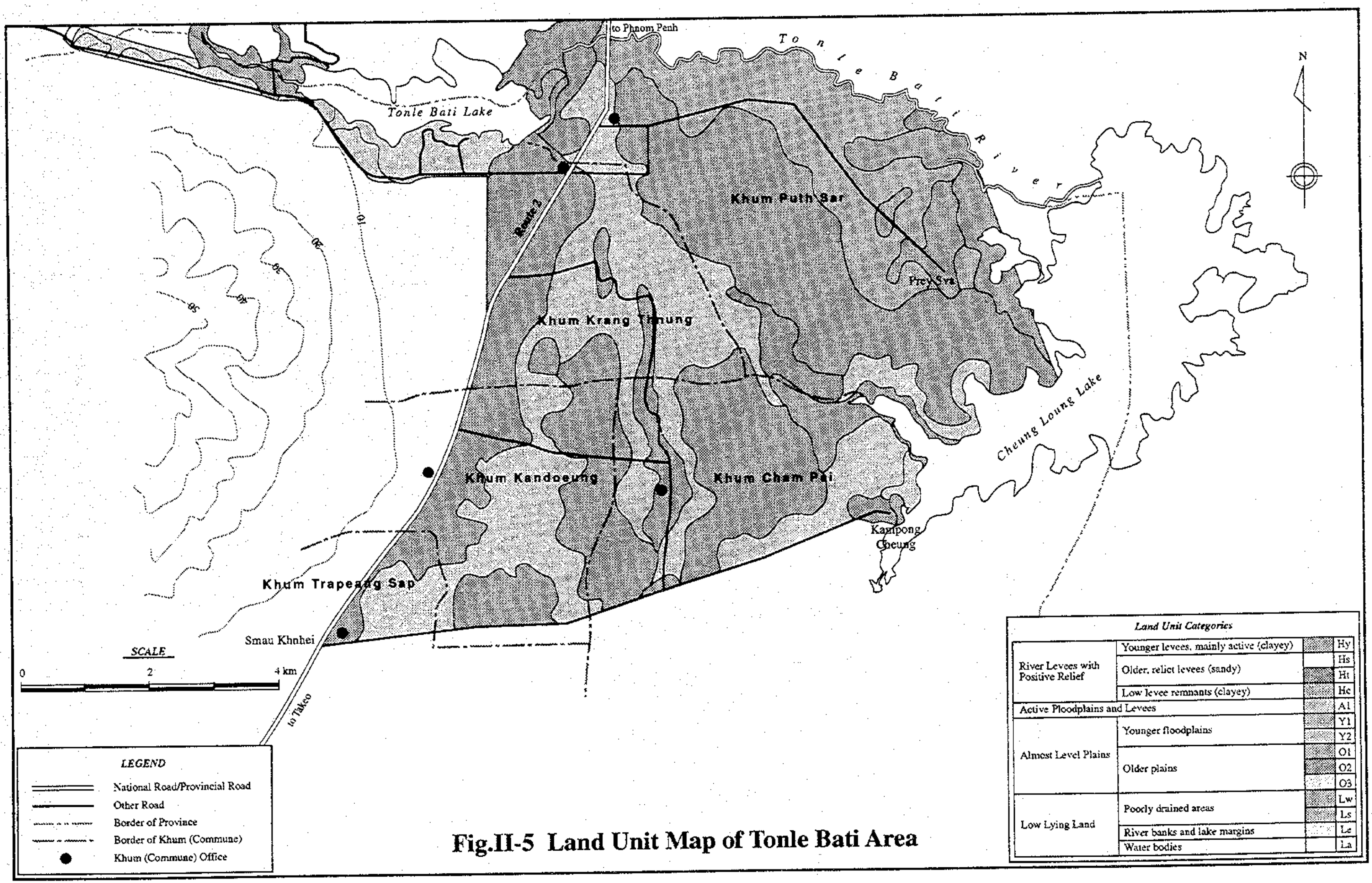

Fig.II-5 Land Unit Map of Tonle Bati Area

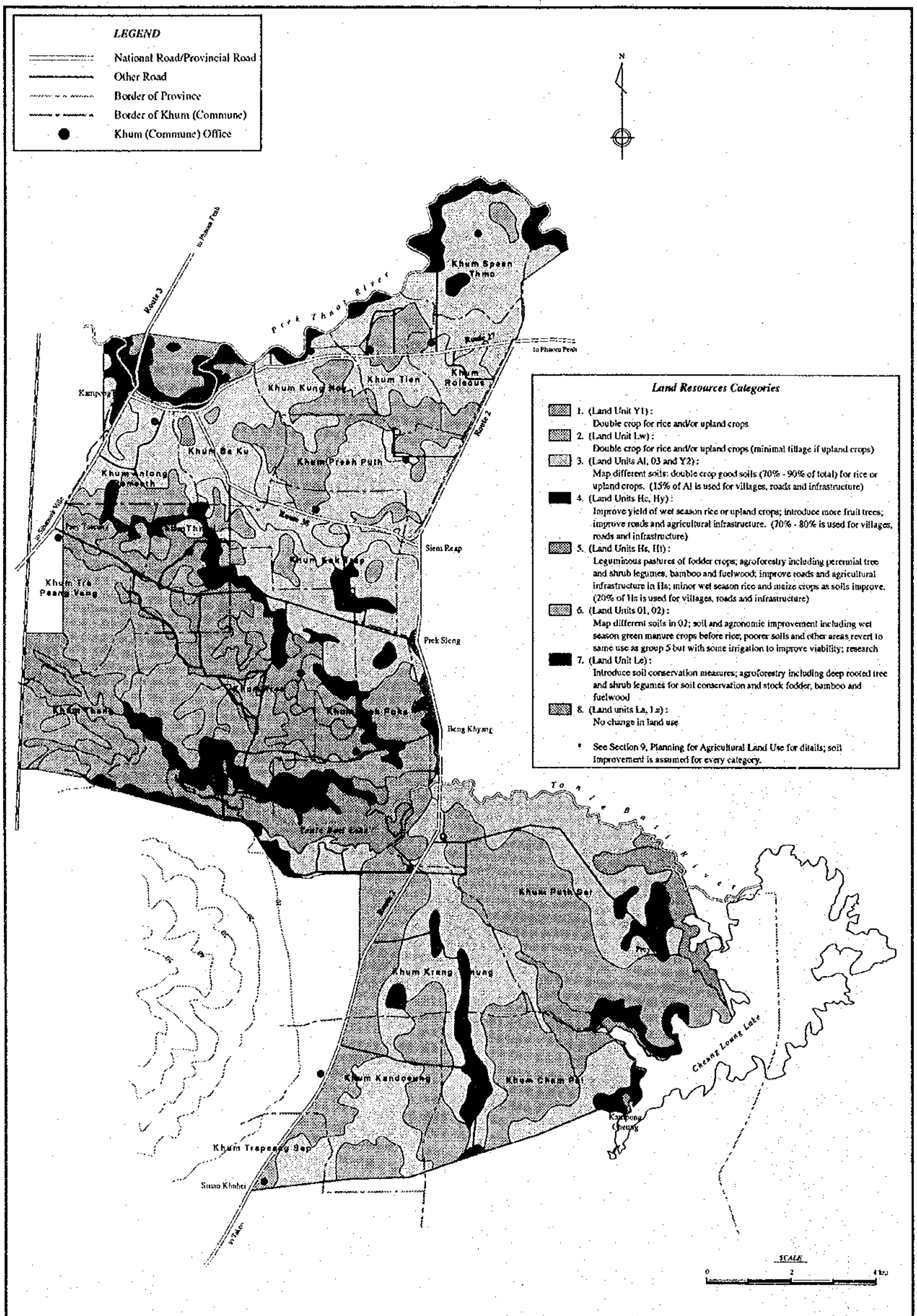

Fig. II-6 Land Resources Develpment Plan

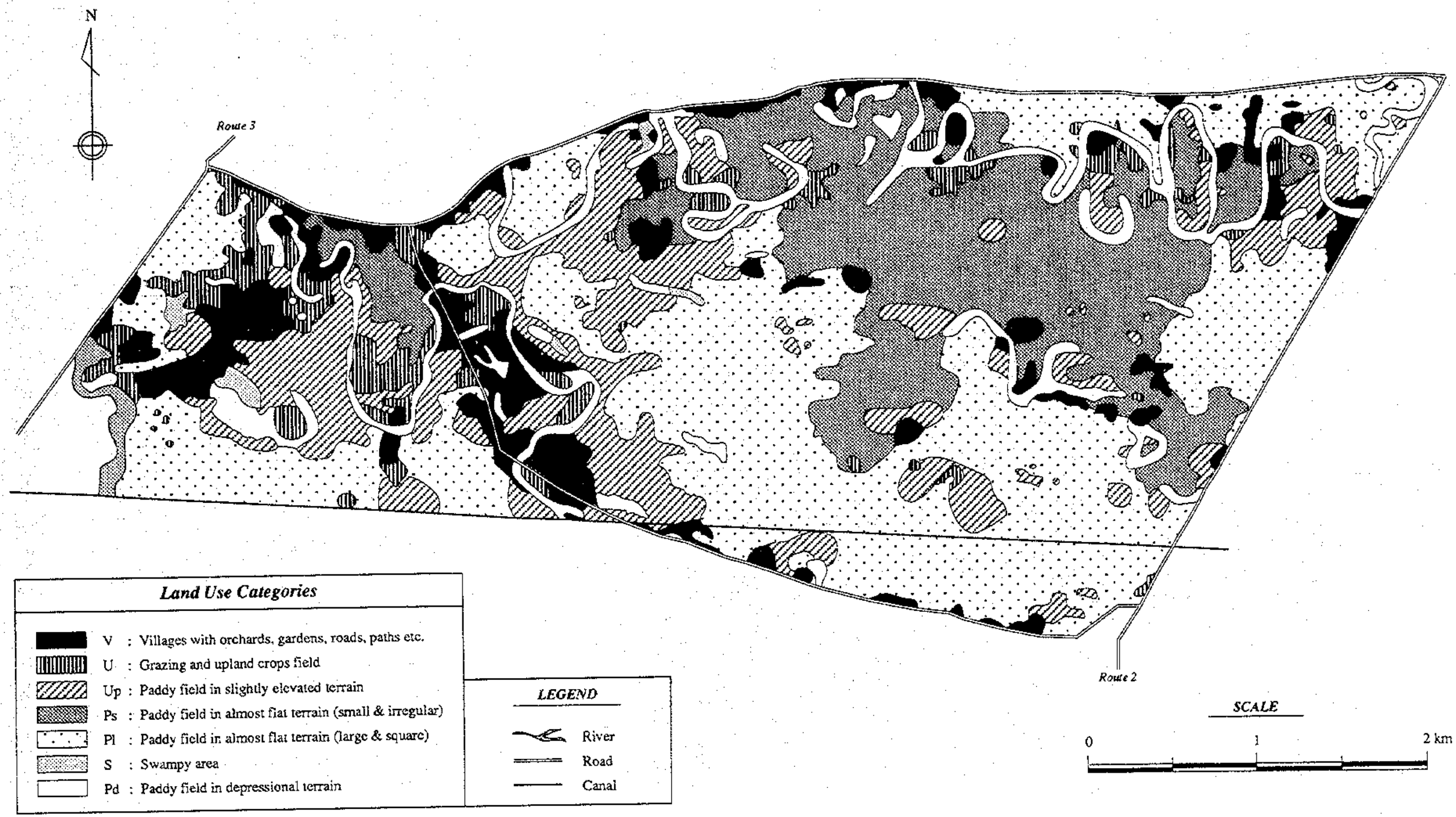

Fig. II-7 Land Use Map of Kandal Stung Priority Area

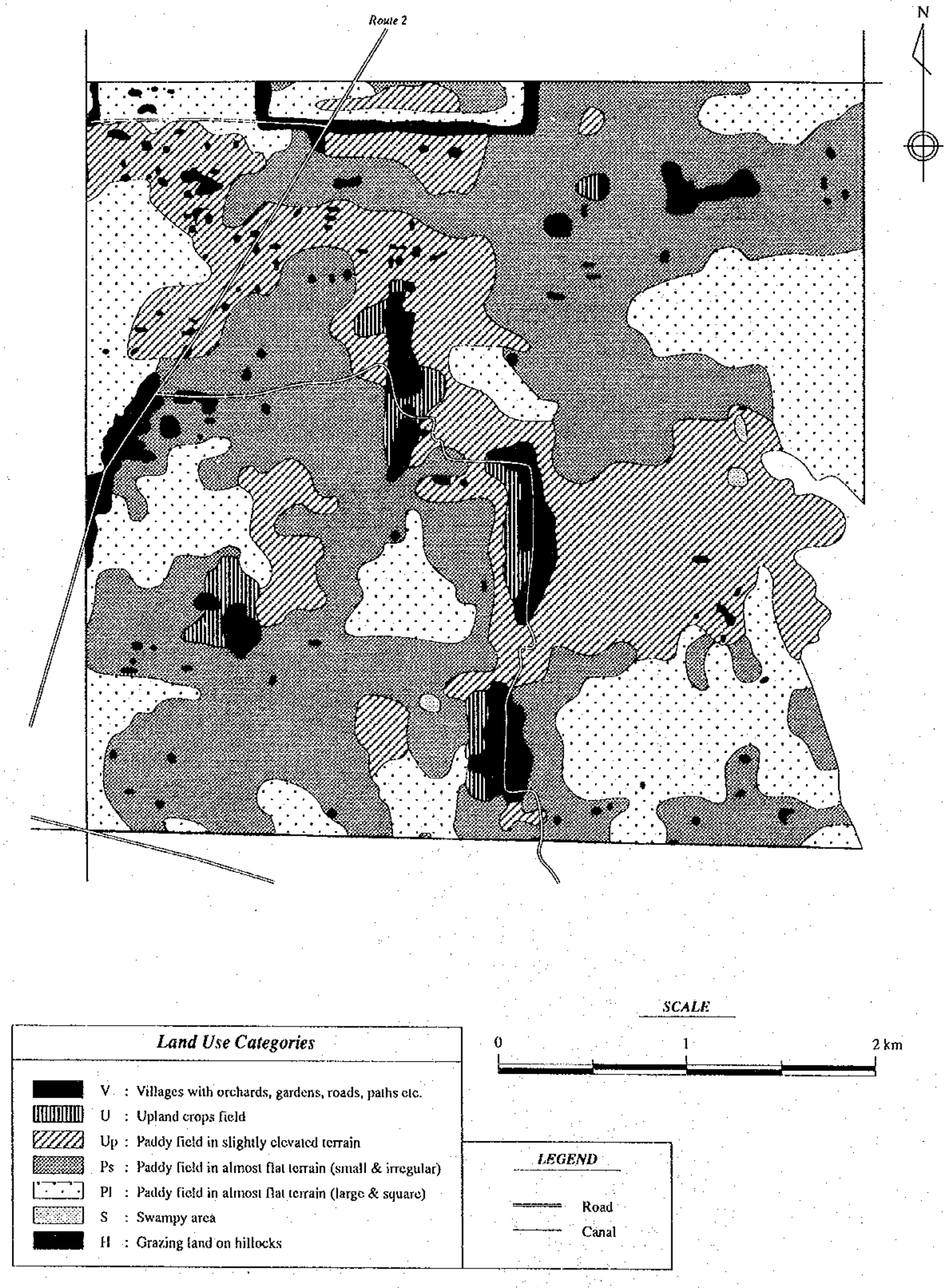

Fig. II-8 Land Use Map of Tonle Bati Priority Area

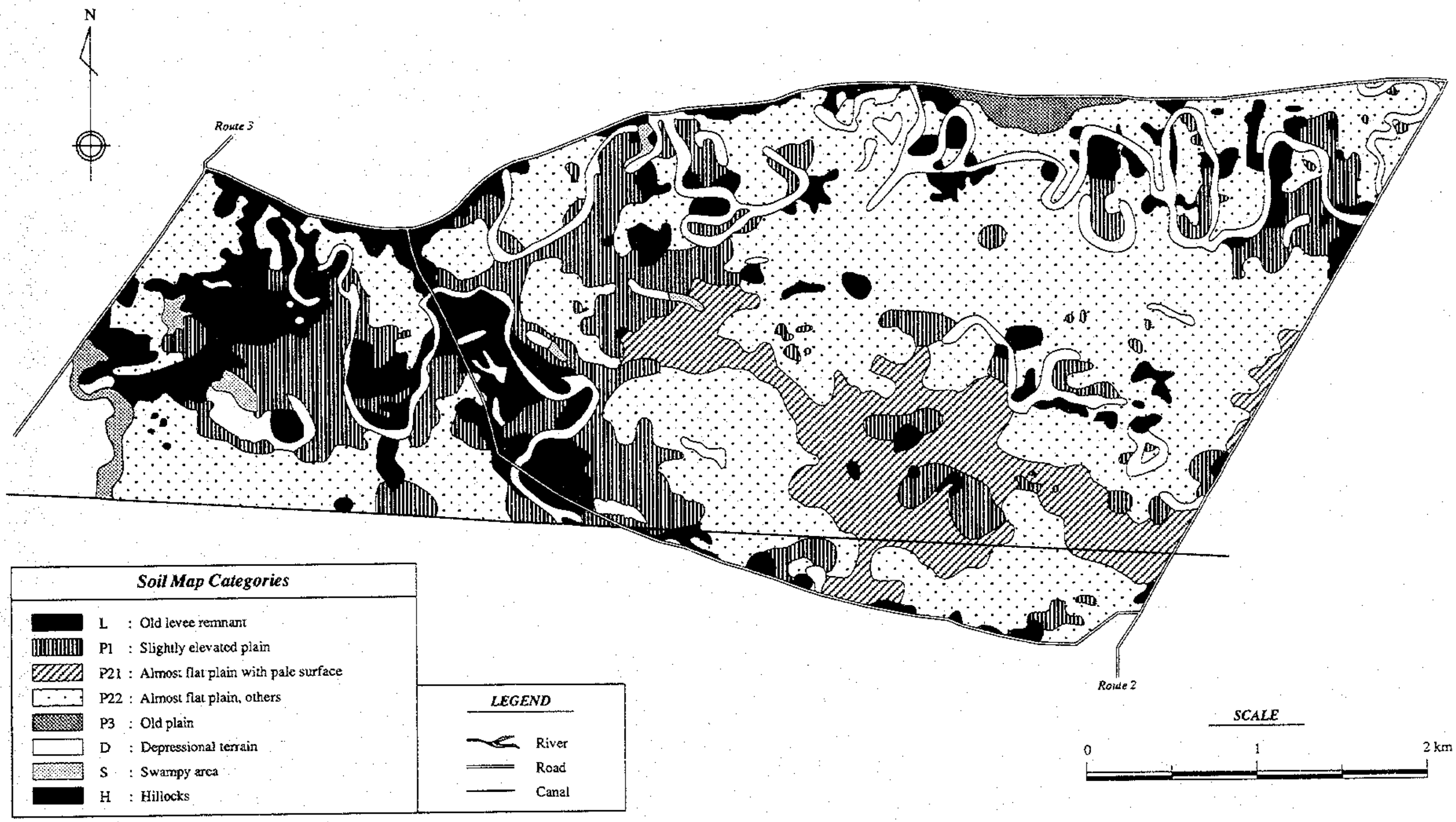

Fig. II-9 Soil Map of Kandal Stung Priority Area

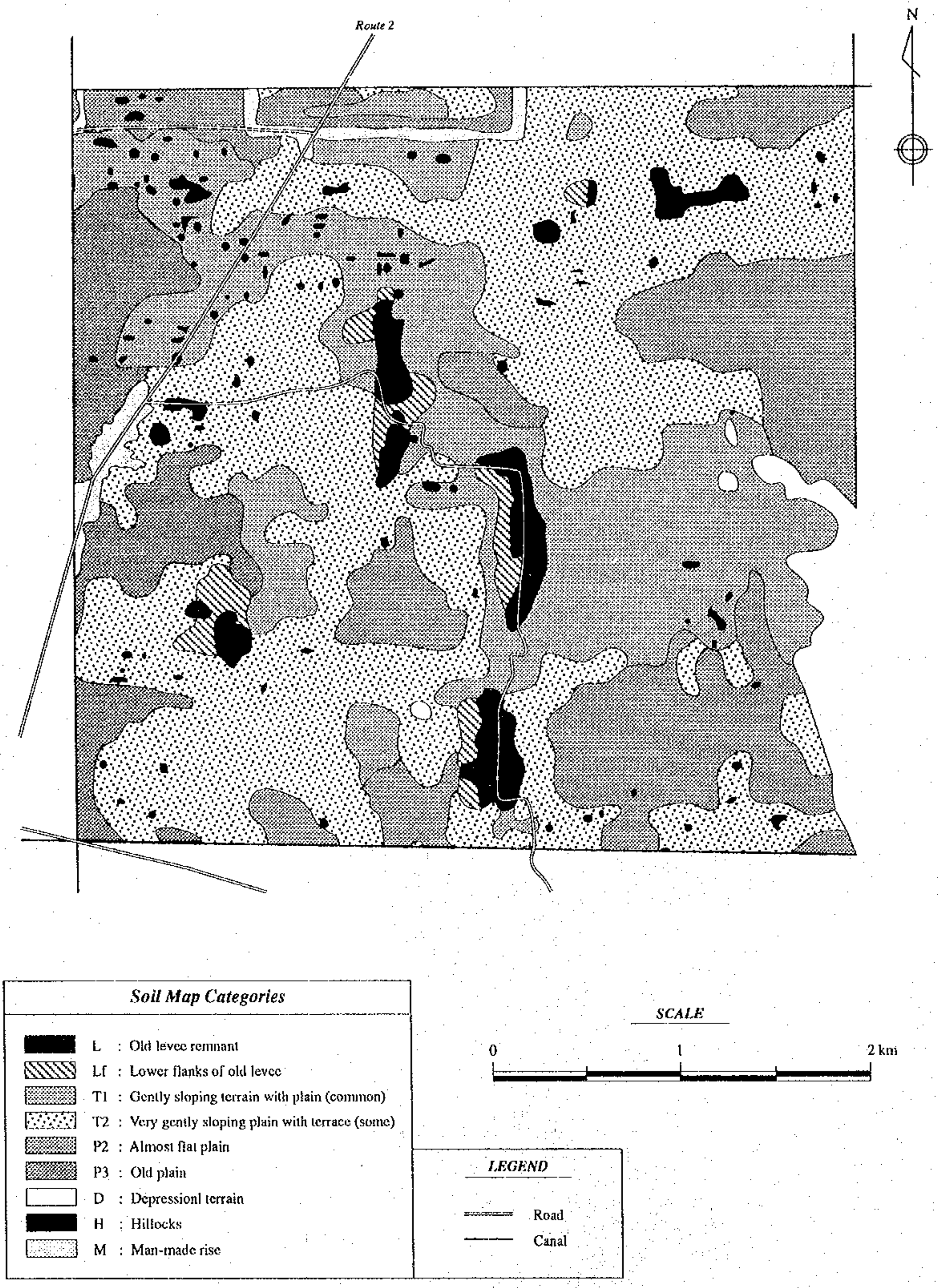

Fig. II-10 Soil Map of Tonle Bati Priority Area

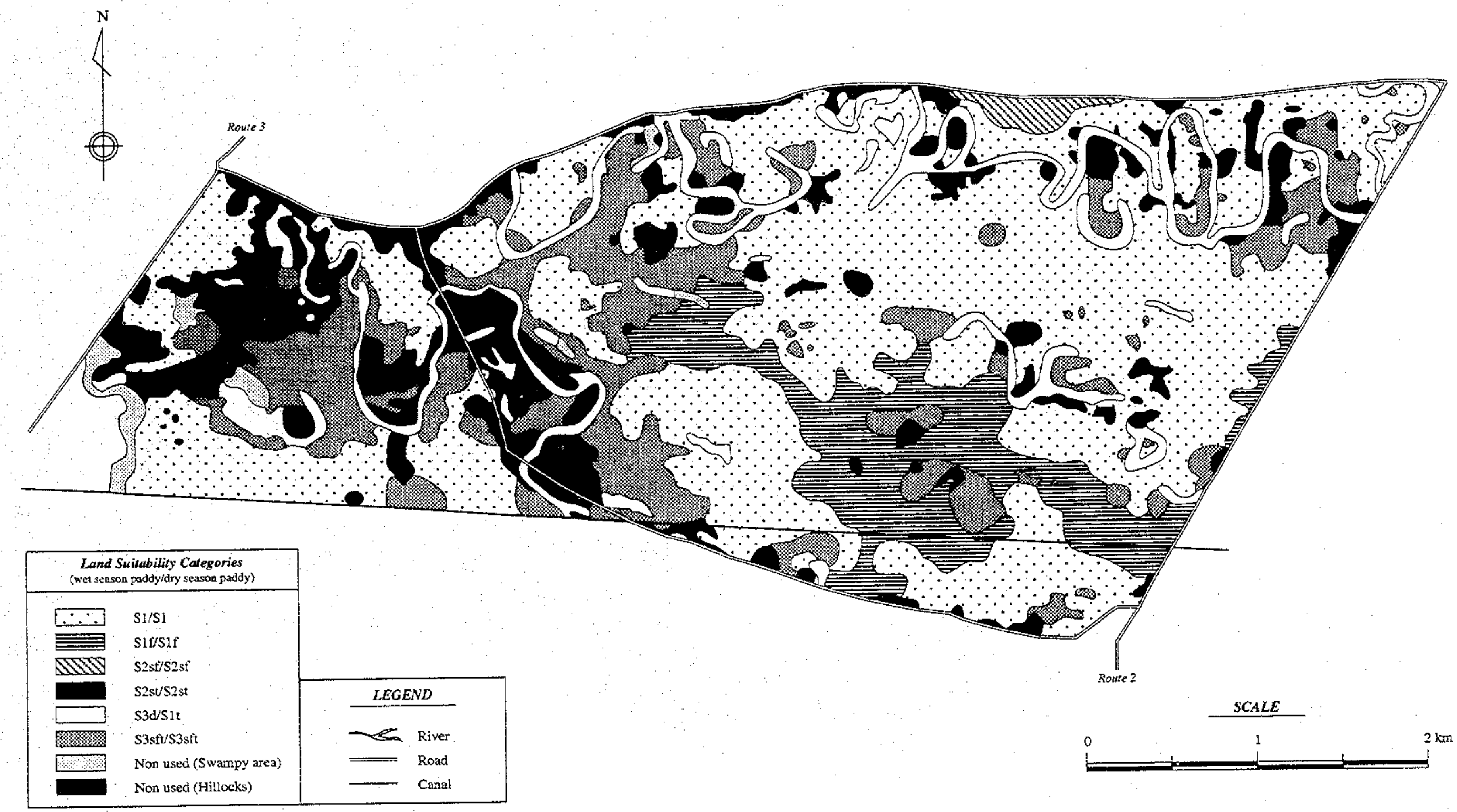

Fig. II-11 Land Suitability Map of Kandal Stung Priority Area (for Paddy) 1/2

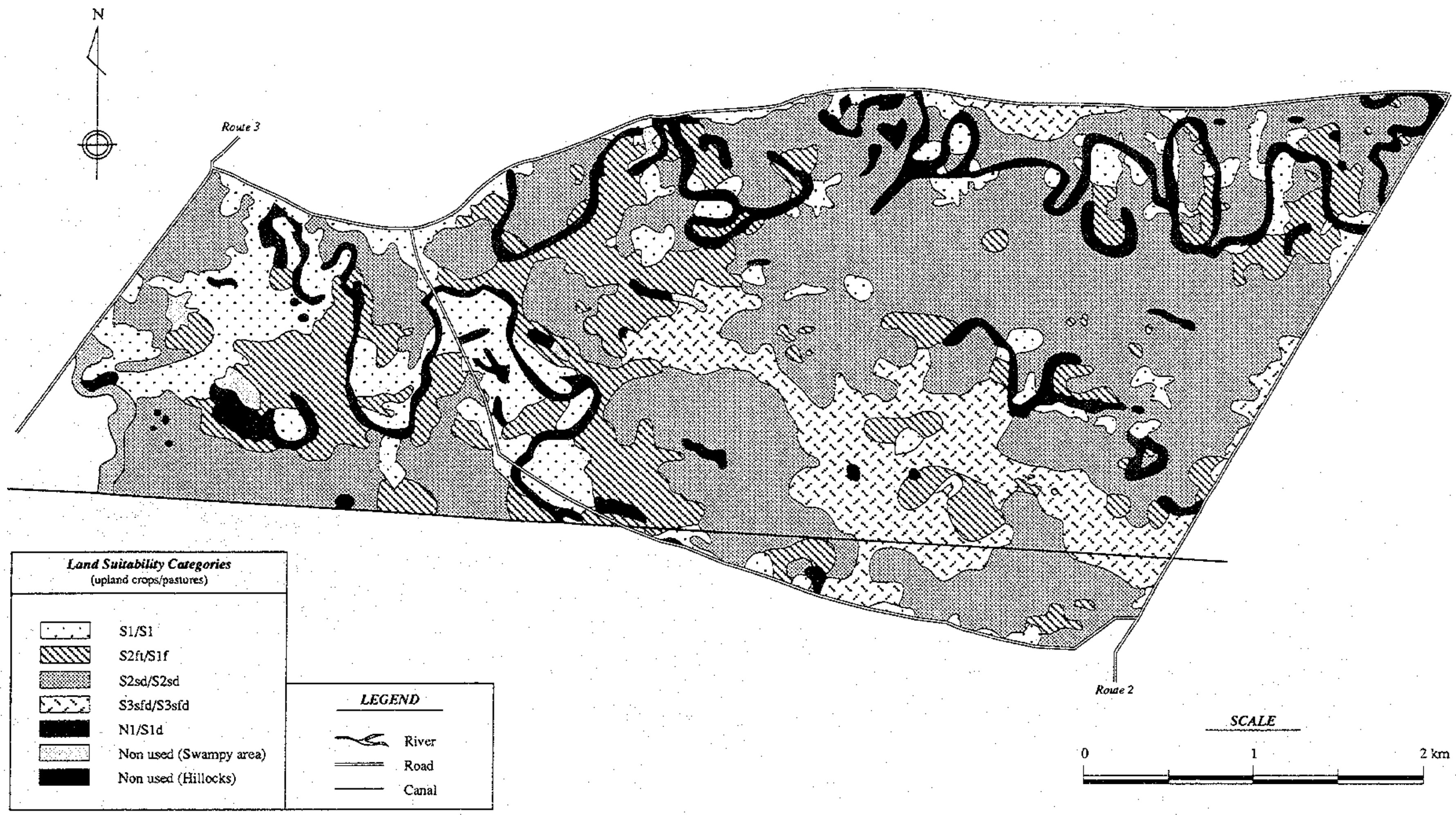

Fig. II-11 Land Suitability Map of Kandal Stung Priority Area (for upland crops) 2/2

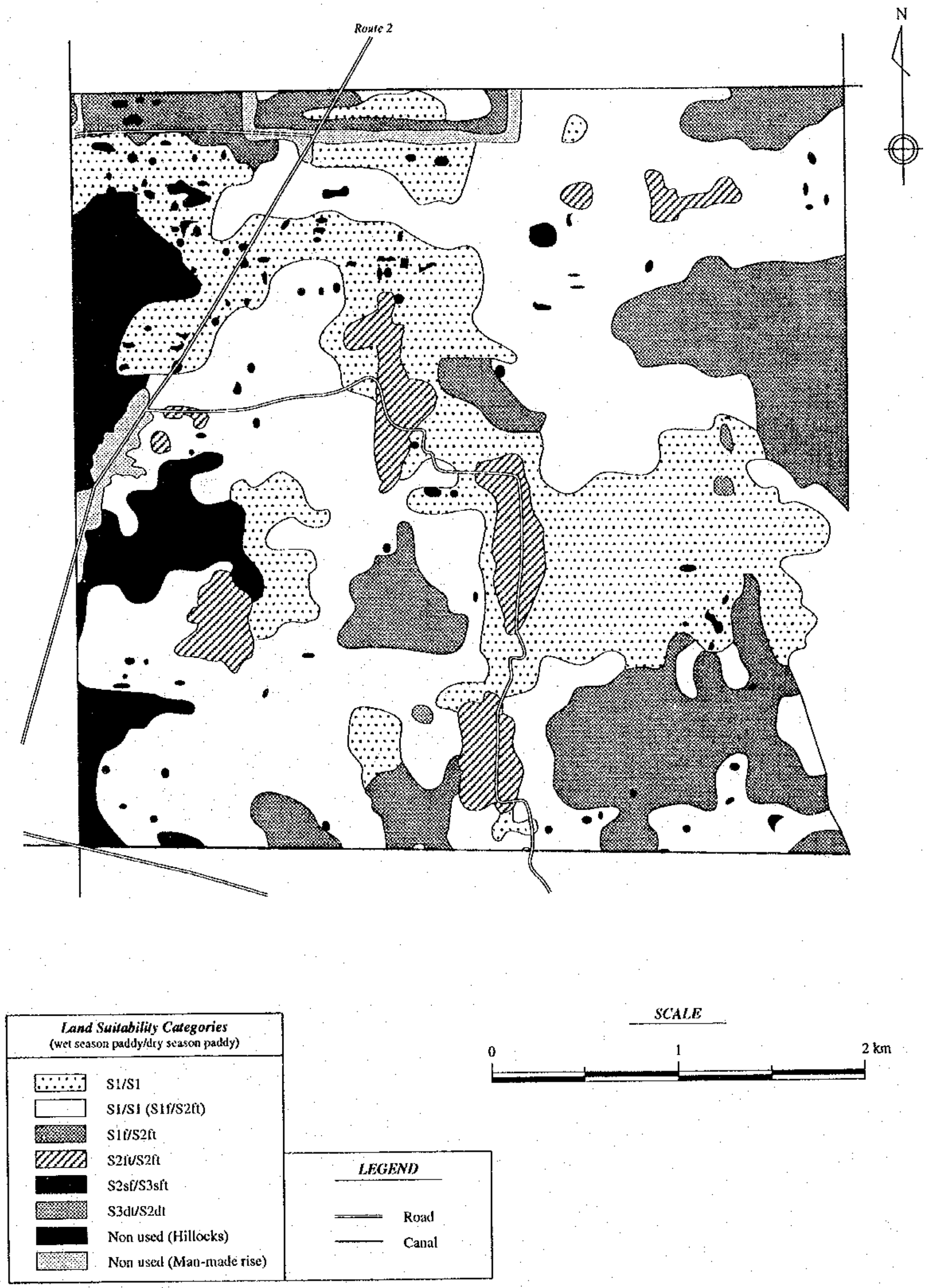

Fig. II-12 Land Suitability Map of Tonle Bati Priority Area (for Paddy) 1/2

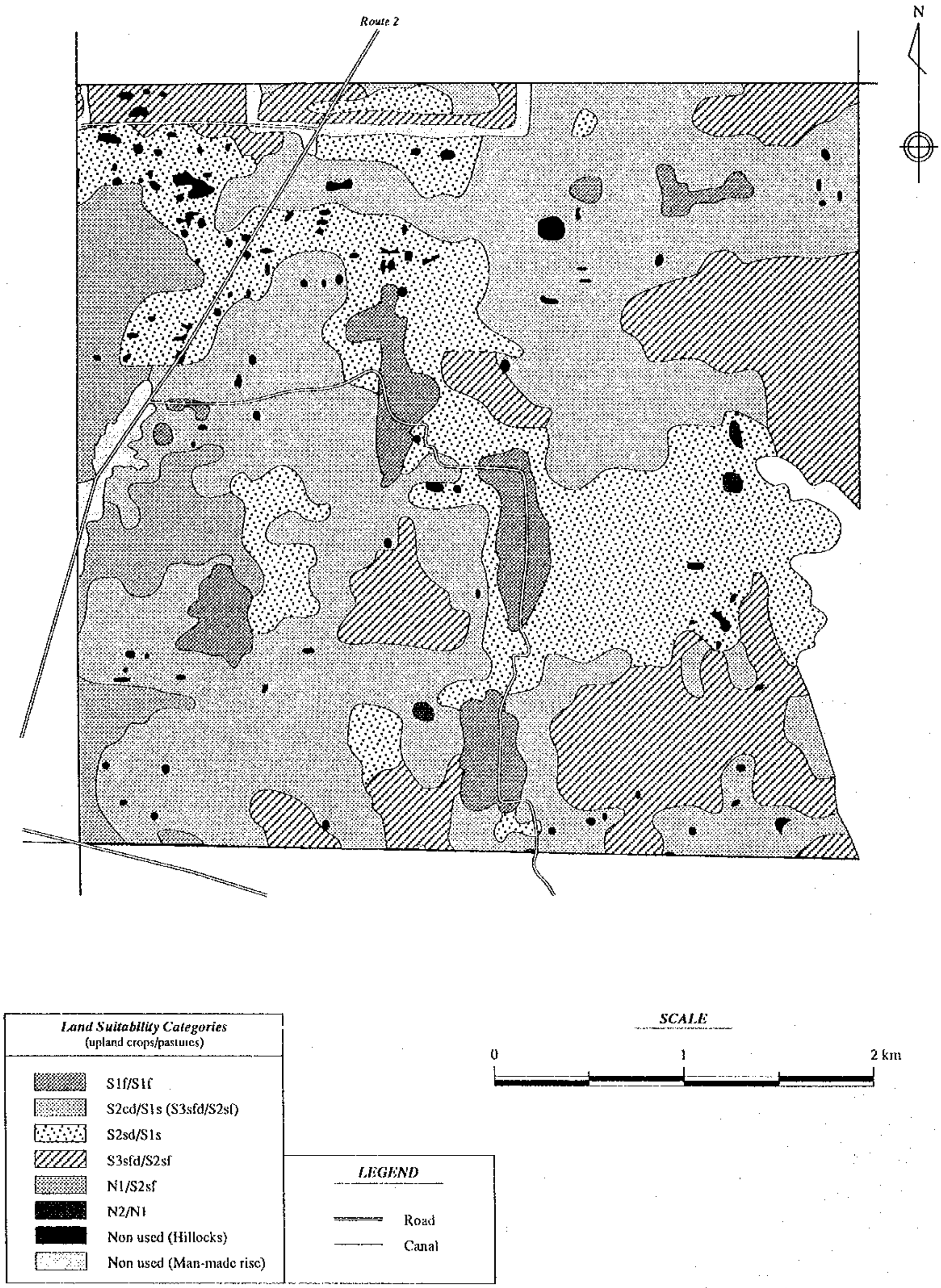

Fig. II-12 Land Suitability Map of Tonle Bati Priority Area (for upland crops) 2/2

APPENDIX II-1

SOIL PROFILE DESCRIPTIONS

FAO Classification:	Eutric Fluvisol
Mapped Land Unit(s):	Hy, A1
Landform:	River Levee
Soil Parent Material:	River alluvium
Soil Permeability:	Moderate
Soil Drainage:	Moderate
Flooding/Inundation:	To 0.5m. once or twice a year
Land Use/Vegetation:	Wet season rice
Summary Description:	Brown, massive, hard-setting silty clay on recent layered alluvium.

A1 (0-15cm):	Dark yellowish brown (10YR4/4), massive, firm, light silty clay with many fine distinct brown mottles; pH 5.8.
B21 (15-40cm):	Brown (10YR4/3), massive, firm medium clay with many medium faint grey mottles; pH 6.5.
B22 (40-100cm):	Brown (10YR4/3), massive, firm, light silty clay with many medium distinct grey mottles; pH 6.0.
BC (100-120cm):	Brown (10YR5/3), massive, very firm medium clay with many medium distinct grey and fine distinct brown mottles; pH5.8.

(The mottling in these soils is due to the presence of small lenses of silt and the weathering of parent material grains)

FAO Classification:	Vertic Cambisol
Mapped Land Unit(s):	A1, Y1, Y2
Landform:	Active floodplain
Soil Parent Material:	River alluvium
Soil Permeability:	Slow
Soil Drainage:	Imperfect - poor
Flooding/Inundation:	30-60cm, 2-3 times a year
Land Use/Vegetation:	Wet season rice
Summary Description:	Deep, yellowish brown, weakly structured, mottled silty medium clay on recent alluvium.

Ap (0-15cm):	Grey (10YR5/1), massive, firm, silty clay loam with brown root-line traces; pH 6.5-7.
B21 (15-40cm):	Brown (10YR4/3) or dark yellowish brown (10YR4/4), firm clay or silty clay with common brown mottles and weak angular blocky structure; pH 6-7.
B22 (40-75cm):	Dark yellowish brown (10YR4/4, 4/6) or yellowish brown (10YR5/6), very firm medium to heavy clay with many medium distinct grey and brown mottles and weak angular blocky structure; pH 6.5-7.5.
B23 (75-120cm):	Yellowish brown (10YR5/4, 5/6) very firm silty clay to medium clay with common medium brown mottles and very weak angular blocky structure; pH 6-7.5.

(The grey colour of the Ap horizon is due to inundation-induced reducing conditions under paddy rice)

FAO Classification:	Eutric Cambisol
Mapped Land Unit(s):	Y2
Landform:	Active floodplain
Soil Parent Material:	River alluvium
Soil Permeability:	Slow to very slow
Soil Drainage:	Imperfect
Flooding/Inundation:	30-60cm, 2-3 times a year
Land Use/Vegetation:	Wet season rice
Summary Description:	Shallow, yellowish brown, silty clay on recent alluvium of low permeability.

Ap (0-15cm):	Greyish brown (10YR5/2), massive, firm silty loam with brown root-line traces; pH 7.
B (15-40cm):	Yellowish brown (10YR5/4), massive, firm silty clay with common medium brown mottles; pH 7.
C (40-120cm):	Brown (10YR5/3), dry, hard, massive silty clay loam with many silt lenses; pH6.5.

(The greyish colour of the Ap horizon is due to inundation-induced reducing conditions under paddy rice. The dryness and apparent very low permeability of the C horizon may be due to the presence of platy silt particles which block soil pores)

FAO Classification:	Dystric or Ferralic Cambisol
Mapped Land Unit(s):	Hc, O3
Landform:	Relict levee
Soil Parent Material:	River alluvium
Soil Permeability:	Slow to very slow
Soil Drainage:	Poor
Flooding/Inundation:	Nil
Land Use/Vegetation:	Villages, transport corridors
Summary Description:	Slightly elevated, poorly drained, dense, mottled heavy clay on old river levees.

A1 (0-15cm):	Brown (10YR4/3, 5/3), massive, hard, fine sandy clay loam; pH 6-7.
B1 (15-30cm):	Dark brown (10YR4/3) or dark yellowish brown (10YR4/4), massive, firm to very firm sandy clay or light clay with a few medium distinct brown mottles; pH 6.5-7.5.
B21 (30-60cm):	Brown (10YR4/4) or strong brown (7.5YR5/6), dense but sometimes weakly structured heavy clay with many fine and medium brown and reddish mottles; some dark cutans; pH 7.5-8.
B22 (60-120cm):	Strong brown (7.5YR4/6, 5/6), very dense, weakly structured heavy clay with many red and grey mottles, a few ferro-manganiferous nodules and dark cutans on ped faces; pH 8.

(the occurrences in land unit O3 are on the small remnants of relict levee 'Hc')

FAO Classification:	Gleyic Acrisol
Mapped Land Unit(s):	O1, O2, O3
Landform:	Old alluvial plain
Soil Parent Material:	Old river alluvium
Soil Permeability:	Slow to very slow
Soil Drainage:	Very poor
Flooding/Inundation:	No natural flooding; man-made floods due to drainage diversion now occur irregularly
Land Use/Vegetation:	Poor quality wet season rice
Summary Description:	Old, strongly mottled, sticky sandy loams over heavy clays with rounded sand grains and very poor drainage.

Ap (0-15cm):	Brown (10YR4/3, 5/3), massive, firm sandy loam or sandy clay loam; pH 5.5.
E or B1 (15-35cm):	Brown (7.5YR5/4) or light brown (7.5YR6/4) massive, sticky, firm sandy clay loam with common to many fine to medium yellow and brown mottles; pH 5-5.5.
B21 (35-75cm):	Strong brown (10YR5/6, 7.5YR5/6), massive, sticky, very firm heavy sandy clay or medium clay with sand, with many red and grey mottles and about 2% ferro-manganiferous nodules; pH 5.
B22 (75-120cm):	Light yellowish brown (10YR6/4) or reddish yellow (7.5YR6/6), massive, very firm heavy clay with sand, with many medium to large red and grey mottles and from 5% to 20% 20mm ferro-manganiferous nodules, sometimes laterite; pH 5.

(Laterite sometimes occurs at shallow depth; all profiles have an increment of medium sized, reddish, rounded sand grains throughout and probably kaolinitic clay minerals)

FAO Classification:	Orthic or Albic Luvisol
Mapped Land Unit(s):	Ht, Hs, O2.
Landform:	Old river levee
Soil Parent Material:	Old river alluvium
Soil Permeability:	Slow to very slow
Soil Drainage:	Very poor
Flooding/Inundation:	Nil
Land Use/Vegetation:	Bamboo or other pioneer vegetation; some poor quality rice; cattle.
Summary Description:	Old, mottled, sticky loamy sands over sandy clays with rounded sand grains and very poor drainage.

A1 (0-10cm):	Brown (10YR4/4, 5/4), massive, firm, loamy sand or clayey sand; pH 5.5-6.
E/A3 (10-45cm):	Strong brown (10YR5/6, 7.5YR5/6), massive, firm or hard sand, loamy sand or clayey sand with a few yellowish mottles; pH 5.5-6.
B21 (45-85cm):	Light brown (7.5YR6/4) or light yellowish brown (10YR6/4), firm to very firm, massive, light sandy clay loam to light sandy clay with common to many medium distinct brown and yellowish mottles; pH 6-7 (or more).
B22 (85-120cm):	Light brown (7.5YR6/4) or yellowish brown (10YR5/4) or darker, massive, dense sandy clay with many medium distinct brown and grey and some reddish mottles; 2-5% small, rounded ferromanganiferous nodules; pH 7-8.

(all profiles have an increment of medium sized, reddish, rounded sand grains throughout and probably kaolinitic clay minerals. The occurrences in land unit O2 are on the small remnants of the old sandy levee 'Hs')

FAO Classification:	Albic or Luvic Arenosol
Mapped Land Unit(s):	Hs
Landform:	Old river levee
Soil Parent Material:	Old river alluvium
Soil Permeability:	Rapid
Soil Drainage:	Well to moderately well drained
Flooding/Inundation:	Nil
Land Use/Vegetation:	Villages and transport corridors; orchards, gardens, cattle; bamboo or other pioneer vegetation.
Summary Description:	Old, deep, somewhat leached reddish sands and clayey sands with a near neutral pH.

A1 (0-10cm):	Brown (10YR4/3), dark yellowish brown (10YR4/4) or redder, soft, massive (single-grained) sand with rounded, coated grains and pH 6-6.5.
B1 (10-50cm):	Reddish brown (5YR5/3), brown (7.5YR5/4) or strong brown (10YR5/6), soft to firm, massive sand or clayey sand with a few brownish mottles and a pH of 6-7.
B2 (50-120cm):	Light reddish brown (5YR6/4), light brown (7.5YR6/4) or strong brown (7.5YR5/6), soft to firm sand or clayey sand with a few brownish mottles and a pH of 7; minor very small ferromanganiferous nodules.

(all profiles contain medium sized, reddish, rounded sand grains with some presumably kaolinitic clay)

OTHER SOILS

The following soils were observed on only a few occasions and appear to be very limited in extent, consequently they were not allocated separate taxonomic status. However, in an intensive irrigation scheme any soil can be important especially if it is sandier, more elevated, less fertile, or less well drained than the usual soils of the land unit concerned. These soils and their locations are described below:

1) A variant of the Gleyic Acrisol that occurs in land unit O1 was found twice in the south east, alongside Lake Cheung Loung. This soil is greyer (commonly brownish yellow; 10YR6/6), has only about 15cm of sandy soil on the surface, and has only medium clay in the B horizons. It is also very poorly drained indeed. It is possible that this soil has had some lacustrine influence from the Tonle Bassac River swamps and backplains.

2) A second variant of the Gleyic Acrisols found only once in land unit O2 but which may occur also to a limited extent in land units O1 and O3 has a very high pH - at least 9 throughout the profile. These are very poor soils and are probably toxic to plant growth. Similarly, a high pH variant of the Orthic/Albic Luvisols occurs occasionally in land units Ht and Hs; these have pH 8-8.5 below about 60-85cm depth. High pH was also occasionally encountered in the Dystric/Ferralic Cambisols of land unit Hc.

2) In land unit Y2 some soils thought to be formed in old river beds were described. These are Regosols, with coarse to medium sand texture profiles and an overlay of sandy clay about 15cm deep. The sand grains are sub-rounded, which implies transport by river water. The overlay of sandy clay is probably a result of years of terracing and cultivation of these soils (along with adjoining soils) for wet season rice. In the wet season the low water holding capacity and rapid infiltration rates of the soils is not important but they appear to be very infertile and produce very poor rice crops.

3) Regosols also occur in the tiny area in the far south which is a small sandy outlier of the rocky hill country that lies to the south west, around Phnom Thma Doh and Phnom Phdau Pam. These were not inspected but local descriptions indicate that they are probably Regosols.

4) Remnant patches of old river levees were also found in land unit Y2. These were not closely inspected as they appear to be quite rare, but from the natural exposures observed they appear to have characteristics between those of the active levees of land unit Hy and the relict ones of land unit Hc.

5) The swamps that occur in land units Lw and Ls were not inspected in detail but probably have very poorly drained, organic - surfaced, strongly mottled clay soils formed in a paludal environment (Gleysols).

6) The soils that occur in land unit Le vary depending upon the land units that adjoin each occurrence, but they are usually eroded or partially truncated.

ANNEX III

GEOLOGY AND EMBANKMENT MATERIALS

ANNEX III

GEOLOGY AND EMBANKMENT MATERIALS

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1. GENERAL

1.1 Scope of Works

The purposes of this investigation are as follows:

a. to obtain general geological information in the project area,

b. to clarify the foundation geology of Kompong Tuol Regulator Site, Tuk Thla Regulator site and National Road No. 3 Dike Site,

c. to select borrow sites and evaluate embankment materials.

In order to achieve the above purposes the following investigations were carried out.

a. Collection of existing geological information.

b. Geological surface survey in the project area.

c. Borehole investigation at the regulator sites in parallel with in-situ permeability tests and standard penetration tests.

d. Laboratory tests of the soil sampled from borehole.

e. Test pit investigation for embankment materials.

f. Laboratory soil tests for embankment materials.

These site investigations were carried out in June and July 1994.

1.2 Data Collection

Existing relevant data and information of Cambodia and the project area were collected through the Department of Hydrology, the Ministry of Agriculture, Forestry and Fisheries.

2. GENERAL GEOLOGY

2.1 General Features

The studied site is underlain by the following geological formations.

Geological age	Formation
Quaternary	Talus
	Old Alluvium
	Young Alluvium
	Recent Alluvium
Triassic	Indosinas Group
Devonian	Quartzite
	Hornblende Granite

2.2 Geological Formation

Characteristics of the above geological formations are described below in the ascending order (from older to younger formations in age).

(1) Devonian Quartzite

This formation underlies the area of Phnum Chong Stoek (Phnum Tatea), south-east of the project area, and outcrops along the ridge of hills.

The Quartzite predominantly consists of quartz and colorless minerals, and is characterized by very hard rock quality.

(2) Hornblende Granite

This formation underlies the area 4 km south-west of Boeng Tonle Bati and outcrops on the tops of the both peaks of Phnum Tatea Do, Phnum Phdau Pam.

The Hornblende Granite consists of holocrystalline quartz (5 - 10 mm in size) predominantly, and small amount of feldspar and hornblende (1 - 3 mm in size). Fresh part of this rock is very hard , although the rock is soft where weathered.

(3) Indosinas Group

This formation outcrops in Phnum Hophu south-west of the project area, predominantly consists of greenish medium-grained hard sand intercalated by shales (5 - 20 m thick), with quartz veins (0.02 - 0.20 m).

The formation strikes 70 degrees from the north to the east, dips 75 degrees to north.

(4) Talus

Talus underlies two main areas: (a) around Phnum (Mt.) Chong Stoek, (b) Phnum (Mt.) Tatea Do and Phdau Pam.

a. Talus around Phnum Chong Stoek consists of 70% of siliceous angular gravel, 30% of fine sand or silt; originated from the Quartzite of the Phnum Chong; with a thickness more than 4 m. This Talus material has been utilized as a construction material for National Road No.2 and No.3.

b. Talus around Phnum Tatea Do and Phdau Pam predominantly consists of coarse grained quartz sand originated from weathered Hornblende Granite. This Talus is considered to be a recharger of ground water because of its high permeability.

(5) Old Alluvium

This formation underlies the alluvium terrace south-east of the project site, elevation of the terrace plane ranges from 10 m to 20 m; outcrops along the Pol Pot Canal extending from the Stung (river) Toch to the south. This is also observed at the side wall between 100 m and 900 m from the Tuk Thla Regulator along the canal extending from Prek Thnot to the west.

This formation predominantly consists of medium-coarse grained quartz sand intercalated by whitish , pail yellowish brown fine-grained soil; shows a sub-horizontal geological structure and lateral change of facies (inter fingering) in every several 10 m distance. Some parts of the coarse sand are cemented by oxidized iron, resulting in laterite; some parts of the fine-grained soil were oxidized to yellowish in color. Gathered manganese grains (10-25 mm in size) and irregular-shaped gypsum nodule (10-100 mm in size) are observed in this formation.

The Old Alluvium is generally susceptible to erosion, particularly the fine-grained soil is dispersive when saturated and subject to piping. On the other hand a part of the coarse sand outcropping on the side wall between 500 - 700 m within the exposed area of 100 m - 900 m from the Tuk Thla Regulator along the canal is dense, forming a vertical cliff. And the whitish fine-grained soil layer which intercalates in the dense coarse sand in this area is firm.

(6) Young Alluvium

This formation underlies the alluvium lower plane, -the elevation of the plane surface ranges from El. 5m to 10 m-, in the north area from a approximate virtual linear line connecting Stoeng Toch and a point 1 - 2 km south of Stoeng Tonle Bati; consists of fine-grained soil and sand with the maximum thickness of 10 m.

The fine-grained soil is very hard when dry, but soft and dispersive when saturated.

This formation overlies the Old Alluvium and underlies the Recent Alluvium in a form of diastem (slight uncomformity).

(7) Recent Alluvium

This formation is exposed on the river bed and the river side of Prek Thnot, Stoeng Toch, and the lake side of Boeng Tonle Bati; consists of very soft sandy fine-grained soil and loose sand with the maximum thickness of 10 m. The sandy fine-grained soil and the loose sand change their faces laterally to each other (inter-fingering).

2.3 Distribution of Geology in the Project Area

Geological cross sections of Kandal Stung Irrigation Area and Tonle Bati Irrigation Area are shown in Figure III-2 and -3, based on the information of the existing wells. The geological information of Kandal Stung Area was obtained from 24-hour-TV, and that of Tonle Bati Area was from UNICEF.

The surface (or shallow) area of Kandal Stung Area is underlain by fine-grained soil of Young Alluvium(yaf), with a thickness of several meters.

Tonle Bati Area is underlain by thick old alluvium deposits which predominantly consists of sand inter-fingering with fine-grained soil .

Below El.-20m approximately, Kandal Stung Area is underlain by a gravel layer (Oag) which is an aquifer for wells. The lowest boundary of this layer is not confirmed.

3. GEOLOGICAL CONDITIONS OF TUK THLA AND KOMPONG TUOL REGULATOR SITES

-Results of Borehole Investigation-

3.1 General Geological Conditions of the Project Site

The site is underlain by Quaternary unconsolidated deposits subdivided into three Alluvium units; (1) Young Alluvium, (2) Old Alluvium and (3) Recent Alluvium, in ascending order, every unit being slightly unconformable (diastem) to each other. These units are observed sub-horizontally.

The stratigraphic sequence of the deposits in the Tuk Thla and Kompong Tuol Regulator sites is outlined in Table III-1, geological map and profiles are shown in Figure III-2, and III-3 respectively.

(1) Old Alluvium

The Old Alluvium predominantly consists of fine-coarse-grained sands (oas) intercalated by fine-grained soils (oaf). The deeper portion than El. 0 m is medium-coarse-grained sand and the shallower than El. 0 m is medium-fine grained sand.

N-value of the Old Alluvium sands (oas) ranges from 8 to greater than 50 and is generally summarized as shown below;

Depth	N-Value
Shallower than El.-7 m	30 - 40
Deeper than El.-7 m	more than 50

Permeability coefficient ranges from 1.0 x 10^{-3} cm/sec to 1.1 x 10^{-2} cm/sec and the average is 5.6 x 10^{-3} cm/sec.

The fine-grained soils (oaf) are widely distributed between El.0 m and 6 m in this area; and less permeable (permeability coefficient ranges from k=3.9 x 10^{-6} to 9.7 x 10^{-6}). However thickness of this layer is confirmed to be approximately 2 m only by the Boreholes BH-1 and BH-2, and probably not continuous in the center of the river at Kompong Tuol regulator site due to erosion by the river.

(2) Young Alluvium

Young Alluvium is sub-divided into fine-grained soils layer (yaf) and fine-medium grained sand layer (yas) in ascending order.

The fine-grained soils (yaf) is observed to above El.6 m, N-value of which was not investigated but is considered to be similar to the Old Alluvium(N-value=13 to greater than 50)

The fine-medium grained sands is limited to above El.11 m at Tuk Thla gate site, and the N-value is greater than 50.

Permeability coefficient of Young Alluvium sand (yas) and fine-grained soil (yaf) were not investigated. Permeability coefficient of Young Alluvium sand (yas) is consider to be similar to the Recent Alluvium sand (ras) (k=2x10^{-3}) . Permeability coefficient of Young

Alluvium fine-grained soil (yaf) is considered to be similar to the Old Alluvium fine-grained soil(oaf) ($k=6x10^{-6}$).

Some parts of the Young Alluvium including both sites for the proposed Kompong Tuol Regulator and the new dike has been eroded by recent rivers.

(3) Recent Alluvium

The Recent Alluvium is sub-divided into the following two strata: (a) fine-grained soil (raf) and (b) fine to medium grained sand (ras). Both strata contacts each other in a form of inter-fingering.

This is distributed between the proposed Kompong Tuol gate and the existing Kompong Tuol gate along the national Road No.3, above El. 2 m. Around the boreholes BH-1 and H-2, the Recent Alluvium is observed above El.2 m, whereas around the borehole BH-3, and BH-4 above El.4 m.

The Recent Alluvium is also observed above El.8 m in the south area 100 m to 400 m along the National Road No.3 from the existing Tuk Thla gate, where this alluvium consists of fine to medium grained sand (ras).

The fine grained soils (raf) are very soft and N-value is smaller than one (1), while the fine to medium grained sands (ras) is very loose to loose and N-value ranges from 4 to 8.

Permeability of the fine to medium grained sands (ras) ranges from $2.0x10^{-3}$ to $3.6x10^{-3}$ cm/sec (average 1.7×10^{-3}). Although the permeability of the fine grained soils (raf) was not investigated, it is considered to be smaller than 2.5×10^{-5} cm/sec.

3.2 Results of Laboratory Soil Test for the Samples from Boreholes

Laboratory soil test was performed for disturbed samples obtained from the boreholes and test pits; and the results are shown in Table III-3.

The specific gravity of the soils (E, raf, ras, yaf, oaf, and oas) ranges from 2.52 to 2.65 which is a smaller side within a range of the specific gravity of non-organic soils. No or very few organic material is identified.

The fine-grained soils are classified into low plasticity clay with a liquid limit lower than 50 %.

Natural water content of the lower part of the existing embankment which consists of fines is 39 % that is in a high range as an embankment. This is because the lower part of the embankment is considered saturated by seepage through the Recent Alluvium sand layer (ras) that the embankment founds on. It is further considered the saturation has lowered the strength of the embankment materials at the lower part.

Natural water content of the Recent Alluvium fine-grained soils is 29 %, thus this sand may be susceptible to consolidation.

According to the grain size distribution, the sandy soil is classified into a range within poorly-graded sands or clayey sands.

3.3 Foundation Geology

3.3.1 Tuk Thla Regulator Site

This site is composed of the fine grained soil (oaf) which is very firm (stiff) (N-value: from 19 to 33), and the sand (oas) which is very dense (N-value: from 21 to greater than 50). Based on this information, the uni-axial compression strength of the fine grained soil (oaf) is estimated to be 2.0 to 4.0 kgf/cm^2; and the internal friction angle of the sand (oas) to be 30 to 40 degrees.

According to the obtained hearing information no seepage failure has taken place at near Tuk Thla regulator site, although the material of the Old Alluvium sand (oas) is considered to be susceptible to piping. The reasons can be explained such that the head difference between the past flood height elevation (approximately El 14 m) and the elevation inside (downstream side) of the dike (approximately El.13 m) was not large enough for causing piping around this area. Hence it is not likely that seepage failure will take place after the reconstruction of the regulator at this site.

3.3.2 Proposed Kompong Tuol Regulator Site

This site is composed of the Old Alluvium sand (oas) and fines (oaf); and the Recent Alluvium sand (ras).

N-values range from 5 to 20 in the Recent Alluvium sand (ras), from 13 to greater than 50 in the Old Alluvium fines (oaf), and from 8 to greater than 50 in the Old Alluvium sand (oas). In particular, the N-values below El.- 8 m in the Old Alluvium sand (oas) are greater than 50. The internal friction angle of the Recent Alluvium sand (ras) and the Old Alluvium sand (oas) are estimated to be 23 to 32, and 29 to 42 degrees respectively; and the uni-axial compression strength of the Old Alluvium fines (oaf) ranges 2.0 to 4.0 kgf/cm^2.

It is reported that seepage took place around this area resulting in the failures of the existing dike during the floods in August 1991, October 1992 and March 1994. These failures are considered to be triggered by seepage failure (failure due to piping) of the foundation (the Recent Alluvium sand (ras)) due to excessive water head difference between the upstream and the downstream of the dike.

At this site not only the Recent Alluvium sand (ras) but also the Old Alluvium sand (oas) are relatively high pervious (k= ranges from 5×10^{-4} to 2×10^{-2}cm/sec) and susceptible to piping, whereas the Old Alluvium fines (oaf) is less pervious and not pipable. However, it should be noted that the Old Alluvium fines varies in thickness from 2 m to 6 m and may possibly discontinue at several places below the resent river bed due to erosion.

3.3.3 Proposed National Road No.3 Dike Site

This site is underlain by the Old Alluvium fines (oaf) and sand (oas); and the Recent Alluvium sand (ras). The Old Alluvium fines (oaf) is less pervious (k = ranges from 4×10^{-6} to 8×10^{-6} cm/sec) and both sand layer of the Old Alluvium (oas) and the Recent Alluvium (ras) are highly pervious (k = ranges from 2×10^{-4} to 2×10^{-2} cm/sec). The high-pervious layers are continuos from the upstream to downstream under the proposed embankment and are considered to be susceptible to piping which could lead to a failure when the water level increases.

3.4 Recommendation for Foundation Treatment

3.4.1 Recommendation Against Underground Seepage Failure

High permeable sand layers: (ras) and (oas) which underlie the proposed embankment and Kompong Tuol Regulator are susceptible to piping as explained above.

As shown in the Section-E of Figure III-5, the sand layer (ras) on which a part of the existing dike is founded decreases its thickness at and around the downstream toe of the dike. Hence it is considered that the past failures were caused partially because that hydraulic gradient and velocity of seepage at this area might have been greater than the critical level. However at the embankment site the less pervious layer -the Old Alluvium fines (oaf), $k=6x10^{-6}$ cm/sec, thickness = 3-5 m- is available between the Recent Alluvium sand (ras) and the Old Alluvium sand (oas), and this layer can be considered to be the bottom of the Recent Alluvium sand (ras) that is subject to piping at the embankment site.

On the other hand, at the proposed Kompong Tuol Regulator site, the less pervious Old Alluvium fines (oaf) is not thick enough (2 m approximately) and likely to discontinue at several place below the riverbed.

Taking into consideration the above geological conditions, the following counter measures against the seepage failure are recommended:

a. At the embankment site, cut-off works such as a row or two of sheet pile should be installed in the Recent Alluvium sand (ras) to the Old Alluvium sand (oas) between the existing Kompong Tuol gate and the borehole BH-1 approximately.

b. At the proposed Kompong Tuol Regulator site (between the tow boreholes, BH-1 and -2) and Tuk Thla Regulator site, the similar type of cut-off works should be installed to required depths. The required depth shall be determined with the empirical theory of creep ratio as this is an issue of seepage failure along the boundary of a concrete structure and its soil foundation. As alternative cut off works, grouting or blanket in the reservoir can be considered. However, grouting will not be effective in unconsolidated materials and large scale blanketing in the reservoir will not be practical, though small scale blanket could be implemented together with installation one or two of sheet-pile (Appendix III-1).

c. At the right abutment of the Kompong Tuol regulator (Takeo side), the fine grained soil(ras) that overlie the surface area of both the inside and outside of the dike will act as a natural blanket. Hence seepage failure is unlikely to occur although small scale of seepage might occur (Appendix III-2).

3.4.2 Consolidation

The Resent Alluvium fine-grained soil ((raf), see Figure III-5)) overlies the Recent Alluvium sand (ras) with a thickness less than 2 m; shows N-values less than 1; and is subject to consolidation. As this material is distributed only at the surface area, it is recommended that the Recent Alluvium fine-grained soil (raf) should be removed.

The Recent Alluvium sand (ras) may be subject to immediate settlement but not to consolidation.

Both of the Old Alluvium fine-grained soil (oaf) and sand (oas) are not subject to either consolidation or immediate settlement.

4. EMBANKMENT MATERIALS

4.1 Investigation of Embankment Materials

4.1.1 Investigation Approach

Embankment material is obtained normally from borrows close to the embankment site from an economical point of view. In this investigation a study was first carried out for the fine-grained soils (yaf) that is available near the site and were utilized for the existing dike.

The dike consisting of the fine-grained soils (yas), however, has failed several times and one of the causes of the failures is due to the following possible unsuitability of the fine-grained soil (yaf) as an embankment material.

i) poorly-graded and low plasticity resulting in low resisitant property against seepage failure,

ii) very low shear strength when saturated,

iii) high dispersion of the particles,

iv) containing a clay material that swells when saturated, resulting in an occurrence of cracks on embankment when dry.

However the fine-grained soil available near the site could be improved in its property by being mixed with either the gravels (Talus(a)) or the laterites available at a distance.

In order to examine these points, a series of laboratory testing was carried out in accordance with the working flow shown in Fig.III-7.

4.1.2 Tested Items and Their Methodology

The tested items and their methodology are as follows;

i) Specific gravity	ASTM D854-92
ii) Gradation analysis	ASTM D422-63
iii) Moisture content of soil	ASTM D2216-92
iv) Compaction test	ASTM D698-91 procedure C
v) Consolidated, undraind compressive strength of cohesive soils in triaxial compression	ASTM D2850
vi) Laboratory permeability test	USBR E-13
vii) Dispersive characteristics of clay soil by double hydrometer	ASTM D4221-91

Grain size analysis of the fine-grained soil was carried out by a hydro-meter; where samples were mechanically agitated with and without chemical dispersants, thereafter a pair of samples (with and without chemical dispersants) were compared on passing percentage of 0.005mm.

% passing 0.005mm(no mechanical agitation nor chemical dispersing agents are used)

% = Degree of dispersion = ---

% passing 0.005mm(mechanical agitation and chemical dispersing agents are used)

% = Degree of dispersion =\f(% passing 0.005mm(no mechanical agitation nor chemical dispersing agents are used, % passing 0.005mm(mechanical agitation and chemical dispersing agents are used)

Classification of dispersion is as follows:

Range	Classification
0-33%	Non-dispersion
34-67%	Moderately dispersion
68-100%	Highly dispersion

viii) Classification of dispersion by chemical analysis

Dispersive soil can be classified by a chemical index that is percentage of dissolved sodium versus total dissolved salts in a soil sample. Dispersive soils normally show high percentage of dissolved sodium. Evaluation of dispersive soil is expressed as percentage of exchangeable sodium (ESP) versus the total dissolved salts as given below.

ESP	7 - 10	Moderate dispersion
ESP	greater than 15	Serious dispersion

ix) X-ray diffraction analysis

Some of clay minerals such as Smectite swell by absorbing water, which causes trouble to embankments. X-ray diffraction analysis was carried out to identify such clay minerals.

4.1.3 Assessment Method of Desirable Embankment Materials

(1) Assessment by physical property -The Earth Manual (USBR; Table III-5) & Sherad (1966; Table III-6)

Requirements for desirable dike embankment materials are as follows.

a. High density and mechanical strength after compaction,
b. Low permeability ,
c. No compressible deformation and swelling deformation,
d. Good workability, especially easy compaction,
e. Stable slop of the embankment even if saturated,
f. No occurrence of cracks on embankment when dry.
g. No organic components in the materials.
h. No high dispersion particles in the materials.

Physical property of the materials satisfied above-stated requirements are as follows.

a. Well-grained materials,
b. Maximum size is 15cm

c. Weight percentage of fine-grained soil (under 0.075mm) versus all earth materials (under 75mm) should be bigger than 15 %.

d. Weight percentage of fine-grained soil (under 0.075mm) versus all earth materials (under 75mm) should be smaller than 50 %

From the above points of view, the Earth Manual (US Department of Interior Bureau of Reclamation) presents a table 'Relative Desirability' for embankment materials.

(2) Assessment by Laboratory compaction, triaxial compression (CD) and permeability test

Mechanical and permeability property of the materials were evaluated based on the tests results.

(3) Assessment by dispersion and swelling

Dispersion property and Swelling property were investigated by the double hydrometer test and chemical analysis; and by x-ray diffraction analysis, respectively.

4.2 Sampling Location and Estimated Quantity of Available Materials

Location of sampling and test pits is shown in Figure-III-4 and Figure-III-6. Test pit logs are shown in Figure-III-12.

The fines with some sand (yaf) of the Young Alluvium can be excavated to 3 m below the ground surface in the north area of sampling point SP-3. On the other hand this material can only be excavated to 1.5 m below the ground surface near test pit TP-8 and TP-9, sampling point SP-4 and SP-2. Estimated quantity of this material available is 150,000 cubic meters approximately.

The gravel with some fines of the Talus-(a) originated from the Quartzite is available at the existing borrow area of Phnum Chong Stoek 24km along the road from Kompong Tuol (see Figure-III-6, SP-1). The thickness of this layer is more than 4 m and approximately 100,000 cubic meters is estimated to be available at this site.

Laterite is available in the following four sites (see Figure III-6).

a. Around Ph Day Cra Home 18 km - 24 km along the road from Kompong Tuol, where laterite underlies widely but as spots with a thickness of 20 cm approximately. Fine-grained soil is underlying beneath laterite. The area around sampling point SP-9 is an existing borrow area. However, estimated quantity is 10,000 cubic meters only.

b. Around Ph Prinh west of the project site, 30km along the road from Kompong Tuol. The thickness was confirmed to range from GL-0.1 to 1.2 m by hand-auger investigation. Fine-grained soil is underlying beneath laterite. Approximately 50,000 cubic meter of laterite is estimated to be available in this area.

c. Around Ph Con Don Pha Cum west of the project site, 28 km along the road from Kompong Tuol ,The thickness was confirmed to range from GL-0.1 to 0.8 m by hand-auger investigation . Fine-grained soil is underlying beneath laterite(sampling point SP-17) . Approximately 100,000 cubic meter of laterite is estimated to be available in this area.

d. The east area of Phnum Toma Pong;10 km from the national road No.4; 40 km along the national road No.3 and 4 from Kompong (Around sampling point SP-6 in Figure-III-6). This site is an existing borrow area for construction. Although investigation was not carried out ,the thickness and the quantity is visually estimated to be more than 1m and 10, 000 cubic meters approximately.

e. The west slop of Phnum Vaset (Around sampling point SP-5 in Figure-III-6),58 km along the road from Kompong Tuol. Although investigation was not carried out, thickness and the quantity of laterite is visually estimated to be more than 1m and 20,000 cubic meters.

4.3 Physical Property of the Embankment Materials

Results of physical property tests is shown in Table-III-7, and grain size accumulation curves of embankment materials are shown in Figure-III-5. The summary of the test is as follows.

(1) The fine-grained soil of Young Alluvium (yaf) around Kompong Tuol (SP-2,-3,-4,-7,-16 and -18)

This fine-grained soil is poorly graded containing 82 - 93% of fines (under 0.075 mm) with few gravels; and generally low plastic showing liquid limits 38-44% and plastic limits 19-23% (SP-2,-3, and-4).

On the other hand the sample from SP-7 is highly plastic showing the liquid limit 62% and the plastic limit 23 % .

(2) The sands of Young Alluvium (yas) around Kompong Tuol (SP-6).

This material is well graded containing 52 % of fines (under 0.075 mm) and 14% of gravels (over 4.75 mm); and is low plastic showing the liquid limit 22% and the plastic limit 15%.

(3) The gravels at Phnum Chong Stoek (SP-1)

This material is well graded containing 43% of gravels (over 4.75 mm) and 13 % of fines (under 0.075 mm).

(4) Laterite (SP-5, -8 and -9)

This material is well graded containing 12-17% of fines (under 0.075 mm), 33 - 55 % of sands (between 0.075 mm and 4.75 mm) and 30 - 50 % of gravels (over 4.75 mm).

4.4 Results of Compaction Test

The test was carried out after ASTM D698 and the results (Moisture contents and Dry Density curves) were shown in Figure III-10. The summary of the test is as follow:

a. The maximum dry density of the fines sampled from SP-2,-3,-4 and the sands with fines (SP-6) ranges from 1.52 to 1.73 t/m^3, 1.93 t/m^3 respectively. It is observed that the maximum dry density is greater and optimum moisture content be smaller as sand content is greater (Figure III-10(1)).

b. The maximum dry density of the gravels and laterite (SP-1,-5 and 8) ranges from 2.05 to 2.08 t/m^3 (Figure III-10 (2)).

c. Two (2) tests were carried out for mixed samples of gravels (SP-1) and fines (SP-3). The maximum dry density and optimum moisture contents of the mixed samples vary according to mix proportion. As contents of gravels is greater, the maximum dry density is greater and the optimum moisture contents is smaller (Figure III-10(3)).

d. Three (3) tests were carried out for mixed materials of laterite (SP-9) and fines (SP-3). As contents of the laterite are greater, the maximum dry density is greater and the optimum moisture content is smaller (Figure III-10 (4)).

4.5 Result of Triaxial Compression Test

Triaxial compression tests (CU) were carried out for the compacted materials (yaf, laterite, and mixed materials) and results were shown in Table III-8.

The summary of the test is as follows.

a. Fine-grained soil near the new dike site(SP-3): Cohesion is 75KPa (approx. 0.74kgf/cm^2), and Internal friction angle is 15 degrees.

b. Laterite (SP-5,SP-8,SP-9): Effective cohesion ranges from 30 to 85 KPa (approx. 29-83kgf/cm^2). Internal friction angle ranges from 20 to 34 degree.

c. Two(2) tests were carried out for mixed materials of gravels (SP-1) and fines (SP-3). Internal friction angles of the mixed materials were 27 and 22 degrees for the sample of mix proportion 5:5 (SP-1:SP-3) and 3:7 respectively. The effective cohesions are 30 KPa (SP-1:SP-3= 5:5) and 20 KPa (SP-1:SP-3=3:7) which are smaller than the SP-3 material. The greater the gravels contents are in the mixed materials, the larger the internal friction angle is.

d. Three(3) tests were carried out for mixed materials of laterite (SP-9) and fine-grained soil (SP-3). The greater laterite contents is in the mixed materials,the larger the effective cohesion and internal friction angle are.

4.6 Result of Laboratory Permeability Test

Permeability tests were carried out for compacted materials after USBR E-13, and results are shown in Table III-8. The summary of the test is as follows.

a. The permeability of the fines sampled from SP-3 is 2.2x10^{-7} cm/sec.

b. The permeability of the laterite sampled from SP-5, SP-8 and SP-9 ranges from 3.3x10^{-6} to 6.3x10^{-4} cm/sec.

c. Permeability of the mixed samples of gravels (SP-1) and fines (SP-3) ranges from 8.2x10^{-6} to 4.3x10^{-6} cm/sec for the samples with mix-proportion of (SP-1:SP-3) =5:5 and (SP-1:SP-3)=3:7 respectively.

d. Permeability of the mixed samples of laterite (SP-9) and the fines (SP-3) with mix-proportion of (SP-9:SP-3) = 7:3, 5:5, and 3:7 was 2.6x10^{-5}, 1.7x10-5 and 6.5x10^{-6} respectively. As the contents of the laterite is greater, the permeability is larger.

4.7 Result of Classification of Dispersion Test

Tests for dispersive characteristics of clay soils by the double hydrometer after ASTM D4221-91 and by the chemical analysis were carried out and the results were shown in Table III-8. The summary of the test is as follow:

a. Fine-grained soil near new dike site: Degree of dispersion of the soils sampled from SP-3, -16, and -18 ranges from 76 % to 97 %. The result indicates that the soils are classified into 'highly dispersive'. Exchangeable sodium percentage (ESP) of the soil sampled from SP-16 is 20% which indicates that SP-16 is classified into 'serious dispersion'.

b. The fine-grained soil at the bottom of Pol-Pot canal, approx. 5 km south from Ph Kompong Toul: Degree of dispersion of the soils sampled from SP-15 is 96 % which indicates that the sample is classified into 'highly dispersive'. Exchangeable sodium percentage (ESP) of soil sampled from SP-15 is 38 % which indicates that SP-15 is classified into 'serious dispersion'.

4.8 Result of X-ray Diffraction of Clay Minerals

X-ray diffraction analysis was carried out for the fine-grained soil near new dike site. As small amount of Smectite, which swells when saturated, was identified by the analysis, it is considered that cracking may occur on the embankment when dry.

4.9 Assessment by Physical Property

The Earth Manual presents a table showing 'Relative Desirability' of embankment materials based on the Unified Soil Classification (see Table III-5). Sherard (1966) also classified embankment materials into five relative desirable categories based on physical properties (see Table III-6). Based on these information, possible embankment materials for this project were evaluated and shown in Table III-7.

Fine-grained soils near the new dike site are considered undesirable based on the criteria of USBR and Sherad. However it will be desirable if those materials are mixed with coarse-grained soils such as the laterite or the gravels.

Judging from the physical property only, the most desirable materials is the mixture of the fine -grained soil and either laterite or gravels (Talus-(a)) with a mix-proportion of 3:7 (fine-grained soil : laterite, or fine-grained soil :gravels in weight).

4.10 Assessment by Chemical Property

Based on the result of the double hydrometer test and the chemical dispersive test, the fines near new dike site (yaf) are dispersive. Furthermore mixing the fines near new dike site (yaf) with the laterite does not decrease the dispersion of the fine-grained soil effectively. Judging from the analysis of exchangeable sodium, dispersion of the fine-grained soils is due to high exchangeable sodium contents.

Moreover Smectite that was identified by the X-ray diffraction analysis may cause cracking on the embankment when dry.

According to the chemical dispersive test, the fine-grained soil near new dike site (yaf) itself is considered undesirable as a dike embankment material even if mixed with either the gravels (Talus-(a)) or the laterite.

4.11 Recommendation

From the results of the physical property, the fine-grained material itself is not desirable for the embankment material though the mixture of the fine-grained material and either the laterites or the graveles is considered desirable. On the other hand, the mixture is not desirable according to the dispersion test by double hydrometer. Therefore neither the fine-grained material alone nor the mixture with the laterite or the gravels can be used for the embankment materials.

In the progress report (II) (August 1994), it was recommended that embankment should be covered with the compacted laterite so that erosion by surface water can be avoided. However permeability of the compacted laterite is revealed to do not so small as expected. Therefore, covering with the compacted laterite will not sufficiently improve the stability of the dike if the dike is constructed with the fine-grained soil.

To cope with the above investigation results the following two alternatives are recommended:

a. Dispersion due to high sodium contents may be decreased by adding Hydrate lime ($Ca(OH)_2$), Alum ($KAl_3(SO_4)_2(OH)_6$) or Gypsum ($CaSO_4{\cdot}2H_2O$) in the dispersive soil. Hence the fine-grained soil near the new dike may be utilized after mixed with these additives.

b. Large quantity of laterite is available around Ph Prinh and Ph.Con Don Pha Cum, from 28 km to 30 km along the road from Ph Kompong. The thickness of the laterite ranges from 70cm to 110cm, and a fine-grained soil layer underlies the laterite. According to the observation of this fine-grained soil soaked in distilled water, the fine-grained soil is considered non dispersive. Therefore mixed materials of the fine-grained soil and the laterite with a mix-proportion of 3:7 (fines: laterite) may be desirable in view of mechanical property, resistance against leakage and dispersion.

Tables

Table Ⅲ－1 Sequence of Strata

Age	Mark	Formation	Columnare Section	Facies	Mark	Soil Classification	N－value	Permeability
Holocene	E	EMBANKMENT		silt;some portion sand or gravel	E		5 to 20	
Holocene	r a	RECENT ALLUVIUM		silt;sandy Clay ;very soft to soft	r a f	fines	smaller than 1	(smaller than 2×10^{-5}cm/sec)
Holocene	r a	RECENT ALLUVIUM		sand;loose	r a s	sand	4 to 18	2 $\times10^{-3}$cm/sec
Holocene	y a	YOUNG ALLUVIUM		sand, silty sand ;very dense	y a s	sand	graeater than 50	(2×10^{-3}cm/sec)
Holocene	y a	YOUNG ALLUVIUM		sandy silt, silt ;firm	y a f	fines	(13 to greater than 50)	(6×10^{-6}cm/sec)
Holocene	o a	OLD ALLUVIUM		silt;sandy silt ;firm to solid	o a f	fines	13 to greater than 50	6 $\times10^{-6}$cm/sec
Pleistocene	o a	OLD ALLUVIUM		sand, silty sand and laterite ;medium dense to very dense	oas	sand	8 to graeater than 50	6 $\times10^{-3}$cm/sec
Pleistocene	o a	OLD ALLUVIUM		gravel;very dense	oag	gravels		
Pleistocene	o a	OLD ALLUVIUM			oal	laterite	greater than 50	

N-value and permeability coeficient without parentheses are obtained from the investigation, and those with parentheses are presumptived.

Table III-2 Result of Permeability Test

discription of geology and soil classification	bore hole No.	depth	soil classification	coeficient of permeability (cm/sec)
RECENT ALLVIUM sands (r a s)	BH−1	2.0− 2.8m	fine to medium sand	3.6×10^{-3}
	BH−1	5.0− 5.5m	coares sand with some silt	5.2×10^{-4}
	BH−2	3.0− 3.5m	clayey fine sand	(2.5×10^{-5})
	BH−2	5.0− 5.5m	medium to coarse sand	2.0×10^{-2}
	BH−3	3.0− 3.5m	medium to coarse sand with some silt	3.0×10^{-3}
	BH−5	5.0− 5.5m	silty fine sand	2.0×10^{-4}
	BH−6	5.5− 6.0m	medium to coarse sand with some silt	1.1×10^{-3}
the geometric mean				1.7×10^{-3}
OLD ALLUVIUM fine-grained soil (o a f)	BH−1	8.0− 8.8m	sandy silt	9.7×10^{-6}
	BH−2	8.0− 9.0m	silt	5.5×10^{-6}
	BH−3	5.0− 5.5m	silt	3.9×10^{-6}
	BH−3	8.0− 8.5m	silt	4.0×10^{-6}
	BH−5	8.0− 9.0m	silt	4.4×10^{-6}
	BH−6	8.0− 9.0m	silt	7.9×10^{-6}
the geometric mean				5.5×10^{-6}
OLD ALLUVIUM sands (o a s)	BH−1	9.0−10.0m	fine sand	1.1×10^{-2}
	BH−2	9.5−10.5m	fine sand	4.8×10^{-3}
	BH−2	14.0−15.0m	fine to medium sand	2.6×10^{-3}
	BH−3	11.0−12.0m	fine to medium sand	3.8×10^{-3}
	BH−3	14.0−15.0m	fine sand with some silt	1.6×10^{-2}
	BH−5	10.5−11.5m	fine sand with some silt	1.0×10^{-3}
	BH−6	12.9−13.5m	fine sand	1.1×10^{-2}
	BH−6	14.0−15.0m	medium to coarse sand	1.1×10^{-2}
the geometric mean				5.6×10^{-3}

TABLE Ⅲ—3 Result of Soil Laboratory Test
(samples from boreholes)

Discription of geology and soil clasification	Sampling location	Result of gradation analysis				Specfic gravity	Moisture content	Result of consistency test			Unified Soil Classification
		gravels %	sands %	fines %	coefficient of uniformity	g / cm³	%	Liquid limits %	Plastic Limits %	Plasticity index %	
E	TP-5 3.0− 3.5m	0	4	96	—		24	30	19	11	CL
r a f	BH-2 2.0− 3.5m	0	25	75	—	2.57	29	31	22	9	CL
r a s	BH-1 2.0− 3.5m	1	86	13	—	2.54	18	N.P.	N.P.	N.P.	SW−SC
	BH-2 5.0− 5.5m	6	84	10	10	2.52	14	N.P.	N.P.	N.P.	SP
	BH-3 3.5− 4.7m	3	93	4	6		17	N.P.	N.P.	N.P.	CL
y a f	BH-6 2.0− 3.2m	2	14	84	—	2.54	12	39	17	22	CL
o a f	BH-1 7.0− 8.5m	0	35	65	—	2.65	18	35	19	16	CL
	BH-6 8.0− 8.5m	0	11	89	—	2.57	15	38	19	19	CL
o a s	BH-1 9.0− 9.5m	1	82	17	—	2.59	18	N.P.	N.P.	N.P.	SC
	BH-1 13.5−14.5m	8	86	6	86	2.54	13	N.P.	N.P.	N.P.	SW−SC
	BH-2 14.0−14.5m	2	36	62	—	2.55	19	N.P.	N.P.	N.P.	CL
	BH-6 4.5− 5.5m	3	86	11	33		15	N.P.	N.P.	N.P.	SW−SC

N.P. : non plastic

Classification of grain size is as follows

gravels : ϕ 4.76 mm−76.2mm
sands : ϕ 0.074mm−4.76mm
fines : ϕ finer than 0.074mm

Coefficient of Uniformity were calculated by the following formula

$$Cu = \frac{D_{60}}{D_{10}}$$

Cu : Coefficient of Uniformity
D_{60} : 60% passing diameter size
D_{10} : 10% passing diameter size

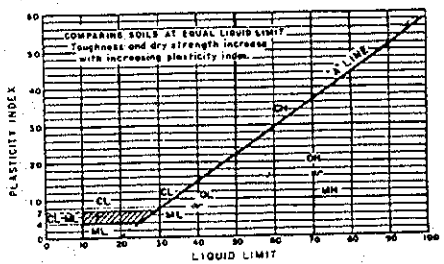
Table III-4 Unified Soil Classification

UNIFIED SOIL CLASSIFICATION
INCLUDING IDENTIFICATION AND DESCRIPTION

Major divisions			Field identification procedures (Excluding particles larger than 3 inches and basing fractions on estimated weights)			Group symbols [1]	Typical names	Information required for describing soils	Laboratory classification criteria
COARSE GRAINED SOILS. More than half of material is larger than No. 200 sieve size [2]. (The No. 200 sieve size is about the smallest particle visible to the naked eye)	GRAVELS. More than half of coarse fraction is larger than No 4 sieve size. (For visual classifications, the ¼" size may be used as equivalent to the No. 4 sieve size)	CLEAN GRAVELS (Little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes			GW	Well graded gravels, gravel-sand mixtures, little or no fines	Give typical name; indicate approximate percentages of sand and gravel, max. size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses.	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between one and 3
			Predominantly one size or a range of sizes with some intermediate sizes missing			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.		Not meeting all gradation requirements for GW
		GRAVELS WITH FINES (Appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below)			GM	Silty gravels, poorly graded gravel-sand-silt mixtures.	For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics.	Atterberg limits below "A" line, or PI less than 4. Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
			Plastic fines (for identification procedures see CL below)			GC	Clayey gravels, poorly graded gravel-sand-clay mixtures.		Atterberg limits above "A" line with PI greater than 7
	SANDS. More than half of coarse fraction is smaller than No. 4 sieve size	CLEAN SANDS (Little or no fines)	Wide range in grain sizes and substantial amounts of all intermediate particle sizes			SW	Well graded sands, gravelly sands, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between one and 3
			Predominantly one size or a range of sizes with some intermediate sizes missing			SP	Poorly graded sands, gravelly sands, little or no fines.	EXAMPLE:- Silty sand, gravelly; about 20% hard, angular gravel particles ½-in. maximum size; rounded and subangular sand grains coarse to fine; about 15% non-plastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM)	Not meeting all gradation requirements for SW
		SANDS WITH FINES (Appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below)			SM	Silty sands, poorly graded sand-silt mixtures.		Atterberg limits below "A" line or PI less than 4. Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
			Plastic fines (for identification procedures see CL below).			SC	Clayey sands, poorly graded sand-clay mixtures.		Atterberg limits above "A" line with PI greater than 7
			IDENTIFICATION PROCEDURES ON FRACTION SMALLER THAN No. 40 SIEVE SIZE						
			DRY STRENGTH (CRUSHING CHARACTERISTICS)	DILATANCY (REACTION TO SHAKING)	TOUGHNESS (CONSISTENCY NEAR PLASTIC LIMIT)				
FINE GRAINED SOILS. More than half of material is smaller than No. 200 sieve size.	SILTS AND CLAYS. Liquid limit less than 50		None to slight	Quick to slow	None	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity.	Give typical name; indicate degree and character of plasticity, amount and maximum size of coarse grains; color in wet condition, odor if any, local or geologic name, and other pertinent descriptive information; and symbol in parentheses.	
			Medium to high	None to very slow	Medium	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays		
			Slight to medium	Slow	Slight	OL	Organic silts and organic silt-clays of low plasticity.	For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions.	
	SILTS AND CLAYS. Liquid limit greater than 50		Slight to medium	Slow to none	Slight to medium	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.		
			High to very high	None	High	CH	Inorganic clays of high plasticity, fat clays.	EXAMPLE:- Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML)	
			Medium to high	None to very slow	Slight to medium	OH	Organic clays of medium to high plasticity.		
HIGHLY ORGANIC SOILS			Readily identified by color, odor, spongy feel and frequently by fibrous texture			Pt	Peat and other highly organic soils.		

Use grain size curve in identifying the fractions as given under field identification.

Determine percentages of gravel and sand from grain size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse grained soils are classified as follows:-
Less than 5% GW, GP, SW, SP.
More than 12% GM, GC, SM, SC.
5% to 12% Borderline cases requiring use of dual symbols.



PLASTICITY CHART
FOR LABORATORY CLASSIFICATION OF FINE GRAINED SOILS

ADOPTED BY - CORPS OF ENGINEERS AND BUREAU OF RECLAMATION - JANUARY 1952

[1] Boundary classifications - Soils possessing characteristics of two groups are designated by combinations of group symbols. For example GW-GC, well graded gravel-sand mixture with clay binder.
[2] All sieve sizes on this chart are U.S. standard

-Unified soil classification chart. From drawing 103-D-347.

Table III-5 Relative Desirability for Embankment Materials

EARTH MANUAL
(U.S. DEPARTMENT OF INTERIOR BUREAU OF RECLAMATION)

Unified Soil Classification Group Symbols	Relative DESIRABILITY for Homogeneous Embankment
GW	-
GP	-
GM	2
GC	1
SW	-
SP	-
SM	4
SC	3
ML	6
CL	5
OL	8
MH	9
CH	7
OH	10
PT	-

No. 1 is considered the best.

Table III-6 Relative Desirability for Resistance Against Leakage

(Woodword, Clyde, Sherard and Associates "A Study of Influence of the Earthquake Hazard on the Design of Embankment Dams, California Department of Water Researches, 1966. 6.)

Relative Desirability against Leakage	Physical Property of Embankment Materials
Very good materials	Well-grained coarse materials mixed gravels, sands and fines. D_{85} is over 2 cm, D_{50} is under 1/4 cm. If fines is non plastic, fines (under 0.075 mm) is approx. 20 %.
Good materials	(1) Well-grained materials, gravels, sands, clayey fines. D_{85} is over 1 cm. Fines is inorganic clay, plasticity index is greater than 12. (2) Plastic clay, plasticity index is greater than 20 %.
Slightly good materials	(1) Slightly well-grained materials. D_{85} is over 3/4 cm, D_{50} is intermediate from 0.5 mm to 3.0 mm. Fines (under 0.075 mm) is approx. 25 %. (2) Moderate plastic clay, plasticity index in greater than 25 %.
Worse materials	(1) Low plastic clay, with no corse-grains (CL, CL-ML). Plasticity index is intermediate from 5 to 8, liquid limit is greater than 25. (2) Moderate to high plastic silt, plasticity index is greater than 10 (ML, MH). (3) Medium sand (from 0.42 mm to 2.00 mm), with some non plastic fines.
Very worse materials	(1) Unformed fine sands with some non plastic silt, D_{85} is smaller than 0.3 mm. (2) Moderate to non plastic silt (ML), plasticity index is less than 10.

Table III − 7 Physical Property of Embankment Materials and Desiability

Discription	Sample No.	Specific gravity	Moisture Content %	Liquid limits %	Plastic limits %	Plasticity index	Gradation analysis			Resistance against leakage (Sherad 1966)	Unified soil classification	Desiability for embankment
							gravels	sands	fines			
Fines;Near new dike site	SP−2		5	38	19	19	0	15	85	slightly good	CL	5
	SP−3	2.585	27	44	23	21	0	7	93	slightly good	CL	5
	SP−4		3	38	20	18	1	11	88	slightly good	CL	5
	SP−6		3	22	15	7	14	34	52	bad	CL − SC	3~5
	SP−7		7	62	23	39	8	7	85	good	MH	9
	SP−16						2	10	88	slightly good	CL	5
	SP−18		11				0	10	90	slightly good	SC	3
Fines;Pol-Pto canal	SP−15						0	12	88	slightly good	MH	9
Gravels;talus-(a)	SP−1		28	N.P.	N.P.	N.P.	43	44	13	slightly good	GM	2
laterite	SP−5	2.574	3	40	21	19	33	55	12	good	SW − SC	3
	SP−8	2.609	12	27	16	11	30	55	15	slightly good	SC	8
	SP−9	2.657	10	N.P.	N.P.	N.P.	50	33	17	slightly good	GM	2
Fines;underlying laterite	SP−17						3	16	81	slightly good	CL	5
Mixed materials; gravels and fines near new dike site	SP-1+SP-3 5 : 5	2.636		38	20	18	17	35	48	good	SC	3
	SP-1+SP-3 3 : 7	2.600		44	23	21	18	20	62	good	CL	5
Mixed materials; laterite and fines near new dike site	SP-9+SP-3 7 : 3	2.655		42	21	21	44	34	22	good	GC	1
	SP-9+SP-3 5 : 5	2.630		47	26	21	29	25	46	good	GC − CL	1~5
	SP-9+SP-3 3 : 7	2.630		40	19	21	15	20	65	good	CL	5

N.P. : non plastic

No.1 is considered the best ↑

Table III －8　Mecanical and Chemical Property of Embankment Materials and Desiability

Discription	Sample No.	Compaction test		Triaxial compression test		Permeability test	Degree of dispersion		Exchangeable sodium percentage		X-ray diffraction of clay minerals
		Maximum dry density t／m³	Optimum moisture content %	C' KPa	φ' degree	coefficient permeability cm/sec	%	Discription	ESP %	Discription	
Fines:Near new dike site	SP－2	1.73	18								
	SP－3	1.52	24	75	15	2.22E-7	76	high dispersion			
	SP－4	1.60	20								
	SP－6	1.93	11								
	SP－7	1.61	21								
	SP－16						91	high dispersion	20.2	serious dispersion	○ kaolinite △ illite·smectite quartz
	SP－18						97	high dispersion			
Fines;Pol-Pto canal	SP－15						96	high dispersion	38.3	serious dispersion	○ quartz △ ilite·kaolinite + smectite
Gravels;talus-(a)	SP－1	2.05	12								
laterite	SP－5	2.07	9	30	34	6.27E-4					
	SP－8	2.08	12	50	34	1.10E-4					
	SP－9	2.05	—	85	20	3.34E-6					
Fines;underlying laterite	SP－17										
Mixed materials; gravels and fines near new dike site	SP-1+SP-3 5 : 5	1.88	13	30	27	8.22E-6					
	SP-1+SP-3 3 : 7	1.75	16	20	22	4.29E-6					
Mixed materials; laterite and fines near new dike site	SP-9+SP-3 7 : 3	1.89	16	100	13	2.63E-5	64	moderately dispersion			
	SP-9+SP-3 5 : 5	1.76	18	20	24	1.71E-5					
	SP-9+SP-3 3 : 7	1.68	16	18	25	6.47E-6	76	high dispersion			

(Clay menerals quantity)
○medium △small +very small

Figures

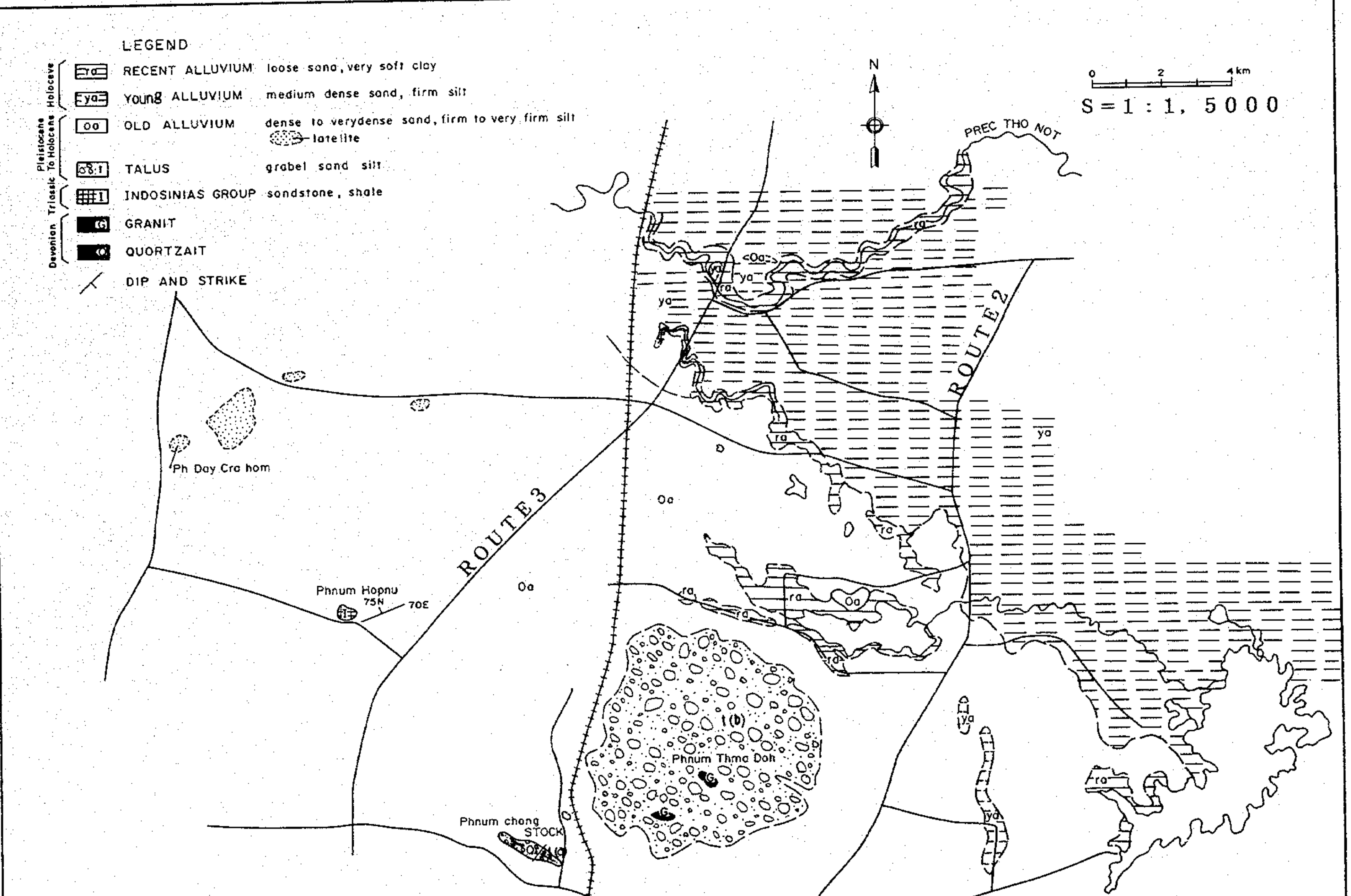


Fig. III-1 Geological Map of in and around Study Area