The basin is generally characterized by topography of peneplain in the late stage of erosion. The terrain is flattened by erosion into low undulating hills and wide open valleys. Some isolated hills with rather steep slopes remain only at places. The bedrocks crop out almost solely on those isolated hills.

2.2 Geological and Geotechnical Evaluation

2.2.1 Khlong Luang Dam Scheme

Dam and reservoir on the Khlong Luang river is situated in the geological province of pre-Cambrian schist. The bedrock is extensively covered with Quaternary terrace/colluvial and flood plain deposits, which are composed of unconsolidated clay, silt and sand, and exposed only locally on some isolated hills. Talus deposits consisting of silty to clayey sand with rock fragments are located surrounding those hills of bedrock outcrops. The exposed bedrocks are intensively weathered.

The schist is dark greenish grey, comprising mica, quartz, chlorite and epidote, and partly shaly and phyllitic. It is often intersected by quartz veins. In the surfacial zone, the schist is decomposed into stiff clayey material, discoloured to pale green and white grey.

Lateritization is developed on the surface, locally forming ferruginous hard pan in a few meters of depth.

Slidings of the unconsolidated terrace deposits and the weathering residuum seem possible on impounding the reservoir. However, they can be of rather slow movement on mildly inclined slopes or only local minor slip-downs, if any. Any substantial threat on the safety of the reservoir and the dam does not appear probable.

According to permeability test data in the bore holes in the damsite, the terrace deposits are not very pervious for their unconsolidated condition, presumably due to their high content of fine material. Yet, occasionally, the permeability shows values in the order of 10^{-3} cm/sec. On the other hand, however, the mildly undulating topography provides thick terrain for inter-basin leakage to pass through. Accordingly, possible loss of water from the reservoir is not deemed substantial.

Geological map of the reservoir area is shown in Fig. 2.

The proposed damsite is located in the vicinity of Ban Nong Krabok, which is situated at about 22 km east of Phanat Nikhom.

Main dam crosses two streams; the Khlong Luang and Huai Sung rivers. A prominent hill, named Khao Nong Nam, forms the left abutment of the main dam and is composed of the pre-Cambrian shales and schists. The right abutment is the undulating uplands, which are wholly underlain by the terrace deposits of sands and gravelly clay. The river valley is approximately 4,000 m in width and is covered by thick flood plain deposits.

A saddle dam is located behind the left abutment of the main dam.

The lowest part of the river valley is at the Khlong Luang river bed, being El. 24.5 m. The crest elevation of dam is limited to El. 45 m at the maximum, owing to the topographic reason of the right abutment of the main dam. The proposed H.W.L. is El. 39.5 m. Geological map of damsite is shown in Fig. 3. A geological profile along the proposed dam axis is presented in Fig. 4.

Standard penetration tests in the bore holes give varied N-value for the unconsolidated deposits of flood plain and terrace/colluvial in the damsite, ranging from 3 to more than 50. It is a general tendency that the N-values lower than 10 are observed only in the flood plain deposits and in the surfacial zone of the terrace/colluvial deposits within about 5 m of depth. In the deeper zone, the N-value varies irregularly depending on the characteristics of component layers. Some parts of the clay layers show 15 to 20, while the others 20 to 50. Though a few N-values lower than 15 are observed in 5 to 9 m of depth in the bore hole KL 3 drilled at El. 40 m on the right abutment, no difficult problems are envisaged in this part where only a few meters of embankment is required.

To place the dam embankment on the deposit with strength that exceeds at least that of the embankment itself (cohesion 1 t/m^2, internal friction angle 30°), the foundation excavation should be made to the depth of 3 to 5 m in the terrace deposits and the flood deposits. On the left abutment on a relatively steep slope of 1/5 to 1/8 in gradient, stable foundation will be reached by approximately 3 m of excavation. Depth of foundation excavation can be less in the upper part of the abutments where the height of embankment decreases.

Permeability, measured in the recently drilled two bore holes BL1 and BL2, shows low value in the order of 10^{-5} cm/sec for the flood plain and terrace deposits under the Khlong Luang valley. The bore hole BL1 revealed that the underlying weathered shale and schist are more pervious, with 1.3 to 7.2 x 10^{-4} cm/sec of permeability coefficient, from 7 m to 20 m of depth, and they are virtually impervious below 20 m. This intermediate zone of permeability in the order of 10^{-4} cm/sec will provide main leakage path on impounding the reservoir. Though the rate of leakage per unit width of a vertical slice of foundation is not very much, the total leakage quantity would be a noticeable amount, considering the very long dam axis. However, it is deemed not reasonable to sink an impervious earth cut-off up to 20 m of depth, while the height of dam is only 14 m above the river bed. If the unconsolidated overburden with low permeability is continuously developed upstream, it may be regarded to function as natural blanket to supress the possible leakage within a reasonable amount. In view of local irregular variation of permeability, however, the continuity of the natural blanket is very dubious.

Under such circumstances, it seems that the most appropriate measure for leakage control is to spread an artificial earth blanket upstream from the earth embankment of the dam. This will be constructed as an extension of the earth blanket on the left bank which has been recommended to control the high leakage area by Sverdrup & Parcel International, Inc. (1973), and cover the right abutment as well, where the interface of the weathered bedrock to the overlying terrace deposit does not rise more than El. 25 m.

The saddle dam site is located on a low ridge behind the isolated hills of the left abutment. The lowest part of the saddle is a little higher than El. 35 m, and the dam embankment will be about 7 m high. The ground surface is covered by clayey colluvial deposit, which makes gradual transition downward to decomposed rock zone. N-value shows more than 50 in the zone deeper than 6 m on the right side and 11 m on the left side. In the upper zone of colluvial deposit, N-value ranges from 13 to 60, with majority falling under the range of 20 to 30. The drilling data in 1973 describes the foundation below 4 m of depth as impervious, though no figures are given. For the rather low embankment in this portion, removal of about 2 m thick organic layer in the surface will be sufficient for foundation preparation. Earth cut-off is to be sunk up to 5 m of depth.

2.2.2 Khlong Yai Dam Scheme

Dam and reservoir area on the Khlong Yai river is widely covered by terrace and colluvial deposits which are composed largely of silty to clayey sand. Fine to medium sized gravels of quartzite and gneissose granite are contained in some layers in various proportions.

Bottom of the river valleys are filled with alluvial flood deposits consisting of sand with gravels.

These Quaternary deposits are underlain by the pre-Cambrian metamorphic rocks which are only locally cropped out. Gneiss is exposed on the ridge to the east of the damsite, and outcrops of schist are located on an isolated hill on the Khlong Ma Mui river, approximately 600 m north of the left abutment of the dam.

The reservoir area is surrounded by the hills composed of unconsolidated terrace and colluvial deposits. There is possibility of land slidings incurred by draw-down of the reservoir. However, those slidings can be of not so rapid speed as to jeopardize the stability of the reservoir and the dam, considering that the slopes are generally as mildly inclined as 1/20 and less.

The terrace and colluvial deposits show moderate permeability falling under the order of 10^{-4} cm/sec, according to the field permeability test. Groundwater levels are also high in those deposits. Though the above permeability is yet higher than substantial watertightness and there can still be some layers of high permeability at places, little possibility of leakage is envisaged for the thick terrain to be traveled through by leakage water from the reservoir.

Geological map of the reservoir is shown in Fig. 5.

Axis of the proposed Khlong Yai dam has approximately 4,000 m of length across three rivers, that is, the Khlong Yai, the Khlong Nong Ai Run and the Khlong Ma Mui, all of which flows southward at the damsite. The deepest valley of Khlong Yai is at El. 34.5 m in the river bed whereas the contemplated H.W.L. is at El. 47.5 m.

Geological map of the damsite is shown in Fig. 6 and geological profile along the dam axis in Fig. 7.

Bed rock is gneissose granite, which is intensively weathered up to 30 m of depth or more. None of the twenty two previous drilling has reached to fresh rock zone.

The intensively weathered gneissose granite show N-value in the standard penetration test higher than 50 in general. Permeability measured in three bore holes, BY1 to 3, shows lower value than 5×10^{-5} cm/sec in the zone deeper than 10 m from the level of the river beds, though some pockets of higher permeabilities are encountered at places in the deeper levels.

The intensively weathered gneissose granite is overlain by the terrace and colluvial deposits in the hills, and by the alluvial flood deposits in the bottom of the valleys. On the left abutment, it is covered by a wide-spread talus deposit in the foot of the gneiss hill.

The terrace and colluvial deposits are 5 to 15 m thick and composed of silty to clayey sand with gravels, ranging in the penetration N-value from 4 to 50. Some irregular variations of the N-value are often observed, while it is commonly low in the surfacial zone within a few meters of depth. Strength as foundation is estimatedly in the proximity of 2.5 t/m^2 for Cohesion and 28° for internal friction angle when N-value be 20. Three to five meter deep excavation is required to remove the surfacial looser zone for foundation of the earth-fill dam.

The alluvial flood deposits, consisting of sand with finer material and/or gravels, are looser than the terrace and colluvial. The standard penetration tests gives N-values lower than 20 for the most part of the flood deposits. Further considering that the deposits contain silty and clayey materials frequently, their viability as a stable foundation of dam embankment seems very dubious. Almost all the flood deposits will have to be removed in preparing the dam foundation.

A few meter deep excavation will be sufficient for the talus deposit on the left abutment.

The recently drilled bore holes BY1 and BY2 reveal that coefficient of permeability shows up to 6.5×10^{-4} cm/sec in both the terrace/colluvial deposits and the upper zone of the intensively weathered gneissose granite. In view of the extraordinarily long dam axis that could result in that much large quantity of water leakage, it is important, in one hand, to take every measure for supressing water seepage amount per unit length of the dam axis, whereas some larger leakage than in the ordinary case should be tolerated in the other hand.

It should be taken into consideration that cement grouting is probably not very effective to improve the permeability in the intensively weathered granitic rock or arkose. Chemical grouting, which could be more effective, will badly increase the cost of foundation treatment, if it should be utilized for the curtain grouting along the 4,000 m long dam axis.

A conceivable way of foundation treatment is to sink an impervious earth cut-off wall to a level in the intensively weathered gneissose granite, where coefficient of permeability is within the magnitude of 10^{-5} cm/sec. This level lies at El. 25 m (about 10 m deep from the ground surface) under the Khlong Yai valley and El. 30 m (also 10 m deep underground) under the Khlong Ma Mui valley. Possible necessity of a certain amount of cement grouting should be taken into consideration for treatment of partial fractures and leakage paths in the cut-off foundation.

On the abutment slopes on both banks, the weathered granite interface under the terrace/colluvial deposits or the talus deposit does not rise parallel to the ground surface, but develops nearly horizontally or in very low gradient at the height several meters lower than H.W.L. This situation makes it unable for the dam in its higher part to abut to the bedrock. It is thereby necessitated to construct the impervious earth cut-off walls inserted long into the terrain of the abutment slopes. Because of relatively low permeability of the deposits, it is estimated that the cut-off wall extending 50 m from the end of the dam crest would be able to decrease total seepage through a wing of unconsolidated deposits to less than 20 ℓ/min.

Possible total leakage rate through the dam foundation is estimated in F.E.M. at 2.4 m^3/min, that is 2 percent of the annual average discharge rate of the rivers; the daily leakage quantity will be 0.004 percent of gross storage capacity of the reservoir.

2.2.3 Khlong Thap Ma Dam Scheme

Dam and reservoir area on the Khlong Thap Ma river is situated in the geological province of the pre-Cambrian schists and gneissose granites. With several exceptional exposures of the schists on isolated hills around the damsite, the bed rock is generally covered by terrace and colluvial deposit mainly consisting of silty to clayey sand. The bottoms of the river valleys are thickly filled with the river alluvial deposits. Talus deposits are extensively formed in the surroundings of the said isolated hills of schists.

Geological and geotechnical features of the reservoir area is essentially similar to those of the Khlong Yai dam scheme, situated in the same river basin. There exists possibility of local land sliding of the unconsolidated terrace/colluvial deposits on draw-down of the reservoir, which, however, would be slow enough to be no substantial threat on the safety of dam. No possibility of serious leakage from the reservoir rim is envisaged.

Geological map of the reservoir area is shown in Fig. 8.

The proposed damsite is located in the vicinity of Ban Map Toen, which is situated at about 9 km northwest of Rayong.

Main damsite is featured by relatively prominent hills trending north-south direction in both abutments and by U-shaped valley buried with the terrace deposits and the recent flood plain deposits. The river valley is underlain by granitic rock in the subsurface deeper than 15 m and by overlying terrace deposits of sandy and gravelly clay. The river bed elevation is approximately El. 10.0 m at the damsite and width of river valley is approximately 800 m at El. 29.0 m.

Saddle dams will be located a little upstream from the left abutment. More saddle dams will be required if dam crest elevation exceeds over El. 35.0 m.

Geological map of the damsite is shown in Fig. 9. A geological profile along the proposed dam axis is presented in Fig. 10.

In the main damsite, the subsurface geological condition has as far been probed with fourteen bore holes. The unconsolidated deposits in the bottom of the valley, which is about 15 m thick over the bed rock, is divided into two zones; one is the recent flood plain deposit with 5 to 7 m of thickness from the ground surface and the other is the older deposit underlying the former. These deposits are dominantly composed of silty to clayey sand with occasional intercalation of clay layers. They show almost irregularly varied N-values in the standard penetration test, ranging from 2 to more than 50. The N-value shows very often less than 20 in the flood plain deposits, which is, therefore, to be removed from the dam foundation. In the other hand the majority of the N-values in the underlying older deposit is higher than 20 or over 30, while the occasionally intercalating clay layers show very low N-values. It appears, however, in the geological profile that those clay layers are not continuous, and they are deemed to form local lenticular pockets. Accordingly, the dam embankment is to be placed on the surface of the older deposit, after about 5 m deep excavation of the flood plain deposit.

Detailed investigation will be required in the future stage of the project for extent of development and distribution of the clay layers.

Whereas the unconsolidated deposits show as high permeability as in the order of 10^{-3} cm/sec, the permeability in the bedrock is within a range from 10^{-4} cm/sec to 10^{-5} cm sec; generally in the order of 10^{-5} cm/sec. For the case that an impervious earth cut-off trench, 4 m wide at the bottom, is sunk to the level of the bedrock surface, the possible leakage is estimated at 0.4 m^3 / min. This is deemed sufficiently acceptable rate.

On the both banks, the dam abuts on the slopes of the hill, composed of schist and covered by silty talus deposits. The slope on the left bank has around 1/4 of gradient. The right bank shows about 1/2 in the lower part and less than 1/10 in the upper part. Thickness of the talus deposit is 3 to 5 m. The underlying schist is intensively weathered to more than 15 m of depth into the condition of residual soil, in which the N-value of standard penetration test is higher than 50. In the past records of the drillings, permeability is reported to be low for the intensively weathered schist, though no figures are given. Approximately 3 m deep excavation of the talus deposits will be required for foundation of the dam embankment. Foundation for the earth cut-off is to be located at about 10 m of depth.

The saddle dams are situated on the hills of schist with covering of talus deposit. Geological conditions are deemed nearly similar to that of the abutments of the main dam.

The saddle on the left bank side is at El. 25 m, that is, 0.7 m lower than H.W.L. Only a few meters of excavation of loose and organic surfacial deposit will be sufficient for the earth cut-off. Permeability of the decomposed bedrock has to be confirmed in the future stage of detailed design.

2.2.4 Foundation of Diversion Weir on the Rayong River

Foundation condition was investigated for two alternative sites of a diversion weir for the scheme of irrigation in the Rayong river basin. The weir sites are located on the Rayong river.

The contemplated height of the weir is 4 m from the present river bed. The main part of the weir is to be designed as concrete gravity dam structure.

Seven meter deep drillings were made at two spots in each alternative damsite. Standard penetration test in USBR specification was performed at one meter intervals in each bore hole.

As all of four bore holes indicate, unconsolidated alluvial deposits are thicker than 7 m, composed of horizontal layers of poorly graded sand with varied particle size. Some thin layers of gravels are encountered at places. Surfacial zone, 1 to 1.8 m thick, is silty or clayey.

The penetration tests indicate varied N-values, ranging from 3 to 33. The surfacial 2 m zone shows low N-values.

The weir of concrete gravity type is to be placed on the alluvial deposit. Strength of the foundation is estimated as below in terms of Terzagi's bearing capacity. It is assumed that the width of the weir base is equal to its height.

$$q_d = c \cdot N_c + 0.5 \gamma \cdot B \cdot N + D_f \cdot N_q$$

where,
- qd: bearing capacity (t/m^2)
- c: cohesion of soil (t/m^2)
- γ: unit weight of soil (t/m^3)
- B: width of foundation (m)
- D_f: depth of foundation below ground surface (m)
- N_c, N, N_q: constants, determined by internal friction angle of soil (ϕ)

Assuming $c = 0$, the internal friction angle ϕ is determined by Dunham's formula,

$$\phi = \phi_o + \sqrt{12\,N}$$

where, N: N-value of standard penetration test

$\phi_o = 20$, when the sand particle is angular and poorly graded.

The value 0.6 t/m^3 is taken for unit weight of soil when it is below ground water table.

The followings are estimated.

Depth	Dam Height	Stress from Dam	Alternative Site 1				Alternative Site 2			
			N for Design	ϕ	q_d	Safety Factor	N for Design	ϕ	q_d	Safety Factor
(m)	(m)	(t/m^2)		(°)	(t/m^2)			(°)	(t/m^2)	
1	5	5.75	3	26	9.06	1.57	3	26	9.06	1.57
2	6	6.90	5	28	16.44	2.38	5	28	16.44	2.38
3	7	8.05	10	31	38.91	4.83	7	29	30.57	3.80
4	8	9.20	10	31	48.72	5.30	10	31	48.72	5.30
5	9	10.35	15	33	96.12	9.30	10	31	58.32	5.63

In terms of bearing capacity, the appropriate depth of foundation excavation is deemed to be 2.5 m to 3 m, to cover 3 in safety factor. In this case, the safety factor as against sliding would be around 2.5, if cohesion is neglected.

Permeability is to be assumed at approximately 1×10^{-2} cm/sec. Though leakage quantity has no substantial significance for this kind of weir, precaution is required against piping in the foundation. Deep cut-off wall or blanket will have to be considered to decrease the velocity of seepage.

Depth of disturbance of the river bed deposit by flood is considered to be little, in the light of an existing weir which has only one meter of foundation depth below the river bed.

2.3 Future Geological Investigation

It is deemed that the geological informations obtained so far are at least sufficient to give a general concept of foundation geology and available construction material that can be a basis of design for the feasibility study. The investigations in the next stage will be performed to confirm the already obtained concept, and to clarify some questions remained in detailed aspects. The subjects to be examined in the future are as follows:

(1) Distribution and Extent of Soft Clay Layers

Some of the previous drillings have encountered soft clay or silt layers below denser or stiffer layers with high N-values. It is necessary to check if those soft layers are only local or extensively developed. If the soft layers are located not very deeper than the contemplated dam foundation level and have substantial extent, the foundation level would have to be reconsidered. To clarify this question, additional drillings closely spaced around the bore holes in question will be required.

(2) Permeability of Foundation

Field permeability test was conducted in the recently drilled bore holes which were located at only three spots in each damsite. It presented seepage condition in terms of permeability coefficient.

In the investigation in 1973, it appears that the seepage condition was examined by observation of drilling water injected into bore holes during the drilling operation and by laboratory permeability test of undisturbed samples.

More field permeability tests are required to check the in-situ condition. It is also recommended to test permeability of the deposits in the valley of Khlong Luang by drilling more than 10 bore holes in the upstream side of the dam axis. If the permeability be consistently low as observed in the previously drilled bore holes on the axis, those deposits might be regarded as reliable natural blanket, thereby reducing cost for seepage treatment of this site.

Permeability tests in several bore holes are recommended for the left abutment of Khlong Luang damsite, of which high permeability was warned in the Report of investigation in 1973.

(3) Trench Cutting

For unconsolidated or semi consolidated deposits, the drilling core samples are often so disturbed that it is not easy to imagine their condition in-situ. Trench cutting to some 5 m of depth on the abutments is recommended for direct observation of the in-situ condition of the deposits. The trench will be also utilized for in-situ permeability test at the bottom.

Quantity of the above additional investigations will be as follows:

Site	Drilling with S.P.T. and Permeability Test	Trench Cutting	Notes
Khlong Luang	30 m x 50 spots (1,500 m)	400 m in total length	Including saddle
Khlong Yai	30 m x 40 spots (1,200 m)	400 m in total length	
Khlong Thap Ma	30 m x 20 spots (600 m)	400 m in total length	Including saddle

3. MATERIAL SURVEY

3.1 General

3.1.1 Outline of Available Materials

The available materials in the vicinity of the project area are outlined as follows:

(1) Talus deposits mainly consist of silty sands and clayey sand (SC - SM) intermixed with fragments of weathered schist or gneiss, and distribute over the gently sloped skirt of lower mountains near the proposed three damsites. These materials appear to be suitable for the impervious core zone of fill dam or earth material of homogeneous earthfill dam.

(2) Terrace deposits consist of clayey soil (CL - ML) with or without sand and gravel, and distribute along the meander belt of rivers in the proposed reservoir areas. These materials have a high clay content which may cause the cracking in embankment, and mixing process with the underlying sand and gravel or other coarse material is required to improve the gradation for the impervious material of fill dam.

(3) Sand is obtainable from Kong Tong Po and Ban Na sand borrow areas located 10 km southeast from Khlong Thap Ma Damsite and 40-km southwest from Khlong Luang Damsite respectively.

(4) Quarried rock is obtainable from the Ban Pak Than, Khao Noen Kraprok, Khao Chon hae, Ban Non Thakhian and Khao Bo Kwang Thong riprap quarries, etc.

3.1.2 Previous Study

For the purpose of foundation design of the proposed dams, foundation investigation was carried out by Sverdrup & Parced International, Inc. under contract with RID. As the results, the under-listed reports were issued in July 1973.

(a) East Region Project, Khlong Yai Reservoir, Ban Khai, Rayong, Foundation Investigation and Recommendation

(b) East Region Project, Khlong Luang Reservoir, Phanat Nikhom, Chon Buri, Foundation Investigation and Recommendation

(c) East Region Project, Khlong Thap Ma Reservoir, Muang Rayong, Rayong, Foundation Investigation and Recommendation

The above three reports contain a little about dam embankment materials.

3.1.3 Requirement of Materials

The required volumes of construction materials are summarized in the following Table.

(Unit: $10^3 m^3$)

Material	Khlong Yai	Khlong Thap Ma	Khlong Luang
Earth	2,100	1,200	2,800
Drain	260	110	270
Riprap	190	80	190

3.2 Possible Borrow Area and Quarry Site

3.2.1 Khlong Luang Damsite

Five borrow areas were initially surveyed and then three borrow areas were finally selected as proposed borrow areas. Their locations are as shown in Fig. 11 and are closely located to the proposed damsite.

Borrow area I is located at the left abutment of the proposed damsite. The material in this borrow area is composed talus deposits and weathered schist. Borrow areas II and III are located from the downstream of the damsite to right abutment, and they are composed terrace and colluvium deposits.

Earth materials available from the three borrow areas were roughly estimated at approximately 3,000,000 m^3, which will be sufficient for construction of the Khlong Luang dam.

3.2.2 Khlong Yai Damsite

Three borrow areas shown in Fig. 12 were investigated.

Borrow Area I is located upstream from the proposed damstie. The soils are composed of terrace and colluvium deposits, and their soil properties are almost the same with those of Borrow Area II.

Borrow Area II lies at the right abutment of the proposed damsite. The soils are finer in particle size, less shearing strength and low trafficability than the soils of Borrow Area III. The soils are composed of terrace and colluvium deposits.

Borrow Area III is located oposite of Borrow Area I, the left abutment of the proposed damsite. The soils comprize talus deposits of gravelly clay with weathered sandstone and quarzite. The talus deposits are widely identified at the left abutment of the proposed damsite.

It is being expected that embankment materials are obtainable sufficiently.

3.2.3 Khlong Thap Ma Damsite

As the same as the Khlong Luang and Khlong Yai damsites, three borrow areas were reconnoitered. Borrow Area I is selected on the right bank of the river and Borrow Areas II and III on the left bank, as shown in Fig. 13.

Soils of the three borrow areas consist of talus deposits of gravelly clay with weathered schist and quartzite. Talus deposits are suitable for earth material and have enough shearing strength, trafficability and imperviousness.

The required quantity for dam construction will be wholly met by three borrow areas.

3.2.4 Sand Borrow Area and Quarry Site

Sand borrow areas are identified in Ban Na near Chon Buri and in Kong Tonpo in Rayong. The Ban Na borrow area is approximately 50 km distant from Khlong Luang damsite. The Kong Tonpo borrow area is located at about 10 km from Khlong Thap Ma damsite and at about 25 km from Khlong Yai damsite. The locations of the borrow areas are shown in Fig. 14.

There are several quarry sites in the Study Area as shown in Fig. 14. The Khabo Kwang Tong quarry is situated within 25 km distant from Khlong Luang damsite. The Ban Non Thakhian quarry is located to the North of Khlong Yai damsite with a distance of about 30 km. The Ban Pak Than quarry is located near to Khlong Thap Ma damsite.

3.2.5 Required and available Quantities

The estimated requirement and available quantities of materials are summarized as follows.

(1) Earth Materials

Damsite	Required Volume (10^3m^3)	Available from Borrow Area (10^3m^3)
Khlong Luang	2,800	3,000
Khlong Yai	2,100	3,000
Khlong Thap Ma	1,200	2,000

(2) Riprap, Filter and Aggregate

Damsite	Required Quantity (10^3m^3)	
	Riprap	Filter
Khlong Luang	190	270
Khlong Yai	190	260
Khlong Thap Ma	80	110

For Khlong Luang and Khlong Yai damsites, riprap, filter and aggregate are planned to be produced in Khabo Kwang Thong and Ban Non Thakhian quarry sites, respectively, from the economic viewpoint. As to Khlong Thap Ma damsite, riprap and coarse aggregate will also be produced at Ban Pak Than quarry, while fine aggregate will be obtained from Kong Tonpo borrow area.

3.3 Characteristics of Materials

3.3.1 Soil Sampling and Laboratory Test

Test pits were duck in all the selected borrow areas. Representative soil samples, which are identified suitable as embankment materials by observation, were taken from some of soil layers for laboratory tests. The locations of test pits are shown in Figs. 3, 6 and 9 for Khlong Luang, Khlong Yai and Khlong Thap Ma damsites respectively. Fig. 15 indicates a log of test pit for Khlong Luang damsite, Fig. 16 for Khlong Yai damsite and Fig. 17 for Khlong Tmap Ma damsite.

On all samples, index properties tests including specific gravity, gradation, Atterberg's limit (consistency) and field moisture content were carried out. On the samples mixed of all samples, engineering properties tests including standard proctor's test, permeability test, consolidation test, triaxial compression test and some index properties tests were conducted.

A triaxial compression test was carried out under two conditions, nemely, unconsolidated undrained condition (UU) and consolidated undrained condition ($\overline{CU}$), on test pieces compacted at three kinds of moisture content; optimum moisture content (O.M.C) and drier and wetter moisture contents than O.M.C (at which 95% of maximum dry density can be attained). In consolidated undrained triaxial compression test, test pieces were applied by back pressure of 2 kg per cm^2 and saturated.

Permeability tests also were carried out on test pieces compacted at the same three (3) kinds of moisture content as in triaxial compression test under the condition of consolidate undrained.

The quantity of laboratory soil tests is tabulated hereunder.

(Unit:Samples)

Test Item	Khlong Luang	Khlong Yai	Khlong Thap Ma	Total
Specific Gravity	13	16	16	45
Gradation	13	16	16	45
Liquid Limit	13	16	16	45
Plastic Limit	13	16	16	45
Compaction	4	4	4	12
Triaxial Comp. (UU)	9	9	8	26
- ditto - ($\overline{CU}$)	9	9	8	26
Permeability	9	9	9	27
Consolidation	3	3	3	9

3.3.2 Results of Soil Tests

The results of soil tests are summarized in Tables 1 or 3. Detailed test data are compiled in Data Book.

3.3.3 Discussion on Soil Properties

(1) Khlong Luang Damsite

The soil materials in the borrow areas are classified as follows:

Borrow Area	Classification		Plasticity Index	
I (PL-2)	GM	(SM-SC)	12 - 13	(16)
IV (PL-1)	SC or GC	(SC)	8 - 12	(8)
V (PL-5)	SM	(SM)	N.P	(N.P)

All materials are suitable for impervious embankment material for fill type dam. However, the material of borrow area V is non-plastic, and seems to be inferior to others in resistance against piping and errosion. The piority is generally as follows:

Priority	Soils by Classification
1	GC
2	SC
3	GM
4	SM

The permeability coefficients of materials compacted at various moisture contents are as follows:

Moisture Content	Borrow Areas I (PL-2)	IV (PL-1)	V (PL-5)
Drier Side at 95% of D	(8.1) 4.3×10^{-6}	(10.7) 7.9×10^{-5}	(5.0) 1.8×10^{-5}
O.M.C (at 100% of D)	(10.3) $< 10^{-8}$	(13.6) 7.8×10^{-8}	(7.5) 9.5×10^{-8}
Wetter Side at 95% of D	(13.1) 3.9×10^{-7}	(17.4) 3.9×10^{-7}	(9.9) 7.6×10^{-6}

The above soil test results in general indicate such tendency as;

(i) The minimum coefficient of permeability is attained at slightly water moisture content than O.M.C.,

(ii) As the moisture content increases from the moisture content at minimum coefficient of permeability, the coefficient of permeability increases gradually.

(iii) As the moisture content decreases from O.M.C., the coefficient of permeability increases abruptly.

Though the permeability tests were not carried out on the materials of borrow area III, the permeability coefficient and corelationship between permeability and moisture content are considered to be similar to those of borrow area IV by the log of test pits (i.e.: observation record on test pits).

The natural moisture contents of each borrow areas are about four percent (4%) drier than O.M.C. Therefore watering system will be required to be furnished at the selected borrow areas.

The shearing strength of materials compacted at various moisture content are as follows:

(a) In Total Stress

	Borrow Areas								
	I (PL-2)			IV (PL-1)			V (PL-5)		
	W (%)	CUU (t/m^2)	øUU (o)	W (%)	CUU (t/m^2)	øUU (o)	W (%)	CUU (t/m^2)	øUU (o)
Drier Side at 95% of D	10.5	7.5	26.0	7.5	11.0	23.5	4.4	5.5	34.5
O.M.C. (at 100% of D)	13.7	4.0	25.5	10.4	4.2	26.5	7.7	5.0	34.0
Wetter Side at 95% of D	17.5	5.4	6.0	13.4	4.5	6.0	10.5	1.8	22.0

(b) In Effective Stress

	Borrow Area								
	I(PL-2)			IV (PL-1)			V (PL-5)		
	W (%)	C' (t/m^2)	ø' (o)	W (%)	C' (t/m^2)	ø' (o)	W (%)	C' (t/m^2)	ø' (o)
Drier Side at 95% of D	10.5	1.0	33.0	7.5	1.0	34.0	4.4	3.5	34.0
O.M.C. (at 100% of D	13.7	1.0	32.0	10.4	1.5	32.0	7.7	2.5	36.0
Wetter Side at 95% of D	17.5	1.2	34.0	13.4	0.8	34.0	10.5	1.0	37.0

The above test results indicate the following general tendency in respect to total stress. Such tendency however is not obvious in effective stress.

(i) The maximum shearing strength is attained at some drier moisture content than O.M.C.

(ii) As the moisture content increases from the moisture content at which the maximum shearing stress is attained, the shearing strength decreases.

Though the triaxial compression test was not carried out on the materials of borrow area III, the shearing strength and corelationship between shearing strength and moisture content similar to those of borrow area IV are estimated.

Since the shearing strengths, in total stress, of materials compacted at the moisture content three percent (3%) higher than O.M.C. decrease abruptly, trafficability for wheel type construction equipments is not prospected when the moisture content of materials is more than three percent higher than O.M.C.

Though any significant differences in engineering properties are not found among borrow areas, according to the index properties, the material of borrow area V is inferior in resistance against piping and erosion. Therefore, the three borrow areas of I, III and IV are selected among the surveyed borrow area.

(2) Khlong Yai Damsite

The soil materials of borrow areas for Khlong Yai dam are classified by index properties as follows:

Borrow Areas	Classification	Plasticity Index
I (PY-1)	SC or CL (SM)	9 - 16 % (15.3)
II (PY-2)	SC,SM or CL(SM)	13 - 19 % (15.8)
III (PY-3)	GC or SC (SM)	13 - 16 % (16.4)
Extra (PY-4)	SM or MH (ML)	15 - 19 % (17.2)

(Symbol and figure in a parenthesis shows classification and value of mixed material respectively.)

Except material classified to MH, all materials are suitable for impervious embankment material of fill type dam. The priority of materials are generally as follows:

Priority	Soils by Classification
1	GC
2	SC
3	CL
4	SM
5	SL

The permeability coefficient of materials compacted at various moisture content are as follows:

Moisture Content	Borrow Areas			
	I (PY-1)	II (PY-2)	III (PY-3)	Extra (PY-4)
Drier Side at 95% of D	1.6×10^{-6} (11.8)	1.6×10^{-6} (8.2)	-	3.0×10^{-6} (10.4)
O.M.C. (at 100% of D)	2.3×10^{-8} (13.8)	4.2×10^{-8} (12.6)	-	9.5×10^{-7} (15.0)
Wetter Side at 95% of D	3.9×10^{-7} (16.9)	2.9×10^{-7} (16.2)	-	1.4×10^{-7} (20.1)

(Unit of permeability coefficient is in cm/sec, and figure in a parenthesis shows moisture content in %)

With respect to a correlation between the permeability and the moisture content, the same general tendency as described in the preceding paragraph (1) is recognized.

The natural moisture content of materials are slightly drier than O.M.C. in the borrow areas I and III, slightly wetter than O.M.C. in the borrow area II, and considerably wetter than O.M.C. in the extra borrow area. Taking into account that the considerably decrement of moisture content by evaporation during construction work, a watering system will be required to be furnished at the borrow areas I, II, and III, to attain the required permeability coefficient.

The shearing strengths of materials compacted at various moisture contents are as follows:

(a) Total Stress

Moisture Content	Borrow Areas								
	I (PY-1)			II (PY-2)			Extra (PY-4)		
	W (%)	CUU (t/m^2)	ØUU (o)	W (%)	CUU (t/m^2)	ØUU (o)	W (%)	CUU (t/m^2)	ØUU (o)
Drier Side at 95% of D	11.8	4.0	23.0	8.0	12.0	19.5	10.8	12.0	25.5
O.M.C. (at 100% of D)	14.3	5.0	22.0	12.5	7.0	20.0	15.5	3.5	19.5
Wetter side at 95 % of D	17.2	5.0	7.0	16.8	4.4	6.0	20.4	4.3	5.0

(b) In Effective Stress

Moisture Content	Borrow Areas								
	I(PY-1)			II(PY-2)			Extra (PY-4)		
	W (%)	C´ (t/m^2)	Ø´ (o)	W (%)	C´ (t/m^2)	Ø´ (o)	W (%)	C´ (t/m^2)	Ø´ (o)
Drier Side at 95% of D	11.8	1.0	32.0	8.0	1.0	29.0	10.8	1.0	31.0
O.M.C. (at 100% of D)	14.3	0.0	32.0	12.5	1.5	30.0	15.5	1.5	30.0
Wetter Side at 95% of D	17.2	1.4	27.0	16.8	1.2	26.0	20.4	1.0	31.0

These test results square with general tendency as follows:

(i) The maximum shearing strength is attained at some drier moisture content than O.M.C.

(ii) As the moisture content increases from the moisture content at which the maximum shearing strength is attained, the shearing strength decreases.

When the moisture content is about 3% higher than O.M.C., the shearing strength in total stress is decreased abruptly, and trafficability for wheele type construction equipment is not prospected when the moisture content of material is more than 3% higher than O.M.C.

Any significant differences in engineering properties among the proposed borrow areas and additionally proposed borrow area (extra borrow area) are not found. However, a soil test, such as cone penetration test on compacted material by which the trafficability for construction equipments are evaluated, has not carried out yet.

Evaluating trafficability by the index properties, and taking hauling distance into account, the borrow area I is evaluated to be the most suitable dam embankment material, and the borrow areas II and III are secondary suitable for dam embankment material.

(3) Khlong Thap Ma Damsite

The soil materials of proposed borrow areas for Khlong Thap Ma are classified, by index properties, as follows:

Borrow Area	Classification	Plasticity Index
I (PT-1)	GM (GM)	12 - 28 (22)
II (PT-2 & 3)	GP-GM,GC or CL-CM (GC)	6 - 16 (17.4 & 16.1)
III (PT-5)	GM,GC or SM	-

All materials are suitable for impervious embankment material of fill type dam. The priority of materials are generally as follows:

Priority	Soils by Classification
1	GC
2	CM
3	SM

The permeability coefficients of materials compacted at various moisture content are as follows:

Moisture Content	Borrow Areas	
	I (PT-1)	II (PT-2)
Drier Side at 95%	(13.8) 7.1×10^{-7}	(12.1) 1.8×10^{-6}
O.M.C (at 100% of D)	(19.3) 2.5×10^{-7}	(15.6) 10^{-8}
Wetter Side at 95% of D	(23.2) 1.3×10^{-7}	(19.9) 3.7×10^{-7}

Concerning corelation between permeability and moisture content, the general tendency, as described in (1) Khlong Luang Damsite, is recognized. Though the permeability test on the soil material of borrow area III (PT-5) was not carried out, the similar permeability coefficients to values noted above are estimated.

The natural moisture content of soil materials of each borrow areas are 2% or 3% drier than O.M.C respectively, therefore watering system will be required to be furnished to execute the compaction work at the moisture content slightly wetter than O.M.C.

The shearing strength of materials compacted at various moisture contents are as follows:

(a) In Total Stress

Moisture Content	Borrow Areas					
	I (PT-1)			(II (PT-2)		
	W (%)	CUU (t/m^2)	øUU (o)	W (%)	CUU (t/m^2)	øUU (o)
Drier Side at 95% of D	15.2	7.5	22.0	12.7	9.5	22.5
O.M.C (at 100% of D)	19.3	5.0	19.0	16.2	5.0	17.0
Wetter Side at 95% of D	23.8	5.0	7.0	19.2	4.8	6.6

(b) In Effective Stress

Moisture Content	Borrow Areas					
	I (PT-1)			II (PT-2)		
	W (%)	CUU (t/m^2)	øUU (o)	W (%)	CUU (t/m^2)	øUU (o)
Drier Side at 95% of D	15.2	1.2	31.5	12.7	1.0	33.0
O.M.C (at 100% of D)	19.3	1.0	31.5	16.2	1.2	31.0
Wetter Side at 95% of D	23.8	0.8	31.5	19.2	1.3	31.0

Concerning relationship between shearing strength and moisture content, the general tendency as described in (1) Khlong Luang Damsite is recognized in total stress, however it is not obvious in effective stress. Though the triaxial compression tests were not carried out on the material of borrow area III, the similar shearing strengths and relationship between shearing strength and moisture content are estimated.

Since the shearing strengths in total strength of materials compacted at the moisture content of 3% or 4% higher than O.M.C, decrease abruptly, trafficability for wheel type construction equipments is not prospected when the moisture content of materials is more than three percent (3%) higher than O.M.C.

Any significant differences, in both index and engineering properties are not found among the proposed borrow areas.

3.3.4 Soil Mechanical Values for Stability Analysis

Based on the results of soil laboratory tests. Design values are determined for shearing strength of earth embankment for stability analysis of dams. The design values are summarized in Table 4. The figures were set forth a little lower than those obtained through tests on materials conpacted at O.M.C.

The design values of unit weights are decided as shown in Table 4, in accordance with the test results of specific gravities and compaction tests, and based on the estimated moisture content of materials at compaction and D values (compaction degree).

The design values for drain and riprap materials are based on experiments.

Shearing strengths and unit weights of foundations are also estimated as shown in Table 4, based on the STP and observation record of drilling cores.

Pore pressure in the earth embankment at completion of embankment works is estimated at 40% of overburden pressure, since the material is prospected to be embanked at moisture content drier than O.M.C.

Concerning the permeability, the permeability coefficients measured in tests are those in vertical direction. it is generally recognized that there is a considerable difference between the permeability coefficient in horizontal direction (kh) and that in vertical (kv) when the embankment is constructed by horizontal thin layers with compaction, and the ratio of the former to the latter are ranged generally from 4 to 16. Considering this fact, the design values of permeability coefficient of earth embankment are determined, based upon the test results, as shown in Table 4.

The design values of permeability coefficient of drain was determined as shown in Table 4 based upon the experience. The design values of permeability coefficient of foundation were determined as shown in Table 4 based upon the field permeability test.

3.4 Future Investigation on Soil Characteristics

The material surveys were conducted in a very short period in parallel with the geological investigation so that it was rather limited in quantity. It is deemed that the informations so far obtained are the minimum quantity for preliminary design of the proposed dams. The investigation in the next stage will be performed to confirm the already obtained concept, and to clarify the characteristics of drain material, the shearing strength of foundation, and some questions remained in detailed aspects. The subjects to be examined in the future are as follows:

(1) Distribution and Extent of Available Earth Material

Only one test pit has been dug for each proposed borrow area, and the quantity of available materials from the selected borrow areas are estimated based upon the geological reconnaissance. It is necessary to confirm whether the required quantity of selected material can be obtained. If the required quantity is not obtainable, other borrow areas should be developed or the design would be changed. To confirm the quantity of selected material, additional test pits, auger borings (or drillings) in the selected borrow areas and additional laboratory soil tests will be required.

(2) Characteristics of Drain Materials

The further investigation should be conducted to identify the drain materials. If appropriate drain materials are available in the vicinity of the proposed damsite, operation of quarry work will be reduced.

(3) Soil Mechanical Properties of Foundation

Dam foundations consist of thick soil layers of quaternary colluvial/terrace deposits, and flood plain deposits. Some soft portions of those soil layers are planned to be removed. The removal extent has been determined by "N"-value. It is necessary to establish the corelations between N-values and shearing strength or compressibility, and to determine the extent of removal by N-values distribution and the corelations established. To establish the corelations between N-values and shearing strengths or compressibilities, ddditional test pits for sampling of undisturbed samples and laboratory soil test will be required.

Quantity of above additional investigations will be as follows:

1) Earth Material

Description	Damsites		
	Khlong Yai	Khlong Thap Ma	Khlong Luang
Test Pit	5m x 3spots (15m)	5m x 3spots (15m)	5m x 3spots (15m)
Auger Boring (or drilling)	5m x 15spots (75m)	5m x 15spots (75m)	5m x 3spots (15m)
Moisture Content	10Nosx18spots (180 Nos)	10Nosx18spots (180 Nos)	10Nosx18spots (180 Nos)
Specific Gravity	3Nosx18spots (54 Nos)	3Nosx18spots (54 Nos)	3Nosx18spots (54 Nos)
Gradation	– " –	– " –	– " –
Atterberg's Limit	– " –	– " –	– " –
Compaction	– " –	– " –	– " –
Triaxial Comp. ($\overline{CU}$)	– " –	– " –	– " –
Permeabiltiy	– " –	– " –	– " –

2) Drain Materials

Description	Damsites		
	Khlong Yai	Khlong Thap Ma	Khlong Luang
Specific Gravity	3 Nos	3 Nos	3 Nos
Gradation	9 Nos	9 Nos	9 Nos
Relative Density	9 Nos	9 Nos	9 Nos
Triaxial Comp.	3 Nos	3 Nos	3 Nos

3) Foundation

Description	Damsites		
	Khlong Yai	Khlong Thap Ma	Khlong Luang
Test Pit	5m x 3spots (15m)	5m x 3spots (15m)	5m x 3spots (15m)
Sampling	3Nosx3spots (9 Nos)	3Nosx3spots (9 Nos)	3Nosx3spots (9 Nos)
Moisture Content	5Nosx3spots (15 Nos)	5Nosx3spots (15 Nos)	5Nosx3spots (15 Nos)
Specific Gravity	5Nosx3spots (15 Nos)	5Nosx3spots (15 Nos)	5Nosx3spots (15 Nos)
Gradation	- " -	- " -	- " -
Atterberg's Limit	- " -	- " -	- " -
Triaxial Comp. ($\overline{CU}$)	- " -	- " -	- " -
- ditto - ($\overline{UU}$)	- " -	- " -	- " -
Consolidation	- " -	- " -	- " -

TABLES

Table 1 SUMMARY OF SOIL TEST : KHLONG LUANG

				(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
SAMPLE NO.				(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
LOCATION				PL-1	PL-1	PL-1	PL-1	PL-2	PL-2	PL-2	PL-2	PL-3	PL-5	PL-5	PL-5	PL-5			
DEPTH (M)				0.3-2.5	2.5-3.0	3.0-4.0	MIXED (0.3-4.0)	0.3-1.3	1.3-2.6	2.6-3.0	MIXED (0.3-3.0)	0.3-2.20	0.3-2.2	2.2-2.5	2.5-2.8	MIXED (0.3-2.8)			
GRADATION	GRAVEL CONTENT (%)			0	1	58	2	37	42	40	31	0	0	0	53	30			
	SAND CONTENT (%)			55	50	21	53	40	33	33	38	75	65	65	34	47			
	SILT CONTENT (%)			28	32	14	33	12	14	10	18	23	26	32	9	21			
	CLAY CONTENT (%)			17	17	7	12	11	11	17	13	2	9	3	4	2			
	Max. Dia (mm)			5	10	75	20	40	40	40	40	5	5	5	40	40			
CONSISTENCY	LIQUID LIMIT (%)			22.0	22.6	25.4	23.2	37.0	38.7	38.7	38.7	-	-	-	-	-			
	PLASTIC LIMIT (%)			13.6	13.2	13.4	15.7	24.3	26.2	25.4	25.1	-	-	-	-	-			
	PLASTICITY INDEX (%)			8.4	9.4	12.0	7.5	12.7	12.5	13.3	13.6	NP	NP	NP	NP	NP			
UNIFIED CLASSIFICATION				SC	SC	GC	SC	GM	GM	GM	SM.SC	SM	SM	SM	SM	SM			
SPECIFIC GRAVITY				2.68	2.69	2.70	2.68	2.77	2.82	2.79	2.77	2.67	2.67	2.66	2.67	2.64			
NATURAL MOISTURE CONTENT (%)				6.9	7.5	6.4	6.3	9.0	7.9	7.5	8.6	12.0	12.0	3.1	2.7	3.7			
COMPACTION	OPTIMUM MOISTURE CONT. (%)						10.2				13.8	11.0				7.3			
	MAX. DRY DENSITY (t/m^3)						1.992				1.870	1.734				2.115			
TRIAXIAL COMP.	U.U	95% of γd max (dry side)	CUU (t/m^2)				11.0				7.5					5.5			
			ϕUU (deg.)				23.5				26.0					34.5			
		100% of γd max (O.M.C)	CUU (t/m^2)				4.2				4.0					5.0			
			ϕUU (deg.)				26.5				25.5					34.0			
		95% of γd max (wet side)	CUU (t/m^2)				4.5				5.4					1.8			
			ϕUU (deg.)				9.0				6.0					22.0			
	$\overline{C.U}$	95% of γd max (dry side)	c' (t/m^2)				1.0				1.0					3.5			
			ϕ' (deg.)				34.0				33.5					34.0			
		100% of γd max (O.M.C)	c' (t/m^2)				1.5				1.0					2.5			
			ϕ' (deg.)				32.0				32.0					36.0			
		95% of γd max (wet side)	c' (t/m^2)				0.8				1.2					1.0			
			ϕ' (deg.)				34.0				34.0					37.0			
PERMEABILITY COEFFICIENT	95% of γd max (dry side) (m/sec)						4.3×10^{-8}				7.9×10^{-7}					1.8×10^{-7}			
	100% of γd max (O.M.C) (m/sec)						$<10^{-10}$				7.8×10^{-10}					9.5×10^{-10}			
	95% of γd max (wet side) (m/sec)						6.1×10^{-9}				3.9×10^{-9}					7.6×10^{-8}			
CONSOLIDATION	YIELD STRESS: Py (t/m^2)						Not Determined				Not Determined					Not Determined			
	COMPRESSION INDEX: Cc						Not Determined				Not Determined					Not Determined			

Table 2 SUMMARY OF SOIL TEST : KHLONG YAI

			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
SAMPLE NO.			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
LOCATION			PY-1	PY-1	PY-1	PY-1	PY-2	PY-2	PY-2	PY-2	PY-3	PY-3	PY-3	PY-3	PY-4	PY-4	PY-4	PY-4
DEPTH (M)			0-1.2	1.2-2.3	2.3-4.1	MIXED (0-4.1)	1.3-2.1	2.1-2.6	2.6-4.0	MIXED (1.3-4.0)	0.6-1.6	1.6-2.5	2.5-3.6	MIXED (0.6-3.6)	0.6-1.3	1.3-3.0	3.0-4.0	MIXED (0.6-4.0)
GRADATION		GRAVEL CONTENT (%)	0	0	8	3	1	2	0	3	35	18	17	30	29	2	2	5
		SAND CONTENT (%)	59	57	39	42	57	63	49	50	32	38	38	33	46	33	39	39
		SILT CONTENT (%)	19	18	25	41	14	17	36	28	16	21	22	18	14	26	26	29
		CLAY CONTENT (%)	22	25	28	14	28	18	15	19	17	23	23	19	11	39	33	27
		Max. Dia (mm)	5	5	20	20	20	20	5	20	40	40	20	40	40	20	10	40
CONSISTENCY		LIQUID LIMIT (%)	27.4	39.2	41.6	35.5	41.6	47.2	31.9	42.3	39.2	41.0	41.0	43.2	44.0	55.0	51.8	48.3
		PLASTIC LIMIT (%)	18.0	24.4	25.2	20.2	24.7	28.0	18.8	26.5	26.5	24.9	24.5	26.8	28.9	36.0	34.5	31.1
		PLASTICITY INDEX (%)	9.4	14.8	16.4	15.3	16.9	19.2	13.1	15.8	12.7	16.1	16.5	16.4	15.1	19.0	17.3	17.2
UNIFIED CLASSIFICATION			SC	SC	CL	CL	SC	SM	CL	SM	GC	SC	SC	SM	SM	MH	MH	ML
SPECIFIC GRAVITY			2.66	2.65	2.65	2.69	2.65	2.69	2.64	2.64	2.70	2.69	2.70	2.71	2.73	2.70	2.68	2.68
NATURAL MOISTURE CONTENT (%)			11.0	11.2	14.8	13.9	16.8	15.7	13.6	15.9	11.9	12.5	14.2	11.2	9.8	29.2	14.1	21.6
COMPACTION		OPTIMUM MOISTURE CONT. (%)				14.0				12.3				14.9				15.3
		MAX. DRY DENSITY (t/m^3)				1.856				1.867				1.800				1.751
TRIAXIAL COMP.	U.U	95% of γd max (dry side) CUU (t/m^2)				4.0				12.0								12.0
		95% of γd max (dry side) øUU (deg.)				23.0				26.0								25.5
		100% of γd max (O.M.C) CUU (t/m^2)				5.0				7.0								3.5
		100% of γd max (O.M.C) øUU (deg.)				22.0				20.0								19.5
		95% of γd max (wet side) CUU (t/m^2)				5.0				4.4								4.3
		95% of γd max (wet side) øUU (deg.)				7.0				6.0								5.0
	$\overline{C.U}$	95% of γd max (dry side) c' (t/m^2)				1.0				1.0								1.0
		95% of γd max (dry side) ø' (deg.)				32.0				29.0								31.0
		100% of γd max (O.M.C) c' (t/m^2)				0.0				1.5								1.5
		100% of γd max (O.M.C) ø' (deg.)				32.0				30.0								30.0
		95% of γd max (wet side) c' (t/m^2)				1.4				1.2								1.0
		95% of γd max (wet side) ø' (deg.)				27.0				26.0								31.0
PERMEABILITY COEFFICIENT		95% of γd max (dry side) (m/sec)				1.6×10^{-8}				1.6×10^{-8}								3.0×10^{-8}
		100% of γd max (O.M.C) (m/sec)				2.3×10^{-10}				4.2×10^{-10}								9.5×10^{-9}
		95% of γd max (wet side) (m/sec)				3.9×10^{-9}				2.9×10^{-9}								1.4×10^{-9}
CONSOLIDATION		YIELD STRESS: Py (t/m^2)				Not Determined				Not Determined								Not Determined
		COMPRESSION INDEX: Cc				Not Determined				Not Determined								Not Determined

Table 3 SUMMARY OF SOIL TEST : KHLONG THAP MA

SAMPLE NO.			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
LOCATION			PT-1	PT-1	PT-1	PT-1	PT-2	PT-2	PT-2	PT-2	PT-3	PT-3	PT-3	PT-3	PT-4	PT-4	PT-4	PT-4
DEPTH (M)			0.7-0.9	1.3-1.6	2.1-2.4	(0.7-2.4)	0.2-0.4	0.9-1.2	1.6-1.9	MIXED (0.2-1.9)	0.0-0.6	0.6-1.7	1.7-1.8	MIXED (0.0-1.8)	0.2-0.4	0.6-0.8	1.0-1.2	MIXED (0.2-1.2)
GRADATION		GRAVEL CONTENT (%)	42	34	38	46	69	50	40	56	1	47	53	57	0	0	1	0
		SAND CONTENT (%)	28	32	17	21	23	31	23	11	40	25	20	19	63	59	71	66
		SILT CONTENT (%)	17	16	21	14	5	12	21	14	44	17	15	13	30	36	23	21
		CLAY CONTENT (%)	13	18	24	19	3	7	16	19	15	11	12	11	7	5	5	13
		Max. Dia (mm)	40	40	40	40	40	40	40	40	10	40	40	40	5	5	10	5
CONSISTENCY		LIQUID LIMIT (%)	37.7	39.0	38.1	52.0	28.1	35.2	37.9	42.2	22.7	34.8	39.1	37.8	-	-	-	-
		PLASTIC LIMIT (%)	24.7	27.3	22.5	30.2	22.5	21.9	24.3	24.8	16.2	21.2	22.8	21.5	-	-	-	-
		PLASTICITY INDEX (%)	13.0	11.7	15.6	21.8	5.6	13.3	13.6	17.4	6.5	13.1	16.3	16.3	NP	NP	NP	NP
UNIFIED CLASSIFICATION			GM	GM	GM	GM	GP-GM	GC	GC	GC	CL-ML	GC	GC	GC	SM	SM	SM	SM
SPECIFIC GRAVITY			2.76	2.70	2.73	2.76	2.83	2.85	2.80	2.78	2.65	2.67	2.68	2.60	2.61	2.67	2.65	2.60
NATURAL MOISTURE CONTENT (%)			3.5	3.5	10.5	15.0	5.0	4.8	12.2	15.9	14.3	13.8	13.5	13.6	7.3	10.5	13.5	13.3
COMPACTION		OPTIMUM MOISTURE CONT. (%)				19.1				18.2				15.8				8.8
		MAX. DRY DENSITY (t/m^3)				1.707				1.732				1.782				2.031
TRIAXIAL COMP.	U.U 95% of γd max (dry side)	CUU (t/m^2)				7.5								9.5				-
		øUU (deg.)				22.0								22.5				-
	U.U 100% of γd max (O.M.C)	CUU (t/m^2)				5.0								5.0				3.5
		øUU (deg.)				19.0								17.0				30.0
	U.U 95% of γd max (wet side)	CUU (t/m^2)				5.0								4.8				3.4
		øUU (deg.)				7.0								6.6				13.8
	C.U 95% of γd max (dry side)	C' (t/m^2)				6.1								0.5				-
		ø' (deg.)				31.5								33.0				-
	C.U 100% of γd max (O.M.C)	C' (t/m^2)				1.0								1.2				1.8
		ø' (deg.)				31.5								31.0				34.0
	C.U 95% of γd max (wet side)	C' (t/m^2)				0.8								1.2				0.6
		ø' (deg.)				31.5								31.0				36.0
PERMEABILITY COEFFICIENT		95% of γd max (dry side) (m/sec)				7.1×10^{-9}								1.8×10^{-8}				1.8×10^{-9}
		100% of γd max (O.M.C) (m/sec)				2.5×10^{-9}								$<10^{-10}$				8.6×10^{-10}
		95% of γd max (wet side) (m/sec)				1.3×10^{-9}								3.7×10^{-9}				3.3×10^{-8}
CONSOLIDATION		YIELD STRESS: Py (t/m^2)				Not Determined												
		COMPRESSION INDEX: Cc				Not Determined												

Table 4 SUMMARY OF DESIGN VALUE

SITE		MATERIAL	UNIT WEIGHT			SHEARING STRENGTH		PERMEABILITY	
			W(WET) (T/M^3)	W(SAT) (T/M^3)	W(SUB) (T/M^3)	COHESION C´ (T/M^2)	FRICTION ø´ (DEG.)	VERTICAL kv (M/SEC)	HORIZONTAL kh (M/SEC)
KHLONG YAI	(1)	Embankment	2.00	2.10	1.10	1.0	28.0	10^{-9}	10^{-8}
		Blanket	"	"	"	"	"	10^{-8}	-
	(2)	Drain	1.85	2.15	1.15	0.0	35.0	$5x10^{-5}$	$5x10^{-5}$
	(3)	Riprap	1.90	2.15	1.15	0.0	40.0	-	-
	(4)	Flood Plain Deposit	1.80	1.85	0.85	2.0	25.0	10^{-5}	10^{-5}
	(5)	Colluvial/Terrace Deposit	1.85	1.94	0.94	2.0	28.0	10^{-5}	10^{-5}
	(6)	Weathered Granite	2.10	2.30	1.30	10.0	35.0	-	$5x10^{-7}$
KHLONG THAP MA	(1)	Embankment	1.97	2.08	1.08	1.0	30.0	10^{-9}	10^{-8}
		Blanket	"	"	"	"	"	10^{-8}	-
	(2)	Drain	1.85	2.15	1.15	0.0	35.0	$5x10^{-5}$	$5x10^{-5}$
	(3)	Riprap	1.90	2.15	1.15	0.0	40.0	-	-
	(4)	Flood Plain Deposit	1.80	1.85	0.85	2.0	25.0	-	10^{-5}
	(5)	Colluvial/Terrace Deposit	1.85	1.94	0.94	2.0	28.0	-	10^{-5}
	(6)	Weathered Granite	2.10	2.30	1.30	10.0	35.0	-	$5x10^{-7}$
KHLONG LUANG	(1)	Embankment	1.98	2.14	1.14	1.0	30.0	10^{-9}	10^{-8}
		Blanket	"	"	"	"	"	10^{-8}	-
	(2)	Drain	1.85	2.15	1.15	0.0	35.0	$5x10^{-5}$	$5x10^{-5}$
	(3)	Riprap	1.90	2.15	1.15	0.0	40.0	-	-
	(4)	Flood Plain Deposit	1.80	1.85	0.85	2.0	25.0	-	$7x10^{-6}$
	(5)	Colluvial/Terrace Deposit	1.85	1.94	0.94	2.0	28.0	-	$7x10^{-6}$
	(6)	Weathered Granite	2.10	2.30	1.30	10.0	35.0	-	$7x10^{-6}$

FIGURES

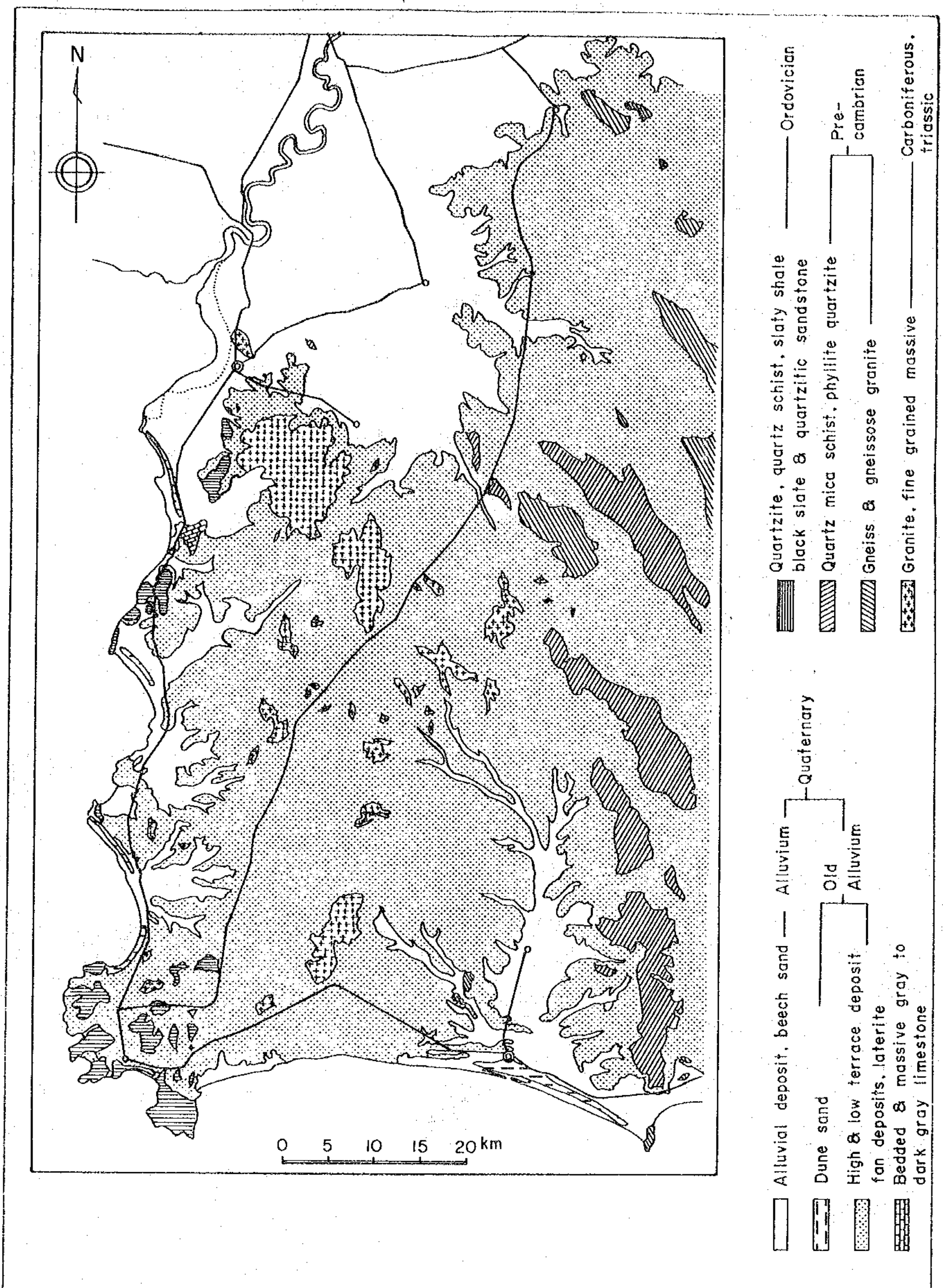

Fig. 1 General Geological Map

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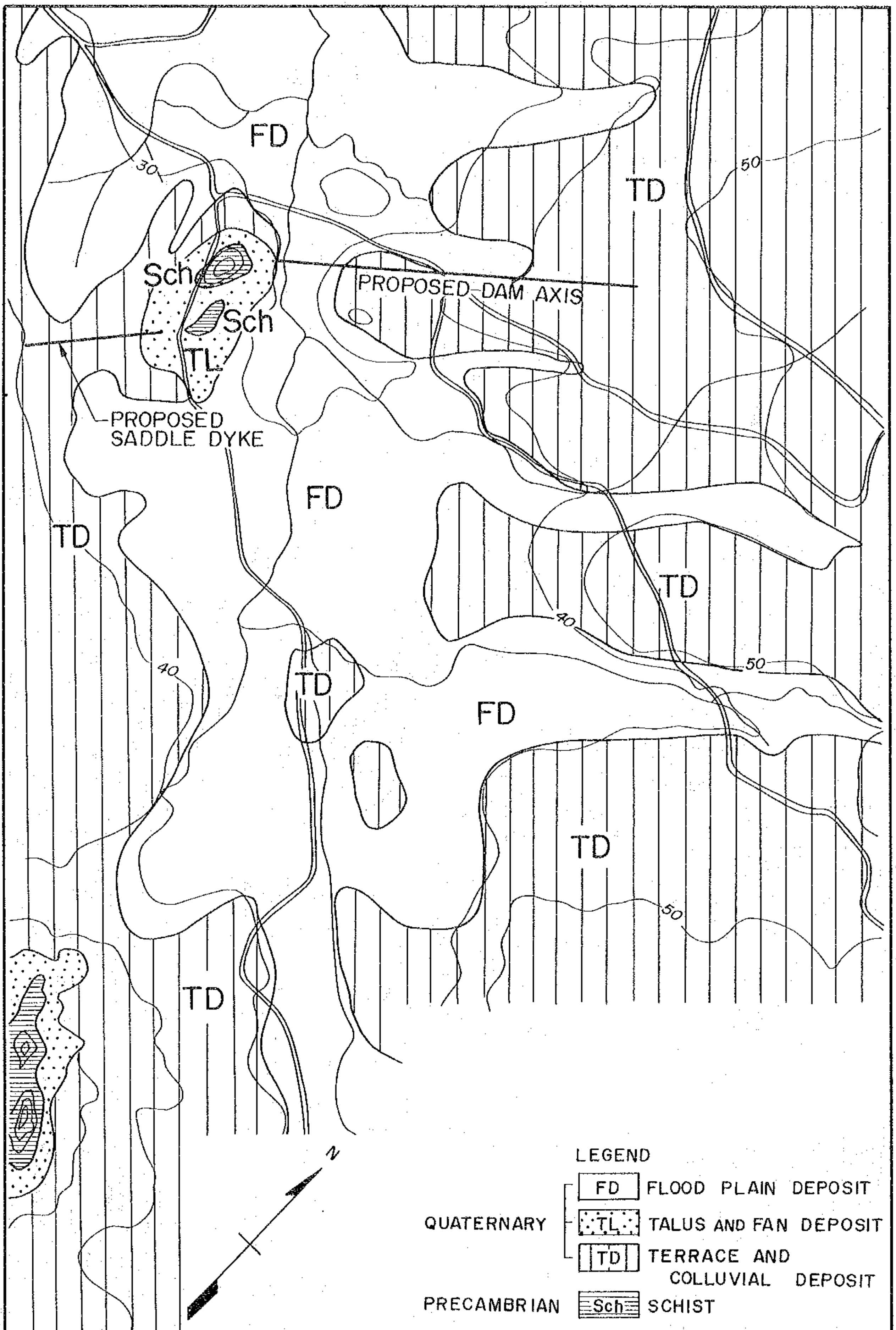

Fig. 2 Geological Map Of Khlong Luang Reservir Area

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THE EAST COAST WATER RESOURCES DEVELOPMENT PROJECT PHASE II
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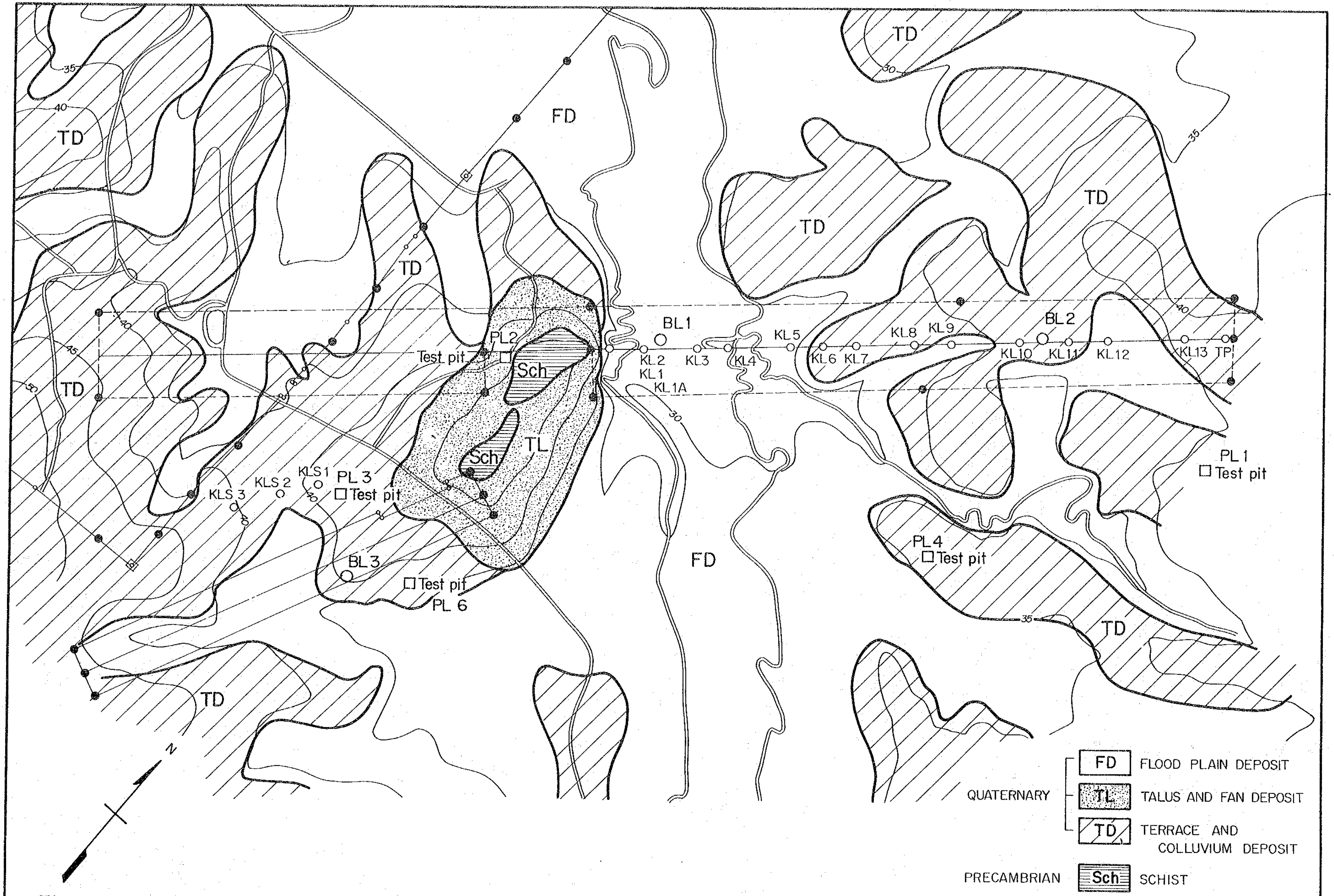

Fig. 3 Geological Map of Khlong Luang Damsite

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THE EAST COAST WATER RESOURCES DEVELOPMENT PROJECT PHASE II
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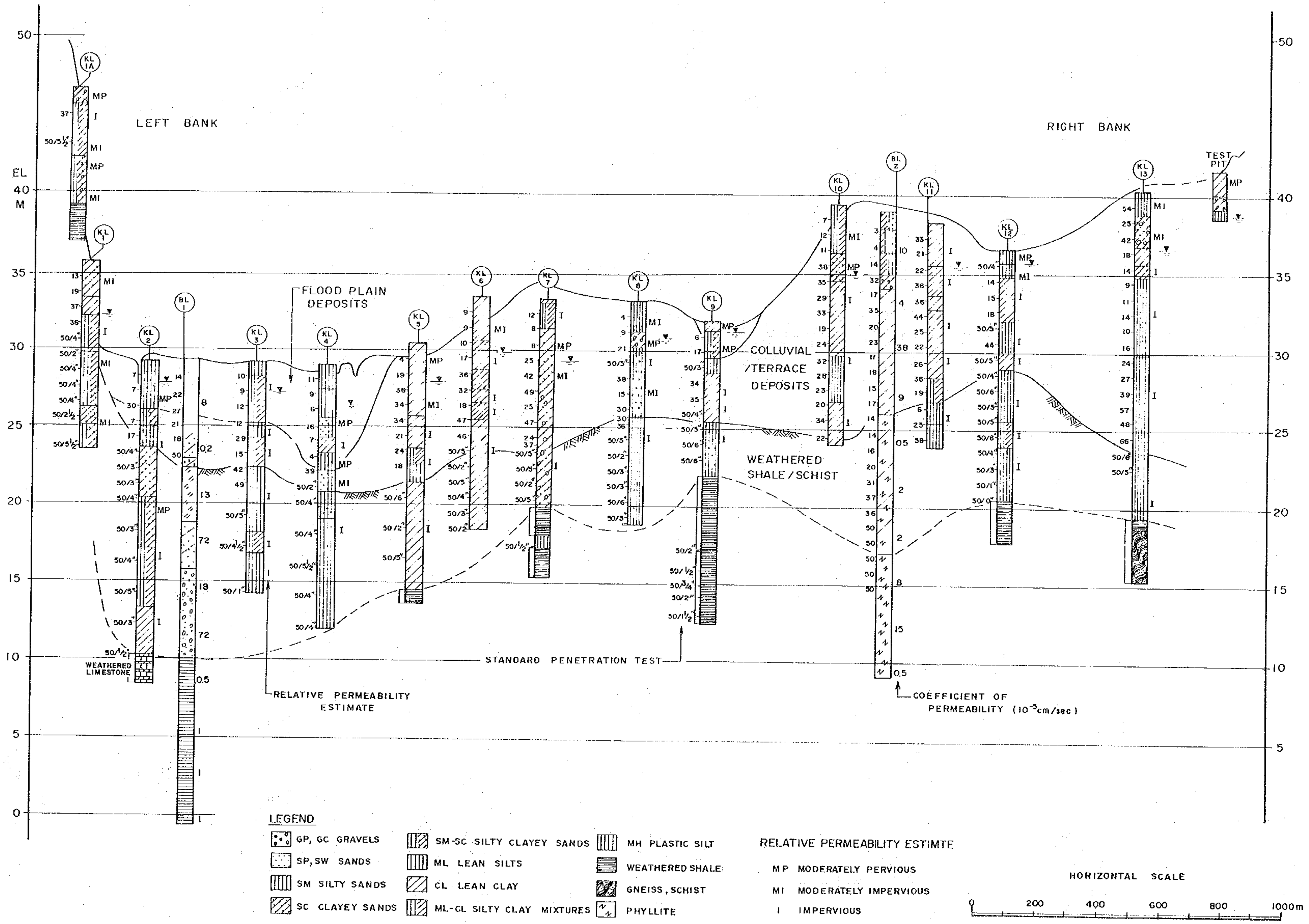

Fig. 4 Geological Profile of Khlong Luang Damsite

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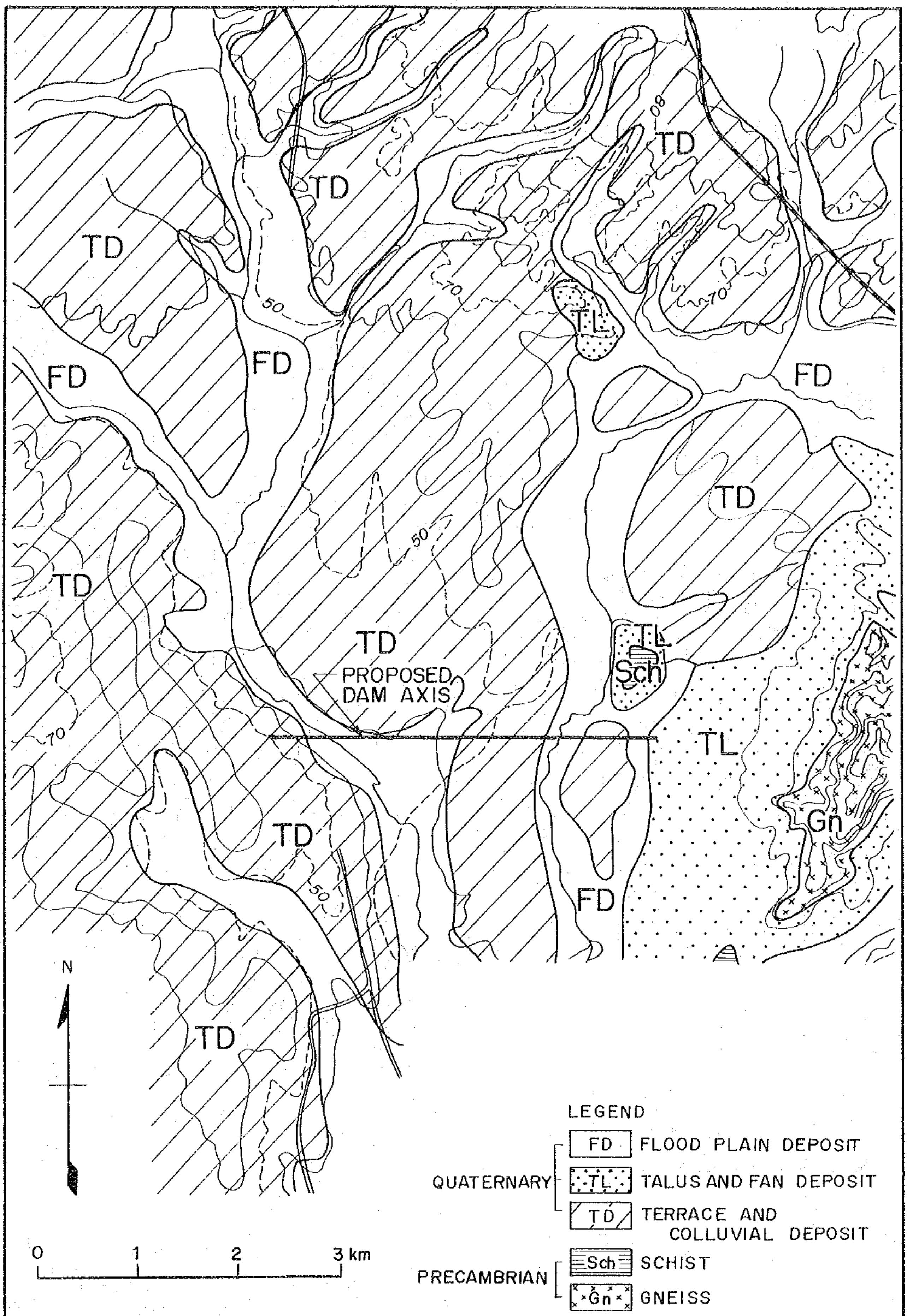

Fig.5 Geological Map Of Khlong Yai Reservir Area

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JAPAN INTERNATIONAL COOPERATION AGENCY

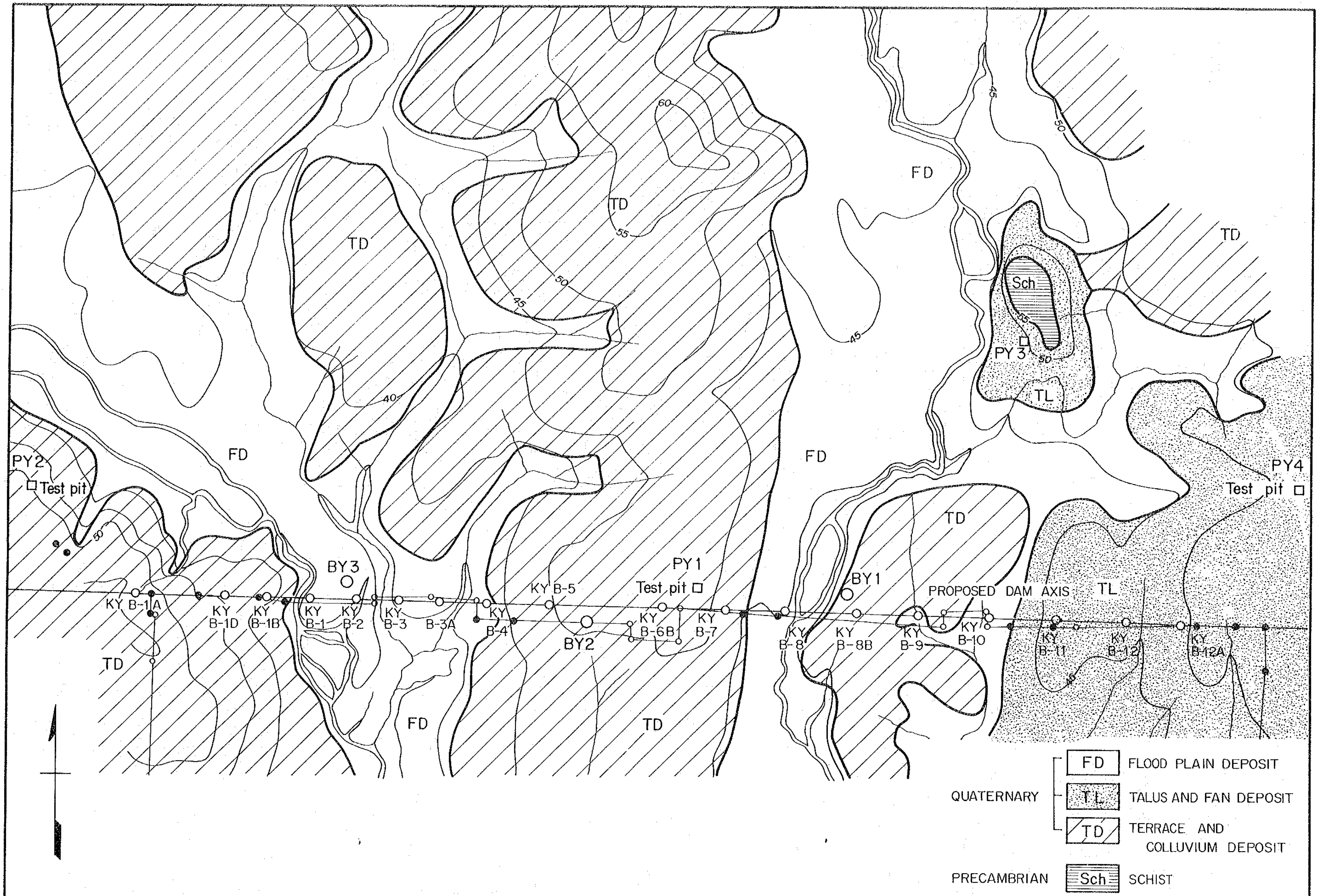

Fig.6 Geological Map of Khlong Yai Damsite

0 100 200 300 400 500 m

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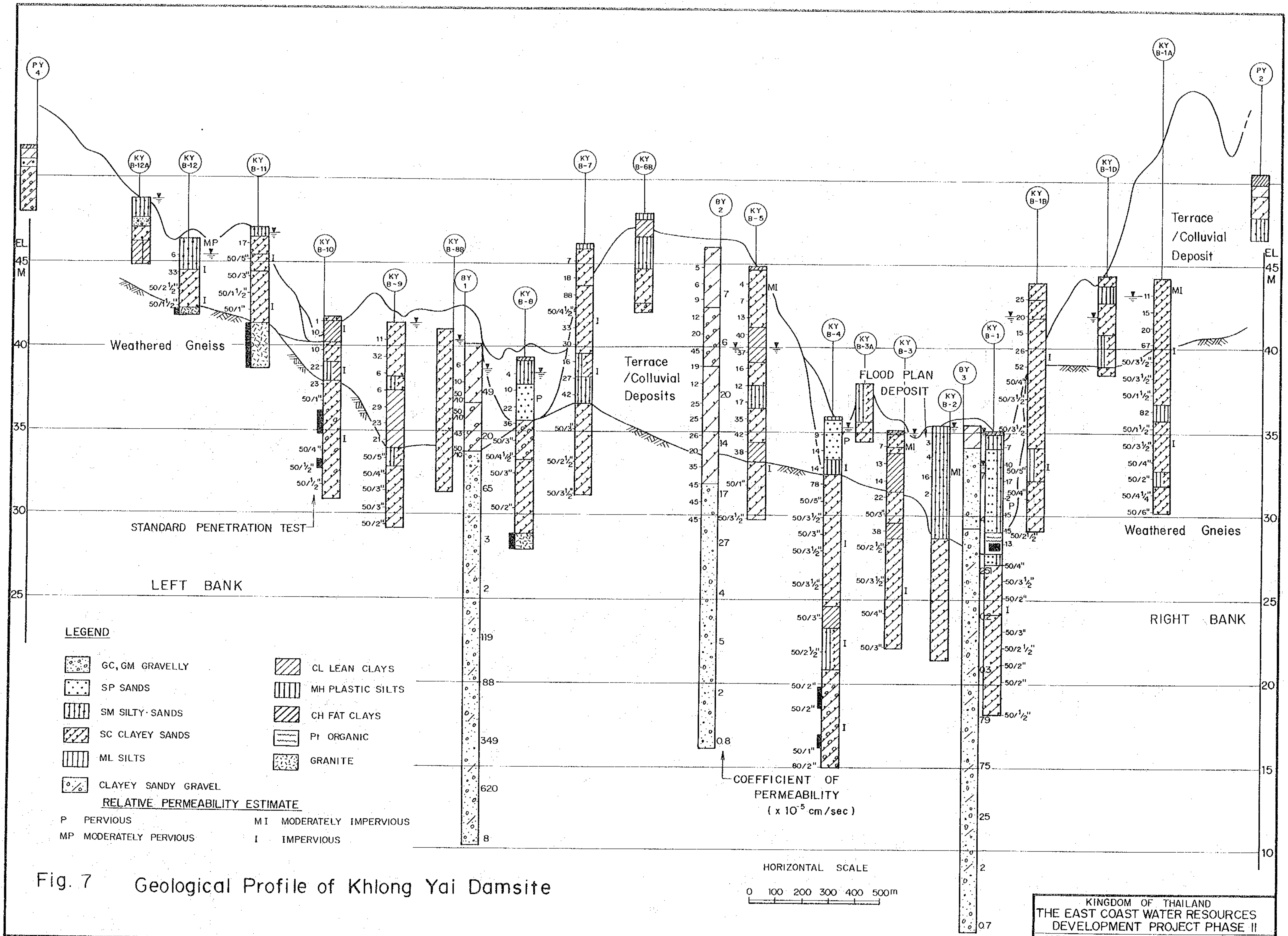

Fig. 7 Geological Profile of Khlong Yai Damsite

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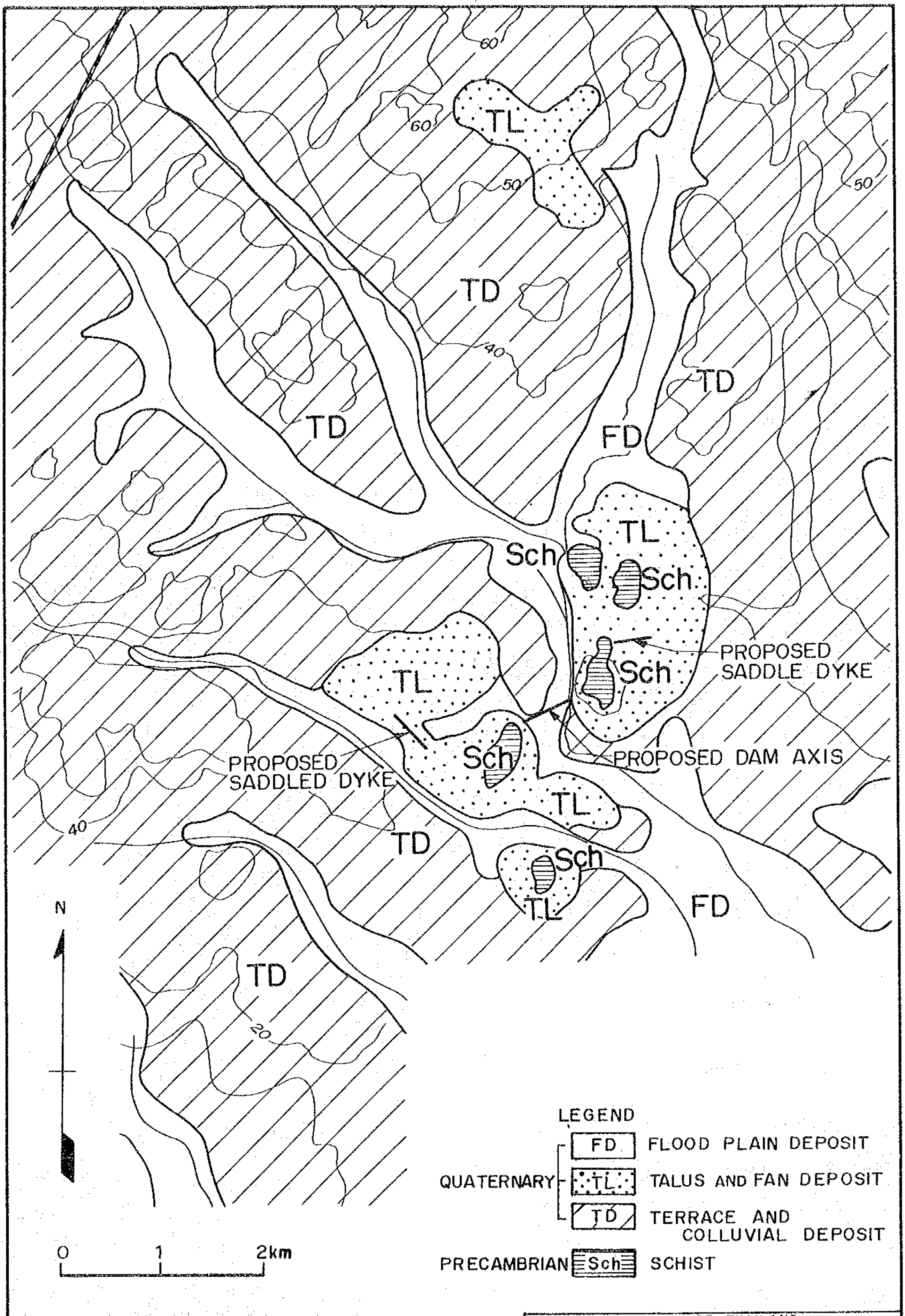

Fig. 8 Geological Map of Khlong Thap Ma Reservir Area

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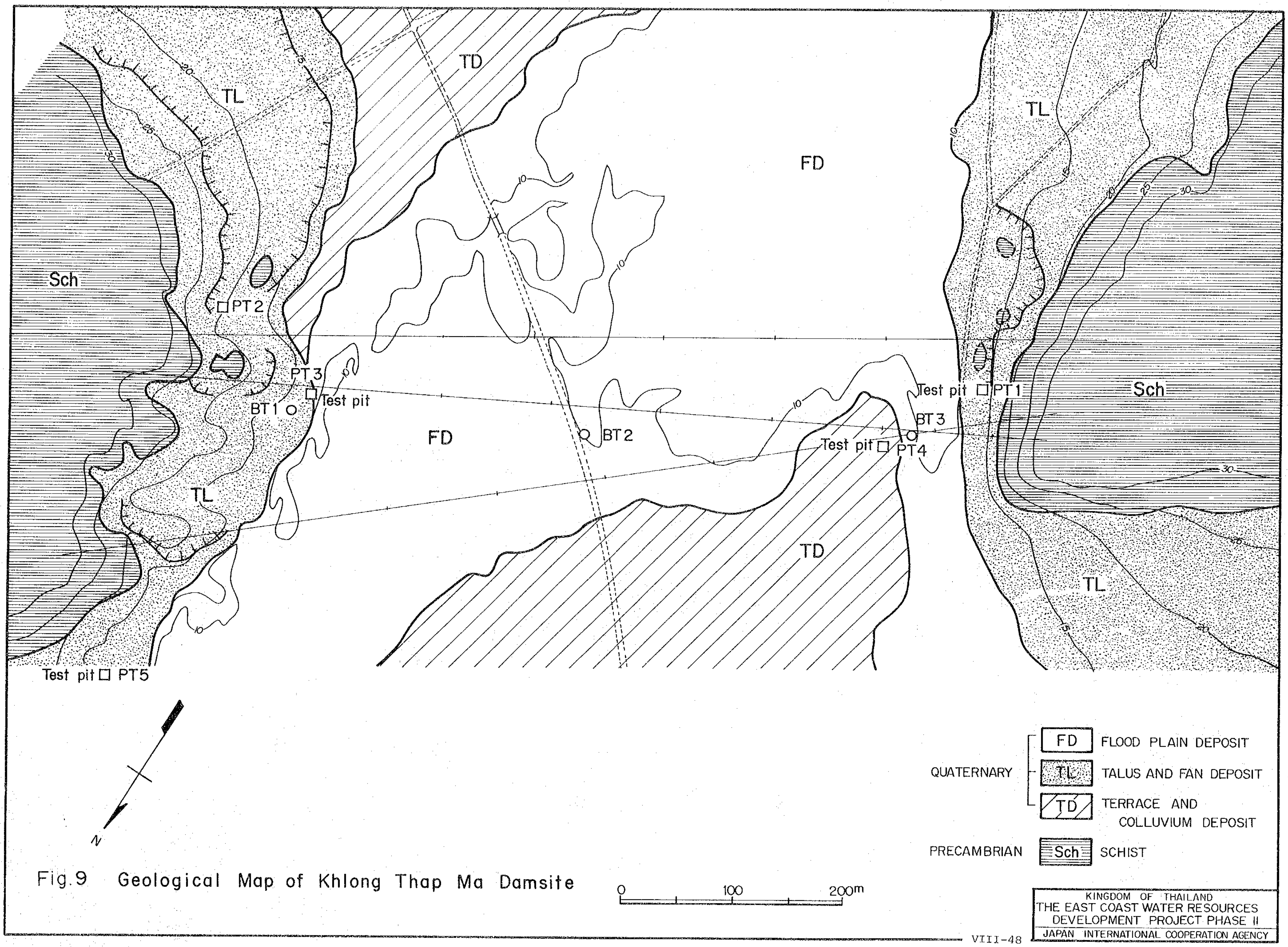

Fig.9 Geological Map of Khlong Thap Ma Damsite

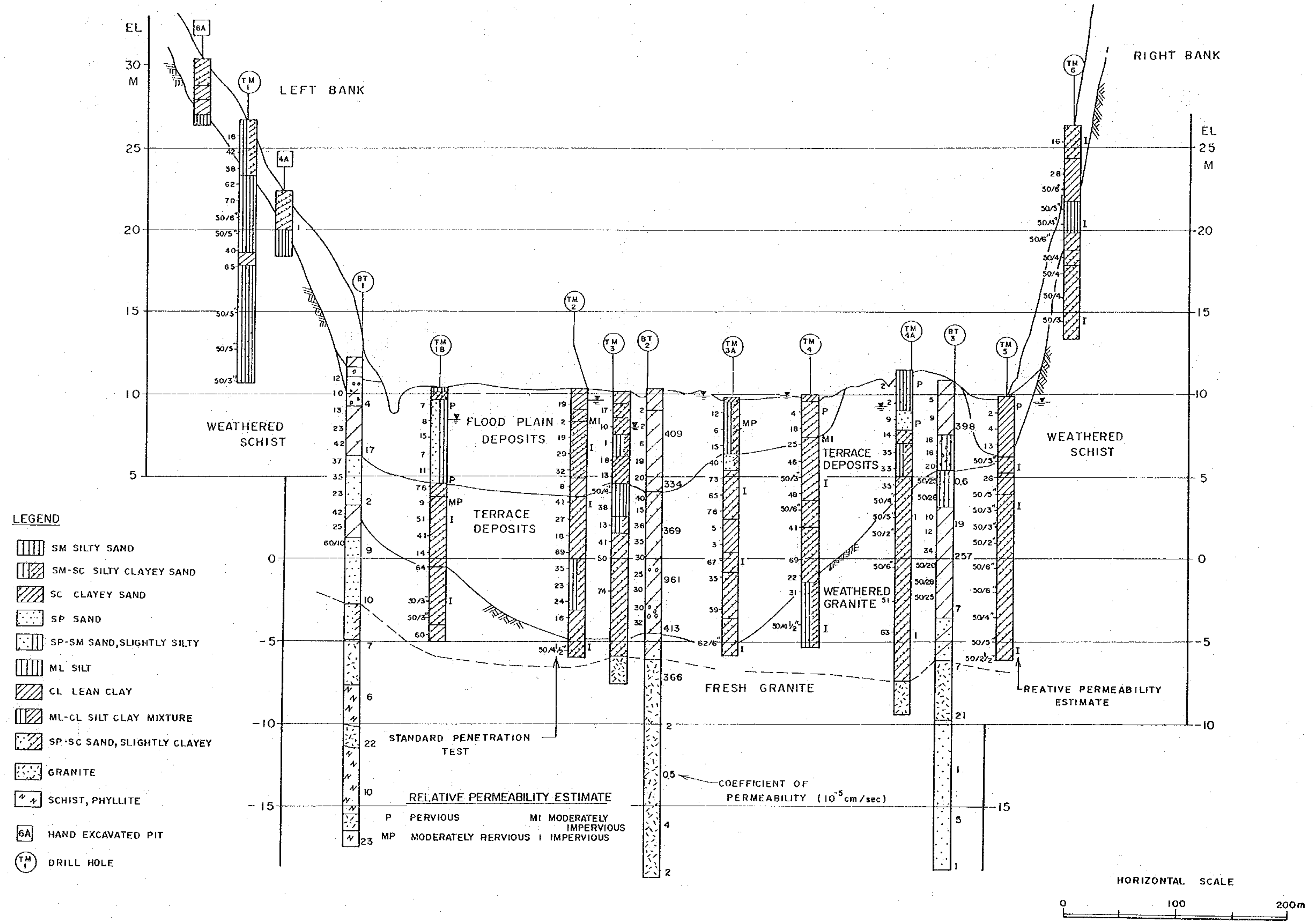

Fig.10 Geological Profile of Khlong Thap Ma Damsite

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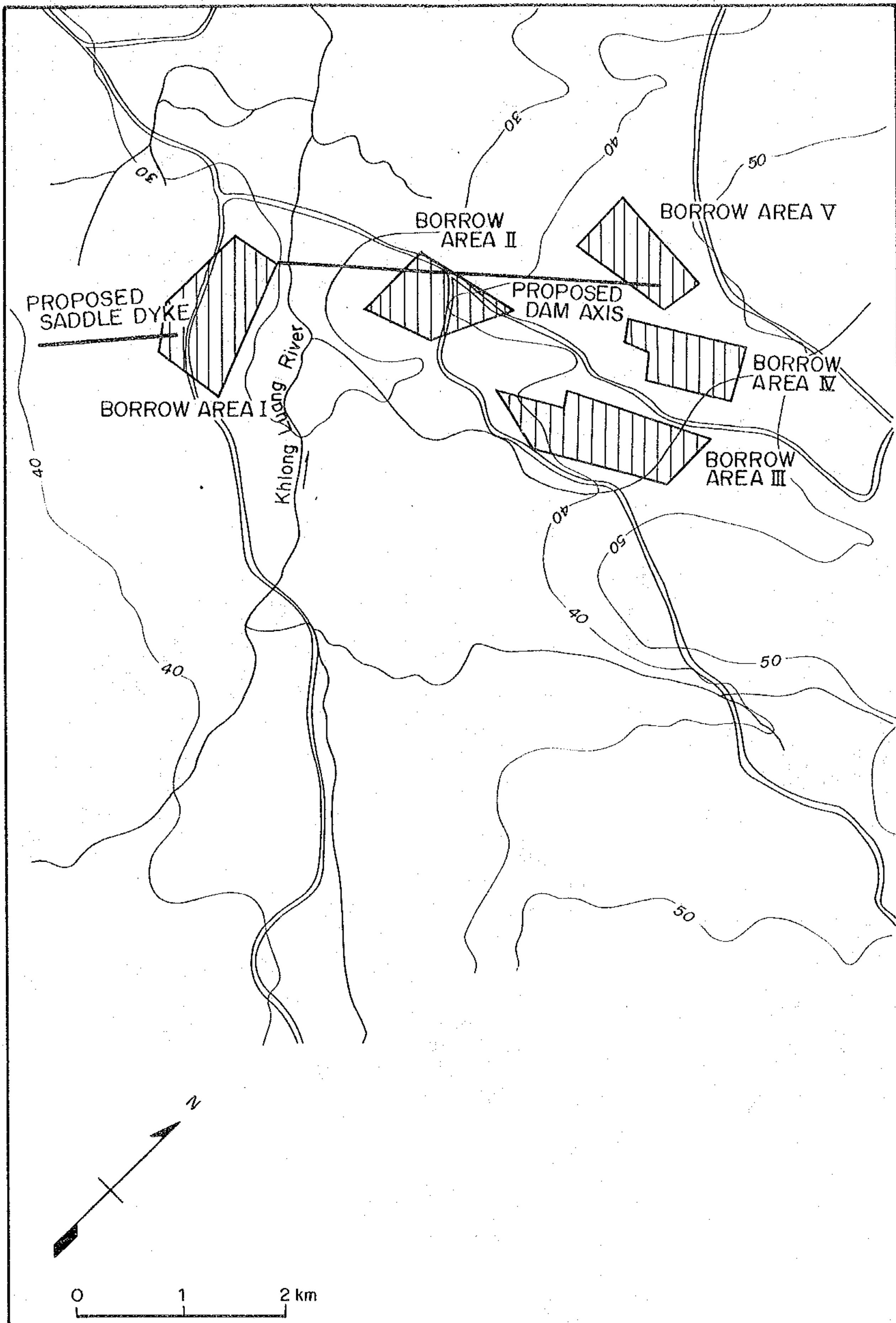

Fig. 11 Location Map of Borrow Areas, Khlong Luang Damsite

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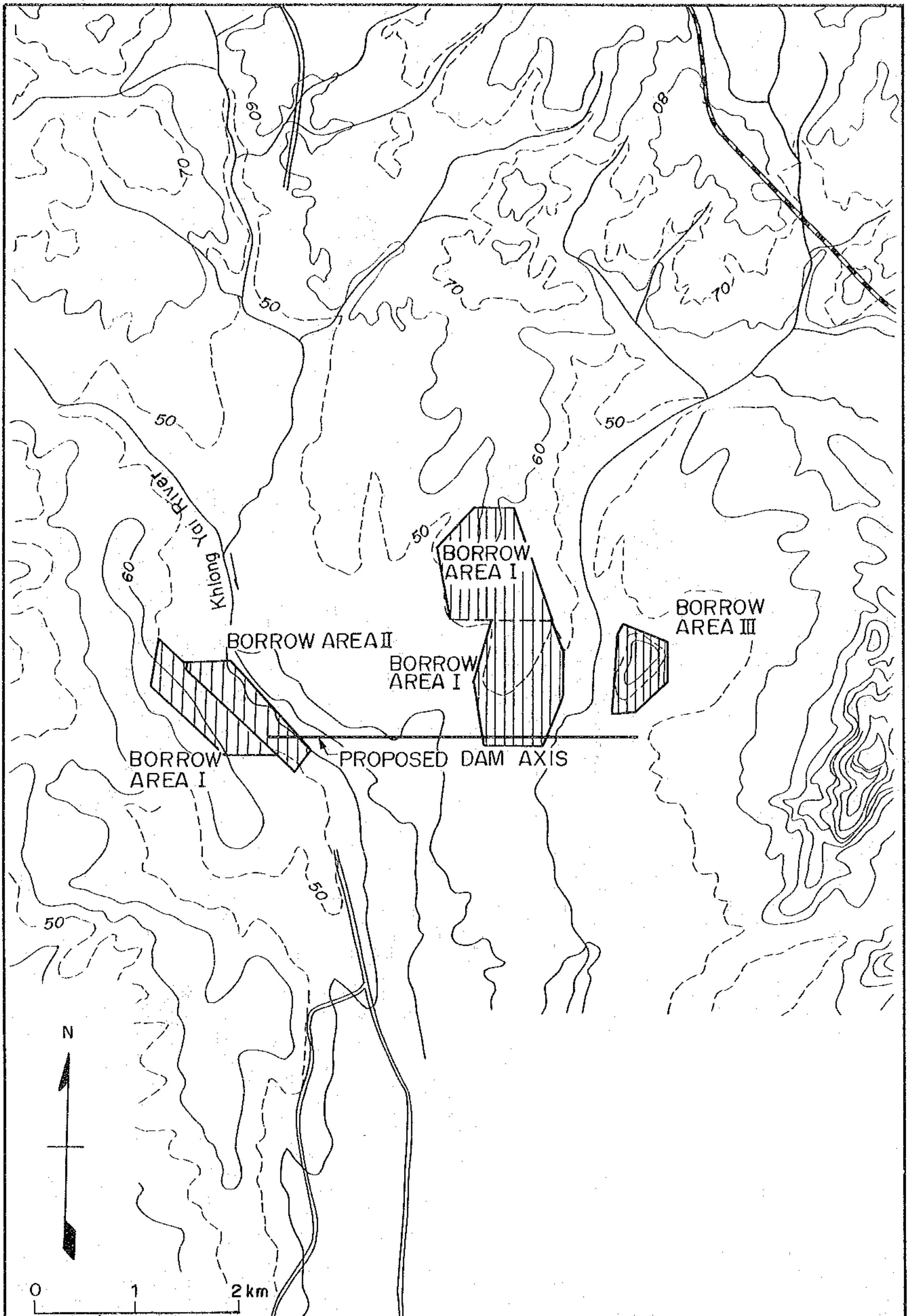

Fig. 12 Location Map of Borrow Areas, Khlong Yai Damsite

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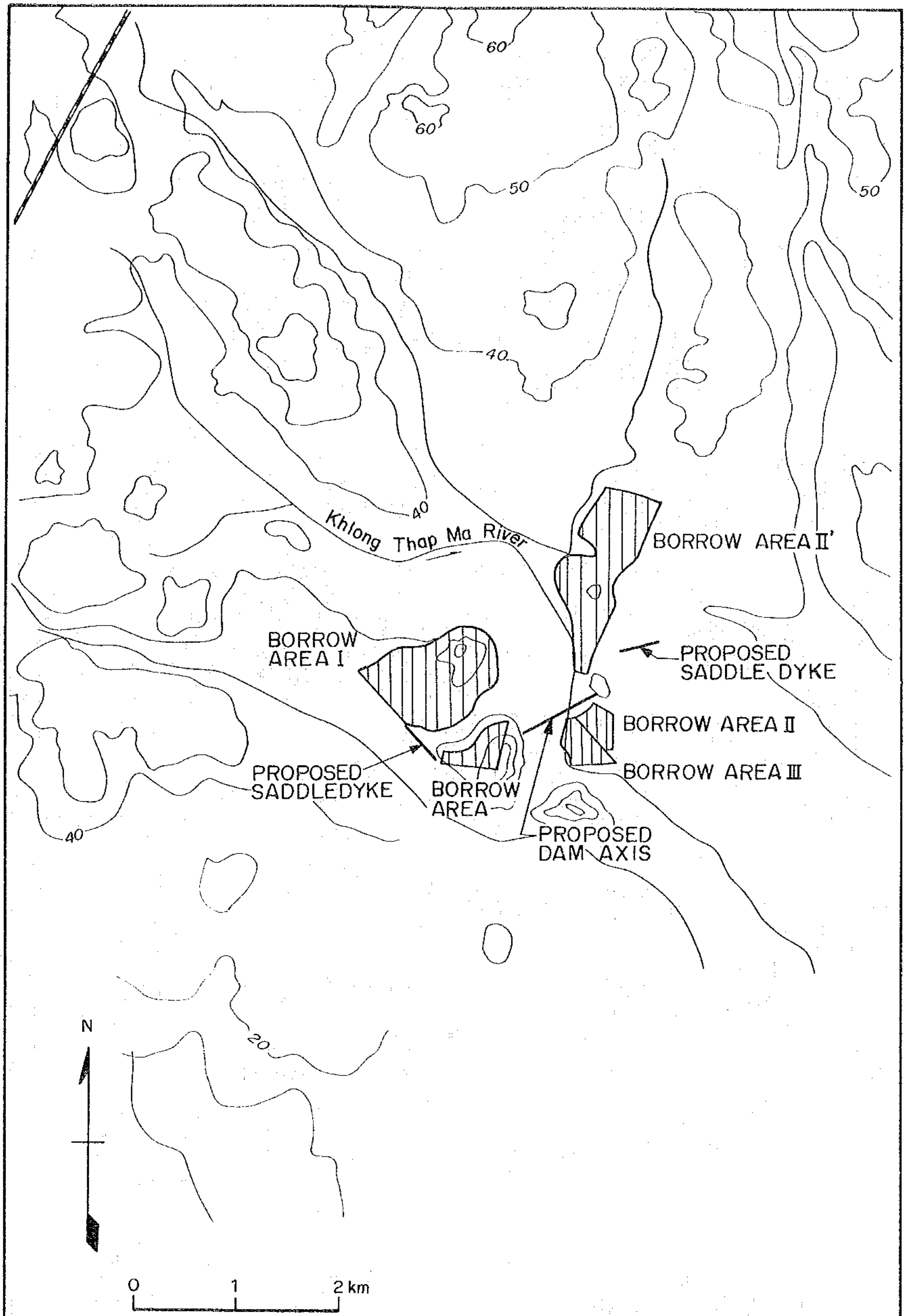

Fig.13 Location Map of Borrow Areas, Khlong Thap Ma Damsite

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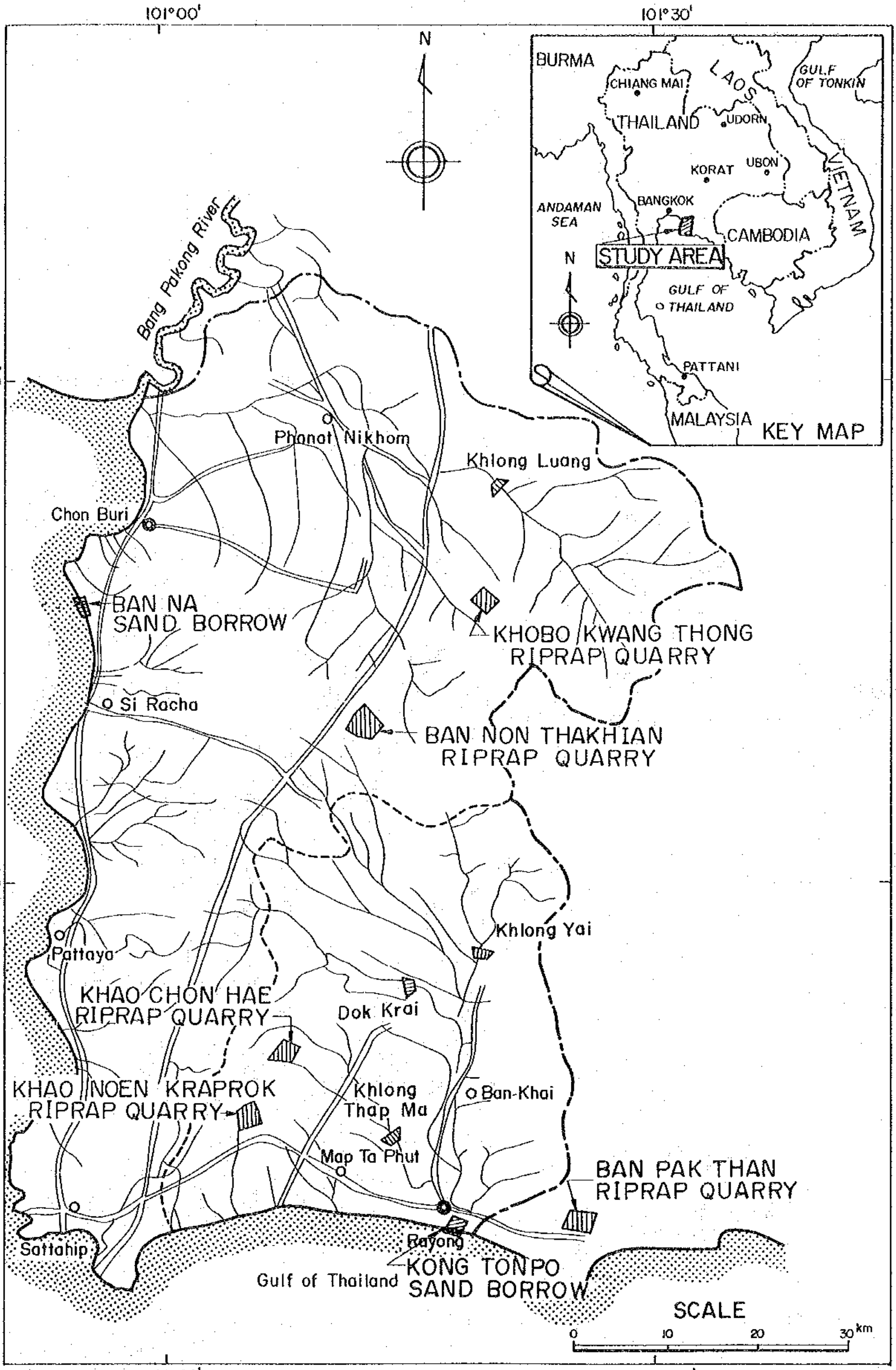

Fig.14 Location Map of Borrow Areas and Quarry sites

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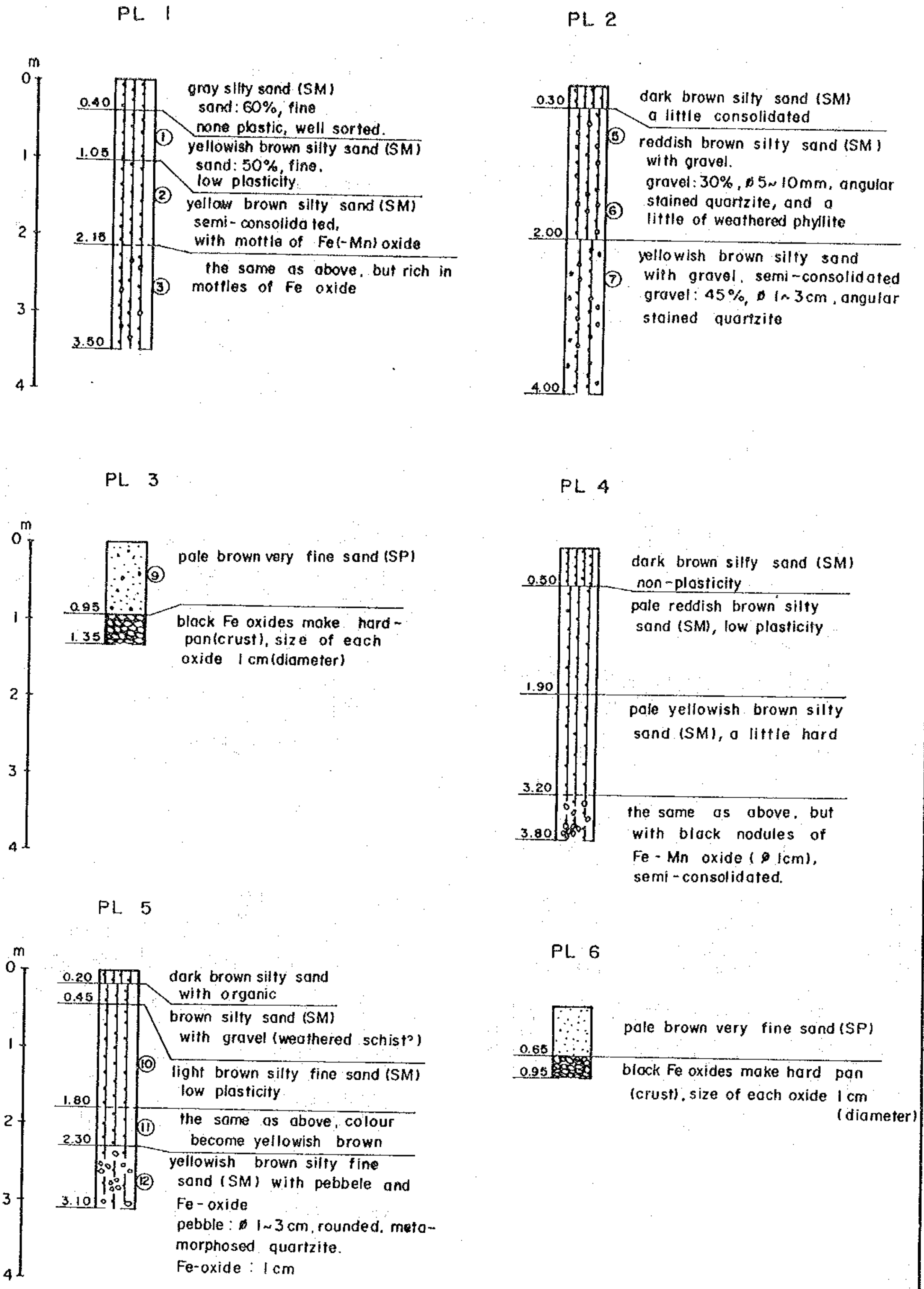

Fig.15 Log of Test Pit, Khlong Luang

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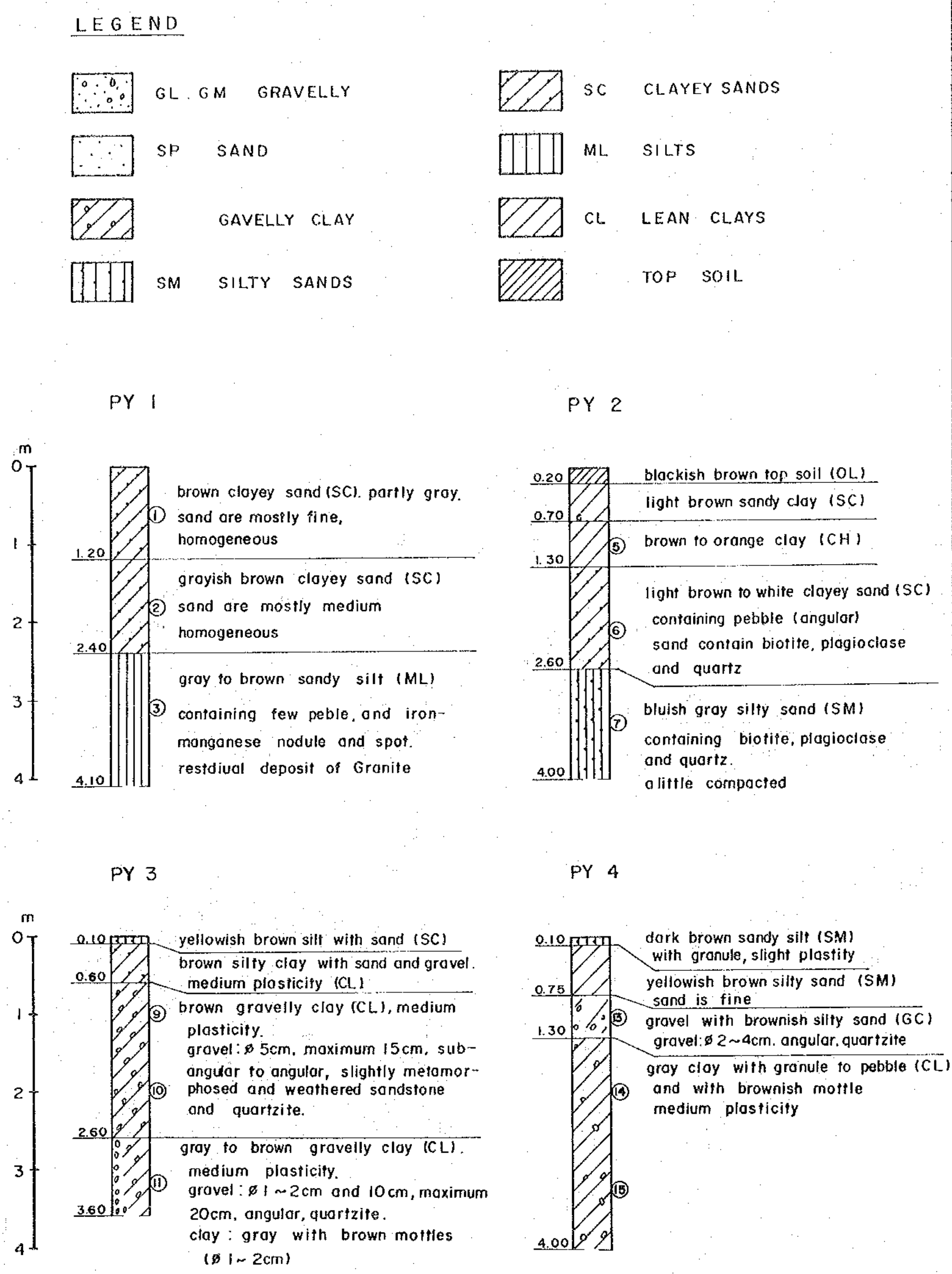

Fig.16 Log of Test Pit, khlong Yai

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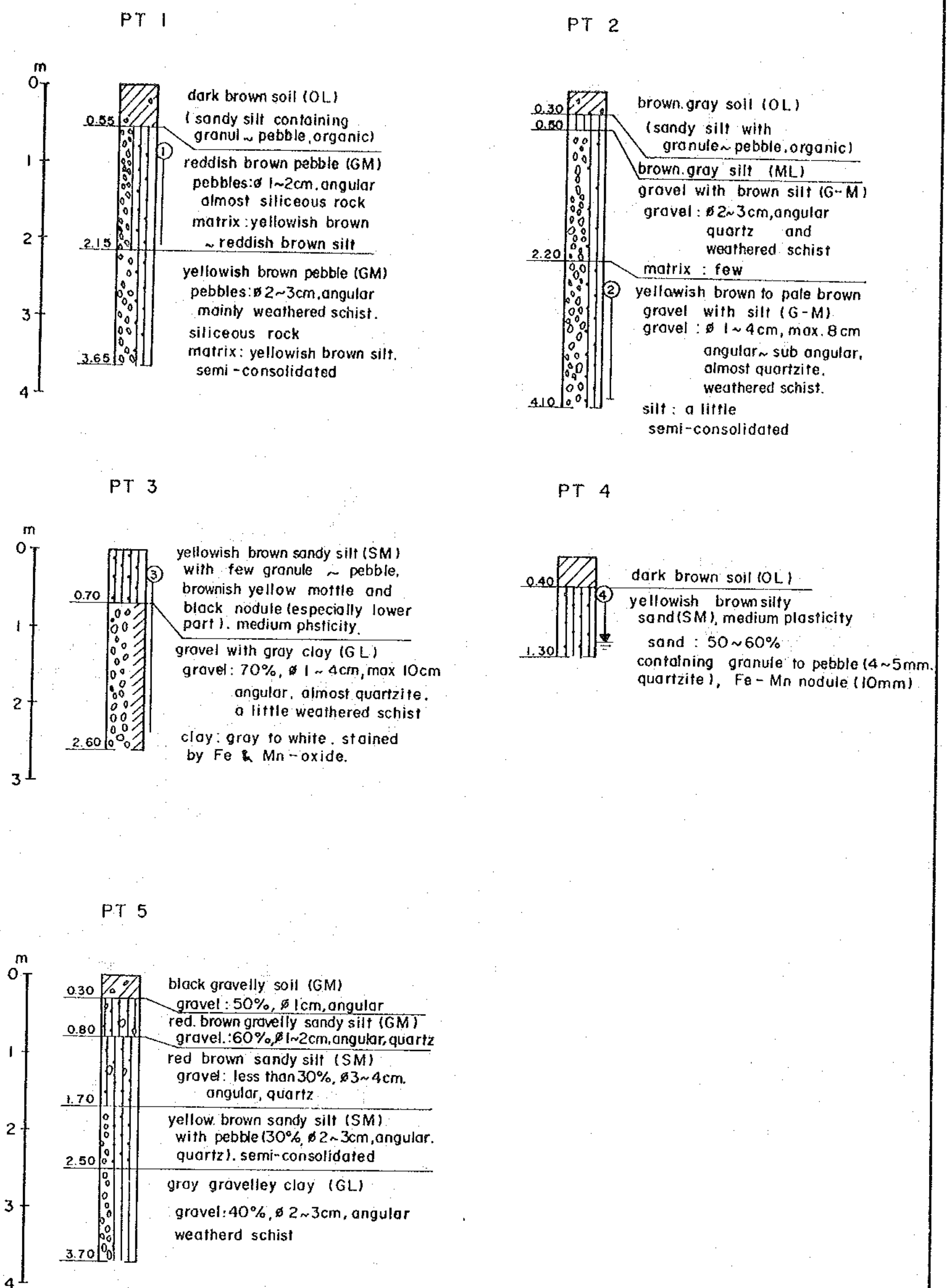

Fig.17 Log of Test Pit, Khlong Thap Ma

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THE EAST COAST WATER RESOURCES
DEVELOPMENT PROJECT PHASE II
JAPAN INTERNATIONAL COOPERATION AGENCY

SECTORAL REPORT IX
GROUNDWATER RESOURCES

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

This report describes the result of preliminary study on groundwater resources in the Study Area based on a reconnaissance survey carried out during a 3-month period from August to November 1982. The study consists of 1) collection of data on groundwater facilities including well logs, 2) inventory and sampling survey on groundwater use, 3) geohydrological field reconnaissance over the Study Area and 4) overall interpretation of the present condition and the development potential.

2. SUMMARY AND CONCLUSION

2.1 Groundwater Use

Since the statistical data on groundwater use was not available in the Study Area, the inventory survey on tube wells and the sampling survey on shallow dug-wells were conducted in this study.

The results of surveys are summarized hereunder as the present groundwater use.

(Unit: $10^6 m^3/yr$)

Zone No.	Tube well			Shallow dug-well			Total
	Industrial	Rural	Sub-total	Municipal	Rural	Sub-total	
1	0.277/1	0.013	0.290	0.087	6.404	6.491	6.781
2	-	0.043	0.043	0.363	1.790	2.153	2.196
3	-	-	-	-	2.850	2.850	2.850
4	-	-	-	0.103	1.318	1.421	1.421
5	-	0.047	0.047	0.134	0.349	0.483	0.530
6	0.016/2	0.398	0.414	0.141	0.275	0.416	0.830
7	-	0.006	0.006	-	2.414	2.414	2.420
8	-	-	-	-	0.408	0.408	0.408
9	0.179/3	-	0.179	-	0.549	0.549	0.728
10	0.077	0.115	0.192	0.249	3.876	4.125	4.317
Total	0.549	0.622	1.171	1.077	20.233	21.310	22.481

/1 Sugar factory

/2 Mineral water production

/3 Gas industry

Tube wells were mostly drilled in diameter of 200 - 300 mm, depth of 20 - 40 m , cased with 150 - 200 mm steel pipe and yielding 15 - 300 m^3/d with 4 - 30 m drawdown. Out of the above, a number of tube wells were drilled and utilized in Phanat Nikhom, Pattaya, Rayong and Ban Khai, but recently abandoned because of extensive salt water intrusion from the sea. Tube wells in rural area aim to supply the potable water in the area of foothills where the phreatic groundwater is not obtainable within the hand-digging depth.

Shallow dug-wells are widely utilized in the floodplain of rivers. Almost 80 % of farm households have own well. Wells were hund-dug with diameter of 0.8 - 2.0 m, depth of 3 - 5 m and mostly not lined except surface portion, but few wells with perforated concrete pipe were also constructed. At the peak of dry season, approximately one-third of shallow dug-well are dried up and the well owners are forced to be dependent on water-seller.

2.2 Aquifer and Recharge

Groundwater development in the area has been made mainly to utilize the local phreatic aquifers in the alluvial deposits along the major rivers and in the coastal plain. Many explorations to find the regional confined or unconfined aquifer in the vast upland were executed but resulted in obtaining very small yield of groundwater due to high clay content and resultant low permeability and also low storage capacity in the terrace deposits.

The alluvial deposits in the floodplains along the major rivers, Khlong Luang river in the north and Khlong Yai river in the south, form a shallow phreatic aquifer. It consists of silty sand, sandy clay and rare gravelly sand layers. Almost entire use of shallow groundwater in the Study Area is made in the floodplains tapping from the alluvial deposits along the major rivers. Rivers and paddy field recharge the aquifer so that remarkable descent of groundwater level takes place during dry season. Another phreatic aquifer is found in the coastal sandy area where old sand-bars and dunes bear small lenticular mass of fresh water floating on the salt water intruded from the sea. This fresh water is recharged by the direct infiltration of rainfall, and locally utilized as potable water by hand dug-wells.

Groundwater in the terrace deposits is rather poor due to its poor hydraulic characteristics, but has been developed in the coastal industrial area near Rayong and in the upland along foothills of mountainous ranges. In the coast, 11 tube wells in depth of 40 m are operating for the natural gas industry tapping more than 50 m^3/d/well from clayey sand layer of terrace deposits. In the upland where the groundwater table is so low, tube wells with yield of 20 - 30 m^3/d were drilled into the terrace or colluvial deposits to obtain potable water. The groundwater in terrace deposits appears to be recharged by vertical infiltration of rainfalls. Regional groundwater flow in the terrace deposits may hardly exist due to its low transmissibility ranging from 3 m^2/d to 10 m^2/d.

2.3 Groundwater Contamination

Salt water intrusion is extensively observed in the tube wells drilled in the alluvial plains of major rivers; Khlong Yai river in the south and Khlong Luang river in the north. In the Khlong Yai alluvial plain, salt water has intruded deeply to the inland up to Amphoe Ban Khai, at about 13 km upstream from the river mouth, where a tube well of ice factory was abandoned due to high salinity after six-year intensive pumping of 109 m^3/d fresh water with drawdown water level of probably 2 m below the sea level. At near the mouth of Khlong Yai river, many tube wells located in Rayong city were also abandoned due to high salinity. The shallow hand dug-wells in this alluvial plain, however, are not suffered by salt water intrusion at present. It is therefore evident that the Khlong Yai alluvial plain is underlain by salty groundwater intruded from the sea and fresh groundwater flows down through the shallow sub-surface, probably down to depth of 10 - 12 m, floating on the salt water. No more tube well development should be allowed in this plain.

In this Khlong Luang alluvial plain, salt water intrusion prevails more extensive up to deeper inland. Wells in and around Amphoe Phanat Nikhom, at about 25 km from the coast, have been suffered by intrusion of high saline water as chloride content attaining 600 ppm. In Amphoe Phan Thong, at about 10 km from the coast, the chloride content in groundwater attains to 3,800 ppm. Therefore, it is also evident that the same condition with the Khlong Yai alluvial plain also exists in this plain, and any more tube well drilling should not be allowed in this plain.

Serious salt water intrusion is also found in Pattaya resort area where fresh groundwater lense in old sandbars has been tapped with dug-wells. Since the fresh water is recharged by direct infiltration of rainfall and hydraulically balanced as to float on the deeper salt water, the recent rapid increment in groundwater extraction demanded by tourism have resulted in sea water intrusion.

2.4 Development Potential

As stated above, the development potential of groundwater in the Study Area appears to be quite low due to 1) salt water intrusion into the alluvial plains and 2) poor hydraulic characteristics of terrace deposits which widely covers the major part of the Study Area.

On the contrary, numerous tube wells in the coastal areas have been abandoned due to groundwater contamination by salt water intrusion.

Therefore, the measures to be taken in this area is not to develop the groundwater but to conserve the groundwater resources to provide for such unforeseen conditions as the extreme drought year.

3. PRESENT CONDITION

3.1 Outline of Hydrogeology

The Study Area is categorized in the two portions from the topographic features. Namely, the flat alluvial land occupies the northern part, being utilized mainly as paddy field and the spaced hill masses characterized by gently undulating peneplain are spread in the most area of the rest, accompanying fan deposits at places along the foot of the hills as well as terrace sediments in the intermontane rivers.

The basement rocks of the area are underlain by the following formations in an ascending order, the Precambrian schist and gneiss, the Ordovician quartzite schist, sandstone and limestone and the Permian limestone. These formations are followed by the granite intrusion with a contact metamorphism.

The Quaternary strata formed of terrace deposits, fan deposits and talus overlie the basement rocks.

Sand pittes, sand dunes and the backward swamps made by sea current are seen in the southern littoral area. The geological map over the Study Area is shown in Fig. 1.

Hydrogeologically, the above basement rocks function as a bottom aquitard, whereas the terrace deposits and the fan deposits composed of sand and gravel in the Quaternary period are the aquifers in the Study Area.

The lower part of these Quaternary system, however, is consolidated deposits associated with clay, laterite and quartz grains, forming an aquiclude. The principal aquifers holding great potential of groundwater in the area are sand and gravels distributed not only in the flat alluvial lowland but also along the river.

3.2 Inventory and Sampling Survey

The groundwater of the Study Area was investigated by the collection of existing documents of deep wells and shallow wells and the site inspection as well.

Total number of the deep wells in the Study Area comes up 134, the details of which are tabulated in Table 1 and the locations are shown in Fig. 2. The drill logs are shown in Fig. 3.

The deep wells are centered in the northern lowland, the southern lowland and in the littoral area. This fact reveals that the groundwater potential areas extracted by deep wells are limited in such portions.

The shallow wells were sampled and inspected in place due to lack of existing records. The brief features of the shallow wells are summarized as follows.

(1) 80 % out of te households in the rural area make use of shallow wells, whereas in the urban area 20 % out of te households do.

(2) The shallow wells ranges in depth from 3 to 6 meters from ground surface.

(3) The shallow wells in the alluvial gravels discharge plenty of groundwater with relatively high water table, while the wells in the terrace and fan deposits discharge a little with low water table.

(4) There happens occasional shortage of water due to low permeability of the layer especially in the dry season.

(5) The shallow wells in the littoral area withdraw perched fresh water in the old sand dune.

The sampling points of shallow wells are presented in Fig. 4 and summary of the sampling survey on shallow wells is given in Table 2. Details of the sampling survey is compiled in Appendix.

3.3 Groundwater Development

The groundwater development in the Study Area has been executed mainly by the government agencies/department as underlisted.

Agency/Department	Nos. of Well	Main Tasks
DMR	27	Groundwater management and rural water supply
RID	23	Irrigation
OARD	-	Rural water supply
DPW, PWWA	69	Rural water supply
Total	119	

Beside the above agency/department, private enterprises implemented the development isolatedly in the coastal zone between Rayong and Sattahip. The sum of 15 tube wells were drilled and has been utilized by private enterprises.

3.4 Groundwater Use

The groundwater use was separately calculated in practical sense according to 10 divisions of the Study Area and was subdivided into industrial, irrigation and domestic uses. Test wells are included as well. The zoning of the Study Area is shown in Fig. 5.

The groundwaters in the deep aquifers are extracted mainly both for industrial use such as sugar factory, gas factory and mineral water factory and for domestic water of the rural area.

The most of the drill logs obtained are based on the results of the test tube wells in the Study Area, some of which were penetrated into the basement rocks. On the basis of the survey, the groundwater use of the deep aquifers are maldistributed at some watershed areas, and moreover the quantities are relatively small.

Furthermore the shallow wells are used for domestic only.

Calculation of groundwater use from deep tube wells

The quantity of abstraction was computed assuming that pumping water at the investigation period are equivalent to water used and summed up on each watershed as shown in Table 3. The number of deep tube wells in the Study Area is 38 and total amount of water use is estimated at 1,171 x 10^3 m^3/yr.

Calculation of groundwater use from shallow wells

A) Water use per capita

On the basis of domestic water supply data in Thailand, water use per capita per day is reported as follows:

Water Use	Urban area	Rural area
	(ℓ)	(ℓ)
Drinking, kitchen and washing use	35	15
Ablution	40	40
Laundering	15	15
Toilet flushing	25	10
Outside cleaning	10	10
User waste	15	20
Total	140	110

Water use per capita per day in Thailand is applied as a basic figure to estimate groundwater use. According to shallow well survey, source of drinking water is generally rain water and/or sold-water, if no pipe water service is available. Accordingly groundwater use per capita is broadly estimated at 105 ℓ/d for urban area and 95 ℓ/d for rural area.

B) Family size

The National Statistics Office reveals that family size in the Study Area are 5.6 in the urban area in average, and 6.43 in the rural area.

The groundwater use per household is therefore calculated as follows:

Urban area : 105 x 5.6 = 588 ℓ/day

Rural area : 95 x 6.43 = 611 ℓ/day

C) Number of shallow wells

Documents in connection with shallow wells in the Study Area are not available. Therefore most of the fundamental data were collected by hearing from the local authorities concerned and sampling survey at sites.

The hearing investigation resulted in that about 80 % of total households in the rural area is assumed to be dependent on shallow wells as domestic water source and the rest to be depending upon pipe-water supply or rainfall. On the contrary, it is estimated that in the urban area 20 % of total households utilizes shallow wells for domestic use whereas the rest are supplied mostly from pipe-water supply accompanying rainfall-fed houses.

Therefore number of the shallow wells were computed for each zone as follows. The number of households refers to the statistics of NSO and is presented in Table 4.

Urban area : number of households x 20 %

Rural area : number of households x 80 %

In case that a zone includes more than two administrative divisions, the number of households is divided proportionally to the areas occupied by each division.

D) Changeable number of shallow wells subject to seasonal water level fluctuation.

The Study Area has two distinct seasons; wet season from April to October and dry season from November to March. The groundwater recharge is dependent mainly on rainfall. The rainfall in the Study Area is fluctuated largely as shown in Fig. 6.

It is clear by the present inspection that one-third (1/3) of the shallow wells in the Study Area are dried in the driest period. Consequently, number of the shallow wells in the dry season is calculated in the following way, multiplied by "season factor", 2/3, during dry season (November to March).

Wet season (April to October)	:	All wells as resulted from (C)
Dry season (November to March)	:	Result of (C) x 2/3.

The groundwater abstraction from the shallow-wells are then calculated as tabulated below.

(Unit : 10^6 m^3/yr)

Zone No.	Rural Area		Urban Area		Total
	Wet Season	Dry Season	Wet Season	Dry Season	
No. 1	4.355	2.049	0.059	0.028	6.491
No. 2	1.218	0.573	0.247	0.116	2.154
No. 3	1.938	0.912	0	0	2.850
No. 4	0.896	0.422	0.070	0.033	1.421
No. 5	0.237	0.112	0.091	0.043	0.483
No. 6	0.187	0.088	0.096	0.045	0.416
NO. 7	1.642	0.772	0	0	2.414
No. 8	0.278	0.131	0	0	0.409
No. 9	0.373	0.176	0	0	0.549
No. 10	2.636	1.240	0.169	0.080	4.125
Total	13,760	6.475	0.732	0.345	21.312

3.5 Aquifer and Groundwater Flow

The aquifers in the Study Area are included mainly in the alluvial deposits. The terrace and the fan deposits composed of consolidated sand, gravel mixed with clay and laterite matrix are making aquiclude system with low permeability. The basement rocks underlie the groundwater basin as an aquitard.

The geologic profiles in Fig. 7 are obtained from the drill logs of the deep tube wells, most of which are penetrated even into the basement rocks, cased with strainer pipes at some depths.

The groundwater from the deep aquifers in the Study Area are developable only in the alluvial area.

The shallow aquifers of the Study Area includes the alluvial, terraces, old fan and old sand dune deposits. Out of these the alluvial deposit has a greatest potential for groundwater exploitation, but the others can yield groundwater in the limited quantity for domestic use.

The water table contours roughly show a harmonious pattern with the topographic relief as seen in Fig. 8. This means that groundwater may flow in accordance with the undulation of the underlying basement rocks.

3.6 Groundwater Contamination

A contamination problem of the groundwater in the Study Area is a sea water intrusion specially in the southern littoral area.

A sea water intrusion is discernible in the most of the alluvial lowland (see Fig. 9). An interface is kept balanced by the under flows of sea water and fresh water.

The alluvial lowland, which contains deep aquifers of some potential of groundwater, is met with the threat of sea water intrusion because of over pumping by the on-going extraction scheme.

The shallow wells are contaminated mainly by surface water and sewage. Not serious problems have been reported so far.

A typical process of groundwater contamination can be seen in Pattaya resort area. The water supply in Pattaya was historically dependent on shallow groundwater which is recharged by direct infiltration of rainfall forming fresh water lenses floating on the saline water. Since the fresh and saline water interface is hydraulically balanced in accordance with the balance in recharge and discharge of fresh groundwater, the recent rapid increment in groundwater extraction demanded by tourism have resulted in a rise of fresh-saline water interface accompanied by sea water intrusion. After the saline water intrusion took place extensively, Map Prachan dam was constructed to convert the source of water supply from groundwater to surface water in 1980. At present, the water supply in Pattaya resort area is entirely derived from pipewater from Map Prachan dam.

4. DEVELOPMENT POTENTIAL

4.1 Groundwater Demand and Supply

The groundwater withdrawn from the deep aquifers in the Study Area is a minor resource among the others. The total water use of 1,171 x 10^3 m^3/year is relatively small.

In this connection the specific capacity of the deep tube wells are illustrated in Fig. 10 in the order of frequency in number and shown in Table 5.

This reveals that most of the wells have low values, indicating small yield with large drawdown of water level. Moreover this resulted from the fact that the deep wells extract from the alluvial aquifers as well as from the basement rocks with low permeability. In conclusion the deep aquifers in the Study Area has no potential to further exploit groundwater in future.

On the other hand the groundwater supply of the Study Area is dependent mainly on the shallow aquifers and rises up to 24,848 x 10^3 m^3/year.

There is no alternative water resource other than the shallow aquifers in the present situation.

The shallow aquifers are recharged from the rainfall.

4.2 Water Quality

As stated in Section 3.5, the phenomena of sea water intrusion has widely occurred in the littoral lowland area. This is because that the deep tube wells are centered in the alluvial lowland and yield of groundwater of more than water recharged probably by lateral flow and vertical infiltration.

Some of the deep tube wells were contaminated by sea water intrusion and were abandoned for use.

4.3 Aquifer Yield

As far as the present utilization of the groundwater is concerned, the water from the deep aquifers has been overpumped, because sea water intrusion has progressed and contaminated in recent years.

It is recommendable to execute a groundwater investigation to phase out an optimum discharge without any demerit on future exploitation, followed by the establishment of a yield control law.

4.4 Development Potential

The aquifer system of the Study Area is summarized as follows. The groundwater in the deep aquifers are contained in the alluvial sand and gravels, whereas the shallow aquifers are made up of not only the alluvial deposits but also the terrace and fan deposits at places, but the latter two shows a low permeability. The basement hard rocks underlie the alluvial plain as an aquitard. On the other hand the deep aquifers in the alluvial lowland have sporadically encountered sea water intrusion due to over-extraction by the tube wells.

Therefore, an additional exploitation of groundwater in the Study Area can be proposed in the neighbouring area out of sea water intrusion places of the alluvial plain. The area proposed, however, is sporadic narrow space and is underlain by the sediments containing thin aquifers. This concludes that there is a small possibility on the future development of the groundwater from the deep aquifers in the Study Area.

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