Plotting Position			
Order	Annual Mean Flow (m3/s)	Weibull Plot (%)	Year
1	4.47	97.05	1984
2	4.79	94.11	1987
3	4.90	91.17	1959
4	5.03	88.23	1965
5	5.36	85.29	1986
6	6.35	82.35	1969
7	6.60	79.41	1976
8	7.25	76.47	1980
9	8.87	73.52	1960
10	9.11	70.58	1958
11	9.22	67.64	1973
12	9.24	64.70	1974
13	9.80	61.76	1972
14	10.16	58.82	1983
15	10.17	55.88	1982
16	10.19	52.94	1966
17	10.95	50.00	1957
18	11.03	47.05	1988
19	11.08	44.11	1981
20	11.90	41.17	1971
21	12.68	38.23	1975
22	12.99	35.29	1985
23	13.01	32.35	1970
24	13.80	29.41	1979
25	13.97	26.47	1967
26	15.40	23.52	1961
27	15.90	20.58	1978
28	16.20	17.64	1977
29	16.53	14.70	1956
30	17.19	11.76	1968
31	20.51	8.82	1964
32	25.51	5.88	1963
33	31.05	2.94	1962

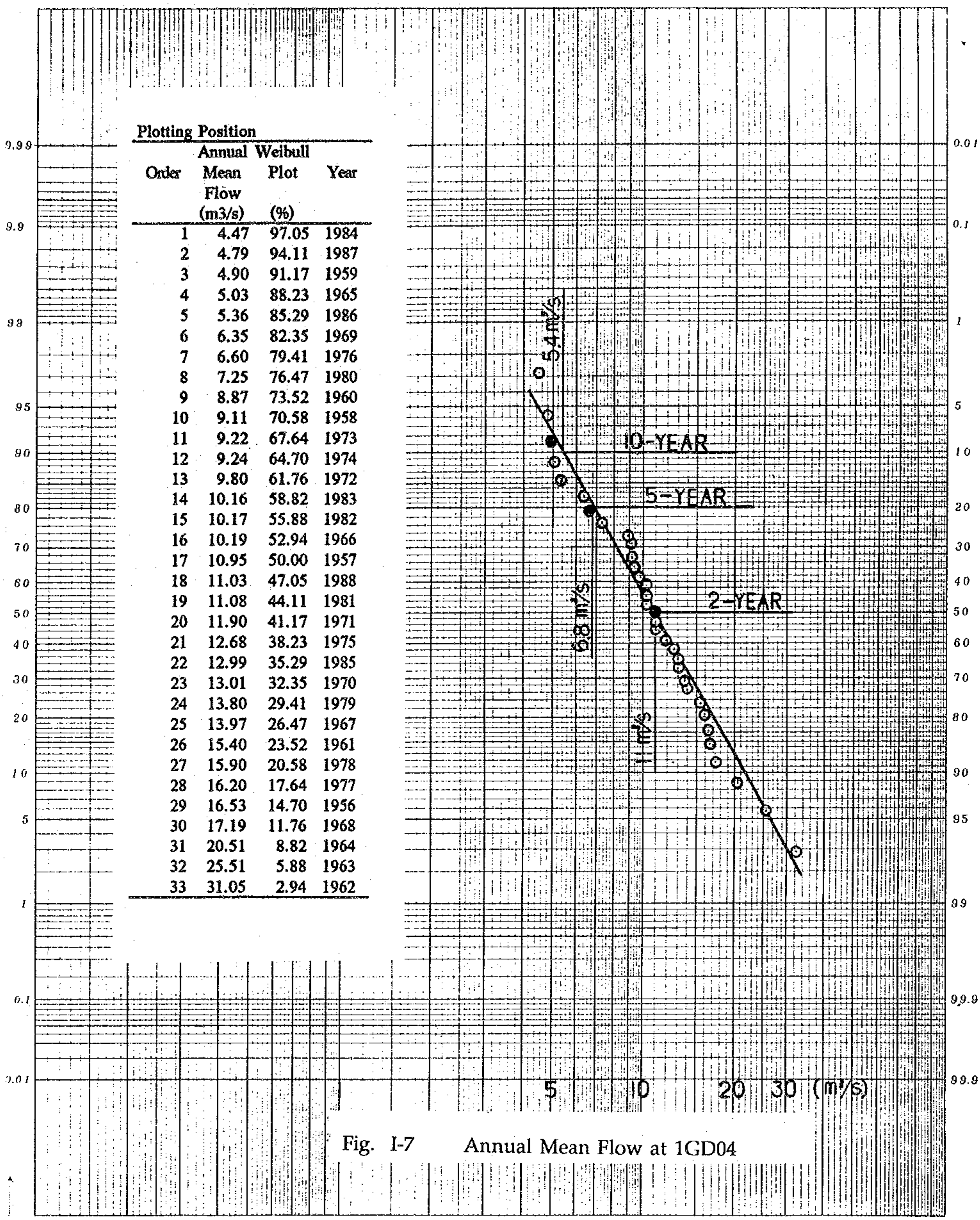


Fig. I-7 Annual Mean Flow at 1GD04

$\log x \longrightarrow$

$$100F \equiv 100 \times \int_{-\infty}^{\log x} u\,dx \quad , \quad 100F \equiv 100 \times \int_{\log}^{+\infty} u\,dx \quad u \equiv \frac{1}{\sqrt{2\pi}} e^{(\log x)^2/2} \quad , \quad x > 0$$

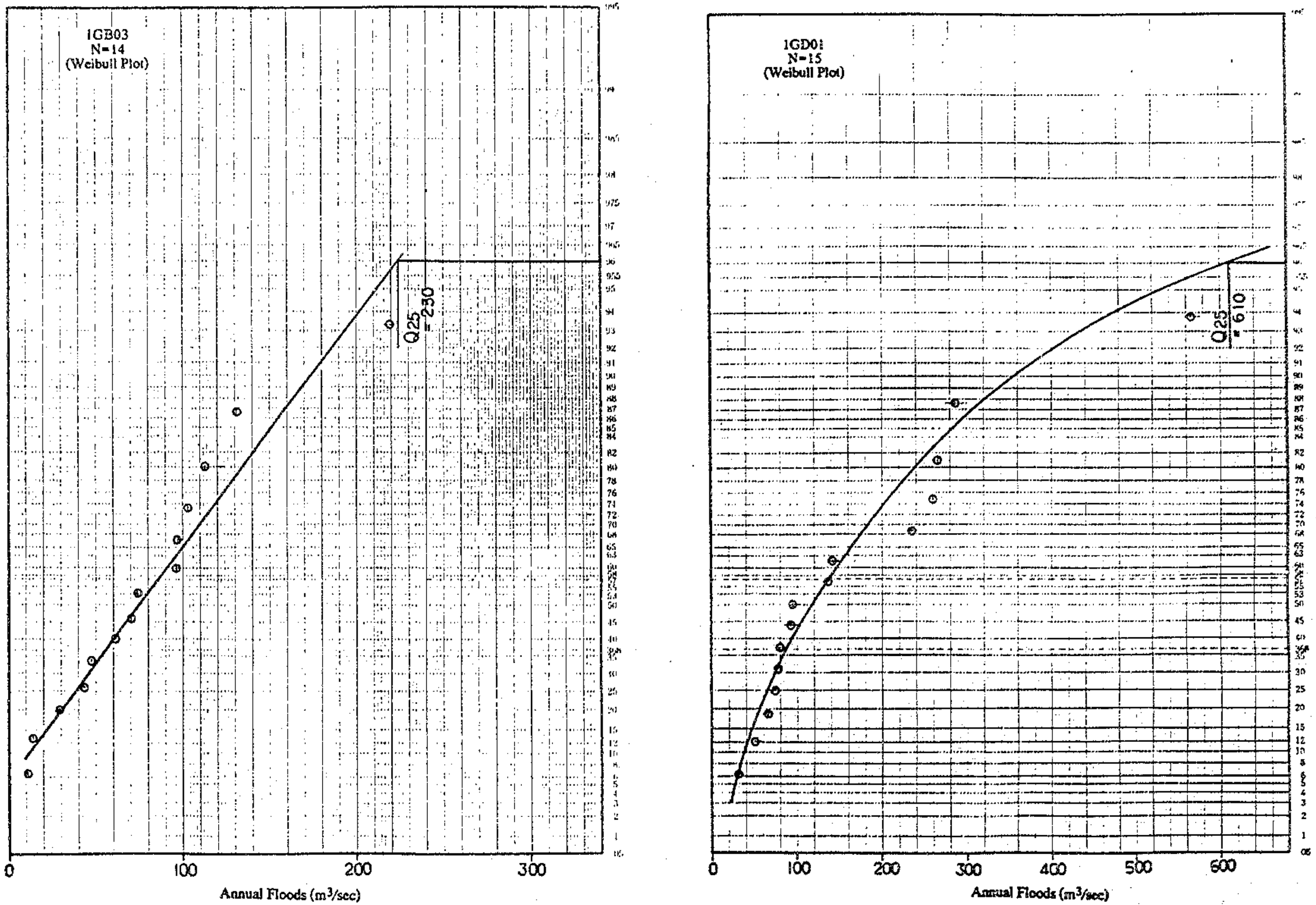


Fig. I-8 Annual Floods-Extreme Probabilities (1 of 4)

REPUYBLIC OF KENYA
KANO PLAIN IRRIGATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

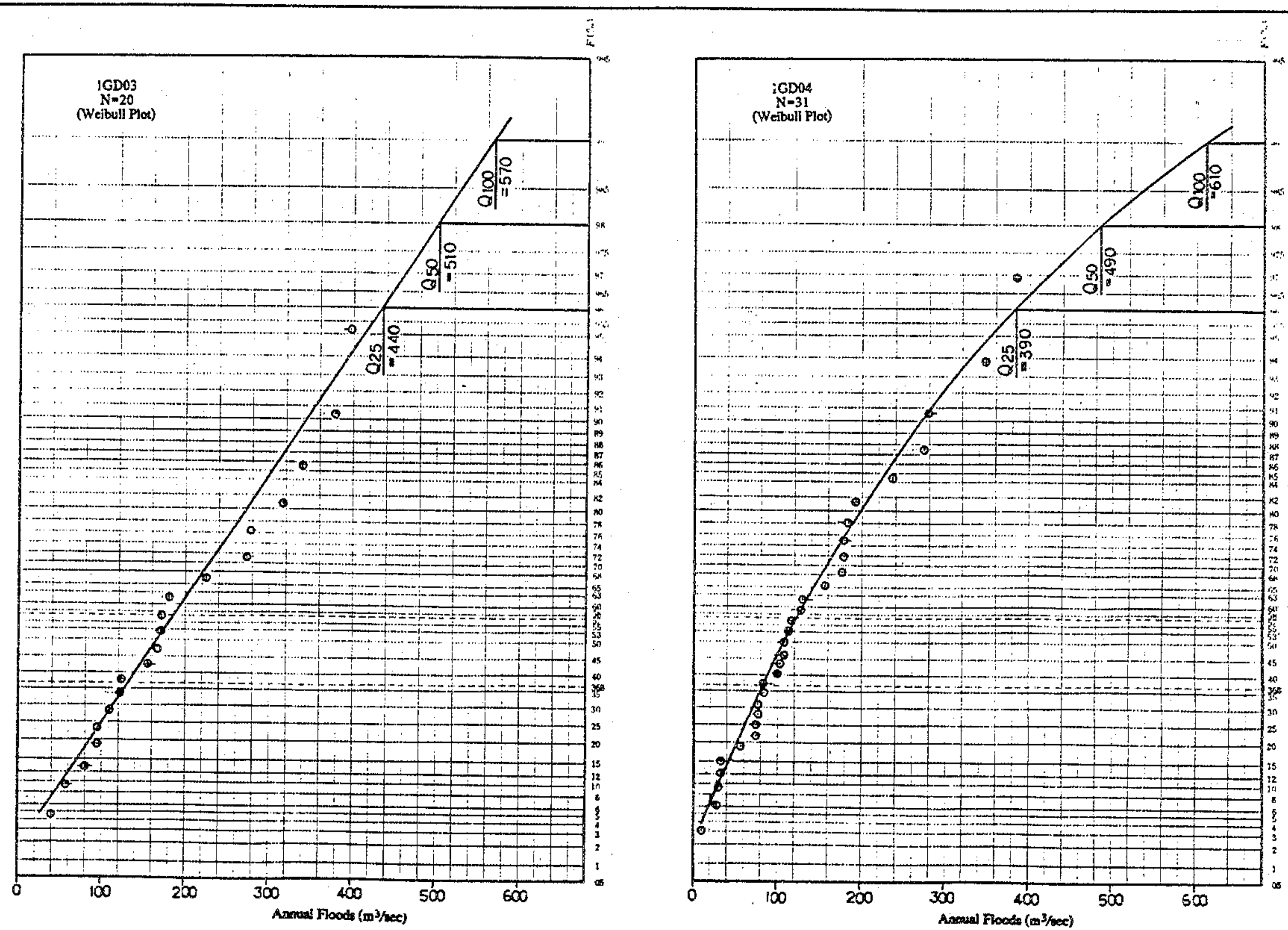


Fig. I-8 Annual Floods-Extreme Probabilities (2 of 4)

REPUYBLIC OF KENYA
KANO PLAIN IRRIGATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

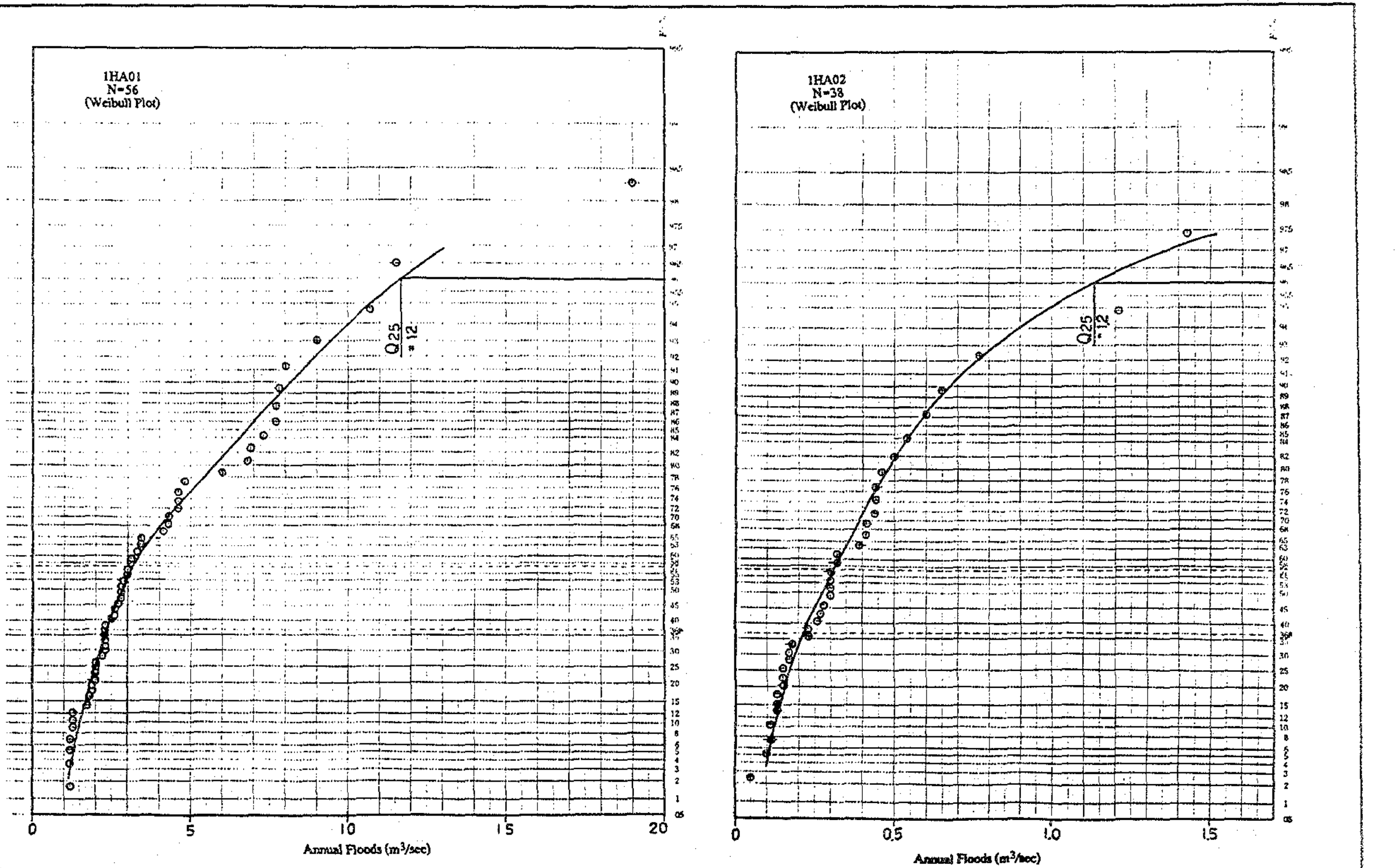


Fig. I-8 Annual Floods-Extreme Probabilities (3 of 4)

REPUYBLIC OF KENYA
KANO PLAIN IRRIGATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

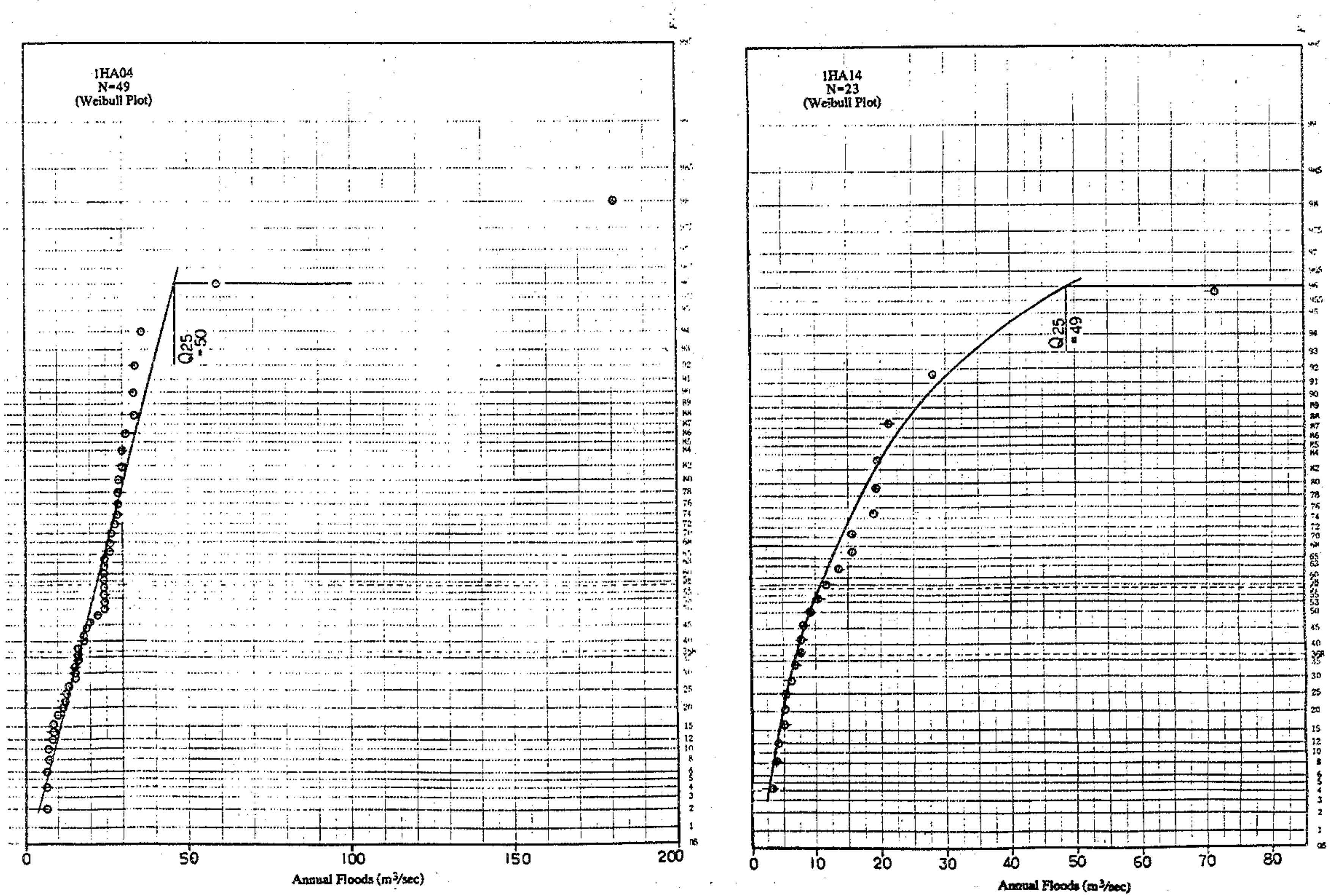


Fig. I-8 Annual Floods-Extreme Probabilities (4 of 4)

REPUYBLIC OF KENYA
KANO PLAIN IRRIGATION PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY

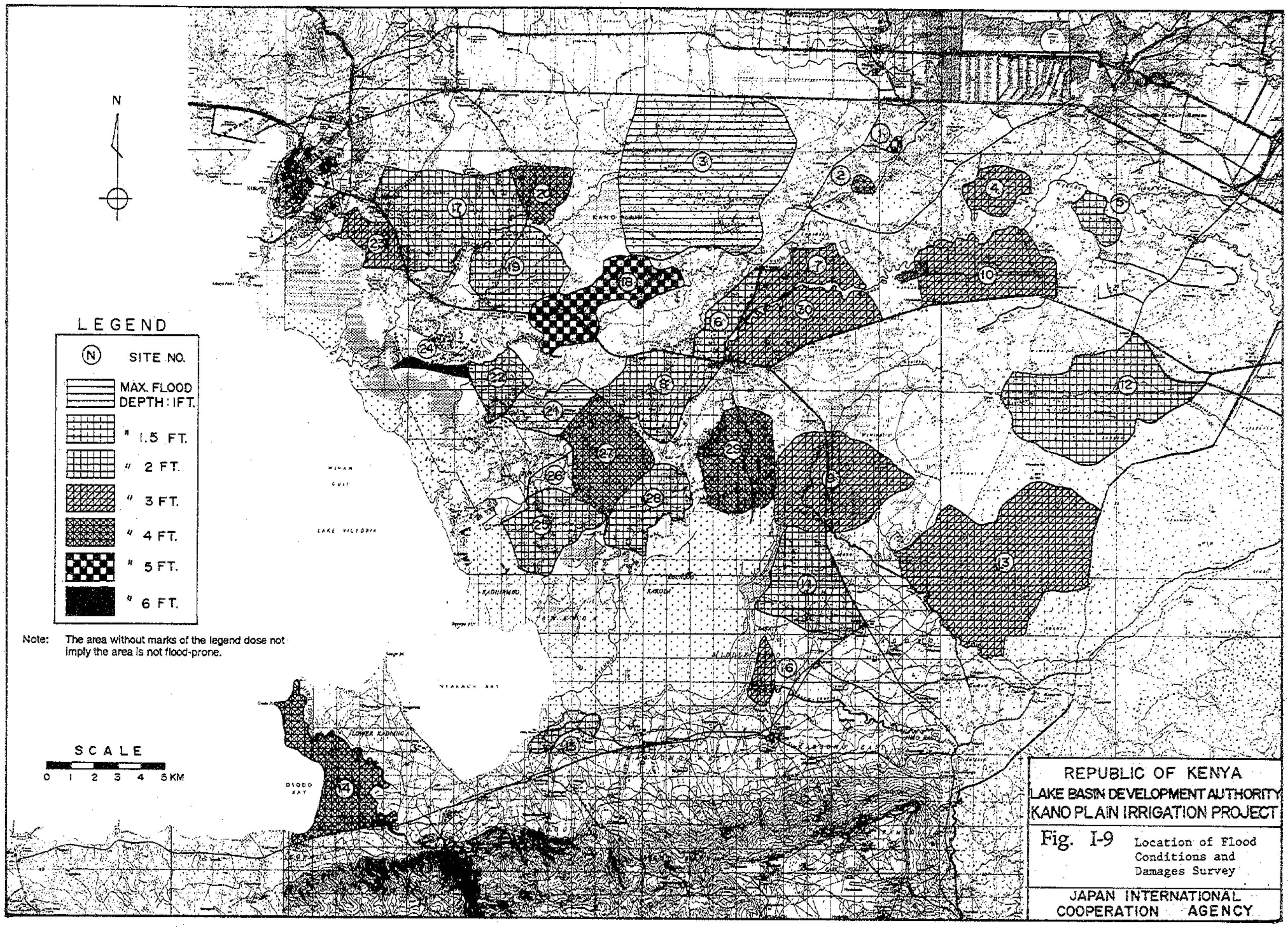
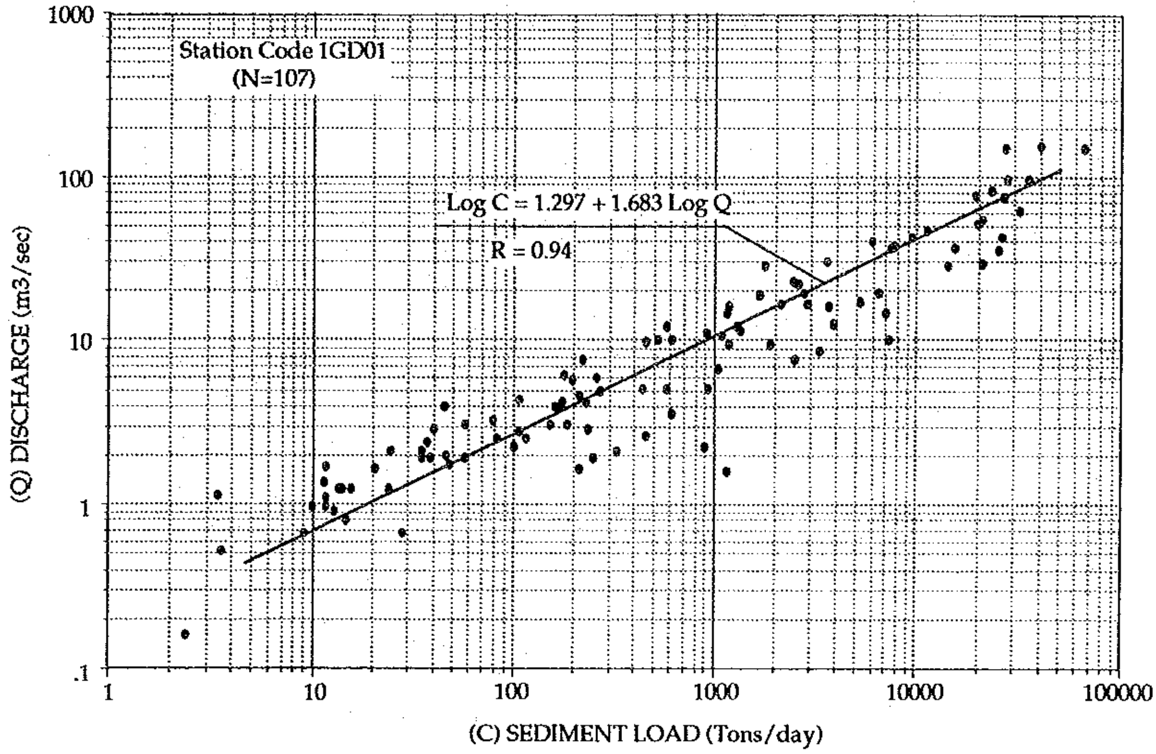


Fig. I-9 Location of Flood Conditions and Damages Survey



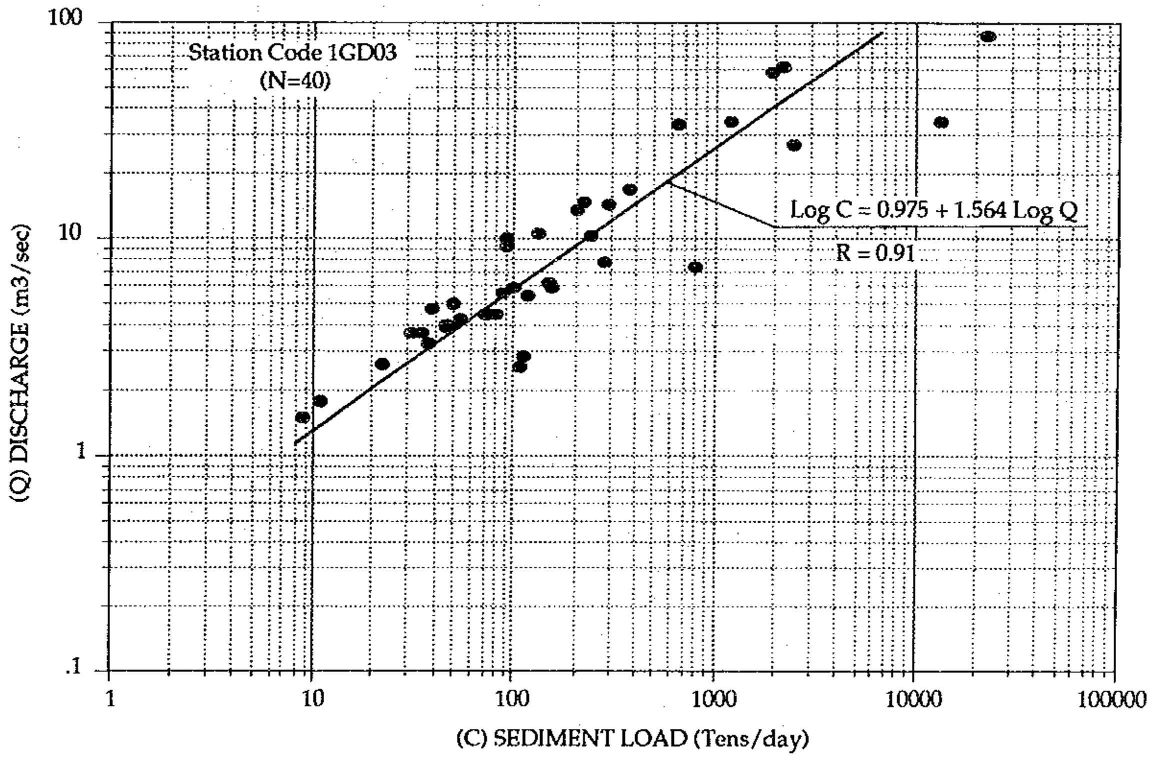
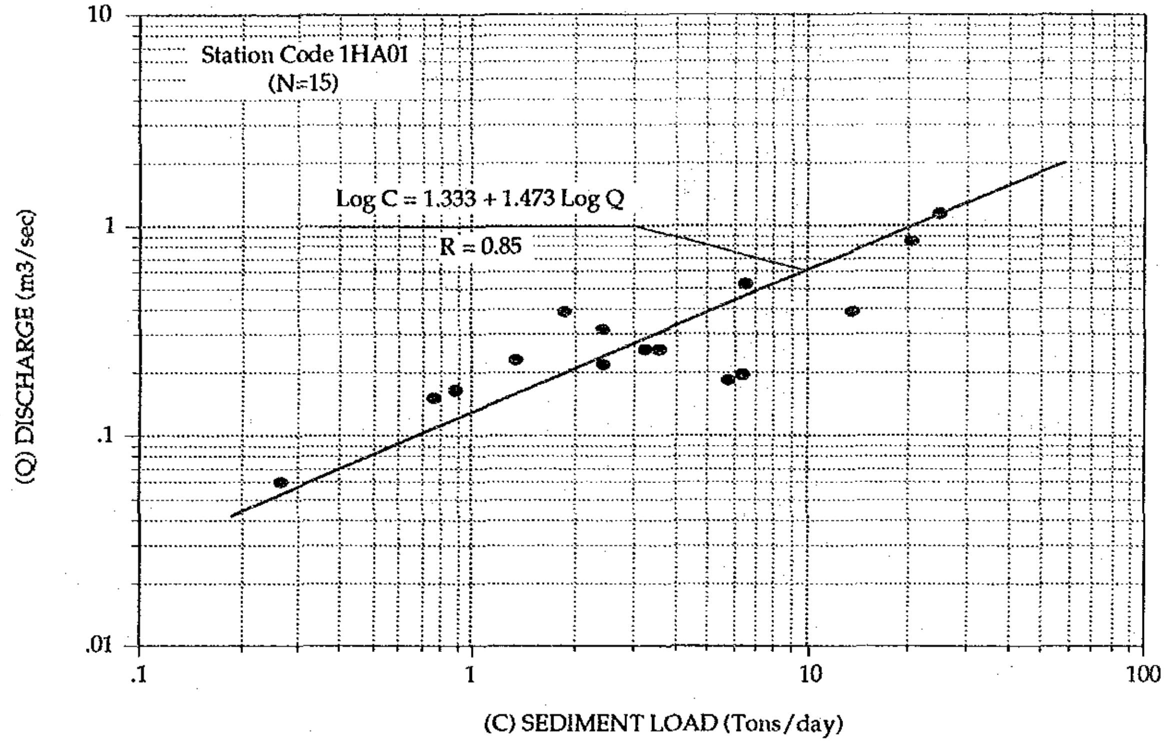


Fig. I-10 Sediment Rating Curve (1 of 3)



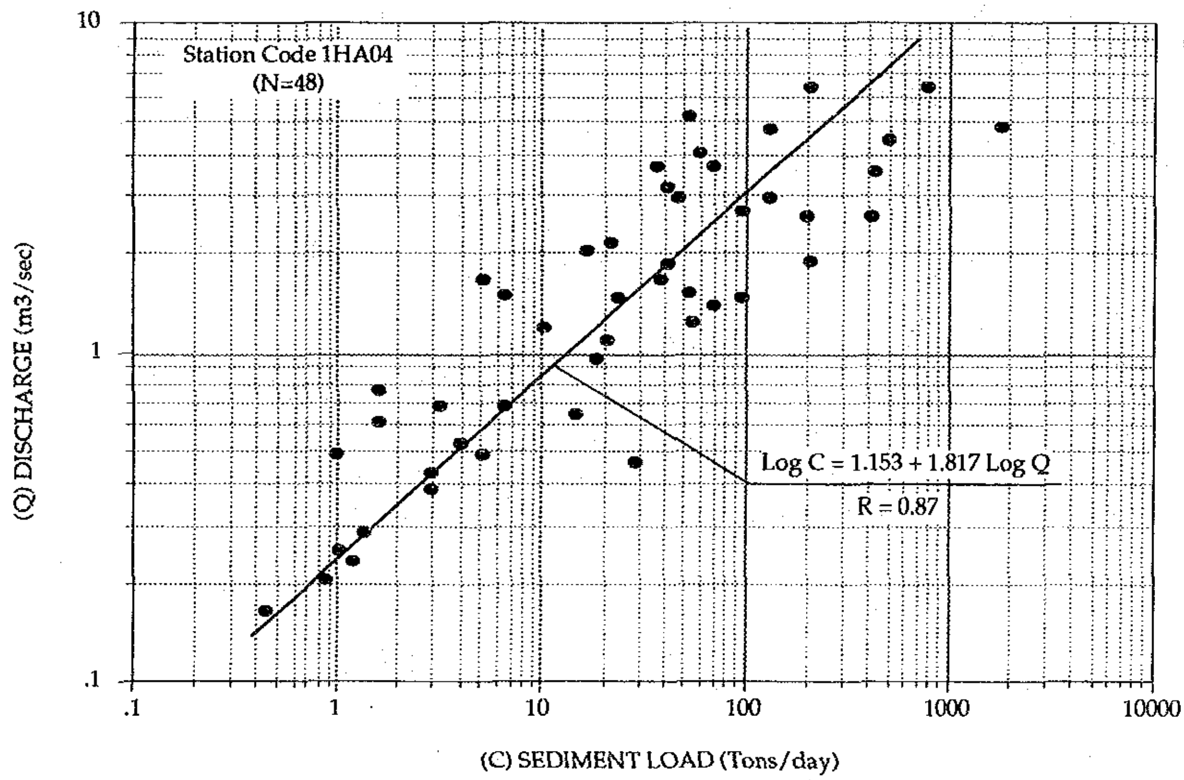


Fig. I-10 Sediment Rating Curve (2 of 3)

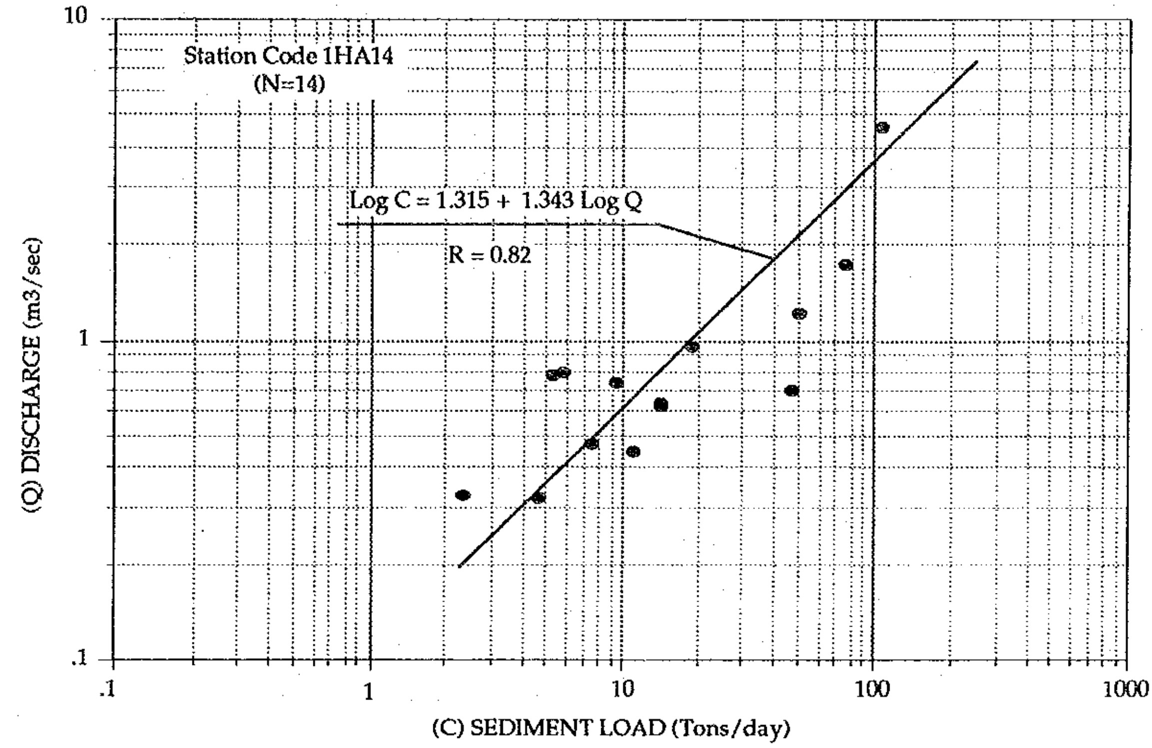


Fig. I-10 Sediment Rating Curve (3 of 3)

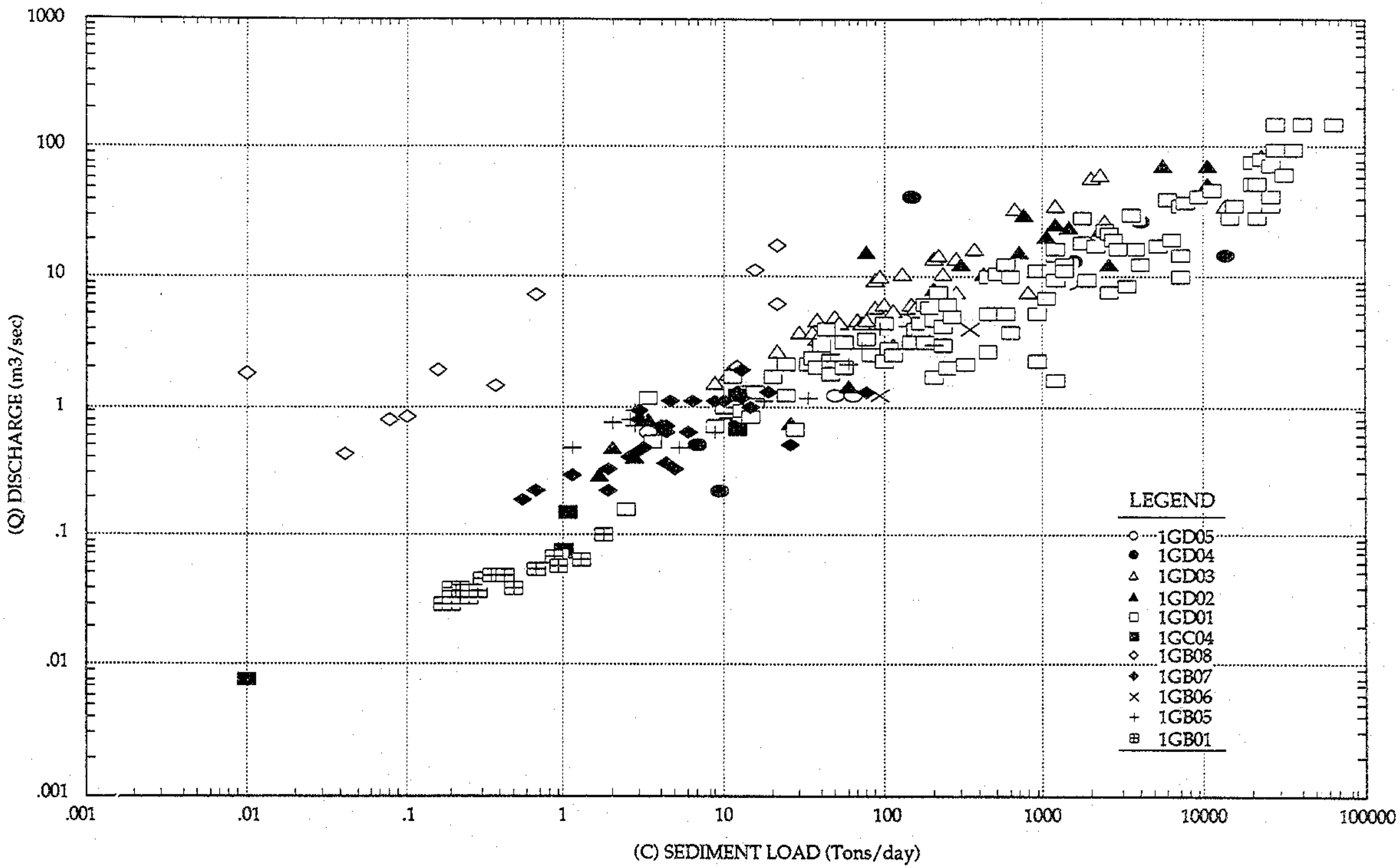


Fig. I-11 Sediment Rating for Subbasin 1G

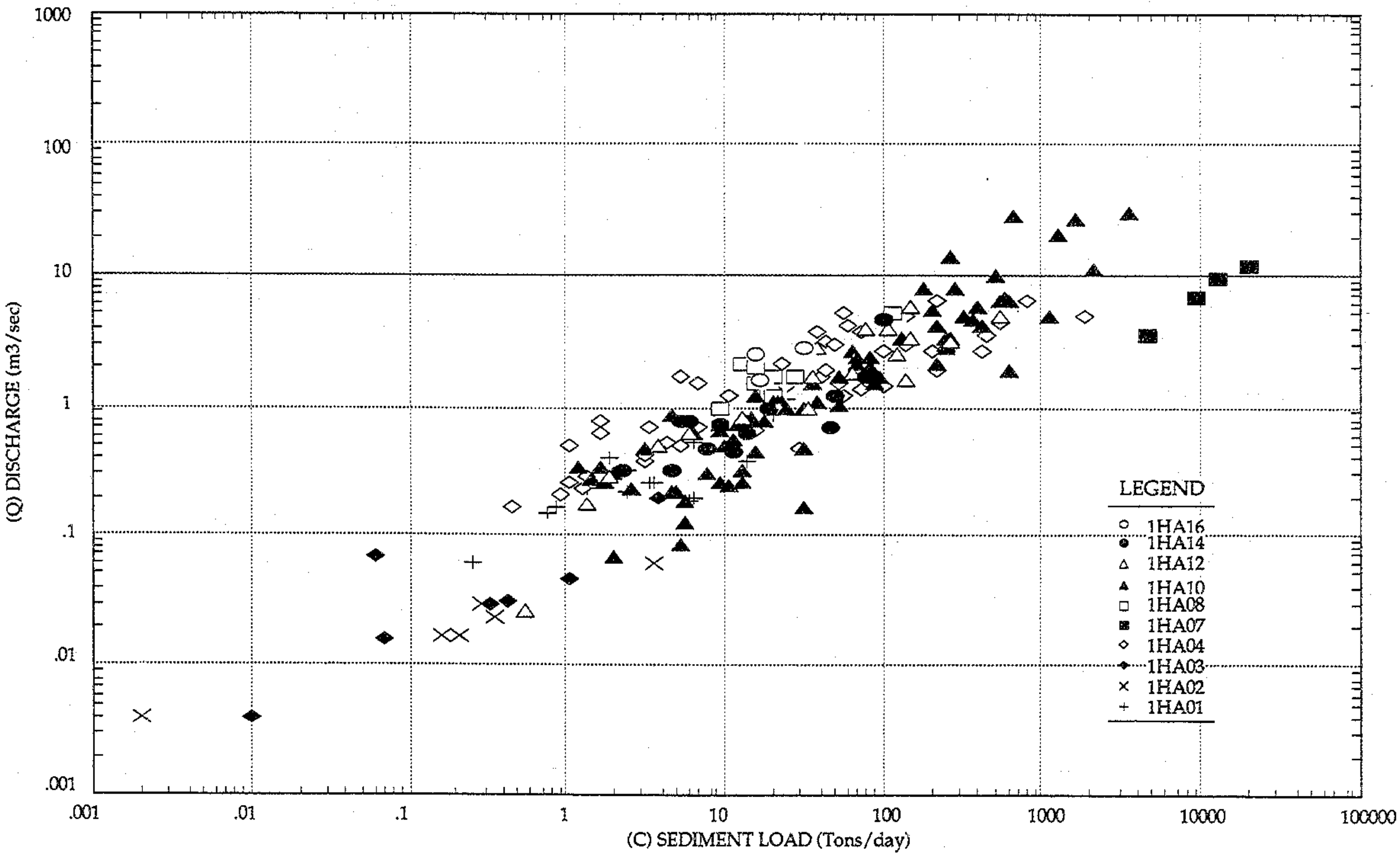
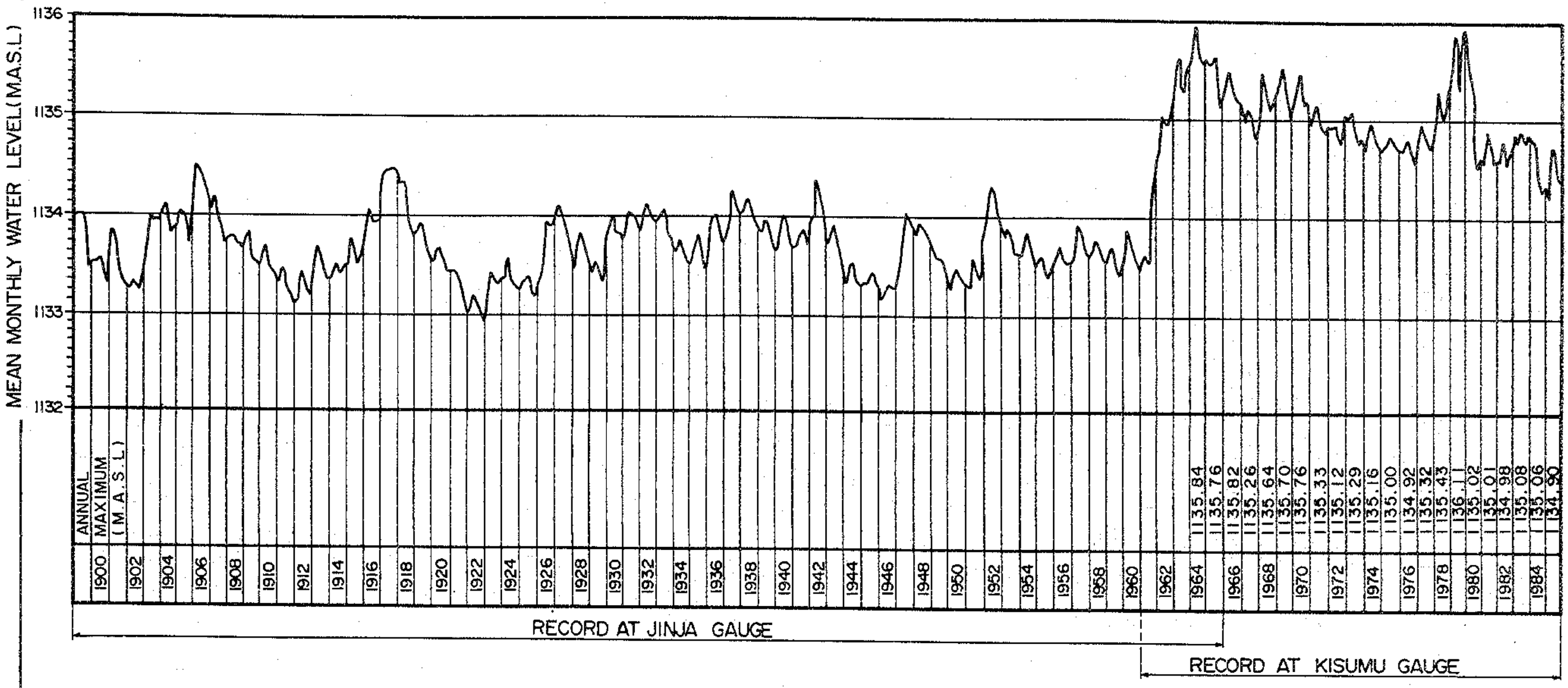


Fig. I-12 Sediment Rating for Subbasin 1H



NB: ZERO OF THE KISUMU GAUGE = 1122·34 (M.A.S.L)

SOURCE (1899-SEP 1964): LAKE BASIN RIVER CATCHMENT DEVELOPMENT RIVER PROFILE STUDIES, VOLUME III, ANNEX A, OCTOBER 1985.

Fig. I-13 Levels of Lake Victoria

REPUYBLIC OF KENYA
KANO PLAIN IRRIGATION PROJECT
JAPAN INTERNATIONAL COOPERATION AGENCY

Annex II

Geology, Soil Mechanics and Engineering Geology

Feasibility Study
on
Kano Plain Irrigation Project

Annex II
Geology, Soil Mechanics and Engineering Geology

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1. INTRODUCTION

The study about geology, soil mechanics, and engineering geology were carried out in the whole project area, along the prospective canal route, and at Nyando intake weir site, from September to October in 1990 and from June to July in 1991.

The first work were commenced by means of the field reconnaissance to grasp the outline of geology in the project area. Based on those outline, the programmes for field investigation and laboratory soil test which would be rendered to the local contractor (H.P. GAUFF KG, Nairobi) were worked out including tender documents.

In the middle of September 1990, JICA team made an agreement with the contractor, and the actual investigation in situ (Augering, Test pitting, Bore hole Drilling, Sounding Test Sampling) were commenced at the end of September under the direction of the Engineer Geologist of JICA study team.

Geological distribution and soil properties were studied in detail through the first and second work. Those result and consideration are set forth from the 2nd chapter and in the end of this volume as Tables and Figures.

The Geology of Kisumu District (on a scale 1:100,000) published by the LBDA in 1988 as part of the report on "Rural Domestic Water Supply and Sanitation Programme (Ref. 1) were first referred to in this survey.

2. GEOLOGY

2.1 General

(1) Physiography

Kisumu District is located between the scarps to the South and the North called the Kendu-Nyabondo Escarpment and Nyando Escarpment respectively. In the east of District, the upland area of elevation between 1,200m and 1,400 m spread out and the Winam Gulf of Lake Victoria is faced to in the west.

Scarps are formed by the main rift fault having the direction E - W to ENE - WSW, which shape the Kavirondo Rift branching from the main north-south oriented Kenya Rift Valley system.

Footslopes are typically found along the Escarpments in the south and the north. Gently sloped piedmont plain and very flat alluvial plain known as the Kano Plain with elevation between 1,135 and 1,300m are widely spread out in the central area of the Kisumu District and the Muhoroni Division.

The Nyando river runs through upland from south-east to north-west in the east of the Kisumu District and turns the direction to south-west in the central alluvial plain after joining the Kundos River. It meanders with its way through plain and pours itself into the central swamp just adjoining to the Winam Gulf.

The other many small rivers also have such a tendency to flow from south-east to north-west as the Asawo, the Awach Kano and the Nyaidho in the east upland area and from north-east to south-west as the Kundos, the Oroba/ Miriu, the Ombey, the Luando and the Kibos/Nyamasaria in the central alluvial plain likewise the Nyando River.

(2) Geology

(a) Regional geology and stratigraphy

The geology in the study area is presented in Fig. II-1 and the stratigraphy in Kisumu District is shown in the table given on the next page which is quoted from the report on "Rural Domestic Water Supply and Sanitation Programme.(Ref. 1)

Rocks of the Nyanzian System of precambrian age are found only in the western part of Kisumu. They don't outcrop in the project area. Precambrian intrusives composed of mainly granitic rocks extends widely in the Kendu Hills, the Nyabondo Escarpment and the Nandi Hills. Tertiary volcanic rocks involves tuff, agglomerate and phonolite lava.

Tuffaceous and agglomeratic beds of miocene age are seemed to underlie in the Kano plain but sincerely it is found in the surface except just a small outcrop under phonolite lava.

Phonolite lava of pliocene age, which shapes the sub- horizontal plateau or uplands, is found in the Nyabondo Plateau of the Nyakach Division, in the east of Nyando Division and around the Kisumu Municipal.

The sediments of pleistocene age are mainly composed of the deposits being both lacustrine and fluviatile of Lake Victoria. They are seemed to distribute generally in the Kano plain but they are mostly covered by colluvial or alluvial deposits.

The recent system consists of talus scree, colluvium and alluvium. Its composition is clays, silts, sands, gravels and lateritic ironstones. Talus screes are found along the foot of escarpment. Colluvium occurs from wide-spread wash-out accumulation which mainly consists of sands, gravels originated from weathered rocks of granite, and forms wide piedmont plains. Alluvium is formed by a large quantities of silt and sand carried by several rivers flow. Reddish brown lateritic ironstones develop usually on the bed of phonolite lava.

Stratigraphy in Kisumu District

Time Period	Rock System	Geological Unit Lithology	Description of Geological Events
QUARTERNARY	RECENT	Alluvium Superficial deposits Talus acrea	Sedimentation of erosion products
	PLEISTONE	Lake deposits and fluviatile sediments intercalated tuffs.	Sedimentation in Kavirondo Rift Valley
TERTIARY	PLIOCENE	Phonolitic lavas	Development of Kavirondo Rift Valley
	MIOCENE	Tuffs Agglomerates	Development of major faults and fractures with associated tissure eruption
PRECAMBRIAN		Dolerites Granites	Intrusives
	NYANZIAN	Ironstone, Charts Ryolites, Agglomerates Andesites, Tuffs Basaltic lava	

Quotation from the Report on Rural Domestic Water Supply and Sanitation Programme published by the Lake Basin Development Authority in 1988 (Ref. 1)

(b) Structure

The lineament map around the project area is shown on Fig. II-2. Main rift faults as mentioned before are the Kendu - Nyabondo Fault forming the Kendu-Nyabondo Escarpment and the Nandi Fault forming the Nyando Escarpment. The lineament in the Kano plain have mainly four direction, namely northeast to southwest, northwest to southeast, north to south and east to west which influence evidently to river flow direction etc, and prescribe the distribution of the phonolite lava and pleistcene deposits. Faults largely participating to geological distribution are also conceptionally shown in Fig. II-2.

(c) Soils and concerning rocks

The surface soils in the Kano Plain are originated from such rocks as follows on the analogy of those natures.

- Black Cotton Soil .... Tuffaceous beds
- Sandy Red Soil .... Granite
- Lateritic Soil and Lateritic Ironstone .... Phonolite

Black cotton soil is mainly composed of clay minerals which are able to content a large quantity of water in the mineral and swell remarkably. Those minerals are usually generated from pyroclastics in origin by the action of weathering, alternating and so on. Hence the peculiar black colour comes from humus, it is the result of strong combination of clay minerals and humus. The widespread black cotton soil in the Kano plain is weathered and/or transported material of tuffaceous beds, which is found mainly in the surface of Alluvial deposit and Pleistcene deposit area.

Sandy Red Soil is derived from granite, since it mainly consists of Quartz grain and is distributed in footslopes and piedmont plains along the escarpment of granitic rocks. It seems to be the result of wash-out deposit of weathered granite by the water in pluvial season.

Though the sandy red soil mentioned above is mainly found in the foot and the piedmont along the escarpment, the black cotton soil is also found, because tuffaceous rocks under-lie in this area. As a result of that, sandy red soil and black cotton soil are mixed together in many part.

Lateritic soil and lateritic ironstone are produced of iron-rich soils and/or rocks by leaching due to strong rainfall and decomposition by strong drying etc. Phonolite is chemically iron-rich, so that lateritic soils and ironstone seem to be derived from phonolite. Its distribution area coincides with phonolite distribution area.

2.2 Canal Route

The surface geology along the prospective canal route is shown on Fig. II-3, and the geological profile along canal route is presented on the Drawing of this Report.

The geologic outline of canal route is mentioned below;

(i) South Nyanza canal (unfigurized) {Sondu main canal}

The geology of this route is mainly granitic rocks, some are weathered and decomposed, and some are fresh and hard. Colluvium mainly made up of sandy soils distribute with some thickness over the granitic rocks. Those constituents are same as the geology of section (ii).

(ii) From the Miriu (Sondu) river to the Ragen village
*(LEFT 5 + 150 - 0, RIGHT 0-6 + 500)

Tuff and tuffaceous soils are bedded on the river terrace developed along the Miriu (Sondu) river.

Granitic rocks and colluvial sandy soils overlieing basement rocks make up the other sections.

Top soil with thickness 0.5m - 1.0m is composed of buff to brown loose sandy silt.

Colluvium is brown to red-brown dense dry gravelly clayey sand. Some part is very hard and cemented. Its thickness is usually around 1m (maximum 3m) on the LEFT side of power station and 2-4 m on the RIGHT.

Granitic rocks have a variation from residual soils of the uppermost layer through the weathered red-brown to light gray-brown decomposed gradually to the harder and less weathered with depth. Thickness of highly weathered zone is various depending on locations, usually ranging from 0 to 1.5m on the LEFT and 2.5 to 5m on the RIGHT.

(iii) From the Ragen village to the Asawo river *(6+500 - 16+200)

Colluvium and/or Black Cotton Soils with thickness 1 to 3m spread out on the Lake Deposits consisting of dark gray to yellowish gray-brown dense uniform sandy clay occasionally including numerous calcrete nodules concentrated or scattered throughout up to 20 mm max.

Colluvium distribute limitedly and thinly (generally less than lm) on the Black Cotton Soils

Black Cotton Soils are able to be largely divided into two types, upper portion is uniform hard dry black clay and lower portion is dark gray-brown clay with scattered calcrete nodules.

(iv) From the Asawo river to the Kiboko village *(16+200-19 + 900)

Black Cotton Soils and colluvium overlie the Lake deposits which is yellow-brown-gray dense hard dry consolidated tuffaceous gravelly sandy silt with scattered calcrete nodules.

Black Cotton Soils are found only between 16 + 200 and 17 + 300 with thickness around 2m.

Colluvium are dark brown mottled dense hard dry clayey sand, spreading out from 17 + 000 with thickness around 1m.

(v) From the Kiboko village to the Awachi Kano river *(19 + 900 - 22 + 000)

This section is composed of colluvium and relatively thick flood deposits comprising loose gray-brown sandy silt. Those thickness is ranging from 3 to 7 m.

Some light brown coarse gravelly semi-indurated layer and phonolite lava may underlie the above.

(vi) From the Awachi Kano river to the Nyaiberg stream *(22 + 000 - 27 + 500)

This section is composed of phonolite lava whose outer surface layer is gravelly scree and lateritic Ironstone (between 25 + 300 and 27 + 500).

Thin sandy to gravelly soils transported by flood cover the ground between 24 + 500 and 26 + 800.

Talus scree consisting of cobble and boulder make up the foot of the Waradho hill. They become occasionally cemented grit along the stream.

(vii) Around the Waradho hill *(27 + 500 - 33 + 000)

Hill slope is made up of phonolite. Tertiary Agglomerate may underlie the phonolite lava between 27 + 500 and 29 + 700.

From 29 + 700 to 33 + 000, Black cotton soils overlie the Hill wash deposits composed of rounded phonolite cobbles well graded down through pebbles to small angular fragments with matrix of black cotton soils.

Thickness of black cotton soil layers is around 1m.

(viii) Around the Nyaidho river *(33 + 000 - 34 + 900)

Black cotton soils with thickness around 1m, and very thin sandy soils make up the surface layer on the bed composed of light brown to yellowish brown horizontally bedded tuffaceous silt to sand with calcrete nodule horizons, and gray-brown dense hard uniform gravelly sandy clay.

Phonolite lava seems to underlie.

(ix) From the Nyaidho river to the Kanyipoia village *(34 + 900 - 37 + 000)

This section is hill slope made up of phonolite. Black cotton soils and Hill-wash deposits overlie the phonolite with thickness 1 - 1.5m from 36 + 200.

(x) From the Kanyipoia village to the Milenya stream *(37 + 000 - 43 + 700)

Hill-wash deposits composed of gray to brown-gray rounded phonolite cobbles well graded down to small fragments with matrix of well cemented sand to grit and/or silt to clay underlie uniform Black Cotton Soils with thickness approximately 1m.

(xi) From the Milenye stream to the Nyando river *(43 + 700 - 47 + 500)

Very cohesive uniform Black Cotton Soils with thickness less than lm make up the outermost surface layer and black-brown silt to clay with scattered small calcrete nodules underlies with thickness 4-5m.

Light brown-gray well consolidated silt to clay with some calcrete nodules is also found under the above.

(xii) From the Nyando river to the Nyakoko village (unfigurized) {North Nyand Main Canal}

This section is composed of the following three layers. The outermost layer is made up of Black Cotton soils with thickness around 3m, upper 2m is very cohesive uniform black clay and lower lm is dark brown silty clay.

Under Black Cotton Soils, red-brown well consolidated tuffaceous silt to clay with numerous isolated calcrete nodules is in existence with 5 to 8 m thickness.

Light gray to yellow-gray horizontally bedded soft tuffaceous rocks underlie the above two.

(xiii) From the Nyakoko village to the Kibos river (unfigurized)
{ North Nyand Main Canal}

Mixed soils of Black Cotton Soils and colluvial sandy soils make up the outer surface layer.

Likewise the section (xii), red-brown silt to clay with numerous calcrete nodules and soft tuffaceous rocks seem to underlie the above.

Phonolite lava underlie around the Kibos river.

(xiv) South Nyando Main Canal (unfigurized)

This canal runs along the Nyando river on its right bank.

The constituents geology along this route are same as those of the section (xii), though their thickness will change.

*Remarks: the number in the bracket shows the cumulative distance from B.P (Sondu/Miriu Power Station).

2.3 Intake Weir Site

The following figures are shown as the geology around intake weir site.

- Fig. II-4, Geological Map around Nyando Intake Weir Site
- Fig. II-5, Geological Section at the Nyando Intake Weir Site
- Fig. II-6, Geological profile along Nyando River
- Fig. II-7, Geological section along canal route at crosspoint with Nyando River.

The surface layer of this area is composed of Black Cotton Soils, Flood deposits, and Terrace (Old river) deposits.

Black Cotton Soils make the outermost surface layer widely on both bank terrace.

Flood deposits distribute limitedly on both near side bank of river, and River deposits is concentrated occasionally area to area in the river bed.

Terrace (Old river) deposits fill the vestige of meandered old river flow bed leveling its surface between 1,175 and 1,180 m, constituents of which are thinly laminated clayey sand and gravels in thickness up to 7 or 8m maximum.

Red soil underlies the above surface layer, which is well consolidated silt to clay with numerous scattered calcrete nodules having 7 to 8m in thickness.

Tuff or tuffaceous rocks make up the basement around these area. Those are horizontally bedded tuffaceous siltstone to sandstone (intercalated with tuff layer), tuff-breccia, tuffaceous sand- to silt-stone and dark grey siltstone having 5-7m, 12m +, 8m+, 5m+ respectively in thickness.

Though those layers are classified into pleistocene Lake Deposit from "stratigraphy in Kisumu District"1/, they are seemed to be of Tertiary age from their rock facies.

2.4 Borrow Material Area

Locations of borrow material area are shown in Fig. II-8, and numberized from No.1 to No.5

Subsurfacial investigation were carried out only at borrow material area No.1 (BC-1, BC-2, TPll and TP-12), which is shown in Fig. II-9.

Borrow material area No.1 is composed of granitic rocks, some portion of which is schistosed.

Colluvium sandy soil covers those rocks having lm or less in thickness.

The area around the location investigated at BC-1 has relatively thick weathered zone up to 7 to 8 m maximum , the other area has usually around 2m in thickness.

Borrow material area No.2 consist of colluvial clayey sand with thickness around lm and tuffaceous sandy silt to clay with scattered calcrete nodules which is dry well consolidated uniform. Thickness of the latter is more than 5m.

Borrow material area No.3 includes lateritic ironstone and phonolite covered with thin (less than 0.5m) flood deposits. Lateritic ironstone has a thickness more than 2.5m and be underlain by fresh and hard phonolite.

Borrow material area No.4 is made up of hillwash deposits covered with black cotton soils with thickness less than lm. Hillwash deposits is composed of gray-brown hard rounded phonolite cobble well graded down through pebble to small fragments with matrix well cemented sand to grit, and silt or clay.

Borrow material area No.5 is located near Kisumu municipal area, constituent of which is lateritic Ironstone bearing relatively high percentage of fine grains.

3. INVESTIGATION AND TEST

3.1 Purposes, Items and Quantities

3.1.1 In situ investigations

Geotechnical investigation in situ is conducted to check geological and soil mechanical conditions of canal route, intake weir site and borrow material area. Location of the site are shown in Fig. II-10.

Items and Quantities of investigation in situ are as follows:

Items and Quantities of Investigation in Situ

Items	Investigation site	Quantities	
		Each site	Total
Bore hole drilling	Intake weir site	45.2m in 2 holes 13.15m in 2 holes	58.35m in 4 holes
Augering	Canal route facility sites	64.4m in 22 holes 36.73m in 10 holes	101.13m in 32 holes
Test Pitting	Canal route	28.2m in 10 pitts	32.92m in 12 pitts
Areas	Borrow material	4.72m in 2 pitts	
Portable Penetration Test	Facility sites	443 nos x 10cm in 10 Locs.	443 nos x 10cm in 10 Locs.
Standard Penetration Test	Intake weir site	6 nos in 2 Locs	6 nos in 2 Locs.

3.1.2 Laboratory tests

The purpose of laboratory test is to get hold of the physical and mechanical properties of soils from respective geologies and to consider the stability and suitability as materials when cutting and banking the canal.

Items and Quantities of laboratory tests are as follows:

Items and Quantities of Laboratory Tests

Items	Q'ty (Nos. of samples)
A Physical test	
1. Specific gravity of soils	71
2. Moisture content of soils	71
3. Particle size analysis	67
4. Consistency of soils	76
5. Density of soils	10
B Mechanical test	
7. Moisture-density relations of soils	11
8. Triaxial shear of soils, (UU)	3
9. Triaxial shear of soils, (CU)	6
10. Permeability	10 (40 test pieces)

3.2 Work Planning

Test Pitting (12 spots) -- Depth 3m
- Canal
  - Undisturbed Sampling (4 spots) -- UU Triaxial test
  - Disturbed Sampling (6 spots) -- CU Triaxial test / Permeability test
- Borrow area for embankment -- Disturbed Sampling (2 spots) -- CU Triaxial test / Permeability test

Augering (32 spots)
- Canal (22 spots) -- Depth 5 m -- physical test
- Facility (10 spots) -- Depth 7 m -- physical test

Sounding (10 spots)
- Penetration test (10 spots)

Core drilling
- Nyando intake weir (1 spot) -- Depth 20 m -- with S.P.T
- Nyando canal facility (1 spot) -- Depth 25 m -- with S.P.T
- Borrow area for embankment (2 spots) -- Depth 10 m -- physical test

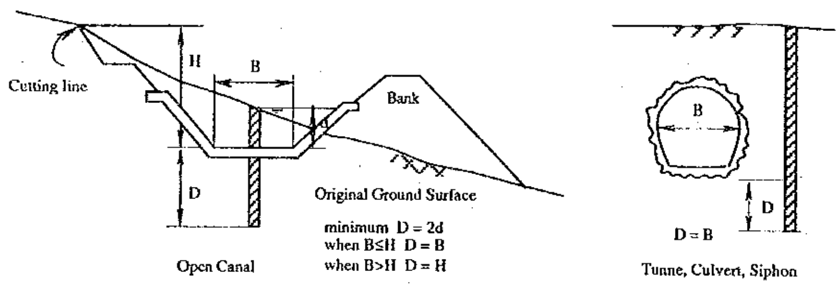
The depths of augering and borehole drilling were planned to be suitable for sufficiently considering the geological conditions.

Test pitting has main purpose for enough sampling necessary for laboratory test as well as geological logging.

The size of pitts is planned referring the above, and sampling depths were decided from respective geological conditions by the Engineer Geologist of JICA team place by place.

The auger holes and pits were set up on the canal route distributed equally, and the drilling holes were at the intake weir site and the borrow material area where two pitts were also excavated for sampling.

The depth of penetration test at canal facility sites is relying on the following figure, considering the tentative scale of canal facilities.



Those planned depths are all maximum cases when there would be no refusal.

Standard Penetration Test (S.P.T) was planned, fundamentally to execute each 1 or 1.5m at bore holes for intake weir site.

However the maximum nos. of blos would be set up 50 as criteria, test was continued up to penetration length completing 30cm as far as possible in a case penetration going on, and test was omitted in a case it would be aparent that N-value was over than 50 from observation of drilling core.

3.3 Methods

3.3.1 Standard penetration test (S.P.T)

Test was carried out on the basis of the authorized standard, that is, connecting the S.P.T. sampler to drilling rod, blossing the knocking head with rammer in 63.5 kgf weight from 75 cm height, then N value is counted as nos. of blos necessary for 30cm penetration.

The standard of S.P.T sampler is as follows:

Whole length	810 mm
Shoe length	75 mm
Barrel length	560 mm
Head length	175 mm
Inner diameter	35 mm
Outer diameter	51 mm
Shoe angle	19° 47'

3.3.2 Portable penetration test

Sounding test at canal facility sites was carried out by portable penetrometer named Kuenzelstab acquirable from the local contractor (H.P Gauff KG), considering the effective mobilization from site to site.

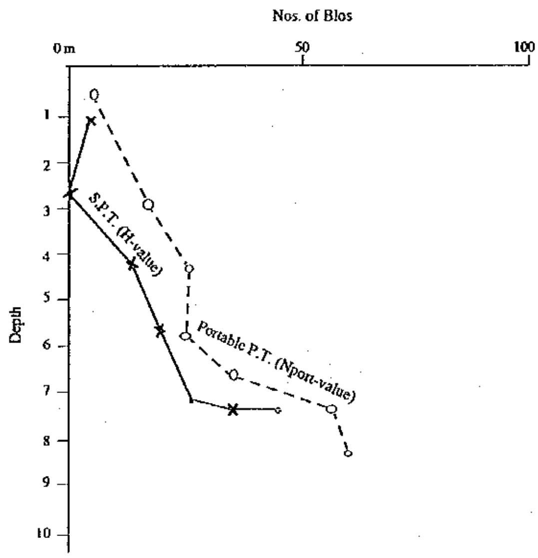
This test is one of dynamic type of sounding, the principles of which is same as S.P.T.

The standard is as follows:

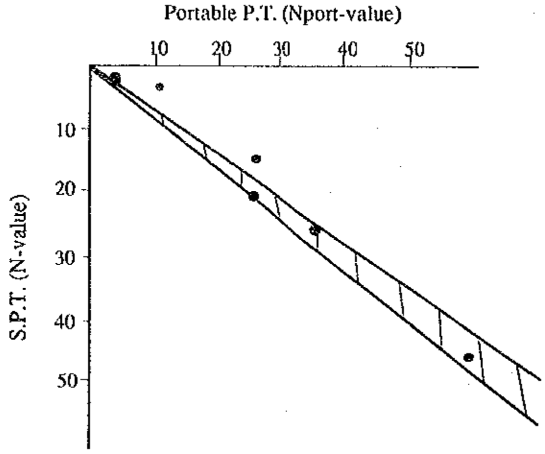
Weight of Rammer	5 kgf
Blos height	50 cm
Mantle corn angle	90°
Corn diameter	28 mm
Penetration length	10 cm

Trial test was carried out at just adjacent point to borehole BII-2 to find the relationship between S.P.T. and Kuenzelstab.

Test results are shown on the following figure:



The figure showing the interrelation between both value is as follows.



The equation interrelating N and Nport is shown approximately as follows from the above figure.

Nport = 1.2 - 1.5 N

Where, Nport : the value tested by Kuenzelstab
N : the value tested by S.P.T

3.3.3 Laboratory test

i) Standards

The tests were performed in accordance with the method specified in the following standard (Ref. 2).

Details are expressed in the respective standard Book (Ref.2).

a) Physical test

1.	Specific gravity of soils	ASTM D 854-48
2.	Moisture content of soils	ASTM D 2216-80
3.	Particle size analysis	ASTM D 422-63
4.	Liquid limit of soils	ASTM D 423-66
5.	Plastic limit plasticity index of soils	ASTM D 424-59
6.	Density of soils	BS 1377 T14

b) Mechanical test

7.	Moisture-density relations of soils, Using 5.5 lb (2.49 kg) rammer and 12" (305 mm) drop	ASTM D 698-78 BS 1337-12
8.	Triaxial shear of soils, unconsolidated undrained (UU)	USBR E 17
9.	Triaxial shear of soils, consolidated undrained (CU)	USBR E 17
10.	Permeability	USBR E-13

ii) Permeability and Triaxial shear test

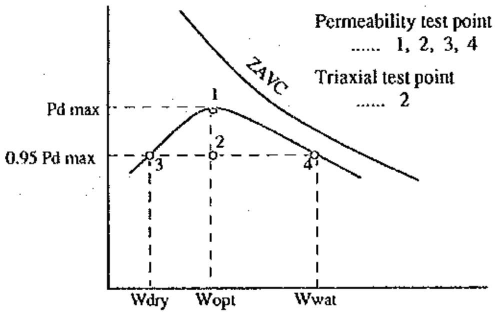
The test points of permeability and triaxial shear with compacted soil samples were carried out as follows:

a) Permeability tests were executed on the following test pieces of each sample.
   1. Test pieces of the maximum dry density pdmax (100 Wopt)
   2. Test pieces of 95% pdmax at dry side on compaction curves (95 Wdry)
   3. Test pieces of 95% pdmax with optimum moisture content (95 Wopt)
   4. Test pieces of 95% pdmax at wet side on compaction curve (95 W wet)

   The tests were conducted by Falling Head Method

b) CU Tri-axial Shear Tests were executed with the test pieces of 95% pdmax with the optimum moisture content

   UU Triaxial Shear tests were carried out with the test pieces of in situ dry density and in situ moisture content.



4. SOIL MECHANICS

4.1 Grouping

Sampled soils are able to be grouped as follows, comparing to geological distribution. Figures in the parentheses are depth of sampling.

Group 1 (Black Cotton Soil, Weathered Lake Deposit)

AC-7	(2.0-2.5)	AC-20	(1.0-2.0)
AC-8	(1.0-2.0)	AC-20	(4.0-5.0)
AC-13	(0.7-1.0)	AC-21	(1.0-2.0)
AC-14	(0.68-0.92)	AC-21	(4.0-5.0)
AC-15	(0.5-1.0)	AC-22	(1.0-2.0)
AC-17	(0.1-0.7)	AC-22	(4.0-5.0)
AC-19	(0.0-0.6)	AF-4	(2.0-2.8)

Group 2 (Lake Deposit...Tuffaceous)

AC-5	(1.0-2.0)	AF-3	(2.0-3.0)
AC-5	(4.0-5.0)	AF-4	(4.0-5.0)
AC-6	(0.6-1.0)	AF-4	(5.0-6.0)
AC-6	(1.5-2.0)	AF-5	(1.2-3.0)
AC-8	(4.0-5.0)	AF-6	(2.0-3.0)
AC-9	(1.0-2.0)	AF-10	(0.69-2.0)
AC-9	(4.0-5.0)		

Group 3 (Dellivium Hillwash Deposit)

AC-14	(0.75-1.3)	AC-18	(0.65-1.5)
AC-16	(0.5-1.0)	AC-19	(0.5-1.0)

Group 4 (Colluvium)

AC-3	(2.0-4.0)	AC-4	(4.0-4.2)
AC-3	(4.0-5.0)	AF-1	(0.33-0.57)
AC-4	(0.65-1.0)	AF-1	(0.57-0.8)
AC-4	(1.0-2.0)	AF-2	(0.4-1.0)
AC-4	(2.0=4.0)	AF-2	(1.0-1.83)

Group 5 (Weathered Granitic Rocks - Residual soils)

AC-1	(3.0-4.0)	AC-2	(3.0-4.0)
AC-2	(1.0-2.0)	AF-3	(4.0-5.0)

Group 6 (Lateritic Ironstone - scree deposit)

AC-10	(0.1-0.5)
AC-11	(0.1-0.5)
AC-12	(0.2-0.7)

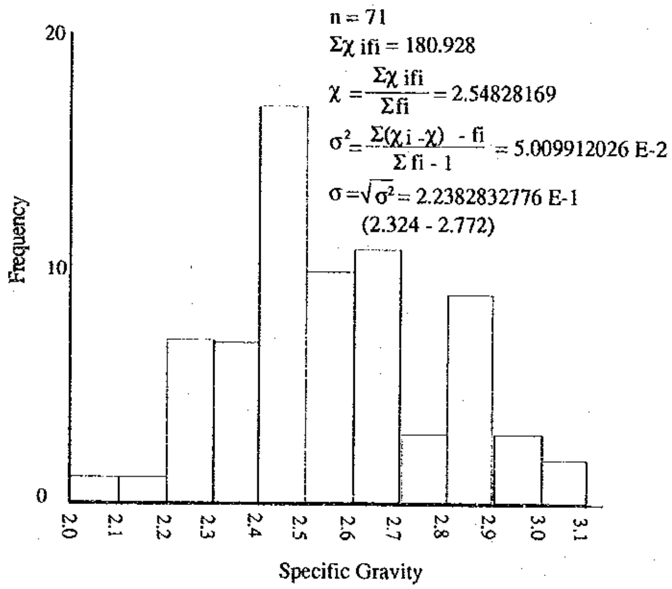
Group 7 (Flood Deposit)

AC-16	(0.1-0.5)
AF-9	(0.0-0.76)
AF-10	(0.0-0.69)

4.2 Physical Properties

a. Specific gravity

The frequency of specific gravity is shown on the following figures:



The values between 2.4 and 2.7 have high frequency. A little smaller values than the above (between 2.2 and 2.4) have been also reported relatively frequently.

The reason of the above light specific gravity is seemed to be that these soils may be composed of such light minerals as follows.

Ref.3

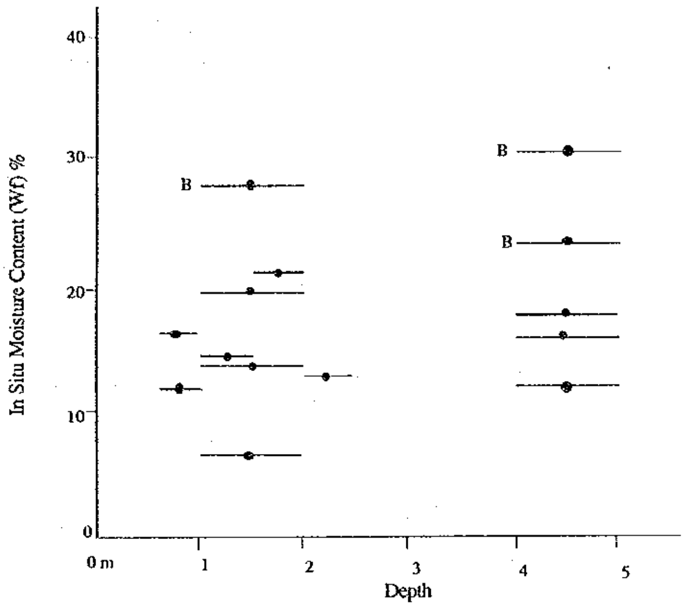
Mineral	Chemical composition	Specific gravity
Halite	NaCl	2.2
Opal	$SiO_2 . H_2 O$	2.1
Gypsum	$Ca(SO_4). 2H_2 O$	2.3
Montmorillonite	$(Al.Mg)_2\ OH)_2\ Si_{24}\ O_{10}$	2±
Analcime	$Na(Al\ Si_2\ O_6)\ H_2\ O$	2.3

Those may be derived from peculier meteologic condition and constituent geology around the area.

It is reported that the main mineral constituent of Black Cotton Soils is Montmorillonite from pedelogical analysis.

b. In site moisture content

The following figure shows the in site moisture content/depth relation chosen from reliable date as truly in situ.

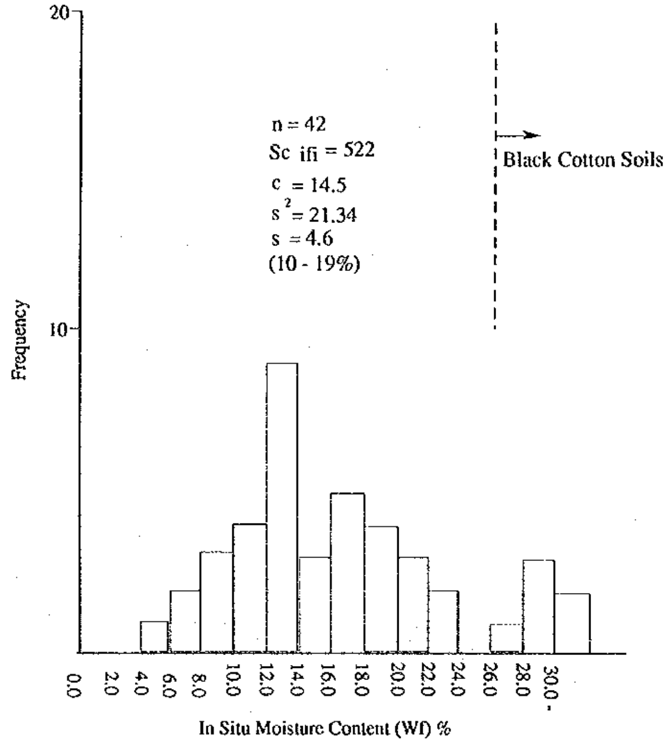


N.B) B —●— shows of Black Cotton Soils

This figure shows that big difference of moisture content with depth is enable to be found, and the soils have generally 10-20% of in situ moisture content except Black Cotton Soils which show more than 25%.

The frequency of in site moisture content is shown on the following figure.

The data from AF series are omitted on account itself of highly influenced by rain or surface flow water because they are located near stream and river.



c. Particle size distribution

Gradation curves of each group are shown at the end of this volume.

The properties of each group is as follows:

i) Group 1
(Black Cotton Soils-Weathered Pleistcene Lake Deposits)

Percent finer than 74μm (Rp.) is more than 70%, and almost of all is in between 85% and 100% having high plasticity. There is also found sand grains 5-10% and very few calcrete nodules.

ii) Group 2
(Pleistocene Lake Deposits ...Tuffaceous)

Rp is in between 60-90%, usually around 70%. The other composition is almost sand and a few pebbles mainly of calcrete nodules.

But several gravelly layers seem to be in exist in a real situation because refusal sometimes happened when augering.

iii) Group 3 (Hillwash Deposits)

From the gradation curve, Rp is more than 70%. But likewise the group 2, this is because of refusal by a lot of gravel when augering, in a real situation gravelly layers were found a lot.

From the field observation, it is composed of mainly pebble and cobble, and several percent of sand and black cotton soils.

iv) Group 4 (Colluvium)

This is the sandy soil composed of 30-60% of Rp, 40-70% of sand, and a few gravels. Sand grains are usually quartz or feldsper derived from granitic rocks. Finer grains are kaolinitic low plastic clay to silt originated from alterated feldsper and/or mica and montmorillonitic high plastic clay from black cotton soils.

v) Group 5 (Weathered granitic rocks - Residual soils)

Gradings, is depend on location and depth. Their particle size distribution resemble to colluvium in case of completely weathered granitic rocks and residual soils.

Percentage of sand and/or gravel grains gradually increase with weather degree becoming lower.

vi) Group 6 (Lateritic ironstone-scree deposits)

These soils are found on the phonolite. Scree deposits is composed of usually hard angular gravel, and a few finer grains which is found around 20% in a surface layer.

Lateritic ironstone is composed of brittle rock fragment and relatively high percent (around 60%) of fine grains as far as that distributing near surface.

vii) Group 7 (Flood deposits)

This is almost composed of fine sand and clayey soils of black cotton soils. Rp is in between 80-90% fine sand around 10%.

d. Consistency

Liquid limit - Plasticity Range is shown in Fig. II-12. As shown in this figure, group 1, 2 and 4 has the apparent respective range.

Group 1 distribute from around A Line of PI 33% LL65% to under A Line of high LL, and soil of this group is classificated into mainly MH to OH.

Group 2 generally have a range slightly over A line in between LL 40-60%, and classificated into CL - CH or MH

Group 4 is plotted in between PI 15-20%, LL20-40% and classificated into SM-SC or CL.

Group 3 and 7 are included in the area of group 1, group 5 is in group 4.

Group 6 has very different properties from place to place.

4.3 Mechanical Properties of Soils

Soil sampled from Test Pitts was utilized for mechanical property tests.

Grouping of soils is as follows:

i) Black Cotton Soils - Weathered Lake Deposits	TP-4, TP-8,T P-10
ii) Pleistcene Lake Deposits (Tuffaceous)	TP-3, TP-5
iii) Hillwash deposits	TP-7, TP-9
iv) Weathered Granitic Rock (Residual soils) - colluvium	TP-1, TP-2, TP-11
v) Lateritic Ironstone	TP-6

a. Compaction Curve

This test was carried out by 2.5kgf rammer method of ASTM D 698-78/BS 1337-12.

The results of each soils are shown in Fig. II-14.

i) Black Cotton Soils - Weathered Lake Deposits (TP-4, TP-8, TP-10), specific gravity of which is very low (2.15-2.2) because it seems to be composed mainly of montmorillonite, show very flat shaped curve so that the effectiveness by compaction is not remarkable.

Maximum dry density (rdmax) is in between 1.20- 1.24t/m^3 and optimum moisture content (wopt) is in between 31-33%. In situ mositure content was 14-28% as of October 1990.

This type of soil lacks stability as embankment material, and traficability is very bad in wet condition.

ii) Pleistcene Lake Deposits (TP-3, TP-5) having also low specific gravity (2.15-2.25) show their rdmax a little larger (1.31-1.42 t/m^3) and wopt a little lower (24-27%) than those of Black Cotton Soils. In situ moisture content was 8-13% as of October 1990.

This soil is also not good for embankment material, though it,s better than Black Cotton Soils.

iii) Hillwash Deposits (TP-7, TP-9), which have relatively high specific gravity (2.55-2.6), show their rdmax relatively high (1.52 - 1.65t/m^3) with wopt in between 20-23%. In situ moisture content was around 13%.

This soil has so enough stability, traficability and compresibility that it may suitable for embankment material provided that they have enough permeability, and in case grain size is lower than allowable maximum diameter

iv) Colluvium - weathered granitic rocks (TP-1, TP-2, TP-11) show steep-shaped compaction curve, that is to say, these soils is compactable well, rdmax is in between 1.65-1.84 t/m^3, and wopt is in between 12-15%. In situ moisture content of this group was 2-3% higher than wopt, showing the different from the other group.

This type of soil is suitable for embankment material.

v) Lateritic Ironstone (TP-6) is that rdmax is 1.52t/m^3 and wopt is 19.1%. In situ moisture content was 8.8%. This soil showed also well compactability, and good enough for embankment material. But it is necessary to pay close attention since they have remarkable different properties place by place.

b. Permeability

Compaction curve/permeability relations are shown on Fig. II-16. What the compaction give an enough effectiveness to the permeability are Colluvium-Weathered granitic rocks, Lateritic ironstone and some Hillwash deposits.

Hillwash deposits depends on its particle size distribution, it is difficult to get enough impermeability in a case it is composed of very few fine grained soil.

Though Black Cotton Soils and Pleistcene Lake Deposits have relatively low permeability, there is very few effect by compaction.

c. Shear strength

The result of Triaxial compression test is as shown in Table II-3, and compiled as follows:

Result of Shear Strength

Group	Cu KN/m^2	øu	Cu KN/m^2	øcu
Black Cotton Soils	0.5-1.7	22.00°-23.00°	1.4	22.50°
Pleistcene Lake Deposits	-	-	2.1-6.0	26.50°-28.0°
Hillwash Deposits	-	-	1.6	30.00°
Lateritic Ironstone	-	-	4.5	29.00°
Colluvium-Residual Soil	4.0	27.00°	1.2	28.00°

Hillwash Deposits, Lateritic Ironstone and Colluvium-Residual Soil have relatively high internal friction angle which contribute to the stability of ground

Black Cotton Soils and Pleistcene Lake Deposits have relatively low internal friction angle even they were tested at or near Wapt. In a case wet condition their internal friction may move on toward zero, though the cohesion increase gradually. Their stability is unable to be guaranteed.

5. ENGINEERING GEOLOGY

5.1 Foundation

a. Intake weir

The foundation for proposed intake weir site is composed of tuff or tuffaceous rocks, the N-value of which were inferred apparently more than 50.

Allowable strength will be able to be decided from the following table.

Allowable Strength/N-value Relation for Foundation

	Foundation Type	Allowable Strength (tf/m^2)	N value	Remarks *qu (kgf/cm^2)
Rock bed	-	100	over than 100	-
Sand bed	-	50	over than 50	-
Mud-stone bed	-	30	over than 30	-
Gravel layer	dense and compact	60	-	-
	the other	30	-	-
Sandy ground	dense	30	30 - 50	-
	medium	20	20 - 30	-
		10	10 - 20	-
	loose	5	5 - 10	-
	very loose	0	less than 5	-
Clayey ground	very hard	20	15 - 30	above 2.5
	hard	10	8 - 15	1.0 - 2.5
	medium	5	4 - 8	0.5 - 1.0
	soft	2	2 - 4	0.25 - 0.5
	very soft	0	0 - 2	less than 0.25
Pyroclastic cohesive soil	hard	15	over than 3 - 5	over than 1.5
	slightly hard	10	3 - 5	1.0 - 1.5
	soft	5	less than 3	less than 1.0

*Unconfined compression strength

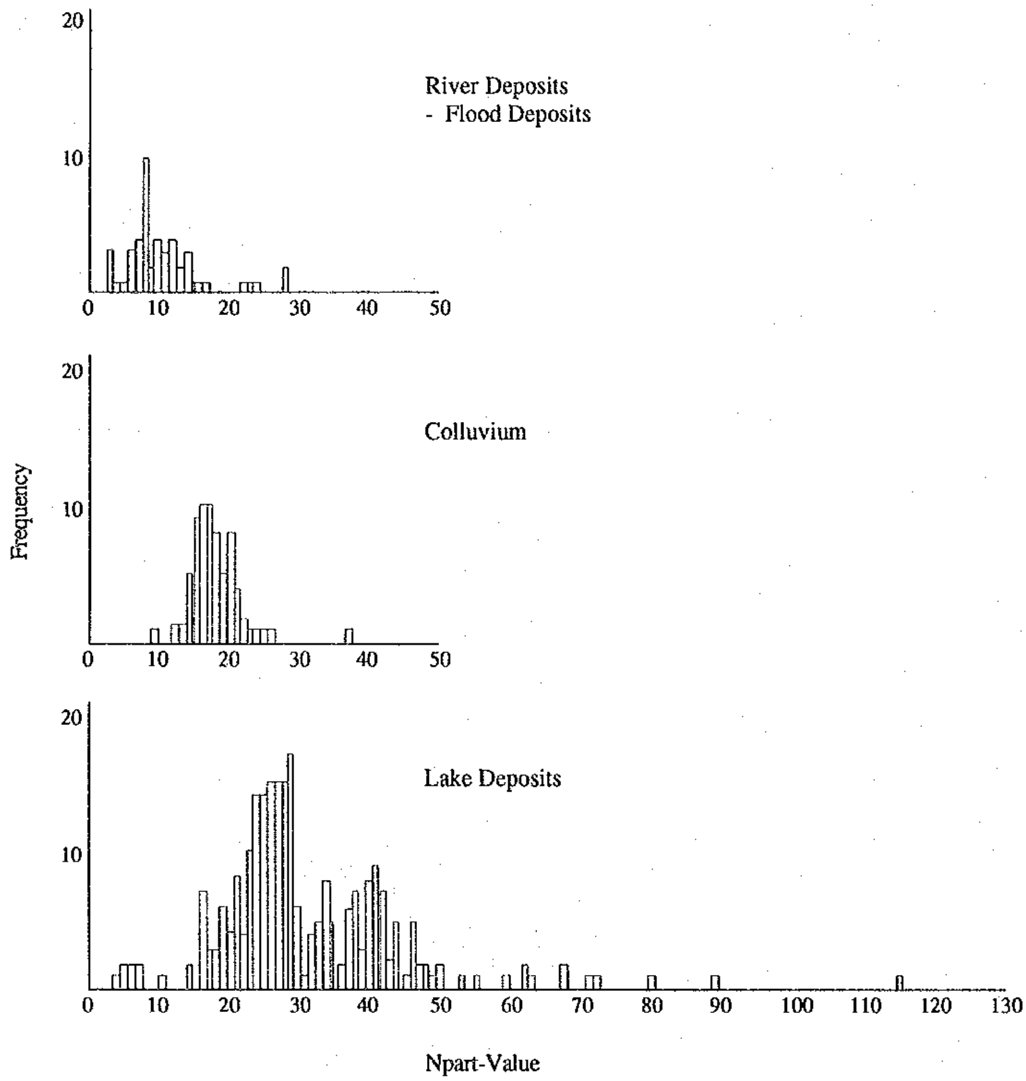
Ref.4 standard for canal design (MAFF at Japan)

Allowable strength at Nyando intake weir site is possible to take more than 30 tf/m from the above table because the base rock of site can be considered as mudstone bed.

b. Canal facilities

Summary of sounding test by Kuenzelstab are shown on the Table II-5.

The frequency of Nport-value as to River-Flood Deposits, Colluvium and Lake Deposits which are able to obtained enough data are shown on the following figure after comparing individual Nport value and geological log.



Nport-value and converted N-value having charge of respective geology are shown in the following table based on statistic analysis of the above figure etc.

Nport and N-value of Respective Geology

Geology	Nport-value	Converted* N-value	Depth
River Deposits - Flood Deposit	mean value 6 ~ 14 minimum 3 max. 29 median = 8 gravelly portion ave. = 9.5 σ = 2.65 (6 ~ 13)	4 ~ 9	max. 3.0 m
Colluvium	mean value 12 ~ 13 minimum 9 max. 28 ave. = 16.97 σ = 2.55 (14 ~ 19)	9 ~ 15	max. 3.7m
Black Cotton Soils	4 ~ 15	2 ~ 10	max. 3 m
Pleistcene Lake Deposit	gravelly portion 30 ~ 50 mediam = 41 ave. = 39.45 σ = 4.8 (35 ~ 45)	23 ~ 30	over than 7 m
	the other 16 ~ 30 median 24 ~ 29 ave. = 24.6 σ = 3.8 (21 ~ 28)		14 ~ 19
Lateritic Ironstone	60 ~ 130	40 ~ 89	about 5 m
Weathered Granitic Rocks	Residual soil 25 ~ 85 the other over than 120	16 ~ 57 more than 80	over than 5 m

N.B) * N-value is converted from mean of Nport-values as converting equation N = 1.5 Nport

From the above tables which present "allowable strength/N-value relation for foundation and Nport" and "N-value of respective geology", the allowable strength for foundation of respective geology result as shown in the following table.

Group	River Deposits - Flood Deposits	Colluvium	Block Cotton Soils	Lake Deposits: Gravelly Portion	Lake Deposits: the Others	Lateritic Ironstone	Weathered Granitic Soils: Residual Soils	Weathered Granitic Soils: the Other
Allowable foundation Strength (tf/m)	5	10	2 - 5	30	10 - 20	30	10 - 30	50

Furthermore, the location need to take care as weak foundation is as follows from data checking Nport-value of AF-1 to AF-l0 listed on Table II-5.

AF-5 (Left bank of the Asawo river)
Depth 0 - 0.9m Nport = 4 - 10 (N' = 2 - 7*)

AF-7 (Right bank of the Awachi Kano branch stream)
Depth 0 - 0.8m Nport = 6 - 12 (N' = 4 - 8*)

AF-8 (Left bank of the Awachi Kano river)
Depth 0-3.0m Nport = 3 - 15 (N' = 2 - 10*)

* where N' is converted N-value as N = 1.5 Nport

c. Canal Embankment

Any grounds except of Flood deposits are inferred stable as a foundation for canal embankment.

5.2 Embankment Material

a. The material estimation

The respective geology will be estimated as the following table as embankment material as to their impermeability, stability, traficability and compressibility considering with their properties of soil mechanics.

Geology (Soil Symbol)	Impermeability	Stability	Traficability	Compressibility	Estimation
Black Cotton Soils (MH-OH)	O - Δ	X	X	X	7
Lake Deposits (CL-CH, MH)	O - X	Δ	Δ	Δ	5
Hillwash Deposits (GC-GW) (SC-SW)	O - X	O - Δ	O - Δ	O	4
Colluvium (SM-SC, CL)	O	O	O	O	1
Weathered Granitic Rocks - Residual Soils (SM-SC)	O - X	O	O	O	3
Lateritic Ironstone (MH-ML.CL) (GC-GM)	O - X	O	O	O	2
Flood Deposits (CL. MH-0H)	O - Δ	Δ - X	Δ - X	Δ - X	6

N.B) As to Black Cotton Soils:

This soil is composed of montmorillonitic clay which swell or shrink remarkably depending upon moisture content.

When it will be dried, many cracks will develop so easily that the embankment failure may be caused.

When Black Cotton Soils be obliged to be utilized by any means, it will be necessary to keep it wet situation, or such a way have to be taken that the other materials fill it immediately when crack develops.

Furthermore it is necessary for considering well about embankment slope stability because its shearing resistance (C,ø) is low as shown in the table presenting the result of shear strenght in Section 4.3.

Similarly, care need to be paid to Flood deposits.

* As compaction earth lining material;

Lateritic ironstone with suitable volume of fine grains and/or colluvium are desirable from the following figure.

Hillwash deposits are also considerable in on condition that they are well graded from clay up to allowable maximum grain size.

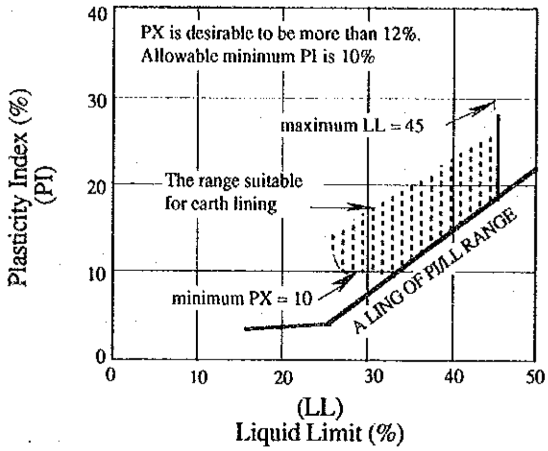


Fig. II-5-1 The Criterion of Consistency as Impermeable and Erosion-resistable Earth Lining Material (Ref.5)

b. Planning of borrow material area

Based on the material estimation, borrow areas are considered from No.1 to No.5 as shown in Fig. II-8.

Geology of respective borrow area was commented in the Chapter I.

The excavatable volume of material is inferred as follows provided that the area are set up as shown in Fig. II-9.

Area (1)	Area (A)	=	1,030,000 m^2
(Colluvium &	Thickness (Average) (T)	=	3 m
Weathered	Volume (V)	=	A x T x 1/3
Granitic Rocks)		=	1,030,000 m^3
Area (2)	Area (A)	=	1,870,000 m^2
(Colluvium &	Thickness (T)	=	1 m
Lake Deposits)	Volume (V)	=	A x T x 1/3
		=	620,000 m^3
Area (3)	Area (A)	=	1,280,000 x m^3
(Lateratic	Thickness (Average) (T)	=	2 m
Ironstone)	Volume (V)	=	A x T x 1/3
		=	850,000 m^3
Area (4)	Area (A)	=	1,000,000 m^2
(Hillwash	Thickness (T)	=	2 m
Deposit)	Volume (V)	=	A x T x 1/3
		=	330,000 m^3
Area (5)	Area (A)	=	1,820,000
(Lateritic	Thickness (T)	=	1 m
Ironstone)	Volume (V)	=	A x T x 1/3
		=	600,000 m^3

N.B. 1/3 as safety factor is multiplied to the inferred total volume respectively.
Remarks: Material from borrow area should be considered secondly after the diversion material study from canal excavation.

5.3 Stability of Cut Ground Along Canal Route

Generally the ground along canal route is very dry, hard and well consolidated except the section composed of flood deposits, and any marks or signs of land sliding are not found around the project area. Furthermore a lot of very steep (almost vertical) river banks or cliffs look keep to be stable except to the case of gully erosion.

The shearing resistance of Black Cotton Soils and colluvium under the condition of in situ dry density and in situ moisture content are tested in laboratory UU Triaxial test as shown in the table presenting the result of shear strenght in Section 4.3. Though the shearing resistance of Black Cotton Soils (uniform cohesive type) is seemed to be reasonable low (c=0.5 1.7 kN/m^2, ϕ = 22° - 23°), the area that Black Cotton Soils are found in thick is not found except a part of embanked section. Therefore it seems that cut ground will be stable except the case of section composed of thickly sedimented flood deposits. However, the protection against gully erosion will be necessary especially to such sandy and/or silty soils as colluvium.

REFERENCE

1. Rural Domestic Water Supply and Sanitation Programme, Lake Basin Development Authority (1988)

2. ASTM (American Society for Testing and Materials), BS (British Standard), USBR (U.S. Bureau of Reclamation)

3. Chronological Scientific Table ... Tokyo Astronomical Observatory

4. Standard for canal designing, Ministry of Agriculture, Forestry and Fishery in Japan (1986)

5. Earth Manual, U.S. Department of the Interior, Bureau of Reclamation (1974)

Tables

Table II-1-1 Materials Test Results Summary Sheet

(AC series-1)

Sample No.	Grading % Passing								In Situ Moisture	Atterberg Limits			Linear shrinkage	SG
	Depth (m)	25 mm	20 mm	10 mm	635 mm	236 mm	425 u m	75 u m	%	LL	PL	PI		
AC-1	3.00-3.15													2.846
	3.15-4.0					100	95	47	10.1	36	18	18	10	2.67
AC-2	1.0-2.0				100	99	84	65	6.7	38	22	16	8	2.457
	3.0-4.0					100	87	60	12.2	29	13	16	8	2.42
AC-3	2.0-4.0				100	98	85	58	13.7	36	20	16	9	2.569
	4.0-5.0				100	97	80	58	16.2	50	30	20	10	2.614
AC-4	0.65-1.0				-	-	-	-	-	-	-	-	-	2.917
	1.0-2.0				100	98	75	51	11.8	40	23	17	8	2.558
	2.0-4.0				100	98	72	47	-	28	13	15	7	2.467
	4.0-4.2				-	-	-	-	7.7	-	-	-	-	2.891
AC-5	1.0-2.0				100	96	89	74	16.8	41	17	24	11	2.461
	4.0-5.0				100	99	82	559	12	41	21	20	10	2.602
AC-6	0.6-1.0		100	99	99	96	82	68	11.8	53	24	29	14	2.622
	1.5-2.0				100	99	82	68	21.1	58	30	28	16	2.474
AC-7	2.0-2.5				100	96	85	69	12.9	66	29	37	18	2.771
AC-8	1.0-2.0		100	99	96	90	82	75	19.7	89	44	45	21	2.398
	4.0-5.0				100	99	92	82	18.1	70	35	35	17	2.654
AC-9	1.0-2.0				100	97	83	67	19.3	50	30	20	11	2.475
	4.0-5.0				100	100	93	70	19.9	51	28	23	13	2.258
AC-10	0.1-0.5	100	87	80	77	70	62	52	-	65	34	31	14	2.517
AC-11	0.1-0.5	100	97	79	60	29	20	17	9.5	31	24	7	3	2.616
AC-12	0.2-0.7		100	98	95	84	69	62	16.2	46	24	22	11	2.521
AC-13	0.7-1.1				100	97	92	89	-	95	55	40	19	2.455
AC-13'	0.0-0.5		100	86	72	48	37	34	-	81	42	39	18	2.612
AC-14	0.6-0.8		100	97	91	69	50	43	16.2	91	48	43	21	2.46
	0.8-1.3		100	99	97	92	88	85	20.8	92	47	45	21	2.308
	0.0-0.5					100	99	97	-	101	58	43	20	2.32
AC-15	0.0-0.5			100	99	97	94	90	-	71	34	37	19	2.414
	0.5-1.0			100	98	94	89	84	21	75	37	38	18	2.331
AC-16	0.5-1.0			-	-	-	-	-	14.5	-	-	-	-	2.857
AC-16'	0.1-0.5					100	96	89	11.4	46	22	24	12	2.183

Source : Prepared by JICA Study Team

Table II-1-2 Materials Test Results Summary Sheet

(AC series-2)

Sample No.	Grading % Passing								In Situ Moisture	Atterberg Limits			Linear Shrinkage	SG
	Depth (m)	25 mm	20 mm	10 mm	635 mm	236 mm	425 u m	75 u m		LL	PL	PI		
AC-17	0.1-0.7					100	97	92	28	100	55	45	22	2.227
AC-18	0.65-1.0			100	98	88	80	69	13.6	80	36	44	21	2.726
	1.0-1.5		100	99	95	86	64	39	15.6	51	23	28	13	3.1
AC-19	0.0-0.6				100	99	92	86	-	113	66	47	22	2.329
AC-19'	0.5-1.0					100	97	93	28.1	88	46	42	20	2.264
AC-20	1.0-2.0					100	100	99	23.5	75	38	37	19	2.435
	4.0-5.0		100	98	95	91	86	83	34.6	76	54	42	22	2.613
AC-21	1.0-2.0						100	99	28	78	36	42	20	2.547
	4.0-5.0			100	99	99	97	94	23.6	85	46	39	19	2.798
AC-22	1.0-2.0				100	99	97	91	-	78	37	41	21	2.871
	4.0-5.0			100	99	99	97	94	30.4	85	46	39	19	2.549

Source : Prepared by JICA Study Team

Table II-1-3 Materials Test Results Summary Sheet
(AF series - 1)

Sample No.	Grading % Passing								In Situ Moisture	Atterberg Limits			Linear Shrinkage	SG
	Depth (m)	25 mm	20 mm	10 mm	635 mm	236 mm	425 u m	75 um	%	LL	PL	PI		
AF-1	0.33-0.57				100	99	73	32	9.7					2.55
	0.57-0.8				100	98	69	39	10.1	34	17	17	8	2.5
AF-2	0.4-1.0					100	81	43	8.3	25	10	15	7	2.459
	1.0-1.83			100	99	85	85	56	14	36	18	18	10	2.337
AF-3	2.0-3.0				100	96	88	66	14.2	46	24	22	12	2.645
	4.0-5.0				100	79	54	32	17.1	34	19	15	7	2.267
AF-4	2.0-2.8					99	84	71	12.3	82	42	40	19	2.252
	4.0-5.0				100	98	86	70	8.2	58	26	32	16	2.385
	5.0-6.0				100	99	84	71	7.9	61	30	31	16	2.643
AF-5	1.2-3.0				100	99	94	85	18.2	56	29	27	15	2.477
AF-6	0.54-1.7			100	100	98	78	51	12.5	75	38	37	20	2.696
	2.0-3.0			100	98	95	84	69	22.1	43	19	24	13	2.643
AF-7	2.0-3.0			100	99	97	90	84	13.4					2.796
	3.0-3.56					100	90	79	14.3	64	28	36	19	2.331
	3.56-4.0	100	95	94	92	88	68	54	16.1	53	25	28	14	2.871
	4.0-5.0				100	96	68	46	18.8	50	26	24	12	2.601
	5.0-5.3			100	98	92	68	48	21.2	57	26	31	14	2.8
AF-8	0.0-2.0						100	83	22.3	47	23	24	11	2.946
	2.0-3.0					100	98	88	20.9	52	22	30	14	2.502
	3.0-4.0					100	95	78	19.4	47	24	23	12	2.551
	4.0-4.05					96	68	46	17.4	50	22	28	14	2.392
AF-9	0.0-0.76				100	99	94	83	20.1	68	36	32	16	3.06
	1.0-2.0		100	98	97	89	57	45	21.3	55	25	30	14	2.829
AF-10	0.0-0.69					100	98	85	21.5	68	37	31	16	2.954
	0.69-2.0				100	99	97	89	21.3	55	31	24	13	2.204
	2.0-2.5				100	100	99	90	21.1	49	29	20	11	2.079
	2.5-2.76					100	99	90	21	48	29	19	10	2.204
	2.76-3.0				100	98	95	88	20.5	54	30	24	13	2.48
	3.0-3.7				100	98	92	85	19.3	29	15	14	8	2.481

Source : Prepared by JICA Study Team

Table II-2 Summary of Test Results
(TP series)

Test Pit No.	Depth (m)	In Situ Moisture %	In Situ Dry Density (kgf/m^3)	Atterberg Limits			
				LL	PL	PI	LS
TP-1	1.5	13.7	1212	38	22	16	9
TP-2	2.8	5.3	1654	30	16	14	7
TP-3	1.5	8	1344	55	28	27	14
TP-4	2	8.8	1353	70	41	4	4
TP-5	2	13	1342	56	28	27	14
TP-6	1.5	17.6	1487	45	25	20	12
TP-7	1.5	-	-	39	21	18	9
TP-8	1.5	13.8	1144	71	41	30	16
TP-9	1.5	13.8	1417	66	33	33	17
TP-10	1.5	27.7	1118	73	41	32	15
TP-11	1.5	15.6	1631	25	18	7	3

Source : Prepared by JICA Study Team

Table II-3 Summary of Mechanical Test Results

Trial Pit No.	Depth (m)	In Situ Moisture %	In Situ dry density (tf/m^3)	*MDD tf/m^3	*OMC	Triaxial shear strength			
						**C-U Test		***U-U Test	
						Cohesive Strength (KN/m^2)	Friction Angle (ϕ)	Cohesive Strength (KN/m^2)	Friction Angle (ϕ)
TP-1	1.5	13.7	1.212	1.836	11.9	-	-	-	-
TP-2	2.8	5.3	1.654	1.658	14.6	-	-	4	27
TP-3	1.5	8.0	1.344	1.317	26.5	6	28	-	-
TP-4	1.5	8.8	1.353	1.328	32.7	-	-	1.7	22
TP-5	2.0	13.0	1.342	1.416	24.3	2.1	26.5	-	-
TP-6	1.5	17.6	1.487	1.628	19.1	4.5	29	-	-
TP-7	1.5	-	-	1.652	20	-	-	-	-
TP-8	1.5	13.8	1.144	1.204	32.5	1.6	30	-	-
TP-9	1.5	13.8	1.417	1.522	23	-	-	-	-
TP-10	1.5	27.7	1.118	1.23	32	1.4	22.5	0.5	23
TP-11	1.5	15.6	1.631	1.761	12.5	1.2	28	-	-

<N.B>

* MDD = Maximum Dry Density
OMC = Optimum Moisture Content
** 95% pd maximum at Optimum Moisture Content.
*** In situ dry density at insitu Moisture Content

Source : Prepared by JICA Study Team

Table II-4 (1/2)
Summary of Permeability Test Results

Location Np.	Depth (m)	Density	Permeability (K) cm/sec
TP-1	1.5	p d100 Wopt	1.1x 10^6
		p d 95 Wopt	2.0 x 10^6
		p d 95 Wwet	1.1 x 10^6
		p d 95 Wdry	1.1 x 10^5
TP-2	2.8	p d100 Wopt	2.2 x 10^7
		p d 95 Wopt	2.9 x 10^7
		p d 95 Wwet	2.3 x 10^7
		p d 95 Wdry	1.6 x 10^6
TP-3	2.8	p d100 Wopt	3.0 x 10^6
		p d 95 Wopt	3.7 x 10^6
		p d 95 Wwet	2.7 x 10^6
		p d 95 Wdry	1.0 x 10^5
TP-4	1.5	p d100 Wopt	1.1 x 10^7
		p d 95 Wopt	2.5 x 10^7
		p d 95 Wwet	1.5x 10^7
		p d 95 Wdry	1.5 x 10^6
TP-5	2	p d100 Wopt	9.6 x 10^7
		p d 95 Wopt	1.6 x 10^6
		p d 95 Wwet	1.1 x 10^6
		p d 95 Wdry	3.3 x 10^6
TP-6	2	p d100 Wopt	4.7 x 10^7
		p d 95 Wopt	6.3 x 10^7
		p d 95 Wwet	4.0 x 10^7
		p d 95 Wdry	1.5 x 10^6
TP-7	2	p d100 Wopt	3.5 x 10^7
		p d 95 Wopt	5.5x 10^7
		p d 95 Wwet	3.3 x 10^7
		p d 95 Wdry	2.3 x 10^6

Table II-4 (2/2)
Summary of Permeability Test Results

Location No.	Depth (m)	Density	Permeability (K) cm/sec
TP-8	2	p d100 Wopt	1.8 x 10^6
		p d 95 Wopt	2.7 x 10^6
		p d 95 Wwet	2.0 x 10^6
		p d 95 Wdry	9.0 x 10^6
TP-9	1.5	p d100 Wopt	1.4 x 10^5
		p d 95 Wopt	1.9 x 10^5
		p d 95 Wwet	1.2 x 10^5
		p d 95 Wdry	5.9 x 10^5
TP-10	1.5	p d100 Wopt	<1 x 10^7
		p d 95 Wopt	<1 x 10^7
		p d 95 Wwet	<1 x 10^7
		p d 95 Wdry	<1 x 10^7
TP-11	1.5	p d100 Wopt	8.0 x 10^7
		p d 95 Wopt	1.4 x 10^6
		p d 95 Wwet	7.2 x 10^7
		p d 95 Wdry	1.0 x 10^5

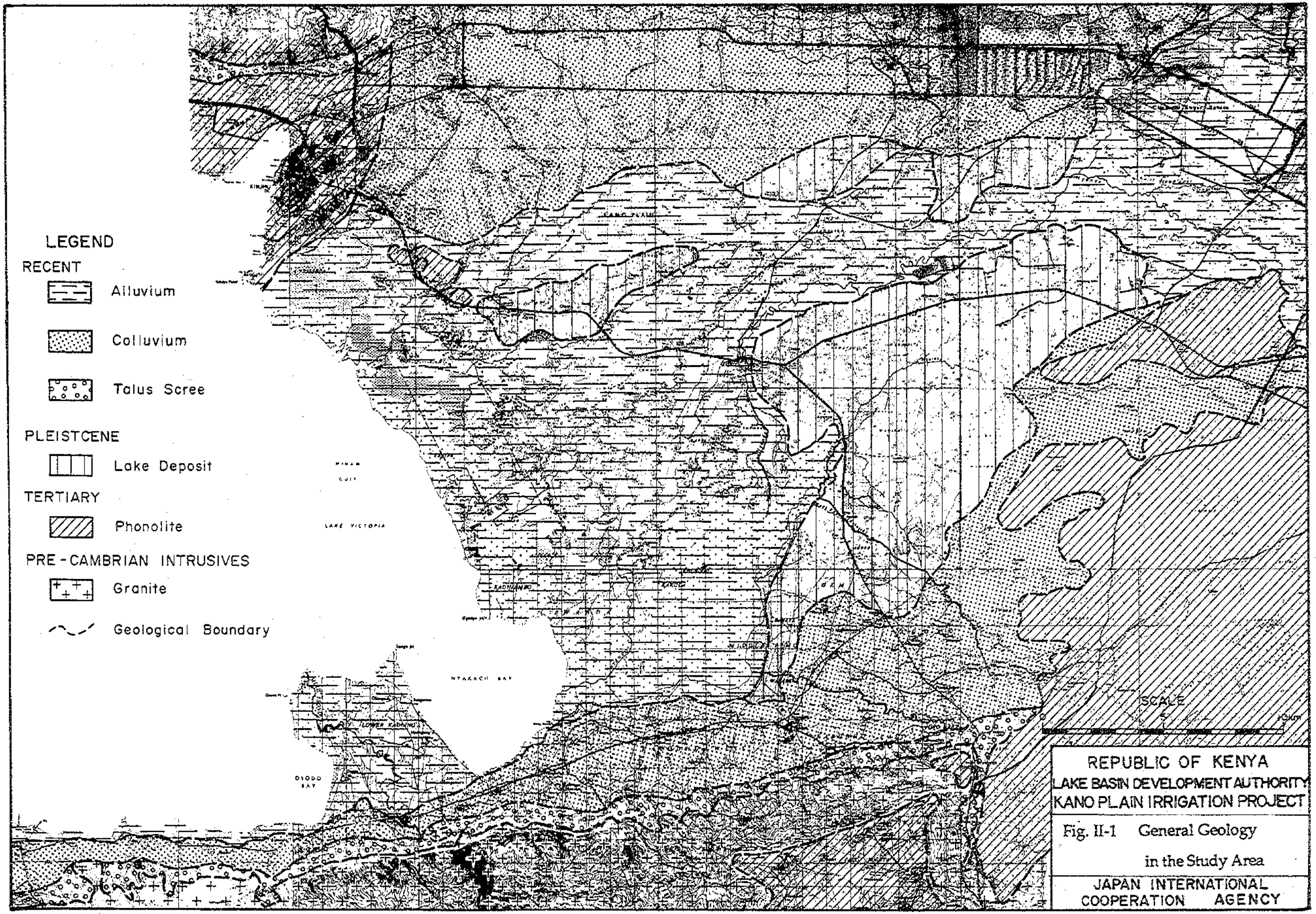
Source : Prepared by JICA Study Team

Table II-5 Summary of Sounding Test by Kuenzelstab

Depth	No. of Blows of Penetrometer									
(m)	AF-1	AF-2	AF-3	AF-4	AF-5	AF-6	AF-7	AF-8	AF-9	AF-10
0.2	14	21	26	21	7	14	8	7	7	17
0.3	22	30	20	23	6	17	12	8	12	24
0.4	14	33	40	16	6	21	10	8	14	29
0.5	14	18	44	17	4	18	6	9	14	23
0.6	16	34	62	24	5	20	6	10	13	22
0.7	17	39	63	26	5	18	8	11	16	28
0.8	17	40	47	25	7	16	11	13	22	15
0.9	37	41	37	25	10	16	14	11	30	30
1	28	36	28	25	14	20	10	8	38	41
1.1	12	24	39	19	16	17	12	12	21	40
1.2	12	28	41	29	21	20	18	10	30	38
1.3	14	43	50	25	21	15	19	9	28	46
1.4	20	33	38	21	18	15	21	8	29	41
1.5	20	32	37	24	14	15	16	8	33	46
1.6	18	33	33	25	24	21	17	8	28	41
1.7	12	28	43	24	23	22	17	6	29	41
1.8	9	23	40	21	28	24	17	7	26	40
1.9	13	60	33	17	28	19	18	8	28	44
2	13	-	29	20	23	25	19	7	61	42
2.1	16	-	34	19	26	26	19	5	36	37
2.2	17	-	35	22	29	36	20	4	39	41
2.3	15	-	38	20	24	35	21	3	33	41
2.4	16	-	33	19	22	34	20	3	42	38
2.5	15	-	27	22	22	26	25	3	42	50
2.6	17	-	24	26	24	28	16	8	49	41
2.7	18	-	25	25	28	29	16	10	109	34
2.8	15	-	23	24	27	26	13	10	49	34
2.9	25	-	26	23	26	29	18	12	117	28
3	36	-	26	24	28	28	18	15	-	59
3.1	24	-	37	18	19	29	15	-	-	41
3.2	37	-	40	23	21	27	15	-	-	46
3.3	33	-	35	25	19	33	16	-	-	42
3.4	71	-	30	28	29	45	17	-	-	19
3.5	-	-	32	27	24	49	16	-	-	27
3.6	-	-	48	26	26	55	15	-	-	27
3.7	-	-	44	25	28	67	19	-	-	26
3.8	-	-	40	21	46	32	26	-	-	63
3.9	-	-	37	24	40	40	27	-	-	66
4	-	-	39	28	42	42	27	-	-	78
4.1	-	-	36	27	27	72	47	-	-	96
4.2	-	-	48	28	35	89	26	-	-	114
4.3	-	-	44	23	38	115	30	-	-	127
4.4	-	-	53	29	29	80	42	-	-	74
4.5	-	-	84	30	29	62	42	-	-	137
4.6	-	-	84	29	33	67	38	-	-	101
4.7	-	-	127	34	16	71	29	-	-	62
4.8	-	-	133	29	16	44	16	-	-	56
4.9	-	-	179	23	25	32	23	-	-	49
5	-	-	159	23	24	30	20	-	-	61
5.1	-	-	-	25	-	30	21	-	-	104
5.2	-	-	-	27	-	28	16	-	-	130
5.3	-	-	-	26	-	29	17	-	-	-
5.4	-	-	-	28	-	31	24	-	-	-
5.5	-	-	-	46	-	25	27	-	-	-
5.6	-	-	-	38	-	26	16	-	-	-
5.7	-	-	-	34	-	25	24	-	-	-
5.8	-	-	-	34	-	29	105	-	-	-
5.9	-	-	-	29	-	29	105	-	-	-
6	-	-	-	28	-	34		-	-	-
6.1	-	-	-	32	-	-	-	-	-	-
6.2	-	-	-	39	-	-	-	-	-	-
6.3	-	-	-	35	-	-	-	-	-	-
6.4	-	-	-	27	-	-	-	-	-	-
6.5	-	-	-	18	-	-	-	-	-	-
6.6	-	-	-	20	-	-	-	-	-	-
6.7	-	-	-	27	-	-	-	-	-	-
6.8	-	-	-	37	-	-	-	-	-	-
6.9	-	-	-	43	-	-	-	-	-	-
7	-	-	-	42	-	-	-	-	-	-

Source : Prepared by JICA Study Team

Figures


LEGEND
RECENT
Alluvium
Colluvium
Talus Scree
PLEISTCENE
Lake Deposit
TERTIARY
Phonolite
PRE-CAMBRIAN INTRUSIVES
Granite
Geological Boundary
LAKE VICTORIA
NYAKACH BAY
SCALE
REPUBLIC OF KENYA
LAKE BASIN DEVELOPMENT AUTHORITY
KANO PLAIN IRRIGATION PROJECT
Fig. II-1 General Geology in the Study Area
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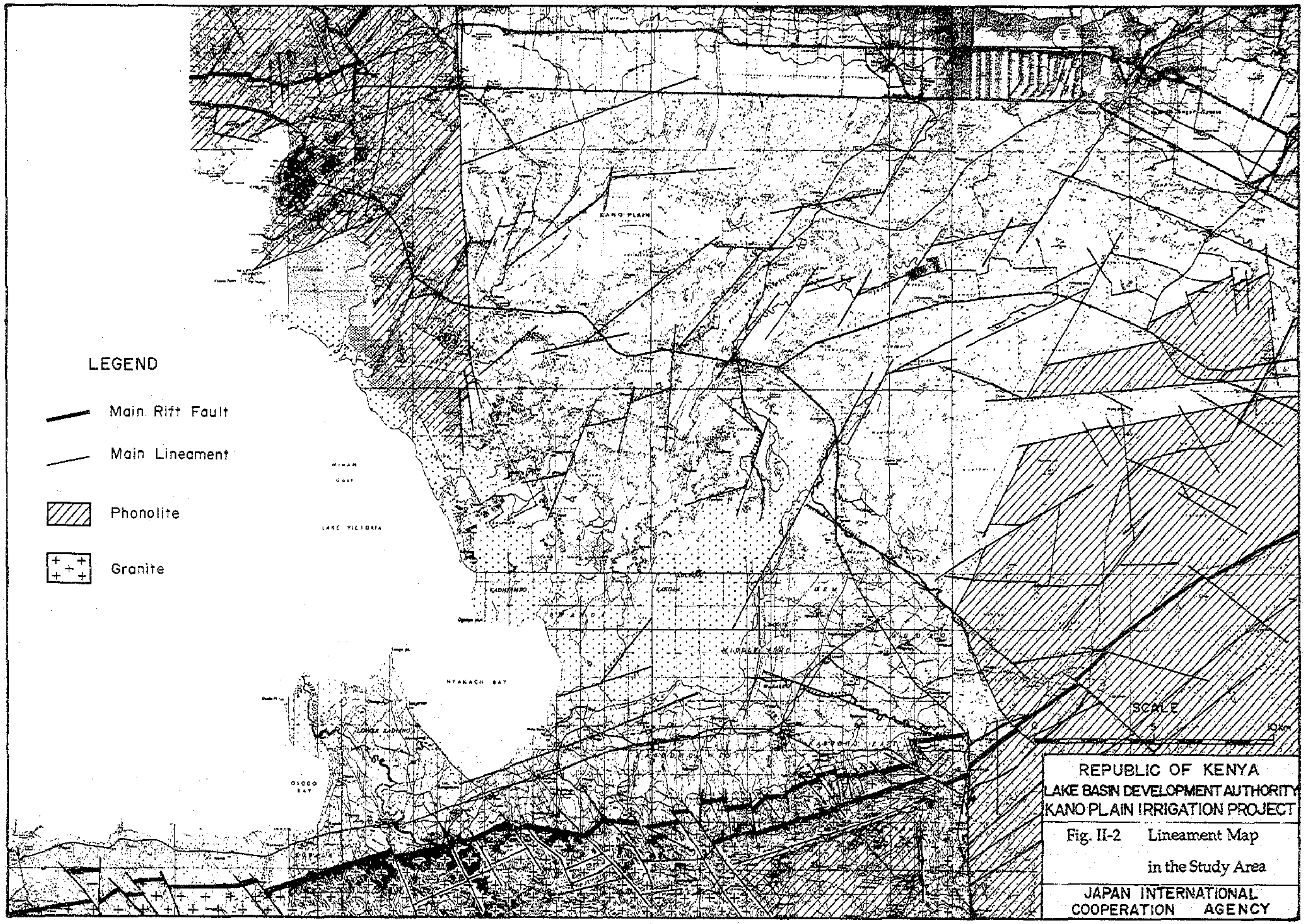

Fig. II-2 Lineament Map in the Study Area

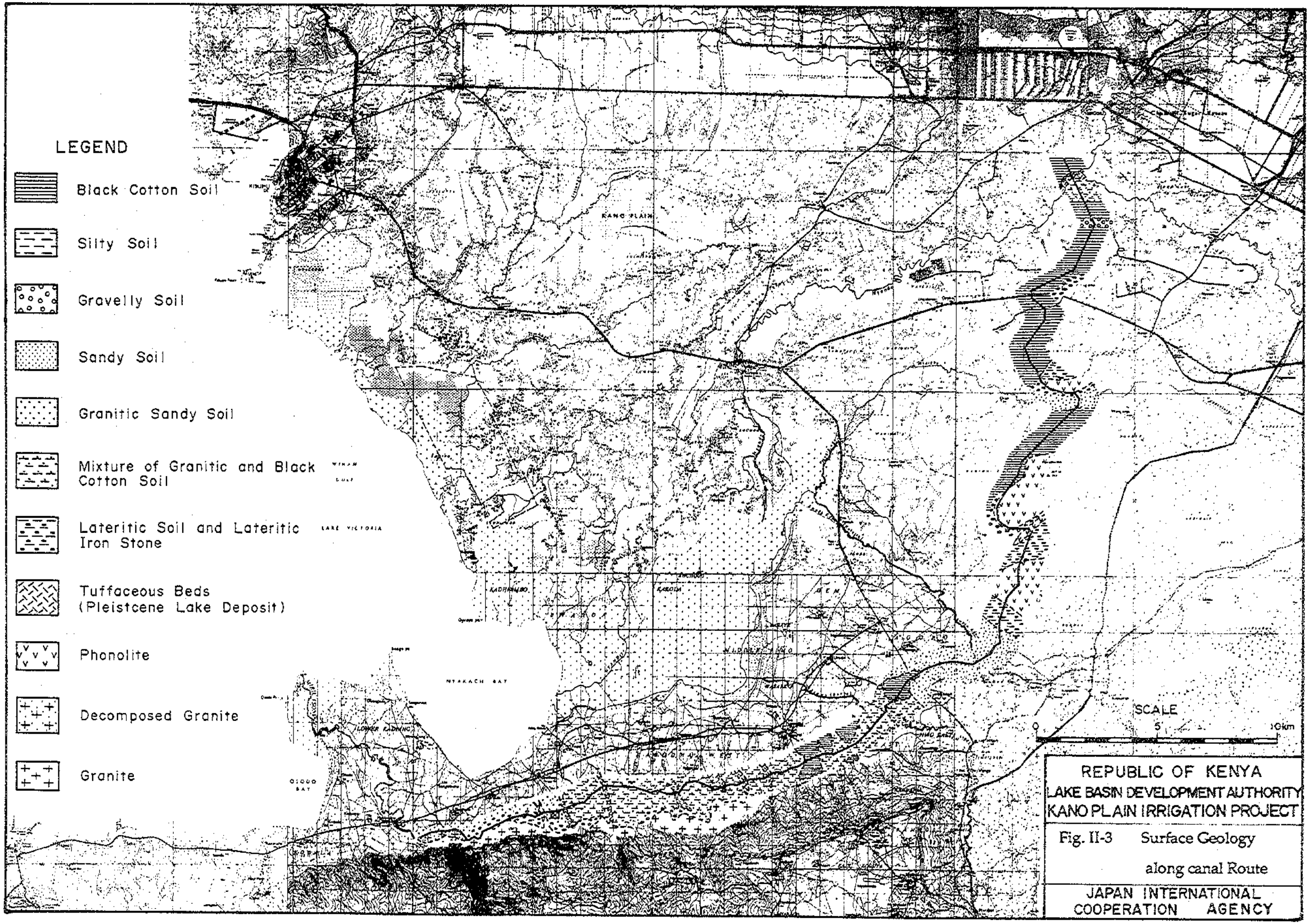

Fig. II-3 Surface Geology along canal Route

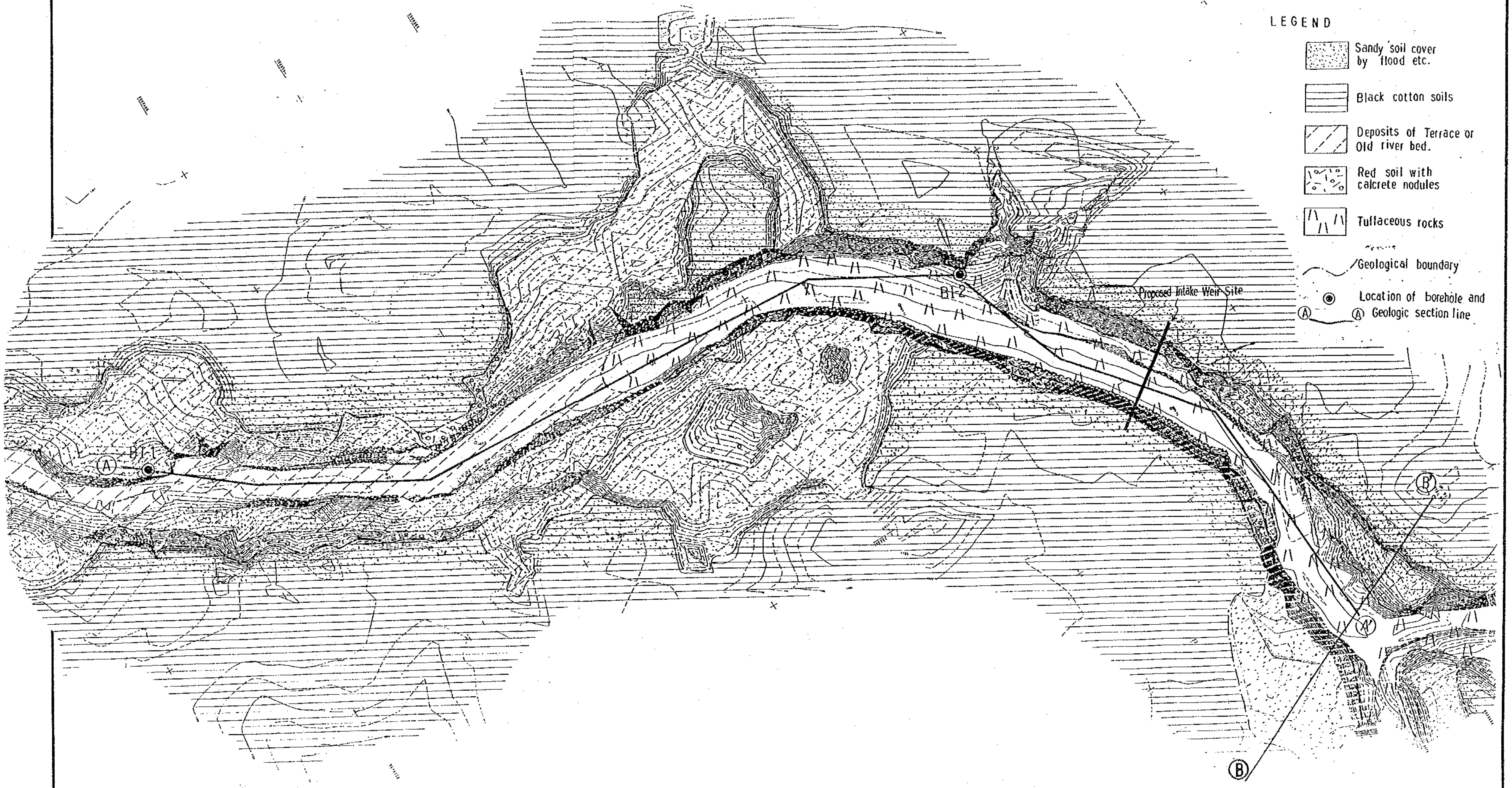

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Fig. II-4 Geological Map around Nyando Intake Weir Site

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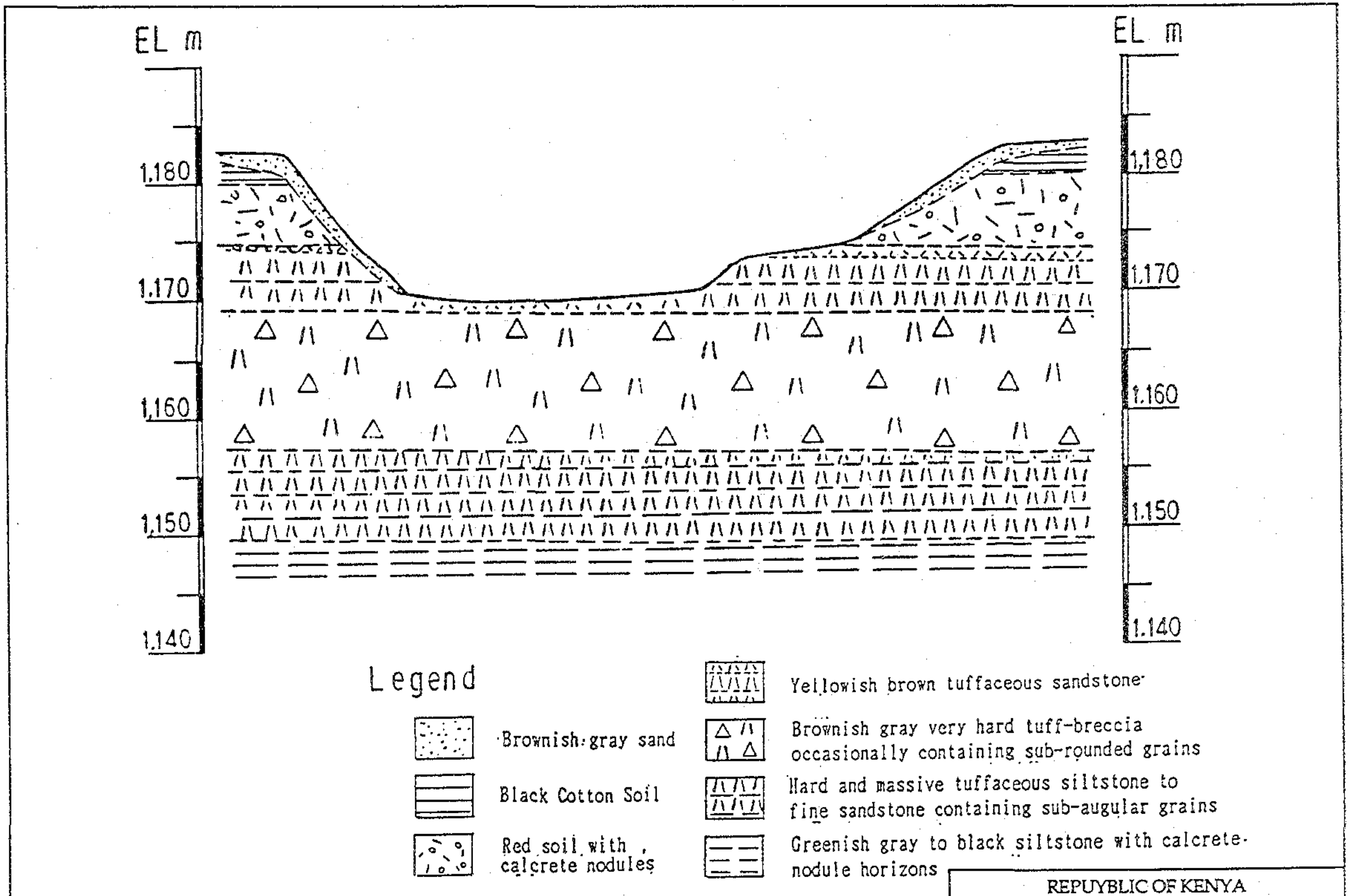

Fig. II-5 Geological Section at Nyando Intake Weir Site

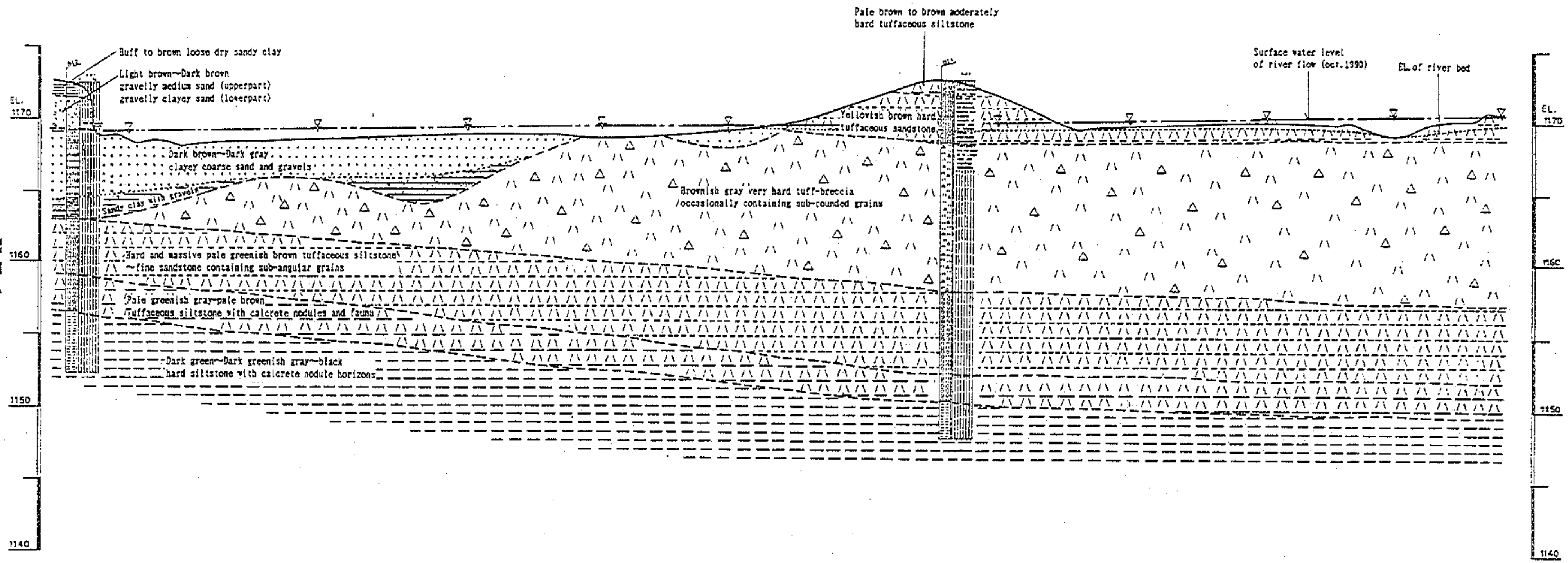

Fig. II-6 Geological Profile along Nyando River

Scale
H = 1 : 4, 000
V = 1 : 400

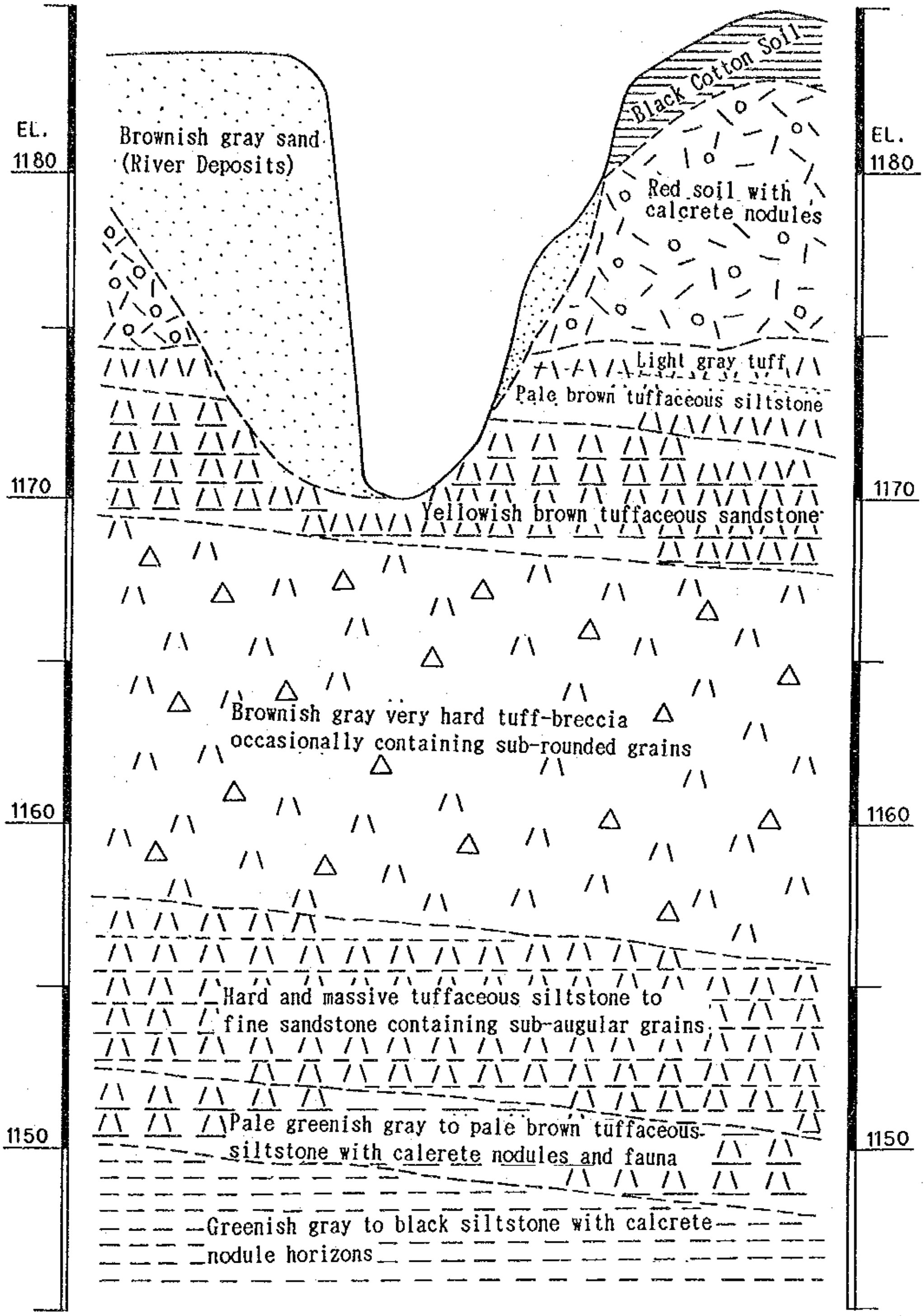

Fig. II-7 Geological section along canal Route at Crosspoint with Nyando River

Scale
H = 1 : 2, 000
V = 1 : 200

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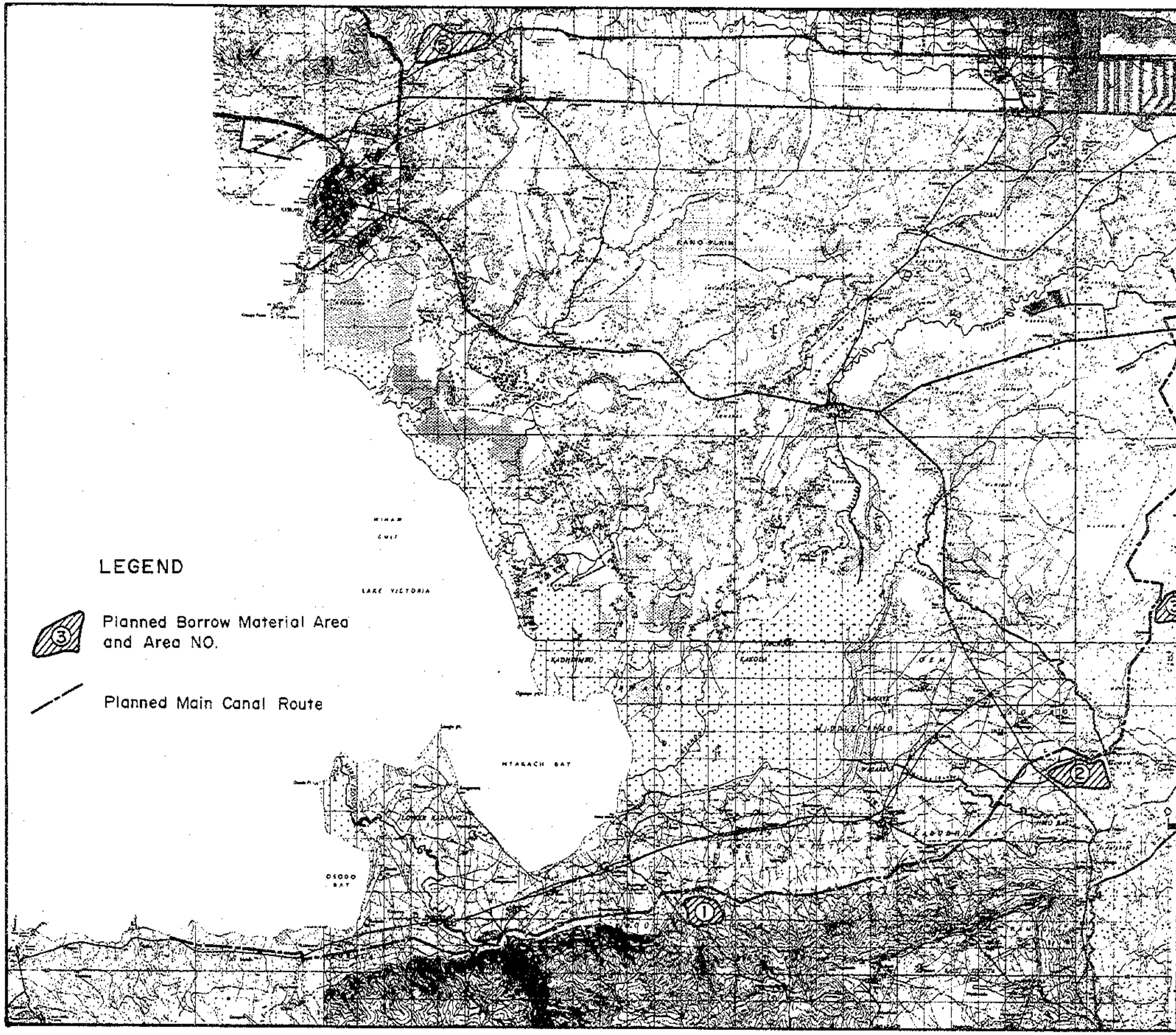

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Fig. II-8 Location Map of Borrow Material Area

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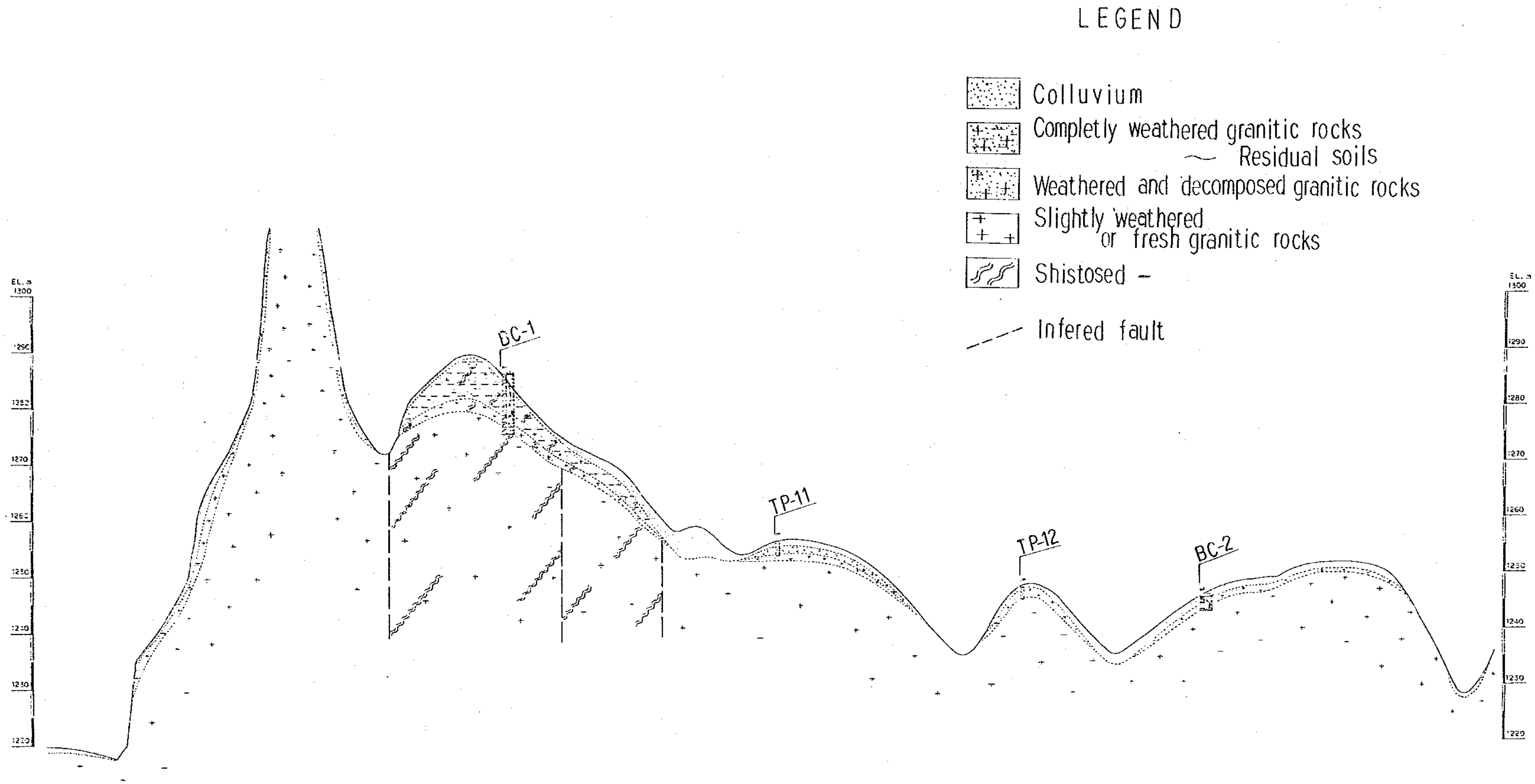

Fig. II-9 Geological Profile at Borrow Material Area 1

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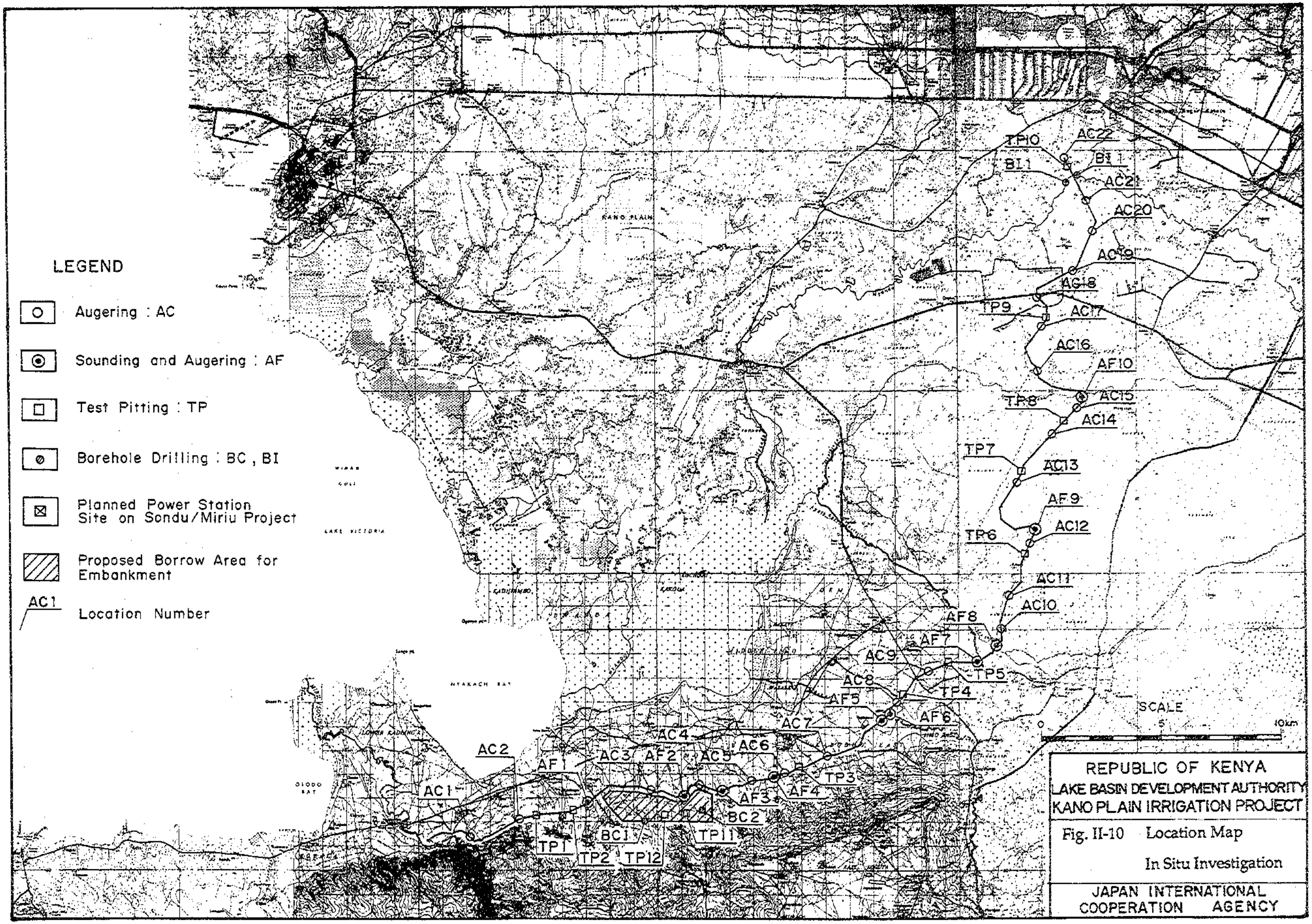

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Fig. II-10 Location Map
In Situ Investigation

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Clay

Silt

Sand

Rounded gravel

Angular gravel

Tuff or tuffaceous soils

Semi-irdurated soils or soft rocks

Lateritic ironstone

Completely weathered granitic rocks or residual soils

Granitic rocks

Tuff or tuffaceous rocks

Tuff breccia

Sand stone

Siltstone

Phonolite

Clayey -

Silty -

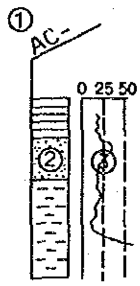
Sandy -

Soils containing some percent of sand

Gravelly (rounded) -

Gravelly (angular) -

Schistosed -



① Location No.
② Logged geological column
③ Depth/penetration value relation

Fig. II-11 A Summary of Logged Geological Column from Auger-holes, Test- pits and Boreholes (1 / 4)

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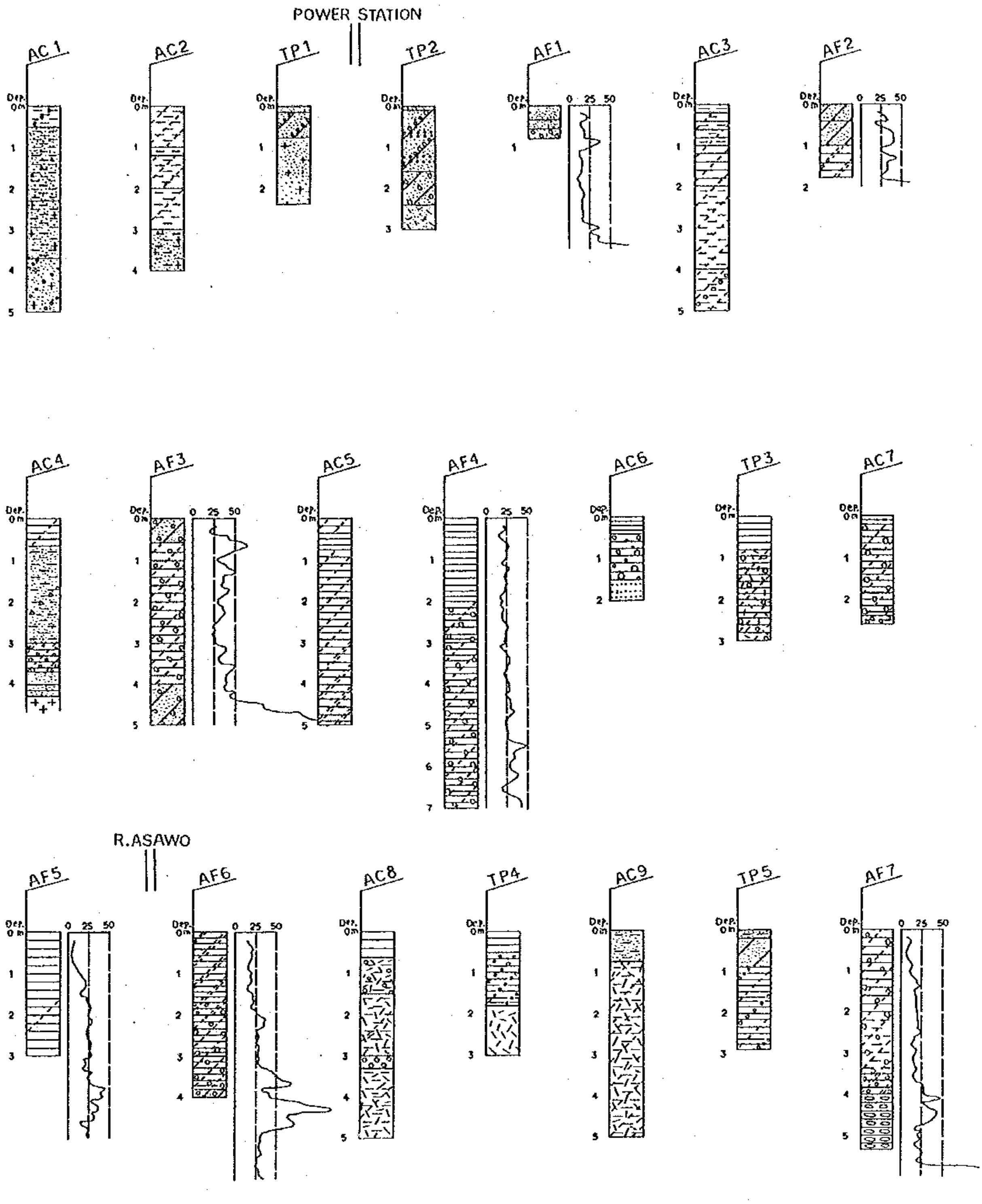

Fig. II-11 A Summary of Logged Geological Column from Auger-holes, Test- pits and Boreholes (2 / 4)

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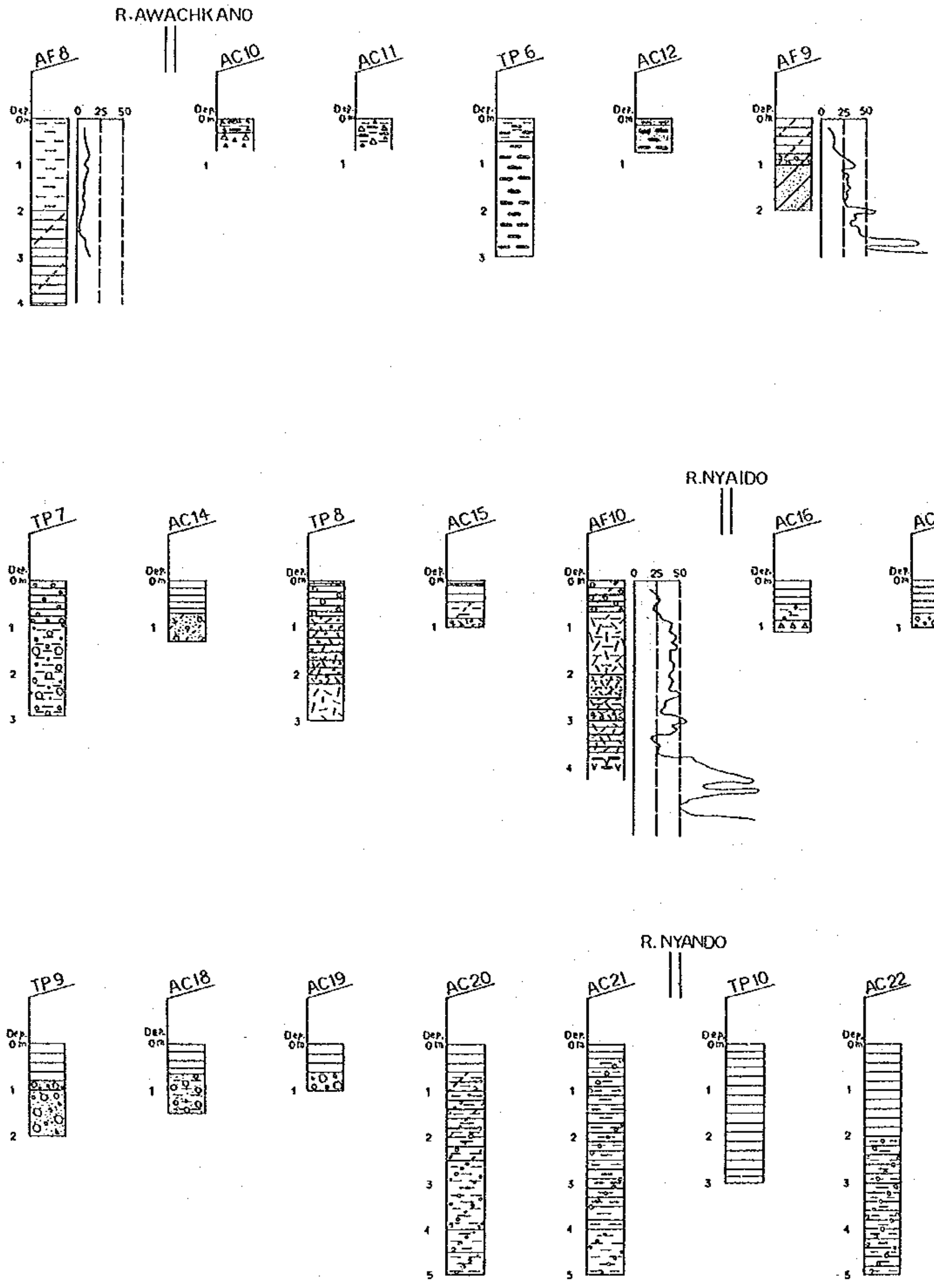

Fig. II-11 A Summary of Logged Geological Column from Auger-holes, Test- pits and Boreholes (3 / 4)

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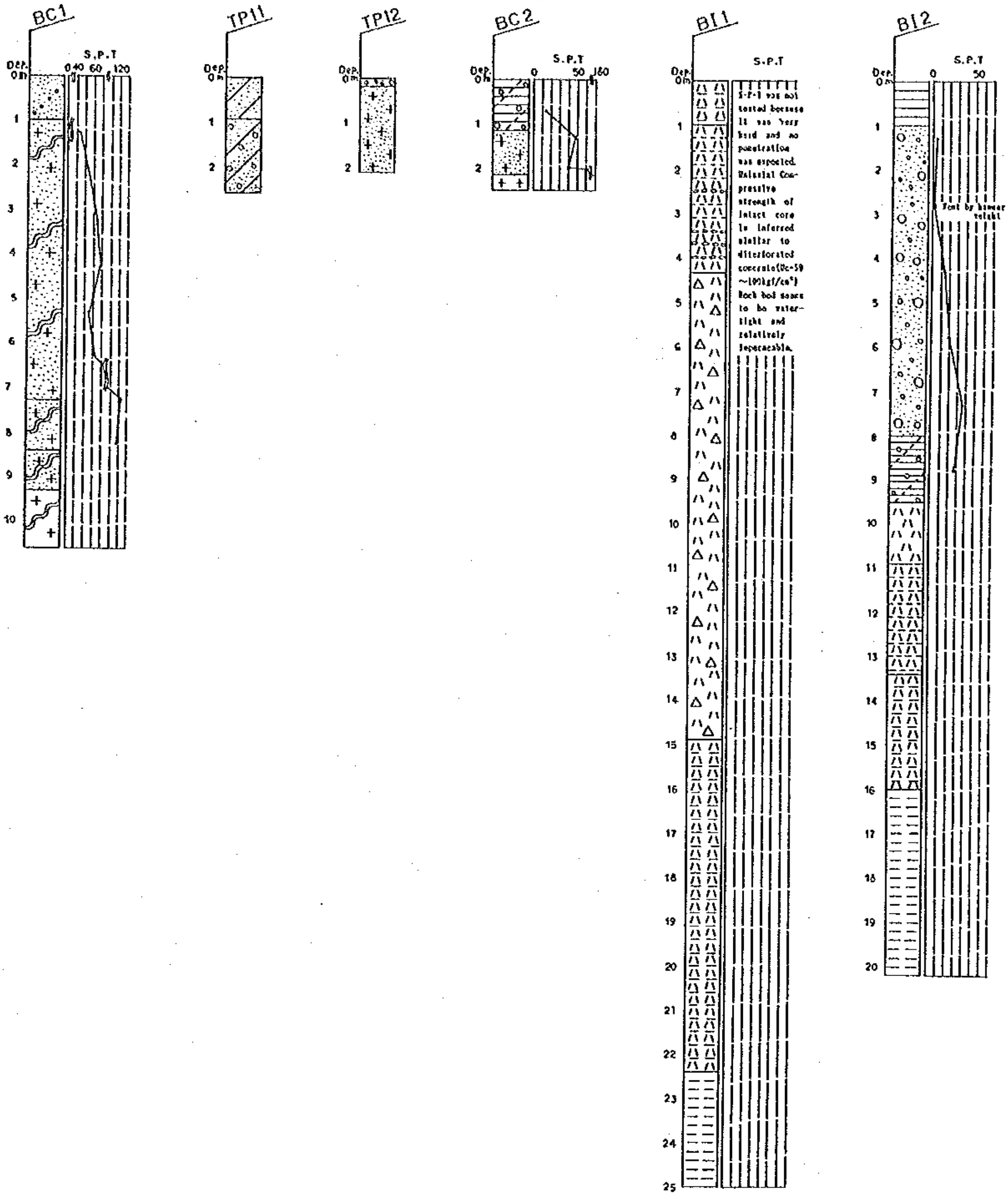

Fig. II-11 A Summary of Logged Geological Column from Auger-holes, Test- pits and Boreholes (4 / 4)

REPUYBLIC OF KENYA
KANO PLAIN IRRIGATION PROJECT

JAPAN INTERNATIONAL COOPERATION AGENCY

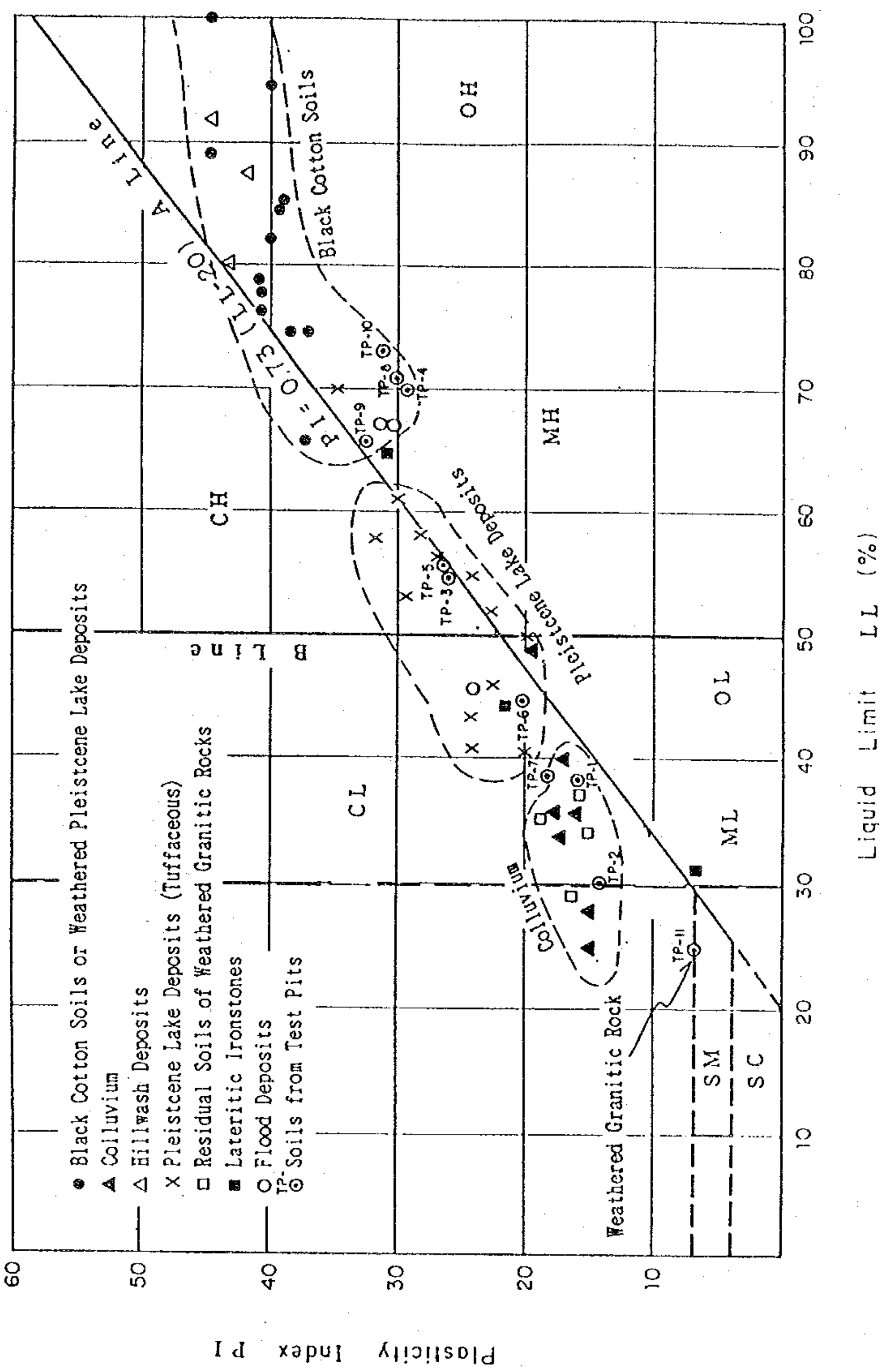

Fig. II-12 Liquid Limit - Plasticity Range

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