered andesite with a grade of D to CL is 3.4 m thick, and the weathered andesite of 3.9 m thick with a grade of CL to CM shows a Lugeon value of 9 (refer to Figure 4.6), underlying the overburden. Fresh dolerite of the CM to CH class appears with a Lugeon value of 5.

The zone fractured by fault without clayey material is located from the depth of 35.7 m to the end of the hole, which is composed of dolerite of CL class with a Lugeon value of 6.

It is concluded Alternative-B is much preferable to Alternative-A and SD3 from the following facts:

- The fault running in Alternative-B occupies the upper portion of the dam foundation where water pressure induced by impounding is not expected to be high,
- The limestone which has soluble and high permeable characteristics in general is not distributed below the dam foundation,
- Riverbed width of Alternative-B is the narrowest in the said three dam axes, and
- The andesite is homogeneously and widely distributed in the foundation. Cracks of andesite may readily be grouted because of no intercalated clay.

4.3 Saddle Damsite

The proposed saddle damsite is located east of Magwagwa village. To avoid a troublesome resettlement issue for the residents in Magwagwa village, the dam axis will be selected some 100 m east, i.e. reservoir side, of the present trunk road connecting Sotik and Sondu.

The scale of the saddle dam will be 20 m high at most and 700 m long. In case of planning the homogeneous earth-fill type dam, embankment material of some 200,000 m^3 and additional reclamation material of some 100,000 m^3 for land levelling of the depression area between the trunk road and the saddle dam will be required. The detail of borrow site is described in Annex III, Construction Material Survey.

The geological investigation to confirm the geology at the saddle dam site was carried out by means of seismic exploration and core drilling, the work volume of which is 600 m (Line SS) for the former and 3 holes (BS1, BS2 and BS3) for the latter. The seismic line selected is 200 m far west to avoid the disturbance of activities in the village.

Figure 4.8 shows the geological profile obtained by seismic exploration and core drilling. The drilling points of BS2 and BS3 were respectively selected on the probable fault lines based on the interpreted results of the seismic line SS.

Geology at the damsite is composed of top soil, residual soil of laterite, fractured andesite and sandstone of Bukoban System. Based on the exploration results of seismic line SS, four layers were detected as shown in Table 4.2.

The 4TH layer has 4.0 km/sec in the section from SS-0 m to SS-390 m, and 4.7 km/sec in the remaining section from SS-390 m to SS-600 m. The layer is inferred to be moderately fresh rocks of CM class. The low velocity zones of 2.6 - 3.1 km/sec with 5 m in width are detected in the four points of SS-225 m, SS-250 m, SS-390 m and SS-490 m.

The 3RD layer of 2.0 - 3.0 km/sec overlies the 4TH layer, in which cracks are developed more than the 4TH layer. The rock in this layer is of CL class. The 2ND layer of 0.9 - 1.1 km/sec is composed of well compacted or consolidated laterite soil and partly weathered rock of D class. The 1ST layer of 0.3 - 0.4 km/sec is of top soil.

The hole of BS1 drilled at SS-125 m is of top soil of 1 m thick (the 1ST velocity layer), residual soil of 1 m to 8.5 m in depth (the 2ND velocity layer), weathered andesite of 8.5 to 10.1 m (the 2ND layer), and moderately fresh andesite with crack intervals of 10 cm to 30 cm (CM class).

The hole of BS 2 drilled at SS-225 m is of top soil (1.5 m), residual soil (1.5 m to 8.25 m), fractured andesite of CL to CM class affected by the fault (8.25 m to 29.4 m), and fresh andesite (29.4 m to 35.25 m) in CM class.

The hole of BS3 drilled at SS-390 m is of top soil and residual soil (0 m to 7.6 m), hard and fresh andesite (7.6 m to 15.35 m) in CM to CH class, fine sandstone (15.35 m to 25.0 m) alternated in CL to CM class, fine sandstone alternated by the other fault (25.0 m to 32.5 m) in D to CL class, and hard quartzite of CM class (32.5 m to 35.1 m).

N-values by the standard penetration test conducted in the soil layers such as top soil and residual soil are over 10 blows below from the depth of 3 m. The permeability coefficients in the soil layer have valves of smaller than $1 x 10^{-4}$ cm/sec. From the Lugeon values given in Figure 4.9, low permeable condition is expected in the basement rocks, even in the fault zone.

Judging from the investigation results mentioned above, an earthfill type dam may be rest on the consolidated residual soil after the excavation of loosen layer and surface portion upto 2 m to 3 m in depth. The leakage from the foundation of residual soil hardly occurs due to its water tightness.

In case of concrete gravity dam, the dam foundation will be rest on the weathered rock of CM class with the seismic velocity of 2.8 - 3.0 km/sec or more, after excavating the soil layer and the heavily weathered rock formation.

4.4 Waterway Route along Alternative-3

Seismic exploration along SW1 (310 m), SW2 (1,010 m), SW3 (1,000 m), SW4 (2,200 m) and SW5 (300 m), and drilling at BW1 (70 m), BW2 (65 m), BW3 (90 m), BW4 (40 m) and BW5 (70 m) were carried out at such selected places as intake site, thin tunnel covering portions, surge tank, penstock line and powerhouse as shown in Figure 4.10. The investigation results reveal moderately good geological conditions, although the drilled results of BW1 and BW2, which are located at the intake and thin tunnel covering portion respectively, show the indications of a fault and/or deeply weathered zone. The result of BW3 drilled at the Chabera Hills reveals the composing of stable andesite mass in good quality not only for surge tank but also for construction materials, quarry sand. A geological plan and profile to depict the geological condition between the surge tank and the outlet in more detail are given in Figure 4.11 taking into consideration the case where the underground powerhouse is proposed.

Tables

Table 2.1 Geological Sequence in the Study Area

AGE	SYMBOL	DESCRIPTION
RECENT	Al	Superficial alluvium Sand, Graves, Silt, Clay
PLEINSTOCENE	Pl	Pl Undifferentiated includes Lake deposits Plt Mau and Londiani Ashes and Tuffs plb Londiani Matic Basalts and Basanites
TERTIARY	Tv	Tv Tertiary volcanics Kericho phonolite and Nyabondo phonolite
PRE CAMBRIAN	B	(BUKOBAN SYSTEM) Ba Rhyolites and tuffs, porphyritic felsites and Andesites Bq Quartzites with some cherts Bb Basalts and porphyritic basalts
PRE CAMBRIAN	Gn	Nyanzian roof pendant (Hornblende gneiss)
PRE CAMBRIAN	N	(NYANZIAN SYSTEM) NR Rhyolite with intercalated tuffs (NRt and Agglomerates, Basalt, Na Andesites, Dasites and Tuffs
ARCHEAN	M	(BASEMENT SYSTEM) Undifferentiated gneiss, schists and quartzites, includes MN-Nyanzian schists and MK-Kavirondian schists
	GD	INTRUSIVES Granites (G3-Post Kavirondian (G2-Post Nyanzian Miriu Granodiorite (G -Undated

Table 3.1 Earthquakes Likely Affecting to the Project (1/3)

NO.	DATE YEAR/MONTH/DAY	LONGITUDE	LATITUDE	MAGNITUDE	DEPTH (km)	DISTANCE (km)
01	1928, 01, 06	36.5 E	0.5 N	7.0	0	195
02	1928, 01, 06	36.2 E	0.2 N	0.0	62	149
03	1928, 01, 10	36.0 E	0.5 N	6.0	0	152
04	1928, 01, 10	36.2 E	0.2 N	0.0	62	149
05	1959, 05, 10	34.5 E	3.0 S	4.2	0	285
06	1959, 05, 10	35.91E	3.19S	4.2	0	315
07	1960, 05, 04	32.46E	1.21S	5.7	0	298
08	1960, 05, 04	32.0 E	0.75S	5.7	0	339
09	1964, 01, 03	35.0 E	3.0 S	0.0	0	278
10	1966, 07, 11	35.0 E	1.0 S	3.7	0	58
11	1966, 07, 24	36.0 E	3.0 S	3.4	0	298
12	1966, 09, 24	36.2 E	0.7 N	0.0	0	183
13	1966, 09, 24	35.0 E	0.0	4.2	0	53
14	1966, 09, 26	36.5 E	0.5 N	4.6	0	195
15	1966, 10, 10	32.4 E	0.2 N	3.8	0	303
16	1966, 10, 30	33.0 E	1.6 S	3.8	0	258
17	1967, 04, 09	32.5 E	3.0 S	3.7	0	396
18	1967, 04, 16	36.0 E	3.0 S	3.8	0	298
19	1967, 07, 04	37.0 E	3.0 S	4.3	0	353
20	1967, 07, 08	36.0 E	3.0 S	4.2	0	298
21	1967, 12, 29	32.2 E	0.2 S	4.2	0	317
22	1967, 12, 29	34.0 E	1.3 N	4.2	0	228
23	1967, 12, 29	31.4 E	3.0 N	4.4	0	558
24	1967, 12, 29	34.0 E	1.3 N	4.1	0	228
25	1967, 12, 29	31.2 E	2.8 N	4.4	0	560
26	1967, 12, 29	34.0 E	1.3 N	4.1	0	228
27	1967, 12, 29	34.0 E	1.3 N	4.1	0	228
28	1967, 12, 29	34.0 E	1.3 N	4.0	0	228
29	1968, 03, 14	33.8 E	1.0 S	3.9	0	149
30	1968, 03, 14	33.8 E	1.0 S	4.1	0	49
31	1968, 03, 16	34.4 E	0.61S	0.0	0	73
32	1968, 03, 16	34.1 E	0.3 S	4.7	0	106
33	1968, 03, 18	34.0 E	0.5 S	3.9	0	116
34	1968, 03, 20	34.42E	0.61S	0.0	13	70
35	1968, 03, 20	34.4 E	0.6 S	0.0	33	72
36	1968, 03, 20	34.3 E	0.5 S	4.6	0	82
37	1968, 03, 21	34.38E	0.58S	0.0	41	74
38	1968, 03, 21	34.2 E	0.5 S	4.5	0	93
39	1968, 03, 21	34.3 E	0.6 S	0.0	34	83
40	1968, 03, 21	34.2 E	0.5 S	4.0	0	93

(Source: International Seismological Centre

Table 3.1 Earthquakes Likely Affecting to the Project (2/3)

NO.	DATE YEAR/MONTH/DAY	LONGITUDE	LATITUDE	MAGNITUDE	DEPTH (km)	DISTANCE (km)
41	1968, 03, 21	34.3 E	0.5 S	4.0	0	82
42	1968, 03, 21	34.37 E	0.6 S	0.0	0	76
43	1968, 03, 21	34.2 E	0.3 S	4.7	0	93
44	1968, 03, 21	34.44 E	0.3 S	0.0	0	70
45	1968, 03, 21	34.1 E	0.6 S	4.1	0	105
46	1968, 04, 01	34.41	0.66S	0.0	0	73
47	1968, 04, 01	33.9 E	0.4 S	4.9	0	127
48	1968, 05, 10	34.4 E	0.69S	0.0	18	75
49	1968, 05, 10	34.3 E	0.4 S	4.9	0	83
50	1968, 06, 13	33.95 E	2.21N	0.0	66	321
51	1968, 06, 13	34.0 E	2.0 N	4.3	0	297
52	1968, 07, 06	33.35 E	1.26S	0.0	30	207
53	1968, 07, 06	33.3 E	1.3 S	3.2	33	214
54	1969, 07, 15	33.6 E	3.0 S	4.0	0	321
55	1969, 08, 26	30.2 E	0.4 N	0.0	0	547
56	1969, 08, 26	33.8 E	0.2 S	4.1	0	141
57	1969, 12, 14	34.02 E	1.25S	0.0	0	142
58	1969, 12, 14	34.8 E	0.7 S	4.5	0	36
59.	1969, 12, 26	36.0 E	3.28S	0.0	33	327
60	1969, 12, 26	36.3 E	2.5 S	4.5	0	263
61	1969, 12, 26	35.8 E	3.2 S	4.0	33	312
62	1972, 09, 10	35.117E	0.299S	4.6	0	22
63	1972, 10, 30	36.554E	2.586S	4.46	0	287
64	1973, 07, 07	35.568E	3.046S	4.5	33	289
65	1974, 12, 06	33.0 E	3.0 S	4.5	0	359
66	1975, 08, 02	37.508E	2.805S	5.1	0	376
67	1975, 11, 29	36.152E	2.398S	4.1	0	245
68	1975, 11, 29	37.013E	2.743S	4.7	0	333
69	1976, 01, 16	37.20 E	3.10 S	4.2	0	376
70	1976, 01, 19	37.466E	2.940S	4.9	26	383
71	1976, 01, 21	37.346E	2.813S	4.5	0	363
72	1976, 02, 05	36.973E	2.784S	4.8	41	333
73	1976, 02, 09	37.386E	2.851S	4.5	0	370
74	1976, 11, 29	36.934E	2.664S	4.2	0	320
75	1977, 03, 19	37.0 E	3.0 S	4.1	0	353
76	1977, 03, 25	37.069E	2.804S	4.3	0	342
77	1978, 04, 05	37.152E	1.717S	4.8	25	272
78	1979, 03, 20	36.0 E	3.0 S	4.4	0	298
79	1983, 11, 02	35.810E	3.001S	4.2	0	291
80	1983, 11, 02	35.819E	2.998S	4.0	0	291

(Source: International Seismological Centre)

Table 3.1 Earthquakes Likely Affecting to the Project (3/3)

NO.	DATE YEAR/MONTH/DAY	LONGITUDE	LATITUDE	MAGNITUDE	DEPTH (km)	DISTANCE (km)
81	1984, 07, 01	36.408E	1.056N	0.0	0	228
82	1984, 07, 01	34.0 E	1.0N	4.0	0	200
83	1984, 10, 09	35.874E	4.187S	0.0	0	420
84	1984, 10, 09	34.8 E	2.6S	3.7	0	236
85	1985, 11, 13	33.70 E	0.50N	0.0	0	184
86	1985, 11, 13	31.20 E	0.50N	4.2	0	440
87	1986, 06, 28	34.026E	0.959S	4.2	10	125

(Source : International Seismological Centre)

Table 3.2 Explanation of the Intensity of Earthquake Shock by Mercalli Scale and Japan Meteorological Agency Scale

MODIFIED MERCALLI INTENSITY (DAMAGE) SCALE OF 1931 (ABRIDGED)

1	Not felt except by a very few under especially favourable circumstances.
2	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
3	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognise it as an earthquake. Standing motorcars may rock slightly. Vibration like passing truck. Duration estimated.
4	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, and doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably.
5	Felt by nearly everyone; many awakened. Some dishes, windows, etc. broken. A few instances of cracked plaster. Unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.
6	Felt by all; many frightened and run outdoors. Some heavy furniture moved. A few instances of fallen plaster or damaged chimneys. Damage slight.
7	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly-built or badly-designed structures. Some chimneys broken. Noticed by persons driving motorcars.
8	Damage slight in specially-designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly-built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed.
9	Damage considerable in specially-designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
10	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
11	Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
12	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

JAPAN METEOROLOGICAL AGENCY INTENSITY SCALE

O	*No sensation:* registered by seismographs but no perception by the human body.
I	*Slight:* felt by persons at rest or persons especially sensitive to earthquakes.
II	*Weak:* felt by most persons. Slight rattling of doors and Japanese latticed paper sliding doors (shōji).
III	*Rather strong:* shaking of houses and buildings. Heavy rattling of doors and shōji, swinging of chandeliers and other hanging objects. Movement of liquids in vessels.
IV	*Strong:* strong shaking of houses and buildings. Overturning of unstable objects. Spilling of liquids out of vessels four-fifths full.
V	*Very strong:* cracking of plaster walls. Overturning of tombstones and stone lanterns. Damage to masonry chimneys and mud-plastered warehouses.
VI	*Disastrous:* demolition of up to 30 per cent of Japanese wooden houses. Numerous landslides and embankment failures; fissures on flat ground.
VII	*Ruinous:* demolition of more than 30 per cent of Japanese wooden houses.

Table 3.3 Estimation of Ground Acceleration at Magwagwa Damsite

		1928.1.6 Magnitude 7.0 Distance 195 km	1972. 9.10 Magnitude 4.6 Distance 22 km
I.S.C 1/	5.3 (MMS)	40 gal	7.2 (MMS) 150 gal
Estiva's formula		24 gal	52 gal
Kawasumi's formula	II - III (2.8) (JMA)	11 gal	II-III(2.2) (JMA) 6 gal
Seismic Zoning Map of Kenya 2/		VI (MMS) Middle third of (JMA)	21.0 - 44.0 gal IV(JMA)25.0 - 80.0 gal 50 gal
World Map of Natural Hazards 3/	VI and VII (MMS) Latter thir of IV (JMA)		VI (MMS)21.0 - 44.0 gal VII (MMS) 44.0 - 94.0 gal IV (JMA) 25.0 - 80.0 gal 50 - 60 gal

1/ International Seismological Centre

2/ Seismic Zoning Map of Kenya
Showing Maximum Observed Intensities (1982-1969)
I.S. LOUPEKINE, JULY 1971

3/ World Map of Natural Hazards
Maximum Intensity (Mercali Scale) once in 50 years, for average ground conditions.

Table 3.4 Earthquake Intensity and its Frequency

A) By I.S.C

Intensity (By MMS)	Frequency in 86 years	Frequency in 100 years	Cumulative number for 100 years (Nc)
<0.1	46	53.49	101.16
0.2 - 0.4	4	4.65	47.67
0.5 - 1.4	13	15.12	43.02
1.5 - 2.4	6	6.97	27.90
2.5 - 3.4	7	8.14	20.93
3.5 - 4.4	6	6.97	12.79
4.5 - 5.4	2	2.33	5.82
5.5 - 6.4	2	2.33	3.49
6.5 - 7.4	1	1.16	1.16
Total	87	101.16	

B) By Kawasumi

(By JMA)	86 years	100 years	(Nc)
0 - 1	4	4.65	9.31
1 - 2	2	2.33	4.66
2 - 3	2	2.33	2.33
Total	8	9.31	