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KINGDOM OF THAILAND
MINISTRY OF AGRICULTURE AND COOPERATIVES
ROYAL IRRIGATION DEPARTMENT

FEASIBILITY STUDY ON THE UPPER PASAK MEDIUM SCALE IRRIGATION PROJECT

VOLUME 2.1
ANNEX

I. HYDROLOGY
II. GEOLOGY AND CONSTRUCTION MATERIALS
III. SOILS AND LAND CLASSIFICATION
IV. AGRICULTURE AND AGRO-ECONOMY
V. AGRICULTURAL SUPPORTING SERVICES

MARCH 1983

JAPAN INTERNATIONAL
COOPERATION AGENCY

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ANNEX - VOL. 2.1

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ANNEX I
HYDROLOGY

ANNEX - I

HYDROLOGY

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ANNEX - I

HYDROLOGY

1. DATA AVAILABLE

1.1 Rainfall Data

The rain gauging stations in the Upper Pasak river valley are located at Ban Nong Bua, Ban Dan Sai, Ban Dan Du, Ban Sila, Kaeng Sida, Lom Sak and Phetchabun as shown in Fig. I-1. The Ban Nong Bua, Ban Dan Sai, Ban Dan Du, Ban Sila and Kaeng Sida stations have been operated by the National Energy Administration (NEA), and the Lom Sak and Phetchabun stations have been operated by the Meteorological Department (MD) under Ministry of Communications. Observation period for each station is as follows:

Station	Observation Period (Year)
Ban Nong Bua	11 (1967 - 1977)
Ban Dan Sai	11 (1967 - 1977)
Ban Dan Du	15 (1963 - 1977)
Ban Sila	16 (1963 - 1978)
Kaeng Sida	16 (1963 - 1978)
Lom Sak	30 (1951 - 1980)
Phetchabun	26 (1956 - 1981)

The rainfall records collected in these stations are compiled in the Data Book.

1.2 Meteorological Data

As meteorological data other than rainfall are observed at only the Phetchabun Meteorological Station, the data observed here is applied for the hydrological analysis in this study. The station is located at the Phetchabun Municipality 16°26' north in latitude and 101°09' east in longitude and provides records on temperature, relative humidity, dew point, evaporation, cloudiness, wind velocity, and sunshine duration. The meteorological data recorded in this station are as given in Table I-1.

1.3 Runoff Data

There exist three water gauging stations in the Upper Pasak river valley as given in Fig. I-1. Among them, the Kaeng Sida gauging station covering the drainage area of about 836 km^2 has been operated by NEA since 1964. The gauging station at the weir of the Pasak Left Bank irrigation project covering the drainage area of about 1,007 km^2 has been operated by RID since 1971 and, the gauging station at the Nam Phung Bridge covering the drainage area of about 268 km^2 was commenced its operation by RID in 1966, but has been intermitted since 1973. The monthly runoffs recorded at these gauging stations are shown in the Data Book.

2. INSTALLATION OF GAUGING STAFFS

2.1 Objectives

No water gauging staff has been installed so far and no runoff data is available in all the watersheds of relevant tributaries. The runoff data in these watersheds should be urgently collected by water gauging for the detailed design works and project operation studies to be carried out in near future.

2.2 Selection of Gauging Site

The gauging site newly installed in the relevant tributaries should fulfil the following conditions:

i) Easy accessibility to site

ii) Stable channel section at site

iii) Linear channel reach in the vicinity of site

The site should be selected in the vicinity of abode of village people for the special convenience of daily observation and should be readily accessible even during flooding season. Channel section of each tributary is likely to be changeable due to scouring or depositing caused by intensive floods. To avoid habitual modification of rating curve, a site of stable channel section would be possibly selected for gauging. Meandering reach in the vicinity of gauging site is also unfavourable for water gauging in hydraulic viewpoint. A site of linear river channel should be selected for water gauging as far as possible. The location selected for each tributary is as roughly sketched in Fig. I-2.

3. WATER RESOURCES

3.1 Major Water Sources

Four proposed sub-projects depend their water resources on the tributaries of the Pasak river. These water sources originate in the eastern hilly ranges of the Pasak river valley and flow in the Pasak river at its left bank respectively. The river channels and drainage areas of these water sources are tabulated as below:

	Water Sources	Drainage Area (km^2)	Channel Length (km) up to Dam Site
i)	Huai Saduang Yai	96	29
ii)	Huai Khon Kaen	322	53
iii)	Huai Yai	75	22
iv)	Khlong Chaliang Lab	77	26

The watershed of each water source is illustrated in Fig. I-3.

3.2 Estimate of Runoff

3.2.1 Runoff Coefficient

Monthly runoff of each tributary is estimated multiplying monthly rainfall by an authorized runoff coefficient, since no runoff data is available in each tributary at this moment. As shown in Fig. I-4, relation between monthly rainfall and monthly runoff coefficient under various watershed condition has been developed by RID and applied for runoff estimate of various river basins. Five lines have been developed in the chart (Fig. I-4) according to terrain condition. In the light of the watershed condition in each tributary, the line-B and the line-C are eligible for the estimate of runoff.

In order to assess the adoptability of the line-B or line-C for the runoff estimation on each tributary, a comparative study is made between the actually measured monthly runoff at the Kaeng Sida station and the monthly runoffs estimated by multiplying the coefficients obtained from the line-B and the line-C by the rainfalls arranged by the Thiesen Method (Fig. I-5), for which the rainfalls observed at five stations; Ban Nong Bua, Dan Sai, Ban Dan Du, Ban Sila and Kaeng Sida, are used (Fig. I-6). The comparison of annual runoff coefficient is also made between the actually measured runoff and the estimated runoffs as shown in Table I-2.

From the above study, it can be concluded that the runoff estimated using the line-C is more close to the actually measured runoff than that estimated using the line-B. In the estimation of runoffs for the Huai Saduang Yai, Huai Khon Kaen, Huai Yai and Khlong Chaliang Lab, therefore, the line-C can be applied within the acceptable range.

3.2.2 Estimate of Monthly Runoff

Monthly rainfall record at the Lom Sak rainfall station is applied for the estimate or runoff in the Huai Saduang Yai and the Huai Khon Kaen watersheds, and the record at the Phetchabun rainfall station is applied for the estimate of runoff in the Huai Yai and the Khlong Chaliang Lab watersheds. As attached to Data Book, monthly runoff of each watershed is computed by multiplying monthly rainfalls by the runoff coefficient obtained from the line-C converting the rainfall depth (mm) into discharge (cms). The computed runoffs are as shown in Fig. I-7 and summarized in Table I-3.

As given in Table I-3, the annual runoff coefficient averages 22.7% for the Lom Sak area and 24.4% for the Phetchabun area on the basis of the coefficient estimated for recent 17 years. The annual yield averages 7.4 ℓ/s/km^2 for the Lom Sak area and 8.4 ℓ/s/km^2 for the Phetchabun area on the yield estimated for the same period. These annual yields are completely enclosed by the lines of 5 ℓ/s/km^2 and 10 ℓ/s/km^2 in the average runoff yield map recently developed by RID (Fig. I-8). Therefore, the estimated runoff for the relevant watersheds is techanically reasonable. It is thus testified that the line-C is applicable for the runoff estimate of the relevant four watersheds.

4. INVESTIGATION ON SIDE FLOW

4.1 Objectives

Numerious ephemeral streams traverse the relevant service areas. Some of them have been intermittently used for irrigation water sources during the rainy season. The water resources endowed in these streams should be incorporated in the irrigation development plan to supplement the limited water resources in the relevant tributaries, if these water resources are fully stable throughout the rainy season. In order to clarify the dependability of the water resources in these streams, hydrological investigation is made on the selected streams.

4.2 Selected Side Flow

In the Lom Sak area, exploitable water resources are relatively abundant as compared with land resources suitable for irrigated agriculture. No supplemental water resources would be required in this area for the time being. Thus, the side flow investigation is concentrated in the Phetchabun area.

Four outstanding side-flow streams are picked out for the investigation. The locations of these streams and their watersheds are illustrated in Fig. I-9. The features of these streams are as summarized below.

	Drainage Area (km^2)	River Length Flow Origin (km^2)	Average River Slop (%)
Huai Nam Lao	38	19	5.0
Khlong Nam Pom	15	11	5.5
Huai Nam Pong	19	11	7.5
Huai Pa Hom	4	3.5	14.5

These four side-flow streams originate in the eastern hilly ranges, flowing down westward across both service areas in Phetchabun area, almost in parallel with the Huai Yai and the Khlong Chaliang Lab, and they are finally disappeared in the paddy fields.

The Huai Nam Lao and the Khlong Nam Pom are blessed with relatively stable water resources during limited rainy season. The water resources in these streams have been led to small area of paddy field by constructing wooden and cobble weirs across the channel. While, the Huai Nam Pong and Huai Pa Hom are extremely depleted, even during the rainy season. The water resources in these streams have been abandoned so far due to negligible small amount of discharge.

In the course of the field investigation, discharge and the cross and longitudinal sections were measured at the runoff sites of these four side-flow streams, which are located near the respective service areas. The discharges measured in respective streams are as small as less than 20 ℓ/sec even immediately after rainfall. The maximum channel capacities of these side-flow streams are estimated to be ranging from 0.7 m^3/sec to 1.5 m^3/sec.

4.3 Assessment of Dependable Water Resources

The Huai Nam Lao and Khlong Nam Pon among the four selected side-flow streams are relatively dependable for irrigation water sources. In fact, the water resources in Huai Nam Lao have been exploited by farmer themselves by constructing humble weir at its middle reach.

The anticipated runoffs from the Huai Nam Lao and Khlong Nam Pom are respectively estimated by the same procedures applied for the runoff estimate of the tributaries. In the procedures, the line for terrain D is picked out in due consideration of the existing watershed condition of the side-flow streams. The results of calculations are compiled in Data Book and summarized in Table I-4.

If the above-estimated runoff is totally used for irrigation by constructing a dam, it would be possible to irrigate about 400 ha in case of the Huai Nam Lao and 500 ha in case of the Khlong Nam Pom respectively, though their economic feasibility seems not so high. Further detailed study on their economic viability is required before the final conclusion for the development is drawn.

5. FLOOD

5.1 Concentration Time

The length and average slope of the main reach of each tributary are measured on the contour map of 1/50,000 scale. For estimation of the concentration time, U.S. Navy and Nemec have developed empirical formulas as shown in Table I-5. The concentration time of each proposed dam site is estimated by applying the above formulas as shown in the following table.

River Basin	River Length (km)	Basin Slope (%)	Average V (m/s) U.S. Navy	Average V (m/s) Nemec	Concentration Time (hr)
Huai Saduang Yai	28.5	5.1	1.22	1.2	7.0
Huai Khon Kaen	52.7	1.8	0.67	0.7	22.0
Huai Yai	21.5	4.7	1.17	1.2	5.5
Khlong Chaliang Lab	26.4	4.4	1.13	1.2	6.5

While, Snyder has developed an empirical formula for the estimation of concentration time as follows:

$$Tc = tp + tr/2$$

where, Tc: Concentration time (hr)

tp: Lag time from mid point of effective rainfall duration (tr) to peak of a unit hydrograph (hr)

$$tp = 0.75 \times Ct \cdot (L \cdot Lc)^{0.3}$$

Ct: Suyder's coefficient (= 1.8)

L : River length from the concerning point to the upstream hem line of the drainage area (km)

Lc: River length from the concerning point to center of gravity of the drainage area (km)

tr: Duration of effective rainfall

$$tr = tp/5.5$$

Using this formula, concentration time for each drainage area is estimated as shown in the following table.

	L (km)	Lc (km)	tp (hr)	tr (hr)	Tc (hr)
Huai Saduang Yai	28.5	17.1	8.5	1.5	9.5
Huai Khon Kaen	52.7	28.7	12.0	2.0	13.0
Huai Yai	21.5	11.8	7.0	1.0	7.5
Khlong Chaliang Lab	26.4	16.2	8.0	1.5	8.5

From above two calculation results for concentration time, shorter values are adopted for safety. The adopted values are shown in the following table.

	Tc (hr)	tp (hr)	tr (hr)
Huai Saduang Yai	7.0	6.4	1.0
Huai Khon Kaen	13.0	12.0	2.0
Huai Yai	5.5	5.1	1.0
Khlong Chaliang Lab	6.5	6.3	1.0

5.2 Probable Rainfall

Annual maximum daily and hourly rainfall data picked out from the Lom Sak and Phetchabun rainfall stations are applied for the estimate of probable rainfalls. The probability analysis is made by both Gumbel and Iwai methods. The values estimated by both methods are averaged for storm runoff analysis. The estimated probable rainfalls for the Lom Sak and Phetchabun areas are summarized in Table I-6.

5.3 Rainfall Intensity

Probable rainfall-intensity is analyzed by following formula;

$$In^{24} = Rn^{24} \cdot Bn$$

where, In^{24}: Intensity in N-year return period (mm/day)

Rn^{24}: 1-day rainfall in N-year return period (mm/day)

Bn : Specific coefficient

$$Bn = a'/(t + b)$$

where, a',b: Specific coefficient

$$b = \frac{24 - B'n}{B'n - 1}$$

$$B'n = \frac{R'n \times 24}{Rn^{24}}$$

(R'n: Hourly rainfall in N-year return period)

$$a = b + 24$$

Therefore, $In^{24} = Rn^{24} \cdot Bn = Rn^{24} \cdot (\frac{a'}{t + b})$

$$= \frac{a}{t + b} \quad \text{(mm/day)}$$

The calculation of "In" is given in Table I-7.

5.4 Probable Flood

5.4.1 Unit Hydrograph

Synthesis hydrograph developed by Snyder is applied for the estimate of probable flood.

Peak discharge and runoff duration are obtainable using the following formula:

$$Qp = 0.275\ Cp \cdot A/Tp$$

where, Qp: Peak discharge of unit hydrograph (m^3/sec)

A : Drainage area

Cp: Snyder's coefficient (Cp = 0.69)

Tp: Time lag

$$Tb = 2A/(3.6\ Qp)$$

where, Tb: Runoff duration (hr)

A : Drainage area (km^2)

Qp: Peak discharge (m^3/s)

The dimension and discharge of the developed unit hydrograph are summarized in Tables I-8 and I-9. The each unit hydrograph is illustrated in Fig. I-10.

5.4.2 Design Storm and Effective Rainfall

To estimate probable flood, hyetograph method is applied for the probable design storm. The peak rainfall is critically arranged to occur at 80% of 24 hr or about 19 hr after the commencement of rainfall. The probable rainfall-intensity formula, previously prepared, are used for setup of the hyetograph by each probability. The developed hyetographs are given in Fig. I-10.

Effective rainfall is estimated by the method recommended by USBR. Based on inspection on watershed condition, hydrologic soil condition in each watershed of the tributary is classified into group-B. The land use or cover in each watershed is categorized into woods or farm woodlots. The hydrologic condition for rainfall infiltration in the relevant watershed is assumed to be low. Finally, the runoff cover number (CN) of 66 and 82 are selected for the rainfall of 10-year return period and that of 100-year and 500-year return period respectively, in due consideration of anticipated antecedent moisture conditions. Effective rainfall is estimated using the following formula:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

where, Q: Direct runoff or effective rainfall (in inches)

P: Storm rainfall (in inches)

S: Maximum potential difference between P and Q (in inches) at time of storm's beginning.
2.2 inches corresponding to CN 82, and 5.15 inches corresponding to CN 66.

5.4.3 Base Flow

Base flow for each tributary is statistically estimated by Gumbel method. The minimum daily discharge during flood month is picked out from the runoff data from 1963 to 1977 at Kaeng Sida gauging station. Then yield discharges are estimated as given in Table I-10 by dividing the minimum daily discharge by the drainage area at Kaeng Sida. Probability analysis is made on these yield discharges. Finally, probable base flows at respective tributaries are estimated by multiplying the probable yield discharges by drainage areas at respective dam sites. The estimated results are given in Table I-11.

5.4.4 Probable Flood

Probable flood hydrograph is derived from the unit hydrograph previously prepared, design storm, effective rainfall and base flow. The calculated results are compiled in the Data Book and graphically shown in Fig. I-11. From the above calculation, the peak and specific discharge of each probability are obtained as follows:

	D.A. (km^2)	Peak Discharge (cms)			Specific Discharge (cms/km^2)		
		Return Period (years)			Return Period		
		10	100	500	10	100	500
Huai Saduang Yai	96	161.8	445.7	577.3	1.7	4.6	6.0
Huai Khon Kaen	322	293.6	821.1	1069.9	0.9	2.5	3.3
Huai Yai	75	94.9	289.5	367.6	1.3	3.9	4.9
Khlong Chaliang Lab	77	80.0	244.2	310.1	1.0	3.2	4.0

The peak discharge and yield estimated in the preceding section are cross-checked with the envelop curve for peak discharge and yield prepared by RID for the Central Thai and Upper Pasak (Fig. I-12). In the light of the plotted yield of Kaeng Sida station, the envelop curves are exhibited with the equivalence of 50-year probability. The estimated peak discharge and yield by each probability are compared with the discharge and yield estimated on the envelop curve as given in Table I-12. The peak discharge and yield estimated using the envelop curve are almost equivalent to 50-year probable ones estimated by unitgraph. Thus, the estimated peak discharge and yield for each tributary are fully testified to be technically reasonable.

6. PROBABLE MAXIMUM PRECIPITATION (PMP) AND PROBABLE MAXIMUM FLOOD (PMF)

6.1 Derivation of PMP

The Upper Pasak river basin is located relatively near the Mekhong river basin. Therefore, the method of PMP derivation for the Mekhong river basin developed by the US Corps of Engineers is applicable for the Upper Pasak river basin. In this method, major storm have been analyzed and adjusted by the following factors.

a) Distance from Vietnam coast

b) Latitude

c) Barrier

d) Terrain within the result of the representative PMP for the Mekhong river basin.

Fig. I-13 shows the enveloping depth-area curves for the Vietnam coast derived for the area from 1,000 km^2 to 50,000 km^2. These DA curves are empirically extended to the area less than 1,000 km^2 to apply for the relevant four tributaries basins, as indicated by dotted lines in Fig. I-13.

From the enveloping curves shown in Fig. I-13, 6-hour, 12-hour, 18-hour and 14-hour duration MPPs in the Khon Kaen watershed are obtained, and the adjustment for aerial distribution on the PMPs obtained in the above are made as follows by applying the method developed by the US Corps of Engineers:

Duration	PMPs obtained from enveloping curve (mm)	PMPs after adjustment for aerial distribution (mm)
6 hours	585	433
12 hours	745	596
18 hours	870	722
24 hours	975	819

Based on the aerially distributed PMPs, the PMPs in the first, second, third and the fourth 6-hour durations are calculated as follows:

1st 6 hours;	433 - 0 =	433	(mm)
2nd 6 hours;	596 - 433 =	163	(mm)
3rd 6 hours;	722 - 596 =	126	(mm)
4th 6 hours;	819 - 722 =	97	(mm)

Furthermore, it is recommended in the feasibility study of Upper Pasak Project prepared by Team Consulting Engineers that adjustment factor of 70% should be applied for the estimated PMP for the Upper Pasak river basin in due consideration of rainfall amount caused by the coastal typhoon. The daily PMP is estimated to be 574 mm/day. The same adjustment would be made for the 1st, 2nd, 3rd and 4th highest 6-hr duration rainfall as given below:

1st 6 hr duration	304 mm
2nd "	115 mm
3rd "	86 mm
4th "	69 mm
Daily PMP	574 mm

6.2 Hyetograph of PMP

Since no enveloping curve for one-hour duration is available in Fig. I-13, the hourly rainfall intensity is estimated using the following formula:

$$rt = \frac{R^{24}}{24} \cdot \left(\frac{24}{t}\right)^{k}$$

where, rt : Rainfall intensity at (t) duration

t : Duration

R^{24}: Daily rainfall

k : Constant

The constant "k" in the above formula is obtained to be 0.5415 by applying the maximum hourly rainfall of 134 mm (304 mm ÷ 6 hr), which is almost equivalent to the probable rainfall with 5,000-year return period. Using the above formula, the hourly rainfall intensities in the respective 6-hr durations are calculated, and furthermore each hourly rainfalls thus calculated are arranged in critical side as shown in Table I-13.

6.3 Effective PMP

Effective rainfall is estimated by the USBR method as described in Section 5.4.2. The equation for the estimate of effective rainfall is;

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

where, Q: Effective rainfall (in inches)

P: Storm rainfall (in inches)

S: Maximum potential difference between P and Q (in inches) at beginning of storm rainfall, 2.2 inches corresponding to CN 82

The calculated results are given in Table I-14 and indicated by unhatching in Fig. I-14.

6.4 Probable Maximum Flood (PMF)

Probable Maximum Flood (PMF) is derived from the previously obtained unit hydrograph (see 5.4.1), the hyetograph of PMP and the effective rainfall. The calculated results are compiled in Data Book and the PMF hydrograph is shown in Fig. I-14 together with the PMP. The peak and specific discharge of each probability are summarized as follows:

	Drainage Area (km^2)	Peak Discharge (cms)	Specific Discharge of PMF (cms/km^2)
1. Huai Saduang Yai	96	966.3	10.1
2. Huai Khon Kaen	322	2111.5	6.6
3. Huai Yai	75	843.5	11.2
4. Khlong Chaliang Lab	77	771.9	10.0

7. WATER QUALITY

Sixteen samples comprising twelve from groundwater and four from surface flow are collected in the Pasak Left Bank, Huai Khon Kaen, Huai Yai and Khlong Chaliang Lab service areas, and analyzed in the RID Laboratory as compiled in Data Book. Water quality for irrigation and drinking purposes is evaluated as described below, based on the laboratory analyses and the US Department of Agriculture and Environmental Protection Agency Standards.

7.1 Quality for Irrigation Purpose

Water quality for irrigation use would be mainly evaluated by three factors, such as salinity concentration, sodium concentration and noxious substances. As given in Fig. I-15, US Salinity Laboratory classifies irrigation water into four grades in view of salinity hazard which is assessed by electrical conductivity and sodium hazard which is assessed by sodium adsorption ratio.

The quality analyses of 16 samples are dotted on the classification chart as shown in Fig. I-15. All the samples collected from surface water and half of the samples collected from groundwater are classified into (C_2 - S_1) grade, i.e. medium salinity hazard and low sodium hazard. So far as the surface water resources are concerned in the project area, there exists no limitation for irrigation use. The laboratory analyses also show that the surface water in the project area contains quite low value of boron and bi-carbonate ion in the light of applicability of boron and bi-carbonate ion by USDA as given in Table I-15. The surface water in the project area is unlimitedly applicable for irrigation in view of the boron and bi-carbonate ion concentration as well as in view of the salinity and sodium hazards.

7.2 Quality for Drinking

The water quality for drinking is examined in the light of the laboratory analyses complied in Data Book and the standard and guidelines issued by US Environmental Protection Agency as shown in Table I-16. The surface water available in the service area is evaluated to be unlimitedly potable. But the groundwater endowed in the limited extent of Huai Yai service area indicates relatively high sulphate concentration. The groundwater in this area should be carefully applied for drinking water.

METEOROLOGICAL DATA

Station	PHETCHABUN	Elevation of station above MSL.	117.93 meters
Index Station	48 379	Height of varometer above MSL.	119.24 meters
Latitude	16°26' N.	Height of thermometer above ground	1.40 meters
Longitude	101°09' E.	Height of wind vane above ground	11.43 meters
		Height of raingauge	1.25 meters

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Rainfall (mm)													
(1964 - 1980, Phetchabun)													
Mean	9.3	17.5	34.8	66.6	153.2	143.6	165.4	184.1	216.5	86.7	9.5	3.1	1,090.[illegible]
Max.	66.9	82.1	116.1	185.0	284.4	279.3	314.1	300.1	381.9	179.6	26.9	17.3	-
Min.	0.0	0.0	0.0	0.1	60.0	65.8	19.8	55.9	108.7	17.0	0.0	0.0	-
(1964 - 1980, Lom Sak)													
Mean	7.9	26.1	37.4	57.1	166.4	137.2	134.5	178.2	192.3	74.0	13.0	5.4	1,027.[illegible]
Max.	51.9	79.7	126.0	116.0	313.5	245.3	333.4	350.1	369.6	194.4	54.8	43.9	-
Min.	0.0	0.9	0.0	1.9	68.7	64.0	40.5	96.5	73.2	3.8	0.0	0.0	-
Pressure (+1,000 or 900 mbs.)													
(1953 - 1975)													
Mean	13.50	11.46	09.78	08.09	06.44	05.55	05.91	05.75	07.09	10.28	12.83	13.76	09.19
Ext. Max.	28.84	24.57	23.31	19.05	15.87	13.07	18.90	14.80	15.87	19.07	22.84	24.92	28.84
Ext. Min.	03.70	01.54	99.79	97.85	97.78	95.94	94.37	96.53	94.10	93.89	03.37	02.99	93.89
Mean daily range	5.63	6.01	6.08	5.76	4.97	4.13	3.96	4.08	4.57	4.94	4.78	5.15	5.01
Temperature (°C)													
(1951 - 1975)													
Mean	24.7	27.3	28.2	30.9	29.8	28.7	28.0	27.5	27.4	27.4	26.1	24.5	27.[illegible]
Mean Max.	32.0	34.2	36.2	37.3	35.2	33.0	32.0	31.5	31.8	32.4	31.9	31.3	33.[illegible]
Mean Min.	14.7	17.9	21.0	23.2	24.0	23.8	23.4	23.4	23.3	22.0	18.8	15.5	21.0
Ext. Max.	38.9	39.1	40.6	43.0	42.4	40.0	36.5	36.7	36.3	36.5	36.4	36.0	43 0
Ext. Min.	2.0	9.5	11.0	13.5	20.7	21.4	20.6	21.0	18.3	15.4	7.5	5.1	2.0
Relative Humidity (%)													
(1951 - 1975)													
Mean	62.0	60.0	60.0	62.0	72.0	78.0	81.0	83.0	84.0	78.0	71.0	64.0	71.0
Mean Max.	91.0	88.7	87.5	87.0	91.7	94.2	95.3	96.2	96.7	95.3	92.8	92.3	92.4
Mean Min.	41.6	39.7	40.3	42.5	55.1	64.3	67.5	70.3	70.1	61.7	52.4	44.3	54.[illegible]
Ext. Min.	16.0	17.0	19.0	21.0	29.0	40.0	46.0	46.0	41.0	35.0	19.0	17.0	16.[illegible]
Dew Point (°C)													
(1951 - 1975)													
Mean	16.0	17.8	20.2	22.0	23.8	24.3	24.2	24.2	24.3	23.0	20.0	16.6	21.4
Evaporation (mm)													
(1957 - 1975)													
Mean-Piché	92.4	95.9	117.5	115.7	82.3	58.1	49.7	42.3	36.7	51.0	66.2	82.1	889.9
Cloudiness (0 - 8)													
(1951 - 1975)													
Mean	3.0	3.2	3.4	4.0	5.9	6.9	7.1	7.3	6.9	5.2	3.9	3.0	5.6
Wind (Knots)													
(1951 - 1975)													
Prevailing Wind	N	S	S	S	S	S	S	S	S	N	N	N	-
Mean Wind Speed	3.6	3.5	4.1	4.6	4.2	4.4	4.4	4.2	3.2	3.7	4.1	4.1	-
Max. Wind Speed	18N,NW	30SW	50N	46N	45S,W	22S	24S	22S	20S	25NE	20N	18N	-
Sunshine Duration													
(1976 - 1981)													
Mean	8.00	7.44	7.99	7.92	6.62	4.98	4.28	3.45	4.22	6.89	8.54	8.24	6.54
Number of Days with													
(1951 - 1975)													
Haze	17.4	21.6	23.1	13.8	1.2	0.7	0.1	0.3	0.6	3.6	7.0	11.5	100.9
Fog	10.6	8.6	5.2	2.9	0.8	0.6	0.8	1.2	2.3	6.6	8.1	8.7	56.4
Hail	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Thunderstorm	0.5	1.4	5.6	11.4	13.4	6.9	5.6	5.9	7.8	6.4	1.3	0.1	66.3
Squall	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

COMPARISON OF OBSERVED RUNOFF COEFFICIENT
WITH ESTIMATED RUNOFF COEFFICIENT AT KAENG SIDA

Water Year	Ovserved Runoff Co. (%)	Estimated Runoff Co. (%)	
		Terrain B	Terrain C
1964	23.2	34.3	30.0
1965	22.8	32.7	28.4
1966	20.4	38.6	34.4
1967	12.6	37.0	32.8
1968	14.3	27.0	22.7
1969	22.1	27.4	23.2
1970	25.0	33.7	29.5
1971	21.4	23.5	19.3
1972	16.8	24.1	19.9
1973	14.9	24.4	20.2
1974	10.3	29.8	25.6
1975	25.4	28.3	24.1
1976	24.6	32.0	27.8
1977	25.1	31.4	27.2
Average	19.5	30.7	26.5

TABLE I-3

SUMMARY OF ANNUAL RUNOFF

	Huai Saduang Yai & Huai Khon Kaen				Huai Yai & Khlong Chaliang Lab			
Water Year	Annual Rainfall (mm)	Annual Runoff (mm)	Runoff Coefficient (%)	Average Yield of Runoff ($\ell/s/km^2$)	Annual Rainfall (mm)	Annual Runoff (mm)	Runoff Coefficient (%)	Average Yield of Runoff ($\ell/s/km^2$)
1,964	1,333.4	368.8	27.7	11.7	1,618.6	534.1	33.0	16.9
65	1,032.0	225.1	21.8	7.1	1,011.3	229.4	22.7	7.3
66	861.7	223.4	25.9	7.1	1,138.9	295.4	25.9	9.4
67	915.6	215.0	23.5	6.8	1,048.6	232.7	22.2	7.4
68	1,048.1	233.7	22.3	7.4	1,080.3	204.4	18.9	6.5
69	934.8	210.9	22.6	6.7	1,105.5	275.7	24.9	8.7
70	1,041.8	241.9	23.2	7.7	1,304.4	357.6	27.4	11.3
71	978.5	199.2	20.4	6.3	886.1	160.4	18.1	5.1
72	925.6	174.0	18.8	5.5	1,031.0	207.1	20.1	6.5
73	792.0	121.9	15.4	3.9	1,012.5	272.0	26.9	8.6
74	1,096.3	181.8	16.6	5.8	979.7	153.8	15.7	4.9
75	1,000.2	197.2	19.7	6.3	927.0	194.9	21.0	6.2
76	1,196.2	285.4	23.9	9.0	1,418.3	463.2	32.7	14.6
77	834.7	134.9	16.2	4.3	947.2	181.5	19.2	5.8
78	1,293.7	445.1	34.4	14.1	1,299.2	419.5	32.3	13.3
79	963.9	172.8	17.9	5.5	731.5	111.5	15.2	3.5
80	1,224.5	333.0	27.2	10.5	994.3	225.3	22.7	7.1
Average	1,027.8	233.2	22.7	7.4	1,090.3	265.8	24.4	8.4

DEPENDABLE WATER RESOURCES OF TRIBUTARIES

Water Year	Annual Rainfall (mm)	Annual Runoff (mm)	Annual Runoff Huai Nam Lao (10 m)	Annual Runoff Khlong Nam Pom (10 m)	Runoff Coefficient (%)	Average Yield of Runoff (ℓ/s/km)
1964	1,618.6	462.9	5,092	6,943	28.6	14.6
1965	1,011.3	184.9	2,033	2,774	18.3	5.9
1966	1,138.9	246.2	2,708	3,693	21.6	7.8
1967	1,048.6	186.8	2,055	2,802	17.8	5.9
1968	1,080.3	156.3	1,719	2,345	14.5	4.9
1969	1,105.5	226.4	2,490	3,396	20.5	7.2
1970	1,304.4	300.2	3,302	4,503	23.0	9.5
1971	886.1	121.4	1,335	1,821	13.7	3.8
1972	1,031.0	161.9	1,781	2,428	15.7	5.2
1973	1,012.5	228.1	2,509	3,422	22.5	7.2
1974	979.7	110.8	1,219	1,622	11.3	3.5
1975	927.0	154.0	1,694	2,310	16.6	4.9
1976	1,418.3	401.7	4,419	6,026	28.3	12.7
1977	947.2	140.7	1,548	2,111	14.9	4.5
1978	1,299.2	361.8	3,980	5,427	27.8	11.5
1979	731.5	79.4	873	1,191	10.9	2.5
1980	994.3	182.6	2,009	2,739	18.4	5.8
Average	1,090.3	218.0	2,398	3,270	20.0	6.9

AVERAGE VELOCITIES OF FLOW IN THE BASIN FOR CONCENTRATION TIME DERIVATION

U.S. Navy Technical Publication	
Average River Slope (%)	Average Velocity (m/s)
1 - 2	0.61
2 - 4	0.91
4 - 6	1.22
6 - 10	1.52

Engineering Hydrology by J. Nemec					
Character of basin	Flat	Mildly rolling	Hilly	Highlands	Mountains
	Average slope of basin				
	0.5 (%)	3 (%)	5 (%)	10 (%)	30 (%)
	Velocity (m/s)				
Swampy	0.07	0.08	0.3	-	-
Forested	0.12	0.2	0.5	0.8	1.2
Grassy pastures	0.2	0.5	0.8	1.2	2.0
Gently sloping valley	0.4	0.7	1.0	1.6	2.5
Steep valley	-	-	1.2	2.2	4.0
Rocky steep cliffs	-	-	-	3.0	5.0

Source: Engineering Hydrology by J. Nemec

DAILY RAINFALL OF EACH PROBABILITY

Return Period (years)	Station	Gumbel (mm/day)	Iwai (mm/day)	Adopted Rainfall (mm/day)
2	Lom Sak	88.8	89.6	89
	Phetchabun	74.8	75.2	75
5	Lom Sak	128.3	123.2	126
	Phetchabun	100.2	98.6	99
10	Lom Sak	154.5	146.2	150
	Phetchabun	117.1	113.2	115
30	Lom Sak	194.1	181.8	188
	Phetchabun	142.5	134.4	139
50	Lom Sak	212.1	198.4	205
	Phetchabun	154.2	143.8	149
100	Lom Sak	236.5	221.3	229
	Phetchabun	169.8	156.3	163
500	Lom Sak	292.8	276.6	285
	Phetchabun	206.0	184.8	195

HOURLY RAINFALL OF EACH PROBABILITY

Return Period (years)	Station	Gumbel (mm/hr)	Iwai (mm/hr)	Adopted Rainfall (mm/hr)
2	Lom Sak	44.8	44.5	44.7
	Phetchabun	46.9	46.5	46.7
5	Lom Sak	57.9	55.3	56.6
	Phetchabun	65.3	61.5	63.4
10	Lom Sak	66.6	62.4	64.5
	Phetchabun	77.5	71.3	74.4
30	Lom Sak	79.7	72.9	76.3
	Phetchabun	95.9	86.1	91.0
50	Lom Sak	85.7	77.7	81.7
	Phetchabun	104.3	92.8	98.6
100	Lom Sak	93.8	84.2	89.0
	Phetchabun	115.6	102.0	108.8
500	Lom Sak	112.5	99.5	106.0
	Phetchabun	141.8	123.4	132.6

Note: Record length 1970 - 77, 1979 - 80, for Lom Sak St.
1970 - 75, 1977 - 80, for Phetchabun St.

PROBABLE RAINFALL-INTENSITY AT LOM SAK

	Return period (years)					
	5	10	30	50	100	150
Rn^{24}	126	150	188	205	229	285
Rn'	56.6	64.5	76.3	81.7	89.0	106.0
In'=Rn' x 24	1,358.4	1,548.0	1,831.2	1,960.8	2,136.0	2,544.0
$Bn'=In'/Rn^{24}$	10.8	10.3	9.7	9.6	9.3	8.9
b=(24-Bn' x 1)/(Bn'-1)	1.3	1.5	1.6	1.7	1.8	1.9
a'=b+24	25.3	25.5	25.6	25.7	25.8	25.9
Bn=a'/(t+b)	25.3/ (t+1.3)	25.5/ (t+1.5)	25.6/ (t+1.6)	25.7/ (t+1.7)	25.8/ (t+1.8)	25.9/ (t+1.9)
$In=Rn^{24}\cdot Bn=\frac{a}{t+b}$	3,188/ (t+1.3)	3,825/ (t+1.5)	4,813/ (t+1.6)	5,269/ (t+1.7)	5,908/ (t+1.8)	7,382/ (t+1.9)

PROBABLE RAINFALL-INTENSITY AT PHETCHABUN

	Return period (years)					
	5	10	30	50	100	150
Rn^{24}	99	115	139	149	163	195
Rn'	63.4	74.5	91.0	98.6	108.8	132.6
In'=Rn' x 24	1,521.6	1,788.0	2,184.0	2,366.4	2,611.2	3,182.4
$Bn'=In'/Rn^{24}$	15.4	15.5	15.7	15.9	16.0	16.3
b=(24-Bn' x 1)/(Bn'-1)	0.60	0.59	0.56	0.54	0.53	0.50
a'=b+24	24.60	24.59	24.56	24.54	24.53	24.50
Bn=a'/(t+b)	$\frac{24.60}{t+0.60}$	$\frac{24.59}{t+0.59}$	$\frac{24.56}{t+0.56}$	$\frac{24.54}{t+0.54}$	$\frac{24.53}{t+0.53}$	$\frac{24.50}{t+0.50}$
$In^{24}=Rn^{24}\cdot Bn=\frac{a}{t+b}$	$\frac{2,435}{t+0.60}$	$\frac{2,828}{t+0.59}$	$\frac{3,414}{t+0.56}$	$\frac{3,656}{t+0.54}$	$\frac{3,998}{t+0.53}$	$\frac{4,778}{t+0.50}$

TABLE I-8

TABLE I-9

DIMENSION OF UNIT HYDROGRAPH

Area	Huai Sadunag Yai	Huai Khon Kaen	Huai Yai	Khlong Chaliang Lab
Drainage Area: A (km^2)	96	322	75	77
River Length from Origin: L (km)	28.5	52.7	21.5	26.4
River Length from Center of Basin: Lc (km)	17.1	28.7	11.8	16.2
Log Time: Tp (hr)	6.4	12.0	5.1	6.3
Unit Time: Tr (hr)	(1.2) 1.0	(2.2) 2.0	(0.9) 1.0	(1.1) 1.0
Concentration Time: Tc (hr)	7.0	13.0	5.5	6.5
Peak Discharge of Unit Hydrograph: q_p (cms)	2.846	5.092	2.790	2.319
Runoff Duration: Tb (hr)	18.7	35.1	14.9	18.4

DISCHARGE OF UNIT HYDROGRAPH

Huai Saduang Yai		Huai Khon Kaen		Huai Yai		Khlong Chaliang Lab	
Time (hr)	Discharge (cms)	Time (hr)	Discharge (cms)	Time (hr)	Discharge (cms)	Time (hr)	Discharge (cms)
0	0.000	0	0.000	0	0.000	0	0.000
1	0.407	2	0.785	1	0.510	1	0.359
2	0.814	4	1.572	2	1.022	2	0.717
3	1.221	6	2.357	3	1.532	3	1.075
4	1.627	8	3.144	4	2.042	4	1.434
5	2.035	10	3.929	5	2.552	5	1.792
6	2.441	12	4.715	6	2.659	6	2.151
7	2.849	14	4.876	7	2.360	7	2.230
8	2.605	16	4.415	8	2.061	8	2.037
9	2.362	18	3.952	9	1.762	9	1.841
10	2.119	20	2.490	10	1.463	10	1.645
11	1.876	22	3.027	11	1.165	11	1.449
12	1.631	24	2.565	12	0.867	12	1.253
13	1.388	26	2.104	13	0.568	13	1.057
14	1.145	28	1.641	14	0.269	14	0.861
15	0.902	30	1.179	15	0.000	15	0.666
16	0.659	32	0.716			16	0.470
17	0.414	34	0.254			17	0.274
18	0.171	36	0.000			18	0.078
19	0.000					19	0.000

MINIMUM DAILY DISCHARGE DURING FLOOD MONTH AT KAENG SIDA, (1963 - 1977)

D.A. = 836 km^2

Year	Minimum Daily Discharge cms	Yield Discharge $\ell/s/km^2$
1963	9.15	10.9
1964	6.04	7.2
1965	8.97	10.7
1966	6.21	7.4
1967	2.04	2.4
1968	2.15	2.6
1969	5.66	6.8
1970	6.48	7.8
1971	4.34	5.2
1972	4.39	5.3
1973	6.17	7.4
1974	1.40	1.7
1975	2.49	3.0
1976	8.08	9.7
1977	6.40	7.7

PROBABLE BASE FLOW AT EACH DAM SITE

Return Period (year)	Probability Yield Base Flow ($\ell/s/km^2$)	Huai Saduang Yai (96 km^2) (cms)	Huai Khon Kaen (322 km^2) (cms)	Huai Yai (75 km^2) (cms)	Khlong Chaliang Lab (77 km^2) (cms)
2	5.98	0.6	1.9	0.4	0.5
5	9.15	0.9	2.9	0.7	0.7
10	11.26	1.1	3.6	0.8	0.9
30	14.44	1.4	4.6	1.1	1.1
50	15.89	1.5	5.1	1.2	1.2
100	17.85	1.7	5.7	1.3	1.4
500	22.37	2.1	7.2	1.7	1.7

TABLE I-12

CROSS-CHECK OF PEAK DISCHARGE AND YIELD BY ENVELOP CURVES

	Peak Discharge Estimated on Envelop Curve (ms)	Estimated Peak discharge (m^3/s) Return Period (years)			Yield Discharge Estimated on Envelop Curve ($m^3/s/km^2$)	Estimated Peak Yield Discharge ($m^3/s/Km^2$) Return Period (years)		
		10	100	500		10	100	500
Huai Saduang Yai (DA=96 km^2)	260	162	446	577	1.7	1.7	4.6	6.0
Huai Khon Kaen (DA=322 km^2)	673	294	821	1070	1.3	0.9	2.5	3.3
Huai Yai (DA=75 km^2)	214	95	290	368	1.8	1.3	3.9	4.9
Kholong Chaliang Lab (DA=77 km^2)	219	80	244	310	1.8	1.0	3.2	4.0

HOURLY RAINFALL AND ARRANGEMENT

t (hr)	rt in 1 hour (mm)	rt in t hours (mm)	Hourly Rainfall (mm)	Hourly Arranged PMP (mm/hr)	2-Hour Arranged PMP (mm/2hr)
1	133.7	133.7	134	11	
2	91.8	183.7	50	11	22
3	73.7	221.2	38	11	
4	63.1	252.4	31	12	23
5	55.9	279.6	27	12	
6	50.7	304	24	12	24
7	46.6	326.3	23	16	
8	43.4	346.9	22	17	33
9	40.7	366.1	19	18	
10	38.4	384.2	18	19	37
11	36.5	401.4	17	22	
12	34.8	417.7	16	23	45
13	33.3	433.3	16	24	
14	32.0	448.3	15	31	55
15	30.8	462.7	14	50	
16	29.8	476.6	14	134	184
17	28.8	490.1	14	38	
18	27.9	503.1	13	27	65
19	27.1	515.7	12	16	
20	26.4	528.0	12	15	31
21	25.7	539.9	12	14	
22	25.1	551.6	11	14	28
23	24.5	562.9	11	14	
24	23.9	574.0	11	13	27

EFFECTIVE PMP FOR SADUANG YAI, YAI, CHALIANG LAB

Time (hr)	Rainfall Distribution (mm)	Accum. Rainfall (mm)	Accum. Effective Rainfall (mm)	Effective Rainfall (mm)
1	11	11	0.0	0.0
2	11	22	1.8	1.8
3	11	33	6.1	4.4
4	12	45	12.8	6.6
5	12	57	20.6	7.9
6	12	69	29.4	8.8
7	16	85	42.0	12.6
8	17	102	56.2	14.2
9	18	120	71.9	15.7
10	19	139	88.9	17.0
11	22	161	109.1	20.2
12	23	184	130.6	21.5
13	24	208	153.3	22.7
14	31	239	183.0	29.6
15	50	289	231.3	48.4
16	134	423	362.6	131.3
17	38	461	400.1	37.5
18	27	488	426.8	26.7
19	16	504	442.6	15.8
20	15	519	457.5	14.8
21	14	533	471.3	13.9
22	14	547	485.2	13.9
23	14	561	499.1	13.9
24	13	574	512.0	12.9

EFFECTIVE PMP FOR KHON KAEN

Time (hr)	Rainfall Distribution (mm)	Accum. Rainfall (mm)	Accum. Effective Rainfall (mm)	Effective Rainfall (mm)
2	22	22	1.8	1.8
4	23	45	12.8	11.0
6	24	69	29.4	16.7
8	33	102	56.2	26.8
10	37	139	88.9	32.7
12	45	184	130.6	41.7
14	55	239	183.0	52.4
16	184	423	362.6	179.7
18	65	488	426.8	64.2
20	31	519	457.5	30.7
22	28	547	485.2	27.7
24	27	574	512.0	26.8

APPLICABILITY OF SALINITY WATER

	EC (Micromohos/cm at 25°C)	Applicability
C_1	0-250	Low-salinity water can be used for irrigation with most crops or most soils.
C_2	250-750	Medium-salinity water can be used for irrigation with plants having moderate salt tolerance in soils of good permeability, without special practices for salinity control.
C_3	750-2250	High-salinity water can be used on soils with special management for salinity control, and plants with good salt tolerance should be selected.
C_4	2250-5000	Very-high-salinity water is not suitable for irrigation under ordinary conditions, but in the case that soils are permeable, drainage is adequate and excess water can be applied to provide considerable leaching, this water can be used for irrigation water.

APPLICABILITY OF SODIUM WATER

	SAR (epm)	Applicability
S_1	0-10	Low-sodium water can be used for irrigation on almost soils.
S_2	10-18	Medium-sodium water can be used for irrigation or soils with good permeability. This water is not suitable on soils with fine-texture having no gypsum ($CaSO_4$).
S_3	18-26	High-sodium water is not suitable or most soils, unless chemical amendment and leaching provide to soils.
S_4	26-	Very-high-sodium water is not suitable for irrigation water except at low and medium salinity, where the solution of calcium from the soils or use of gypsum or other amendments may make the use of water feasible.

APPLICABILITY OF BORON WATER

B (ppm)	Applicability
1	This water can be used for almost crops.
1-2	This water can be use for boron semi-tolerance crops.
2-4	This water can be use for boron tolerance crops.

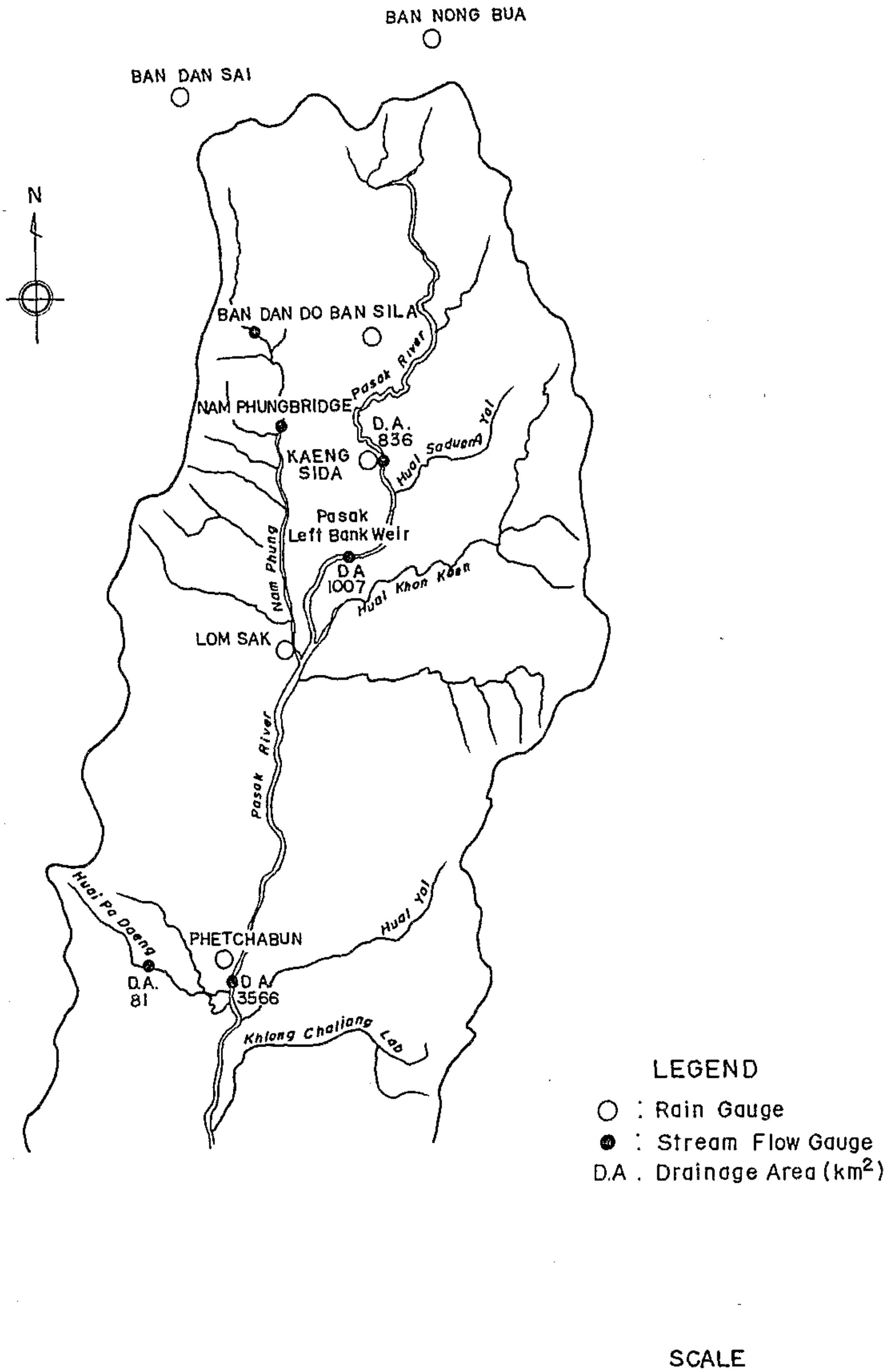
APPLICABILITY OF BICARBONATE ION WATER

RSC (megle)	Applicability
-1.25	This water can be use in safety.
1.25-2.50	This water can be use having treatment, leaching and adequate drainage to prevent from aggregation of soil salinity.
2.50-	This water is not suitable for irrigation purposes.

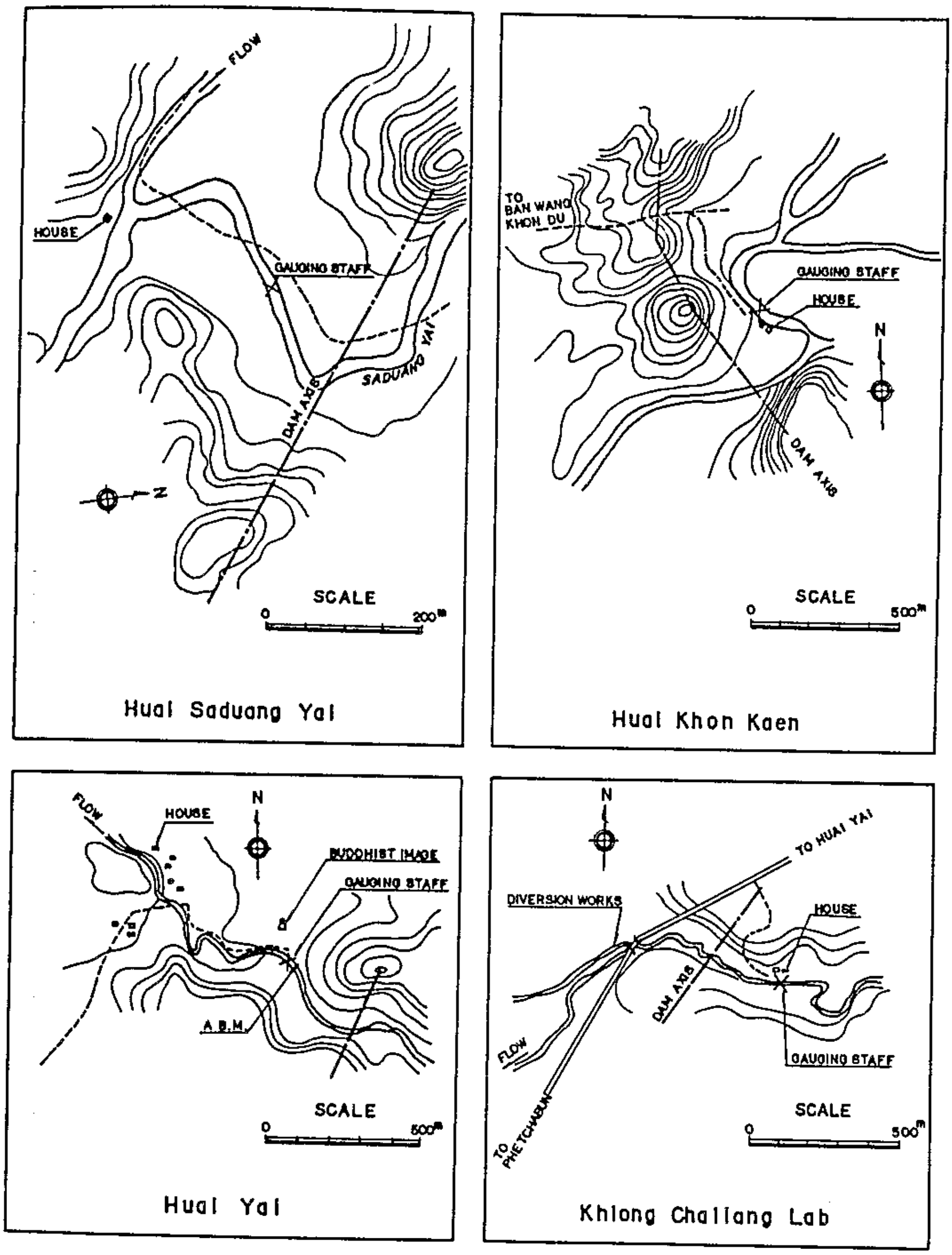
STANDARDS AND GUIDELINES FOR DRINKING WATER (UNIT PPM)

	Approval limits	
	Aesthetics	Health
Arsenic (As)		0.1
Barium (Ba)		1.0
Cadmium (Cd)		0.01
Chloride (Cl)	250.0	
Chromium		0.05
Copper (Cu)	1.0	
Carbon Chloroform extract (CCE)		0.7
Cyanide (CN)		0.2
Fluoride (F)		0.6-1.8
Iron (fe)	0.3	
Lead (Pb)		0.05
Manganese (Mn)	0.05	
Mercury (Hg)		0.002
Methylene-blue active substances	0.5	
Nitrate nitrogen (NO_3 as N)		10.0
Selenium (Se)		0.01
Silver (Ag)		0.05
Sulfata (SO_4)	250.0	
Total dissolved solids	(No limits designated)	
Zinc (Zn)	5.0	
Aldrin		(pending)
DDT		(pending)
Dieldrin		(pending)
Chlordane		0.003
Endrin		0.0002
Heptachlor		0.0001
Heptachlor epoxide		0.0001
Lindane		0.004
Methoxychlor		0.1
Toxaphene	0.005	
Organophosphorus insecticides		
Azodrin	0.003	
Dichlorvos	0.01	
Dimethoatc	0.002	
Ethion	0.02	
Chlorophenoxy herbicides		
2,4-D	0.1	
2,4,5-T (2,4,5-TP and Silvex)	0.01	

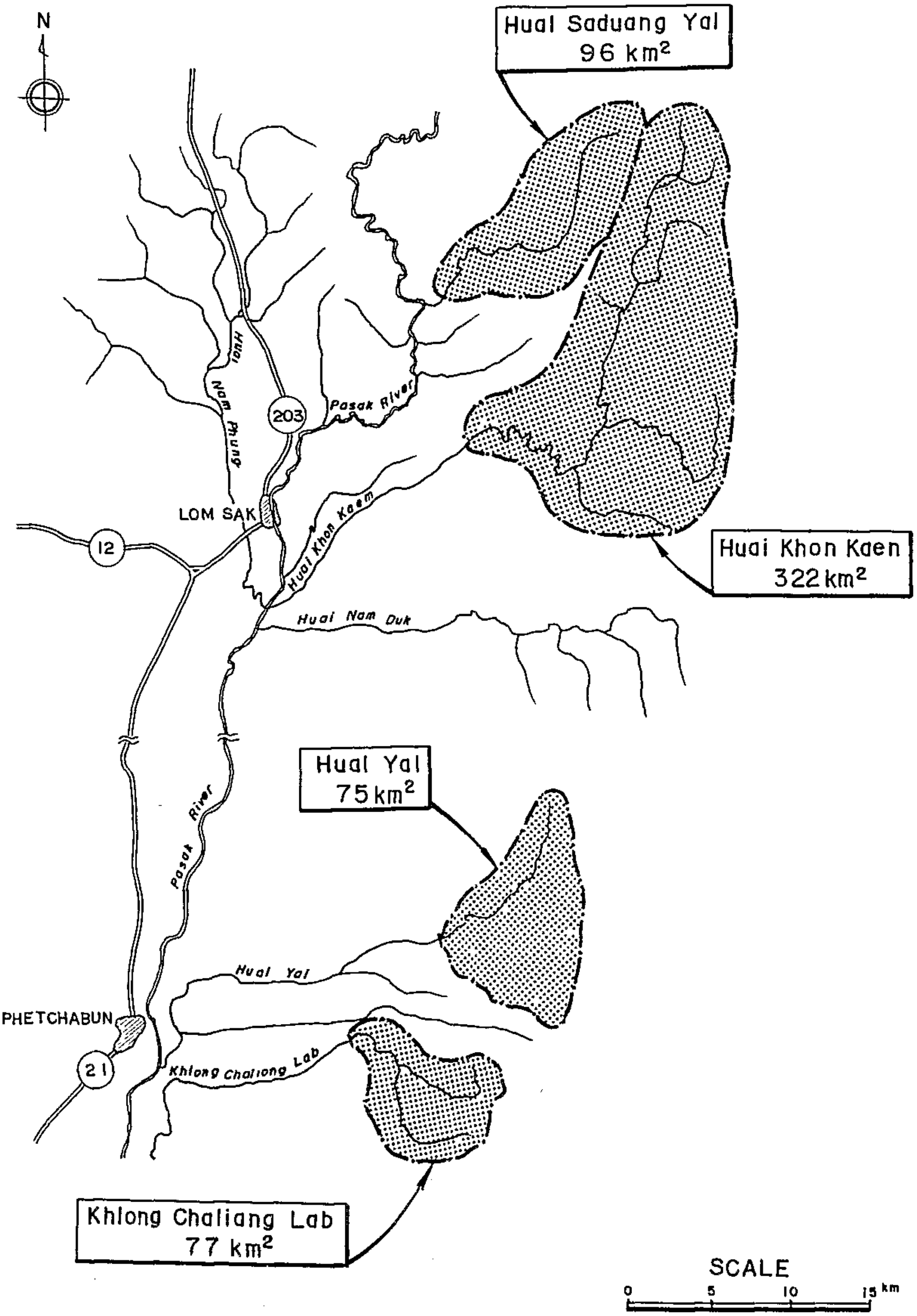
Source: Water Supply Division, Environmental Protection Agency - 1974



LOCATION OF GAUGING STATION
(Upper Pasak Basin)



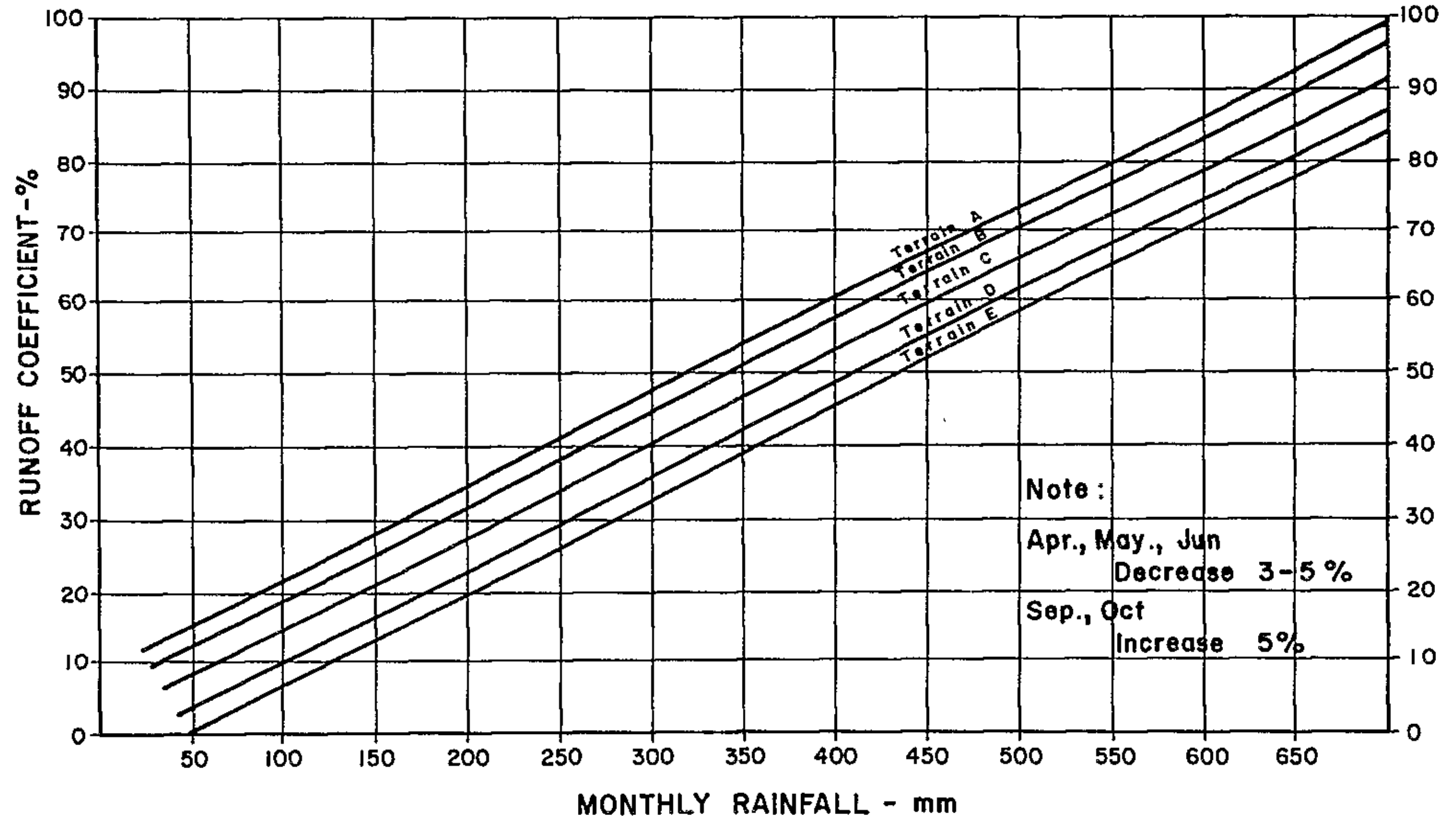
LOCATION OF GAUGING STAFF



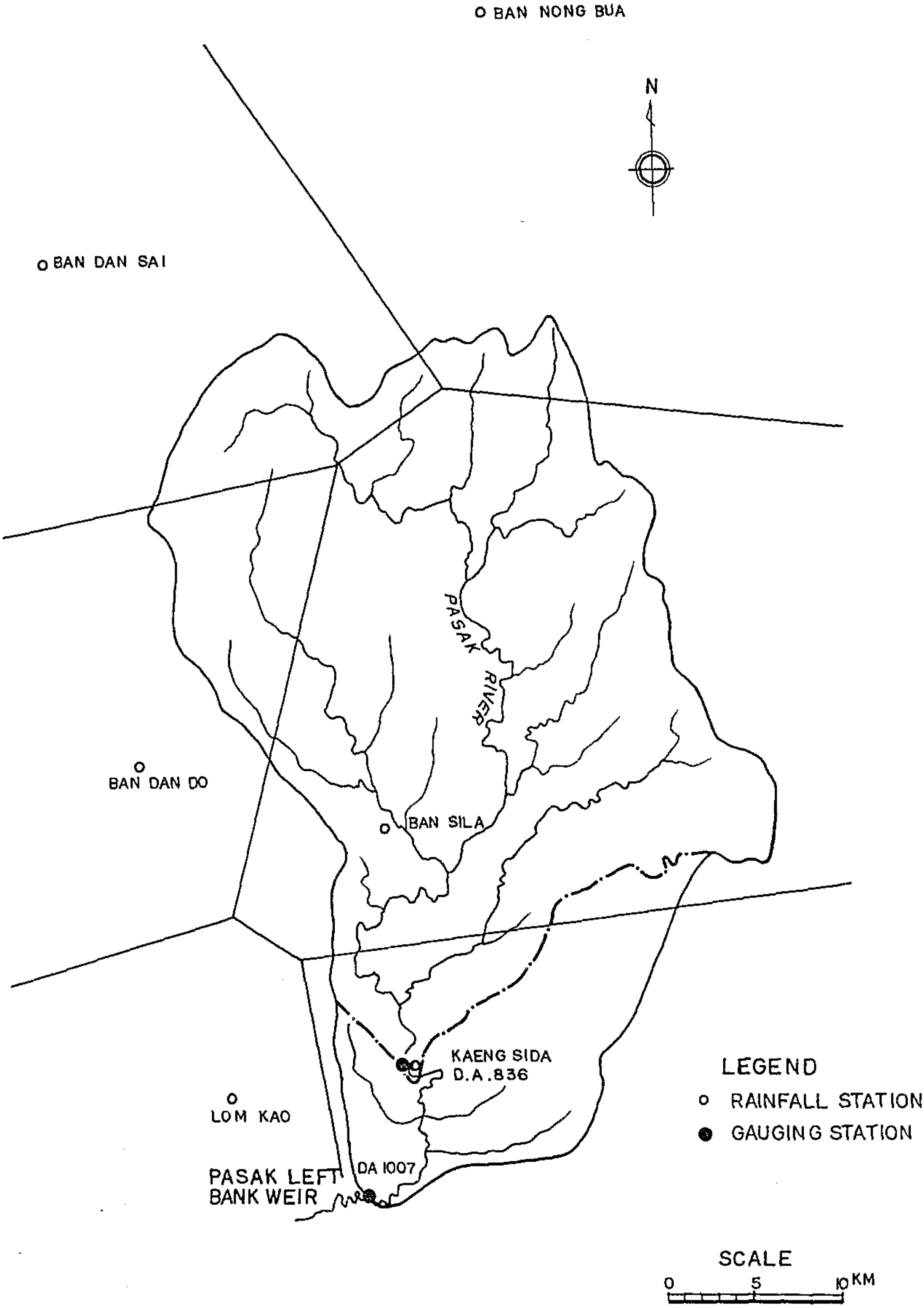
WATERSHED OF EACH TRIBUTARY

Type of Terrain

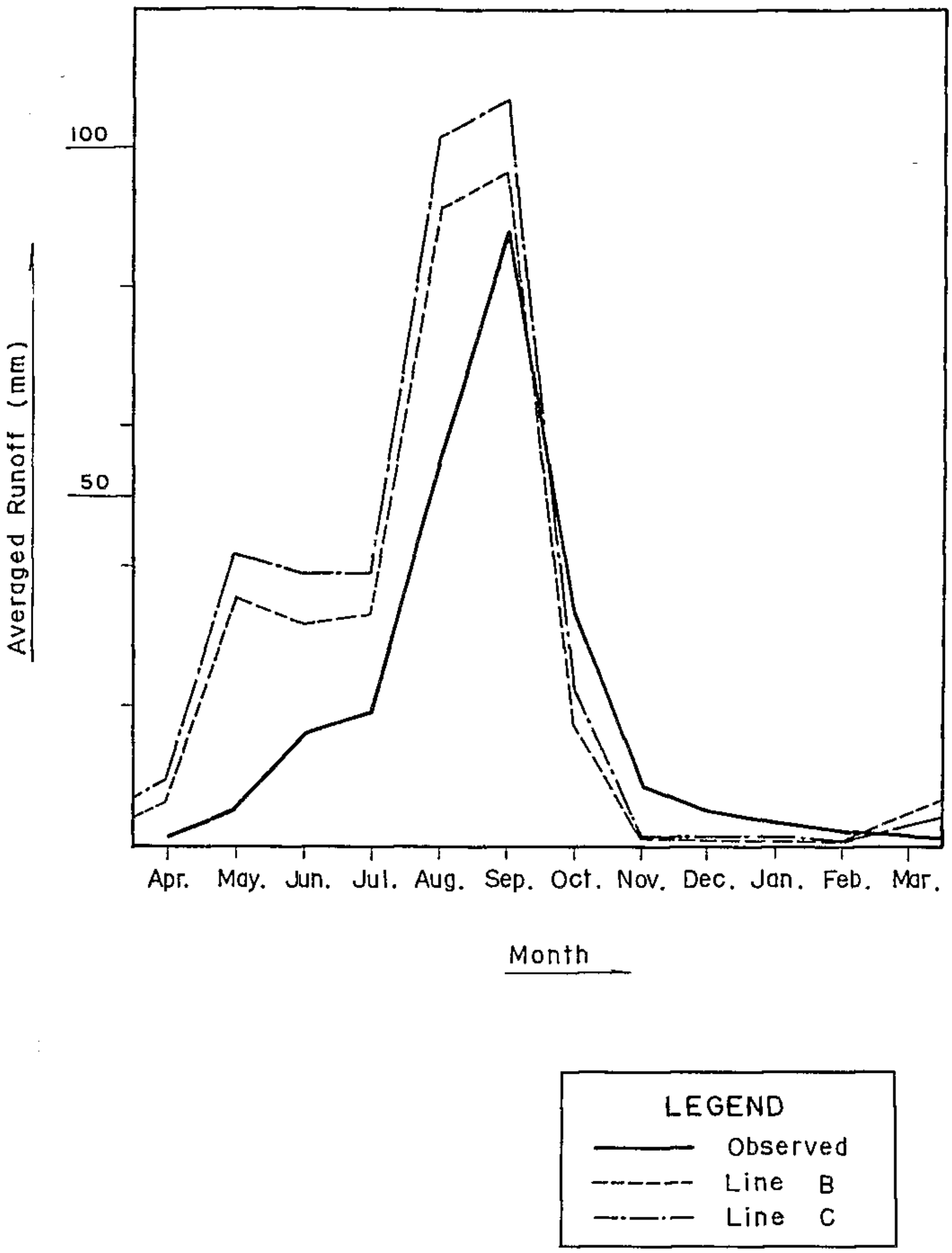
A — Steep mountainous area, no paddy field.
B — Rather steep area, open forest.
C — Rolling area, open forest, some paddy fields.
D — Gentle slope area, many paddy fields.
E — Flat area, many paddy fields.



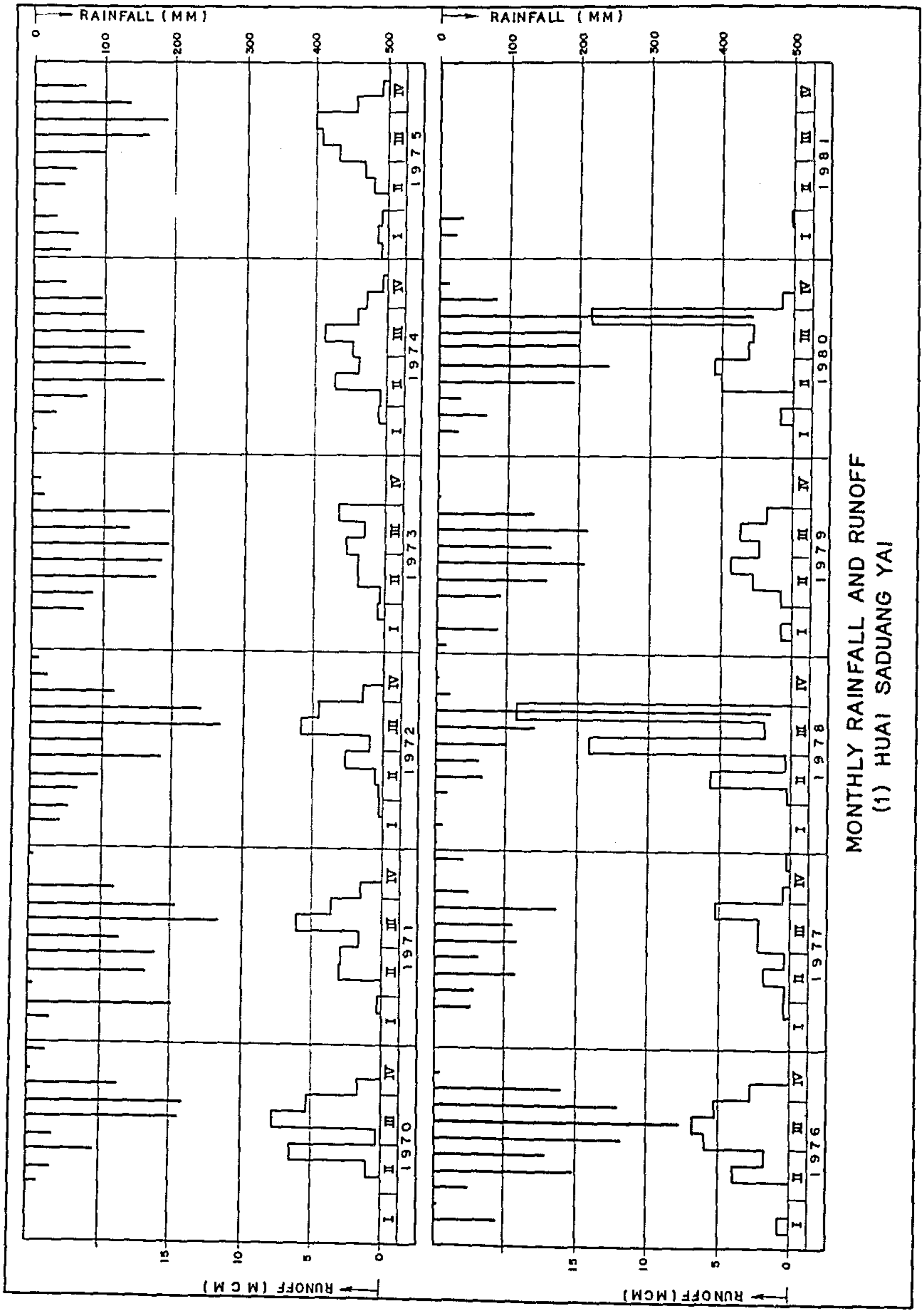
ESTIMATE OF RUNOFF COEFFICIENT
(Developed by RID)



KAENG SIDA AND PASAK LEFT BANK WEIR BASIN

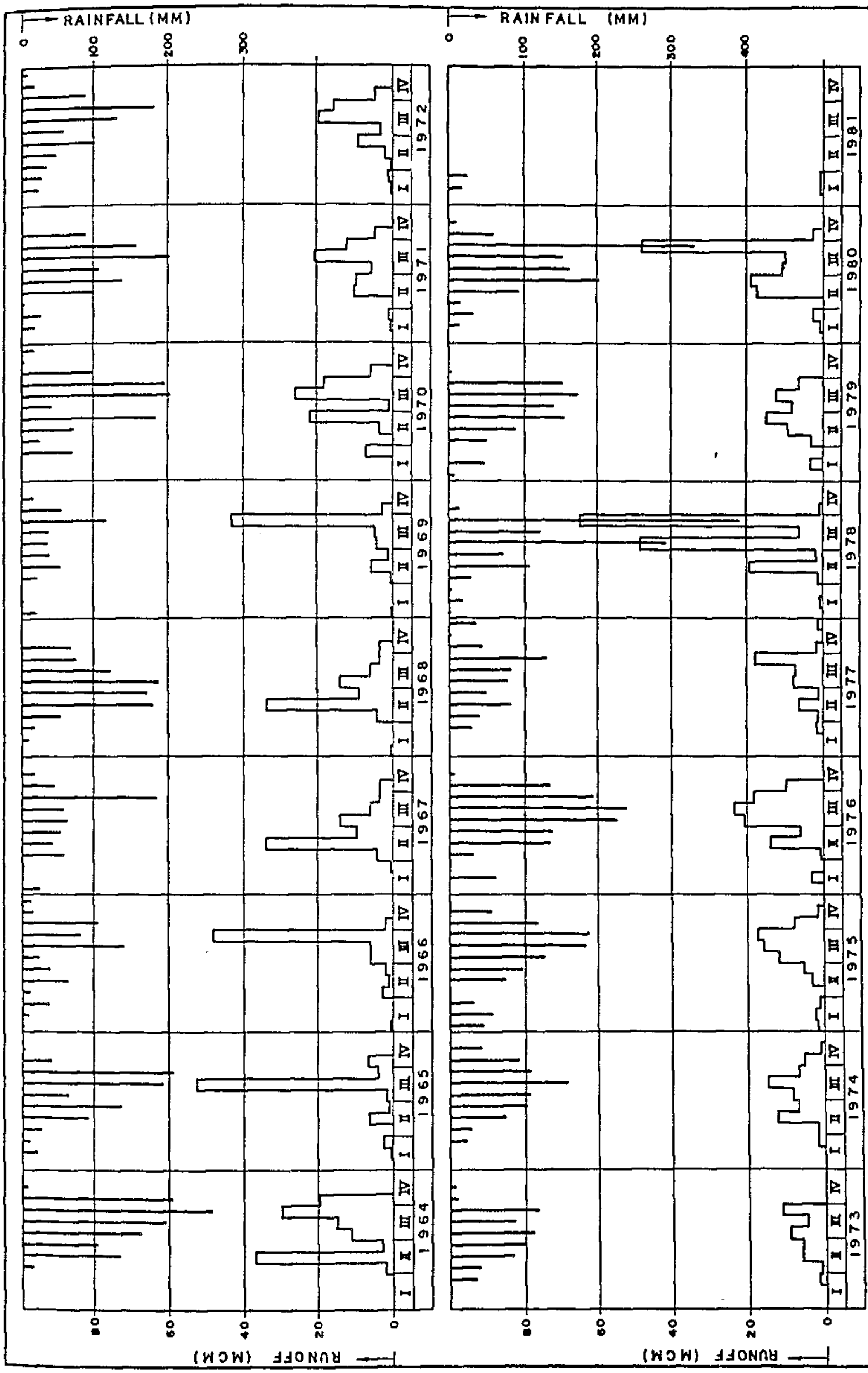


COMPARISON BETWEEN OBSERVED AND ESTIMATED RUNOFF



MONTHLY RAINFALL AND RUNOFF
(1) HUAI SADUANG YAI

FIG. I-7
(2)



MONTHLY RAINFALL AND RUNOFF
(2) HUAI KHON KAEN

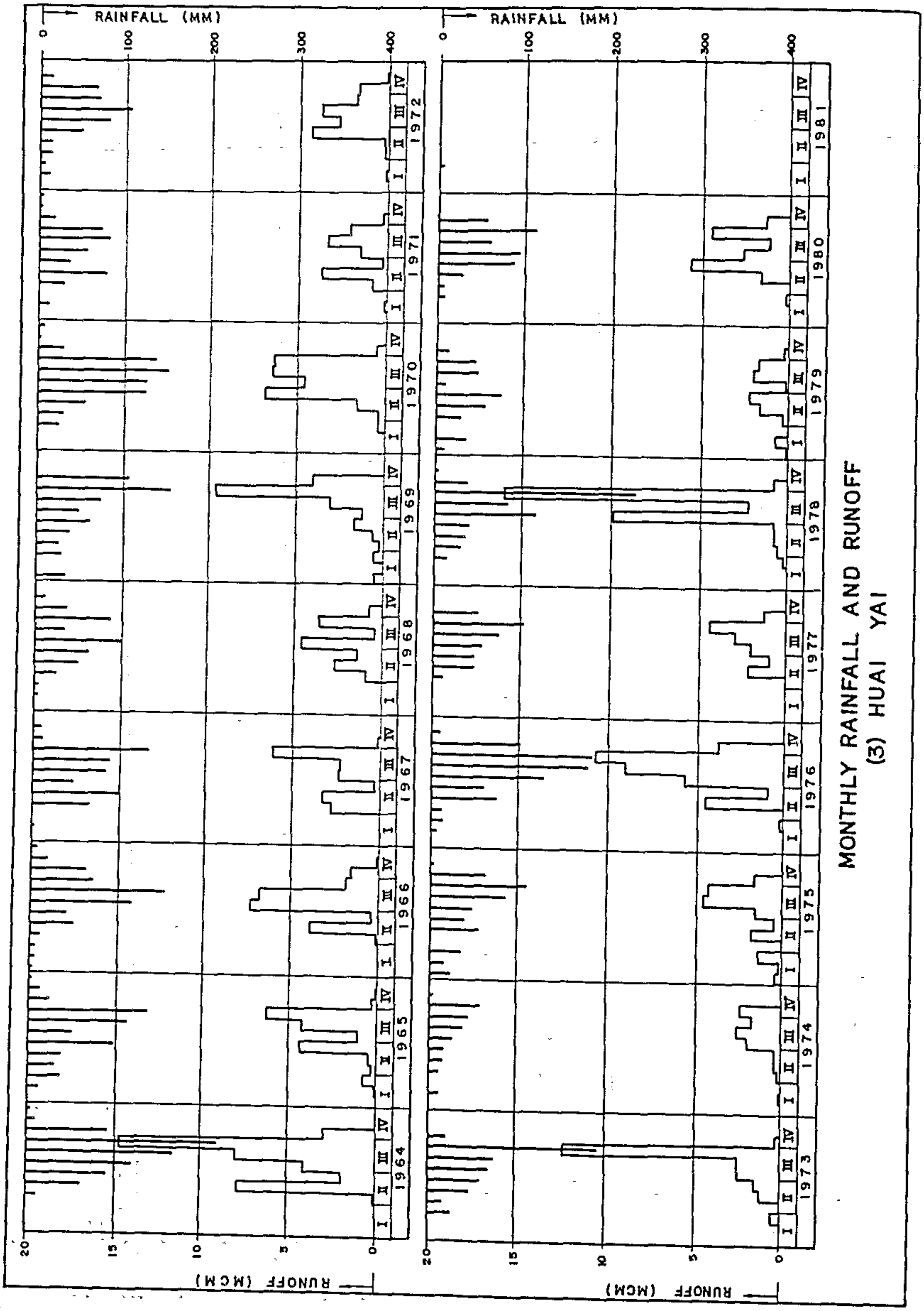
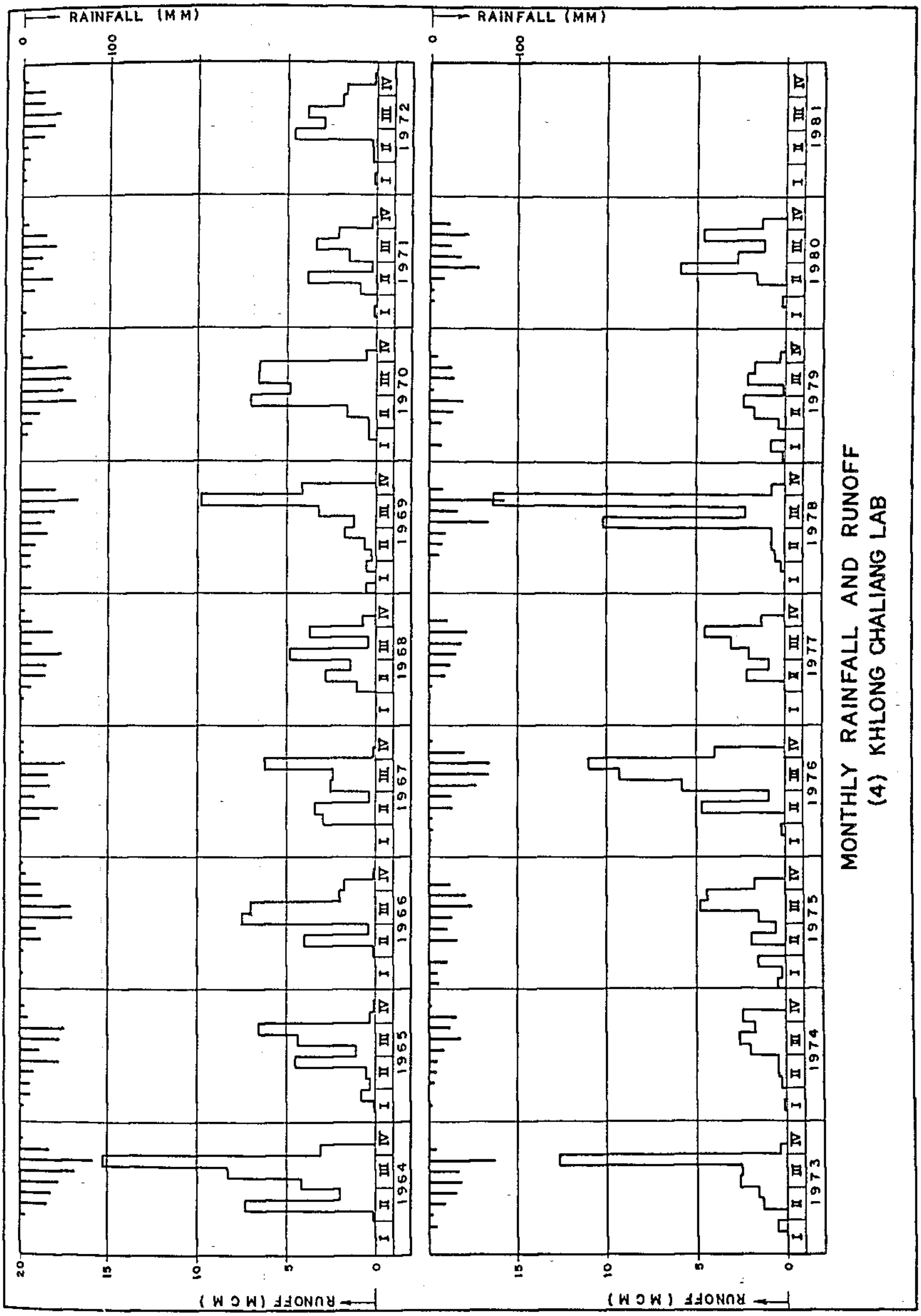
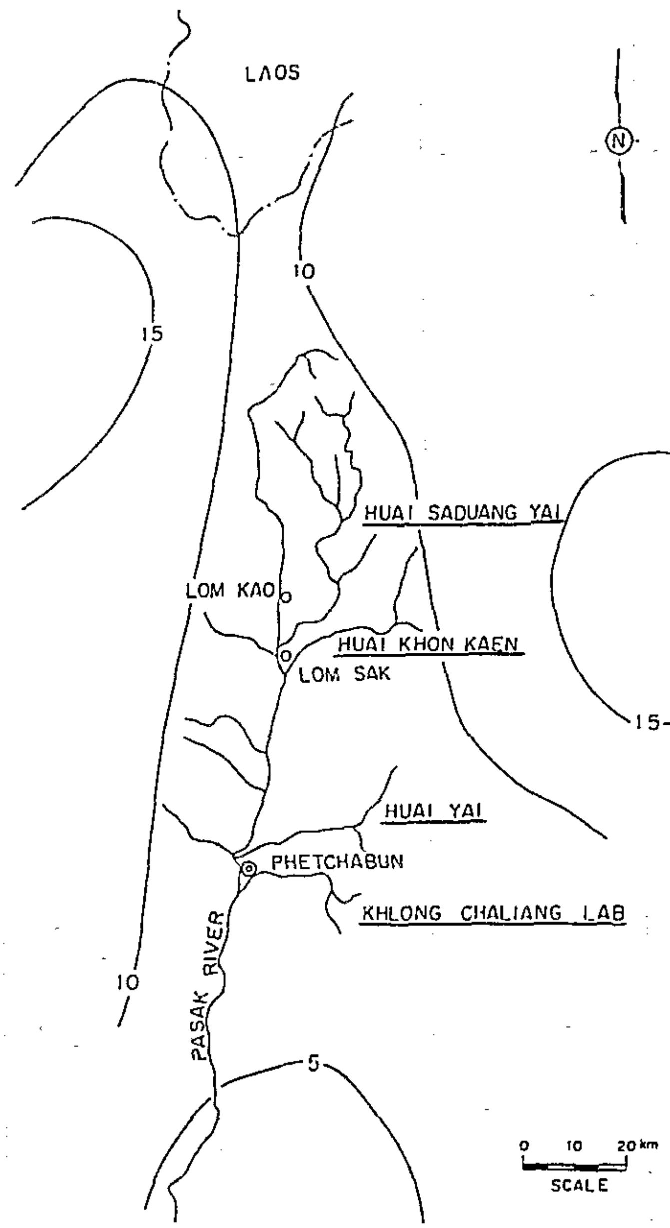

MONTHLY RAINFALL AND RUNOFF
(3) HUAI YAI
RAINFALL (MM)
RUNOFF (MCM)
0
100
200
300
400
20
15
10
5
0
I
II
III
IV
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981

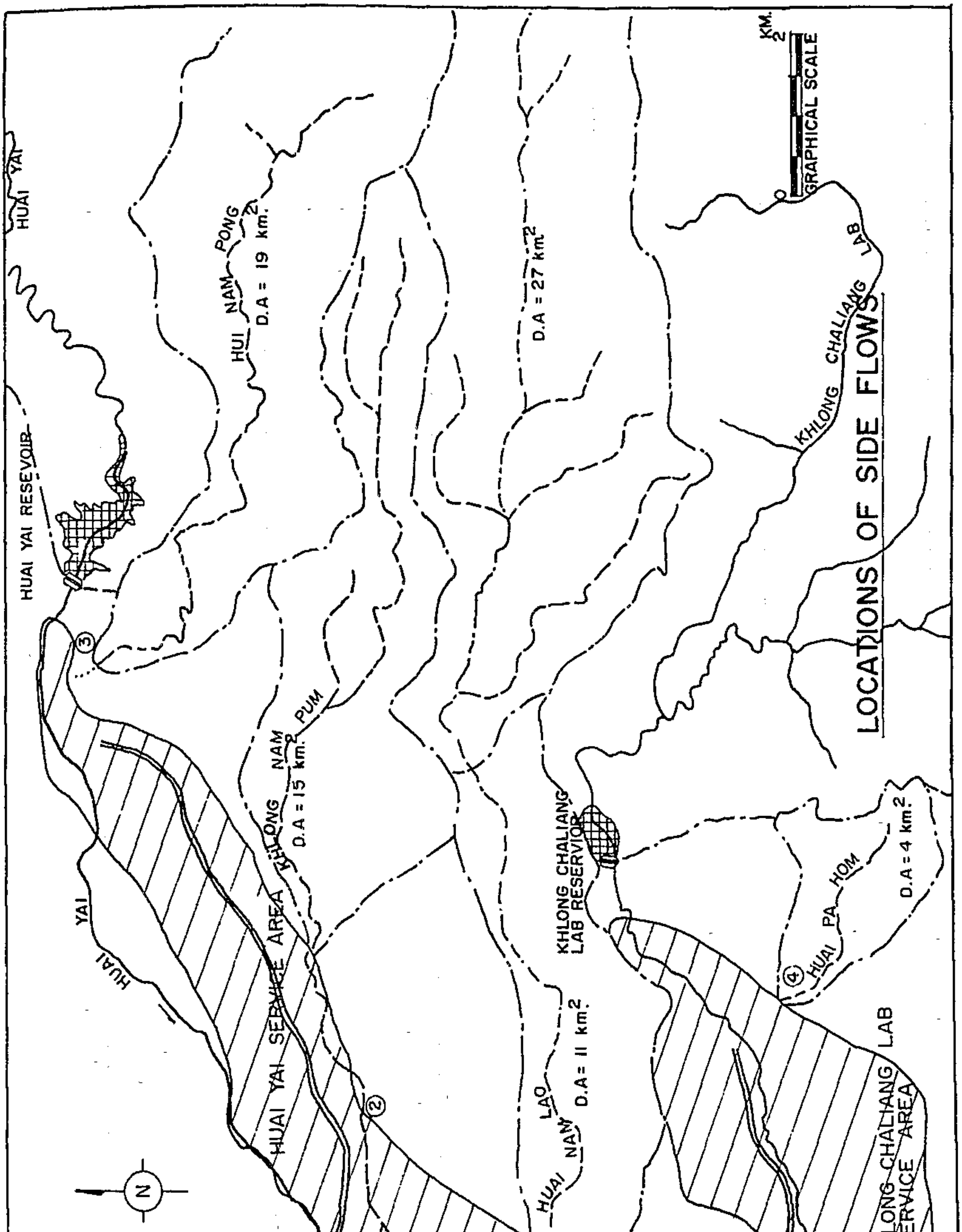
FIG. I-7
(4)

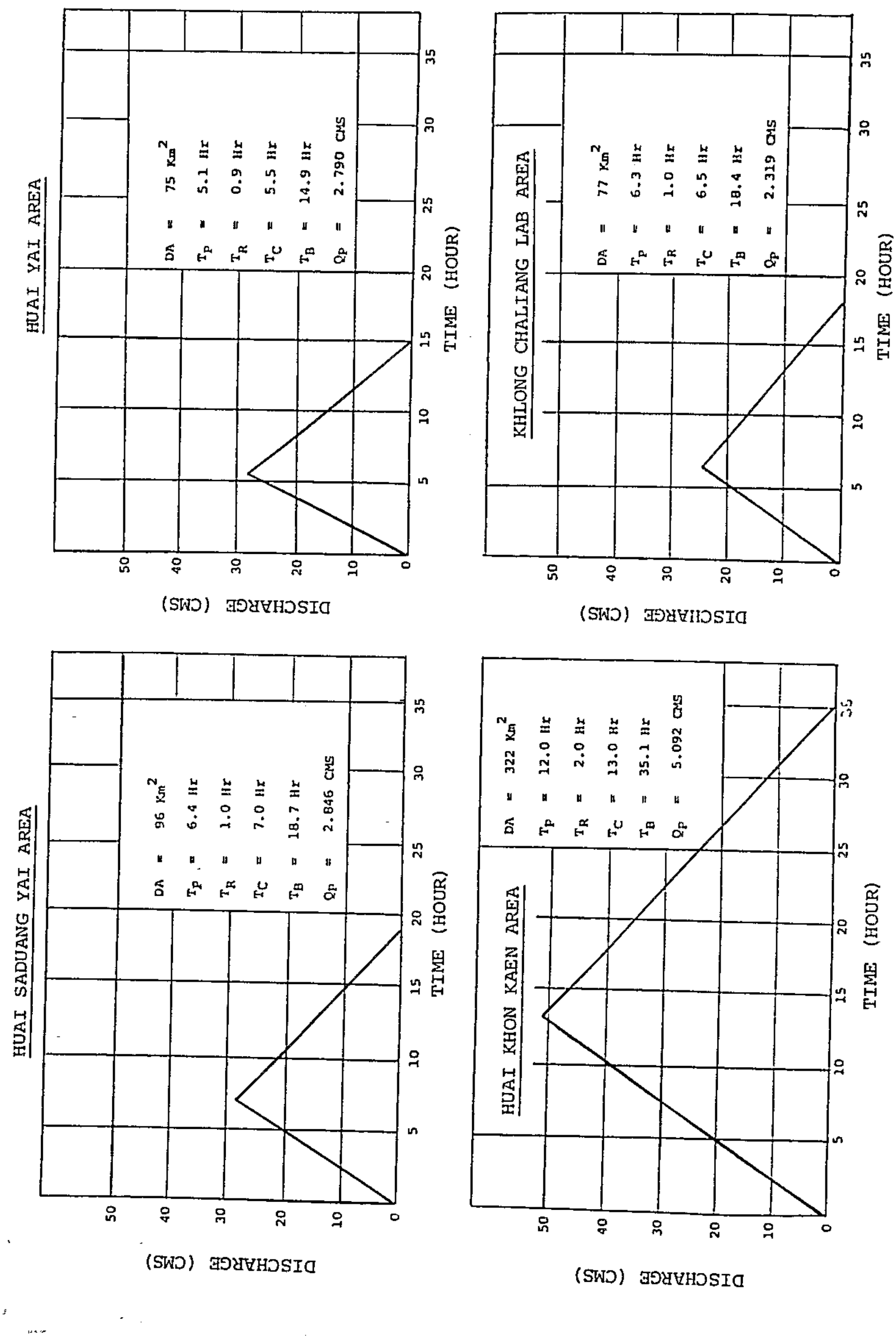


MONTHLY RAINFALL AND RUNOFF
(4) KHLONG CHALIANG LAB

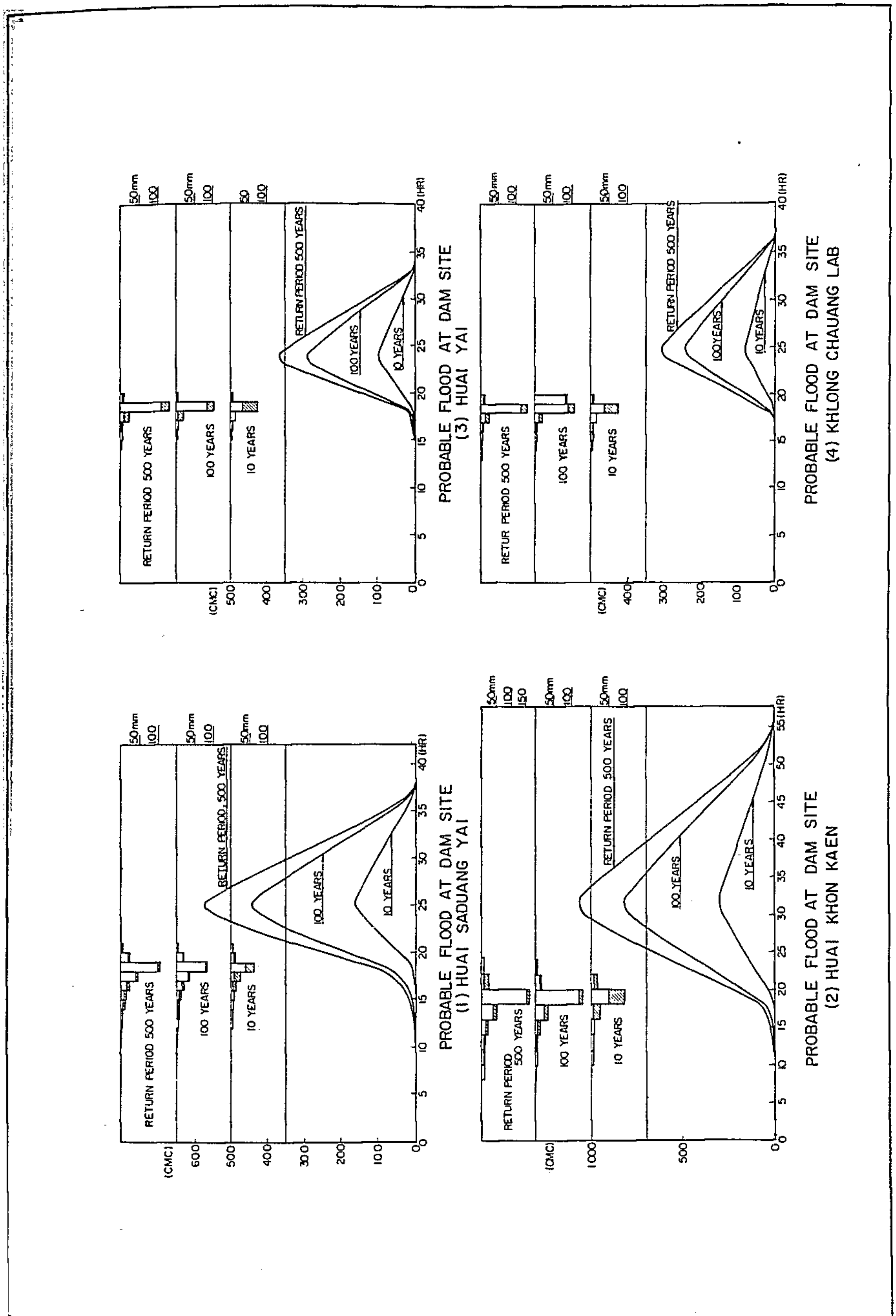


AVERAGE YIELD OF RUNOFF
(l/Sec/km²)

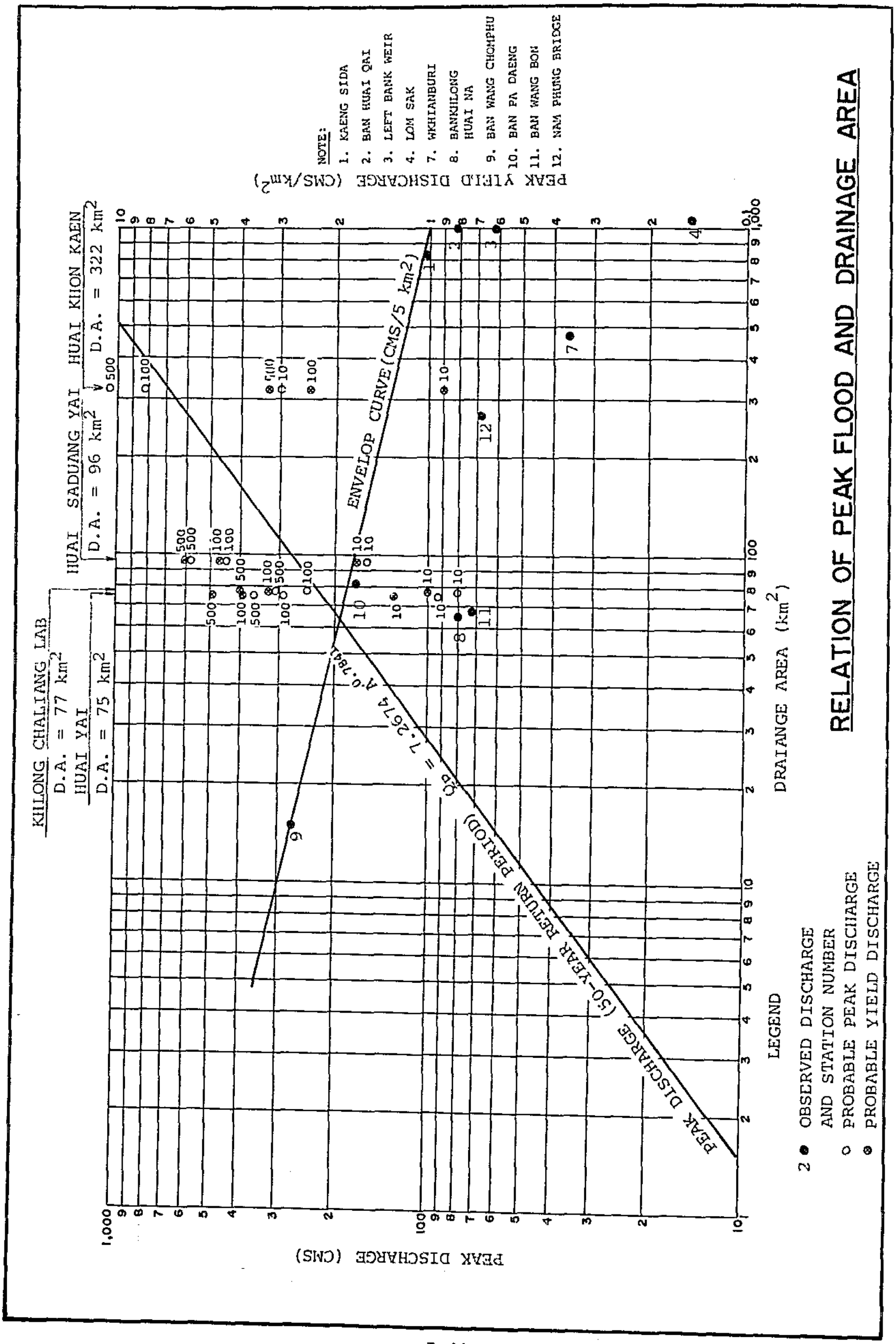

LOCATIONS OF SIDE FLOWS
GRAPHICAL SCALE
KM. 2
HUAI YAI
HUAI YAI RESEVOIR
HUI NAM PONG
D.A = 19 km.2
D.A = 27 km2
KHLONG CHALIANG LAB
KHLONG NAM PUM
D.A = 15 km.2
HUAI YAI SERVICE AREA
KHLONG CHALIANG LAB RESERVIOR
HUAI PA HOM
D.A = 4 km.2
HUAI NAM LAO
D.A = 11 km2
KLONG CHALIANG SERVICE AREA
TO PHETCHABUN
TO PHETCHABUN
N
1
2
3
4

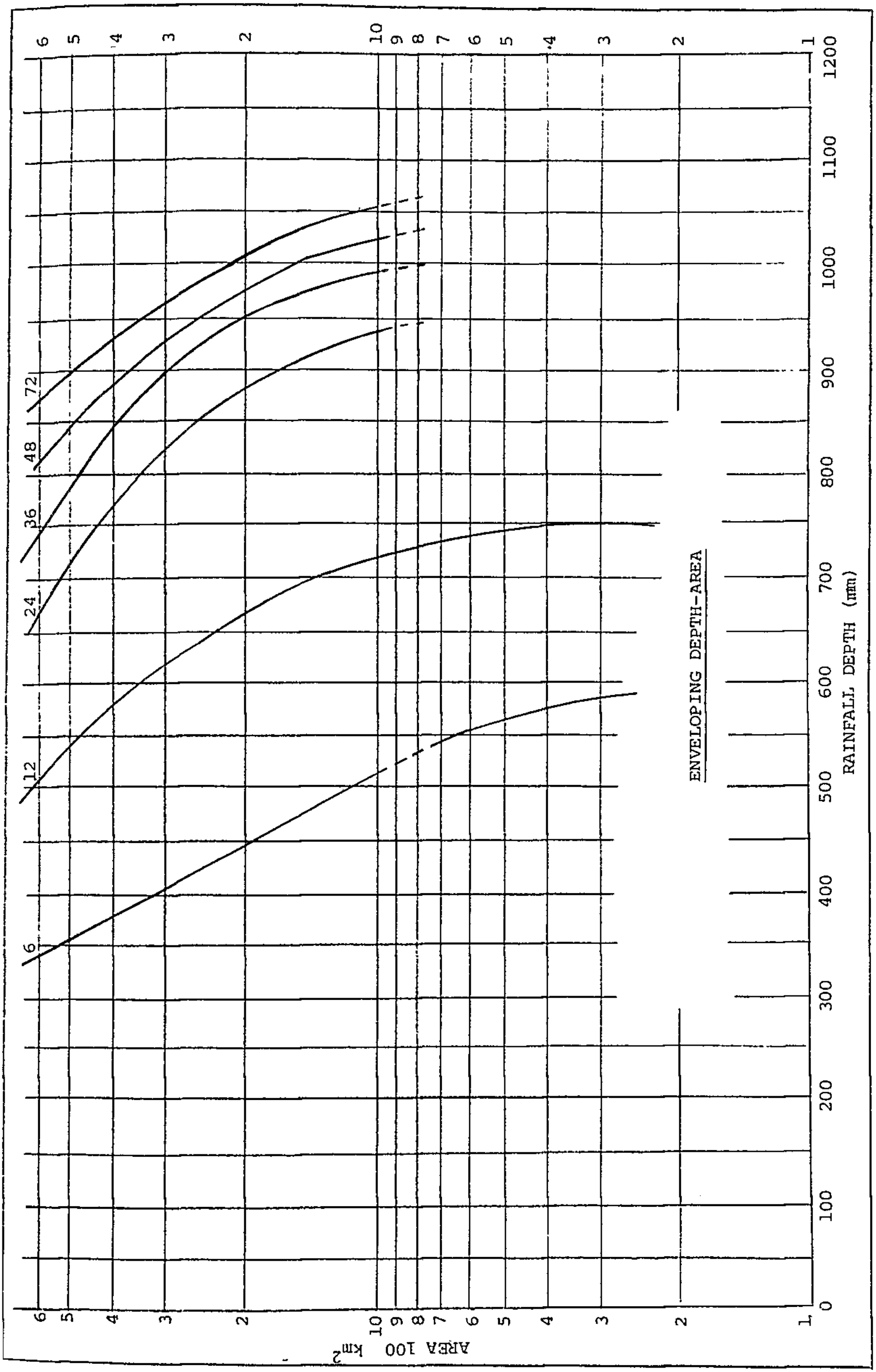


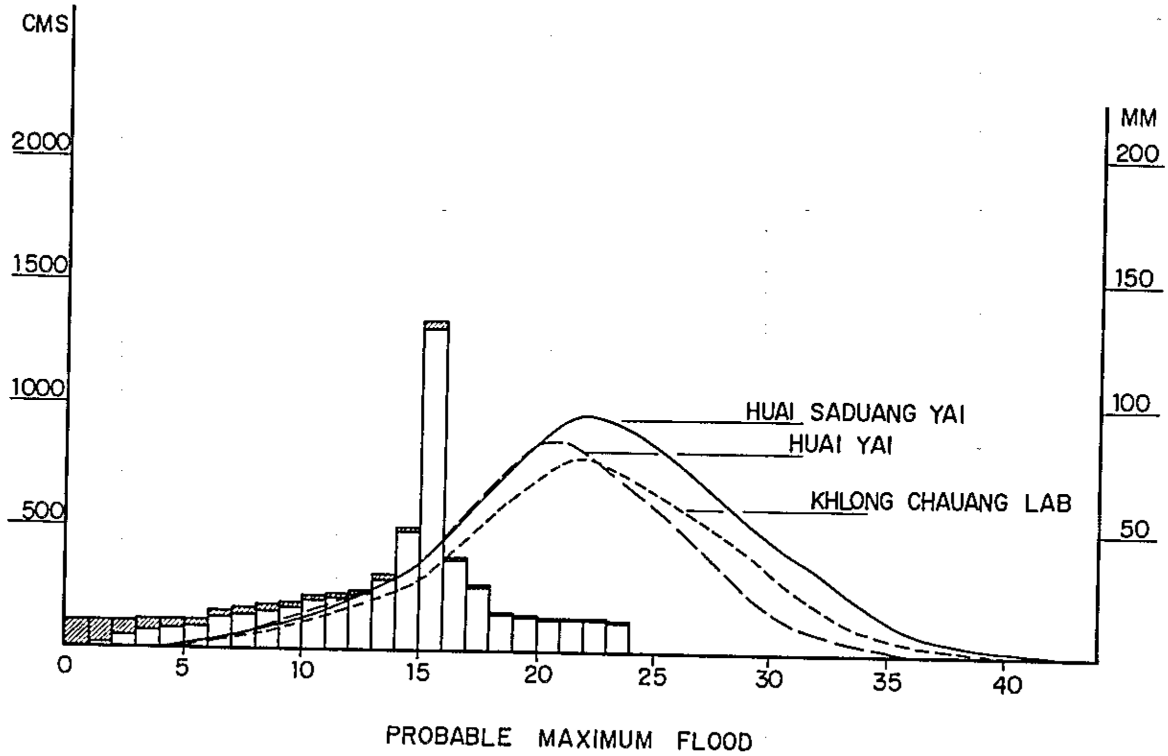
UNIT HYDROGRAPH AT EACH DAM SITE



(CMC)
RETURN PERIOD 500 YEARS
100 YEARS
10 YEARS
50mm
100
(HR)
PROBABLE FLOOD AT DAM SITE
(1) HUAI SADUANG YAI
PROBABLE FLOOD AT DAM SITE
(2) HUAI KHON KAEN
PROBABLE FLOOD AT DAM SITE
(3) HUAI YAI
PROBABLE FLOOD AT DAM SITE
(4) KHLONG CHAUANG LAB


RELATION OF PEAK FLOOD AND DRAINAGE AREA
PEAK DISCHARGE (CMS)
PEAK YIELD DISCHARGE (CMS/km²)
DRAIANGE AREA (km²)
KILONG CHALIANG LAB
D.A. = 77 km²
HUAI YAI
D.A. = 75 km²
HUAI SADUANG YAI
D.A. = 96 km²
HUAI KHON KAEN
D.A. = 322 km²
ENVELOP CURVE(CMS/5 km2)
PEAK DISCHARGE (50-YEAR RETURN PERIOD)
Qp = 7.2674 A^0.7841
NOTE:
1. KAENG SIDA
2. BAN HUAI QAI
3. LEFT BANK WEIR
4. LOM SAK
7. WKHIANBURI
8. BANKILONG
HUAI NA
9. BAN WANG CHOMPHU
10. BAN PA DAENG
11. BAN WANG BON
12. NAM PHUNG BRIDGE
LEGEND
2 ● OBSERVED DISCHARGE AND STATION NUMBER
○ PROBABLE PEAK DISCHARGE
⊗ PROBABLE YIELD DISCHARGE


ENVELOPING DEPTH-AREA
RAINFALL DEPTH (mm)
AREA 100 km²
6
12
24
36
48
72
0
100
200
300
400
500
600
700
800
900
1000
1100
1200


CMS
2000
1500
1000
500
MM
200
150
100
50
HUAI SADUANG YAI
HUAI YAI
KHLONG CHAUANG LAB
0
5
10
15
20
25
30
35
40
PROBABLE MAXIMUM FLOOD

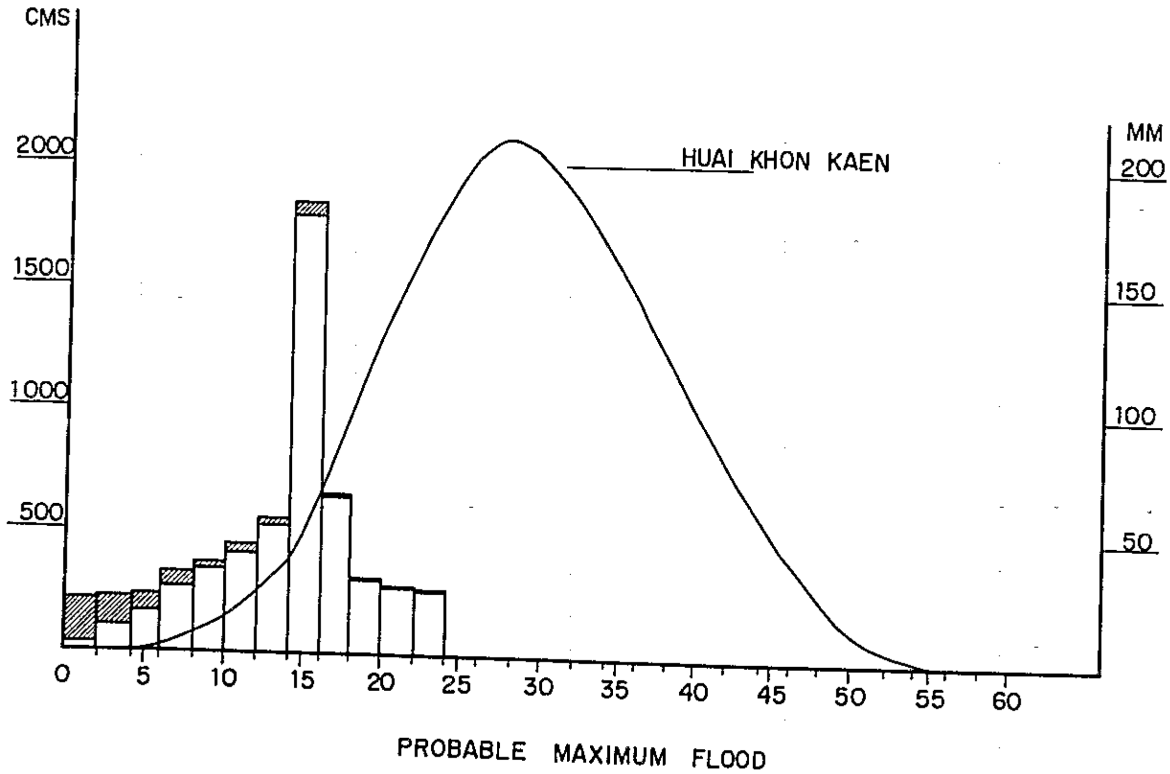

CMS
2000
1500
1000
500
MM
200
150
100
50
HUAI KHON KAEN
0
5
10
15
20
25
30
35
40
45
50
55
60
PROBABLE MAXIMUM FLOOD

FIG. I-15

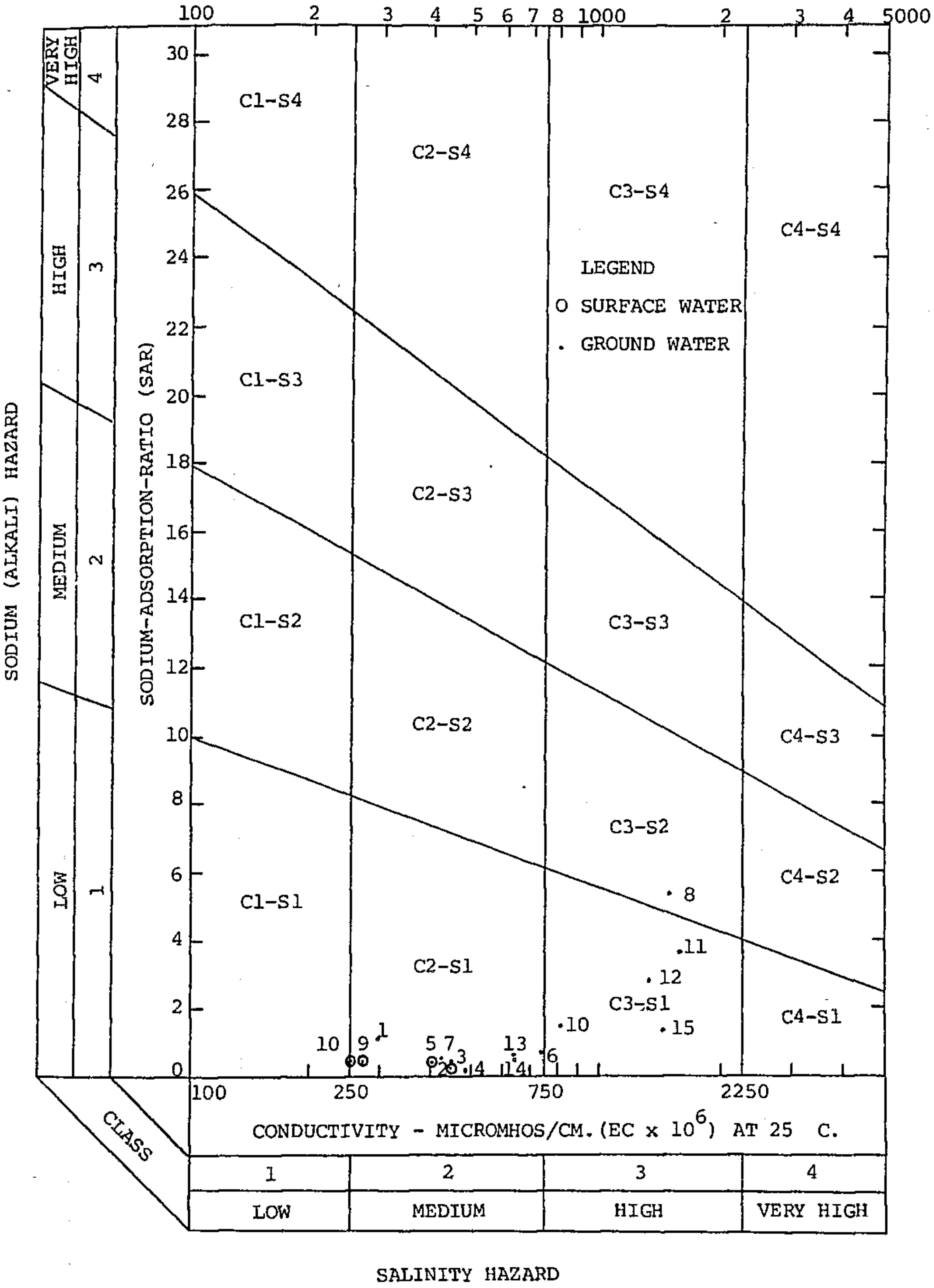


DIAGRAM FOR CLASSIFICATION OF IRRIGATION WATER

ANNEX II

GEOLOGY AND CONSTRUCTION MATERIALS

ANNEX - II

GEOLOGY AND CONSTRUCTION MATERIALS

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ANNEX - II

GEOLOGY AND CONSTRUCTION MATERIALS

1. GENERAL

The project area is geologically situated in the eastern wing of tectonic basin, namely, the Upper Pasak Valley, which extends in N-S direction with width of about 20 km. The Upper Pasak Valley is a tectonic downwarp formed in the Paleozoic sedimentary rocks and has been filled since Tertiary by terrestrial deposits derived from the uplifted mountain ranges which bound to the Valley with N-S trending marginal faults in the east and west.

The proposed four dam sites are wholly located in the foothills of the eastern mountain range, at which the tributaries of Pasak river emerge from mountainous steep ravines to the low rolling hilly land, dissecting the Paleozoic sedimentary rocks with formation of shallow valleys with wide flood plain and meandering river channels. The proposed canals are so aligned as to pass the diluvial gentle undulating land spread over the eastern part of Pasak Valley.

As illustrated in the geological map (FIG. II-1) and the stratigraphical table (TABLE II-1), the project area is underlain by sedimentary rocks of Permian, Triassic and Tertiary and covered with the Pleistocene and Recent fluviatile deposits. The sedimentary rocks form a wide zonal structure extending in N-S direction and are mutually in unconformable relationship.

In the eastern mountainous range and the foothills, where the drainage basins, reservoirs and dam sites of proposed four dams are wholly located, Nam Duk Formation of Middle Permian extends in N-S direction forming a 20 - 30 km wide strip. The Nam Duk Formation is composed of primarily alternating beds of shale and sandstone folded along N-S trending axis. The Khorat Formation of Triassic distributes intermittently along synclinal axis forming higher mountain peaks. Intrusion of igneous rock (granite, diorite and gabbroic diorite) in the form of small stock is found within Permian formation.

In the western mountainous range of the Valley, limestone of Pha Nok Formation of Lower-Middle Permian extends also in N-S direction with width of 500 - 700 m. This limestone is the most important source of riprap material and aggregates in the Valley.

In the Pasak Valley, the Tertiary system limitedly distributes at about 1 km downstream of the Khlong Chaliang Lab dam site, and appears to be widely plunged beneath the Quaternary deposits. The Quaternary deposits consists of terrace deposits which widely spreads over the eastern part of the Valley underlying the proposed canal routes and irrigation areas, and of alluvial deposists along the meandering belts of Pasak river and its tributaries.

2. GEOLOGICAL INVESTIGATION AT DAM SITES

2.1 Previous Investigations

Prior to the pre-feasibility study made by JICA in 1981, RID had carried out geological investigations which included drillings, hand augerings and test-pit investigations at four dam sites, i.e. Huai Saduang Yai, Huai Khon Kaen, Huai Yai and Khlong Chaliang Lab. The following table shows the number of drillings done by RID in the past.

Dam Site	Drilling Site	Number of Drilled hole
Huai Saduang Yai	right abutment	2
	left abutment	2
	river bed	1
	Sub-total	5
Huai Khon Kaen	right abutment	1
	saddle	3
	left abutment	1
	river bed	2
	Sub-total	7
Huai Yai (original site)	right abutment	24
	left abutment	6
	river bed	1
	spillway	3
	outlet	3
	Sub-total	37
Khlong Chaliang Lab	right abutment	2
	left abutment	1
	river bed	1
	Sub-total	4
	TOTAL	53

In the pre-feasibility study time, the following investigations and studies were carried out by the JICA study team:

(a) collection and review of the data on general geology in and around the project area;

(b) review and analysis on the results of geological investigation made by RID;

(c) reconnaissance and geological investigation at each dam and reservoir sites;

(d) material survey in and around the proposed borrow areas; and

(e) examination of drilled cores kept in the Pa Daeng project office.

2.2 Supplemental Investigations for Feasibility Study

During the pre-feasibility study time, many geological data and information were accumulated particularly for the dam sites. In order to elucidate the geological conditions at appurtenant structures such as spillways and outlet structures and availability of construction materials such as embankment materials, filter and riprap materials and concrete aggregates, however, further additional geological and soil mechanical investigations were needed. And in the pre-feasibility report these investigations were requested to be completed before start of the feasibility study. Further request was made by the pre-feasibility study team for the geological investigation at the newly proposed Huai Yai dam site which was shifted for around 500 m upstream from the original dam site following the result of technical and economical comparison made by the pre-feasibility study team.

In response to the requests, RID started the investigations from the beginning of 1982 and has completed all the drillings and laboratory tests as shown in TABLE II-2.

In addition to the review and analysis of the geological and soil mechanical data collected by RID, the expert of study team carried out reconnaissance extensively in and around the dam and reservoir sites and along the main irrigation canal routes to judge the possibility of land sliding after creation of the reservoirs and to check the availability of construction materials. Examination of the core samples collected from each dam site was also made to check the weathered conditions of base rock, existence of structural weak points, lithofacis and the depth of quaternary deposits.

3. SITE GEOLOGY AT DAM AND RESERVOIR

3.1 Huai Saduang Yai Dam and Reservoir Site

The dam site is located on the Huai Saduang Yai; about 1.5 km upstream from the confluence with the Pasak river. At the dam site, the Huai Saduang Yai runs southeastward taking a meandering course. The shape of gorge at the dam site is relatively symmetric having a side slope of 25° - 26° on the right bank and about 20° on the left bank, which provides very attractive condition for the construction of fill dam. Along both banks of the river, 200 m - 400 m wide terraces develop and extend up to the reservoir area. The skirts of mountain near the dam site are covered with terrace deposits overlain with talus deposits.

The bedrock at the dam site is composed of predominant sandstone and shale of the Nam Duk Formation of the Paleozoic Middle Permian period, forming alternate strata. The sandstone is gray to dark gray coloured, fine to medium grained, and hard and massive rock. The shale is dark gray to reddish brown coloured and rather soft rock as compared with the sandstone, having a tendency to cleave readily from the bedding plane. The strata strike N3°E - N22°E and dip west at 30° - 50°, and in places, folded on a north to south axis in the area.

According to the drilling survey results (FIG. II-2), the bedrock along the dam axis is deeply weathered; the deepest among the four dam sites. The weathered depth is 7 m - 11 m at the left bank abutment and riverbed, 15 m - 20 m at the right bank abutment, 10 m - 15 m along the hilly ridge, where the spillway will be constructed, and 4 m - 6 m at the outlet structure site. The groundwater table is observed at 0 m - 5 m below the ground surface in the valley portion and 15 m - 20 m in the hilly ridge portion.

The permeability tests conducted at the site show the rather high Lugeon values; more than 20, to the depth of 13 m - 18 m in the riverbed and more than 25 m at both right and left bank abutments and at the upstream side of the spillway site (FIG. II-6). These high permeabilities are mainly due to the existence of cracks in the rocks. These high permeabilities can however be improved by grouting.

The riverbed portion in the reservoir area is covered with 4 m thick river deposits being composed of sand and gravels, but their distribution is limited within 100 m upstream and 200 m downstream from the dam axis. The terrace deposits covering the reservoir area mainly consist of silty clay and clay, most of which are reddish brown in colour. The thickness of this layer is about 6 m - 7 m. The talus deposits covering the skirt of mountain in the reservoir area is mainly composed of clayey soil intermixed with shale fragments. As a whole, the reservoir area has a gentle topography and its geological condition appears to be stable against the land sliding even after the creation of reservoir.

3.2 Huai Khon Kaen Dam and Reservoir Site

The dam site is located on the Huai Khon Kaen; 24 km upstream from the confluence with the Pasak river, or about 1.5 km eastward of the Wang Khon Du village in the Lom Sak district. The topography at the dam site is characterized by two humps created by erosion along the present river course and the old river course. The topography in the reservoir area is formed by hilly terrain dissected by the Huai Khon Kaen and further circumscribed by rolling foothills. River terraces develop along the present and old river courses.

The bedrock around the dam site is composed of predominant shale and hard sandstone of the Nam Duk Formation of Permian Period, forming alternate strata. The sandstone is gray to dark gray coloured and fine to medium grained. The shale is black to black gray coloured and has a tendency to cleave readily from the bedding plane when weathered, but very steady when fresh. Geologic structure in this site is characterized by north-south trending folds. The strata strikes N10°W - N20°E and dips east 70° - 80°.

According to the results of drilling investigation (FIG. II-3), the highly weathered zone of bedrock along the dam axis reaches down to 5 m - 7 m in the riverbed and flat area, 10 m - 15 m along the hilly ridges and less than 10 m at the spillway and outlet structure sites. The position of groundwater table accords to the topography; 0 m - 7 m below the ground surface in the valley portion and 14 m - 30 m in the hilly ridge portion.

The permeability tests show that the bedrock with the Lugeon value of more than 20 continues down to 10 m - 15 m in the riverbed and the valley portion, also 10 m - 15 m along the dam axis and at the spillway and outlet structure sites, and 15 m - 20 m along the hilly ridges. The bedrock below the abovementioned depth is less permeable except some portions, where the Lugeon values of more than 20 are partly observed. These high permeabilities may be attributed to the existence of weathered portions, but not due to the existence of faults or fructured zone. Therefore, these high permeabilities can be improved by grouting.

Both banks of the river in the reservoir area are widely covered with 7 m - 10 m thick terrace deposits being composed of sand and gravels. The skirt of mountain in the reservoir area is mainly covered with talus deposits consisting of clayey soil intermixed with shale fragments. Judging from the topographic and geological conditions in the reservoir area, there might be a less chance of land sliding even after the creation of reservoir.

3.3 Huai Yai Dam and Reservoir Site

The dam site is located about 25 km upstream of the Huai Yai from the confluence with the Pasak river. The gorge at the dam site is blessed with favourable topographic condition for the construction of fill dam, having a bottom width of 100 m and side slope of more than 20° on the left bank and about 15° on the right bank. The thickness of top soil covering both bank is less. The topography in the reservoir area is formed by gently-sloped hills and river terraces developing along both banks of the meandering river.

The bedrock at the dam site is categorized in Nam Duk Formation of Permian Period and consists of hard sandstone and sandy shale forming alternate strata. There exists intrusive rock of gabboroic diorite which extends in north-south direction passing nearby the mountain top of EL. 226 m on the left bank of the Huai Yai; about 300 m upstream of the dam site. The sandstone is dark gray in colour and massive in texture. The sandy shale is black gray in colour and has a tendency to cleave readily from the bedding plane in weathered condition, but steady in unweathered condition. The gabbroic diorite is black gray in colour and very massive in texture.

The bedrock at the dam site strikes N7°E - N15°E and dips east at 70° - 80°, but those along the upper reaches of the river dip west at 60° - 65°. From this fact, it is considered that the dips of the bedrock has been dominated by the north-south fold structures. The distribution of intrusive rock seems to be concordant with sedimentary rock structures. According to the interpretation of aerial photograph, it was recognized that a lineament runs in direction of N20°W - S20°E passing through the saddle located on the right bank; approximately 400 m upstream from the dam site, and suspected that a zone of fractured rock might exist along the lineament, but field survey as well as the results of drillings conducted at the saddle portion did not show any existence of such zone.

According to the results of drillings (FIG. II-4), the highly weathered zone has not developed deep in and around this dam site; 2 m - 3 m at both right and left bank abutments, 6 m - 8 m in the flat area and 6 m - 9 m at the spillway and outlet structures sites. These drilling results also indicate that the bedrock at this dam site is quite stable as dam foundation; the best among the four dam sites. The position of groundwater table in the area accords to the topography; 3 m - 7 m in the valley portion and 14 m - 22 m in the hilly ridge portion.

The permeability tests conducted in the area show high Lugeon values of 20 to the depth of 25 m in both valley and hilly rige portions, despite the stable bedrock is expected as mentioned above. These high permeabilities may be attributed to the existence of openings along bedding plane, which can be closed by grouting. The permeability tests also show low Lugeon values of less than 10 below the depth of 25 m.

In the reservoir area terrace deposits are widely destributed along the river for the depth of 5 m. The deposits mainly consist of sand. The skirt of mountain in the reservoir area is mainly covered with talus deposits being composed of clayey soil intermixed with weathered rock. In this reservoir area quaternary deposits are also widely distributed mainly along the upper reaches of the river; 500 m - 600 m upstream from the dam site. This area can be used as the borrow area for embankment materials. Through the reconnaissance,any trace of collapse and collapsible deposits and slopes are not observed in the reservoir area, and accordingly there might be no suspicious factor for the land sliding after ponding.

3.4 Khlong Chaliang Lab Dam and Reservoir Site

The dam site is located about 28 km upstream of Khlong Chaliang Lab from the confluence with the Pasak river, or 12 km east of the Phetchabun municipality. The dam site is selected at the narrow neck, where the river debouches from the mountain, and the shape of gorge is relatively symmetric having a side slope of about 25° on the right bank and about 30° on the left bank. Long and narrow reservoir area is circumscribed by foothills. River terraces develop along both banks of the river.

Due to less existence of outcrops, it is difficult to observe the geological condition in the area precisely. However, based on visual inspection of the site and the results of drillings, it may be concluded that the bedrock at the dam site is categorized in Nam Duk Formation of Middle Permain Period and consists of hard sandstone and shale forming alternate strata. The sandstone is greenish gray in colour and composed of predominant fine grain size. The shale is black to black gray in colour and has a tendency to cleave readily from the bedding plane in weathered condition. The strata strike N30°W - N50°W and dip north at 40° - 60°. The geologic structure can not be confirmed through field inspection, but it may be concluded that there exists a folding axis running in NW - SE direction.

According to the results of drillings (FIG. II-5), the highly weathered zone of bedrock along the dam axis reaches down to 4 m - 5 m at the right bank abutment, 7 m - 8 m at the left bank abutment and the riverbed portion and 6 m - 8 m at the spillway and outlet structure sites. The groundwater table is observed at about 12 m below the ground surface at both bank abutments, and descends toward the riverbed almost according to the topography.

The permeability tests conducted at the dam site show rather high Lugeon values; more than 20, to the depth of 8 m - 10 m in the riverbed and 13 m - 15 m at both right and left bank abutments. These high permeabilities are mainly due to the existence of cracks in the rock structures. These high permiabilities can however be improved by grouting.

The riverbed portion in the reservoir area is covered with 6 m thick terrace deposits being composed of sand and gravels, but their distribution is limited within a narrow area and can not be expected as borrow area for the embankment materials. As a whole, the reservoir area has a gentle topography and its geological condition appears to be stable against the land sliding even after impounding the reservoir.

4. SITE GEOLOGY AND SOIL CONDITIONS ALONG IRRIGATION CANALS

4.1 Field Survey and Findings

In the most cases, the proposed irrigation canals will pass through three different topographies; gently-sloped skirt of mountain, diluvial plain and finally alluvial plain, because all the dam sites are selected at the debouching joints of the rivers. The following table shows the canal reaches grouped according to the respective topography.

	Topography	Huai Khon Kaen		Huai Yai	Khlong Chaliang Lab
		L.M.C.	R.M.C.		
(a)	Gently-sloped skirt of mountain	0 - 5.0 km 8.5 - 8.8 km	0 - 0.5 km	0 - 0.6 km	-
(b)	Diluvial plain	6.5 - 8.5 km	0.5 km	0.6 km	0.0 km
(c)	Alluvial plain	5.0 - 6.5 km	-	-	-

The followings are brief descriptions of typical strata in the respective areas.

(1) Gently-sloped skirt of mountain

Weathered rock is thinly overlain by talus and terrace deposits widely distributed over the area. Both talus and terrace deposits are composed of clayey soils intermixed with sand and gravels. The bedrock consists of weathered sandstone, shale and mudstone of Nam Duk Formation of Middle Permain Period or Chaliang Lab Formation of Tertiary Period. Since these deposits and bedrock had been formed in very old time and have become stable, their bearing capacity is big enough for the construction of canal structures.

(2) Diluvial plain

This area is covered with terrace deposits, talus deposits and fan deposits. According to the observation in test pits, terrace deposits consist of hard clayey soils which can stand for the vertical cutting, and just below this layer there lies a gravel layer. Talus and fan deposits are composed of clayey soils intermixed with fragments of weathered rock. These layers lie over bedrock and their thickness varies from place to place. Since this area is covered with hard clayey soil, all the layers have big bearing capacities enough for the construction of canal structures.

In the construction of canal embankment particularly at swamp portion, however, proper drain is needed to maintain good work quality.

(3) Alluvial plain

There is no clear boundary between the diluvial plain and the alluvial plain. The alluvial lowland is only observed along the Huai Khon Kaen Left Main Canal, where organic soils prevail, though their depth is less.

4.2 Characteristics of Weathered Rock and Soil

According to the visual observation of outcrops and the drilling results, the weathered rock in the project area is soft having many joints and a tendency to cleave readily from the bedding plane, and can be ripped easily. The permeability of this rock is high because of existence of openings along bedding plane in the rock.

As mentioned in the above, all the terrace deposits, talus deposits and fan deposits extending over the project area generally consist of hard clayey soils intermixed with gravels or fragments of weathered rock, and can be used as impervious zone materials for the construction of fill dam. The natural water contents of these soils except the soils distributed in swamp area are low, and the stability of these soils is not lowered even after the disturbance. These soils can, therefore, easily be treated when construction. The soils distributed in swamp area, particularly below the groundwater table, have high liquidity, and therefore the disturbance of these soils should be avoided when construction.

Alluvial deposits in the project area are composed of clayey soil with high natural water contents and organic soils. This layer has less bearing capacity, and the soils are not suitable for the embankment. The soils in paddy fields have almost the same character as that of the alluvial deposits.

5. CONSTRUCTION MATERIALS

5.1 General

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

(1) Talus deposits mainly consist of silty soils (ML-GM) intermixed with fragments of weathered sandstone and shale, and distribute over the gently sloped skirt of mountains nearby the proposed four dam site. This materials appears to be suitable for the impervious core zone of fill dam.

(2) Terrace deposits consist of clayey soils (CL-ML) with or without sand and gravel, and distribute along the meander belt of rivers in the proposed reservoir areas with width of 100 m - 150 m at both left and right bank. The sand and gravel content varies widely from 1% to 49% so far as determined by laboratory test on samples obtained from test-pits, and also occasional sand and gravel layers were found underneath the clayey deposits. This materials has a high clay content which may cause the cracking in embankment, and mixing process with the underlying sand and gravel or with the riverbed deposits is needed to improve the gradation for the core material of fill dam.

(3) Riverbed deposits consist of sand and gravel (GW) and distribute narrowly in the river channels of each reservoir area with width of 20 m - 40 m and thickness of 6 m in the maximum. An extensive riverbed deposits occur in the Pasak river at the section from the confluence with the Huai Saduang Yai to about 10-km downstream. Riverbed deposits in the Pasak river can be expected as the source of concrete aggregates and filter material.

(4) Sandstone/shale and its weathered zone underlie the mountains and gently sloped skirts, where whole proposed dam sites and reservoirs are located. Depth of weathered zone is deemed to range from 5 m in the valley flanks to 23 m at the ridges around the dam sites. Sandstone and shale occur generally as a frequent alternation with occasional thick sandstone layers. Weathered zone can be excavated without explosives and used for the shell zone of fill dam as the random fill materials.

(5) Quarried rock is obtainable from the existing Silalat crushing plant located 15-km southwest from Lom Sak and Saluong crushing plant located 15-km south from Phetchabun. Both plants produce aggregates and rip-rap rock from Paleozoic limestone layers.

The approximate required volume of construction materials are summarized in the following table.

(Unit: 1,000 m³)

Material	Dam Site	Huai Saduang Yai	Huai Khon Kaen	Huai Yai	Khlong Chaliang Lab
Fill Materials	Core zone	180	550	150	160
	Shell zone	820	2,830	620	630
	Filter zone	50	130	50	70
	Riprap	30	90	30	50
	Total	1,080	3,600	850	910

5.2 Possible Borrow Area

The locations of 16 test pits dug in this study are shown in FIG. II-7 through FIG. II-10, and the description of soil condition in each test pit is made in TABLE II-3.

5.2.1 Huai Saduang Yai Area

(1) Core material

For this area, two borrow areas are selected as shown in FIG. II-7. TP-1 in the downstream borrow area and TP-4 in the upstream borrow area show that the soils are composed of terrace deposits of clayey soil with less content of sand and gravels. The terrace deposits widely destributed over the reservoir area are mostly composed of clayey soil. These soils are well compacted. In TP-2 and 3 in the downstream borrow area, it is observed that the soils are composed of talus deposits of clayey soil intermixed with fragments of weathered sandstone and shale. The thickness of terrace deposits is more than 3 m, and that of the talus deposits varies from place to place, overlying the weathered bedrock.
The gravel-intermixed clayey soils of talus deposits can be used as core materials, but their available quantities are not clear, because these layers are found in very limited areas and their depths vary from place to place. If the shortage of the core materials is found during the construction time, the mixed layers of clayey soils and riverbed materials in the terrace deposit area will be used as the core materials.

(2) Random material

Random material is obtainable from the low rolling hills in the left flanks of reservoir area within 1,000 m from the dam site. Based on the results of boring investigation in and around the dam site, it is presumed that the hills are underlain by predominant sandstone and shale, and covered by the highly weathered zone of 5 m - 12 m thick and the moderately weathered zone of 8 m - 11 m thick. These weathered zone are likely excavatable with heavy equipment without explosives, and could be used for the random fill. Available volume of this material is estimated as 700 m x 200 m in area and 10 m in average thickness amounting 1,400,000 m^3. Minor difficulty in embankment with the moderately weathered shale might be exist because of its quick weathering and crumbling phenomena by repetition of saturation and drying which takes place in the upstream shell zone of dam. Therefore, such a material highly containing shale fragments should be used for the downstream shell zone of dam. The detailed check of distribution of predominant shale area should be done with borings prior to the detailed design stage.

5.2.2 Huai Khon Kaen Area

(1) Core material

Two borrow areas are selected in this area as shown in FIG. II-8. The borrow area - (A) is selected in the reservoir area, where the soils are composed of gravels, sand and silty gravels of terrace deposits and talus deposits. The borrow area - (B) is selected around 1-km west from the dam site. The soils in the borrow area mainly consist of clayey soil. For the use of these soils as core material, therefore, it is necessary to mix these soils with the soils excavated in the borrow area - (A).

(2) Random material

Weathered bed rock is obtainable from the left flanks of reservoir area within 1,500 m from the dam site. A predominant sandstone area is found in the left bank at about 700 m to 1,200 m upstream from the dam site, and expected to produce the random material with volume of 1,500,000 m^3 from the area of 500 m x 200 m with 15 m thick on an average. This weathered sandstone would be used for the upstream shell zone. For the downstream shell zone, a random fill with weathered shale would be suggested to be utilized. The huge volume of said material distributes in the reservoir area. Further investigations and laboratory tests are required to define the borrow area and to determine the mechanical characteristics of weathered shale.

5.2.3 Huai Yai Area

(1) Core material

Four borrow areas are selected in the downstream area from the dam site as shown in FIG. II-9. In these borrow areas, clayey soils of the terrace deposits are found in the depth of 2.5 m from the ground surface and sand and gravel layers below 2.5 m depth. For the use of these soils as the core materials, it is needed to mix the soils excavated from both clayey soil layers and the sand and gravel layers.

(2) Random material

The random materials can be found in the sand and gravel layers in the same borrow area of core material, but there might be some difficulty of excavation below the groundwater table. Since these borrow areas are far located from the dam site, the transporation cost will become high. The availability of random materials should therefore be checked in the reservoir area.

As for the weathered rock, predominant sandstone area is found in the low rolling hills at about 300 m downstream of left abutment. The available volume of rippable weathered sandstone is estimated at about 800,000 m^3 in the area of 300 m x 400 m with thickness of 7 m on an average. This material might be much preferable for the random fill.

5.2.4 Khlong Chaliang Lab Area

(1) Core material

A borrow area is selected on the left bank of the Khlong Chalinag Lab; around 1-km downstream from the dam site, as shown in FIG. II-10. Since this borrow area is covered with clayey soils intermixed with gravels, the excavated materials in this borrow area can be used as the core materials without any treatment.

(2) Random material

Weathered sandstone is obtainable from a small hill in the left bank at about 700-m upstream from the dam site. The available volume might be about 600,000 m^3 from the area of 200 m x 300 m with thickness of 10 m on an average. This material would be used for the upstream random fill of shell zone. For the downstream shell zone, weathered shale would be obtained from the foothills of left flanks of reservoir area within 1,000 m from dam site.

5.2.5 Required and Available Quantities of Embankment Materials

(1) Core and random materials

The following table shows the approximate required and available quantities of embankment materials.

(Unit: 1,000 m^3)

Dam Sites	Dam Embankment Volume		Available Quantities	
	Core Zone	Shell Zone	Core Materials	Random Materials
Huai Saduang Yai	180	820	340	w.s.s. 1,400
Huai Khon Kaen	550	2,830	900	w.s.s. 1,500
Huai Yai	150	620	3,270	w.s.h. limit less
Khlong Chaliang Lab	160	630	300	w.s.s. 600

(w.s.s.-weathered sandstone, w.s.h.-weathered shale)

(2) Riprap, filter and aggregate

There exist pure sand and gravel layers in very limited areas near all the dam sites except Huai Khon Kaen, where the sand and gravel layer of terrace deposits is found in the reservoir area. The bedrock distributed at the all dam sites consists of shale and sandstone of the Middle Permain Period, forming alternate strata. These rocks, particularly for shale, are not suitable as riprap materials, because the rock has a tendency to cleave readily from the bedding plane when submerged. From these reasons, the quarry sites for filter and riprap materials and concrete aggregates should be found out in the other areas.

For the construction of Huai Saduang Yai and Huai Khon Kaen dams, all these materials will be transported from the existing Silalat crushing plant located 15-km southwest from Lom Sak, where limestone is available. Since these two dam sites are located near the Pasak river, the filter materials and concrete aggregates can also be expected from the Pasak river.

As for the construction of Huai Yai and Khlong Chaliang Lab dams, all the materials will be procured from the existing Saluong crushing plant located 15-km south from Pnetchabun, where also limestone is available.

5.3 Characteristics of Material

5.3.1 Soil Sampling and Laboratory Test

In order to know the availability and suitability of soils in the project area as the impervious zone materials for fill dams, soil sampling and laboratory test are conducted in this study period. Four clayey soil samples are selected in the respective four areas mentioned above and first tested for their physical properties. After knowing their physical properties, two samples are selected out of four in the respective areas for the mechanical tests. The testing items conducted are mentioned below:

(1) Physical test

- specific gravity
- natural moisture contents
- gradation
- liquid limit
- plastic limit

(2) Mechanical test

- compaction test
- permeability test
- consolidation test
- shear test by applying the triaxial compression test (UU and CU)

All the above tests were carried out by RID laboratory based on the ASTM Standard. For the permeability test, the samples are prepared at the optimum moisture content, and for both consolidation and triaxial compression tests, the samples are compacted at γd max x 95 % (wet side).

The number of soil samples for each testing items is shown in TABLE II-2.

5.3.2 Results of Tests

The results of the laboratory tests are mentioned in TABLE II-4 and the followings are brief descriptions of tested results.

(1) Physical properties

(a) Specific gravity

The specific gravity of the soil in the project area ranges from 2.62 to 2.73. Generally, the specific gravity of talus deposits is greater than that of terrace deposits. This tendency can be explained by the facts that the terrace deposits are mainly composed of clayey soil carried by floods, while the talus deposits are composed of weathered bedrock.

(b) Natural moisture contents

The natural moisture contents of the soils, all of which are collected above groundwater table, are summarized below:

Strata	Lowest	Highest	Mean
Terrace deposits	12.9%	22.9%	18.3%
Talus deposits	12.3%	20.7%	16.3%

There is less difference in the natural moisture contents between terrace deposits and talus deposits, and both deposits show fairly low percentage. This low percentage is mainly due to the facts that all the samples were collected near ground surface in the dry season. It is therefore considered that the actual values of these soil should be higher than the above.

(c) Consistency

Following table shows the liquid limits and plastic limits tested on the samples of terrace and talus deposits.

Strata	Liquid Limit (%)			Plastic Limit (%)		
	Lowest	Highest	Mean	Lowest	Highest	Mean
Terrace	27.5	42.2	35.6	19.8	29.5	24.8
Talus	39.9	53.4	45.4	27.5	34.7	31.1

Using these liquid limits and plastic limits, the consistency index (Ic) is calculated by the following formula:

$$Ic = \frac{WL - W}{Ip}$$

where, Ip: Plasticity index

WL: Liquid limit

W : Natural moisture contents

For most samples, the consistency index is equal to or more than 1. This means that the natural moisture contents are almost equal to or less than plastic limit, and the soil stability is not lowered even after the soil is disturbed by adding some water.

(d) Gradation

FIG. II-11 shows the gradation curves of the samples. As is clear from this figure, the terrace deposits contain 70% - 90% of fine-grained materials; less than 0.074 mm, while the talus deposits contain 35% - 55% of fine-grained materials and 20% - 40% of gravels with the grain size of more than 4.76 mm.

The uniform coefficient (Uc) and curvature coefficient (U'c) of the terrace deposits and $Uc > 10$ and $U'c = 1 \sim 3$, which show the well graded grain size, though the content of fine-grained materials is slightly high. While, those of the talus are $Uc > 50$ and $U'c < 1$, which show the less content of sand.

(2) <u>Mechanical Properties</u>

(a) Compaction characteristics

The results of the standard proctor compaction test are shown in FIG. II-12, while average values are summarized as follows:

Strata	γdmax (g/cm^2)	Wopt (%)	W95 (%)	γdmax x 0.95 (g/cm^3)	Wn (%)
Terrace deposits (almost clay)	1.724	16.9	20.9	1.638	18.7
Terrace deposits (including gravel)	1.827	14.5	18.7	1.736	17.2
Talus deposits	1.644	19.9	24.4	1.562	16.3

Note: γdmax: Maximum dry density
Wopt : Optimum moisture content
W95 : Highest water content to obtain 95% of γdmax
Wn : Natural moisture contents

In the above table, all the values for the terrace deposits (including gravel) and the talus deposits have been obtained by the standard tests after removing gravel retained on a 4.75 mm sieve, and accordingly these values should be different from those during actual construction. Since the embankment materials to be used for the construction would include gravel, larger γdmax and smaller Wopt can be expected. By increasing the compaction energy, larger γdmax and smaller Wopt than the values stated foremost can also be obtained. As a shole, it can be said that all samples show γdmax of more than 1.60 g/cm^3, and the tested soils are stable having a high density.

The compaction test also indicates that the optimum moisture content of the terrace deposits is 2% - 3% smaller than the natural moisture content of 16% - 19%, and that of the talus deposits is 3% - 4% higher than the natural moisture content (FIG. II-13). Particularly for the talus deposits, natural soils contain more gravel than tested soils and the optimum moisture content would be lower than the tested value, hence optimum moisture content would be almost the same as the natural moisture content.

In conclusion, the soils in the project area are mechanically suitable for the dam embankment. However, when the embankment work is carried out in the condition of W95, it is necessary to increase the soil moisture content by 2% - 3% for most of the soils.

Specimens for the following mechanical tests are prepared under the condition that the dry density is to be 95% of the maximum dry density ($\gamma dmax$) with a water content slightly more than the proctor optimum.

(b) Permeability

The results of permeability tests are summarized as follows:

Strata	Coefficient of Permeability: K (cm/sec)
Terrace deposits (almost clay)	1.0, 2.7, 1.0 x 10^{-7}
Terrace deposits (including gravel)	4.4 x 10^{-7}
Talus deposits	6.2, 2.0, 6.9, 2.0 x 10^{-7}

Since the terrace (including gravel) and talus deposits include sand and gravel, the permeability values thereof are slightly bigger than that of the terrace deposits (almost clay). All values, however, are in the order of magnitude of 10^{-7} cm/sec, so that the soils in the project area can be said to be impervious.

The direction of water flow in specimens for laboratory testing is vertical to the compacted layer, whereas the flow of water through a dam is parallel to the bedding planes. This fact means that the permeability values in the field are larger than those of laboratory tests, though there would not be as large a difference as an order of magnitude.

(c) Consolidation

The results of consolidation tests are summarized as follows:

Strata	Pc (t/m^2)	Cc
Terrace deposits (almost clay)	60, 80, 40	0.19, 0.14, 0.17
Terrace deposits (including gravel)	30	0.14
Talus deposits	30, 47, 41	0.20, 0.21, 0.21

As a whole, the values of rather small compression index: Cc of less than 0.2 and the values of rather large yield stress of consolidation: Pc of more than 30 t/m^2 present no problem for compressibility.

According to the gradation curves, the terrace and talus deposits are classified as clayey materials or clayey materials with gravel. The consolidation tests, however, characterize the same as sandy materials having no problem for compressibility.

(d) Shear test by triaxial compression

Unconsolidated - undrained shear tests and consolidated - undrained shear tests are carried out so as to obtain shear strength characteristics of materials for stability analysis of conditions during the construction period and for conditions after dam settlement.

- Unconsolidated - undrained shear test

FIG. II-14 (a) shows all circles of stress obtained by tests and Mohr's strength envelop. Although the values of cohesion "c" and angle of internal friction "ø" is slightly different between terrace deposits (almost clay) and others depending on the gravel content, c of 0.27 kg/cm^2 and ø of 15° for all materials are applicable.

- Consolidated - undrained shear test

FIG. II-14 (b) shows all circles of stress obtained by tests and Mohr's strength envelop. There is no large dispersion depending on the gravel content for this test, and the values can be determined to be c' of 0.15 kg/cm^2 and ø of 30°.

5.3.3 Physical and Mechanical Properties of Soil

For this project the borrow areas of impervious core materials of dams will be selected in the terrace deposits area or talus deposits area. The terrace deposits contain 70 - 90% fine-grained particles to a depth of 3 m from the surface. Since this grain size distribution tends to cause cracking in embankment after banking, it is desirable that these materials be mixed with coarse sand and gravel materials before use as the impervious zone materials. The gradation curve of the materials used for the construction of the Srinagarind Dam is shown in FIG. II-15 as a reference.

As the impervious core materials in the project area are classified as CL and ML - CL according to the Unified Soil Classification, and in addition, the consistency index thereof is 1 or greater, it may be assumed that said materials are sufficiently stable for embankment use. Furthermore, the results of consolidation testing characterize the materials to be sandy, featuring lesser consolidation settlement.

On the basis of the above results, it is desirable that the terrace deposits be mixed with sand and gravel before use as the impervious zone materials, although it is considered as still possible to utilize said terrace deposits as impervious zone material without and additional admixture of coarser material. As the talus deposits contain a less amount of fine-grained particles compared to the terrace deposits, as well as featuring a consistency index of more than 1, said material could be used in its present form for the impervious zone.

5.3.4 Soil Mechanical Values for Stability Analysis of Embankment

Soil mechanical values for stability analysis of the embankment are derived from the results of soil mechanical tests for impervious core material and from the existing data for random material.

(1) Impervious core material

(a) Density

Density is determined as follows:

Dry density: $\rho d = 0.95 \times \gamma dmax$; 95% of $\gamma dmax$ obtained by compaction test

Wet density: $\rho t = (1 + w)\rho d$

where, w: Optimum moisture content

Saturated density: $$\rho sat = \frac{1}{\frac{1}{Gs} + \frac{w}{Sr}} \cdot \rho w \cdot (1 + w)$$

where, Gs: Specific gravity

ρw: Density of water (Pw = 1)

Sr: Degree of saturation (Sr = 100%)

Out of the proposed four dams, terrace deposits are to be used for impervious core for the Huai Sanduang Yai, Huai Khon Kaen and Huai Yai dams, whereas for the Khlong Chaliang Lab dam the talus deposits are to be used for impervious core. The average values obtained by soil tests and the determined values for stability analysis are listed below.

	Average of Tests			Values for Stability Analysis		
	ρ_d	ρ_t	ρ_{sat}	ρ_d	ρ_t	ρ_{sat}
Huai Saduang Yai						
Huai Khon Kaen	1.643	1.915	2.136	1.6	1.9	2.1
Huai Yai						
Khlong Chaliang Lab	1.565	1.872	2.101	1.5	1.8	2.0

Submerged density: ρ_{sub} is determined by the following formula:

$$\rho_{sub} = \rho_{sat} - 1$$

(b) Shear strength

Based on the results of shear tests (FIG. II-14), the values of cohesion "C" and angle of internal friction "ϕ" are determined as follows:

- Unconsolidated - undrained

Although there is some dispersion of the test results depending on the gravel content, cohesion of 0.27 kg/cm^2 and angle of internal friction of 15° can be expected on the average. The values for stability analysis are determined as follows and are adopted for the four dams.

Cohesion: $C = 0.25$ kg/cm^2
Angle of internal friction: $\phi = 15°$

- Consolidated - undrained

There is no notable dispersion of the test results, and said results indicate a linear relation between τ and σ. Accordingly, the following values are determined for stability analysis.

Cohesion: $C' = 0.15$ kg/cm^2
Angle of internal friction: $\phi' = 30°$

(c) Coefficient of permeability

As all the values of permeability tests for the four dams range from 1×10^{-7} cm/sec to 7×10^{-7} cm/sec, the materials can be said to be impervious. Considering the fact that the flow of water through the dam is parallel to the compacted layers, the value for dam design is determined as follows:

Coefficient of permeability: $K = 5 \times 10^{-6}$ cm/sec

(d) Values for dam settlement analysis

Dam settlement "ΔH" is defined as follows:

$$\Delta H = \left(\frac{W \cdot Hb^2}{2E} + \frac{W \cdot Ha \cdot Hb}{E}\right) \cdot A$$

$$E = \frac{Pm}{S}$$

where, Ha: Embankment height above an arbitrary point
Hb: Embankment height below the point
W : Unit weight of embankment
Pm: Maximum possible load
S : Total settlement
A : Coefficient of settlement (A = 0.35)

The amount of settlement at dam crest (Ha = 0) is defined as follows:

$$\Delta H = \frac{1}{2E} \cdot W \cdot h^2 \cdot A$$

where, $h = Ha + Hb$

The value E is determined based on the relation between σ' and Δ (FIG. II-16) for each dam as follows:

	E (kg/cm2)
Huai Saduang Yai	55
Huai Khon Kaen	110
Huai Yai	96
Khlong Chaliang Lab	74

(e) Pore water pressure

Pore water pressure "U" is defined by the Hilf method, which is based on consolidation test, as follows:

$$U = \frac{Pa \cdot \Delta}{Va + h \cdot \Delta w - \Delta} = \frac{Pa \cdot \frac{\Delta H}{H_o}}{n_o\ 1 - (1-h)\frac{S_o}{100} - \frac{\Delta H}{H_o}}$$

where, n_o: Porosity ($n_o = 100 - \frac{d}{Gs} \cdot 100$)

Gs: Specific gravity

γd: Dry density (g/cm^3)

h : Degree of air solution in water (h = 0.0198)

Vw: $Vw = n_o \cdot \frac{S_o}{100}$ (%)

S : Degree of saturation (%)

Va: $Va = n_o \cdot (1 - \frac{S_o}{100})$ (%)

Pa: Atmospheric pressure at the site (Pa = 1.032 kg/cm^2)

Δ : Compressive volume ratio ($\Delta = \frac{H}{H_o}$ %)

H_o: Thickness of settlement layer

ΔH: Compression volume

In addition, the total stress and pore water pressure mentioned above have an approximate relation of the following formula:

$$\sigma = \sigma' + U$$

where, σ : Total stress (kg/cm^2)

σ': Effective stress (kg/cm^2)

The calculated results are shown in TABLE II-5.

(2) Random material

Since soil tests have not been carried out for weathered sand stone of bedrock as random material, based on existing data of characters of weathered sand stone of the Pasak river basin and in Japan the necessary values for design of the dam are estimated. The determined values of random material are shown in the following table in contrast to those of impervious core material.

	Huai Saduang Yai		Huai Khon Kaen		Huai Yai		Khlong Chaliang Lab	
Dry density ρd (g/cm³)	1.6	1.9	1.6	1.9	1.6	1.9	1.5	1.9
Wet density ρt (g/cm³)	1.9	2.1	1.9	2.1	1.9	2.1	1.8	2.1
Saturated density ρsat (g/cm³)	2.1	2.2	2.1	2.2	2.1	2.2	2.0	2.2
Cohesion* C (kg/cm²)	0.25 0.15	0.1 0.1	0.25 0.15	0.1 0.1	0.25 0.15	0.1 0.1	0.25 0.15	0.1 0.1
Angle of internal* friction ø (°)	15 30	25 30	15 30	25 30	15 30	25 30	15 30	25 30
Coefficient of permeability K (10^{-6} cm/sec)	5	100	5	100	5	100	5	100

Note: Left side ; Impervious core material
Right side ; Random material
Top side ; Unconsolidated-undrained
Bottom side; Consolidated-undrained

STRATIGRAPHYCAL TABLE

AGE	GROUP	FORMATION	SYMBOL	GEOLOGICAL ASPECT
QUATERNARY			Qa	Alluvial deposit
			Qt	Terrace gravel, talus, delluvial deposit
TERTIARY		CHALIANG LAB	Cl	Shale, yellowish gray Calcareous mudstone
LOWER — MIDDLE JURASSIC	KHORAT	PHRA WIHAN	Pw	Sandstone with shale
LOWER JURASSIC		PHU KRADUNG	Pk	Shale Sandstone
UPPER TRIASSIC		NAM PHONG	np	Sandstone Conglomerate Shale
PERMO TRIASSIC		HUAI HIN LAT	hf	Tuff Agglomerate
MIDDLE PERMIAN		NAM DUK	nd	Shale Sandstone Limestone
LOWER-MIDDLE PERMIAN		PHA NOK KHAO	pn	Limestone Chart Shale
IGNEOUS ROCKS			G	Granite, diorite, gabbroic diorite

GEOLOGICAL INVESTIGATION AND SOIL TEST

	Huai Saduang Yai		Huai Khon Kaen		Huai Yai		Khlong Chaliang Lab	
	Re-quested	Com-pleted	Re-quested	Com-pleted	Re-quested	Com-pleted	Re-quested	Com-pleted
1. Drilling (No. of holes)								
(1) Dam axis	0	0	0	0	5	5	0	0
(2) Saddle	1	1	0	0	1	1	0	0
(3) Spillway	4	4	6	6	4	4	4	4
(4) Outlet	2	2	2	2	2	2	2	2
Total	7	7	8	8	12	12	6	6
2. Soil Test (No. of test holes)								
(1) Soil sampling	4	4	4	4	4	4	4	4
(2) Physical test								
- Specific gravity	4	4	4	4	4	4	4	4
- Natural moisture content	4	4	4	4	4	4	4	4
- Natural gradation	4	4	4	4	4	4	4	4
- Liquid limit	4	4	4	4	4	4	4	4
- Plastic limit	4	4	4	4	4	4	4	4
(3) Mechanical test								
- Compaction	2	4	2	4	2	2	2	4
- Permeability	2	2	2	2	2	2	2	2
- Consolidation	2	2	2	1	2	2	2	2
- Triaxial compaction	2	2	2	1	2	2	2	2

INSPECTION RESULTS OF BORROW PITS

Dam Site	Borrow Pit No.	Depth (m)	Unified Soil Classification
Huai Saduang Yai	TP. 1	0 - 3.0	dark reddish brown-coloured and well-consolidated clayey soil with less natural moisture contents
	TP. 2	0 - 1.0	reddish brown-coloured clayey soil intermixed with shale fragments
		1.0 - 1.5	weathered sandstone
	TP. 3	0 - 1.0	clayey soil intermixed with shale fragments
	TP. 4	0 - 2.5	clayey soil of terrace deposits with less natural moisture contents
Huai Khon Kaen	TP. 1	0 - 1.5	high weathered zone of bedrock and shale with well-developed joints
	TP. 2	0 - 1.5	clayey soil with less intermixed sand and gravels and less natural moisture contents
	TP. 3	0 - 3.0	clayey soil with less natural water contents and partly sandwiching the clayey soil intermixed with gravels
	TP. 4	0 - 1.5	clayey soil with less intermixed gravels
Huai Yai	TP. 1	0 - 2.9	clayey soil with less intermixed gravels and less natural moisture contents
	TP. 2	0 - 2.8	- do -
	TP. 3	0 - 2.2	- do -
		2.2 - 2.6	sand and gravel layer containing ø2 mm - ø20 mm rounded gravels and much clay
	TP. 4	0 - 1.7	clayey soil with less intermixed gravels and less natural moisture contents
		1.7 - 2.4	sand and gravel layer containing ø1 mm - ø30 mm rounded gravels and clay
Khlong Chaliang Lab	TP. 1	0 - 1.9	well-consolidated clayey solid containing weathered sandstone and shale fragments and with less natural moisture contents
	TP. 2	0 - 1.6	- do -
		0 - 1.3	- do -
		0 - 1.2	- do -

SUMMARY OF SOIL TEST
(Huai Saduang Yai)

		TP. No. 1	TP. No. 2	TP. No. 3	TP. No. 4
Sample No.		TP. No. 1	TP. No. 2	TP. No. 3	TP. No. 4
Sample Depth (m)		0.30-3.00	0.25-1.25	0.25-1.00	0.30-2.70
		Terrace dep.	Talus dep.	Talus dep.	Terrace dep.
Gradation	Gravel (%)	0	37.0	41.0	0
	Sand (%)	1.0	26.5	22.5	29.0
	Silt (%)	80.5	16.0	34.0	58.5
	Clay (%)	18.5	20.5	12.5	12.5
	Max. Diameter (mm)	4.76	38.1	38.1	2.38
	Coefficient of Uniformity Uc	12.2	-	1.815	15.8
	Coefficient of Curvature U'c	2.53	-	0.14	2.10
Consistency	Liquid Limit W_L (%)	42.2	53.1	53.4	30.4
	Plastic Limit W_p (%)	29.5	34.7	34.5	22.7
	Plastic Index I_p	12.7	18.4	22.7	7.7
	Consistency Index I_C	1.78	2.03	1.73	0.97
Classification		CL	GM	GM	CL
Specific Gravity of Soil G_S		2.62	2.72	2.71	2.63
Natural State	Water Content W (%)	19.6	15.7	20.7	22.9
	Wet Density γt (g/cm^3)				
	Void Ratio e				
	Degree of Saturation S_r (%)				
Mechanical Properties – Triaxial Compression	Type of Test *			UU / CU	UU / CU
	Cohesion C (kg/cm^2)			0.36 / 0.12	0.23 / 0.08
	Angle of Internal Friction ϕ (°)			14.5 / 30	11.4 / 31.6
Mechanical Properties – Consolidation	Yield Stress of Consolidation P_c (kg/cm^2)			30	40
	Compression Index C_c			0.20	0.17
Mechanical Properties – Compaction	Maximum Dry Density $\gamma dmax$ (kg/cm^2)	1.652	1.604	1.545	1.763
	Optimum Moisture Content Wopt (%)	17.5	21.0	24.2	15.4
Mechanical Properties – Permeability	Coefficient of Permeability K (cm/sec)		6.2×10^{-7}		1.0×10^{-7}

* UU: Unconsolidated, undrained, CU: Consolidated, undrained,

SUMMARY OF SOIL TEST

(Huai Khon Kaen)

Sample No.				TP. No. 1	TP No. 2	TP. No. 3	TP. No. 4	
Sample Depth			(m)	0.30-1.30	0.30-1.50	0.60-2.70	0.30-1.50	
				Talus dep. weathered rock	Terrace dep.	Terrace dep.	Terrace dep.	
Gradation		Gravel	(%)	40.0	1.0	7.0	0	
		Sand	(%)	38.0	18.0	28.0	18.5	
		Silt	(%)	16.0	56.5	52.0	68.5	
		Clay	(%)	6.0	24.5	13.0	13.0	
		Max. Diameter	(mm)	38.1	9.52	19.1	2.38	
		Coefficient of Uniformity	Uc	317.3	18.13	19.66	16.8	
		Coefficient of Curvature	U'c	7.26	0.94	1.02	3.09	
Consistency		Liquid Limit	W_L (%)	39.9	37.9	38.4	31.0	
		Plastic Limit	W_p (%)	27.5	24.8	26.8	22.7	
		Plastic Index	I_p	12.4	13.1	11.6	8.3	
		Consistency Index	I_C	2.22	1.58	1.83	2.20	
Classification				GM	ML	ML	ML	
Specific Gravity of Soil			G_S	2.69	2.63	2.66	2.66	
Natural State		Water Content	W (%)	12.3	17.2	17.2	12.9	
		Wet Density	γt (g/cm^3)					
		Void Ratio	e					
		Degree of Saturation	Sr (%)					
Mechanical Properties	Triaxial Compression	Type of Test	*				UU	CU
		Cohesion	C (kg/cm^2)				0.4	0.08
		Angle of Internal Friction	ϕ (°)				12.7	30
	Consolidation	Yield Stress of Consolidation	P_C(kg/cm^2)				80	
		Compression Index	C_C				0.137	
	Compaction	Maximum Dry Density	$\gamma dmax$ (kg/cm^2)	1.769	1.692	1.731	1.796	
		Optimum Moisture Content	Wopt(%)	15.9	17.8	18.0	14.4	
	Permeability	Coefficient of Permeability	K (cm/sec)	2.0×10^{-7}			2.7×10^{-7}	

* UU: Unconsolidated, undrained, CU: Consolidated, undrained,

SUMMARY OF SOIL TEST
(Huai Yai)

			TP. No. 1	TP No. 2		TP. No. 3		TP. No. 4
Sample Depth		(m)	0.50-2.80	0.50-2.70		1.90-2.60		0.50-1.60
			Terrace dep.	Terrace dep.		Terrace dep.		Terrace dep.
Gradation	Gravel	(%)	0	0		35.0		1.0
	Sand	(%)	7.0	11.5		14.0		22.5
	Silt	(%)	58.0	63.0		30.0		57.5
	Clay	(%)	35.0	25.5		21.0		19.0
	Max. Diameter	(mm)	4.76	4.76		38.10		9.52
	Coefficient of Uniformity	Uc	-	20.8		1,625.0		18.18
	Coefficient of Curvature	U'c	-	109.5		0.035		0.92
Consistency	Liquid Limit	W_L (%)	41.0	38.8		33.6		27.5
	Plastic Limit	W_p (%)	28.2	26.5		22.2		19.8
	Plastic Index	I_p	12.8	12.3		11.4		7.7
	Consistency Index	I_C	1.55	1.55		1.32		1.52
Classification			ML	ML		CL		CL
Specific Gravity of Soil		Gs	2.68	2.66		2.62		2.62
Natural State	Water Content	W (%)	21.1	19.7		18.6		15.8
	Wet Density	γt (g/cm^3)						
	Void Ratio	e						
	Degree of Saturation	Sr (%)						
Mechanical Properties: Triaxial Compression	Type of Test	*		UU	CU	UU	CU	
	Cohesion	C (kg/cm^2)		0.35	0.14	0.30	0.10	
	Angle of Internal Friction	ϕ (°)		14.5	30.5	16.5	30.2	
Mechanical Properties: Consolidation	Yield Stress of Consolidation	P_C (kg/cm^2)		60		30		
	Compression Index	C_C		0.19		0.134		
Mechanical Properties: Compaction	Maximum Dry Density	$\gamma dmax$ (kg/cm^2)	1.696	1.739		1.816		1.838
	Optimum Moisture Content	Wopt (%)	18.0	17.0		14.0		15.0
Mechanical Properties: Permeability	Coefficient of Permeability	K (cm/sec)		1.0×10^{-7}		4.4×10^{-7}		

* UU: Unconsolidated, undrained, CU: Consolidated, undrained,

SUMMARY OF SOIL TEST
(Khlong Chaliang Lab)

				TP. No. 1	TP No. 2	TP. No. 3	TP. No. 4
Sample No.				TP. No. 1	TP No. 2	TP. No. 3	TP. No. 4
Sample Depth			(m)	1.10-1.90	0.50-1.60	-	-
				Talus dep.	Talus dep.	Talus dep.	Talus dep.
Gradation		Gravel	(%)	19.0	37.0	19.0	48.0
		Sand	(%)	23.5	23.5	26.0	12.0
		Silt	(%)	43.0	22.5	40.5	28.0
		Clay	(%)	14.5	17.0	14.5	12.0
		Max. Diameter	(mm)	38.1	38.1	38.1	38.1
		Coefficient of Uniformity	Uc	62.1	1,714	91.3	1,031
		Coefficient of Curvature	U'c	0.77	0.12	0.91	0.15
Consistency		Liquid Limit	W_L (%)	40.0	41.9	41.4	47.8
		Plastic Limit	W_p (%)	29.3	29.4	28.7	33.4
		Plastic Index	I_p	10.7	12.5	12.7	14.4
		Consistency Index	Ic	2.14	2.10	1.76	2.34
Classification				ML	GM	ML	GM
Specific Gravity of Soil			Gs	2.62	2.69	2.67	2.73
Natural State		Water Content	W (%)	17.1	15.7	18.8	14.1
		Wet Density	γt (g/cm^3)				
		Void Ratio	e				
		Degree of Saturation	Sr (%)				
Mechanical Properties	Triaxial Compression	Type of Test	*	UU / CU	UU / CU		
		Cohesion	C (kg/cm^2)	0.6 / 0.11	0.35 / 0.15		
		Angle of Internal Friction	ϕ (°)	11.5 / 30	12.5 / 26.4		
	Consolidation	Yield Stress of Consolidation	P_c (kg/cm^2)	47	41		
		Compression Index	C_c	0.21	0.21		
	Compaction	Maximum Dry Density	$\gamma dmax$ (kg/cm^2)	1.622	1.667	1.643	1.660
		Optimum Moisture Content	Wopt (%)	18.8	18.7	20.2	20.5
	Permeability	Coefficient of Permeability	K (cm/sec)	6.9×10^{-7}	2.0×10^{-7}		

* UU: Unconsolidated, undrained, CU: Consolidated, undrained,

SUMMARY OF CALCULATED PORE WATER PRESSURE

HUAI SADUANG YAI

Δ	σ (No. 3)	σ (No. 4)
1	0.35	0.20
2	0.83	0.56
3	1.53	1.07
4	2.48	2.11
5	3.87	3.58
6	6.14	6.15
7.1	13.29	-
7.14	-	16.19

HUAI KHON KAEN

Δ	σ (No. 1)	σ (No. 4)
1	0.25	0.25
2	0.64	0.62
3	1.32	1.42
4	2.51	2.68
5	4.58	4.71
6	7.94	8.02
7	14.40	14.33
7.45	-	21.89
7.47	21.95	-

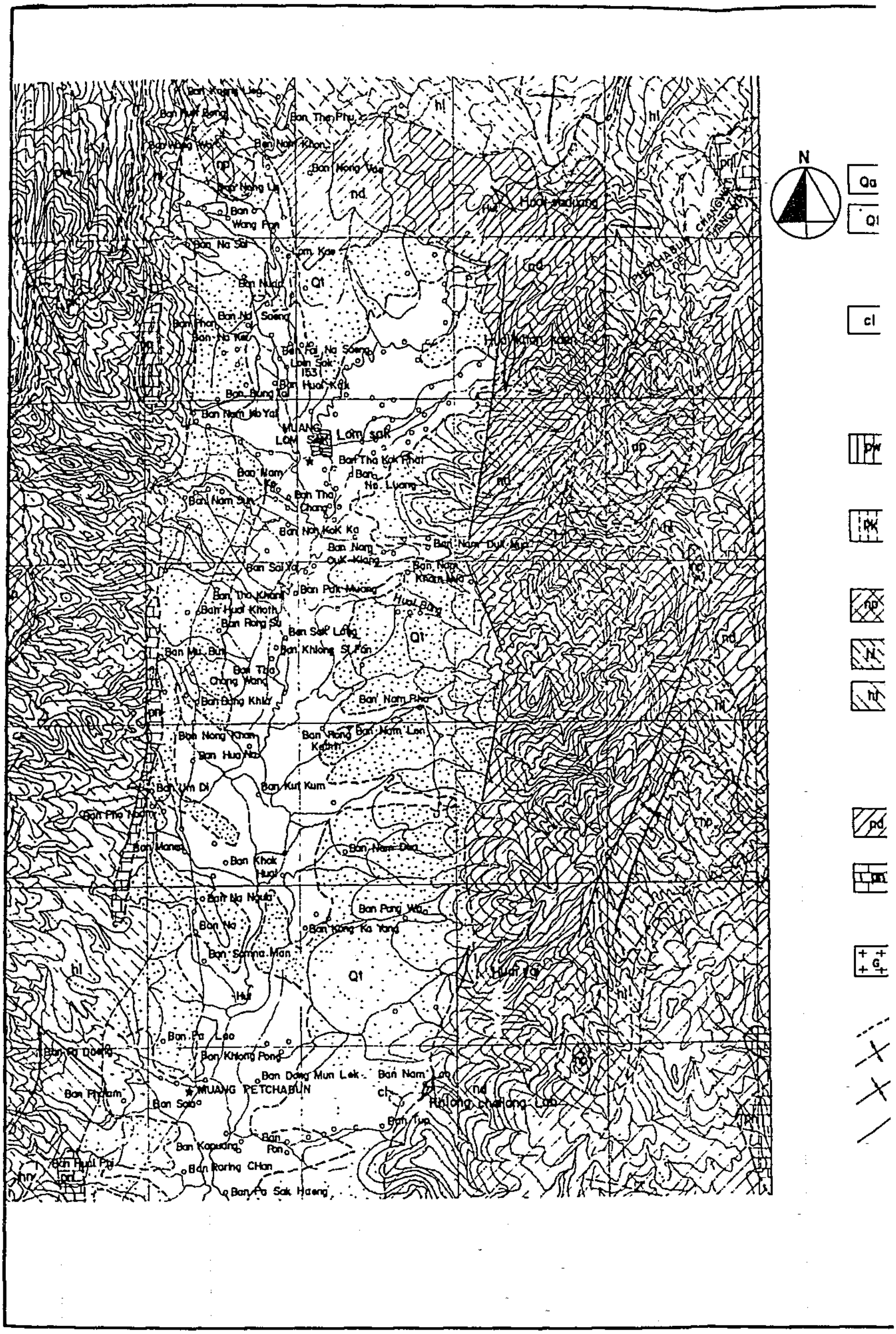
HUAI YAI

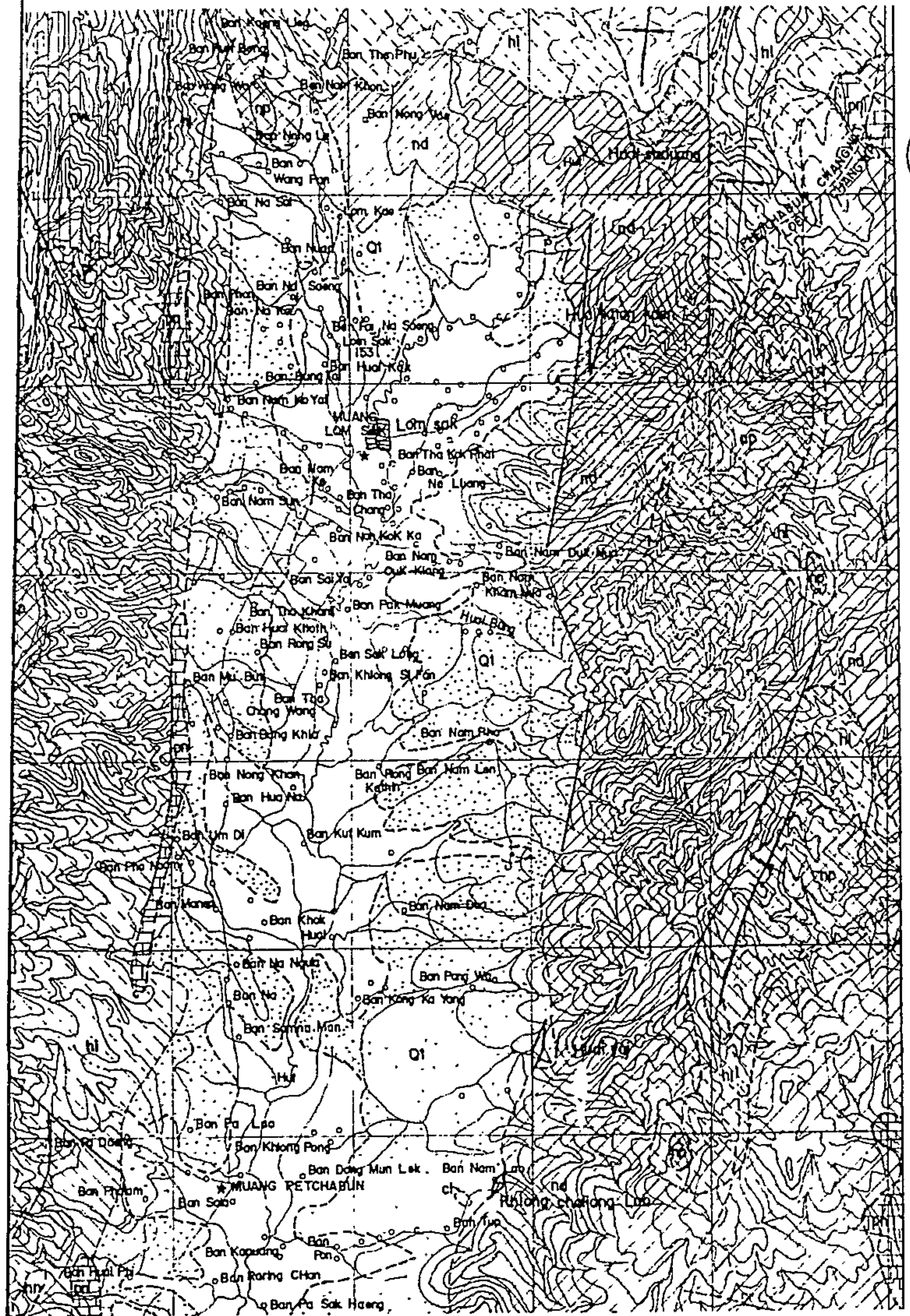
Δ	σ (No. 2)	σ (No. 3)
1	0.38	0.29
2	1.13	1.01
3	2.36	2.11
4	4.18	3.45
5	6.94	5.35
6	13.15	9.51
6.18	15.87	-
6.51	-	16.41

KHLONG CHALIANG LAB

Δ	σ (No. 1)	σ (No. 2)
1	0.22	0.25
2	0.67	0.99
3	1.40	2.15
4	2.40	3.34
5	3.85	4.72
6	5.63	6.41
7	7.83	8.73
8	10.92	13.41
8.59	-	21.24
9	18.21	-
9.27	23.25	-

Note: Δ ; Compression amount ratio to original volume (%)
σ ; Total stress (kg/cm^2)

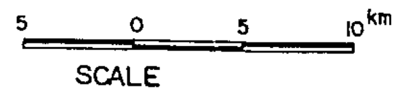

N
Qa
Q1
cl
Pw
Pk
np
hl
pd
G
Ban Thn Phu
Ban Nam Khon
Ban Nong Yae
Ban Wang Pan
Ban Na Sai
Ban Nua
Ban Na Soeng
Ban Tai Na Soeng
Lom Sak
Ban Huai Kok
Ban Bung Tal
MUANG LOM SAK
Lom sak
Ban Tha Kok Phai
Ban Na Luang
Ban Nam Sun
Ban Tha Chang
Ban Na Kok Ka
Ban Nam Duk Kiang
Ban Nam Duk Mai
Ban Sai Yai
Ban Pak Muang
Huai Bang
Ban Huai Khoth
Ban Rong Su
Ban Sak Long
Ban Khlong Si Pan
Ban Mu Bun
Ban Tha Chang Wang
Ban Bung Khla
Ban Nam Pho
Ban Nong Kham
Ban Hua Na
Ban Rong Kenin
Ban Nam Len
Ban Um Di
Ban Kut Kum
Ban Pho Ngam
Ban Mane
Ban Khok Huai
Ban Nam Dio
Ban Na Ngua
Ban Pong Wa
Ban Na
Ban Kong Ka Yang
Ban Somna Man
Huai Ra
Ban Pa Lao
Ban Pa Daeng
Ban Khlong Pong
Ban Dong Mun Lek
Ban Nam Lao
Ban Phlam
MUANG PETCHABUN
Ban Sao
Khlong Chaliang Lao
Ban Tup
Ban Kopuang
Ban Pan
Ban Raring CHan
Ban Huai Phi
Ban Pa Sak Haeng



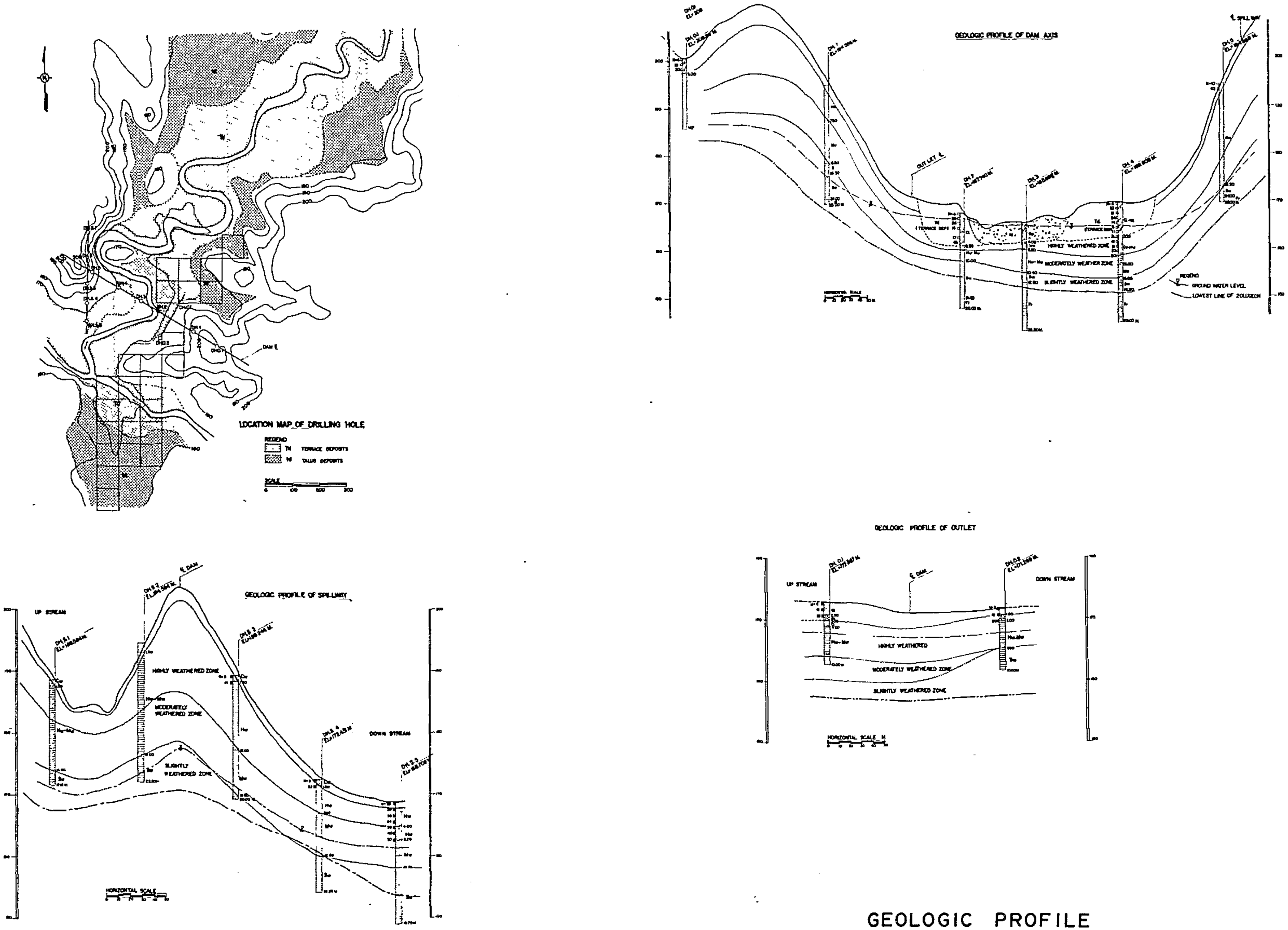
		Formation	Group	Age
Qa	Alluvial deposit			QUATERNARY
Qt	Terrace gravel, talus, colluvial deposit			QUATERNARY
	UNCONFORMITY			
cl	Shale : yellowish gray, calcareous. mudstone : white, calcareous welbedded	CHALIANG LAB		TERTIARY
	UNCONFORMITY			
pw	Sand stone, white pink orthoquartzitic cross bedded massive pebble layering on the upper bed, with some reddish brown and gray shale	PHRA WIHAN	KHORAT	LOWER MIDDLE JURASSIC
pk	Shale, brown, reddish brown, purplish red, micaceous siltstone, sandstone brown, gray, micaceous small scale cross bedded, with some lime-noduled conglomerate.	PHU KRADUNG	KHORAT	LOWER JURASSIC
np	Sandstone; reddish brown. brown, cross-bedded. conglomerate, pebbles of quartz, quartzite chert red siltstone. up to 10 cm. in diameter shale siltstone brown, reddish brown.	NAM PHONG	KHORAT	UPPER TRIASSIC
hl				
hl	Tuff, agglo merate rhyolite			PERMO TRIASSIC
	UNCONFORMITY			
nd	Shale; gray to black. sandstone, yellowish brown. fine-grained; limestone, lense and bedded. highly disturbant.	NAM DUK		MIDDLE PERMIAN
pn	Limestone, gray massive to thick bedded chert; black noduled or thin bedded. with thin bedded, gray shale	PHA NOK KHAO		LOWER - MIDDLE PERMIAN
	IGNEOUS ROCKS			
G	Granite, diorite gabbroic diorite			

SYMBOLS

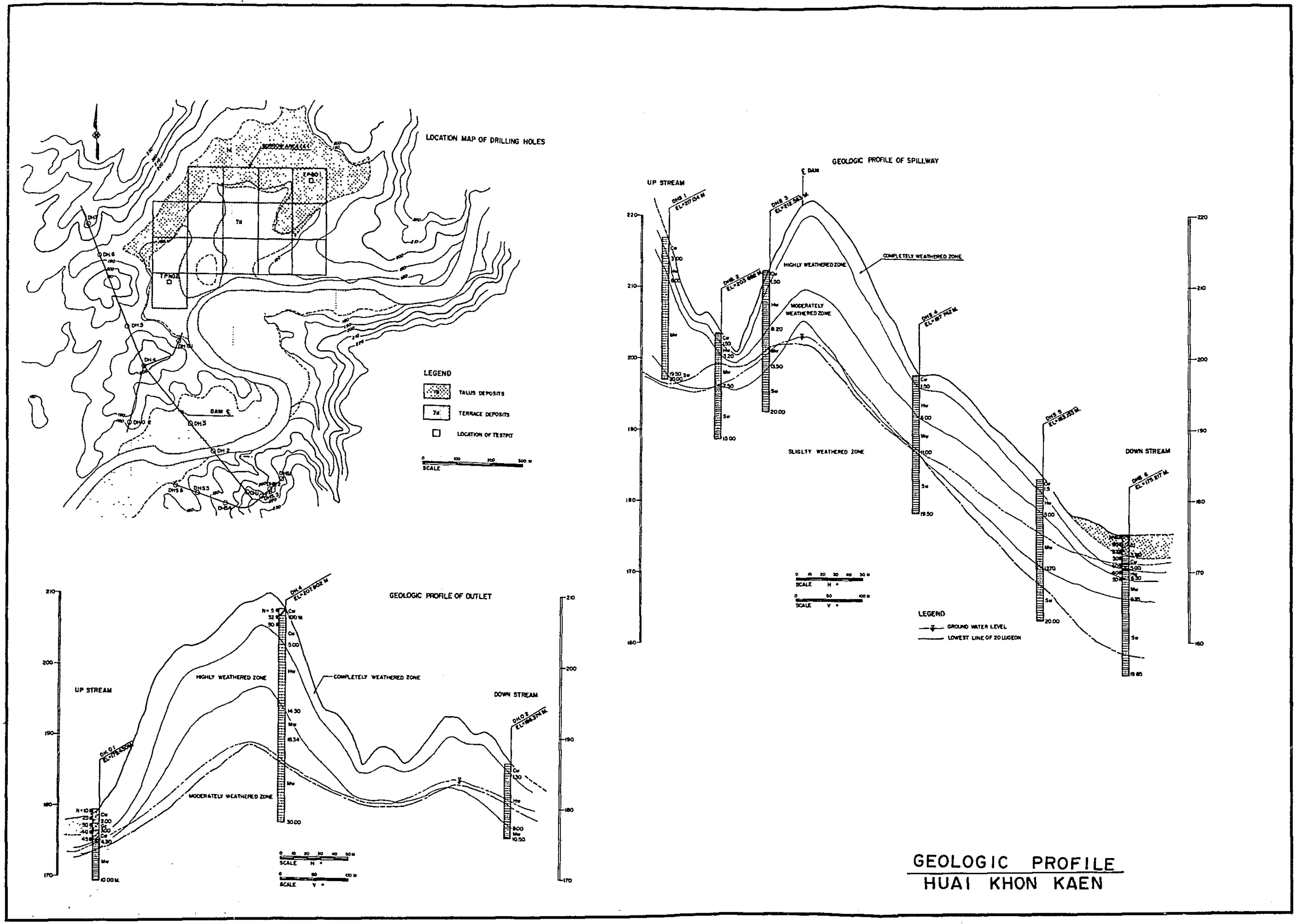
- Boundary
- Anticline, with plunging direction
- Syncline with plunging direction
- Fault



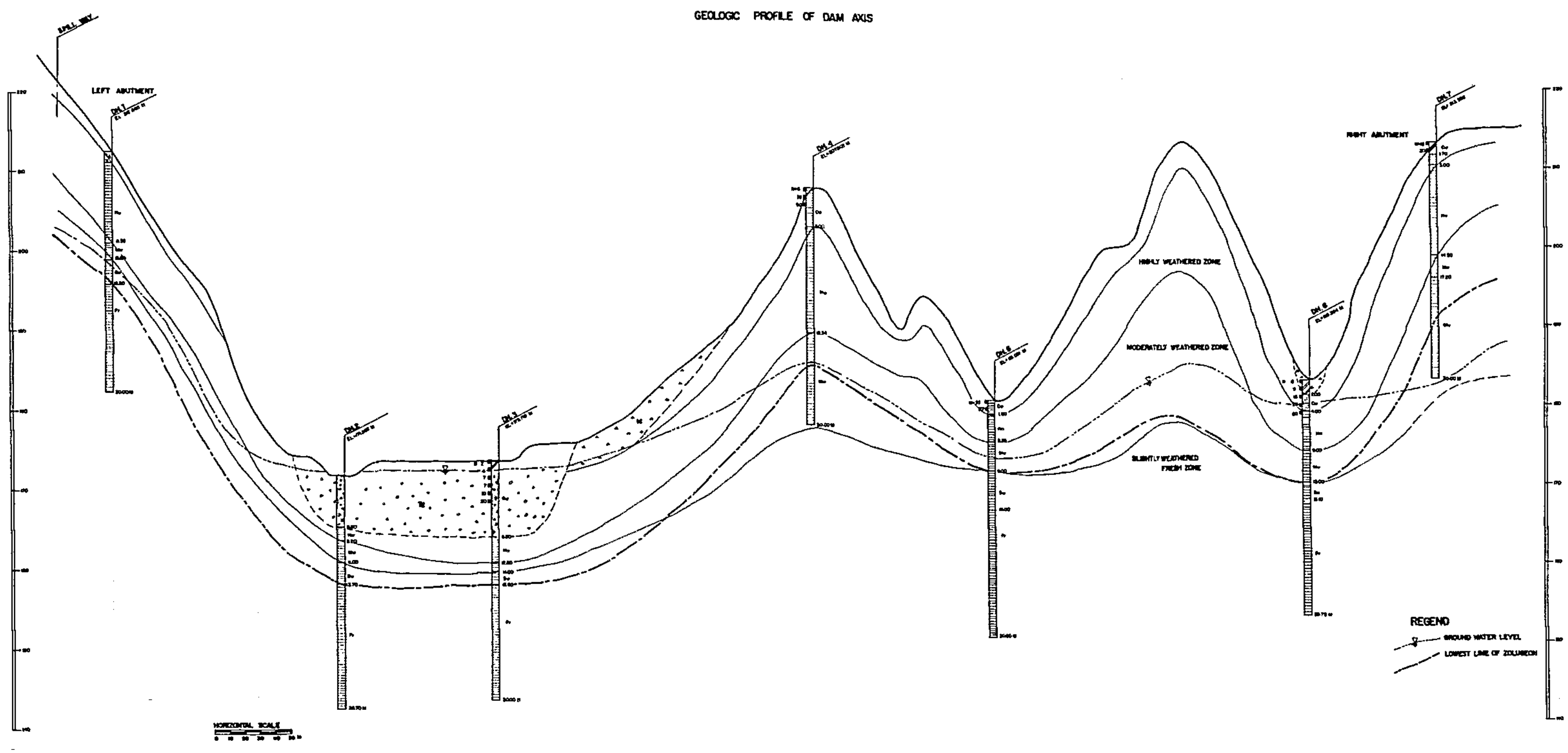
GEOLOGICAL MAP



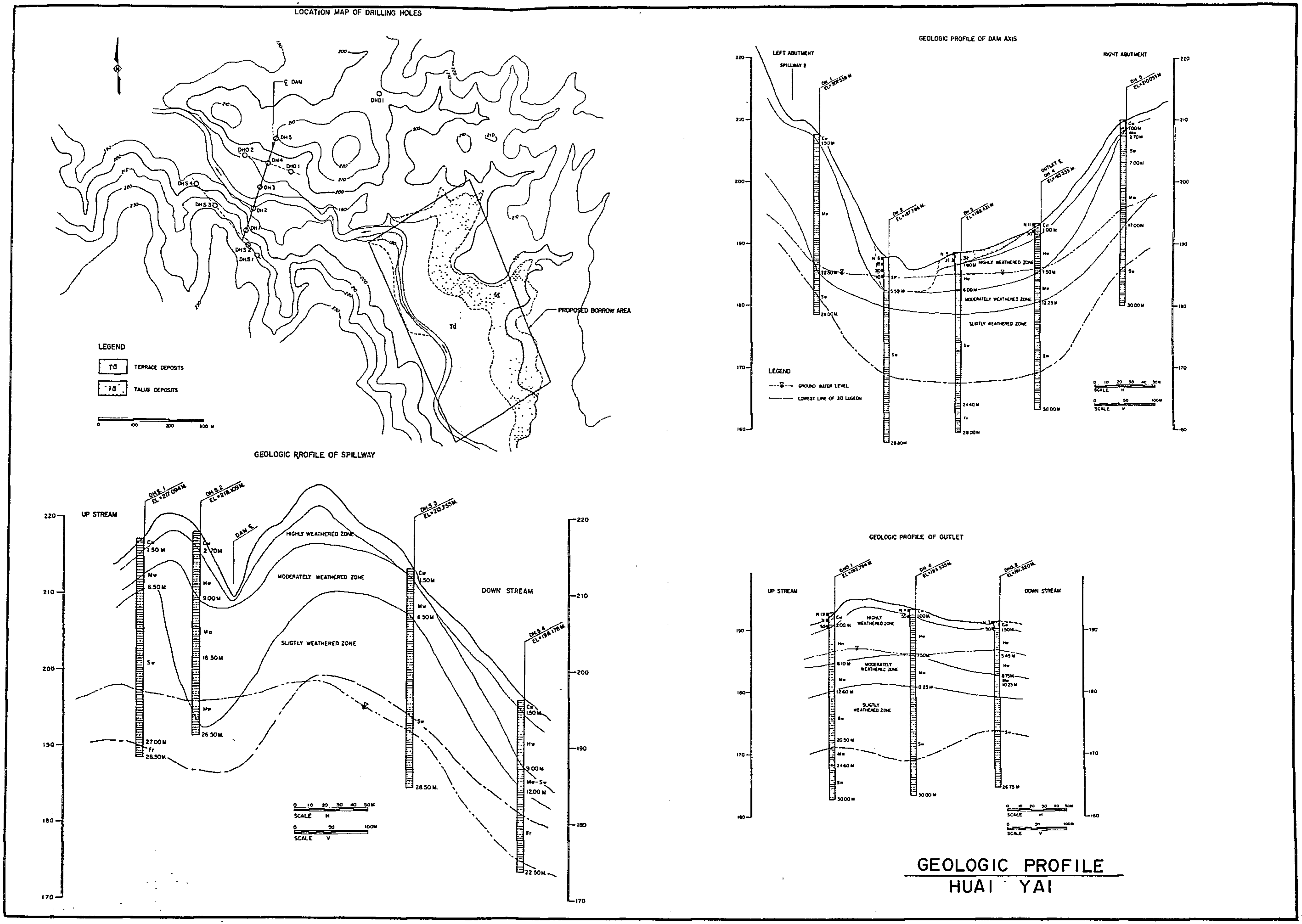
GEOLOGIC PROFILE
HUAI SADUANG YAI



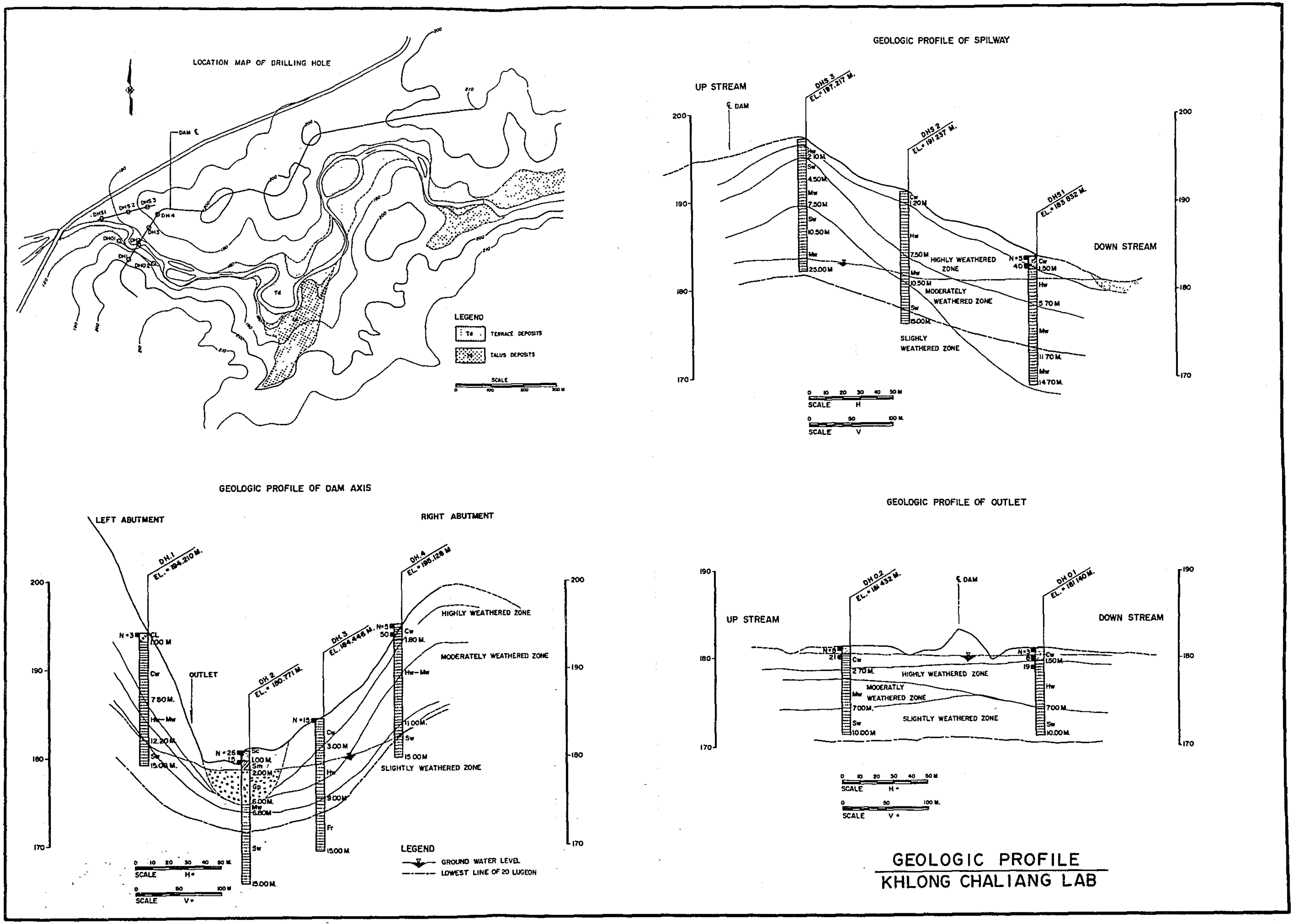
GEOLOGIC PROFILE
HUAI KHON KAEN



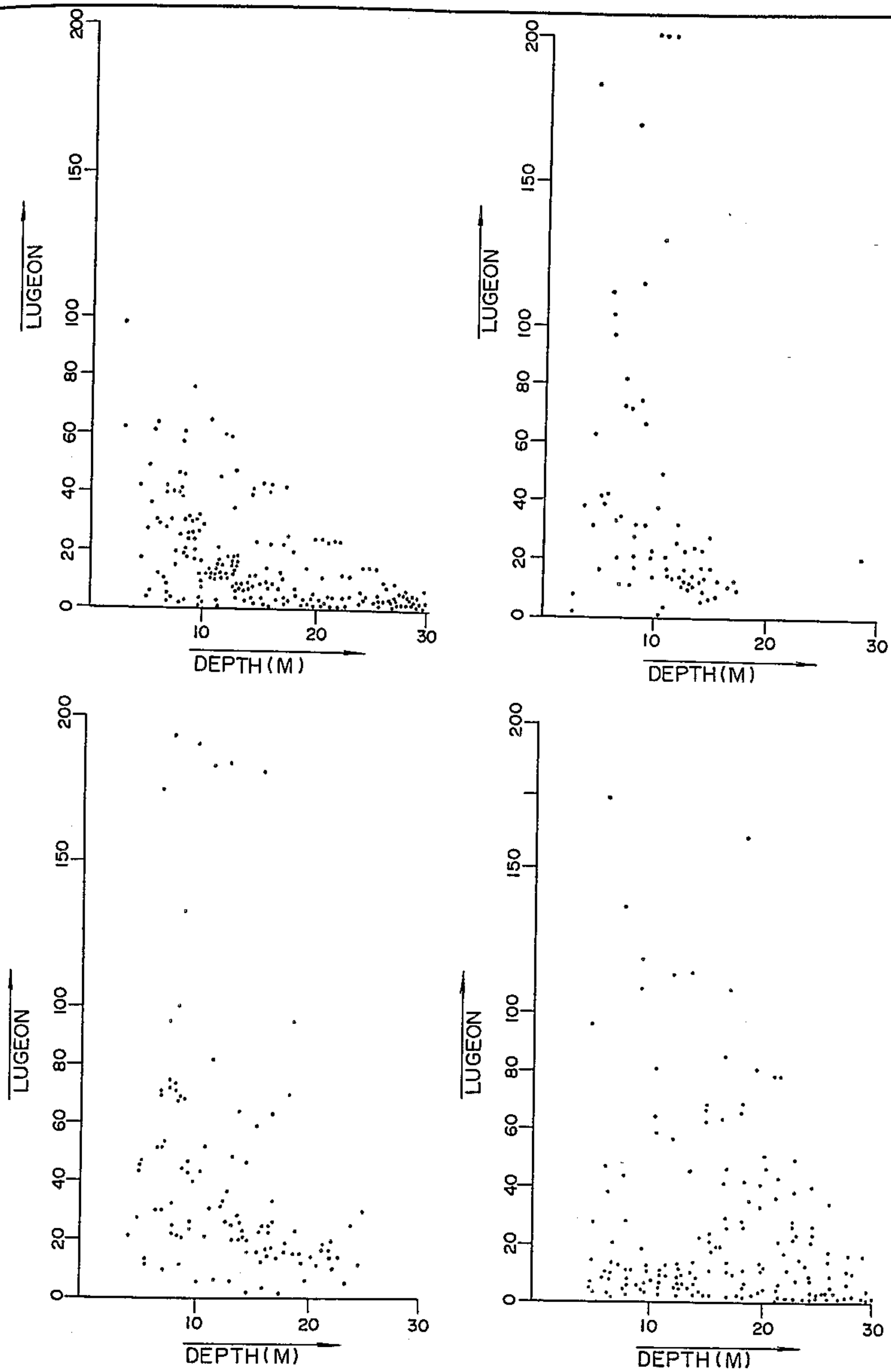
GEOLOGIC PROFILE
HUAI KHON KAEN



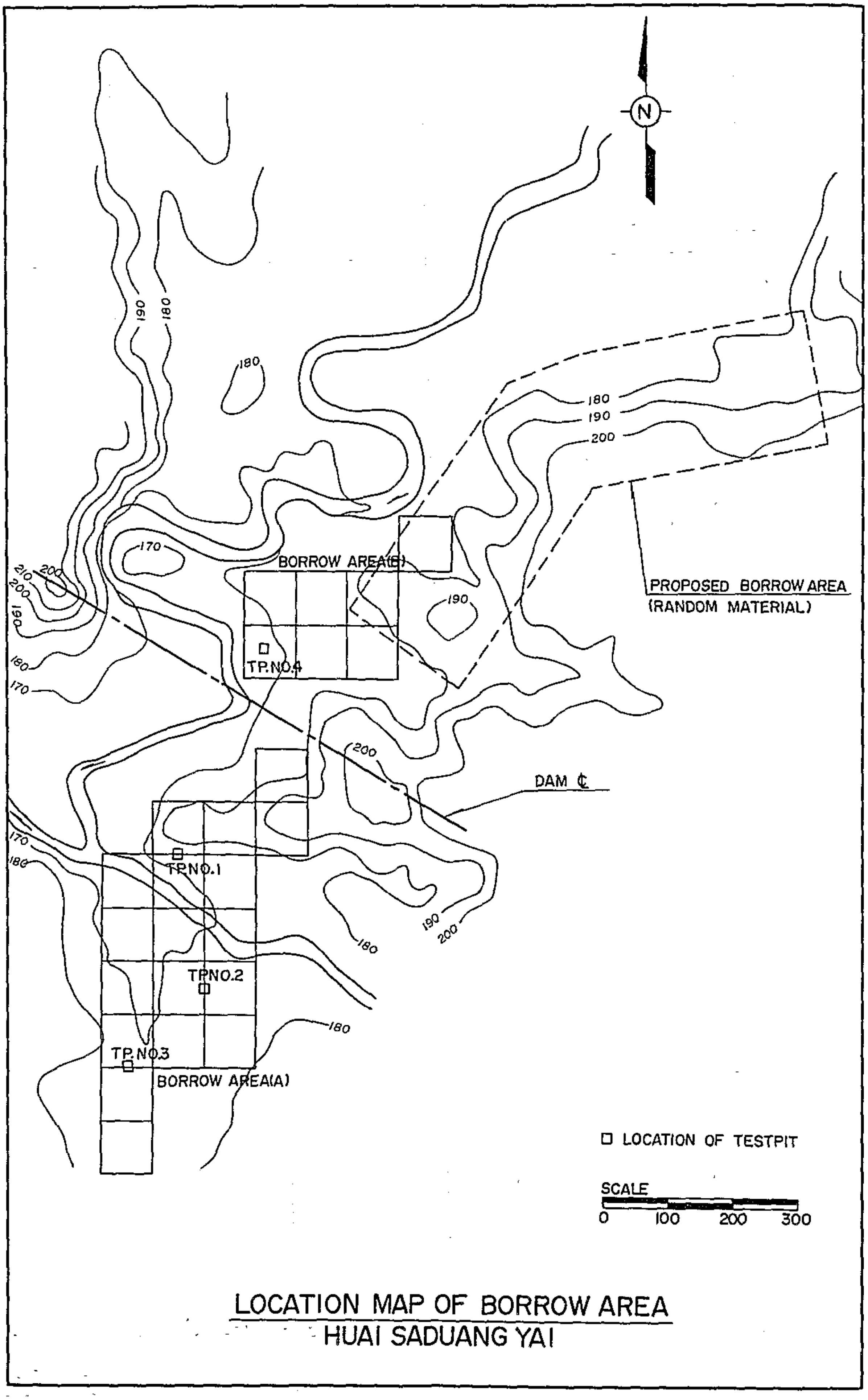
GEOLOGIC PROFILE
HUAI YAI



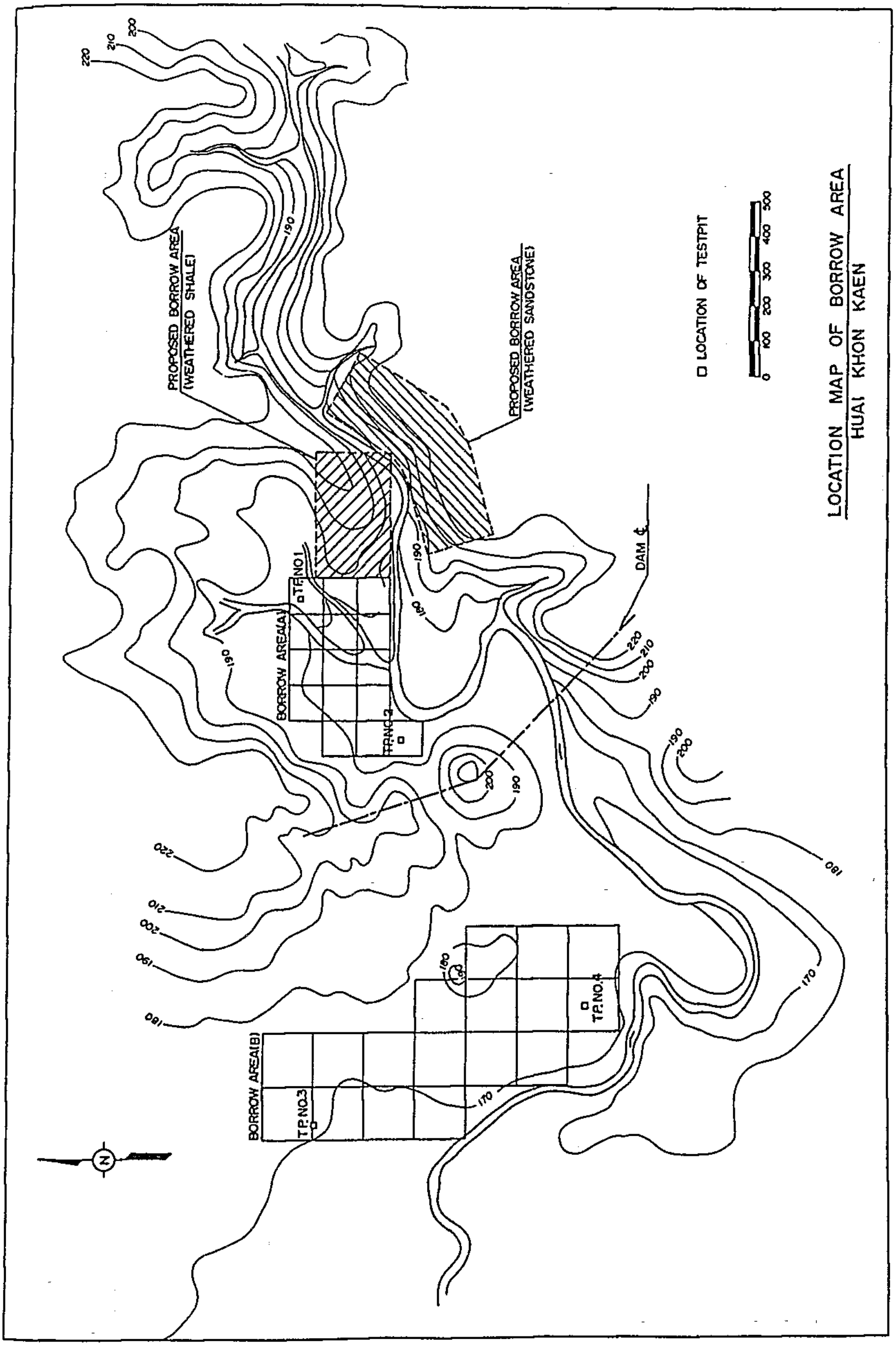
LOCATION MAP OF DRILLING HOLE
DAM ℄
DHS1
DHS2
DHS3
DH4
DHS
DH01
DH02
DH1
Td
LEGEND
Td TERRACE DEPOSITS
TALUS DEPOSITS
SCALE
GEOLOGIC PROFILE OF SPILWAY
UP STREAM
℄ DAM
DHS 3 EL.= 197.217 M.
DHS 2 EL.= 191.237 M.
DHS1 EL.= 185.852 M.
DOWN STREAM
HIGHLY WEATHERED ZONE
MODERATELY WEATHERED ZONE
SLIGHLY WEATHERED ZONE
SCALE H
SCALE V
GEOLOGIC PROFILE OF DAM AXIS
LEFT ABUTMENT
RIGHT ABUTMENT
DH.1 EL.= 194.210 M.
DH.2 EL.= 180.771 M.
DH.3 EL.= 184.446 M.
DH.4 EL.= 195.128 M
OUTLET
HIGHLY WEATHERED ZONE
MODERATELY WEATHERED ZONE
SLIGHTLY WEATHERED ZONE
LEGEND
GROUND WATER LEVEL
LOWEST LINE OF 20 LUGEON
SCALE H=
SCALE V=
GEOLOGIC PROFILE OF OUTLET
UP STREAM
DOWN STREAM
℄ DAM
DH02 EL.= 181.432 M.
DH01 EL.= 181.140 M.
HIGHLY WEATHERED ZONE
MODERATELY WEATHERED ZONE
SLIGHTLY WEATHERED ZONE
SCALE H=
SCALE V=
GEOLOGIC PROFILE
KHLONG CHALIANG LAB



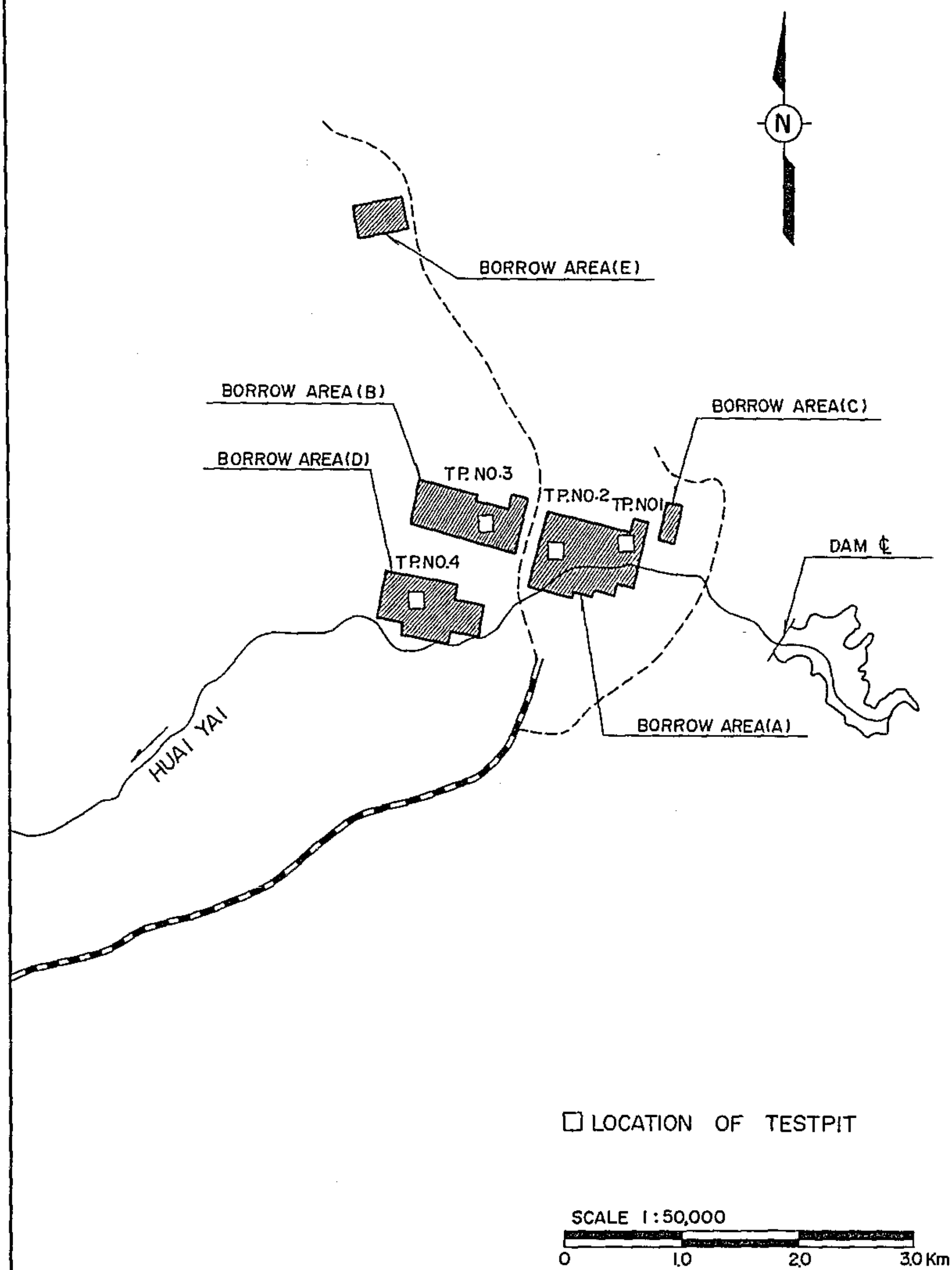
DISTRIBUTION CHART OF LUGEON VALUE



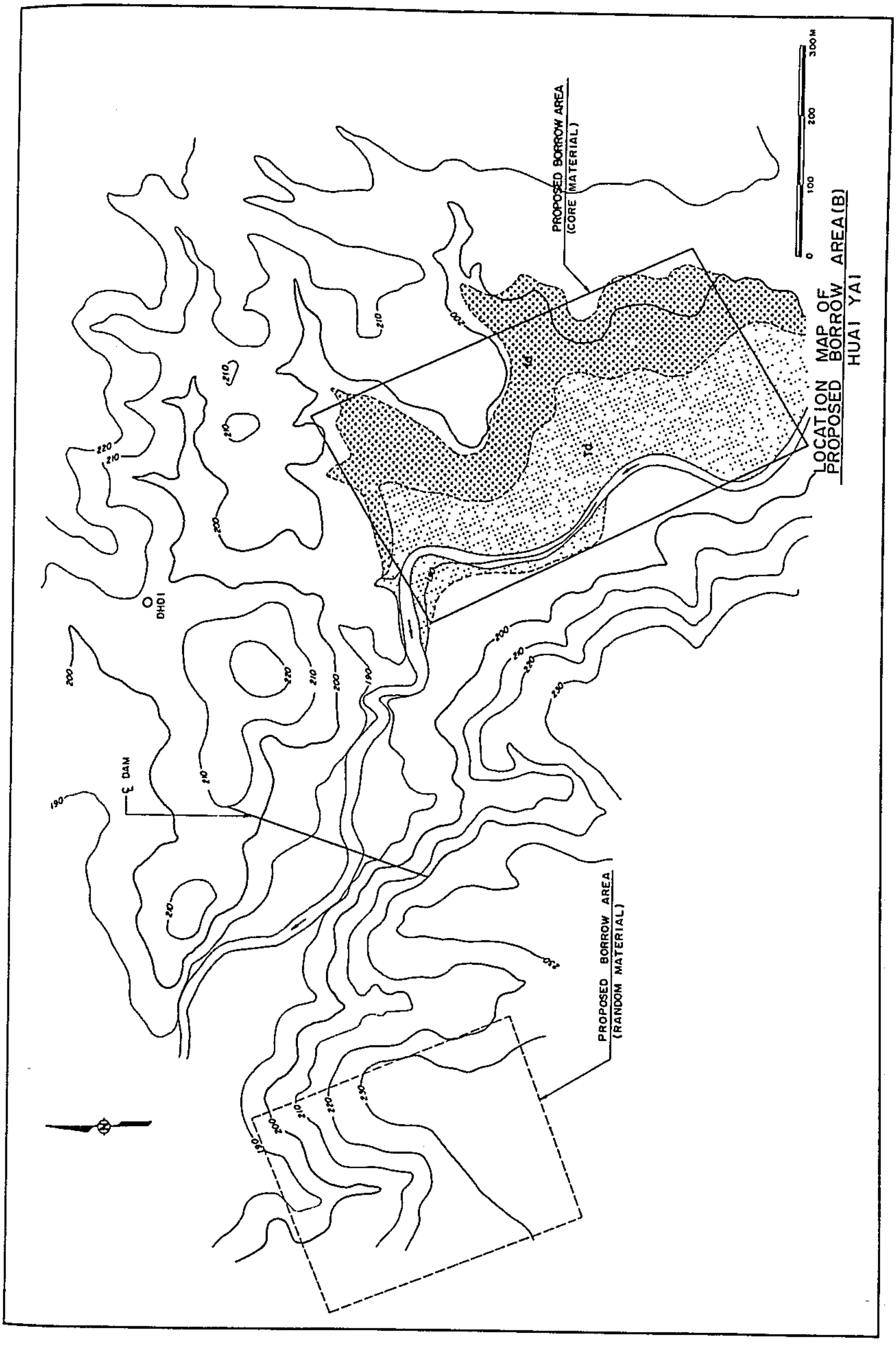
LOCATION MAP OF BORROW AREA
HUAI SADUANG YAI

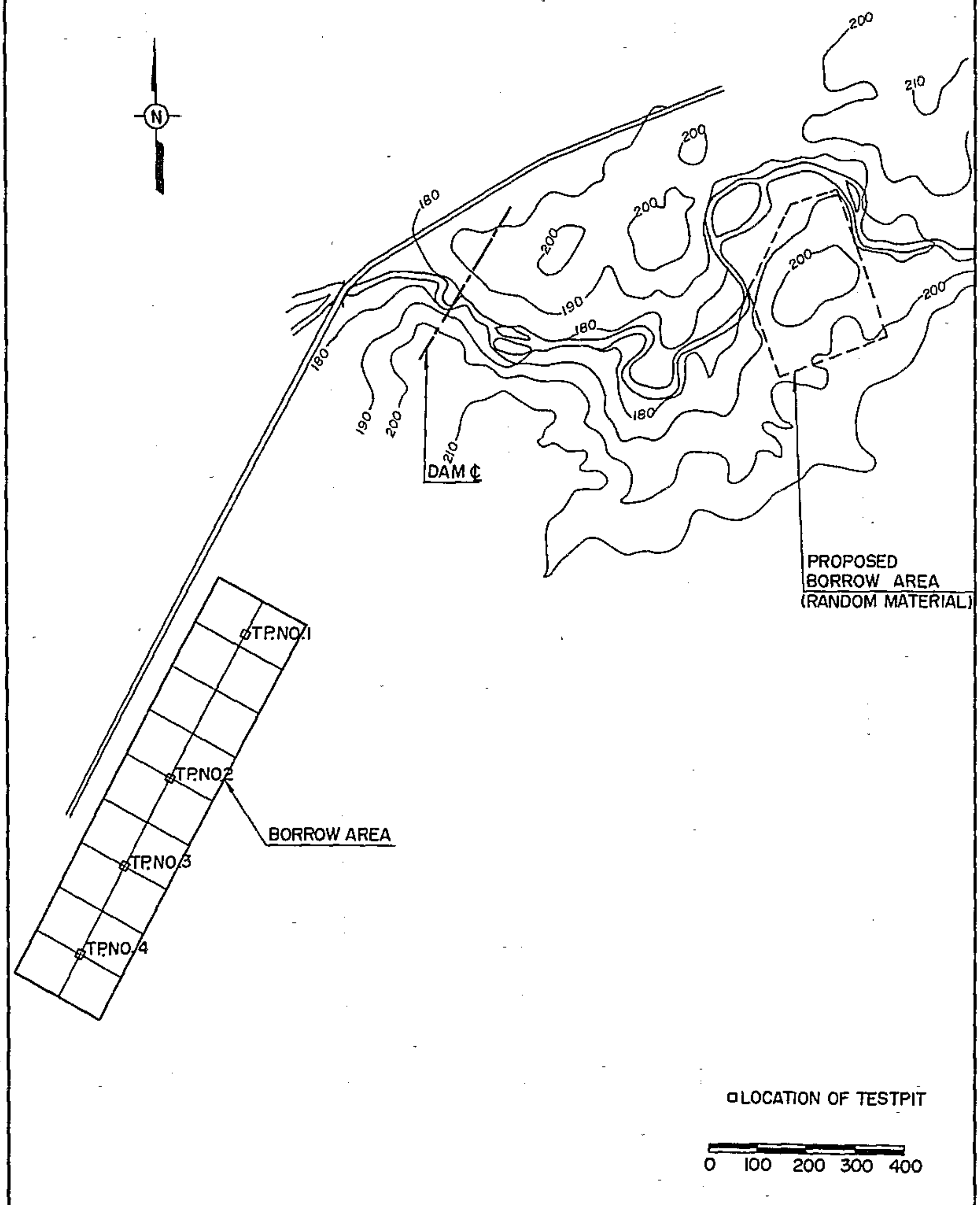


LOCATION MAP OF BORROW AREA
HUAI KHON KAEN

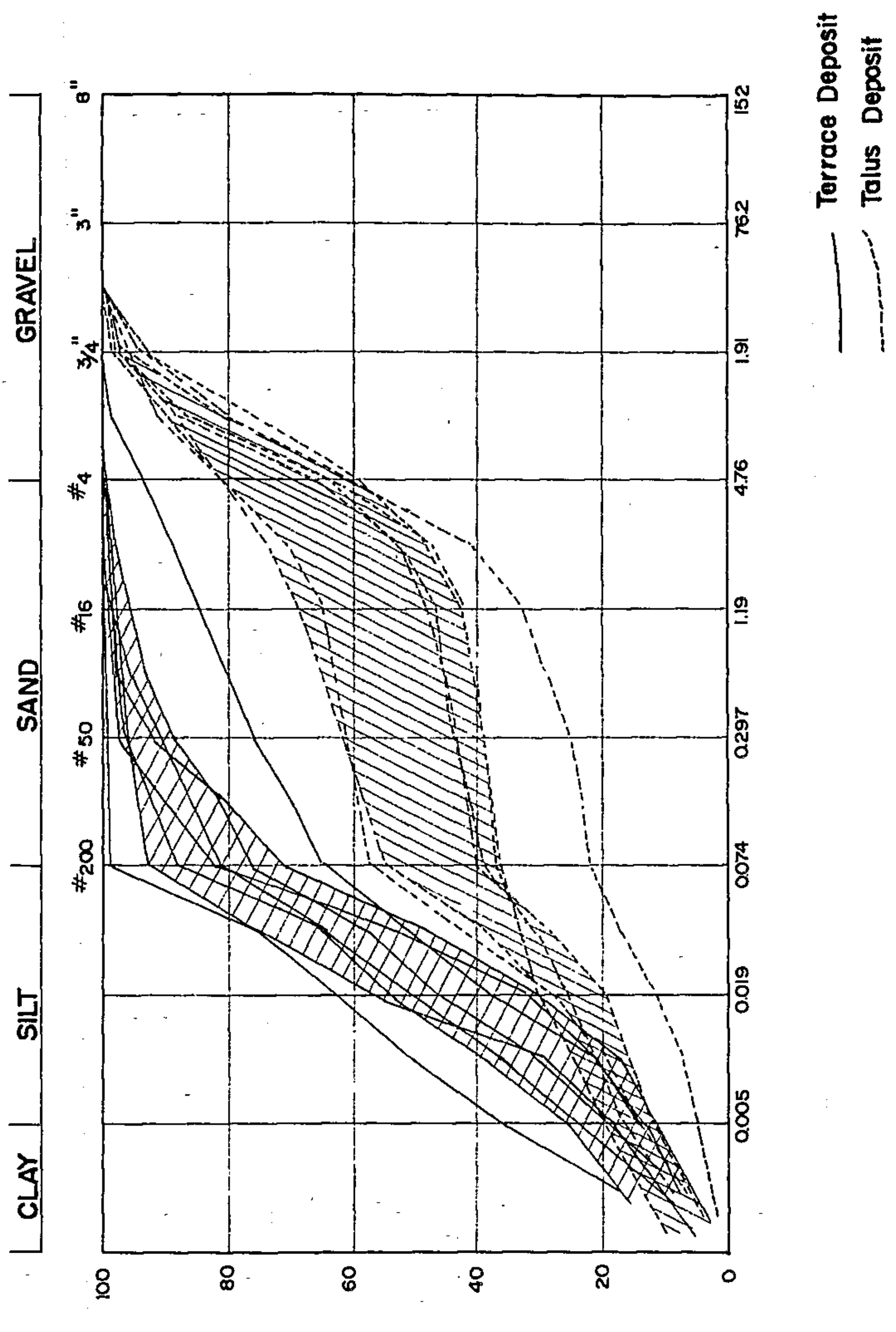


LOCATION MAP OF BORROW AREA (A)
HUAI YAI

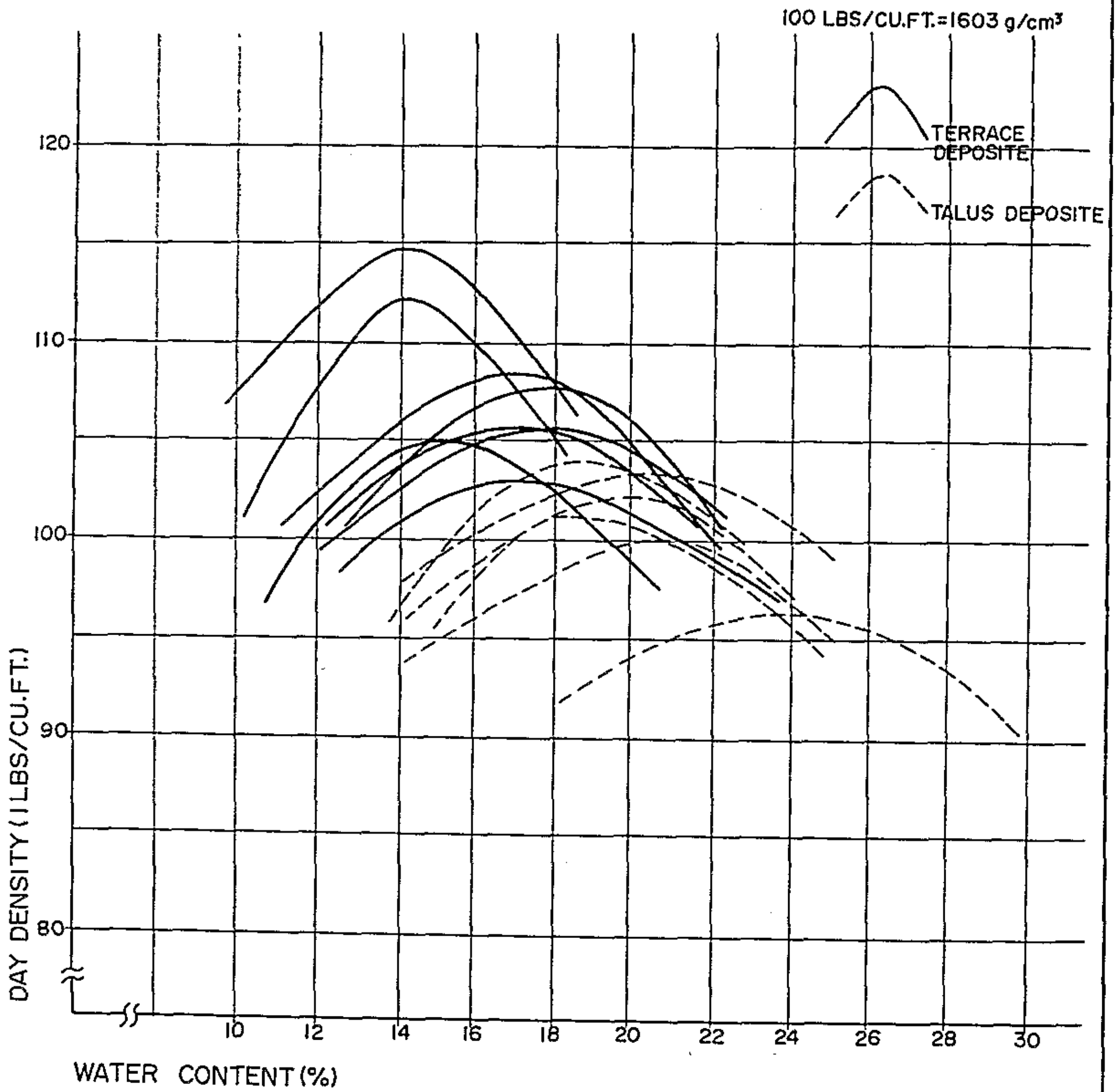

LOCATION MAP OF
PROPOSED BORROW AREA(B)
HUAI YAI
PROPOSED BORROW AREA
(CORE MATERIAL)
PROPOSED BORROW AREA
(RANDOM MATERIAL)
DH01
℄ DAM
0
100
200
300 M



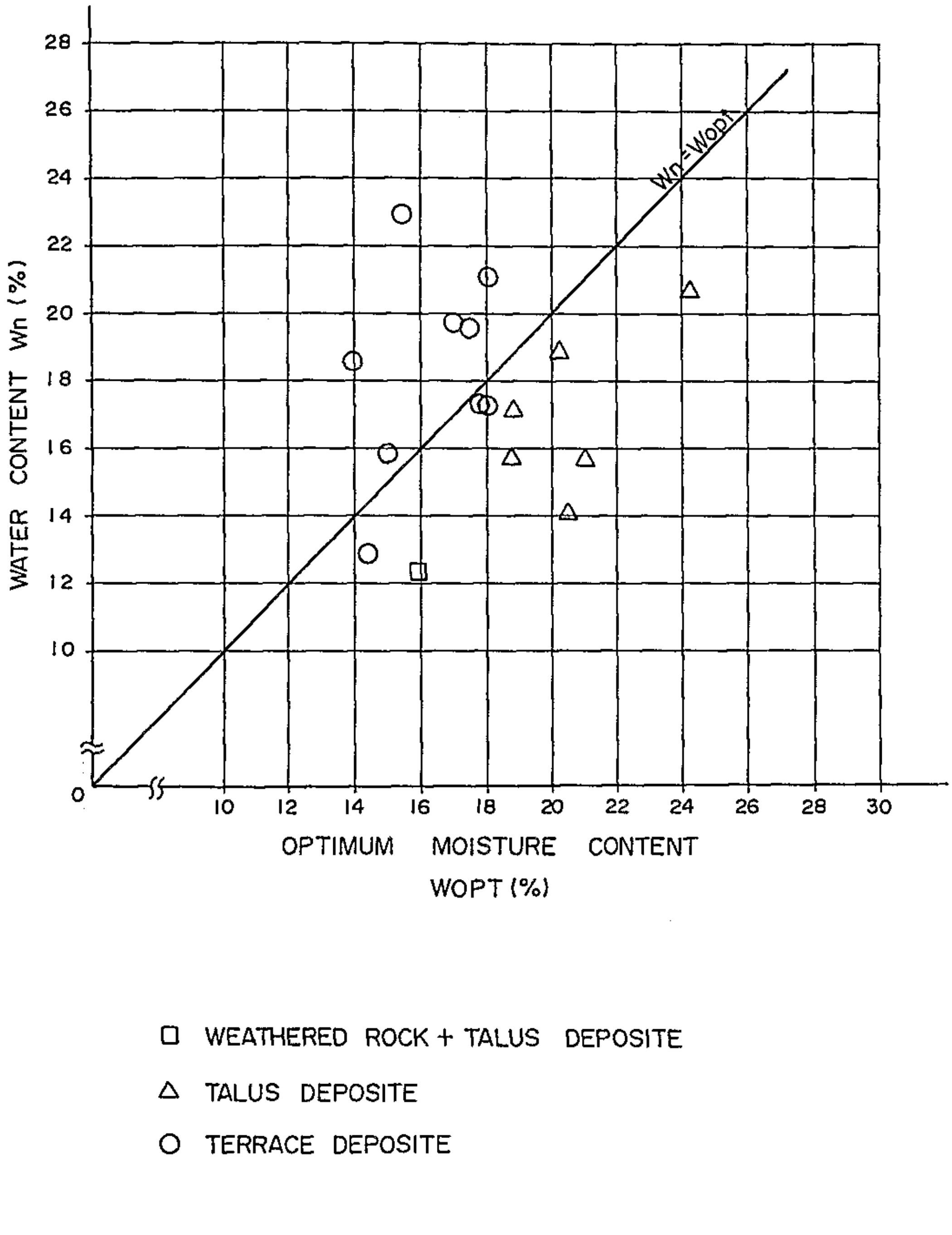
LOCATION MAP OF BORROW AREA
KHLONG CHALIANG LAB



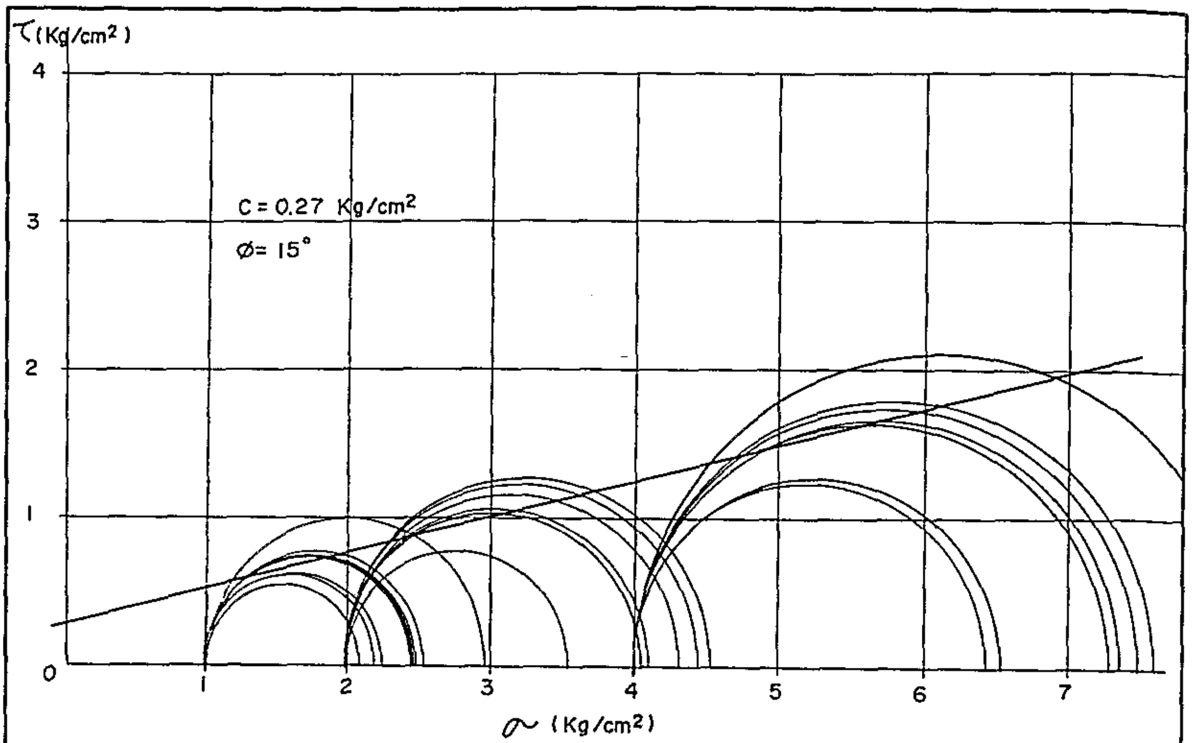
GRADATION CURVE



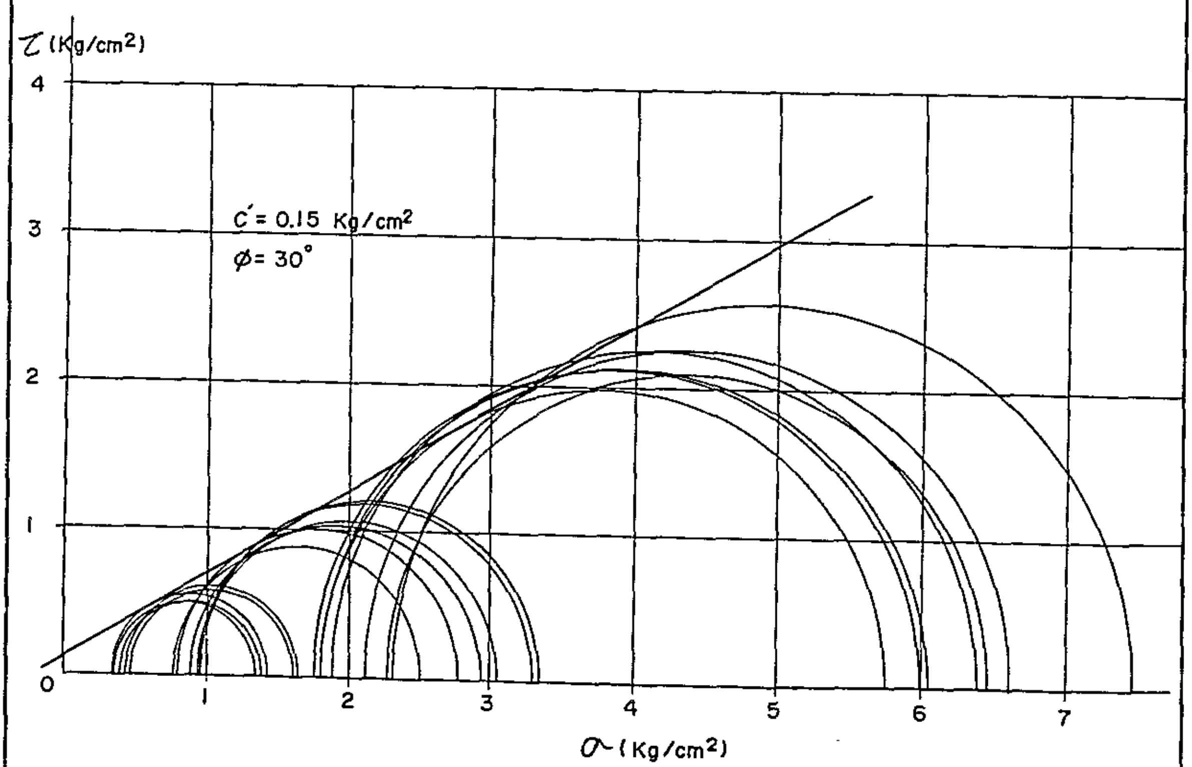
MOISTURE~DRY DENSITY CURVE



DISTRIBUTION CHART OF Wn~Wopt



SHEAR TEST BY TRIAXIAL COMPRESION (A)
(UNCOSOLIDATION ~ UNDRAINED)



SHEAR TEST BY TRIAXIAL COMPRESSION (B)
(CONSOLIDATION – UNDRAINED)