2. LAND SUBSIDENCE

2.1 Brief History

Subsidence is a gentle lowing of the surface due to the removal of water from the underlying sediments and the subsequent compression of the clays in the sequence. This problem is related to the explosion of groundwater and to the geological characteristics of the underlying sediments. Bangkok area is situated over 1,800 m of soft sediments, mostly sand and clay.

Rapid urbanization, modernization and industrialization are all demanding more water, however the water supply service can not keep up with the demand. This eventually has increased the groundwater usage, which caused land subsidence.

The subsidence of Bangkok has been studied since 1967. An extensive study was undertaken in the mid seventies by the Asian Institute of Technology which has established sufficient data to identify the problem. The results of field investigations in 1986 shown on Fig. 2.1.1, indicate that Bangkok Metropolis has already settle more than 150 cm since 1933.

Land subsidence has a huge effect on the drainage conditions. The land subsidence has been monitored by RTSD for about 20 years at both surface monuments and benchmarks founded on the first sand lauer at about 23 m- MSL. The results of the obserbations (Fig. 2.3.5) show that at some locations the total subsidence from commencement of the observations is about one meter, in some areas the total subsidence of the land surface has been in the order of 1.5 m or beyond. The results also show that the deep benchmarks experience about half the subsidence rate of the surface benchmarks.

The land subsidence phenomenon was widely recognized in Bangkok since 1970's. Though there were several opinions on the cause of this phenomenon, some studies, namely , AIT(1978), AIT & DMR(1982), JICA & DMR(1995), BMA & NEDECO(1996), JICA &BMA(1996),and the surface leveling conducted by RTSD in 1978 clarified the cause and extent of land subsidence happening in Bangkok Metropolis. And now, the annual changes in the groundwater levels of the PD, the NL, and the NB Aquifer and in the subsidence rates have been monitored by GSD/DMR in Bangkok Metropolis and vicinity .

2.2 Groundwater Use

Groundwater use in the Bangkok area started in 1954 to supplement the requirement of the Metropolitan Waterworks Authority (MWA) for public water supply. Over the years, the pumpage steadily increased with additional private use as the public water supply facility could not cope with the demand. Historical record of pumpage for public water supply by the MWA was available, but for private pumpage, only estimates were provided by the DMR since there was no law regulating the use till

1978. After the promulgation of the Groundwater Act in 1978, statistics of the total number of private wells and the total rate of withdrawal were available. (JICA/DMR Study, 1995). Groundwater utilization in Bangkok and adjacent areas can be classified into:

(1) Domestic Use

Since the MWA cannot cover its entire service area with surface water supply, groundwater are being pumped from deep aquifers to supply houses, condominiums, hotels, restaurants, et. Rapid urbanization accompanied by recent economic boom hastened the growth of residential and shopping areas in the suburbs of Bangkok Metropolis. This situation accelerated the need for more groundwater pumping for domestic use.

(2) Industrial Use

Since the incept of industrial promotion in Thailand, the growth of industry has been remarkable in the last 3 decades, particularly in Bangkok and its vicinity. Accordingly, the need for water in these industries grew rapidly that public water supplies became inadequate. Most of industries, therefore, have to invest for their own water supply, i.e., by pumping groundwater.

(3) Agricultural Use

Although groundwater is used for agriculture in many parts of the country, the quantity abstracted is still not large. This is due to the fact that agricultural farms beyond the reach of irrigation canals are still rained. Groundwater is used mostly as a supplementary source to irrigate cash crops after harvesting rice (JICA/DMR, 1995).

2.3 Estimate of Land Subsidence

2.3.1 Groundwater Level

The hydrological classification is divided eight (8) aquifers by DMR (1992). Groundwater levels in Phra Pradaeng (PD), the Nakhon Luang (NL), and the Nontha Buri (NB)Aquifers have been declining since 60's due to increasing groundwater withdrawals. The total decline reached a maximum of over 40m to 60m in each aquifer (JIC/DMR, 1995).

Based on the groundwater level records compiled by DMR (1992), the patterns of groundwater level changes can be categorized into five (5) types which are described as follows (Fig. 2.3.1).

Type A Water level is rapidly declining

Type B Water level is rapidly declining with a short

iod of recovery between 1984 and 1987

Type C Water level has recovered since 1984

Type D Water level is slowly declining

Type E Water level is stable or not changing

Fig. 2.3.1 shows the central area of Bangkok belongs to Type C and is surrounded by Type B areas. Existing and newly developed industrial and housing districts are in Type A areas. This spatial distribution of patterns of behavior of groundwater level change clearly displays the effect of the measures adopted in the critical zones of Bangkok since 1983 and delineates areas of increasing groundwater withdrawals.

Fig. 2.3.2 shows the annual changes in the groundwater levels in the east-west profile. Groundwater surface depression spread towards Bang Kapi and Minburi and reached its lowest point in 1982. As a result of the regulation enforced by the Act, groundwater recovered in the central area, but kept on declining in the western and eastern ends. Although groundwater levels recovered in Minburi in 1985, it declined again in 1986. And now, Minburi Area is most lowest groundwater levels about NL Aquifer.

2.3.2 Estimate of Land Subsidence

Recently, Analysis of Land subsidence are showed as follows four (4), namely, there are JIC & DMR(1995), BMA & NEDECO(1996), JIC & BMA(1996), and GSD/DMA (1995, 1996) .

(1) JICA & DMR(1995); THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY;

Land subsidence model and groundwater flow were used to predict the future groundwater levels and subsidence up to year-2017 using nine (9) different future pumping scenarios (table 2.3.1). Using the worst scenario, the models predicted that land subsidence would reach a maximum of 200 cm by year-2017. While, using the best scenario, the models predicted that the maximum total land subsidence would be 35 cm by year-2017(Fig. 2.3.3).

(2) JICA & BMA(1996); THE STUDY ON URBAN ENVIRONMENTAL IMPROVEMENT PROGRAM IN BANGKOK METROPOLITAN AREA;

The land subsidence would accelerate flood problems more seriously in suburban areas. This project adopted the worst scenario-1 of JICA/DMA Project (1995). The simulated land subsidence map are digitized (Fig. 2.3.4, Table 2.3.2).

(3) BMA & NEDECO-APAN-WDC(1996); MASTERPLAN FOR BASIC INFRASTRUCTURE SYSTEMS AND PRELIMINARY DESIGN FOR THE FLOOD PROTECTION AND DRAINAGE SYSTEMS IN EASTERN SUB-URBAN BANGKOK;

The land subsidence has been monitored by RTSD for about 20 years at both surface monuments and benchmarks founded on the first sand layer at about 23 m- MSL. The results of the observations (Fig. 2.3.5) show that at some locations the total subsidence from commencement of the observations is about one meter, in some areas the total subsidence of the land surface has been in the order of 1.5 m or beyond. The results also show that the deep benchmarks experience about half the subsidence rate of the surface benchmarks. After the year 1985 the rate of land subsidence has been substantially reduced (Fig. 2.3.6) till 1 to 3 cm/yr. in most of the project area while in the south-east corner the subsidence just outside the area continues at rates of 4 to 5 cm/yr. (BMA/NEDEC-SPAN-WDC, 1996) . And, BMA (1996) determined the pattern of land subsidence as follows:

Northern Boundary	0.02 m/yr. along K. Rangist and Pahon Yothin Road.
King's Dike	0.02 m/yr. along the entire dike.
Chao Phraya River	0.01 m/yr. along the river upstream, and 0.02 m/yr. downstream of Rama IX Bridge.

(4) GSD/DMR(1995,1996); REPORT OF SURVEYING SPECIAL ELEVATION FOR OBSERVE WELL GROUND WATER ELEVATION AND BENCHMARK AT GROUNDWATER STATION IN BANGKOK METROPOLIS AND VICINITY.

As showing in Fig. 2.3.7 , ground surface levels duration of 1994-1995 and 1995-1996 have been declining, especially in the southeast, southwest and northeast of Bangkok, where major industrial areas are located.

Fig. 2.3.8 - Fig. 2.3.11 are showing land subsidence of ground level with in other depth. These differential settlement gauge are set up each aquifer; BK, PD, NL, NB. In the present state, Auifer level of Nontaburi (NB) is most declined about east suburban area.

The land subsidence would accelerate flood problems more seriously in suburban areas. Now land subsidence has slowed down in the central area of Bangkok as a result of regulation, the suburban areas still receive significant land subsidence. BEIP (JIC and BMA ,1996) shows that the land subsidence is 20 mm/year in Bangkok, and 40-55 mm/year in Minburi and Lat Krabang. This could result in serious flood problems in the **suburban areas** of Bangkok.

The Study Team introduced land subsidence plan of BMA& NEDECO(1996) for eastern sub-urban Bangkok. In the west Bangkok, we referred to the project of Tha Chin River Project for the land subsidence.

Land subsidence for pumping ground water is not recognized to the north of Si Ayutthaya. Because now, its evidence is not pointed out that's area. Therefor, except Bangkok metropolitan area and its vicinity, We don't need to consider land subsidence. However, in the soft ground, we must calculate settlements consolidation and immediate by loading.

After this, land subsidence will cause serious economic losses and triggered a host of environmental problems. Although, regulation of water supply must be reinforce not only in the central area of Bangkok but also in the suburban area.

3. TOPOGRAPHY AND GEOLOGY IN THE RIVER RENOVATION

3.1 Topography and Geology in the River Renovation

3.1.1 Topography

Tertiary basins in Thailand are mainly N-S trending fault-bounded grabens and half grabens. Sixty-one Cenozoic basins including Tertiary basins (**Fig. 1.2.3**), occurring in the country both onshore and offshore areas, have been recognized. For consideration of the geotechnical aspects the geologic setting of the project area is an important factor. Located in the lower half and coastal region of the Lower Central Plain of Thailand the marine deposits play an important role in all civil engineering works. The Lower Central Plain also called the Lower Chao Phraya Basin is situated in a depression zone originated by crustal movements during Tertiary time. The entire area of the Basin is of about 250 km length, stretching form Nakhon Sawan to the Gulf of Thailand and of average width of 200 km (Fig. 3.1.1). The surface elevation above Mean Sea Level along the central part increases from 0.5 to 1.5 m, which is the surface level within the City of Bangkok (distance to the sea about 100 km), to 25 m in Nakhon Sawan (distance to the sea about 250 km). Besides, ground settlement is progressing every year due to pumping up of ground water.

3.1.2 Geology

Central plain of Thailand lays in a south-north structural fault which was the result of orogenic movement during the Tertiary period (Fig. 3.1.2). To the West, a band of fault of Paleozoic extends south-north toward Thai-Malay peninsular. To the East, the bearing strata is bordered with Korat Highland. The northern border ends at Kuropra bow-like zone of Nakonsawan. To the south, the rift valley extends as far as the South China Sea. The low central plain of Thailand is filled by rare alluvial of shallow sea deposit and delta sedimentation in geological hollow. During the neweast period of diluvium, the Chao Phraya met transgression and experienced regression some 45000 to 14000 years ago. The shore line of Bangkok Bay at 3000 years ago is shown in **Fig. 1.2.7**. The depth of the bedrock has been found to vary from about 400 m to more than 1800 m . The bedrock is overlain by sediments, deposited under different environmental conditions. Alluvial, deltaic and shallow sea sediments can be differentiated.

3.2. Bangkok Soft Clay

As shown in **Fig.3.2.1**, Bangkok clay is distributed 150 km from the mouth of the Chao Phraya River to Singburi and is distributed 130 km east and west with the Chao Phraya River as the center and occupies about 18000 km^2 in area.

The vertical distribution of Bangkok clay depends on its location from the edge of the distributed area to the center of the accumulation basin. And this maximum depth is about 20 m as shown in **Fig.3.2.2.** The layers of Bangkok clay are classified roughly into the upper soft clay layer and the lower stiff clay layer, according to their origin and the mechanical properties of each layer. Bangkok soft clay is distributed to the north 100 km from the mouth of the Chao Phraya River to Ayutthaya and extends 130 km east and west with the Chao Phraya River as its center and this area is about 14000 km^2. Besides, the surface layer of soft clay is called "weathered clay" because of the influence of salinity leaching, etc. which was the result of long- term weathering following marine regression since 2700 years ago. It is generally considered, in terms of historical geology, that Bangkok soft clay of the upper layer was formed by marine transgression in the Jomon era(Flandrian transgression in Europe), 5000~3000 years ago. On the other hand, Bangkok stiff clay of the lower layer is a sediment layer of the Diluvial age from the first to the middle, and forms the lowest layer of the delta sediments, namely fluvial deposits of the **old Chao Phraya River.**

3.3 Soil profile ablut Model Area

3.3.1 Soil Profile along Chaophraya River

It may be presumed **Fig. 3.3.2** about soil profile along Chao Phraya River from soil exploration . Location of soil survey is shown in **Fig. 3.3.1**.

3.3.2 Soil Profile about Sing Buri Area along Lop Buri River

It may be presumed **Fig. 3.3.4** about soil profile of embankment subsurface from the result of soil exploration about Sing Buri Area along Bangkeao River. Location of cross section is shown in **Fig. 3.3.3**.

3.3.3 Soil Profile about Ang Thong Area along Bangkeao River

It may be presumed **Fig.3.3.5** about soil profile of embankment subsurface from the result of soil exploration about Ang Thong Area along Bangkeao River.

3.3.4 Soil Profile about Sena Area along Noi River

It may be presumed **Fig. 3.3.6(b)** about soil profile of embankment subsurface from the result of soil exploration about Sena Area along Noi River. Location of cross section is shown in **Fig.3.3.6(a)**.

3.3.5 Soil Profile about Ban War Taku along Bang Luang River

It may be presumed **Fig. 3.3.7** about soil profile of embankment subsurface from the result of soil exploration about Wat Taku along Bang Luang River.

In the result, **Bangkok soft clay** covered on Diluvial stiff clay in the south of Ayutthya of Delta Area. And it was found through collected Boring logs that some part area of north Ayutthya along Bang Luang River and Bang Bal River is underlain soft soil. The result of this examination leads to our presumption that these soft clay of alluvial deposits overlie fault and syncline (**Fig. 3.1.2**).

4. INVESTIGATION OF ENGINEERING CHARACTERISITICS IN THE CONSUTRACT FOUDATION

4.1 Physical Properties of Bangkok Soft Clay

Weathered clay has a ratio of **over-consolidation** higher than soft clay. This is because the strata experienced repetition of draining and cementation. Meanwhile, the ratio of over consolidation of soft clay is generally known to be slightly more than 1.0. According to experimental result, the soft clay is in practice a normal consolidated clay. Soft clay has color of middle light to dark gray in typical cases. It contains shell and humus. Fine sand in lens and silt seam share 20 % in area ratio. Clay is also found. The sell is of sea bivalve and the same as the ones found living in the Siam bay. Salt content is very high, 20 %, proving the sea born nature. Hard clay is definitely older than soft clay and separated by clear discontinuous face or erosion surface. Mineral composition of clay is 50 % kaolinite, 30 % montmorillonite, and 20 % illite.

Table 4.1.1 gives a summary of physical properties of Bangkok soft clay. From the results mentioned above, the physical characteristics of Bangkok soft clay can be summarized as follows:

(1) Natural moisture content (W_0) is slightly lower than the liquid (LL) in the weathered clay layer and decreases as depth increases.

(2) Mean value of plasticity limit (PL) is 32.9 % and is constant in depth direction. Liquid index (IL) is less than 1.1 and decreases as depth increases. Bangkok soft clay which consists of weathered clay and non-weathered soft clay is classified into "CH" on a plasticity chart based on the unified soil classification system. The relationship between plasticity index (PI) and liquid limit (LL) can be expressed by linear relationship.

(3) Bangkok soft clay is divided into normal clay and active clay according to Skempton's classification based on soil activity.

$$\text{Activity (A)} = \frac{\text{Plasticity Index (PI)}}{\text{content of clay which is less than } 2\,\mu\text{m (\%)}}$$

(4) Wet density (γ t) is within the range of $1.34 \sim 1.78$ t/m^3 and this valuedecreased according to plasticity index (PI).

(5) It can be recognized that the sensitivity ratio (St) increases as the liquid index (IL) increases as the liquid index (IL) increases, as has been suggested by Skempton.

(6) From the simple comparison between effective overburden pressure (σz) of foundation and consolidation yield stress (Pc), it can be said that weathered soft clay is overconsolidated clay and non-weathered soft clay is slightly overconsolidated clay and normally consolidated clay. Because the overconsolidation ratio (OCR) of weathered clay is more than 2.0 and the OCR of non-weathered soft clay is 1.0 ~1.3.

(7) In-site undrained shear strength (Su) under natural sedimentary environment is as follows:

Weathered clay	Su = 0.9 ~ 2.28 t/m^2
Non-weathered soft clay	Su = 0.81 ~ 4.15 t/m^2

4.2 Mechanical Properties of Bangkok Soft Clay

Bangkok soft clays are of **low shear strength** , **high compressibility** and **low permeability** , and many are sensitive (liquefy during disturbance), although the Bangkok Soft Clay is only " **slightly quick** ".

4.2.1 Standard Penetration Test

Standard Penetration Test is an indication of relative density of sand and fine gravel and in a less reliable manner the consistency of clay as shown in the Table 4.2.1 and Table 4.2.2 (Terzaghi, K., and Peck R. B., 1948).

Table 4.2.1 Relative Density of Sand

Blows	Relative Density of Sand
0 - 4	Very loose
4 - 10	Loose
10 - 30	Medium
30 - 50	Dense
Over 50	Very dense

Table 4.2.2 Consistency of Cohesive Soils

Blows	Consistency
0 - 1	Very soft
2 - 4	Soft
4 - 8	Medium
8 - 15	Stiff
15 - 30	Very stiff
Over 30	Hard

The generalized soil profile and some important soil properties were plotted versus depth as shown in **Fig. 4.2.1** and **Fig. 4.2.2** for Bung Pibul Watana and Bung Nong Bon, respectively.

4.2.2 Cohesion and Shear Strength

The shearing strength of a sample of soil can be determined from the unconfined compressive strength. For practical purposes it can be taken as one half the unconfined compressive strength of the clay sample.

$$Cu = 1/2\ qu$$

where

Cu : cohesion (tf/m^2)

qu : unconfined compression strength (tf/m^2)

The values of the unconfined compressive strength corresponding to the various consistencies are shown in Table 4.2.3.

Table 4.2.3 Relation of Cu and N value

Consistency	Cu (tf/m^2)	N
Very soft	Less than 2.5	Less than 1
Soft	2.5 - 5.0	1 - 2
Medium	5.0 - 10.0	2 - 4
Stiff	10.0 - 20.0	4 - 7.5
Very stiff	20.0 - 40.0	7.5 - 15
Hard	Over 40	Over 15

Based on published literature, an average engineering properties of Bangkok clay and the first sand layer may be summarized as follows:

Table 4.2.4 General Soil parameters in Bangkok

(ESUB project, BMA/NEDECO, 1996)

	C (kN/m^2)	ϕ (°)	γ (kN/m^2)
Soft Clay	15	0	16
Stiff Clay	100	0	18
Sand	0	35	20

Now, We suggest about general soil parameter of Bangkok Clay in Table 4.2.5 and Table 4.2.6.

Table 4.2.5 Cohesive Soil parameters of Bangkok Clay

(by Saito JICA PRO, 1998)

	C (kN/m^2)	ϕ (°)	γ (kN/m^2)	N (SPT)
weathered Soft Clay	Less 12.5	0	16	0 - 2
Soft Clay	12.5 – 25	0	16	2 - 4
Medium Stiff Clay	25 – 50	0	18	4 - 8
Stiff Clay	50 – 100	0	18	8 - 15
Very Stiff Clay	100 – 200	0	20	15 - 30
Hard Clay	Over 200	0	21	Over 30

Table 4.2.6 Cohesionless Soil parameters of Bangkok Clay

(by Saito JICA PRO, 1998)

	C (kN/m^2)	ϕ (°)	γ (kN/m^2)	N (SPT)
Very Loose	0	Less 25	17	0 - 4
Loose	0	25 - 30	16	4 - 10
Medium Dense	0	30 - 35	18	10 - 30
Dense	0	35 - 40	18	30 - 50
Very Dense	0	Over 40	20	Over 50

5. PROBLEMS OF DESIGN AND CONDTRUCTION

This chapter deals with the practice of subsurface engineering, with the potential sources of trouble that may be encountered in that practice, and with the means at our disposal to anticipate and avoid the detrimental consequences of the potential sources of trouble in this project.

5.1 Ground Improvement

5.1.1 Drainge Prior to Excavation

In an excavation with given dimensions, extending to a given depth below the water table, the quantity of water that must be disposed of and the time required for draining the surrounding soil depend on the permeability and the compressibility of the soil.On jobs of average size the planning of the drainage provisions does not require accurate information concerning the permeability of the subsoil.

(1) Methods of Drainage

To obtain satisfactory results at least expense, the method of drainage should be adapted to the average permeability of the soil surrounding the site, to the depth of the cut with reference to the water table, and on small jobs, to the type of equipment most readily available at the site. Values within which the coefficient of permeability k has been found to vary in individual representative deposits of the most common types are given in **Table 5.1.1**. According to their coefficients of permeability, soils may be divided into five groups as indicated in **Table 5.1.2**.

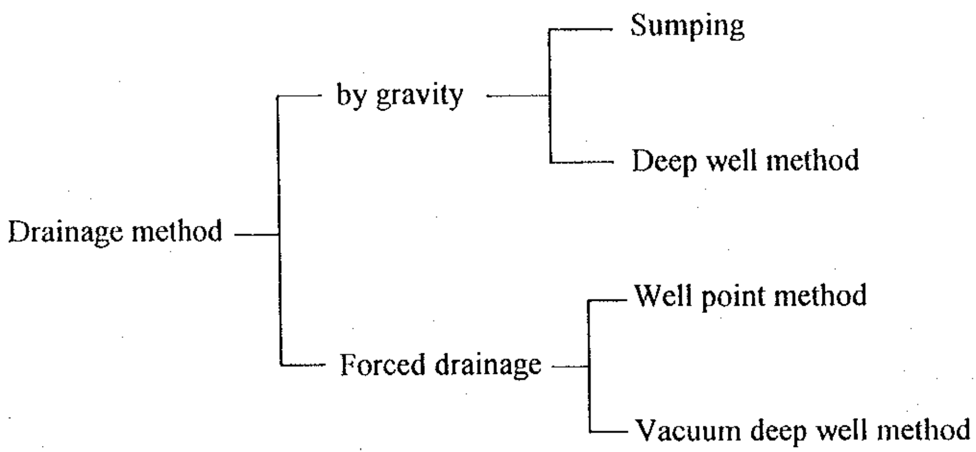
Table 5.1.1 Coefficient of Permeability of Common Natural Soil Formations

Formation	Value of k (m/s)
River deposits	
Rhone at Genissiat	Up to 4×10^{-3}
small steams, eastern Alps	2×10^{-4} to$^{-2}\times10^{-3}$
Missouri	2×10^{-4} to$^{-2}\times10^{-3}$
Mississippi	2×10^{-4} to 10^{-3}
Glacial deposits	
Outwash plains	5×10^{-4} to$^{-2}\times10^{-2}$
Esker, Westfield, Mass.	10^{-4} to 10^{-3}
Delta, Chicopee, Mass.	10^{-6} to 1.5×10^{-4}
Till	Less than 10^{-6}
Wind deposits	
Dene Sand	10^{-3} to 3×10^{-3}
Loess	$10^{-5}\pm$
Loess loam	$10^{-6}\pm$
Lacustrine and marine offshore deposits	
Very fine uniform sand, Cu = 5 to 2	10^{-6} to 6×10^{-5}
Bull's liver, Sixth Ave., N.Y., Cu = 5 to 2	10^{-6} to 5×10^{-5}
Bull's liver, Brooklyn, Cu = 5	10^{-7} to 10^{-6}
Clay	Less than 10^{-9}

Table5.1.2 Classification of Soils According to Their Coefficients of Permeability

Degree of Permeability	Value of k (m/s)
High	Over 10^{-3}
Medium	10^{-3} to 10^{-5}
Low	10^{-5} to 10^{-7}
Very Low	10^{-7} to 10^{-9}
Particularly impermeable	Less than 10^{-9}

The drainage of open excavations is generally accomplished "drainage by gravity" by conducting the water that seeped into the excavation to shallow pits called sumps and "forced drainage" by pumping it out of these pits. Generally drainage method is as follows:



5.1.2 Compaction,pile,and preloading

(1) Compaction of Fills

Banking material is more stabilized by compaction. there is important to select material and satisfactory compaction. Practically, compaction energy is given by vibration, rolling, and impact load. Compaction not only increases the density of a soil permanently increases the ratio of the effective horizontal to effective vertical pressures. Thus, it produces an effect similar to that of overconsolidation. Material of high plasticity such as upper weathered Bangkok soft clay shows overcompaction which compaction energy with high water content decrease strength by remolding.

(2) Pile Driving, Sand Piles, and Stone Columns

Soft silt below the water table is transformed by ***pile driving*** into a semiliquid state. Hence, instead of inducing compaction, pile driving weakens the soil at least temporarily. The compaction of such strata can be accomplished only by some process of drainage, by surcharging, or by a combination of the two.Because the piles driven for compaction may serve no useful purpose after the compaction is accomplished, or under some conditions may deteriorate, ***sand piles*** are sometimes used in place of structural piles. A casing with a hinged or detachable end plate is driven to accomplish the densification, filled with sand, and then withdrawn. To force the sand from the casing it may be necessary to cap. The pile spacing is usually 3 to 5 diameters. In soils of low permeability the sand piles also serve as drains to accelerate consolidation.

(3) Preloading or Surcharging

Compressible soils such as soft clays, loose silts, and most organic soils may be consolidated by ***surcharging*** or ***preloading***. The area is covered by a hill having a weight per unit area great enough to consolidate the soil sufficiently to increase its strength or reduce its compressibility to the required extent within the time available for the preloading operation. Because the preloading should compress the soil, the magnitude of preloading are designed failure during the operation.

5.2 Earth Pressure and Stability of Slopes

5.2.1 Retaining walls

Retaining walls are structures that support soils at slopes steeper than their angle of repose. Before the advent of reinforced concrete, most retaining walls consisted of stone masonry or mass concrete. Because their resistance to earth pressure was derived from their own weight, they were known as ***gravity walls*** (Fig.5.2.1 a). With the introduction of reinforced concrete, ***semigravity***, ***cantilever*** (Fig.5.2.1 b). Although the before type types of retaining walls are still in wide use, an increasing fraction of retaining walls has consisted of reinforced soil, a composite material in which the soil and reinforcement form a stable unit capable of resisting the backfill pressures and transferring them to the foundation (Fig.5.2.1 c, d). The reinforcement usually consists of approximately horizontal steel rods, known as ***soil nails,*** grouted into drilled holes or driven into the soil at close spacing and connected to a facing also installed as excavation proceeds (Fig.5.2.1 e). Irrespective of the type of retention system, two requirements must be satisfied: the stability of the retention system as a whole must have an adequate factor of safety against sliding, overturning, or excessive settlement; and the retention system itself, whether a structural wall or a mass of reinforced soil, must have sufficient strength to withstand the forces to which it will be subjected. These two requirements are categorized as external stability and internal stability.

5.2.2 Stability of slopes in open cuts

Every mass of soil located beneath a sloping ground surface or beneath the sloping sides of an open cut has a tendency to move downward and outward under the influence of gravity. If this tendency is counteracted by the shearing resistance of soil, the slope is stable. Otherwise a slide occurs. The material involved in a slide may consist of naturally deposited soil, of man – made fill, or of a combination of the two. In this article only slides in natural soil are considered. Slides in natural soil may be caused by such external disturbances as undercutting the foot of an existing slope or digging an excavation with unsupported sides. On the other hand, they may also occur without external provocation on slopes that have been stable for many years. Failures of this nature are caused either by a temporary increase in porewater pressure or by a progressive deterioration of the strength of the soil.

(1) Slides in Fairly Homogeneous Bangkok Soft Clay

If the side of a cut in a thick layer of soft clay rise at the standard slope of 1^{-5} : 1, a slide is likely to occur before the cut reaches a depth of 3 m. The movement has the character of a base failure associated with a rise of the bottom of the cut approaches the surface of the soft material. Experience has shown that sliding failures during construction in masses of homogeneous saturated soft clay take place under undrained conditions. The factor of safety against sliding of the slopes of proposed cuts in such clay can be estimated in advance of construction. However, discontinuities in the clay, consisting of sand or silt partings, may invalidate the results of the computation.

(2) Quick Clay Flows

After a slope on soft clay fails, the movement usually stops as soon as the tongue of the slide has advanced to a moderate distance from its original position. There is, however, a notable exception to this behavior. **In quick clays** such as **Bangkok soft clay** extensive progressive slides occur from time to time, often without obvious provocation. The movement begins as a small slides, usually at the bank of a stream, but the deformation of the sliding material transforms the clay into a thick slurry that flows out and deprives the new escarpment of its support, whereupon another slip occurs.

5.2.3 Design and Stability of Embankments

Levees serve to protect lowlands against periodic inundation by high water, storm floods, or high tides.

(1) Types of Base Failure

Levees must be constructed near the flood channels, irrespective of subsoil conditions. Even levees must occasionally be located at sites underlain by undesirable materials. In all these instance the design on the embankment must be adapted not only the character of the available fill material, but also to the subsoil conditions.

Base failures may occur in several different ways. The fill may sink bodily into the supporting soil. Such an accident is referred to as ***failure by sinking*** or ***breaking into the ground***. On the other hand, the hill together with the layer of soil on which it rests may spread on an underlying stratum of exceptionally soft clay or on partings of sand or silt containing water under pressure. This is known as ***failure by spreading***. If the embankment retains a body of water, it may also fail by ***piping***, as a consequence of backward erosion from springs that emerge from the ground near the toe of the fill.

(2) Method for Investigating Stability

The design of a embankment to be constructed above clay strata should always be preceded by a thorough soil exploration. The results of the exploration inform the designer about the soil profiles and the physical properties of the subsoil. The next step is to compute the factor of safety to the fill with respect to failure of its base. Under normal conditions, the foundation conditions are not considered satisfactory unless the factor of safety with respect to a base failure during or immediately after construction is at least 1^{-5}.

The conditions for the stability of the base of embankment and the methods for preventing base failures are discussed in the following sequence: embankment on very soft or marshy ground, embankment on thick strata of fairly homogeneous soft clay, fills on stratified ground containing fairly homogeneous layers of soft clay, and embankment on clay containing sand or silt partings. Subsoil conditions of the first two types are likely to be associated with failures by **sinking**, and those of the last two types with failures by **spreading**. For example, We tried to calculate **embankment slope stability** and **embankment settlement** in the following.

(3) Caluculation of Stability

We tried to calculate settlement analysis and slope stability analysis from the result refer consideration. Marine sediments Area of the Lower Central Plain (Fig. 1.1.3) is should be examine settlement and slope stability. North of Ayutthaya in Delta is not problem of stability, because subsoil of these area is stiff or medium stiff clay.

(a) Settelemnt analysis

Fills and embankments that are wide compared with the thickness of the underlying compressible ground produce a one-dimensional state of compression of the ground.

In here, embankment boundary conditions are imposed the following:

(i) Low embankment

(ii) In anticipation of traffic loading

(iii) sensitive to subsoil condition

Settlement calculation is used by linear consolidation theory by Terzaghi's and Δe method.

The most general expression for the settlement resulting from one-dimensional compression is

$$S = \Delta e \,/\, 1 + e_0 \times L_0$$

where L0 is the initial thickness of the consolidating layer.

Now, we tried to calculate settlement analysis in Bangkeao Canal Area and Lop Buri Area.

● Sena Area along Noi River (South of Ayutthya)

In the result of calculation, settlement is about 20 cm by embankment height $1^{.5}$ m, settlement-time is 696 days by 90 % degree of consolidation (**Fig.5.2.2.a**).

But, variable of calculation is presumed, if detail design would be practice, regular investigation, boring , sounding and soil tests for clay would have to be carried out.

Design condition

Basal Condition

calculation method of settlement: Δe method

settlement of sand layer: not consideration

Soil condition

Number of layer:2

Layer condition

strata No. unit weight Classification compression Index pre-consolidated stress

	γ (tf/m^3)		(Cc)	q_0 (tf/m^2)
1	1.58	0	0.35	2.0
2	0.58	0	0.35	0
3	0.80	5	0	0

classified0: double drainage, 1:sigle drainage(up), 2:single drainage (down). 3:sand (N=0～4),4:sand (N=4～10),5:sand (N=10～30).

(1) Calculation of settlement by Δe method

$$S = e_0 - e_1 / 1 + e_0 \times H \quad \cdots\cdots\cdots \ (e_0 > e1)$$

e_0: void ratio of P_0 or q_0 which layer

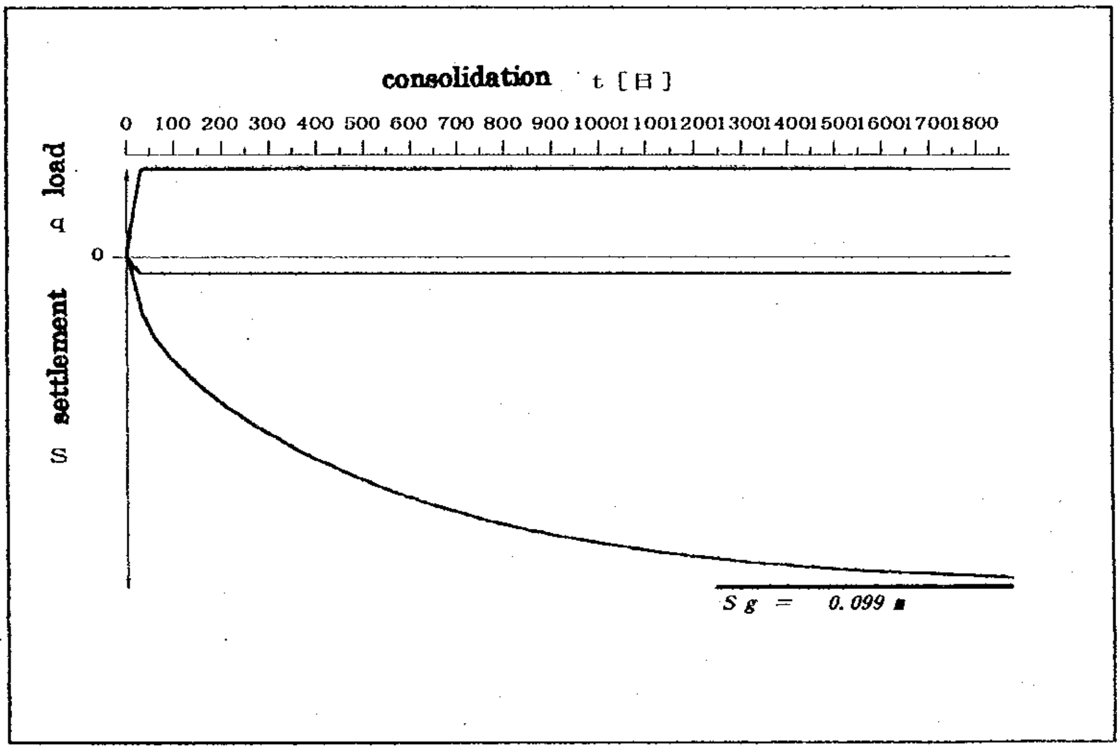
e_1: void ratio for $P_0 + \Delta P$

Strata Unit thickness Initial void ratio Consolidated e_0-e_1/1+e_0 Settlement

No.	H (m)	e_0	void ratio(e_1)		S (m)
1	1.00	1.4740	1.4237	0.0203	0.020
2	6.75	1.4174	1.3532	0.0642	0.179
3	7.25	0.5530	0.5512	0.0018	0

total settlement Σ S :0.20 m

(2) Illustrated of consolidation settlement-time



● **Ban Wat Taku along Bang Luang River**

In the result, settlement is about 6 cm by embankment height 1.5 m, settlement-time is 1024 days by 90 % degree of consolidation (**Fig.5.2.2.b**).

But, variable of calculation is presumed, if detail design would be practice, regular investigation, boring , sounding and soil tests for clay would have to be carried out.

Design condition

Basal Condition

calculation method of settlement: Δ e method

settlement of sand layer: not consideration

Soil condition

Number of layer:4

Layer condition

strata No. unit weight Classification compression Index pre-consolidated stress

	γ (tf/m^3)		(Cc)	q_0 (tf/m^2)
1	1.41	0	1.35	2.0
2	0.80	4	0	0
3	0.60	0	0.35	0
4	0.80	5	0	0

classified0: double drainage, 1:sigle drainage(up), 2:single drainage(down)
3:sand (N=0~4),4:sand (N=4~10),5:sand (N=10~30).

(1) Calculation of settlement by Δe method

$S = e_0 - e_1 / 1 + e_0 \times H$ ········· ($e_0 > e_1$)

e_0: void ratio of P_0 or q_0 which layer

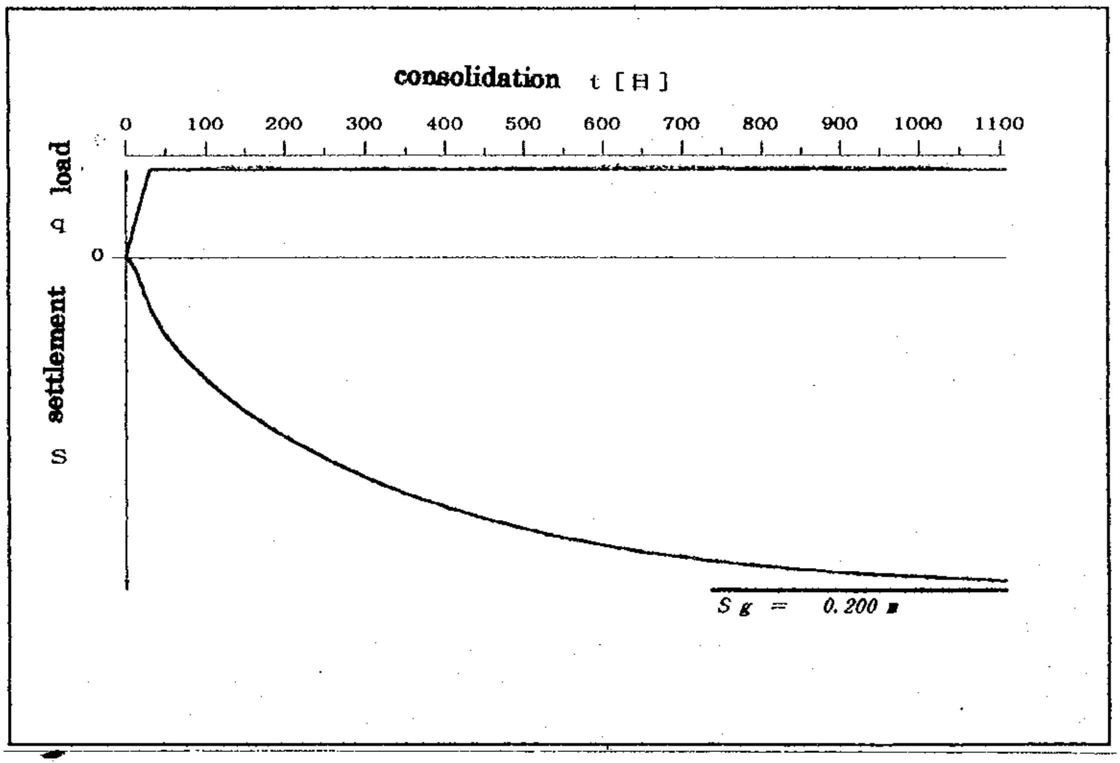
e_1: void ratio for $P_0 + \Delta P$

Strata Unit thickness Initial void ratio Consolidated e_0-e_1/1+e_0 Settlement

No.	H (m)	e_0	void ratio(e_1)		S (m)
1	0.50	2.7730	2.7354	0.0100	0.005
2	5.80	0.7498	0.7396	0.0102	0
3	13.00	1.6849	1.6656	0.0072	0.094
4	3.45	0.5446	0.5441	0.0005	0

total settlement Σ S :0.099 m

(2) Illustrated of consolidation settlement-time



● Sing Buri Area and Ang Thong Area (North of Ayutthya)

The soil property around the north area of Ayutthaya can bear the weight of embankment. because these area was almost overlain by stiff to medium stiff clay. In addition, all of the concerned structures are existing embankment in place without any sign of settlement problem.

(1) Slope stability analysis

Calculation of slope stability was used in circular arc method (effective stress analysis) by parameter suggested retreat. With the result, safety factor Fs = 2.5 in Sena Area, Fs = 1.5 in Ban Wat Taku, Fs = 4.5in Sing Buri and Ang Thong of slope embankment is obtained a slope of 1:2, height Of 1.5m (Fig. 5.2.3, Fig.5.2.4, Fig.5.2.5, Fig.5.2.6). But, variable of calculation is presumed, if detail design would be practice, regular investigation, boring , sounding and soil tests for clay would have to be carried out.

(2) Result of Model Calculation

The result of model calculation is shown in Table 3.2.1.

Table 5.2.1 Result of Model Calculation

Location	Settlement	Slope Stability
SingBuri	Stable (Stiff subsoil)	Stable (Fs = 4.485, Slope = 1:2)
AngThon	Stable (Stiff subsoil)	Stable (Fs = 4.485, Slope = 1:2)
BanWatTaku	9.9cm 1196day (90 %)	Stable (Fs = 1.467, Slope = 1:2)
Sena	21.5cm 696day (90 %)	Stable (Fs = 2.548, Slope = 1:2)

It follows from this that these ground is safety for consolidation and slope stability in north area of Ayutthya, except for along Bang Luang River and Bang Bal River.

5.3 Foundations

5.3.1 Foundation for structures

The foundation is the part of a structure that transmits the weight of structure onto the natural ground. If a stratum of soil suitable for sustaining a structure is located at a relatively shallow depth, the structure may be supported directly on it by a ***spread foundation***. However, if the upper strata are too weak, the loads are transferred to more suitable material at greater depth by means of ***piles*** or ***piers***. Spread foundations are of two types. If a single slab covers the supporting stratum beneath the entire area of the superstructure, the foundation is known as **mat** or **raft**. If various parts of the structure are supported individually, the individual supports are known as **spread footings**, and the foundation is called a **footing foundation**. A footing that supports a single column is called an **individual footing**; one that supports a group of columns is a combined footing, and one that supports a wall is a **continuous footing**. The depth of foundation **Df** is the vertical distance between the base of the footing or pier and the ground surface, unless the base is located beneath a basement or, if the structure is a bridge, beneath the surface of the river. In these instances the depth of foundation is referred to the level of the basement floor or to that river bed. The principal difference between footings and piers lies in the value of the ratio Df/B, where B is the width of the base. For footings Df/B commonly ranges between 0.25 and 1, whereas for piers it is usually greater than 5 and may be as great as 20. However, monolithic supports for bridges are also generally called piers, irrespective of the value of Df/B.

5.3.2 Footing foundations

The most important step in the design of a footing foundation is the evaluation of the greatest pressure that can be applied to the soil beneath the footing without causing either failure of the loaded soil or excessive settlement. Because of the great variety of soils and combinations of soils in practice, no single method for determining the allowable soil pressure is applicable under all circumstances. The procedure must always be adapted to the soil conditions revealed by the subsurface exploration. In particular, the procedure depends on the **significant depth** or **depth of influence**.

The significant depth depends not only on the size of the footing and on the size of the footing and on the load it supports, but also to a high degree on the soil profile and the physical properties of the soils. If the initial tangent modulus of the soil increases as the depth below a footing increases, the significant depth may be somewhat less than the width ***B*** of the footing. On the other hand, if the soil beneath the footing becomes softer with depth, the significant depth may be equal to several times the width ***B***.

Footings on Clay such as Bangkok Soft Clay

In particular, a footing underlain by soft clay such as Bangkok soft clay may fail catastrophically the first time it is loaded. Therefore, the first step in developing the design of a footing on clay is to determine its ultimate bearing capacity.

5.3.3 Raft foundations

The factor of safety of raft foundations on clay is practically independent of the size of the loaded area. It is commonly very low, and several failures have occurred.

The settlement is not necessarily uniform, but it follows a fairly definite instead of an erratic pattern. The pattern differs, however, if the soil located within the seat of settlement consists of sand or of clay.

Rafts on Clay such as Bangkok Soft Clay

The maximum permissible value for the soil pressure beneath rafts on clay, that beneath footings on clay, is obtained by dividing the ultimate net bearing capacity (qd) by a factor of safety F equal to 3 for dead load and not more than 2 for dead load plus extreme combinations of live load. However, because of the large dimensions of the area covered by a raft and the rapid increase of settlement of clay with increasing size of the loaded area. It is always necessary to find out, at least by a crude estimate, whether the settlement will be tolerable.

5.3.4 Pile foudations

A structure is founded on piles if the soil immediately below its base does not have adequate bearing capacity or if an estimate of costs indicates that a pile foundation may be the most economical. Piles may also be used to resist lateral or uplift forces. With respect to the manner in which they transfer their load, piles may be divided into three categories:

(1) Friction piles in coarse-grained very permeable soil. These piles transfer most of their load to the adjacent soil through side resistance, often referred to as skin friction. Driving such piles in groups reduces the porosity and compressibility of the soil within and around the groups. Therefore, piles of this category have sometimes been called **compaction piles**.

(2) Friction piles in very fine-grained soils of low permeability. These piles also transfer their load to the soil appreciably. Foundations supported by piles of this type are known as **floating pile foundations**.

(3) **Point-bearing** or **end-bearing piles**. These piles transfer their load onto a firm stratum located at a considerable depth below the base of the structure.

5.4 Consideration of Foundation Problem on the Soft Clay

It has been shown in various studies that land subsidence in Bangkok is caused by pumping up ground water. On the other hand, In the Lower Central Plain called the Lower Chao Phraya Basin the problem is one of determining river construction deformation and failure in the soft clay and design-execution management.

The primary consideration in any design should be the followings:

- To design to be unification of substructure and ground.
- To design to be strong against shear failure within construction body.
- To Improvement ground in weak subsoil to increase soil strength.
- To reconsider to decrease the road of construction.

Now, in Bangkok area general pile foundations have their pile tips in the first stiff clay or first sand at about 20 to 30 m. The heavy superstructure foundations such as overpass of highway have their pile tip in the second sand at 50 to 60 m.

6. GEOTECHNICAL ASPECT

6.2 Soil Exploration

6.1.1 General

In general, earth and rock have very complicated and diverse properties, and accordingly various methods are adopted for their investigation. Therefore, when this standard is applied, other conditions, especially topographic, meteorologic, soil, geological conditions must be sufficiently examined to flexibly meet the situation based on the sufficient understanding of the precise object of the investigation.

6.1.2 Investigation Procedure

Soil exploration shall be made according to the following sequence in principle

- Preliminary investigation
- Site reconnaissance
- Regular investigation

(1) Preliminary investigation

In the preliminary investigation, the following existing data should be collected as required.

- Soil exploration data
- Geological surveys data
- Topographical maps and aerial photographs
- Disaster records
- Hydrological data
- Meteorological records

(2) Site Reconnaissance

In site reconnaissance, the conditions in the area to be covered by the investigation shall be confirmed based on results of the preliminary investigation. Sampling, sounding, etc.

At the site, observation should be made as to topographic matters such as talus, alluvial fans, landslides, faults, terraces, sand dunes, swamps, and rivers with bed above ground, and furthermore, as to such matters as lithology, geological structure and ground water, to know soil conditions.

(3) Regular Investigation

In regular investigation, field tests such as bearing strength tests and permeability tests, and laboratory tests such as shearing tests and consolidation tests shall be made to obtain the required data.

(a) Regular Investigation

In regular investigation, boring and sounding tests shall be made as required as follows:

(i) Boring

Boring shall be made at 200 meters intervals along the design alignment of the levee. The boring depth shall be about 3 times the design levee height as standard. In the boring, the stratum structure shall be confirmed, and N values shall be obtained according to standard penetration tests. Furthermore, using samples, laboratory tests shall be made to identify the soil.

(ii) Sounding tests

Sounding tests shall be made at 50 to 100 meters intervals along the design line of the levee, for the relatively soft layer on the surface, according to Dutch double tube cone penetration test or Swedish sounding test.

(iii) Arrangement of results

The result of boring investigation and sounding tests shall be recorded together on a soil profile drawn on a scale of 1 to 100 along the design alignment in principle.

(b) Idenrification of Poor Subsoil

For the poor subsoil which has been found to correspond to any of the following as a result of the regular investigation, further investigation shall be made.

(i) When the ground is clay

- Ground in which the N values by standard penetration tests are 3 or less.
- Ground in which Dutch double tube cone penetration values are 3 kg/cm or less.
- Ground which settles with a load of 100 kg or less in Swedish sounding tests
- Ground in which unconfined compressive strength, qu is .0.6 kg/cm or less.
- Ground of alluvial clay in which natural water content is 40 % or more.

(i) When the ground is organic soil

(ii) When the ground is sandy

- Ground in which the N values by standard penetration tests are 10 or less
- Ground of fine sand of even grain size.

(c) Policies in the Investigation of Poor Subsoil

In the investigation of poor subsoil, the following investigation shall be made as regular investigation

(i) Sounding tests

(ii) Sampling

(iii) Soil tests

(iv) Data arrangement

(d) Sampling

(i) Sampling methods

In the case of weak clay ground, sampling shall be made, by using a thin wall sampler or foil sampler.

In loose sand ground in which undisturbed samples are difficult to obtain, sampling shall be by boring.

(ii) Sampling points

When the size of poor subsoil is small, sampling shall be made at one point found to be weakest as a result of the sounding tests, and when the scale is large, sampling shall be made at 100 meters intervals along the design alignment of the levee.

In loose sand ground, sampling shall be made at one point in each site or at 500 meter intervals, depending on the scale.

(iii) Sampling depth

Sampling depth shall be as far as the thickness of the weak layer which is not surmised to affect the levee as a result or the main investigation and sounding tests. In the case of weak clay, a range of $N < 8$ to 10 can be considered as the sampling range.

Sampling by a thin wall sampler shall be made at 2 meter intervals in the depth direction and for each soil layer. In the case of loose sand ground, sampling shall be made to a layer of $N = 15$ or more

(e) Soil Tests

Sampling shall be subject to the following tests depending on the conditions of ground.

(i) For clay

- Mechanical analysis of soil,
- Natural water content test,
- Specific gravity test,
- Unit weight test,
- Consistency test,
- Unconfined compression test,
- Consolidation test,
- Triaxial compression test,
- Other tests

(ii) For peat soil, etc. which are difficult in taking undisturbed samples

- Natural water content test,
- Specific gravity test,
- Consolidation test,
- Volatile solids test,
- Other tests

(iii) For loose sand

- Mechanical analysis of soil,
- Specific gravity test,
- Natural water content test,
- Other tests

6.1.3 Investigation of Banking Material

The following investigation shall be made as required for selecting the materials for the embankment.

(1) Preliminary investigation and site reconnaissance

(2) Regular investigation

(a) Sampling

(b) In-Situ tests

(3) Data arrangement

For especially important constructions, field compaction tests must be made according to soil compaction tests.

(4) Suitable as embankment material

For embankment material, the following shall be demand to satisfy the function of the embankment.

(a) Grain size distribution is well-graded

(b) Maximum grain size is less than 10 to 15 cm.

(c) Parts of fine-grained (less than ϕ 0.075 mm) soil is more than 15 % of earth material (less than ϕ 75mm).

(d) Silt fraction is not so much.

(e) Fine-grained fraction (less than ϕ 0.075 mm) is not so much

Therefore, suitability material is (GM), (GL), (SM), (SC), (ML), (CL) should be judged in reference to the " Unified Classification Method for Soils " shown in Table 6.1.1.

6.2 Test Embankment (Experimental construction)

In the ground for which any measure for preventing leakage must be taken, an experimental construction shall be made in the field as required, to examine the effect of preventive work. The effect of preventive work shall be judged by investigating the variation of ground water before and after the execution of the preventive work and comparing the results. In order to achieve the above-stated objectives, the Study covers followings:

6.2.1 Subsoil survey

Subsoil surveys at experimental work sites shall be carried out to get enough subsoil information for analysis of embankment behavior

6.2.2 Research on materials for embankment

Research on materials for reinforcement of embankment shall be carried out for determining durability, physical characteristic, and availability

6.2.3 Experimental works

The experimental works will cover; 1) planning and designing of road construction with the following countermeasures and necessary measurement instruments, 2) implementation of the above planned roads.

End

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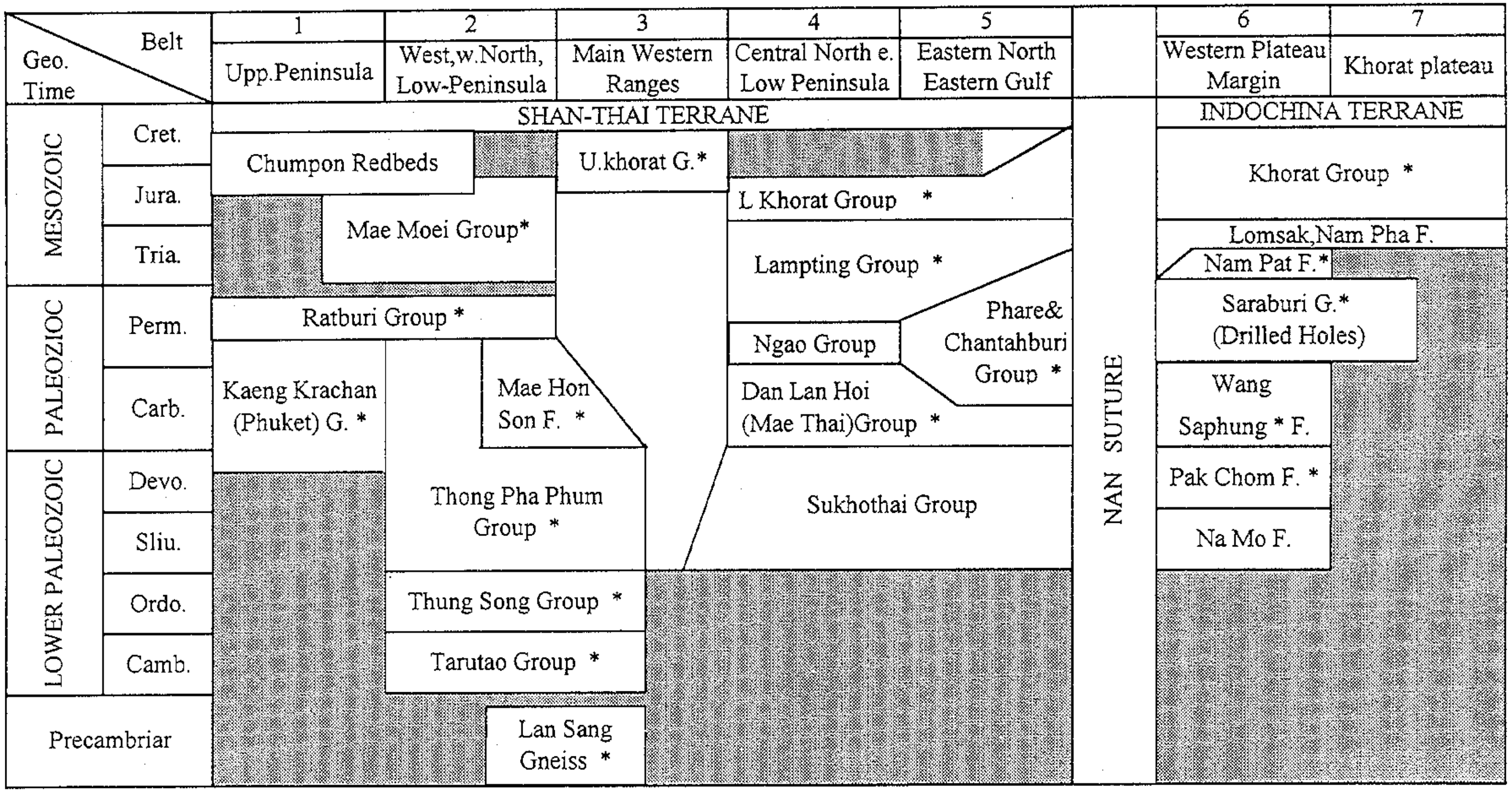
Tables

Table1.2.1 GENERALIZED STRATUGRAPHIC NOMENCLATURE FOR THAILAND



Note1:within the seven stratigraphic belts on Shan-Thai and the Indochina cratons divided by the Nan Suture.
Note2:Names with *are adopted by the DMR in new 1:2,500,000 geologic map.

Table 1.2.2 CORRELATION OF QUATERRARY DEPOSITS THAILAND

	Northern Intermontain basin (Lampang basin)	Northeastern Thailand: Khorat Plateau Area (Udomchoke,1969)	Northeastern Thailand: Low-land Area (Trug Kula Ronghai,TKR)	Central Plain: Upper Central	Central Plain: Lower Central	Southern Thai Peninsula (Songkhla Lake Basin)
HOLOCENE	Meander belts Floods plain **PHASE V** Alluvium	Alluvium Flooddeposits shells and sherds Wind blown sand Red and yellow loess	Sand of meander belt Clay Non-organic sand	Mender belt Flood plain **Terrace I** (Sawankalok earthenware)	Top soil alluvivial Subtidal Shell&peat (5,000-4,000 -yrs) *Intertidal* — Soft Clay mem	Fliviat/Recent beach dep Channel/Lacustrine Old beach ridge/Tidalfat peat(4,300-6,600yrs) *Flood plain*
PLEISTOCENE UPPER	Laterite Fluviatile deposits **PHASE IV** Laterite Basaltic flow **PHASE III** Nam Mae Jong Fm. (0.65-0.95mys) deep erosion	Organic Sand (34,000-20,000 yrs BP) Ferricrete Young Gravel beds with *tektite(0.7 my)*	Organic Sand Lower non-organic sand	Allivial fan Fm — Kam Phaeng Phet Fm. ? — ?	Estuarine Deltaic sand/silt — Stiff Clay mem Locustrine marl Fm ?	fluviatile dep *Redsoil Fm* *Laterite*
PLEISTOCENE MIDDLE	Laterite **PHASE II** Gravel bed **PHASE I** *Mae Taeng Fm*	Older Gravel beds (Phu Khao Thong Fm)	Alluvial sediments of unknown composition	Fluviatile coarse sand and gravel with remains of(Terrace III) Hippopotamaus, Stegodon and Buballis — Ping Fm.	*Phra Pradaeng mem* *Phra Nakhon mem*	Pediments/Gravel bed. (Terraces)
PLEISTOCENE LOWER		Bedded Iron oxides and Geothits Basalt	Erosion		*Phra Prakan mem* ?	*Laterite* ?
PLIOCENE	Claystone,Siltstone Sandstone	Weathered Khorat Group	Wethered Mahasarakham Fm.	Upper Miocene	Pllo-Miocene	Weathered Older rocks

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Table 1.2.3 DESTRUCTIVE EARTHQUAKES AFFECTING BANGKOK

Month/ Day	Year (AD)	Place	Latitude	Longitude	Description	Intensity
7/16	1799	Bangkok	13° 45'N	100° 31'E	Earthquake occurred.	V
12/7	1799				Earthquake occurred.	V
2/24	1832				Earthquake occurred.	V
10/22	1833				Earthquake occurred.	V
11/24	1833				Earthquake occurred. More intense than previous.	VI
3/26	1835				Water in the river swayed and spilled.	V
3/16	1839	Bangkok	13° 45'N	100° 31'E	General panic among the people;those who lived in house-boatswere tossed about as the oscillating water sloshed back and forth from one bank to another This quake was also felt in Burma where a rift in the ground surface was reported.In Thailand the quake died out east of the Bang Pakong River.It was not felt on the eastern side of the river neither in Pana Nikom District nor at Cholburi Province.	VII
10/?	1841				Earthquake occurred.	V
2/16	1860				Lamp swayed.	V
3/?	1874				Earthquake occurred.	V
2/16	1886				Earthquake occurred,roof shaken 4-5 times,chandaliers swayed.	VI
11/22	1886				Earthquake swayed houses 6-7 times from east toward west.	VI
11/30	1887				Earthquake occurred.	V
2/17	1975	Bangkok			Slight damaged and injuries in Bangkok. Felt throughout central and northern Thailand.	VI
4/22	1983	Bangkok			Slight damaged in Bangkok,Nakhon Pathom and Kanchanaburi Province. Felt strongly throughout central part of Thailand.	VI
12/3	1990	Bangkok			Result of the earthquakes which occurred in Siam on the 3rd, and 4th of December as reported to the Minister of the Interior from the various Provinces as follows;In Bangkok the shock was felt at about 2 o7clock on slight tremor.	

after Bangkok data from Nutalaya (1983)

Table 2.3.1 RESULTS OF FUTURE SIMULATION

SCENARIO No.	RESULTS		REMARKS
	WATER LEVEL	LAND SUBSIDENCE	
1	Straight drop in all area. Lowest W.L. = -190m in 2017.	Sharp increase in all area. Max.L.S. = 200cm by 2017.	Worst scenario.
2	Recovered from 1998 in BKK,NTB,SPK. Step rise and drop in PTM. Drop continues in SSK. Lowest W.L. = -170m in 2017.	Stabilized from 1997 in BKK,NTB,SPK. Increase rate from 2004 in PTM. Sharp increase in PTM and SSK. Max.L.S. = 175cm by 2017.	Effective in BKK,NTB,and SPK. Better than Scn. 1 in PTM. Severe in SSK.
3	Stabilize then drop in critical zone. Straight drop in PTM and SSK. Lowest W.L. = -190m in 2017.	Slightly decrease rate in critical zone. Sharp increase in PTM and SSK. Max.L.S. = 190cm by 2017.	Still worse in critical zone. Severe in PTM.and SSK.
4	Clear recovery in critical zone. Straight drop in PTM and SSK. Lowest W.L. = -187m in 2017.	Stabilized then slightly rebuond in critical zone. Sharp increase in PTM and SSK. Max.L.S. = 175cm by 2017.	Effctive in critical zone. Severe in PTM.and SSK.
5A	Slight recover the slight drop in BBK,NTB, and SPK. Decrease drop rate in PTM and SSK. Lowest W.L. = -114m in 2017.	Decrease rate in new critical zone from 2001. Max.L.S. = 96cm by 2017.	Subsidence by 2017 is less than 100cm in the Study Area,but more than 50cm in BKK,PTM,SPK and SSK.
5B	Clear recovery from 2001 in new critical zone. Lowest W.L. = -65m in 2017.	Stop then slightly rebound in new critical zone. Max.L.S. = 66cm by 2017.	Subsidence by 2017 is less than 50cm in eastern area,but more than 50cm in south Western area.
5C	Gentle recover from 2001 in new critical zone. Lowest W.L. = -103m in 2017.	Almost stop from 2001 in new critical zone. Max.L.S. = 74cm by 2017.	2.5% if annual pumpage decrease is still effective to stop land subsidence. Large subsidence occurs by 2000.
6	Drop rate decrease from 1995 to 2000. Lowest W.L. = -87m in 2017.	Subsidence rate by 2001 become 2/3 compared with Scenario 5C. Max.L.S. = 48cm by 2017.	Reduction of pumpage increasing rate is effective. Less than 50cm subsidence in SSK.
7	Drop rate become smaller from 1995 to 2000. Lowest W.L. = -80m in 2017.	Subsidence rate by 2001 become 1/2 compared with Scenario 5C. Max.L.S. = 36cm by 2017.	Most effective scenario. Subsidence by 2017 is mostly 10cm to 30cm.

after JICA & DMR (1995) : The Study on Management of Groundwater and Land Subsidence in the Bangkok Metropolitan Area and Its Vicinity.

Table 2.3.2 SUBSIDENCE STATISTICS BY DISTRICT

District	<-50 (cm)	-50 to -75 (cm)	-75 to -100 (cm)	-100 to -125 (cm)	-125 to -150 (cm)	-150< (cm)	Total
Bang Kapi	0	13.084	20.942	11.051	0	0	45.077
Bang Khen	0	47.539	30.802	0	0	0	78.341
Bang Kho-Laem	0	0	8.459	0	0	0	8.459
Bang Khun Thian	0	72.876	27.185	14.735	36.267	5.490	156.553
Bang Phlat	0	0	8.652	3.205	0	0	11.857
Bang Rak	0	0	2.197	1.846	0	0	4.043
Bang Sue	0	1.140	11.947	0	0	0	13.087
Bangkok Noi	0	0	0.743	11.555	0	0	12.298
Bangkok Yai	0	0	0	6.241	0	0	6.241
Bung Kum	0	62.773	0.346	0	0	0	63.119
Chatu Chak	0	1.438	31.040	0	0	0	32.478
Din Daeng	0	0	3.499	4.979	0	0	8.478
Don Muang	0	31.659	26.911	0	0	0	58.57
Dusit	0	0	9.305	1.998	0	0	11.303
Huai Khwang	0	0	1.833	14.517	0	0	16.35
Jomthong	0	0.984	15.992	6.776	0	0	23.752
Khlong San	0	0	0.325	5.691	0	0	6.016
Khlong Toei	0	0	9.832	18.122	0	0	27.954
Lat Phrao	0	13.643	14.901	0	0	0	28.544
Latkrabang	0	13.660	36.739	77.555	0.637	0	128.591
Minburi	14.862	119.990	21.023	19.414	1.979	0	177.268
Nong Chok	133.243	62.370	39.318	6.126	0	0	241.057
Nong Khaem	0	0.462	6.414	11.996	28.087	0	46.959
Pathumwan	0	0	5.996	2.084	0	0	8.08
Phasi Charoen	0	0	3.175	15.076	38.370	0	56.621
Phaya Thai	0	0	9.009	0.064	0	0	9.073
Phra Khanong	0	0	21.272	7.417	5.253	0	33.942
Phra Nakhon	0	0	0	5.394	0	0	5.394
Pom Prap Sattruphai	0	0	0	2.445	0	0	2.445
Prawet	0	28.534	20.413	12.430	4.098	0	65.475
Ratburana	0	0	19.247	16.766	8.073	2.636	46.722
Ratchathewi	0	0	4.496	2.727	0	0	7.223
Samphanthawong	0	0	0	1.409	0	0	1.409
Sathon	0	0	7.106	0.142	0	0	7.248
Suan Luang	0	3.629	14.321	2.792	0	0	20.742
Taling Chan	0	0	25.294	48.262	14.047	0	87.603
Thonburi	0	0	1.322	6.812	0	0	8.134
Yan Nawa	0	0	12.263	0.142	0	0	12.405
Total	148.105	473.781	472.319	339.769	136.811	8.126	1578.911

after JICA & BMA (1996)

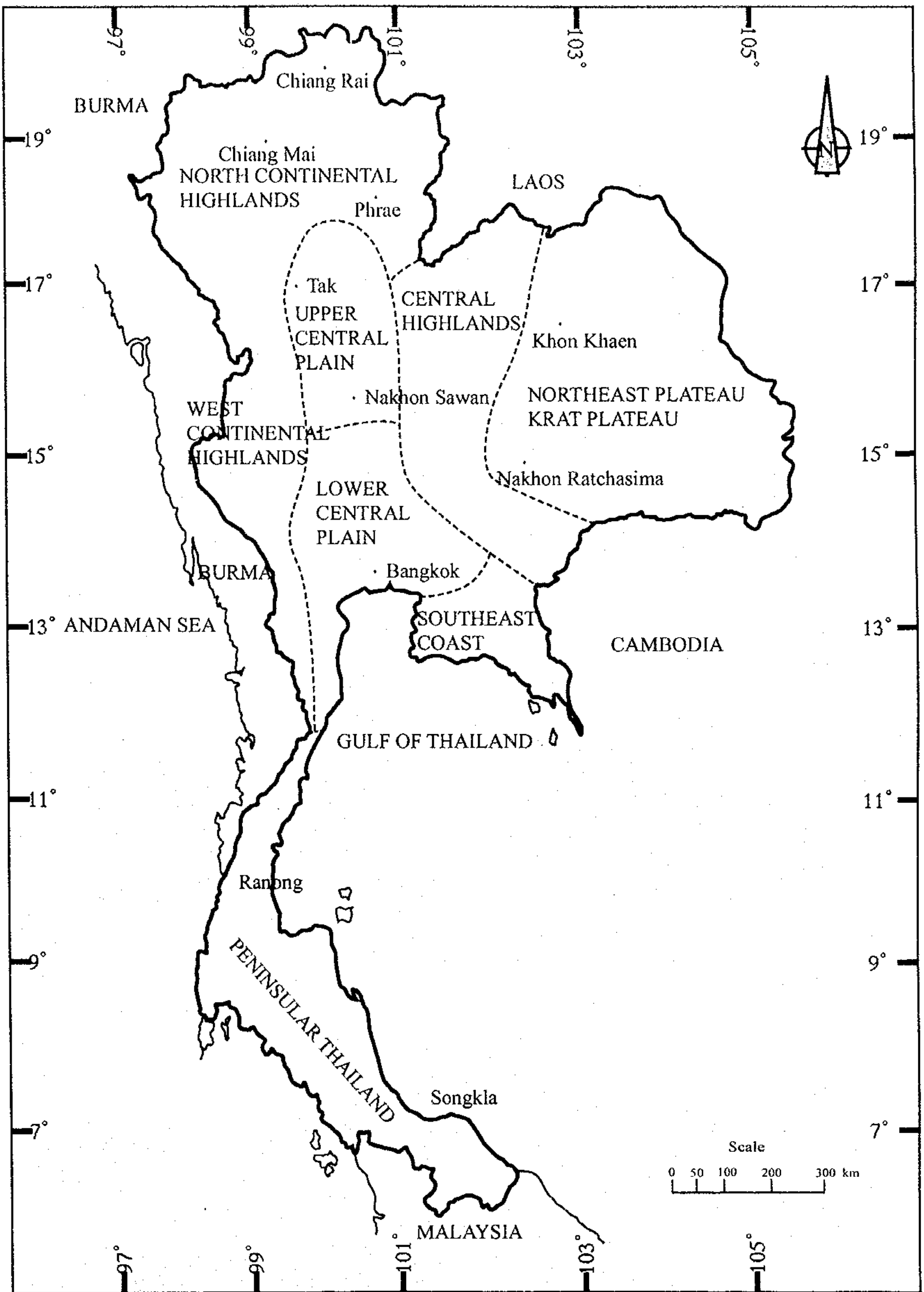
Table 4.1.1 SUMMARY OF PHYSICAL PROPERTY OF BANGKOK SOFT CALY

Items	Bangkok Soft Clay	
	Weathered clay in upper layes	Non weathered soft clay in lower layes
Soil classification	CH	CH
Grain size distribution	sand 0 ~ 12 % silt 9 ~ 55 % clay 30 ~ 91 %	
Specific gravity	2.64 2.75	
Wet unit weight	1.34 ~ 1.78 t/m^3	1.37 ~ 1.67 t/m^3
Void ratio	1.01 ~ 3.47	1.46 ~ 3.49
Natural moisture	3.70 ~ 126.0 %	47 ~ 126 %
Plastic limit	20.0 ~ 48.0 %	23.0 ~ 53.0 %
Liquid limit	59.0 ~ 121.0 %	57.0 ~ 123.0 %
Plasticity index	38.0 ~ 81.0 %	31.0 ~ 83.0 %
Liquidity index	0.46 ~ 1.10 %	0.46 ~ 1.07 %
Activity	0.586 ~ 1.36	0.52 ~ 1.282
Sensitivity ratio	3.2 ~ 11.3	1.6 ~ 9.0

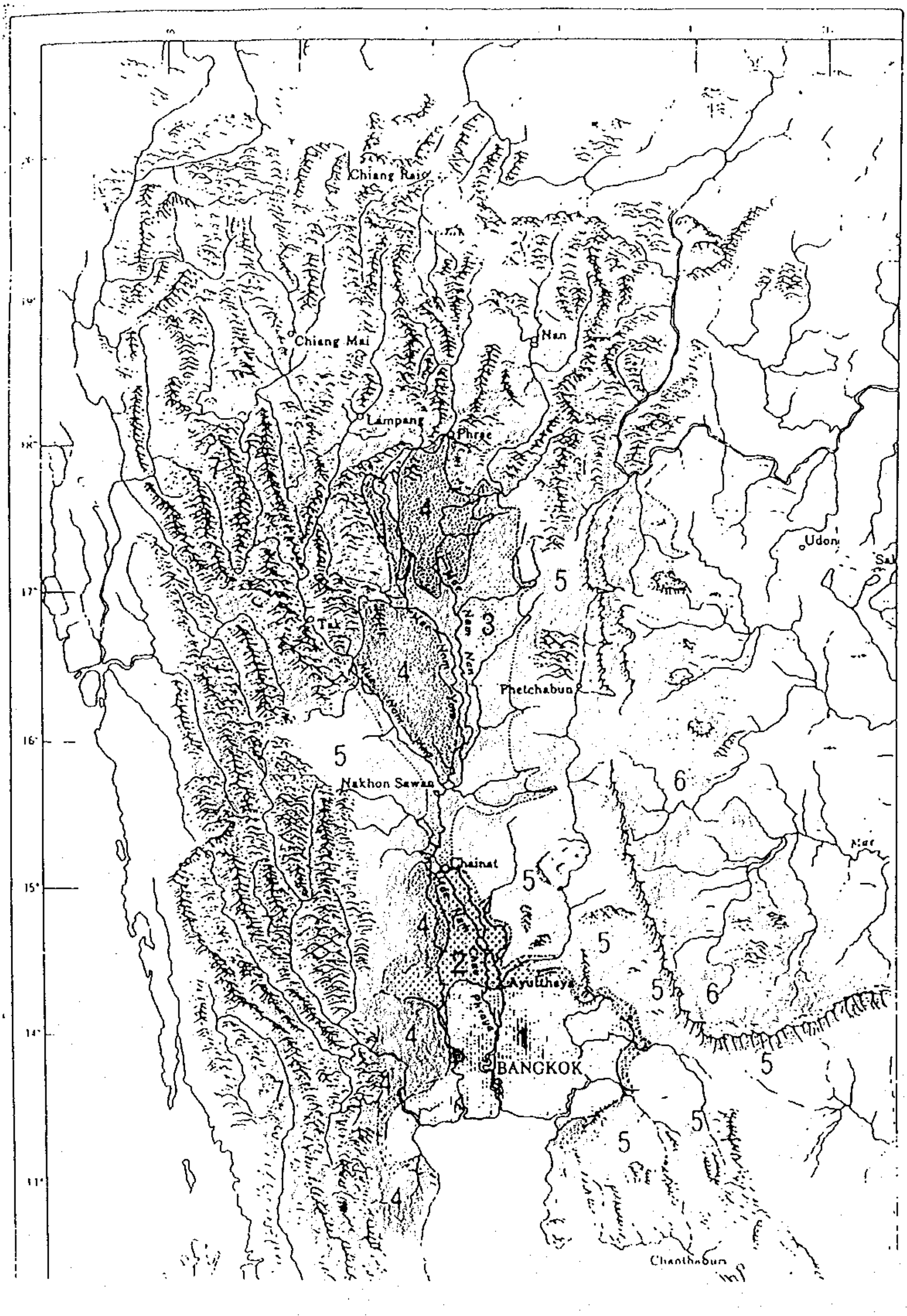
Table 6.1.1 UNIFIED CLASSIFICATION METHOD FOR SOILS

Major classification (field classification procedure)						Classification symbol	Typical names
Coarse-grained soil (the amount remaining after 74 μ ,sieving is more than 50%)	Gravel (the amount remaining after 4.76 mm sieving is more than 50% of the coarse-grained content.)	Clean gravel	Wide in grain size distribution with grains of intermediate grain sizes contained requlariy			GW	Gravel good in grain size distribution Gravel-sand mixed soil Little or not containing fine grains at all
			Containing much grains certain sizes and not those of intermediate sizes			GP	Gravel bad in grain size distribution Gravel-sand mixed soil Little or not containing fine grains at all
		Gravel containing fine grains	Non-plastic fine grains (see ML. For classification procedure)			GM	Silty gravel Gravel-sand-silt mixed soil
			plastic fine grains (see CL. For classification procedure)			GC	Clayey gravel Gravel-sand-silt mixed soil
	Sand (the amount passing a 4.76 mm is more than 50% of corse-grained content)	Clean gravel	Wide in grain size distribution with grains of intermediate grain sizes contained requlariy			SW	Sand good in grain size distribution Gravelly sand Little or not containing fine grains at all
			Containing much grains certain sizes and not those of intermediate sizes			SP	Sand bad in grain size distribution Gravelly sand Little or not containing fine grains at all
		Gravel containing fine grains	Non-plastic fine grains (see ML. For classification procedure)			SM	Silty sand,sand-silt mixed soil
			plastic fine grains (see CL. For classification procedure)			SC	Clayey sand,sand-clay mixed soil
Fine-grained soil (the amount passing a 74 μ sieve is more 50%)			Dry strength (Property by crushing)	Dilatancy (Reaction to vibration)	Toughness (consistency close to plastic limit)		
	Silt and Clay, LL $\leqq$ 50		Nil to low	Fast to slow	Nil	ML	Inorganic silt, very fine sand, rock flour, silty or clayey fine sand
			Medium to high	Nil to very slow	Medium	CL	Inorganic clay low or medium in plasticity, gravelly clay, sandy clay, silty slay, less viscous clay
			Low to medium	slow	Low	OL	Organic silt low in plasticity and organic silty clay
	Silt and Clay, LL $>$ 50		Low to medium	Slow to nil	Low to medium	MH	Inorganic silt, micaceous or diatomaceous fine sand or silt, or elastic silt
			High to very high	Nil	High	CH	Highly plastic inorganic clay
			Medium to high	Nil to very slow	Low to medium	OH	Moderately or highly plastic organic clay
Highly organic soil			This can be easily identified by color, odor, spongy touch, fibrous viscous compositon.			PT	Peat, much and other highly organic soil

Figures



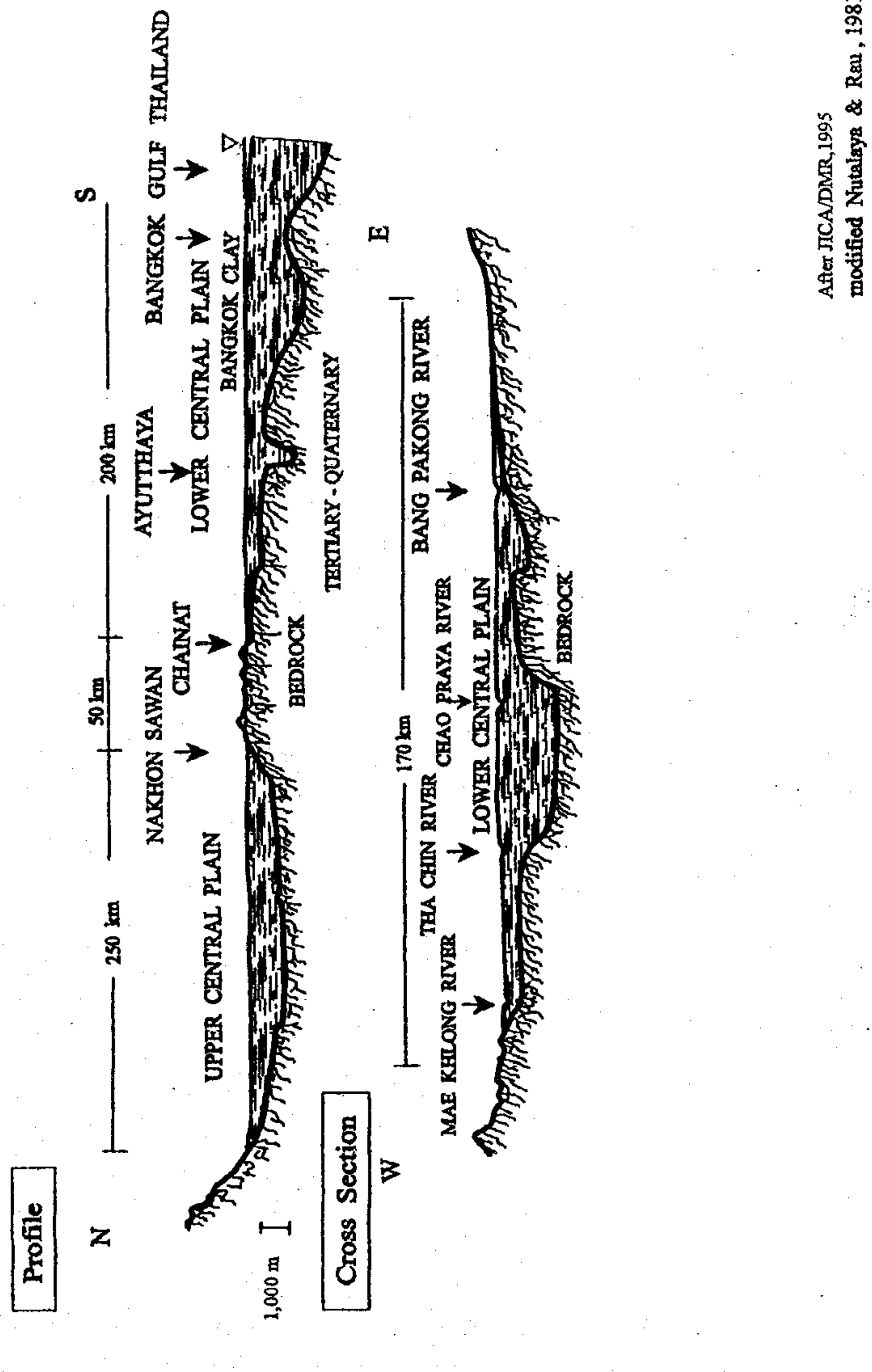
STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig. 1.1.1 THE MAIN PHYSIOGRAPHIC REGIONS OF THAILAND
CTI ENGINEERING CO., LTD AND INA CORPORATION	



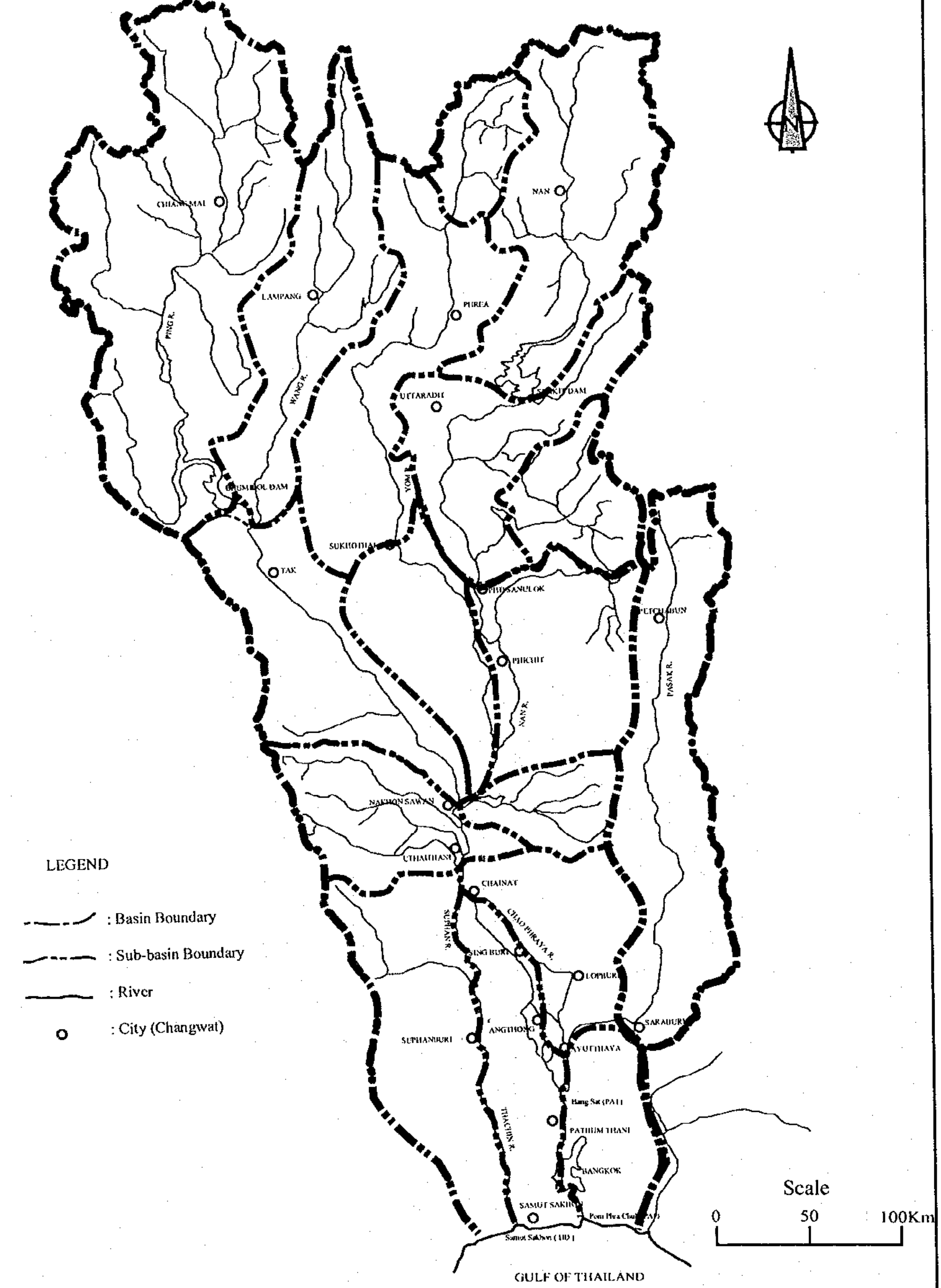
Topographic features of the Central plain: 1 – Bangkok plain; 2 – lower Central plain; 3 – upper Central plain; 4 – alluvial fans; 5 – pediments and/or pediplains; 6 – Khorat plateau; 7 – western mountain belt

(Relief adapted from Brown, G.F. *et al.* 1951)

STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.1.1.2 TOPOGRAPHIC FEATURES OF THE CENTRAL PLAIN
CTI ENGINEERING CO., LTD AND INA CORPORATION	



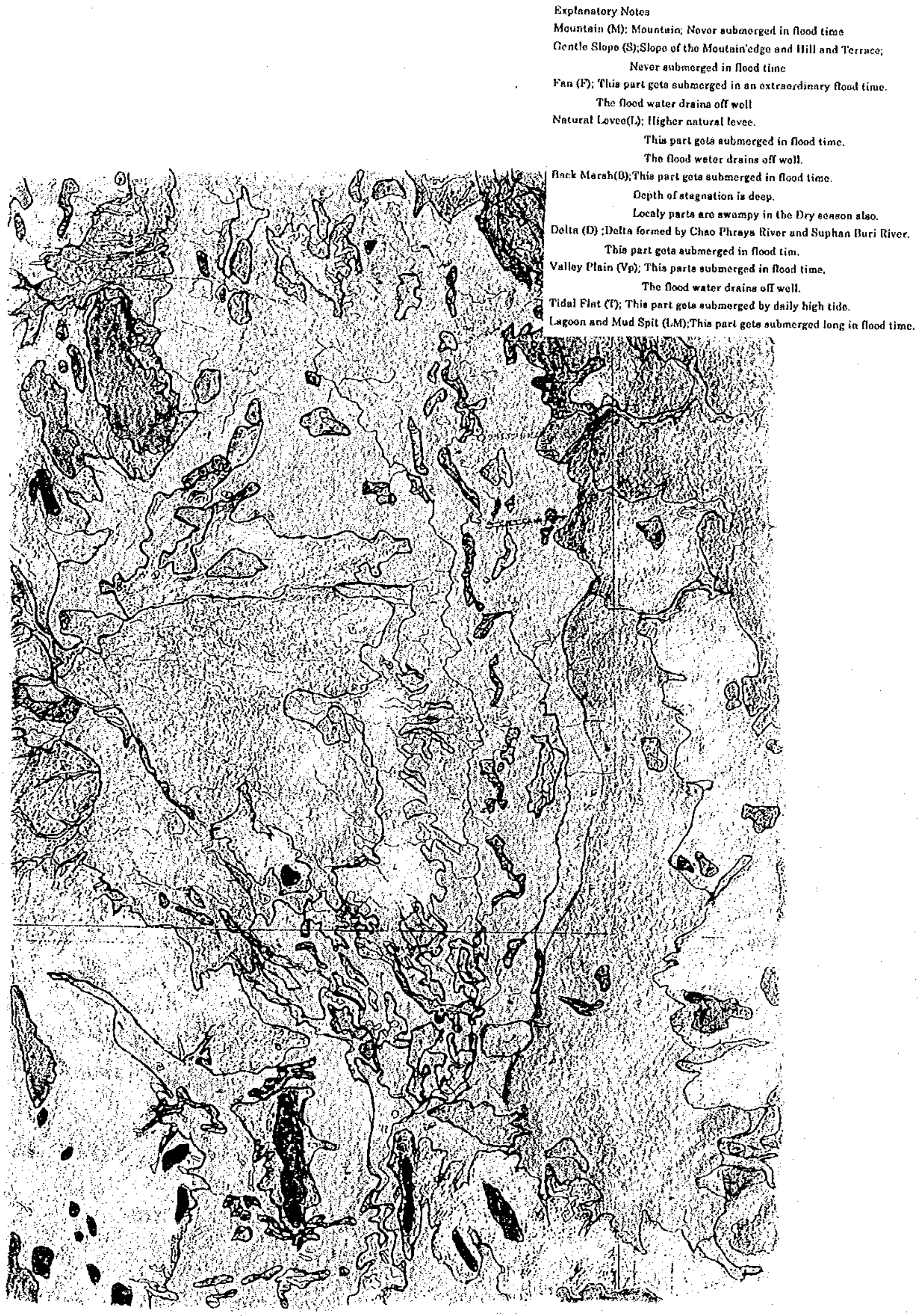
STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.1.1.3 SCHEMATIC PROFILES OF THE CENTRAL PLAIN
CTI ENGINEERING CO., LTD AND INA CORPORATION	



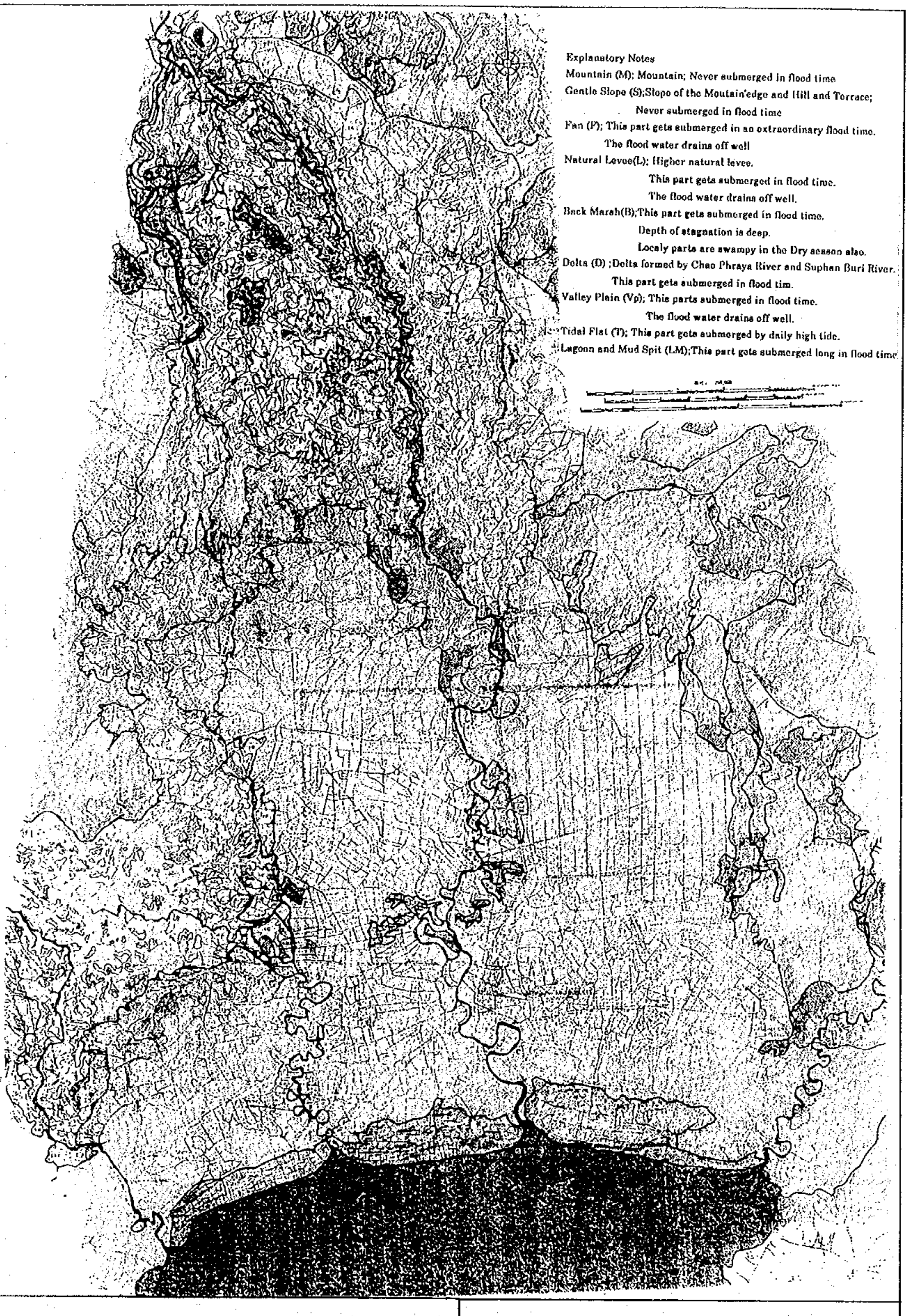
STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN

CTI ENGINEERING CO., LTD AND INA CORPORATION

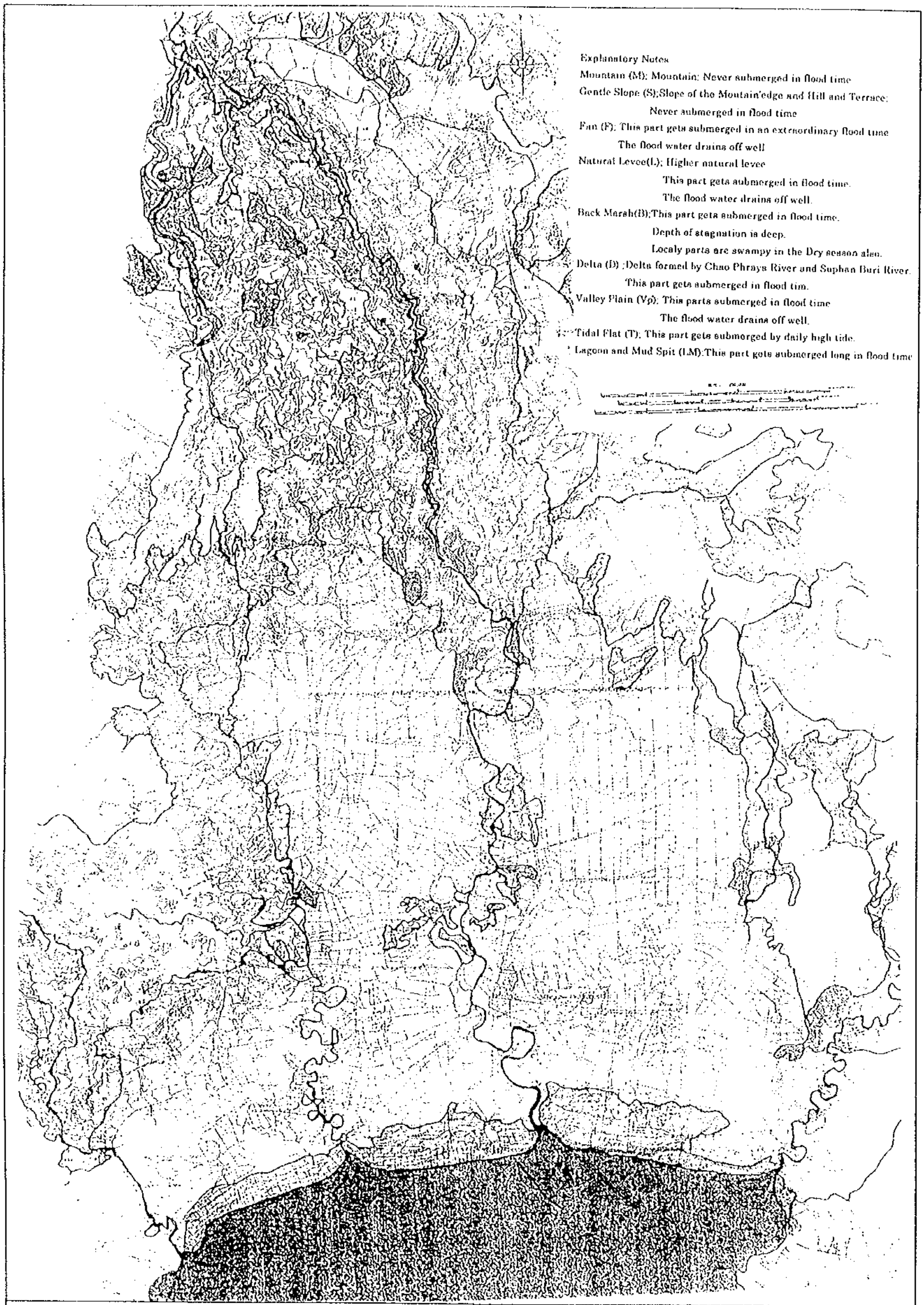
Fig.1.1.4
THE CHAO PHRAYA RIVE BASIN



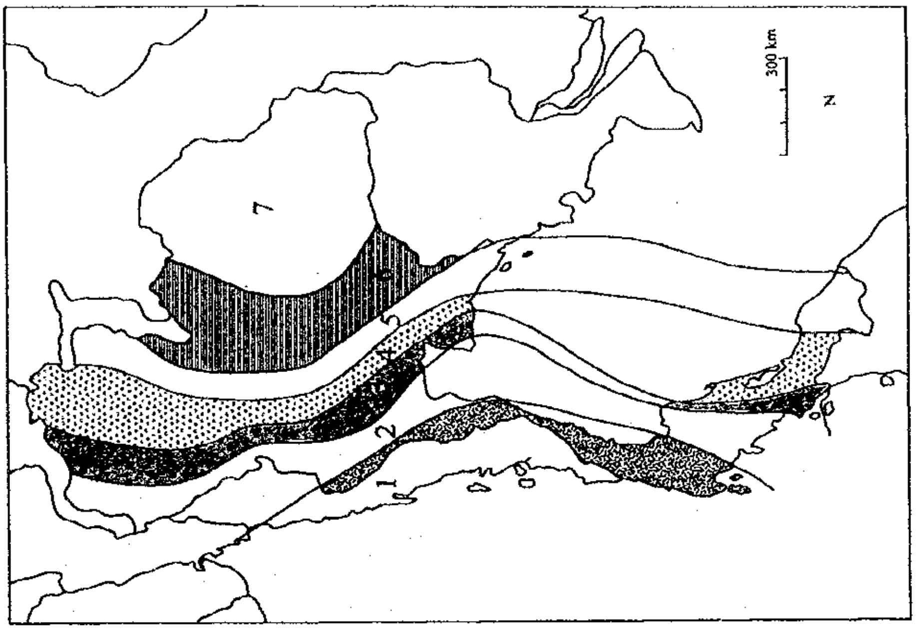
STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.1.1.5 GEOMORPHOLOGICAL LAND CLASSIFICATION MAP FOR FLOOD-INUNDATED OF THE UPPER CENTRAL PLAIN
CTI ENGINEERING CO., LTD AND INA CORPORATION	



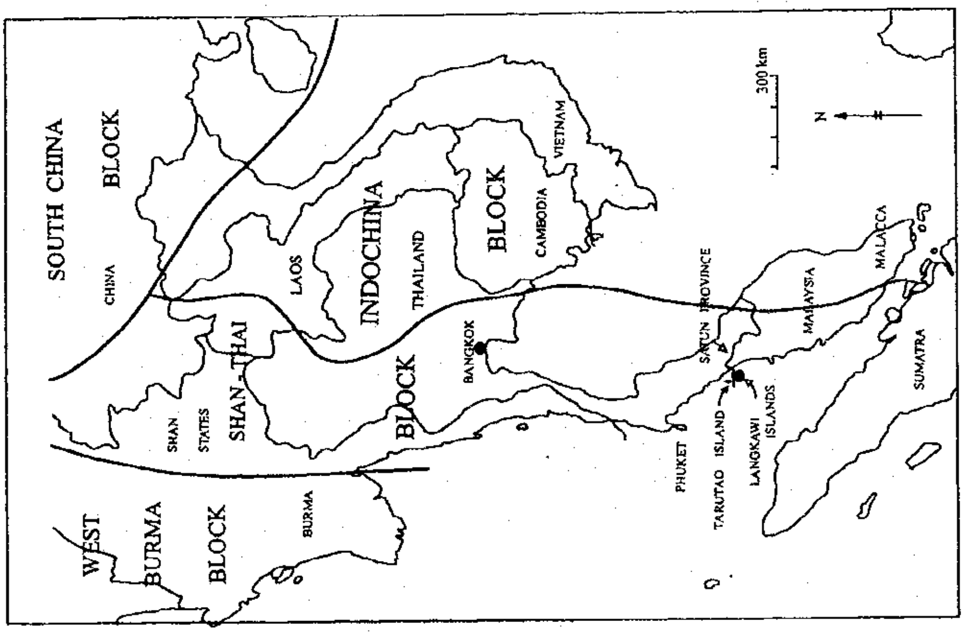
STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.1.1.6 GEOMORPHOLOGICAL LAND CLASSIFICATION MAP FOR FLOOD-INUNDATED OF THE LOWER CENTRAL PLAIN
CTI ENGINEERING CO., LTD AND INA CORPORATION	



STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.1.1.6 GEOMORPHOLOGICAL LAND CLASSIFICATION MAP FOR FLOOD-INUNDATED OF THE LOWER CENTRAL PLAIN
CTI ENGINEERING CO., LTD AND INA CORPORATION	

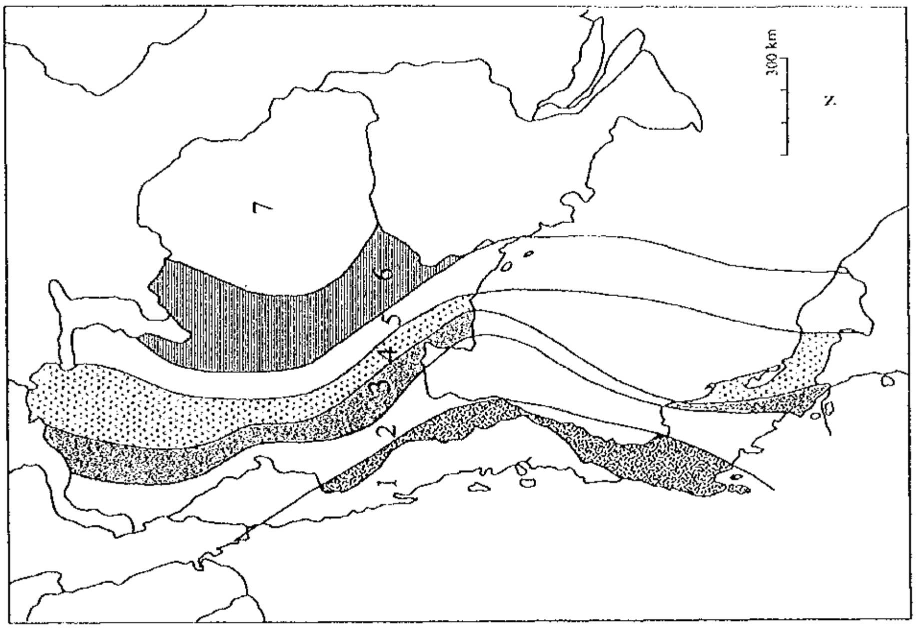


Seven stratigraphic belts of Thailand : 1-5 on Shan-Thai and 6-7 on Indocchina terranes

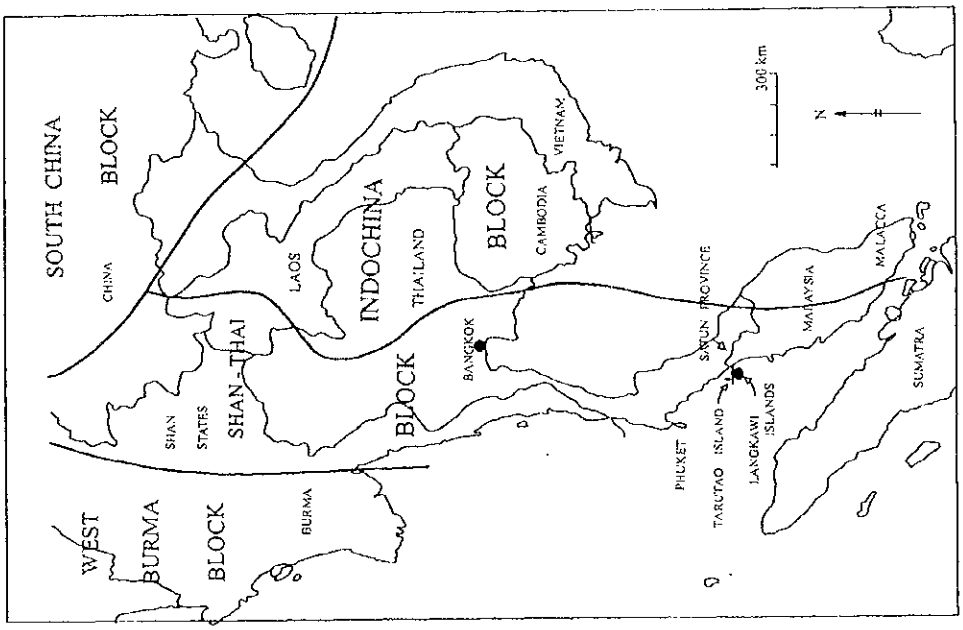


Locality map

STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig .1.2.1 REGIONAL STRATIGRAPHIC UNITS OF THAILAND
CTI ENGINEERING CO., LTD AND INA CORPORATION	

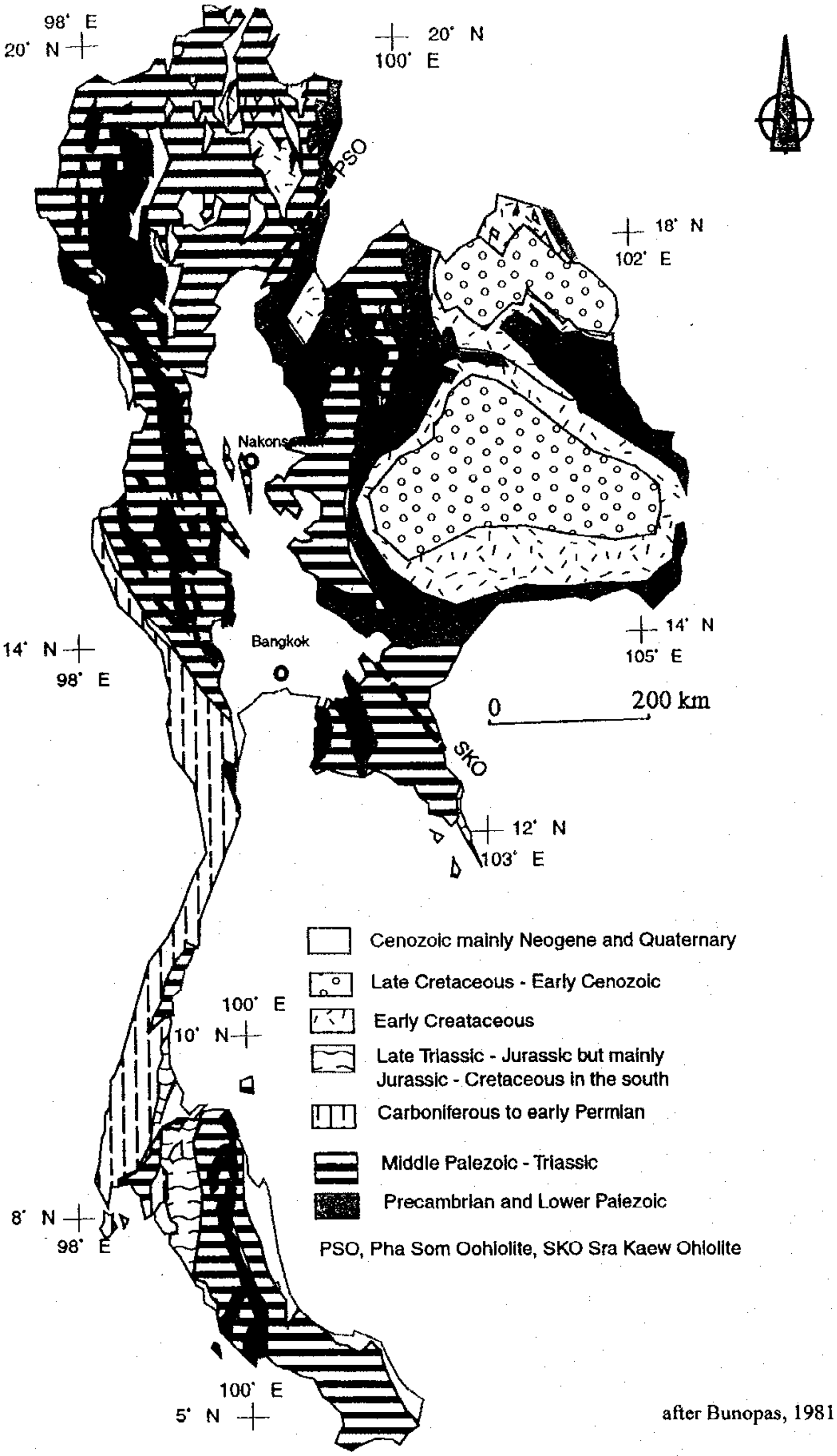


Seven stratigraphic belts of Thailand : 1-5 on Shan-Thai and 6-7 on Indochina terranes

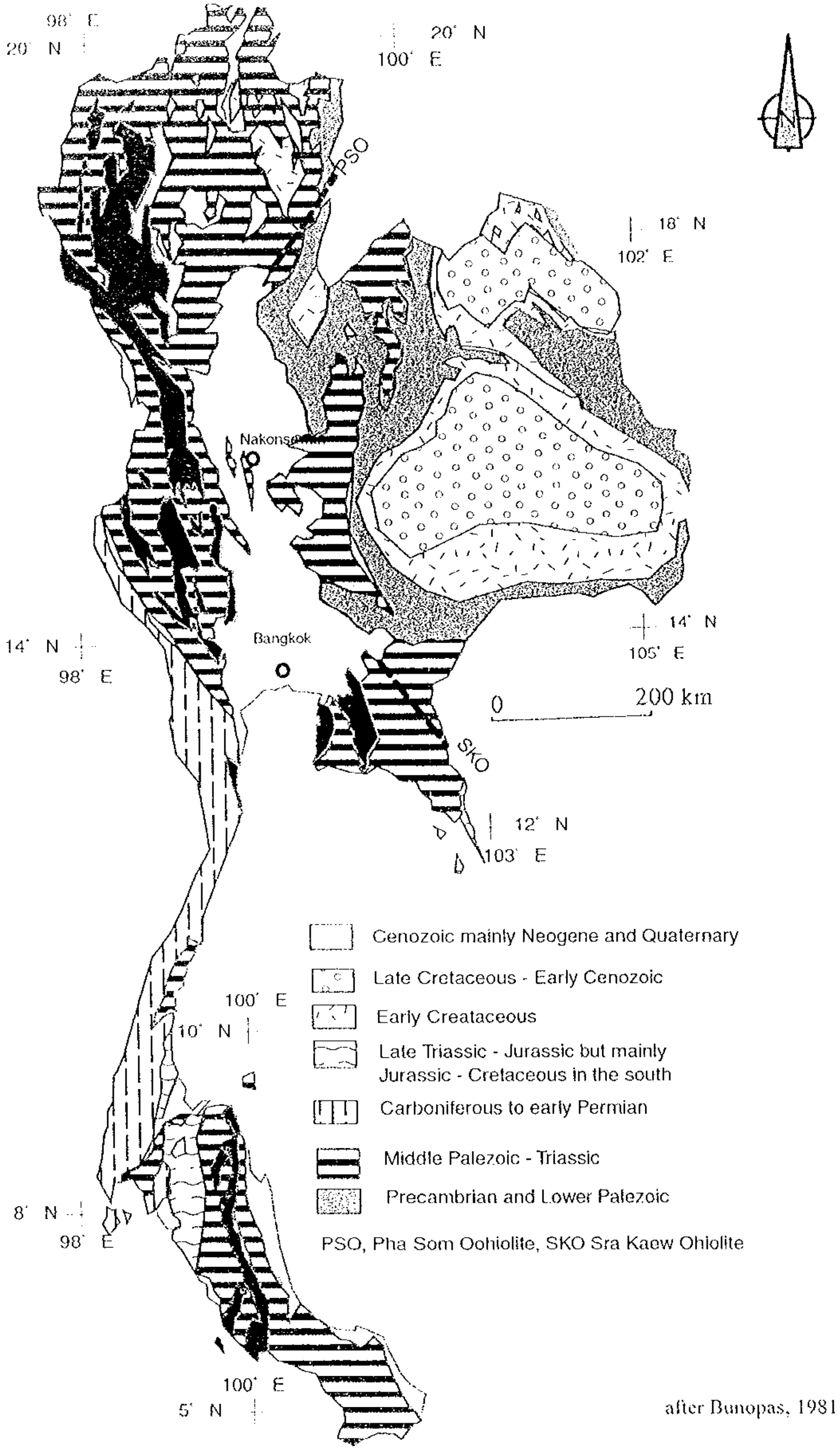


Locality map

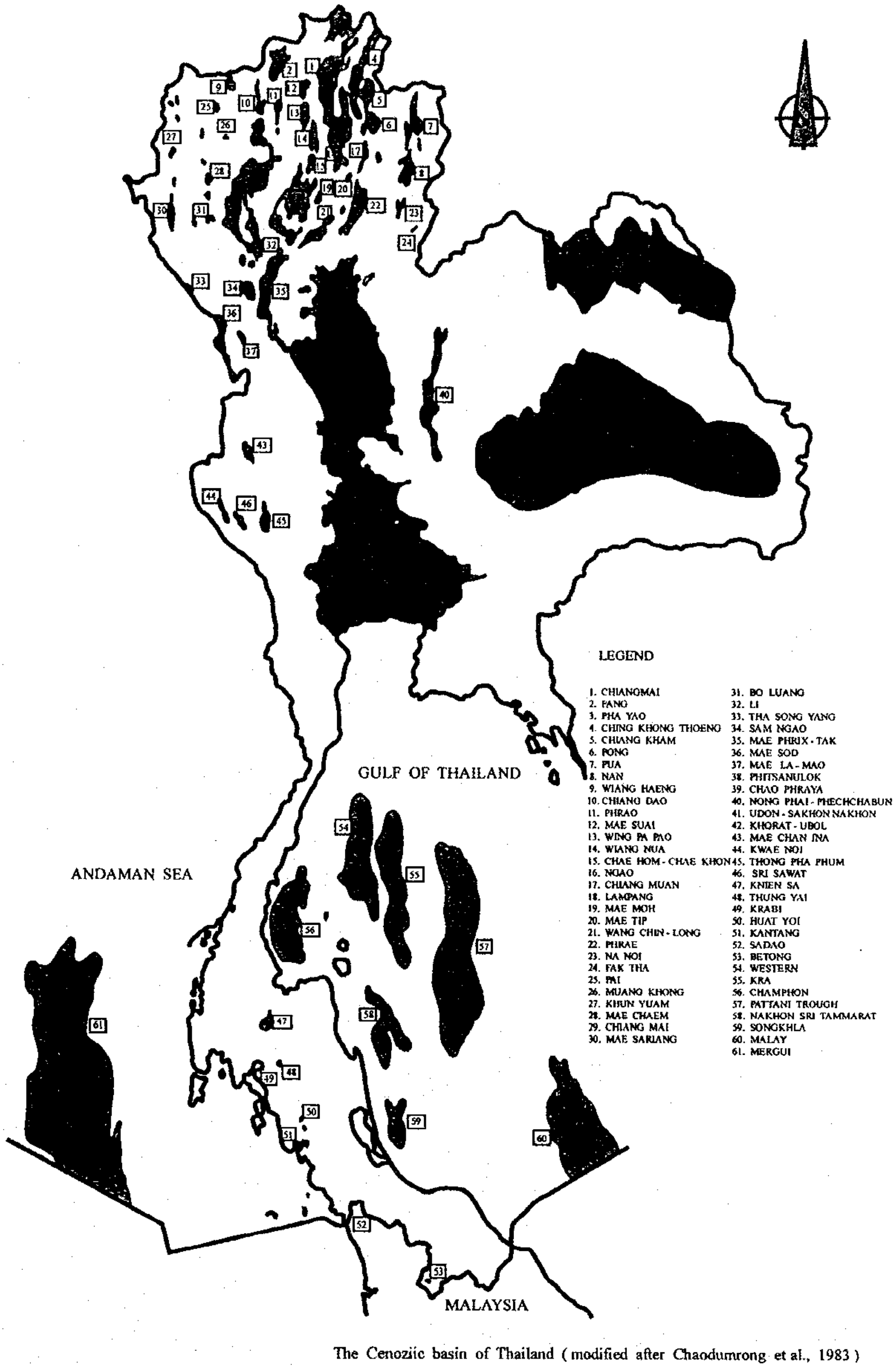
STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig .1.2.1 REGIONAL STRATIGRAPHIC UNITS OF THAILAND
CTI ENGINEERING CO., LTD AND INA CORPORATION	



STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig .1.2.2 REGIONAL GEOLOGICAL MAP
CTI ENGINEERING CO., LTD AND INA CORPORATION	

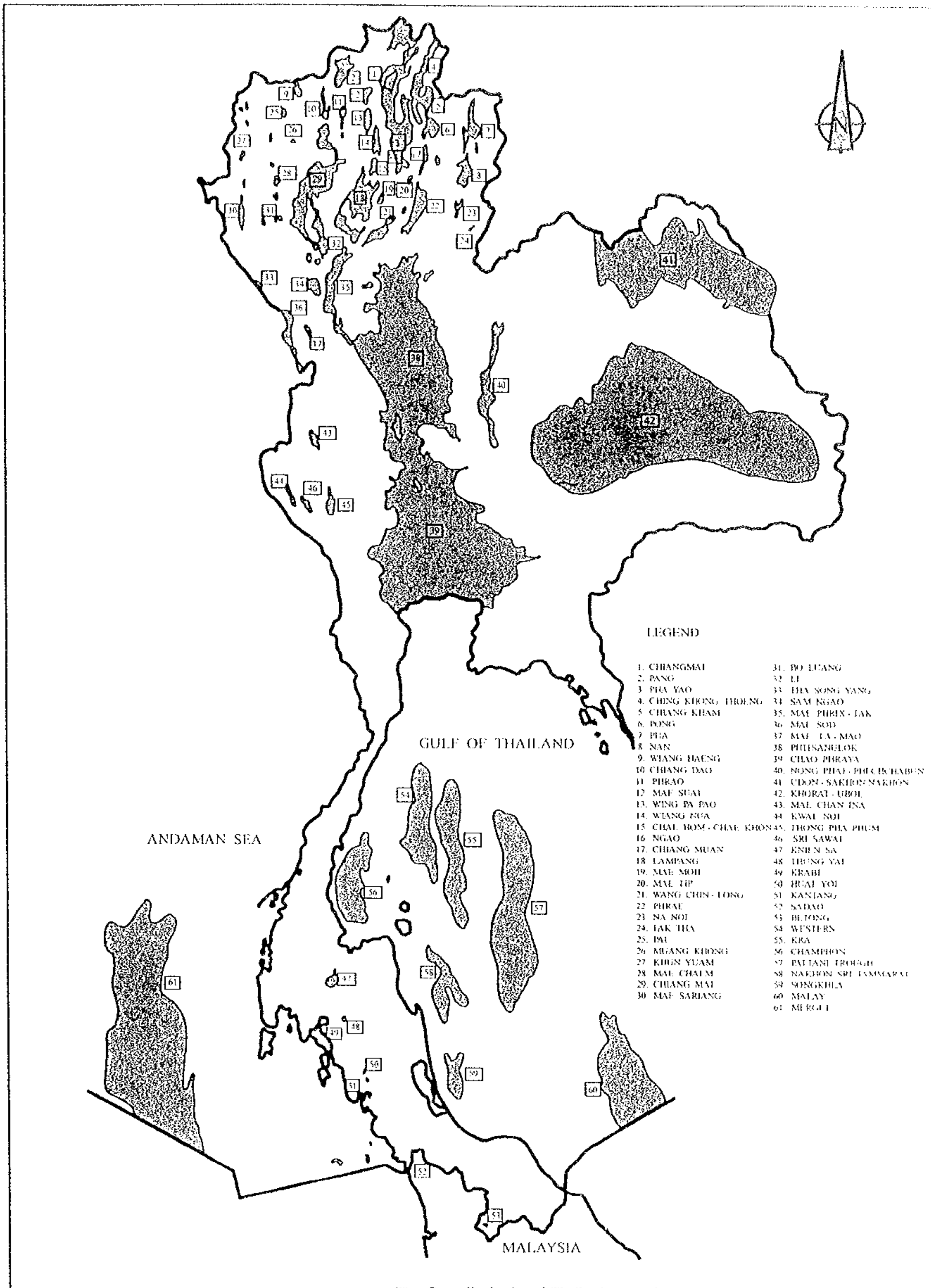


STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig 1.2.2 REGIONAL GEOLOGICAL MAP
CTI ENGINEERING CO., LTD AND INA CORPORATION	



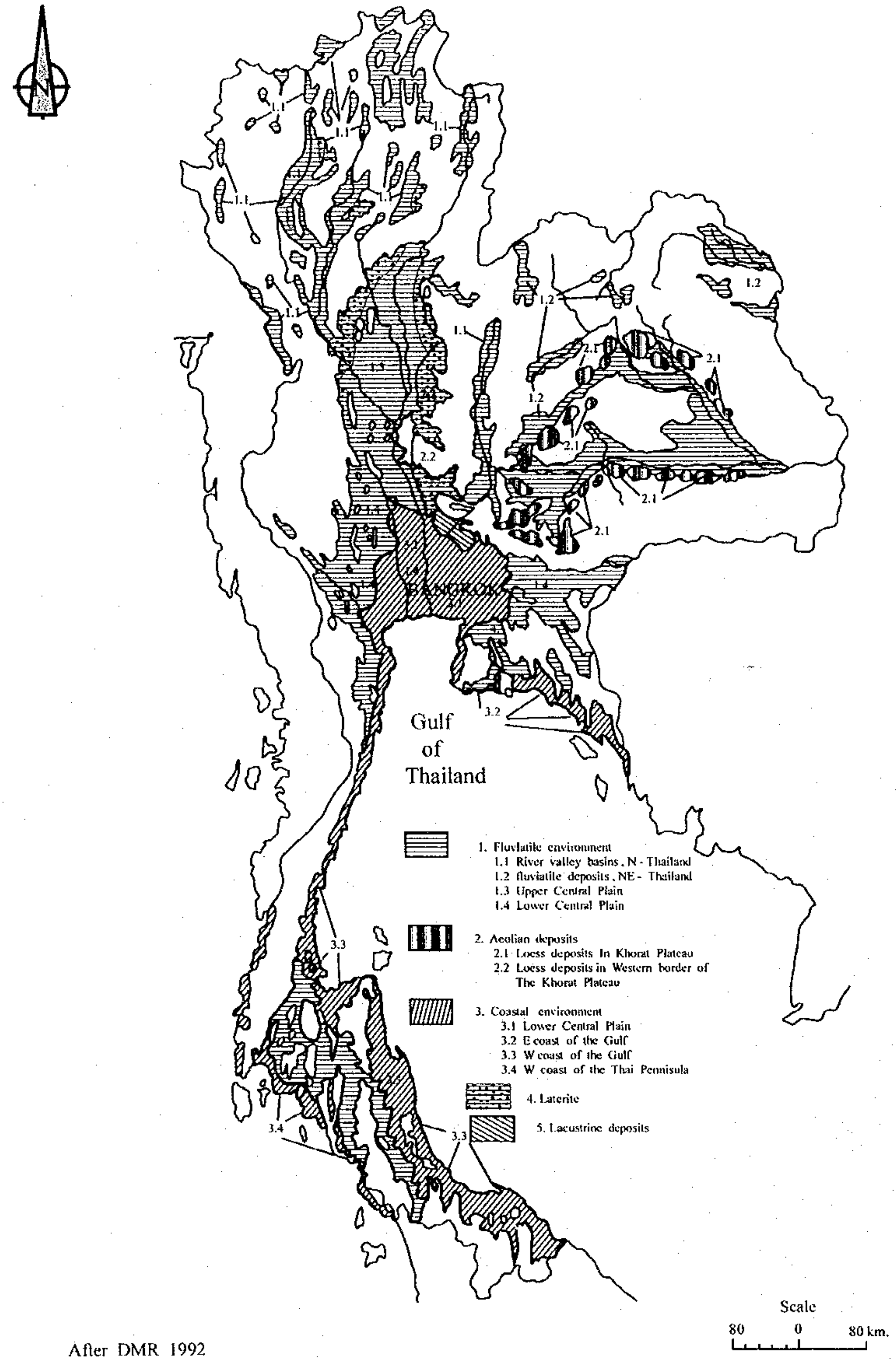
The Cenoziic basin of Thailand (modified after Chaodumrong et al., 1983)

STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig . 1.2.3 THE CENOZOIC BASIN OF THAILAND
CTI ENGINEERING CO., LTD AND INA CORPORATION	



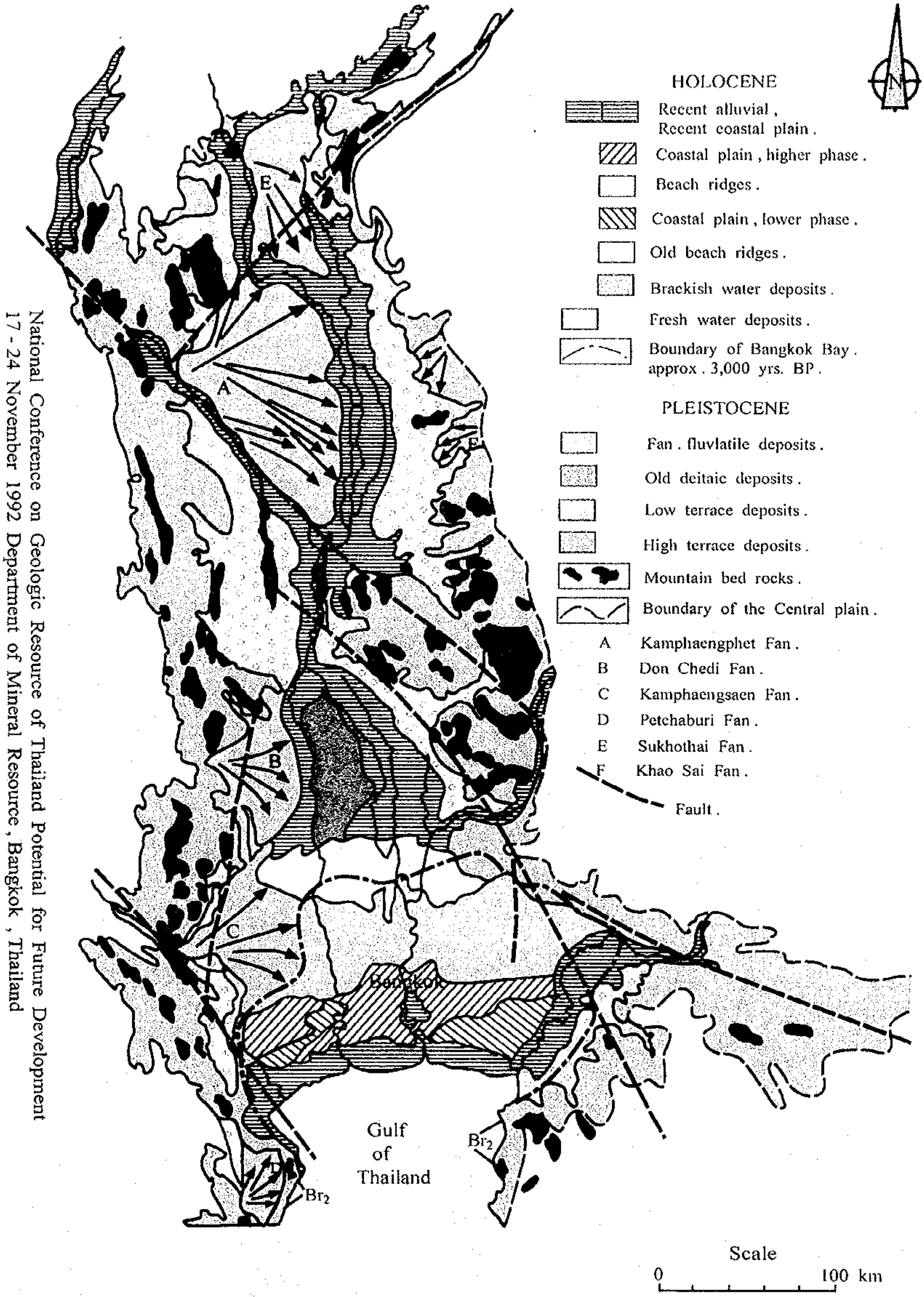
The Cenoziic basin of Thailand (modified after Chaodumrong et al., 1983)

STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig . 1.2.3 THE CENOZOIC BASIN OF THAILAND
CTI ENGINEERING CO., LTD AND INA CORPORATION	



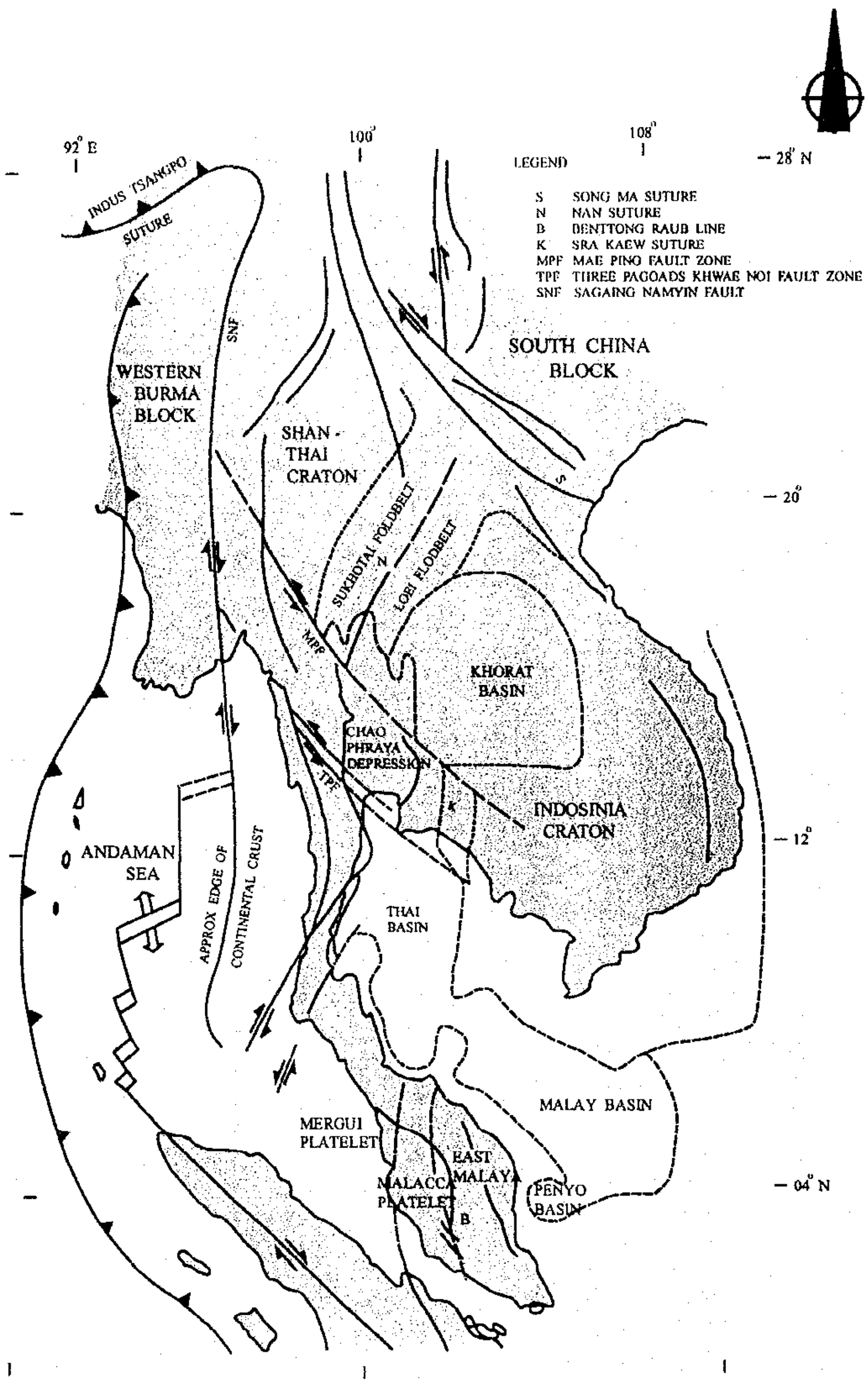
After DMR 1992

STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig . 1.2.4 THE DISTRIBUTION OF QUATERNARY DEPOSITS OF THAILAND
CTI ENGINEERING CO., LTD AND INA CORPORATION	



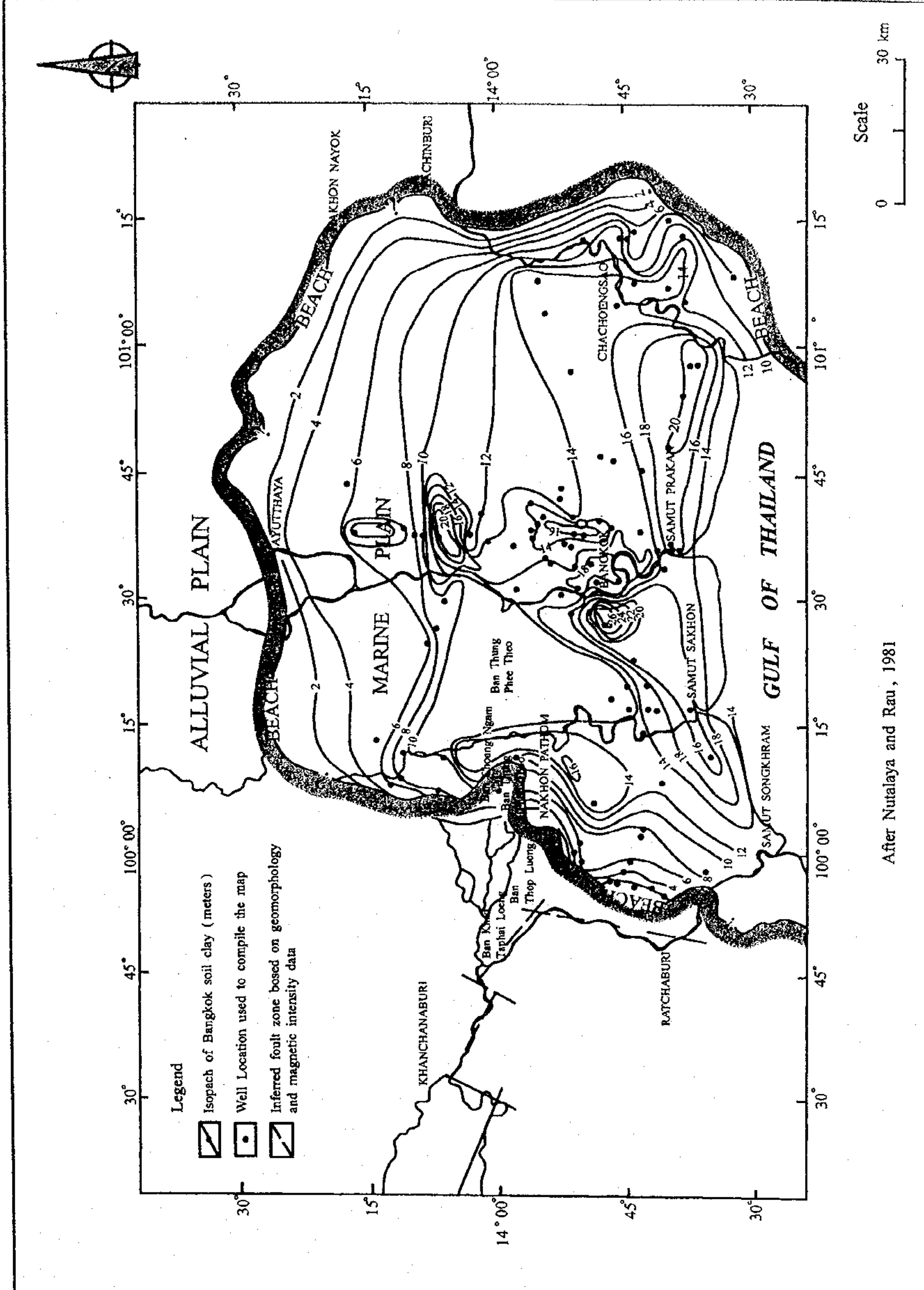
After DMR 1992

STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig. 1.2.5 GENERALIZED SURFICIAL GEOLOGY OF THE CENTRAL PLAIN OF THAILAND
CTI ENGINEERING CO., LTD AND INA CORPORATION	



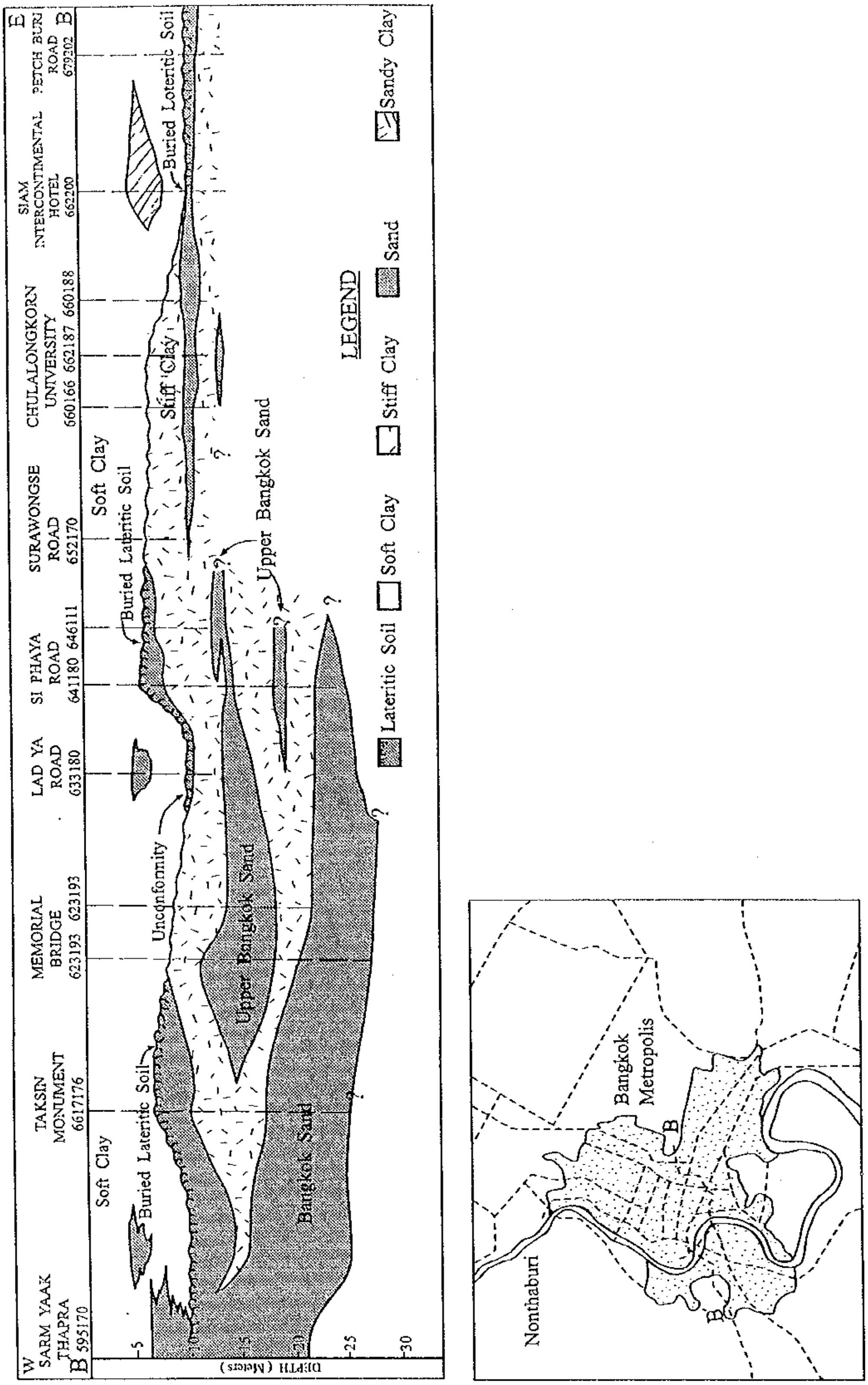
After Bunopas & Vella, 1993

STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig. 1.2.6 MAJOR TECTONIC FEATURES OF CONTINENTAL SOUTHEAST ASIA
CTI ENGINEERING CO., LTD AND INA CORPORATION	



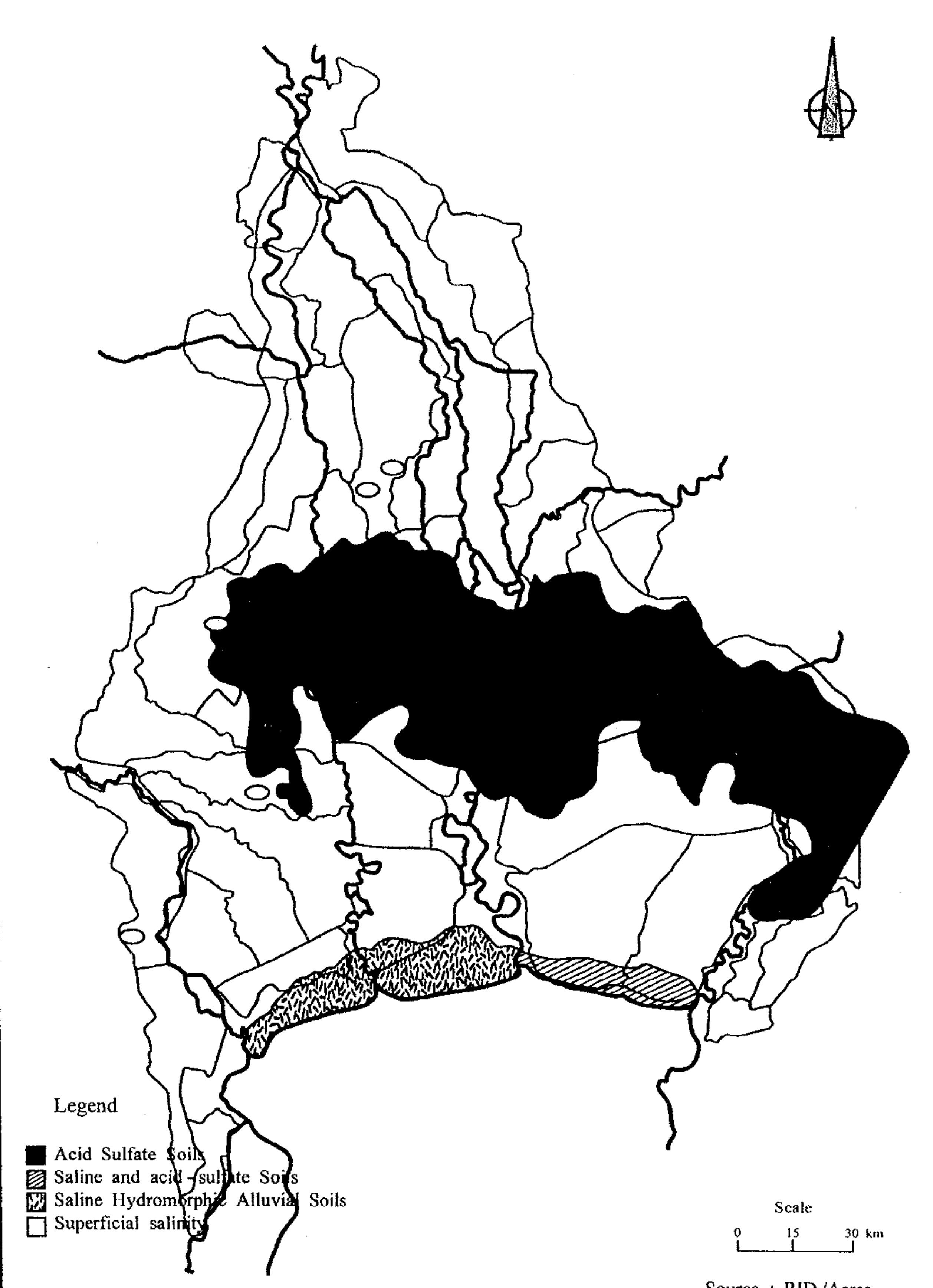
STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig . 1.2.7 MARINE AND ALLUVIAL SEDIMENTS OF THE LOWER CENTRAL PLAIN
CTI ENGINEERING CO., LTD AND INA CORPORATION	

East - west cross section through Bangkok metropolis showing the stratigraphic relations of the upper part of the section



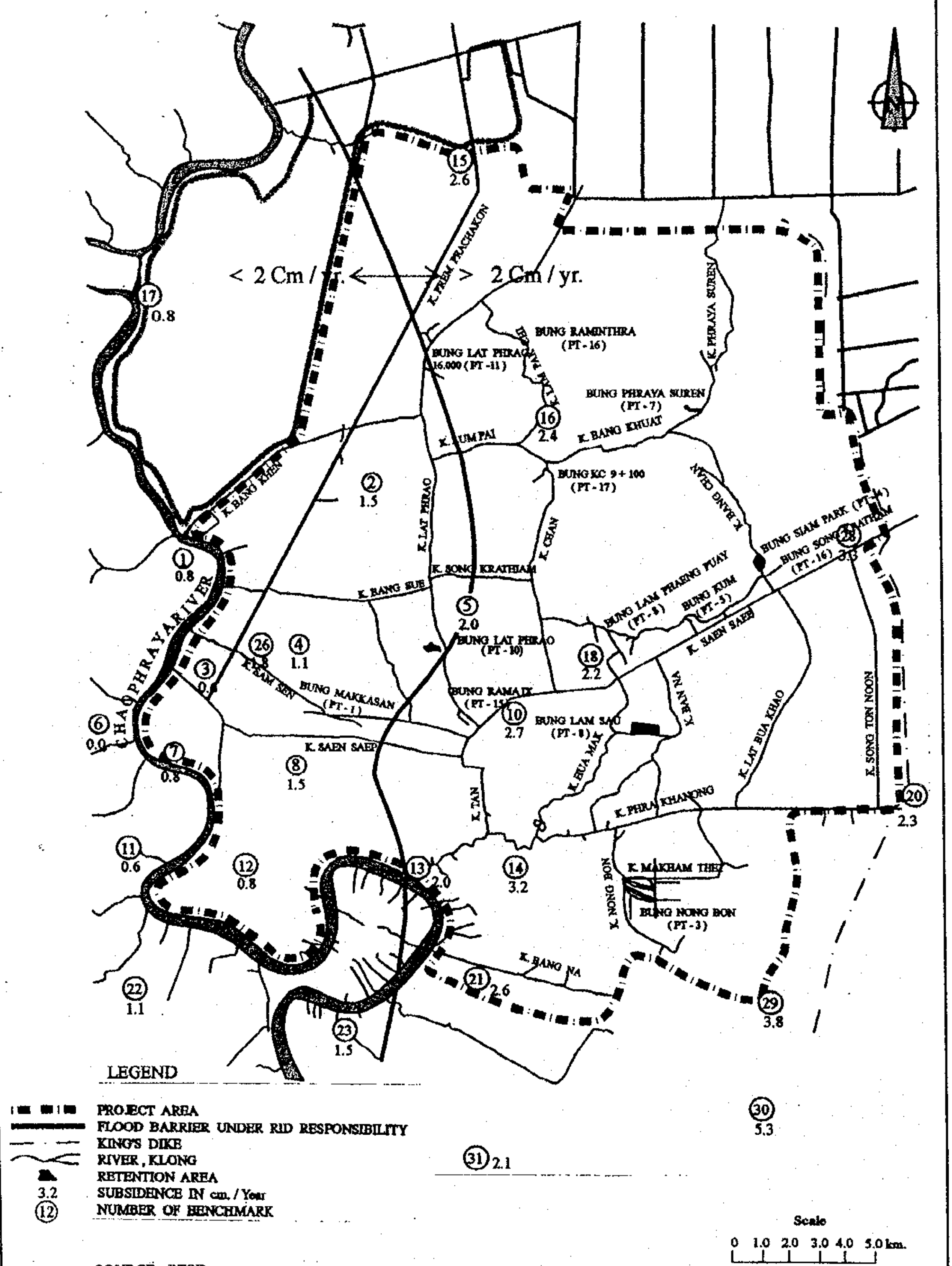
(Source : J.L. Rau et al, 1981)

STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig . 1.2.8 THE STRATIGRAPHIC RELATION OF BANGKOK METROPOLIS
CTI ENGINEERING CO., LTD AND INA CORPORATION	



Source : RID /Acres

STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig . 1.2.9 TAXONOMY OF DEMINANT SOIL SERIES
CTI ENGINEERING CO., LTD AND INA CORPORATION	



SOURCE : RTSD
AFTER : BMA/NEDCO-SPAN-WDC(1996)

STUDY ON INTEGRATED PLAN FOR FLOOD MITIGATION IN CHAO PHRAYA RIVER BASIN	Fig.1.2.10 MAP OF THE EARTHQUAKE EFFECTS IN THAILAND AND ADJACENT AREAS
CTI ENGINEERING CO., LTD AND INA CORPORATION	