

However, the sea level was believed to be at about 60m to 100m below the present level worldwide at that time. Hence, 17,000 YBP is not acceptable as the age of deposition of the Stiff Clay. It is estimated that the deposition took place in the Allerød time of 11,000 YBP to 12,000 YBP.

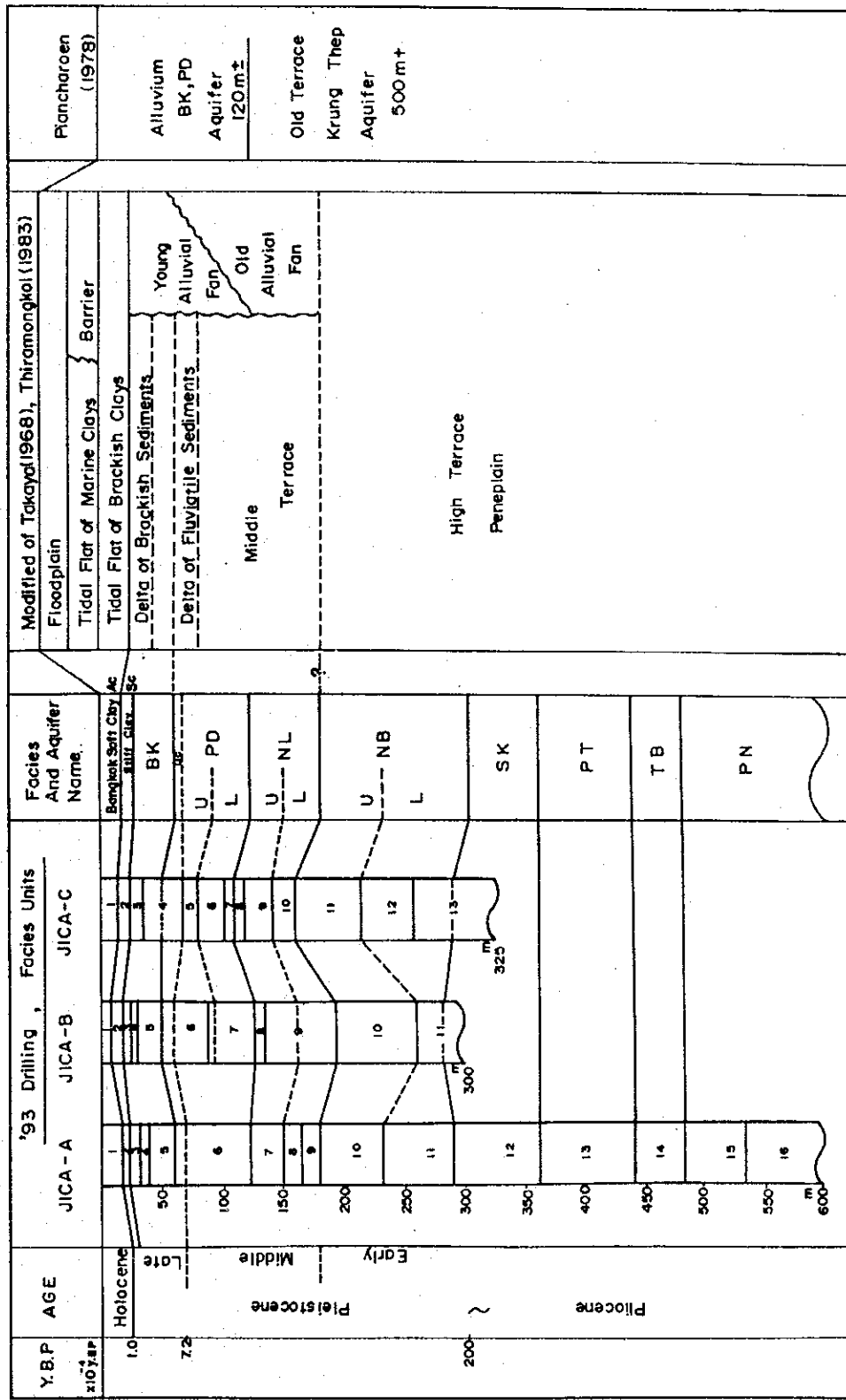
3.5 Recharge to the Basin

Considering the landforms and sediments, the recharge to the aquifers may occur through the mountains, hills, terraces, and fans which are located in the west and east of the plain and through the Chao Phraya River (see Figure 3.1.2). However, these sediments are mostly composed of fine grain materials. Besides, the sediments are intercalated with clay bed, which originated from deep weathering, and consolidated calcareous bed. The clayey confining beds of the deep strata are thick and distributed widely underground. This may suggest a low natural recharge rate to the basin.

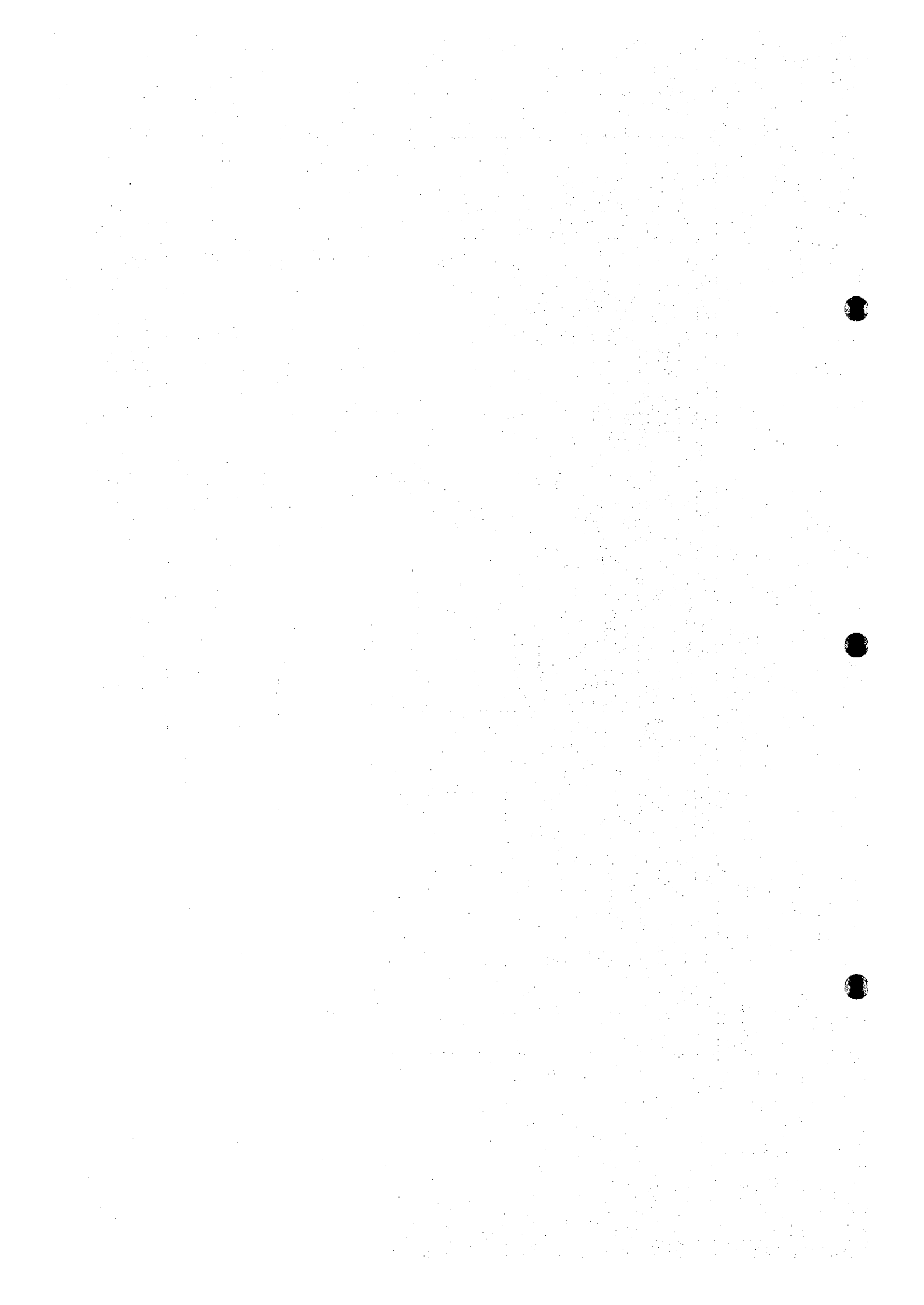
The Chao Phraya River may directly recharge the Bangkok Aquifer through the sand beds of flood origin. However, BK is mostly covered by the Bangkok Clay. The clay bed which separates BK and PD is thick and distributed widely. Hence, groundwater flow from adjacent aquifers may be very small.

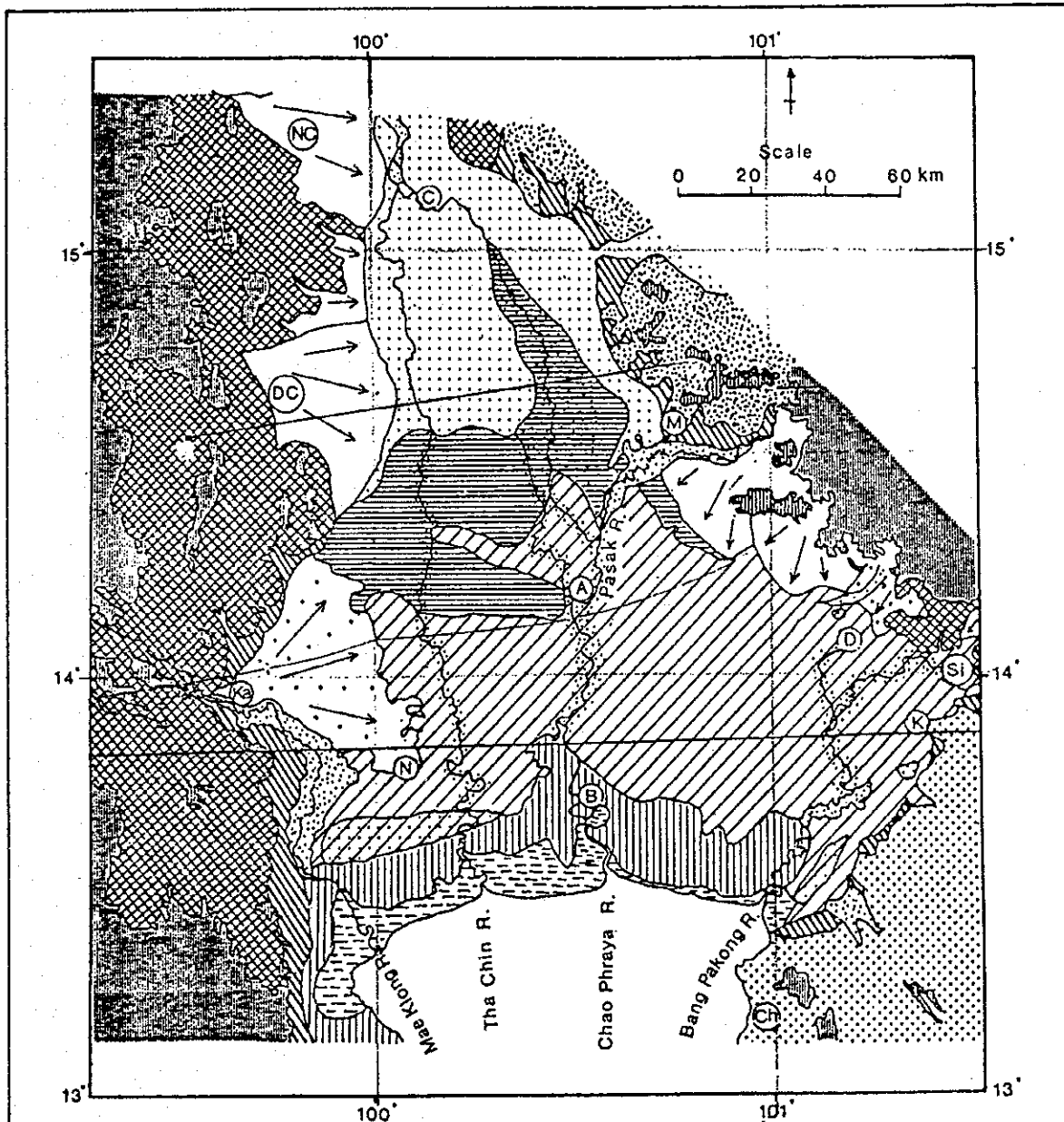
In a previous study on isotope hydrogeology conducted by DMR and IAEA, ^{14}C dating indicated the age of groundwater to be older than 10,000 YBP to 30,000 YBP, which also suggests a low recharge and a slow circulation of groundwater.

Table 3.1.1 STRATIGRAPHY OF THE LOWER CENTRAL PLAIN



BK: BK Formation, Bangkok Aquifer
 PD: PD Formation, Phra Pradaeng Aquifer
 NL: NL Formation, Nakhon Luang Aquifer
 NB: NB Formation, Nonthaburi Aquifer
 SK: SK Formation, Sam Khok Aquifer
 PT: PT Formation, Phaya Thai Aquifer
 TB: TB Formation, Thon Buri Aquifer
 PN: PN Formation, Pak Nam Aquifer



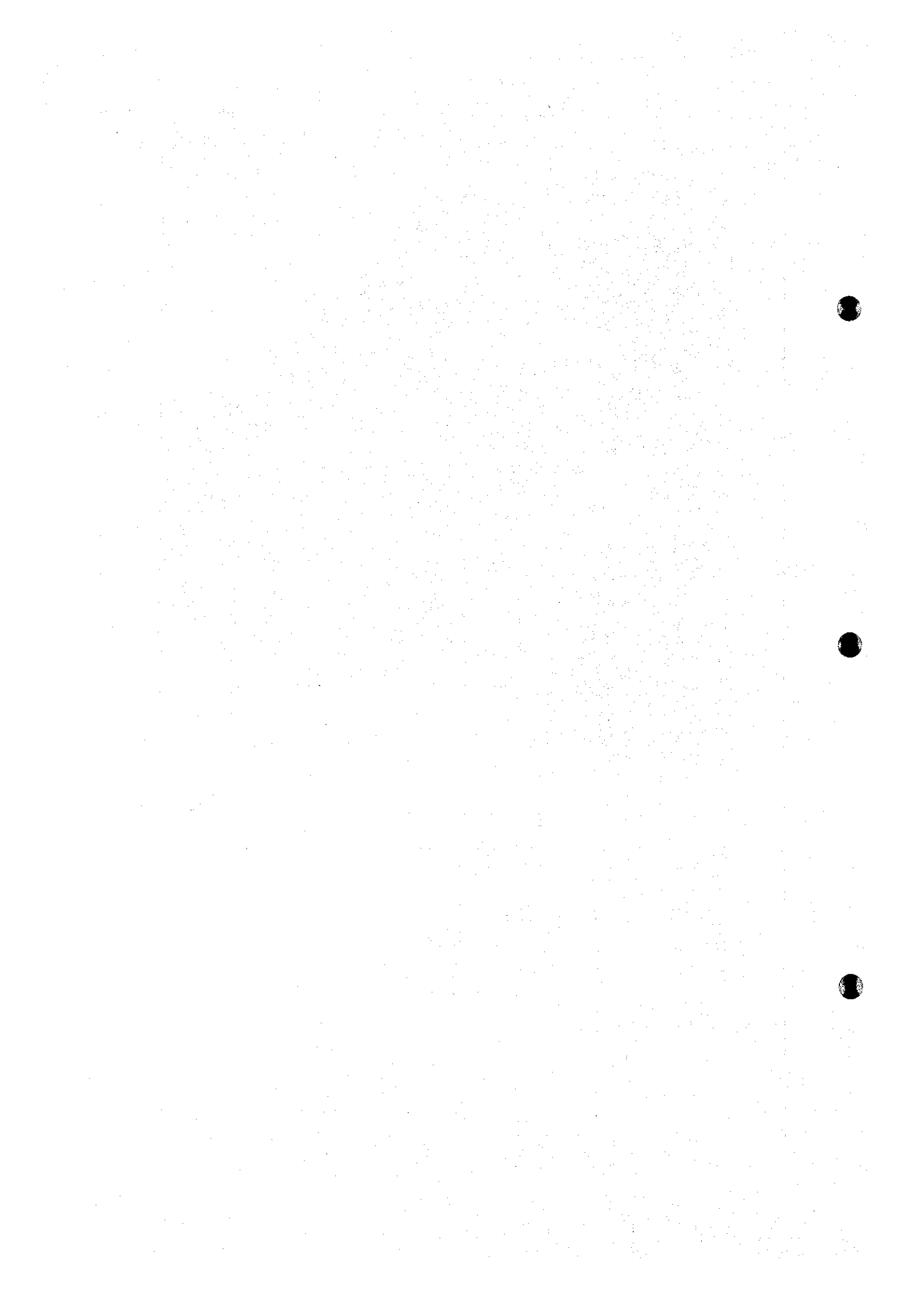


(A) Ayutthaya (B) Bangkok (C) Chai Nat (D) Chon Buri (E) Ban Dong
 (K) Khok Pib (M) Kanchanaburi (N) Ban Mo (S) Nakhon Pathom
 (X) Si Maha Phot (Y) Don Chedi fan (Z) Nong Cheng fan

- | | | |
|------------------------------|-----------------------------|----------------------------|
| Tidal zone | Delta of brackish sediments | High terrace |
| Flood plain | Delta of fluvial sediments | Fenepain |
| Barrier | Young alluvial fan | Structural terrace in marl |
| Tidal flat of marine clays | Old alluvial fan | Mountains and hills |
| Tidal flat of brackish clays | Middle terrace | |

After Narong Thiramongkol (1983)

Figure 3.1.1	GEOMORPHOLOGICAL MAP OF THE LOWER CENTRAL PLAIN
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



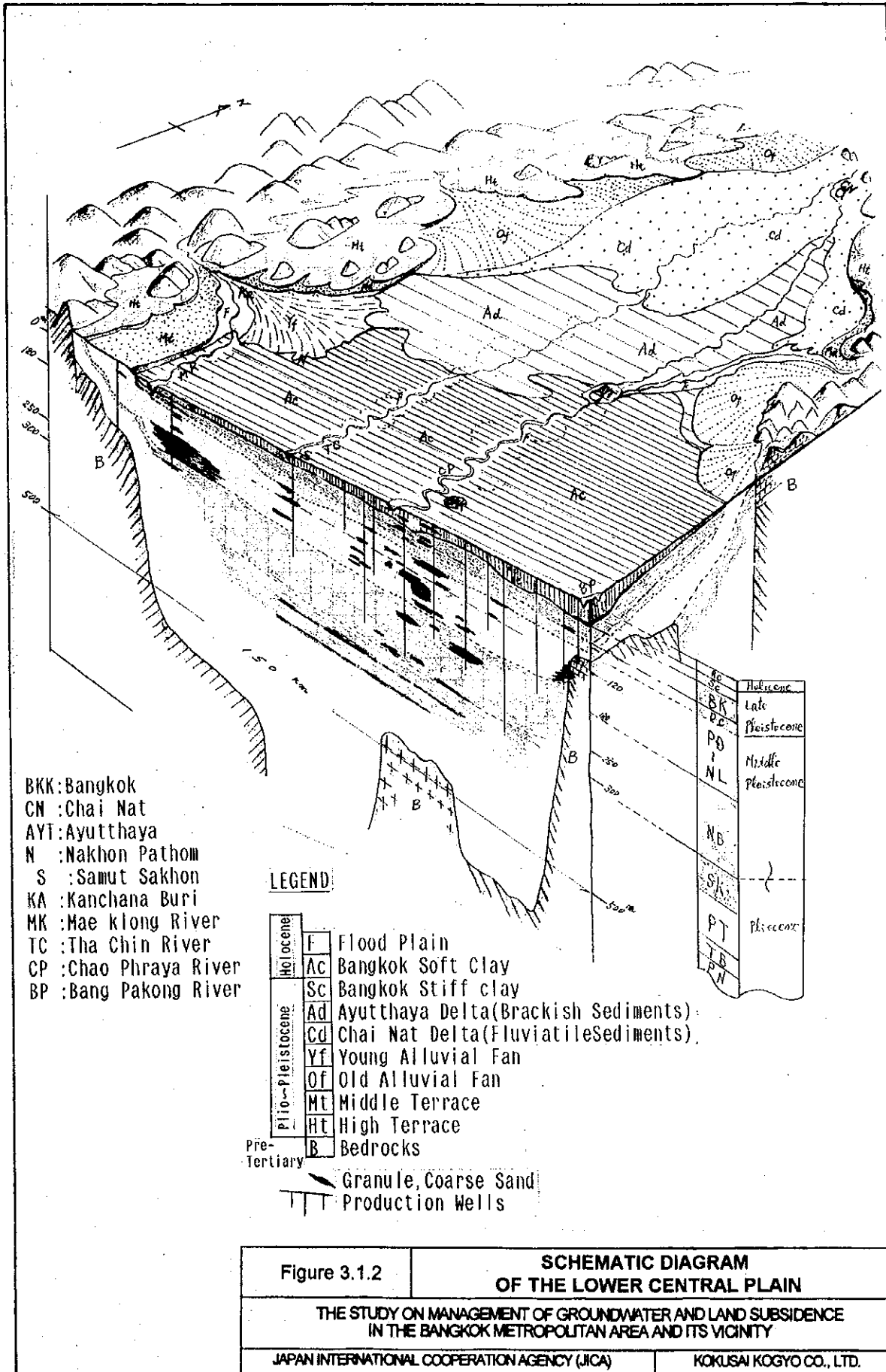
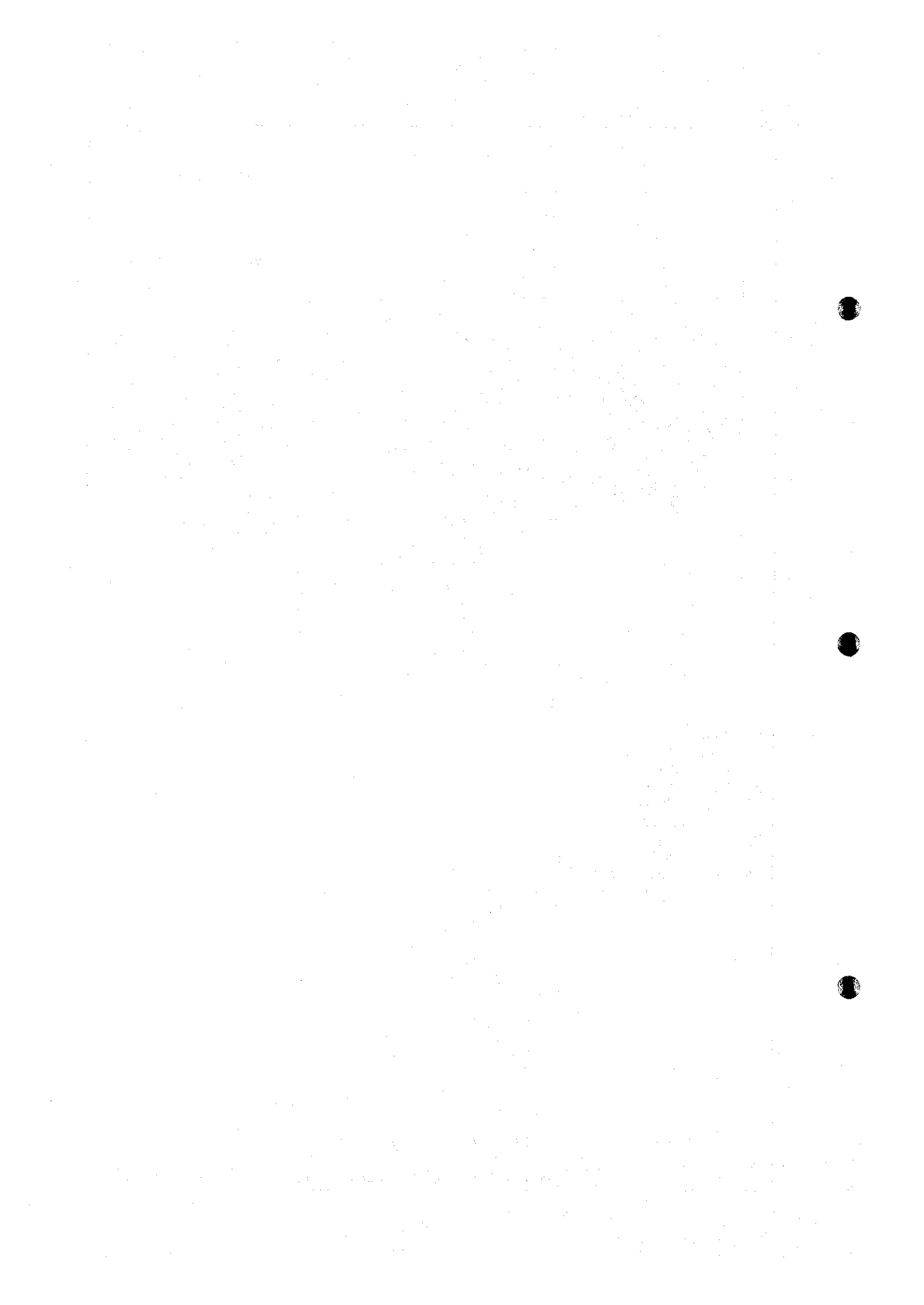
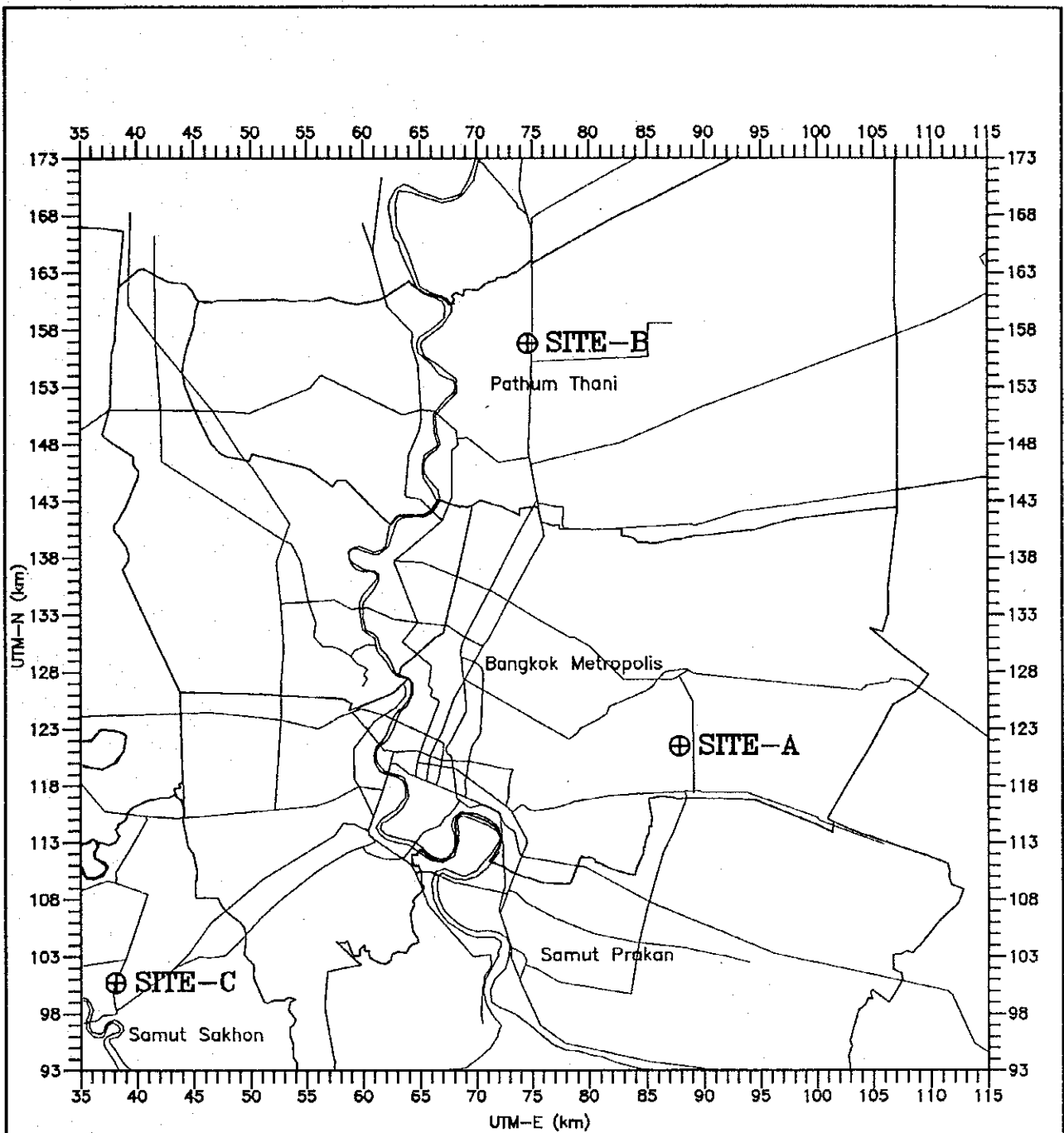


Figure 3.1.2 **SCHEMATIC DIAGRAM OF THE LOWER CENTRAL PLAIN**

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) KOKUSAI KOGYO CO., LTD.

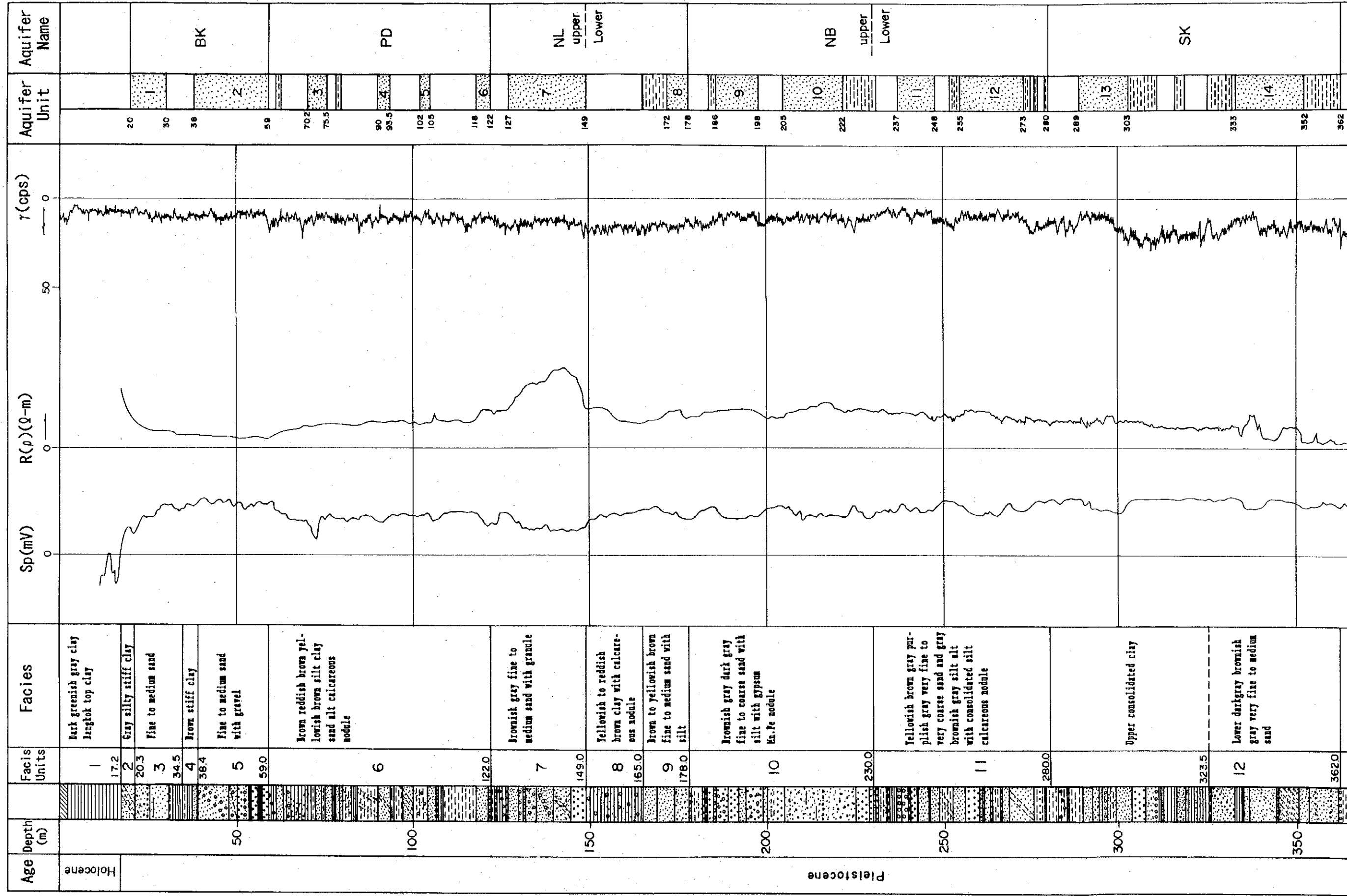




	UTM GRID	LONGITUDE	LATITUDE	LOCATION
SITE-A:	879215	100°44'17"	13°45'26"	ROM KLAO VILLAGE, NHA, LAT KRABANG
SITE-B:	746568	100°37'02"	14°04'41"	AIT CAMPUS, PATHUM THANI
SITE-C:	381007	100°16'35"	13°34'23"	RON RIAN WAT KLONG KRU, SAMUT SAKHON

Figure 3.2.1	LOCATION MAP OF DRILLING SITES
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

JICA - A LOGGING



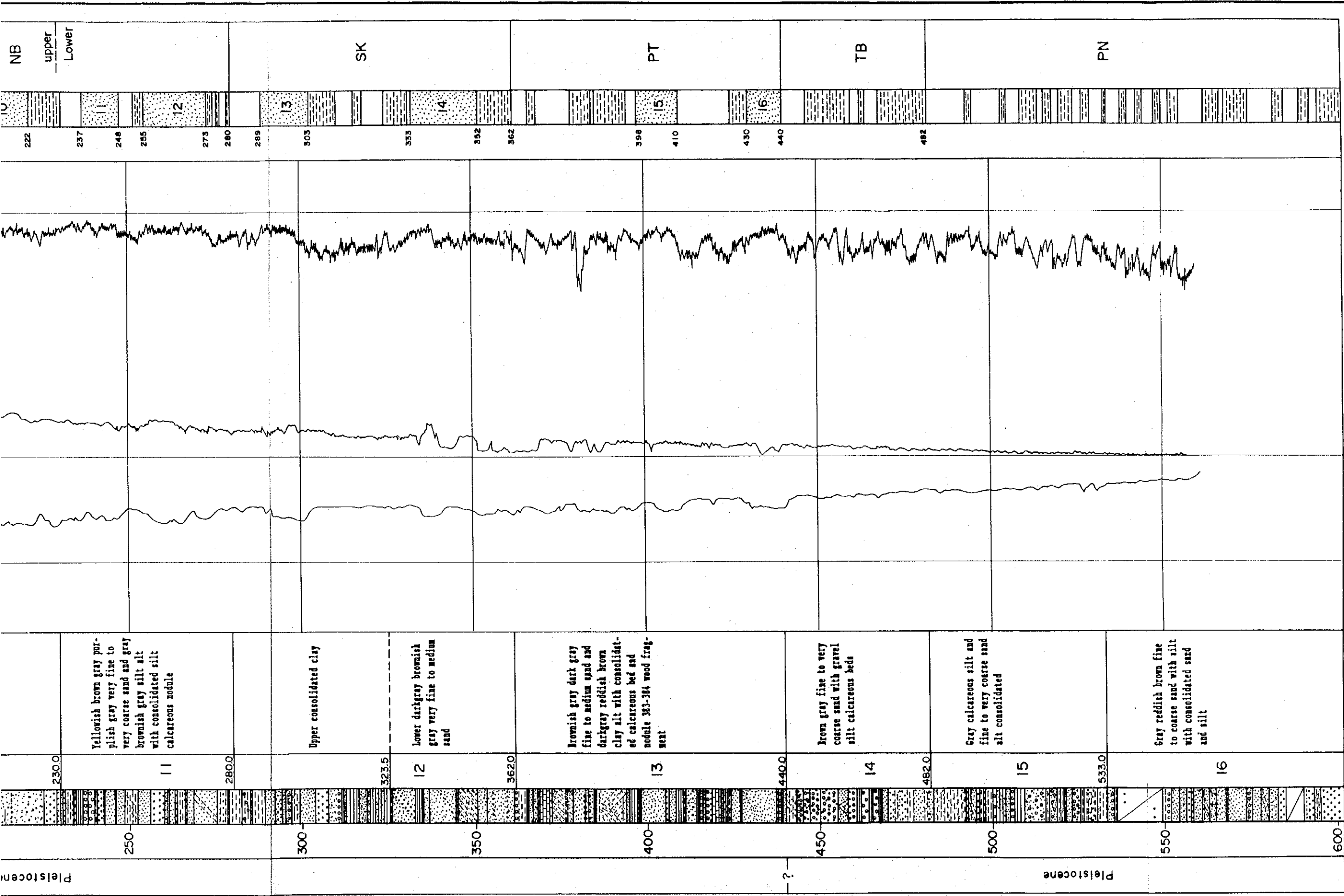


Figure 3.2.2 JICA - A Logging and Aquifer
 THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE
 IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY
 JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) KOKUSAI KOGYO CO., LTD.

JICA - B LOGGING

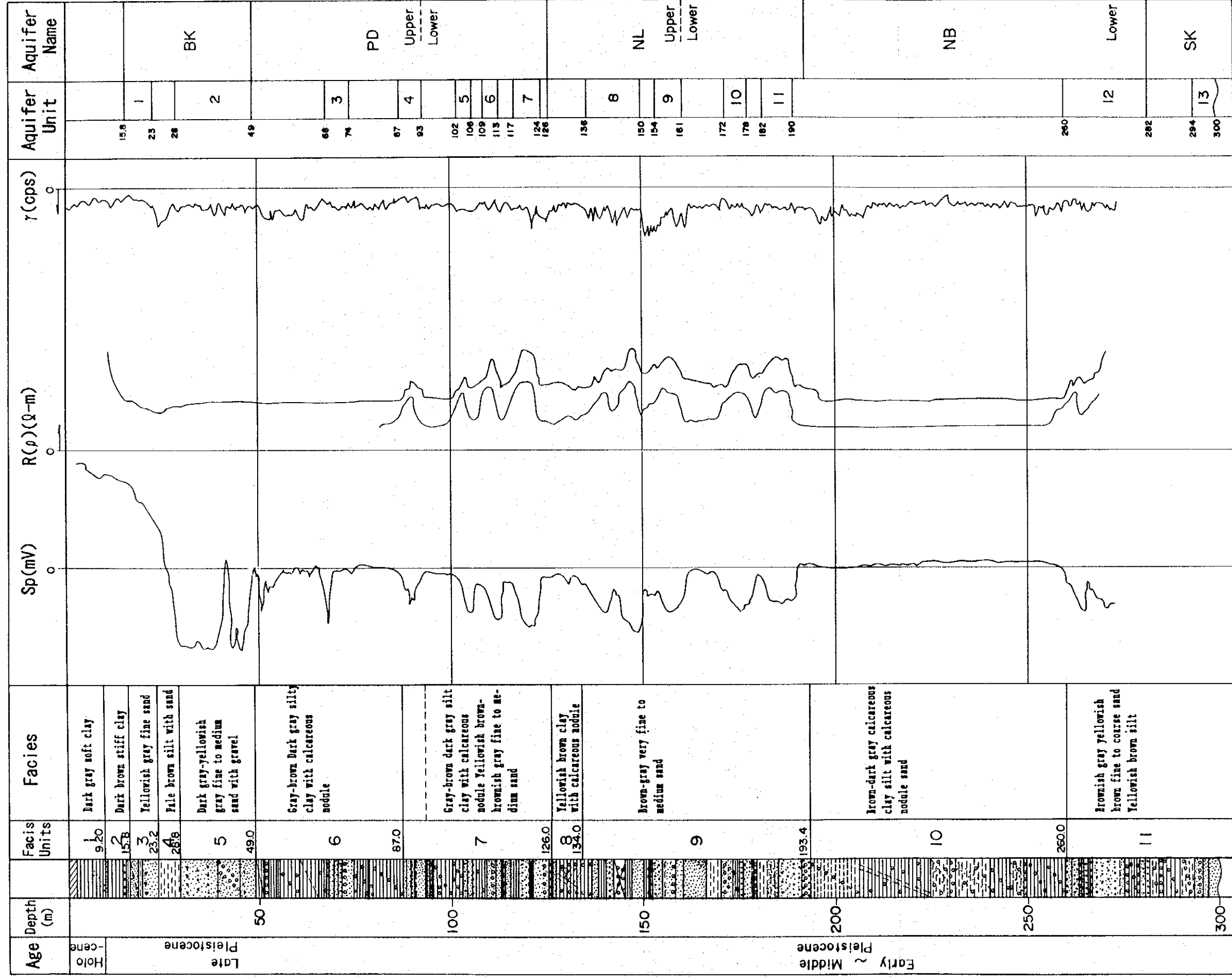


Figure 3.2.3 JICA - B Logging and Aquifer
 THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE
 IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY
 JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) KOKUSAI KOGYO CO., LTD.

JICA - C LOGGING

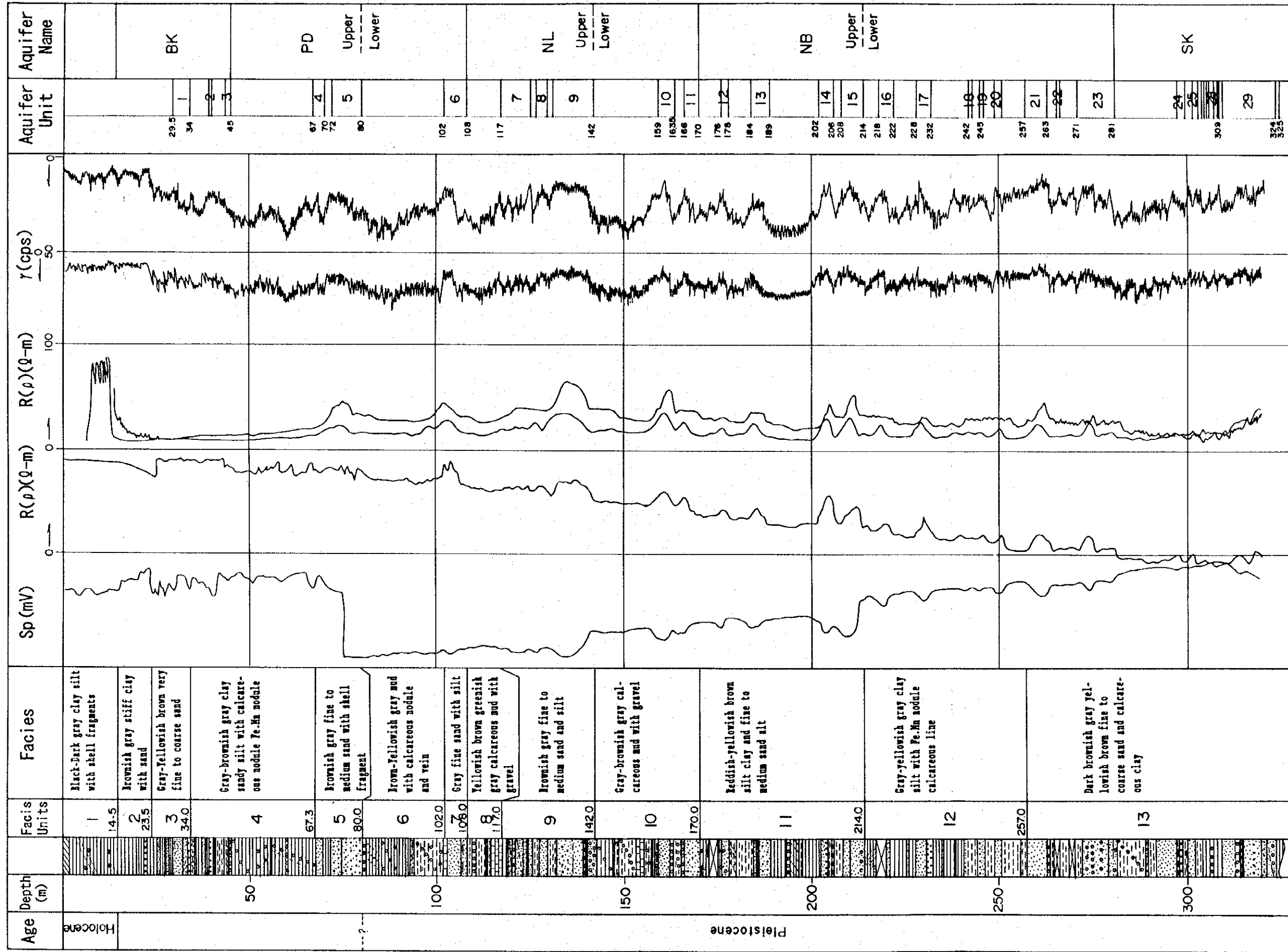
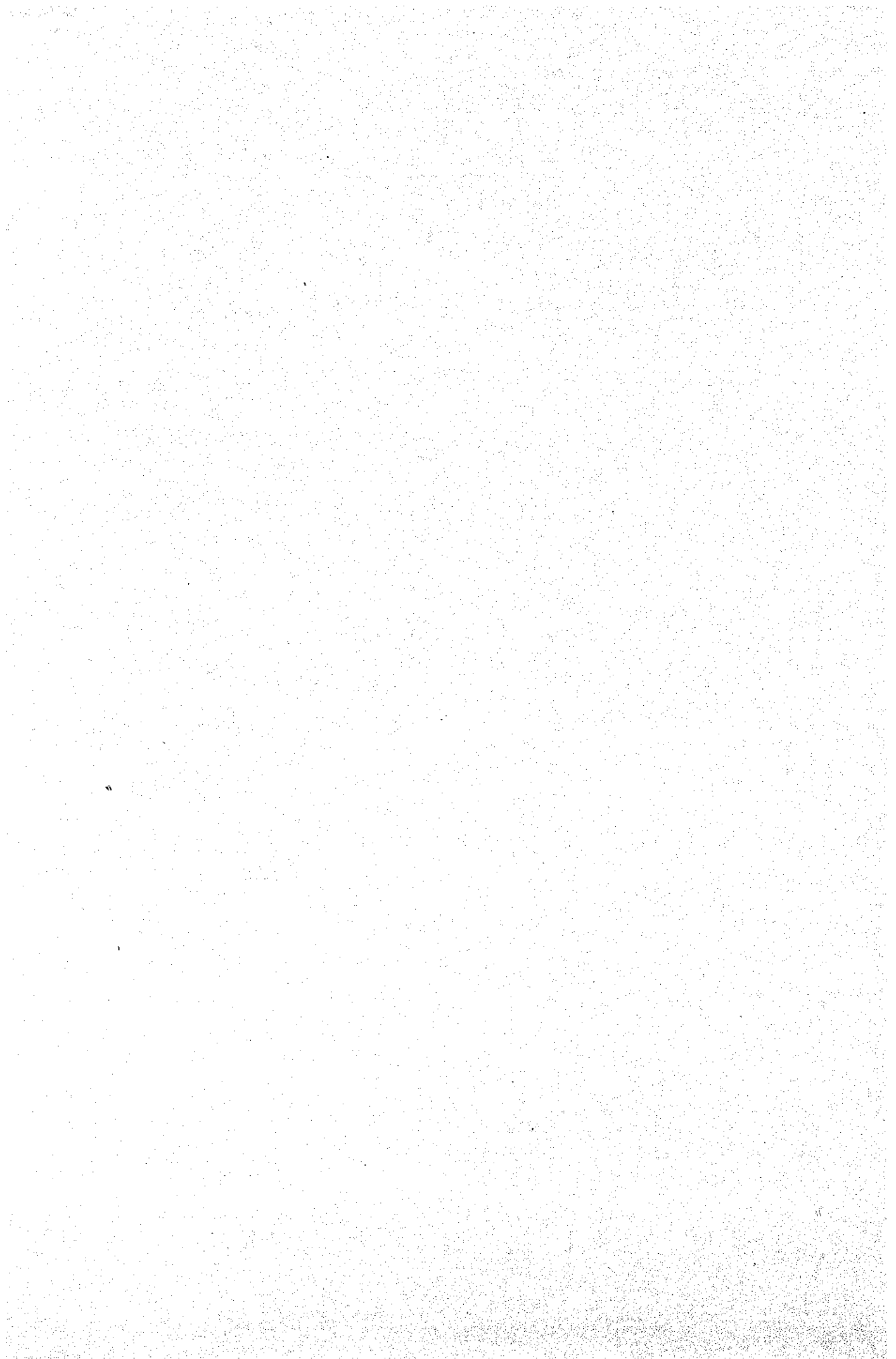
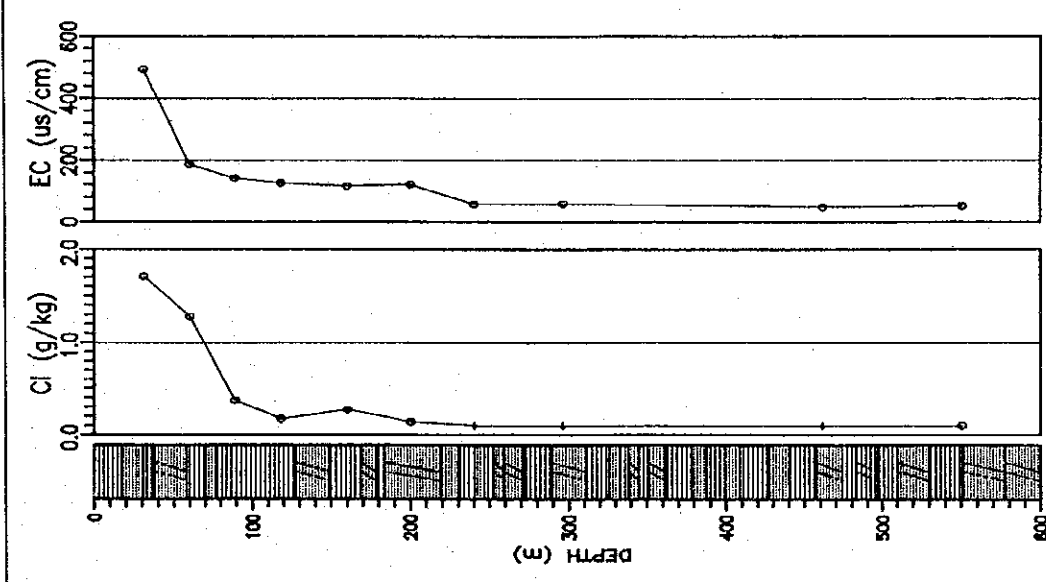


Figure 3.2.4 JICA - C Logging and Aquifer

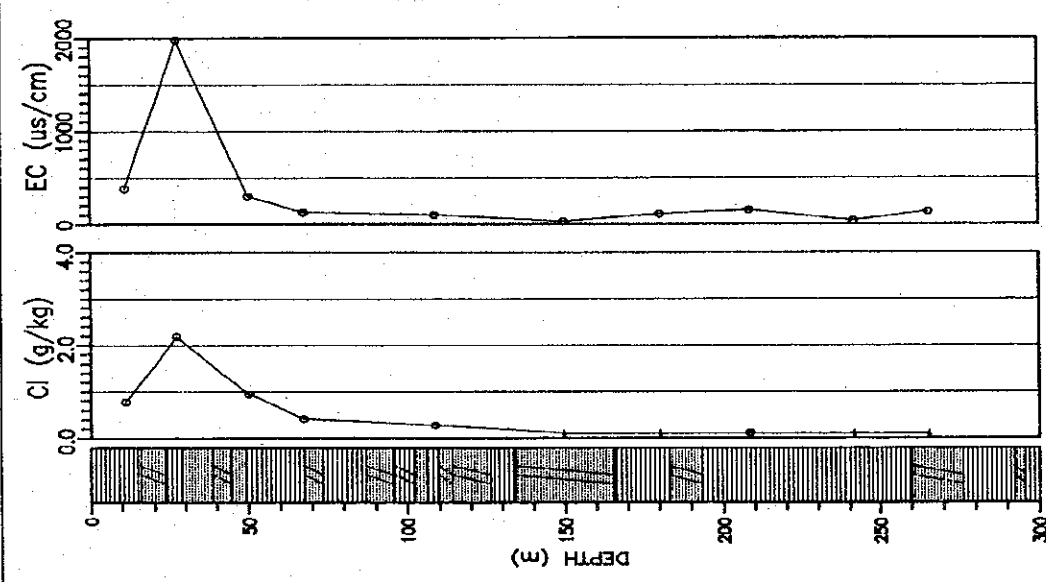
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) KOKUSAI KOGYO CO., LTD.

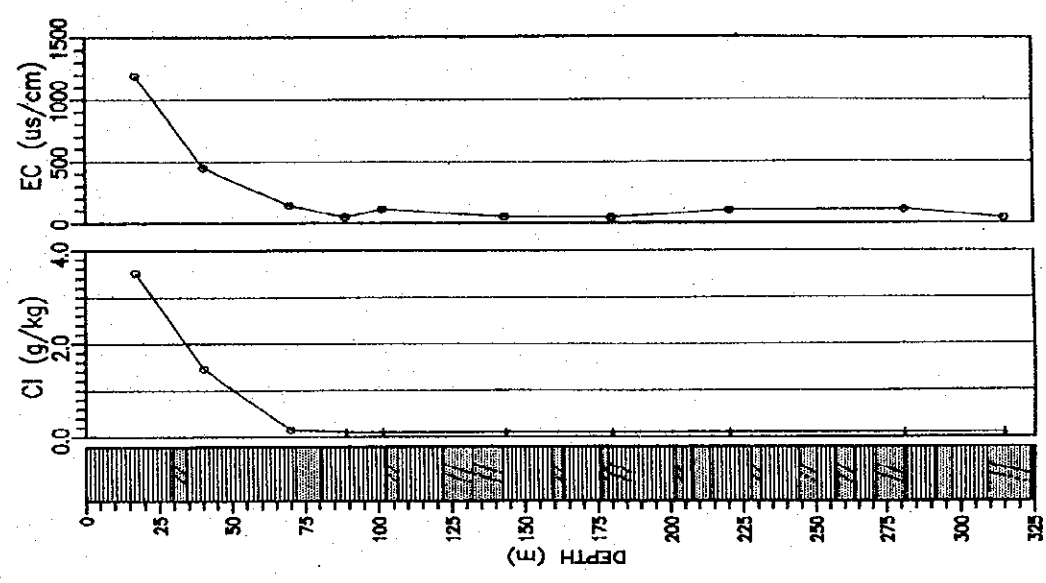




SITE - A

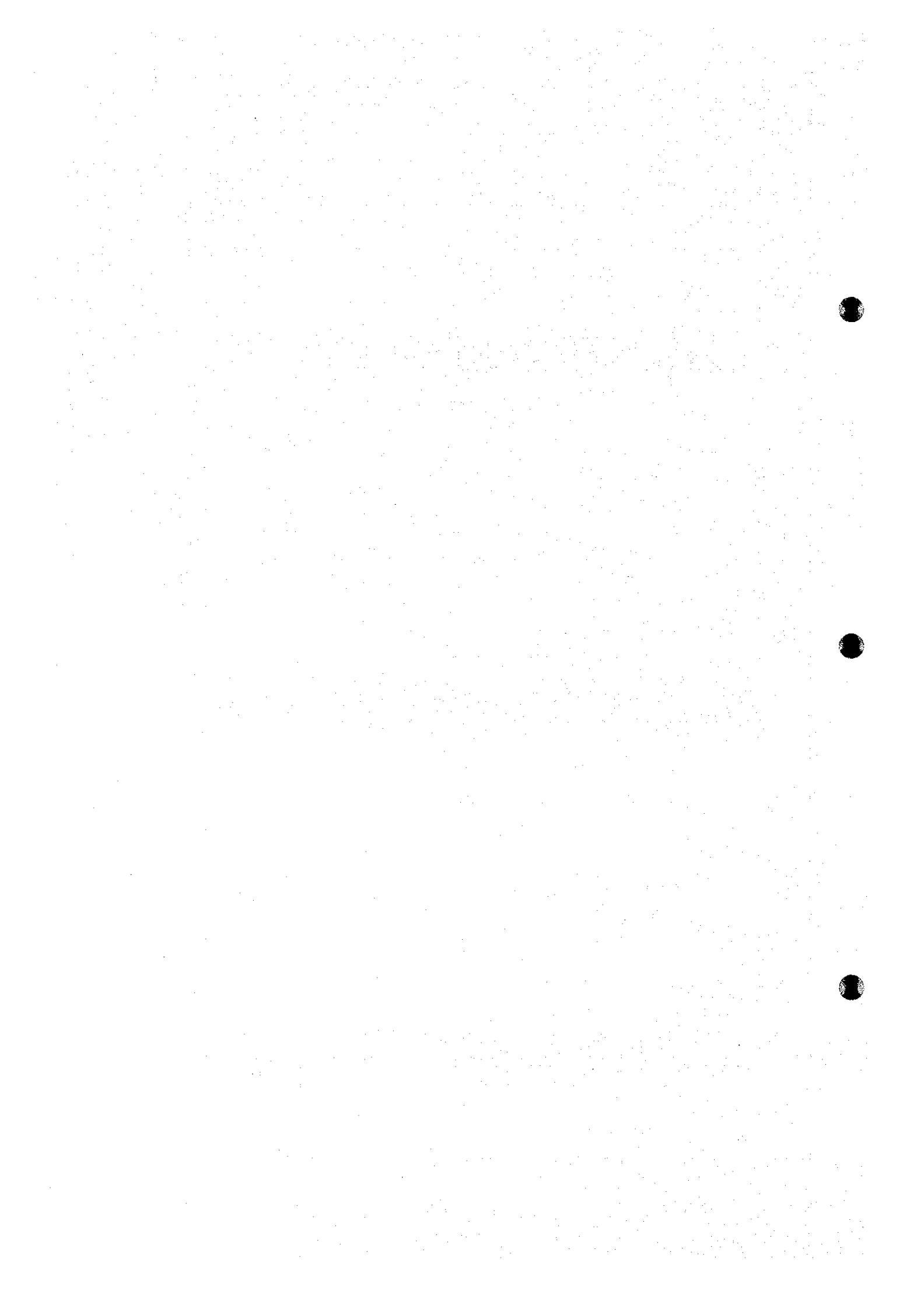


SITE - B



SITE - C

Figure 3.2.5 SALT CONTENT ANALYSIS
 THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE
 IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY
 JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) KOKUSAI KOGYO CO., LTD.



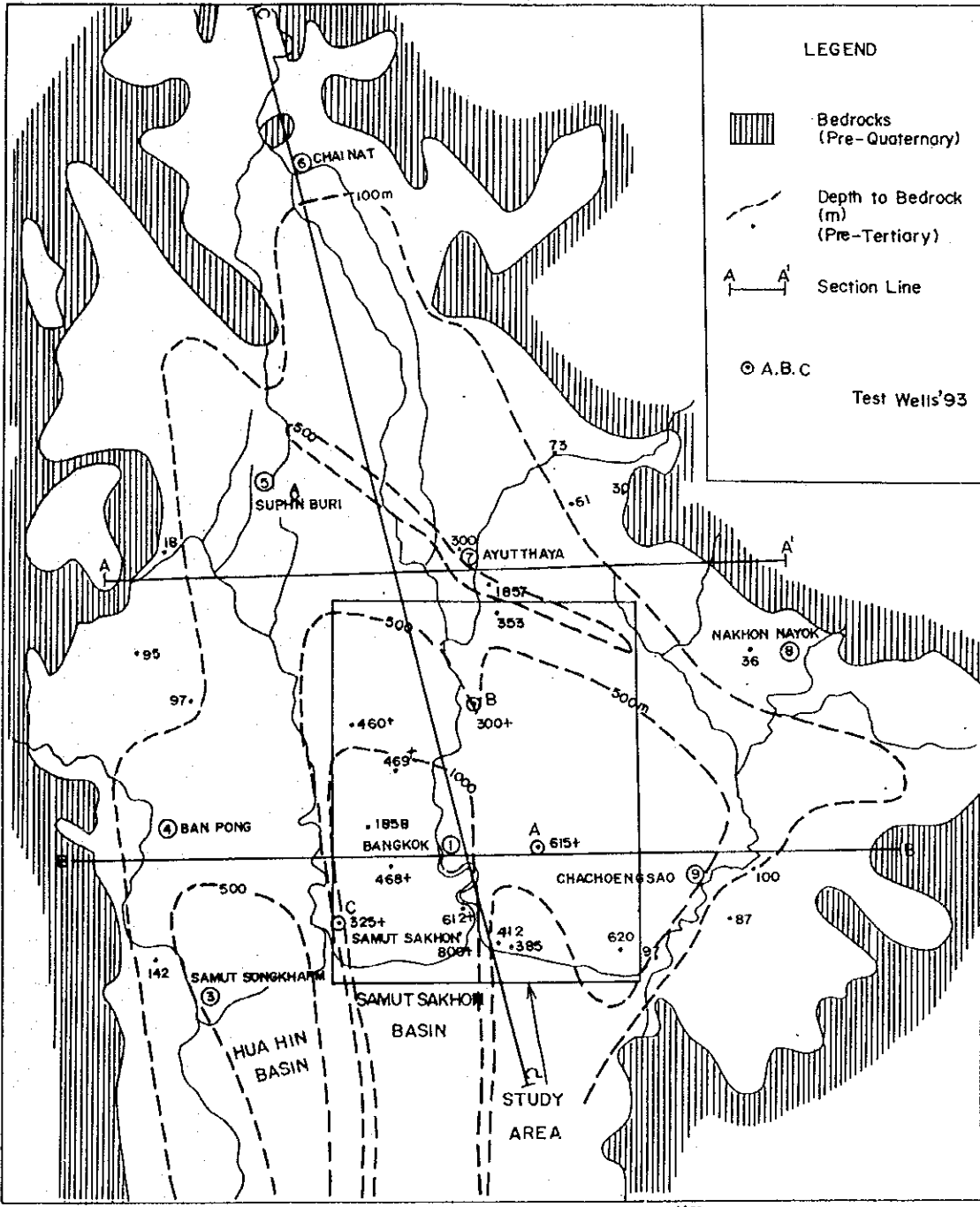
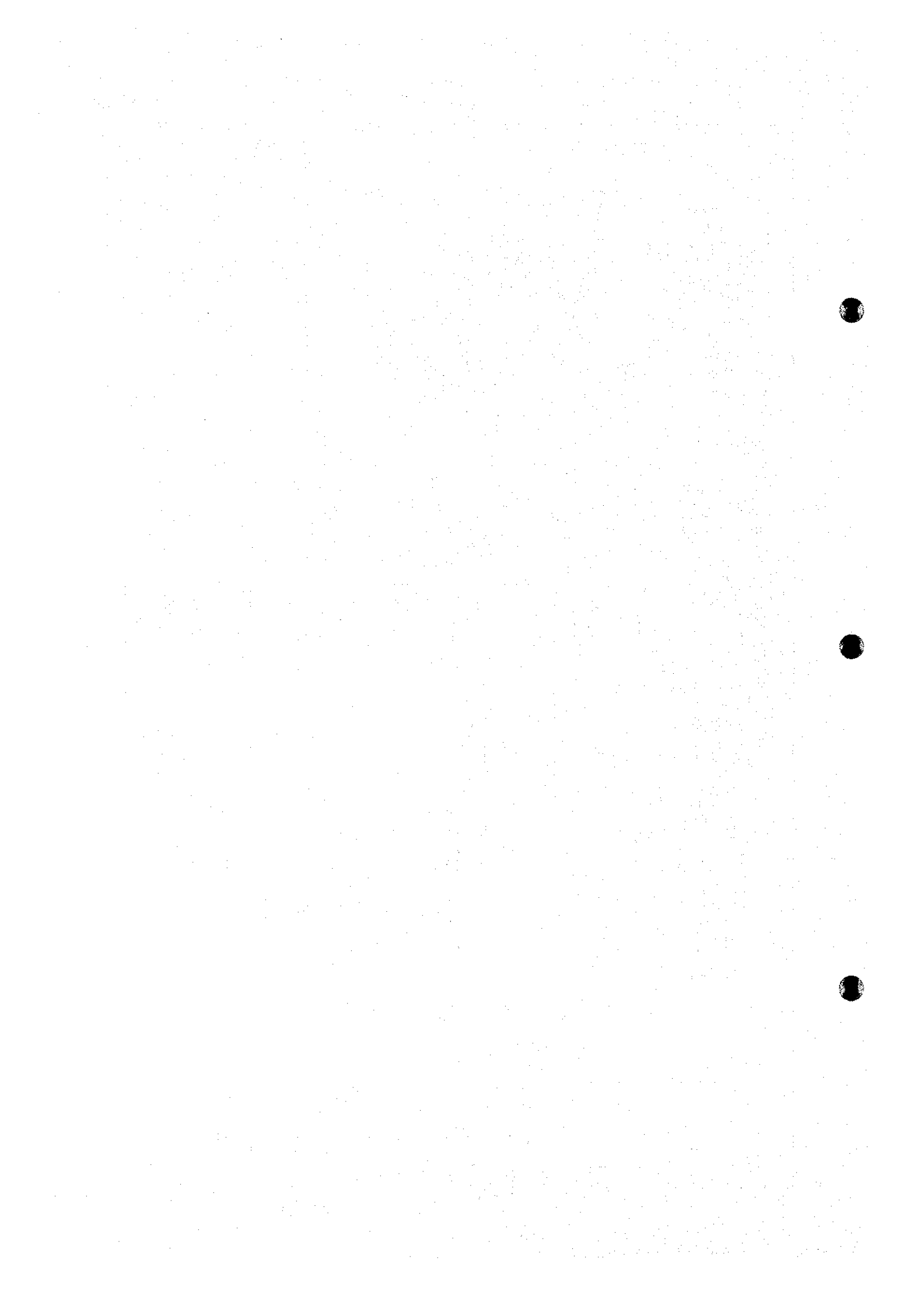
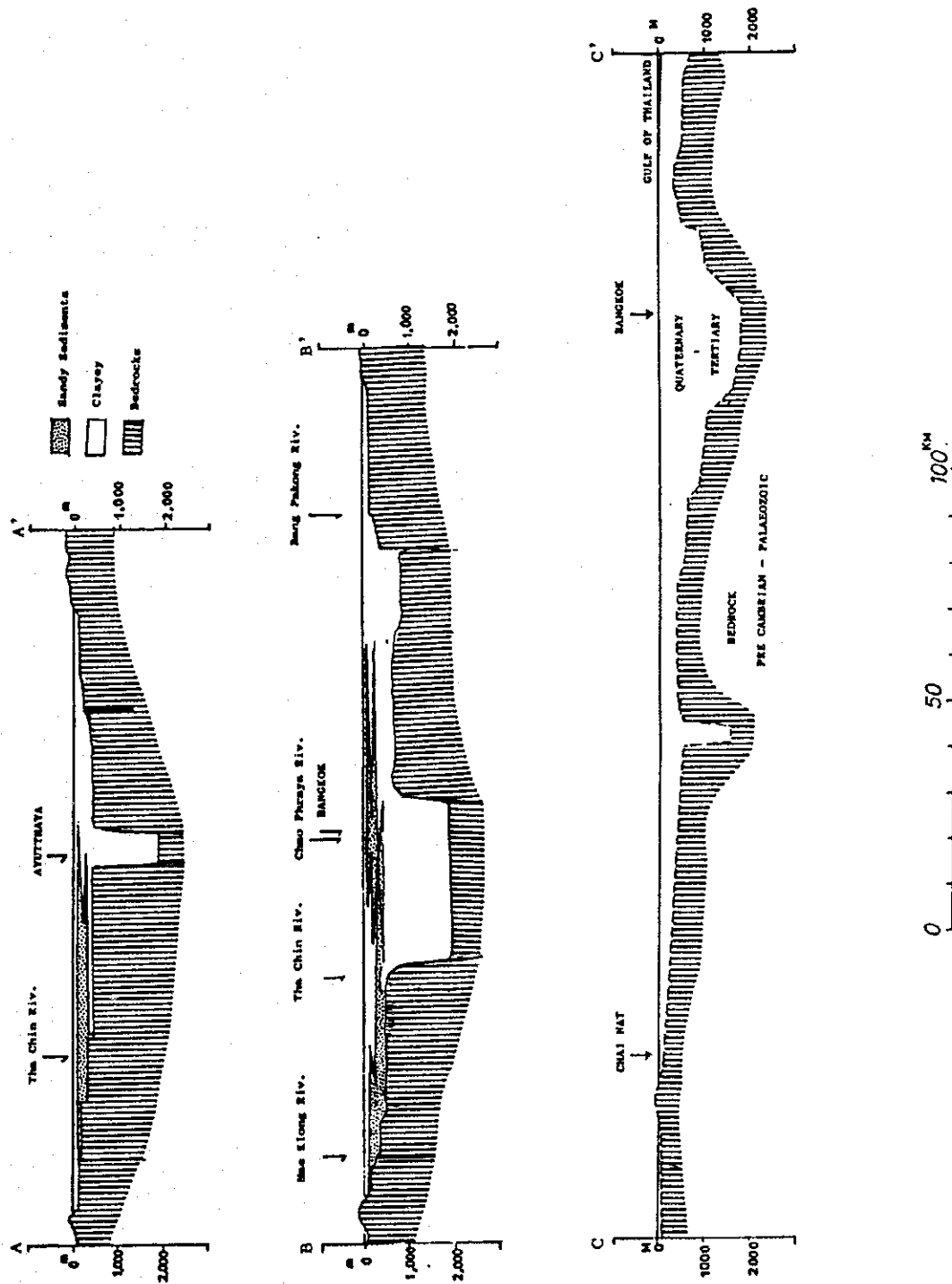


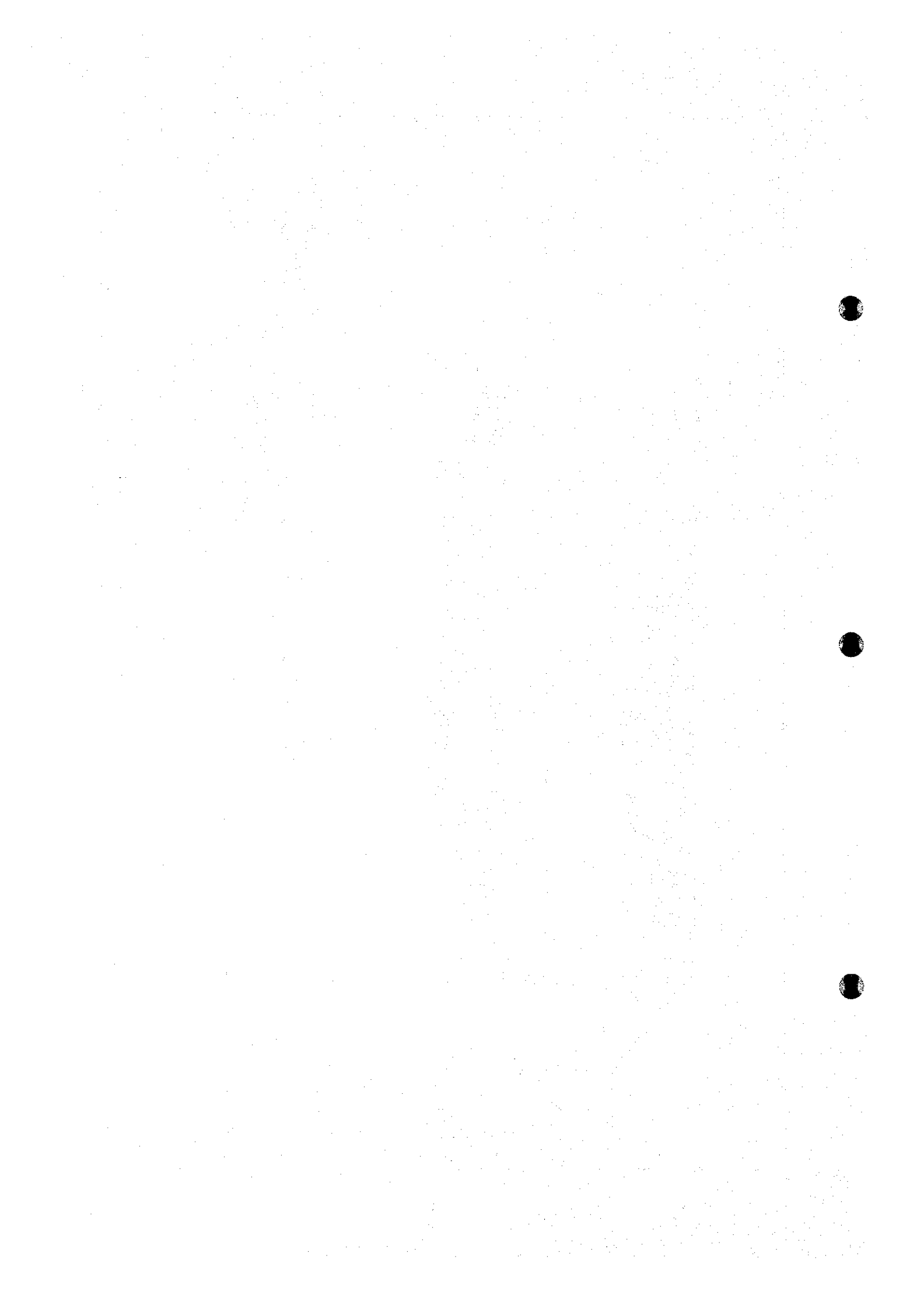
Figure 3.3.1	SEDIMENTARY BASIN OF THE LOWER CENTRAL PLAIN
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

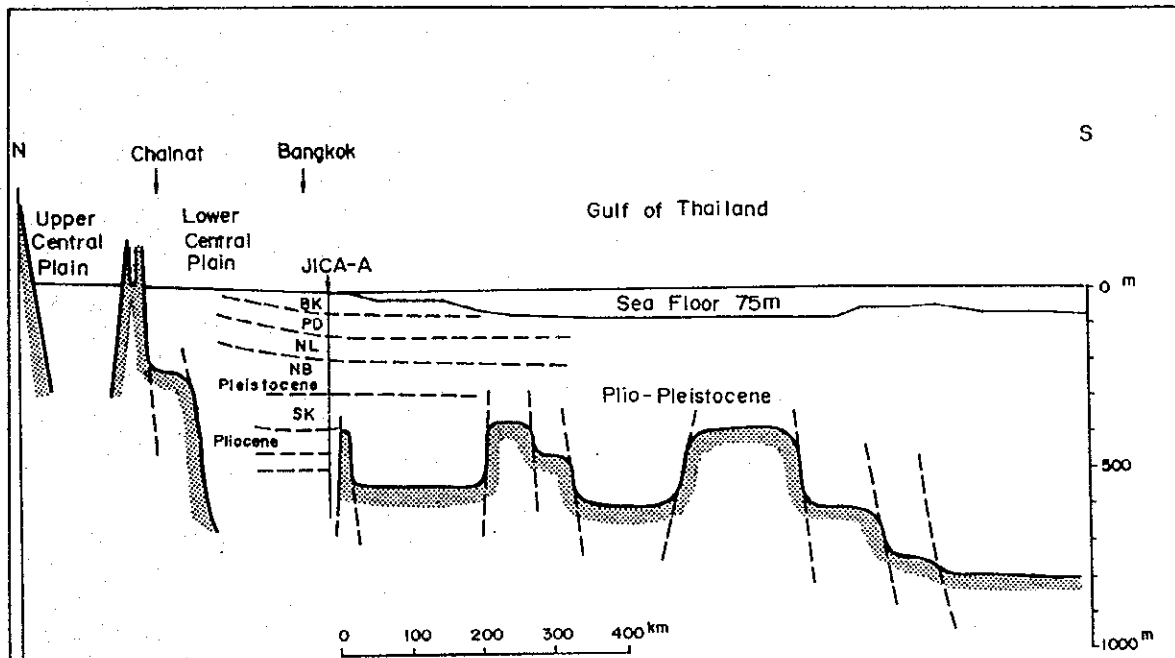




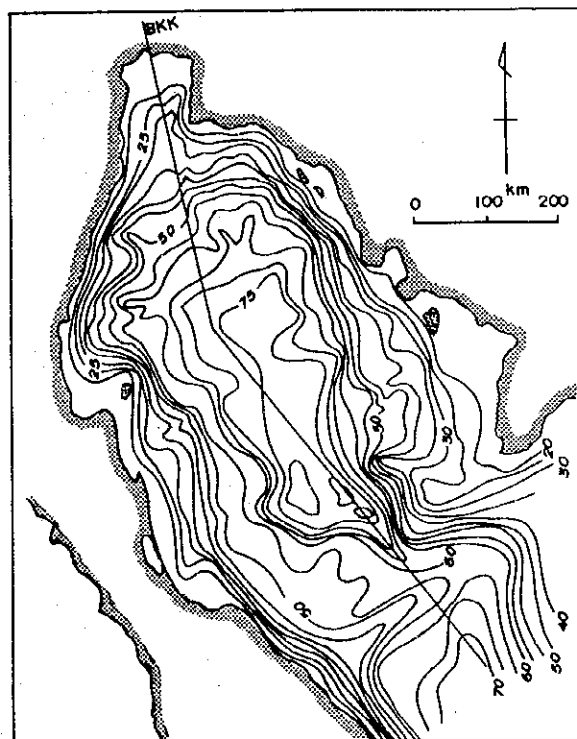
A and B, modified of Nutalaya and Rau (1981)

Figure 3.3.2	PROFILE OF THE BEDROCK STRUCTURE
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.





Modified of Achalabuhti (1978), COP(1991)



Sea Floor Contour Map
(Sinsinsakul et.al. 1985)

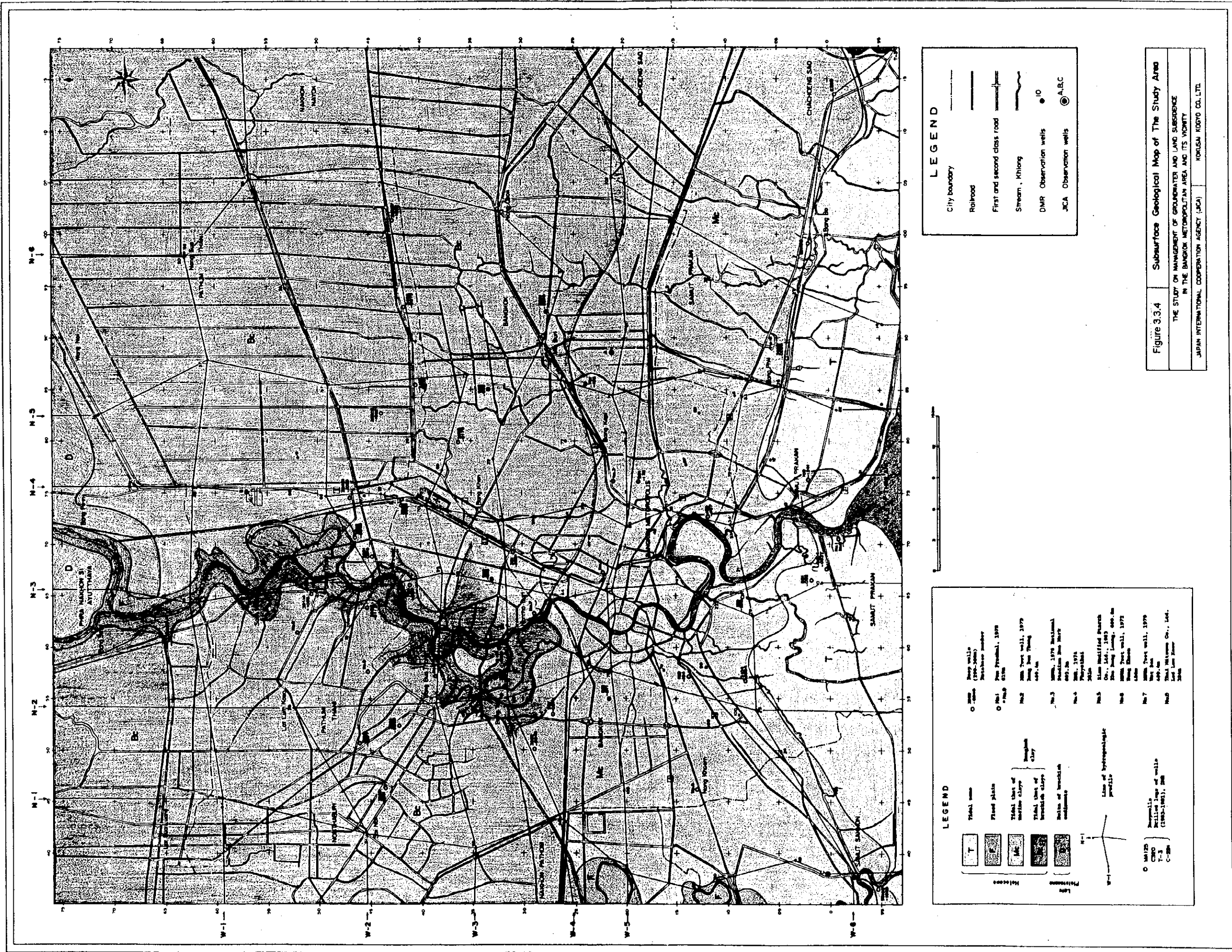
Figure 3.3.3

**SCHEMATIC PROFILE
OF THE GULF OF THAILAND**

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE
IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

KOKUSAI KOGYO CO., LTD.



LEGEND

- City boundary
- Railroad
- First and second class road
- Stream, Khlong
- DMR Observation wells
- JICA Observation wells



LEGEND

- Tidal zone
- Filled plate
- Tidal flat of marine clay
- Tidal flat of brackish clay
- Marine clay
- Marine of brackish water
- Line of hydrogeologic profile
- Normal range of wells
- DMR (1963-1967), JICA
- JICA

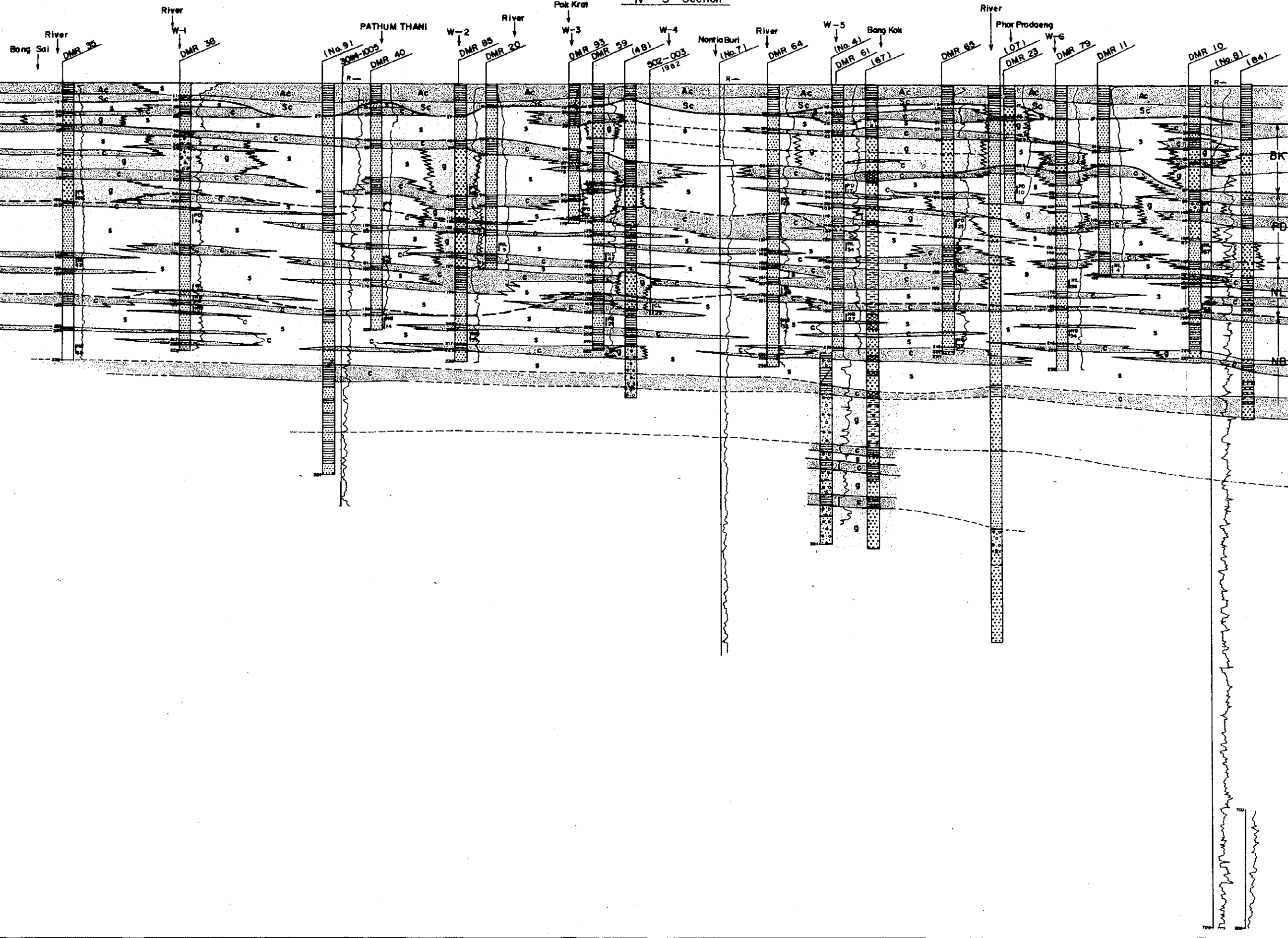
No. 1	DMR well, 1979	Station No. 1079
No. 2	DMR well, 1979	Station No. 1078
No. 3	DMR well, 1979	Station No. 1077
No. 4	DMR well, 1979	Station No. 1076
No. 5	DMR well, 1979	Station No. 1075
No. 6	DMR well, 1979	Station No. 1074
No. 7	DMR well, 1979	Station No. 1073
No. 8	DMR well, 1979	Station No. 1072
No. 9	DMR well, 1979	Station No. 1071
No. 10	DMR well, 1979	Station No. 1070

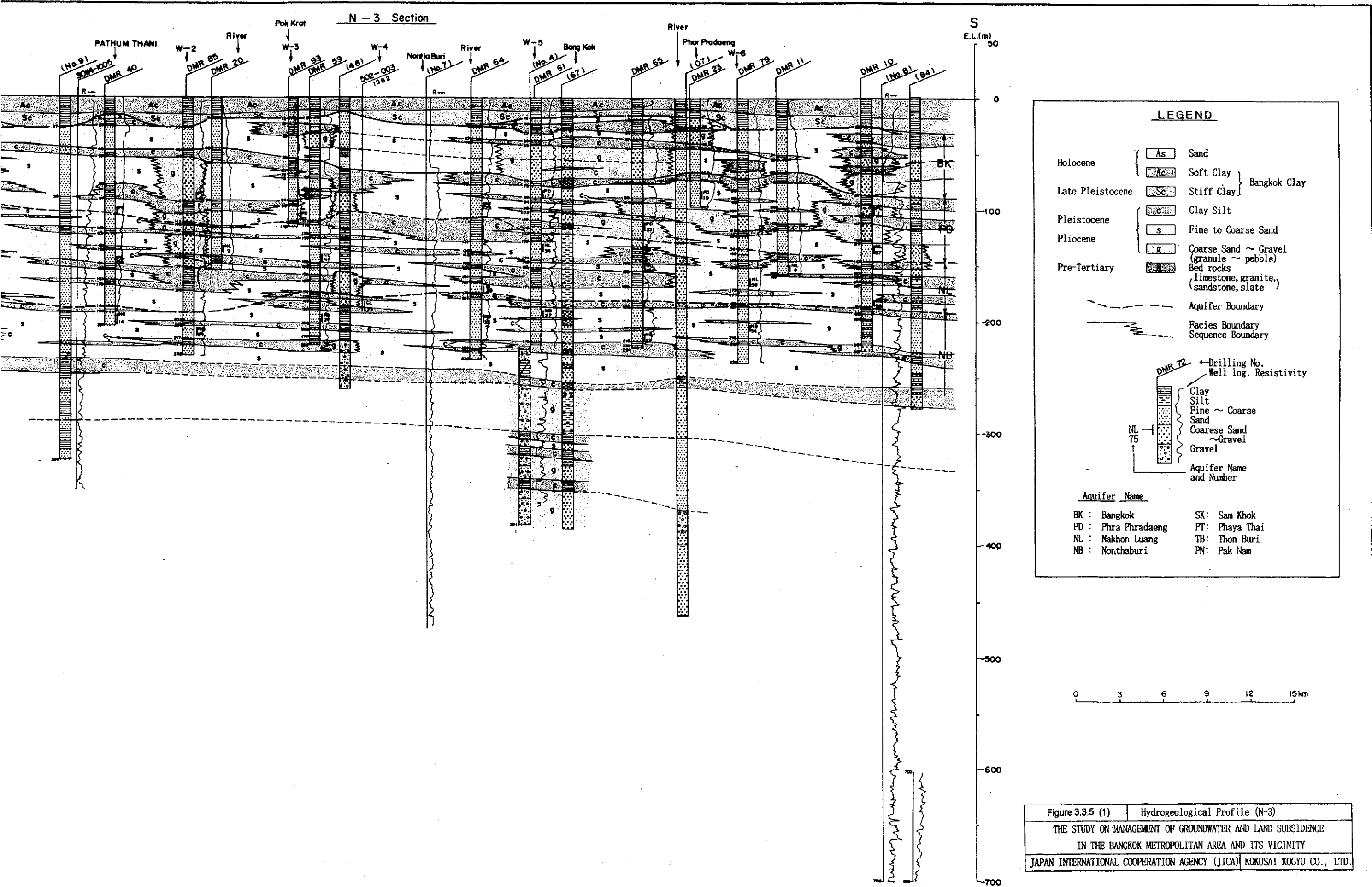
Figure 3.3.4 Subsurface Geological Map of The Study Area
 THE STUDY OF MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE
 IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY
 JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) KOKUSAI KOSYO CO. LTD.

N-3 Section

N
E.L.(m)
50
0
-100
-200
-300
-400
-500
-600
-700

S
E.L.(m)
50
0
-100
-200
-300
-400
-500
-600
-700





LEGEND

Holocene	As	Sand	
	Ac	Soft Clay	} Bangkok Clay
Late Pleistocene	Sc	Stiff Clay	
Pleistocene	c	Clay Silt	
Pliocene	s	Fine to Coarse Sand	
	r	Coarse Sand ~ Gravel (granule ~ pebble)	
Pre-Tertiary	R	Bed rocks (limestone, granite, sandstone, slate)	

- - - - - Aquifer Boundary
 - - - - - Facies Boundary
 - - - - - Sequence Boundary

← Drilling No. Well log. Resistivity
 DMR 72
 Clay
 Silt
 Fine ~ Coarse Sand
 Coarse Sand ~ Gravel
 Gravel
 Aquifer Name and Number
 NL 75

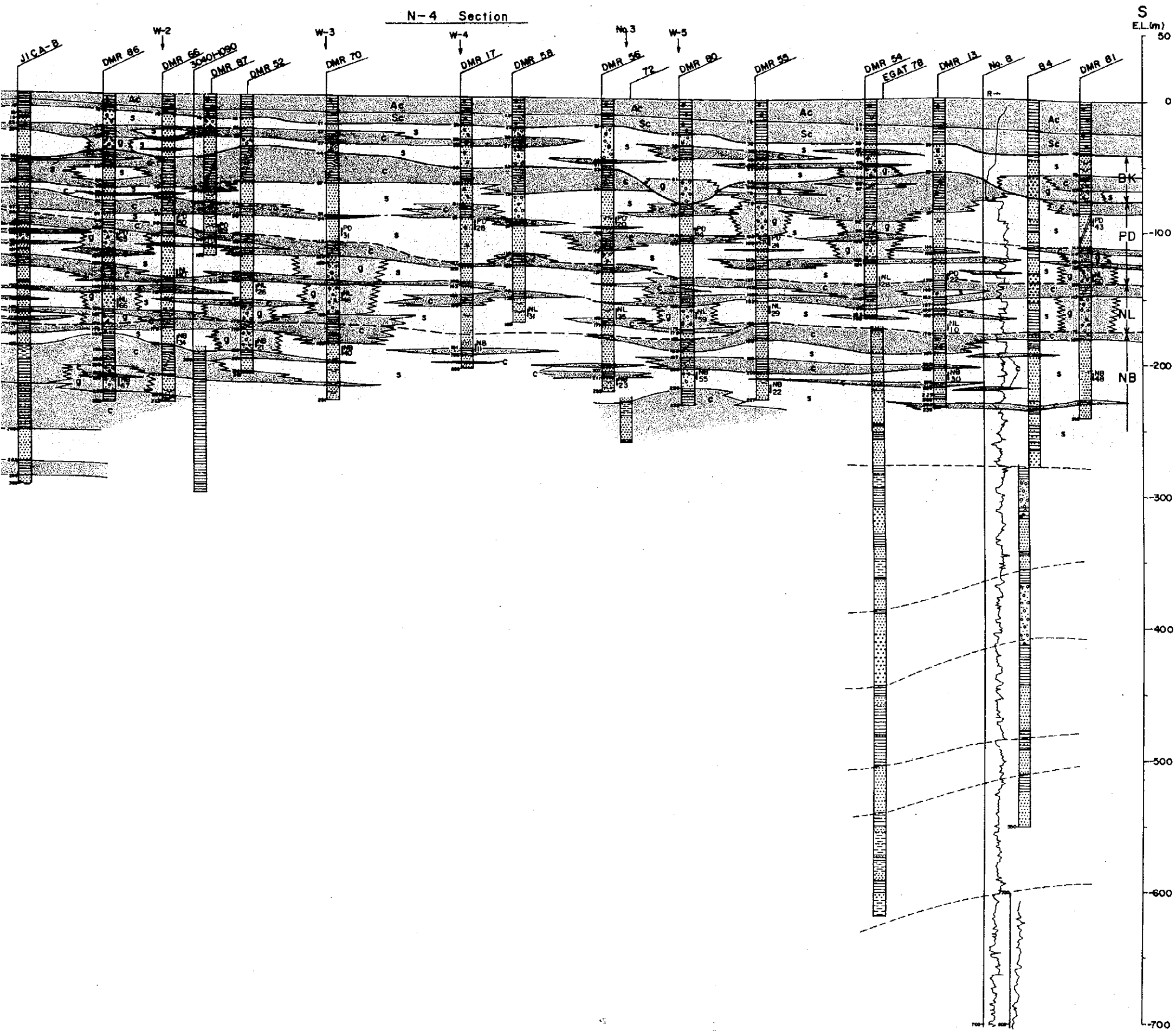
Aquifer Name

BK : Bangkok	SK : Sam Khok
PD : Phra Pradaeng	PT : Phaya Thai
NL : Nakhon Luang	TB : Thon Buri
NB : Nonthaburi	PN : Pak Nam

Figure 3.3.5 (1) Hydrogeological Profile (N-3)

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE
 IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) KOKUSAI KOGYO CO., LTD.



LEGEND

Holocene	As	Sand	
	Ac	Soft Clay	} Bangkok Clay
Late Pleistocene	Sc	Stiff Clay	
Pleistocene	c	Clay Silt	
Pliocene	s	Fine to Coarse Sand	
	g	Coarse Sand ~ Gravel (granule ~ pebble)	
Pre-Tertiary		Bed rocks limestone, granite, sandstone, slate	
		—	Aquifer Boundary
		—	Facies Boundary
		—	Sequence Boundary

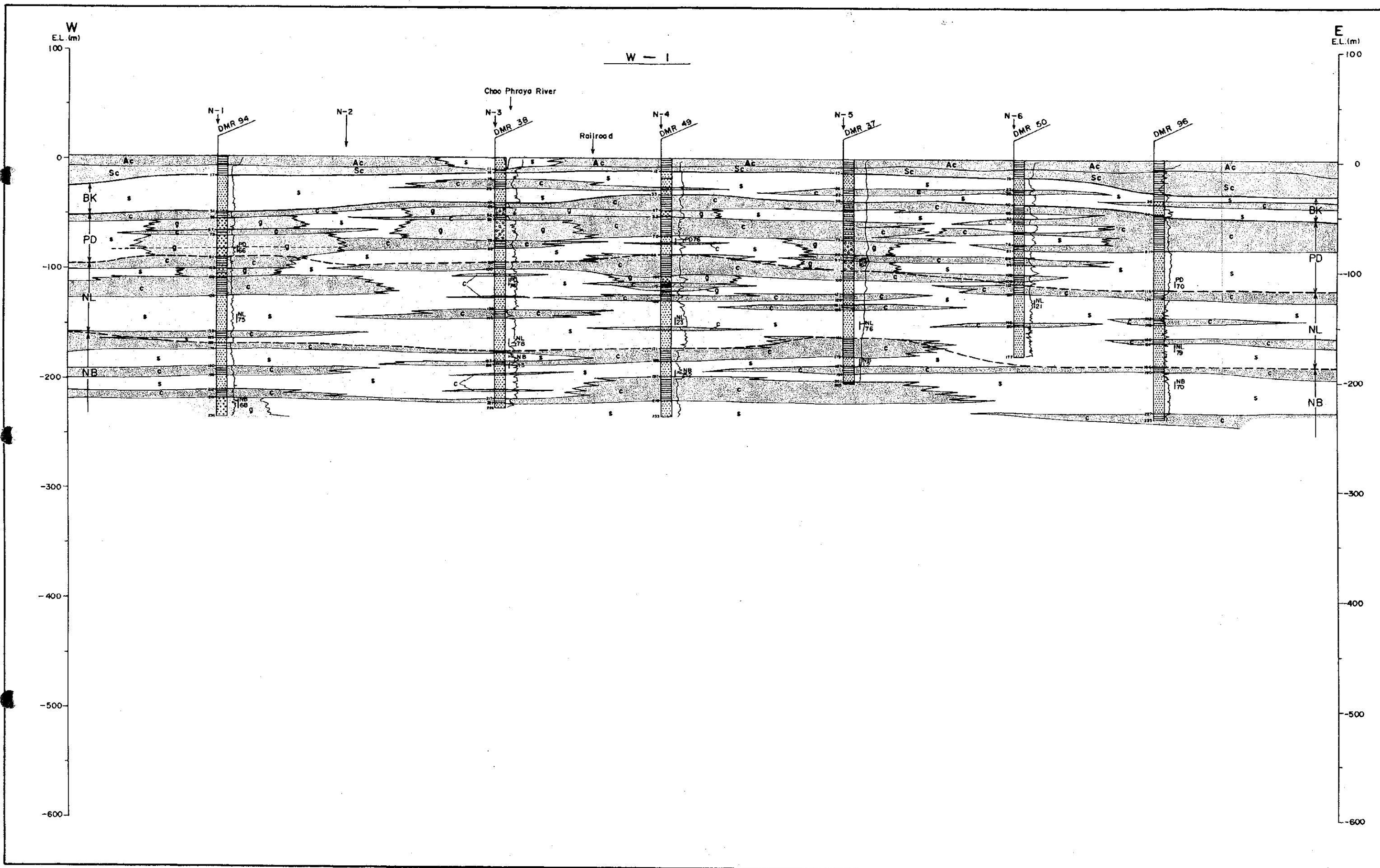
← Drilling No.
 Well log. Resistivity

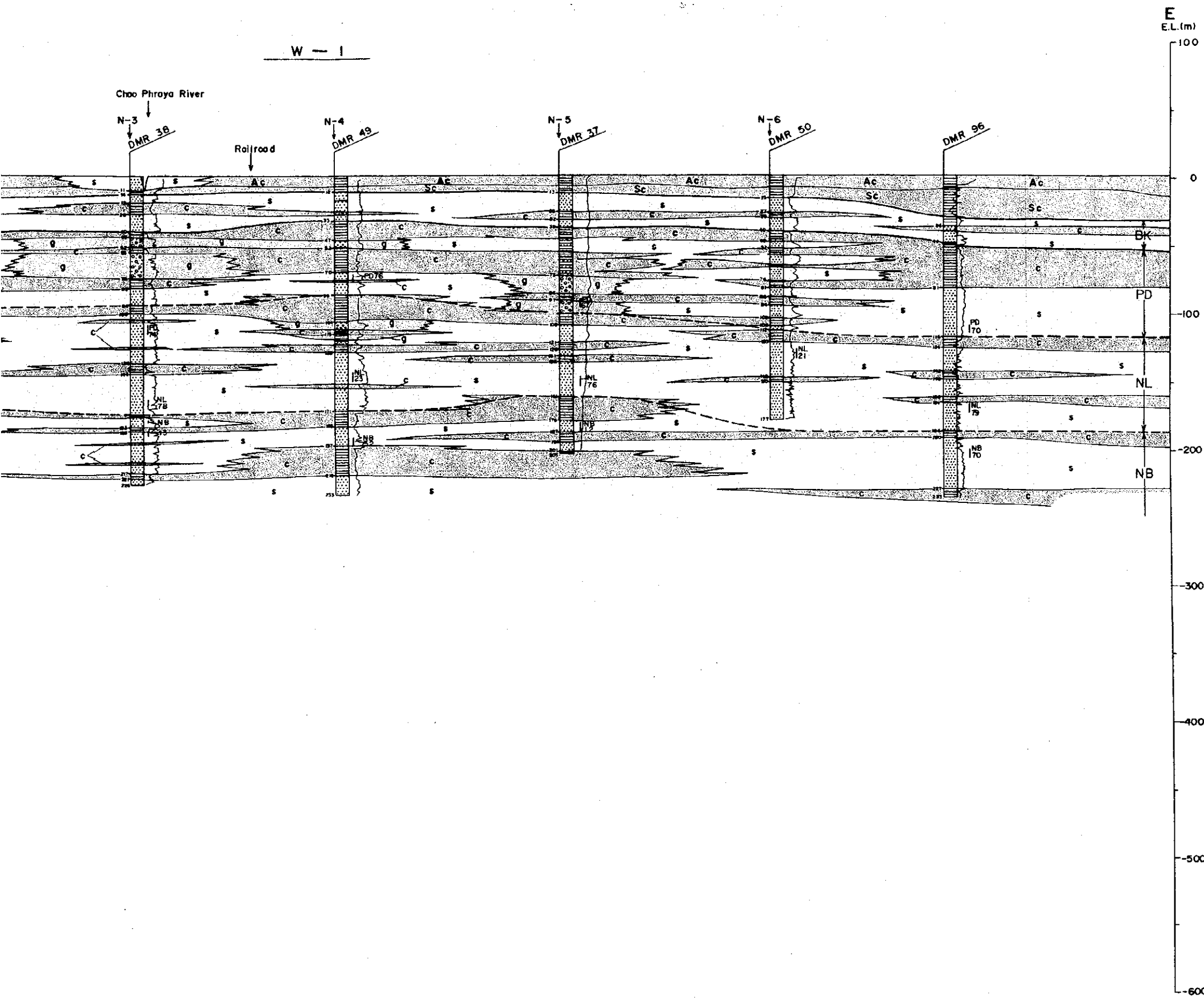
Aquifer Name

BK : Bangkok	SK : Sam Khok
PD : Phra Phradaeng	PT : Phaya Thai
NL : Nakhon Luang	TB : Thon Buri
NE : Nonthaburi	PN : Pak Nam



Figure 3.3.5 (2) Hydrogeological Profile (N-4)
 THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE
 IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY
 JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) KOKUSAI KOGYO CO., LTD.





LEGEND

Holocene	As	Sand	} Bangkok Clay
	Ac	Soft Clay	
Late Pleistocene	Sc	Stiff Clay	
Pleistocene	C	Clay Silt	
Pliocene	s	Fine to Coarse Sand	
	g	Coarse Sand ~ Gravel (granule ~ pebble)	
Pre-Tertiary	B	Bed rocks (limestone, granite, sandstone, slate)	

- - - - - Aquifer Boundary
 ~~~~~ Facies Boundary  
 - - - - - Sequence Boundary

DMR T2 ← Drilling No.  
Well log. Resistivity

NL 75

Clay  
Silt  
Fine ~ Coarse  
Sand  
Coarse Sand  
~Gravel  
Gravel

Aquifer Name  
and Number

|                     |                 |
|---------------------|-----------------|
| <u>Aquifer Name</u> |                 |
| BK : Bangkok        | SK : Sam Khok   |
| PD : Phra Phradaeng | PT : Phaya Thai |
| NL : Nakhon Luang   | TB : Thon Buri  |
| NB : Nonthaburi     | PN : Pak Nam    |

**Figure 3.3.5 (3)** Hydrogeological Profile (W-1)

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE  
IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) KOKUSAI KOGYO CO., LTD.

W-6 Section

W  
E.L.(m)  
50  
0  
-100  
-200  
-300  
-400  
-500  
-600  
-650

MD 165

Moe Klong River

X 67

Tho Chin Riv.  
Somut Sakhon

N-1  
DMR 62

JICA C

DMR 24

N-2  
DMR 25

3104-0004

N-3  
DMR 79

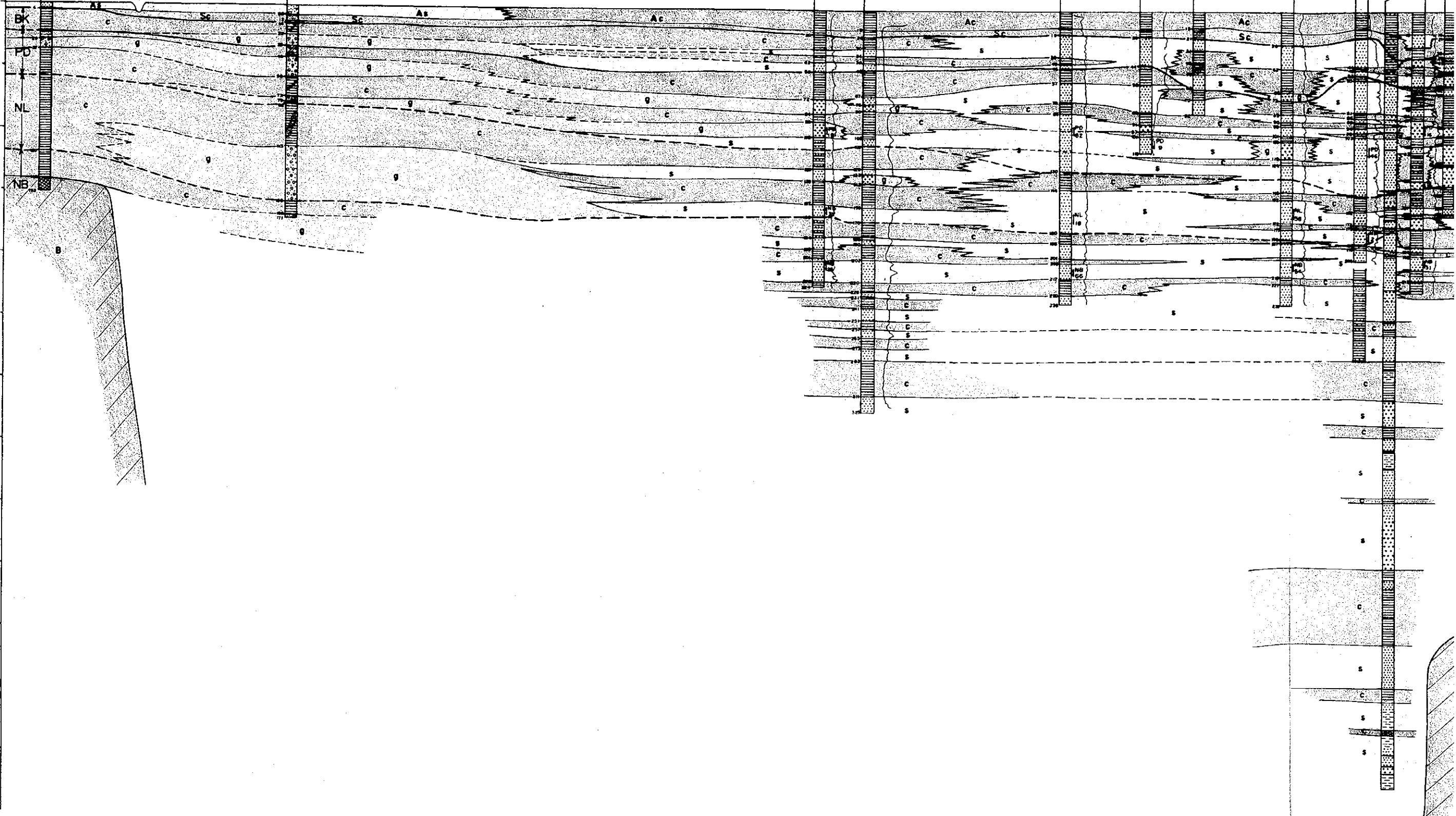
Pharu Phradoeng  
Chao Phraya Riv.

(107/1)  
DMR 21  
(78)

N-4  
DMR 5

BK  
PD  
NL  
NB

B



Tho Chin Riv.

W-6 Section

Somut Sakhon

N-1

DMR 62

JICA C

DMR 24

N-2

DMR 25

3104-0004

N-3

DMR 79

Phra Phadoeng

Chao Phraya Riv.

(07/11)

DMR 21

N-4

DMR 53

DMR 54

DMR 9

DMR 72

DMR 83

Bong Phi

N-5

DMR 26

3903-0004

DMR 18

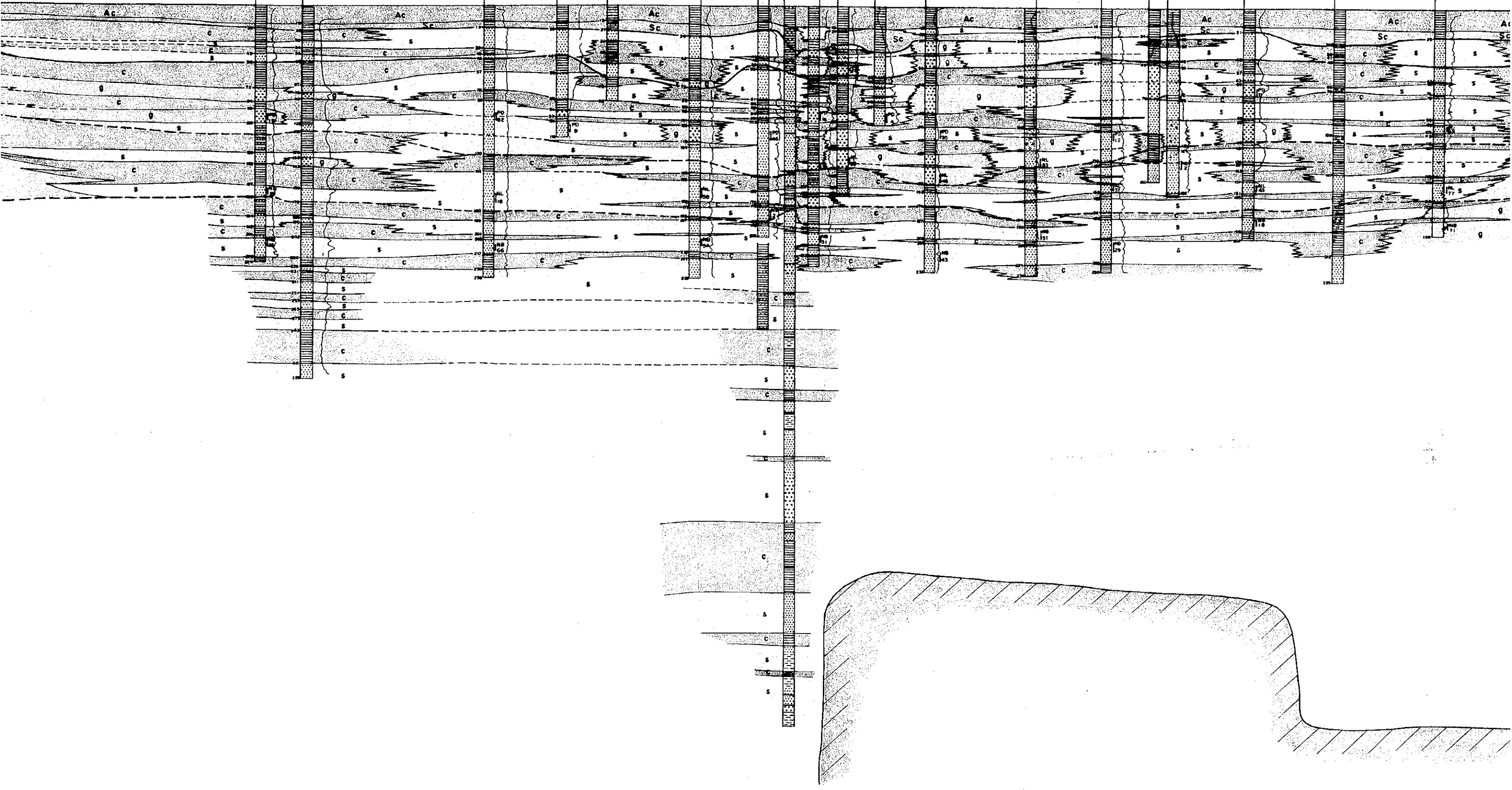
N-6

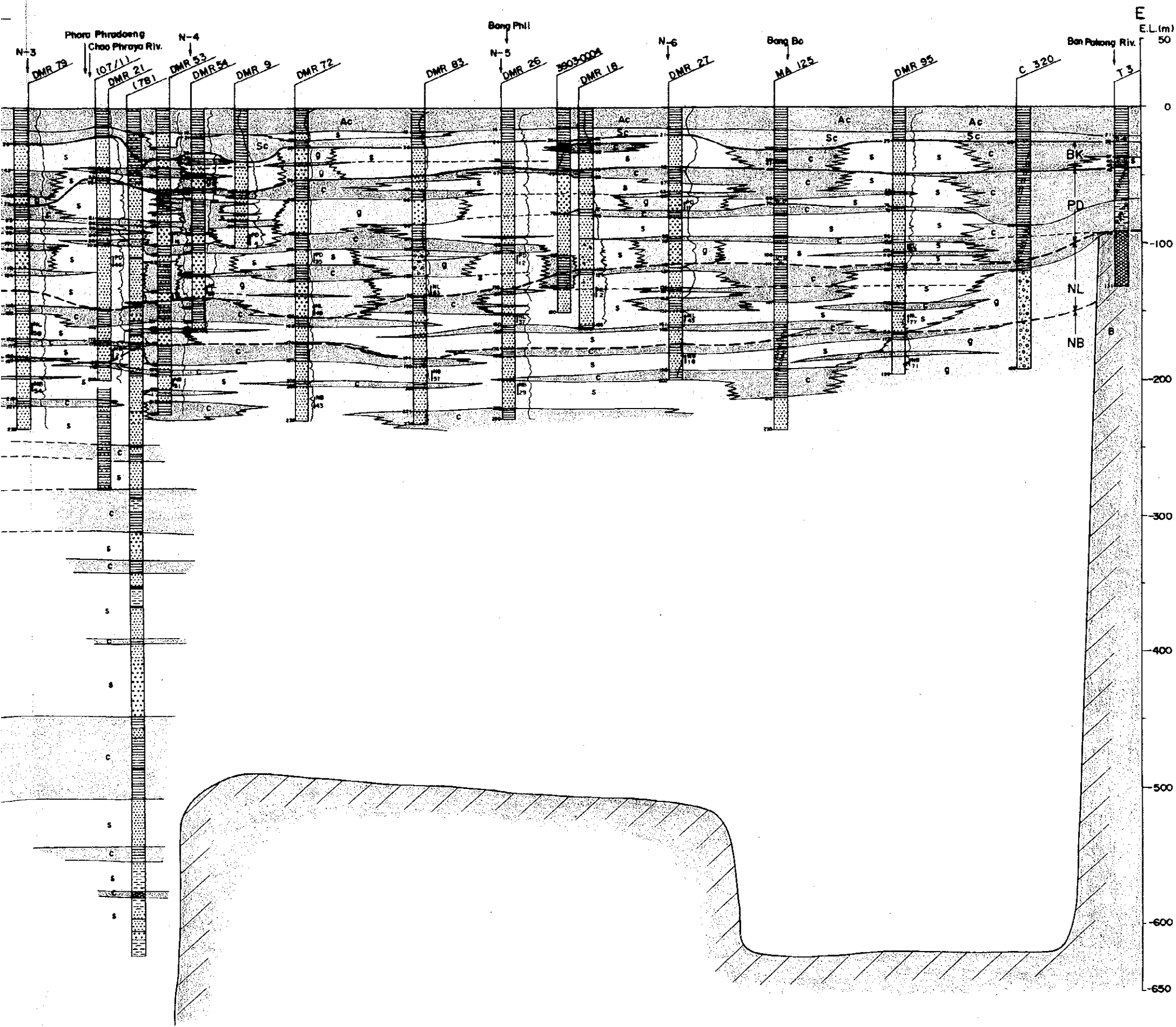
DMR 27

Bang Bo

MA 125

DMR 95





**LEGEND**

|                  |    |                                                  |                |
|------------------|----|--------------------------------------------------|----------------|
| Holocene         | As | Sand                                             | } Bangkok Clay |
|                  | Ac | Soft Clay                                        |                |
| late Pleistocene | Sc | Stiff Clay                                       |                |
| Pleistocene      | c  | Clay Silt                                        |                |
| Pliocene         | s  | Fine to Coarse Sand                              |                |
| Pre-Tertiary     | g  | Coarse Sand ~ Gravel (granule ~ pebble)          |                |
|                  | B  | Bed rocks (limestone, granite, sandstone, slate) |                |

--- Aquifer Boundary  
 --- Facies Boundary  
 --- Sequence Boundary

DMR 72 ← Drilling No.  
 Well log. Resistivity  
 Clay  
 Silt  
 Fine ~ Coarse Sand  
 Coarse Sand ~ Gravel  
 Gravel  
 Aquifer Name and Number

Aquifer Name

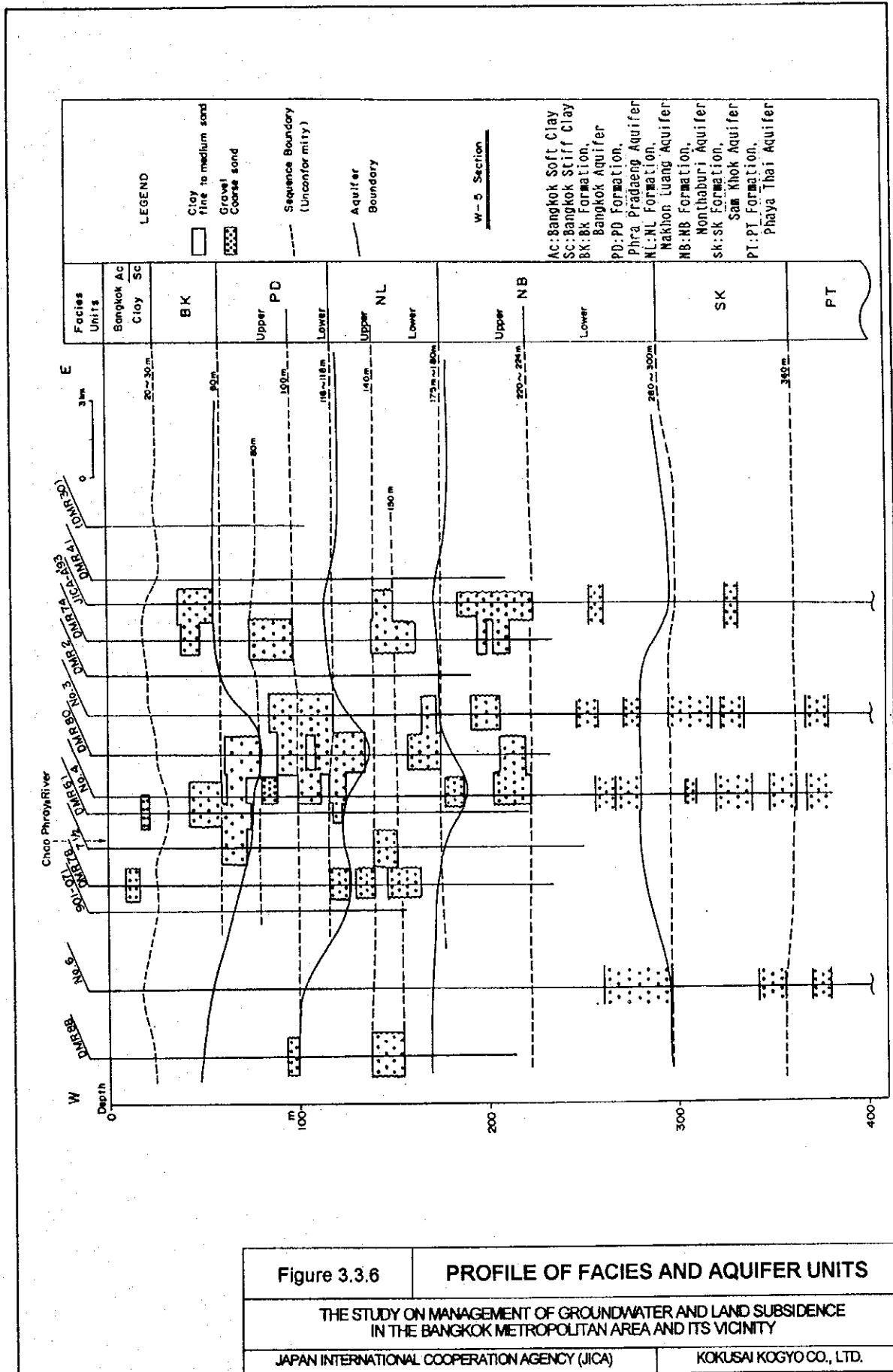
|                     |                 |
|---------------------|-----------------|
| BK : Bangkok        | SK : Sam Khok   |
| PD : Phra Phradaeng | PT : Phaya Thai |
| NL : Nakhon Luang   | TB : Thon Buri  |
| NB : Nonthaburi     | PN : Pak Nam    |



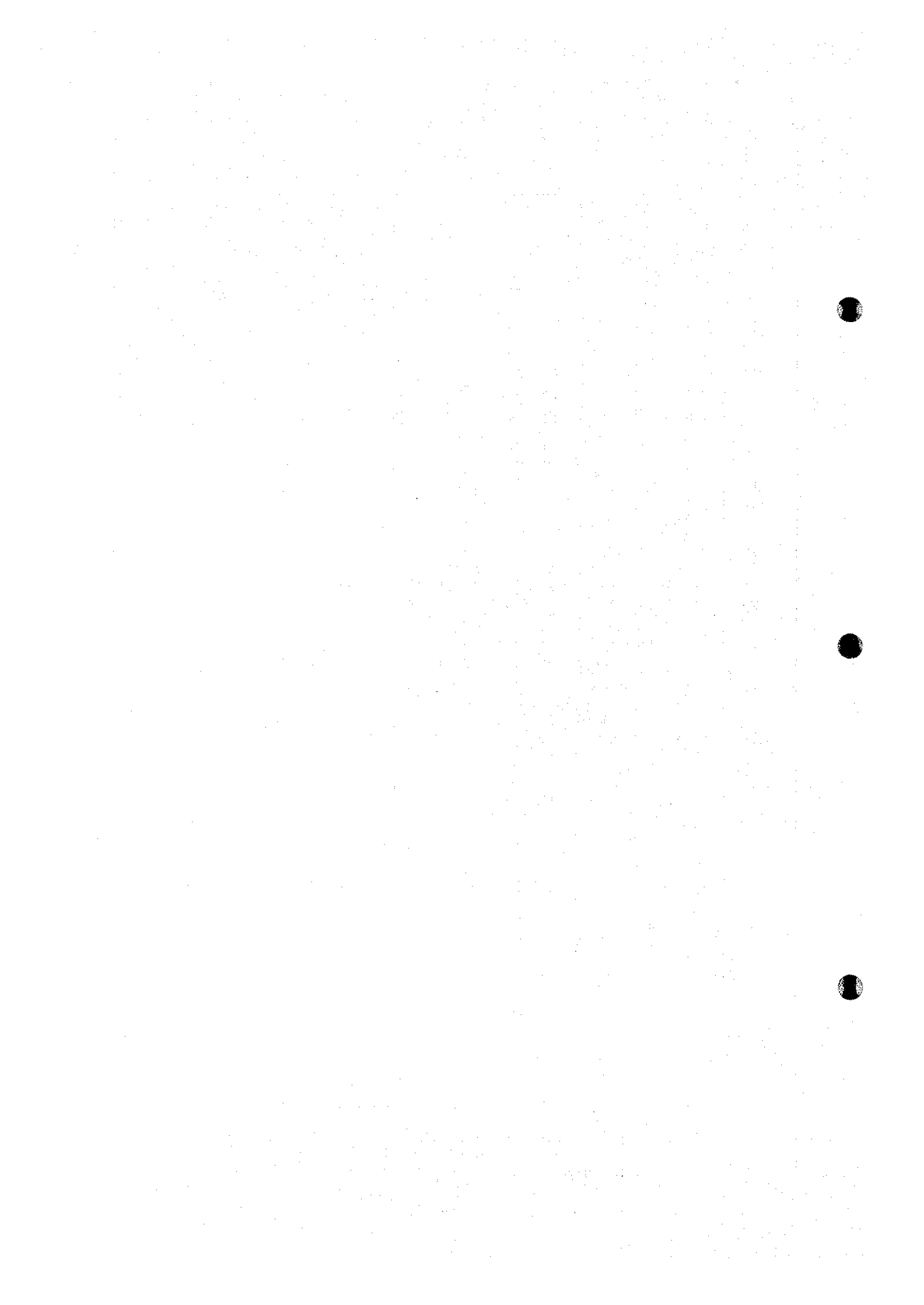
Figure 3.3.5 (4) Hydrogeological Profile (W-6)  
 THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE  
 IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY  
 JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) KOKUSAI KOGYO CO., LTD.

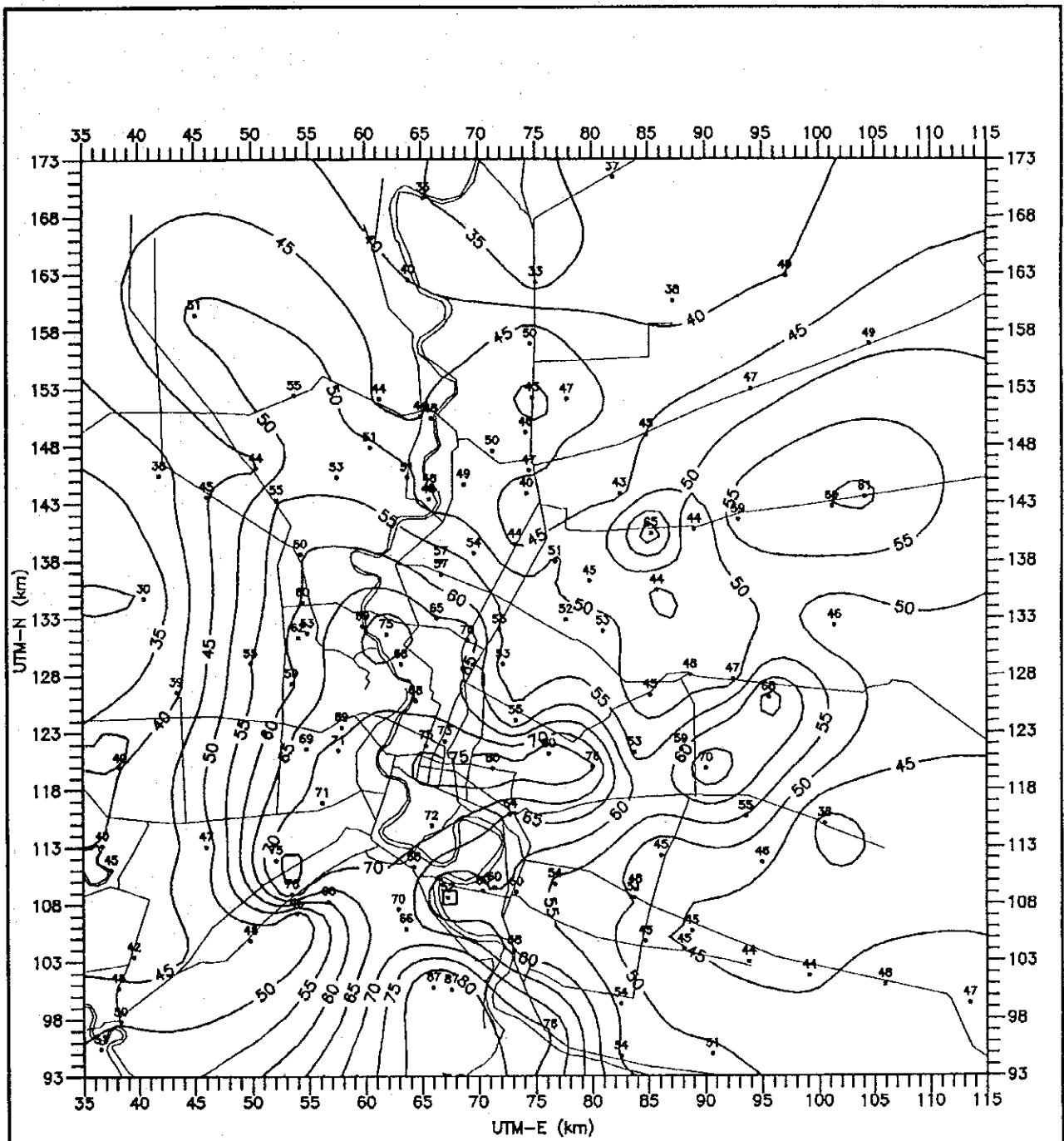










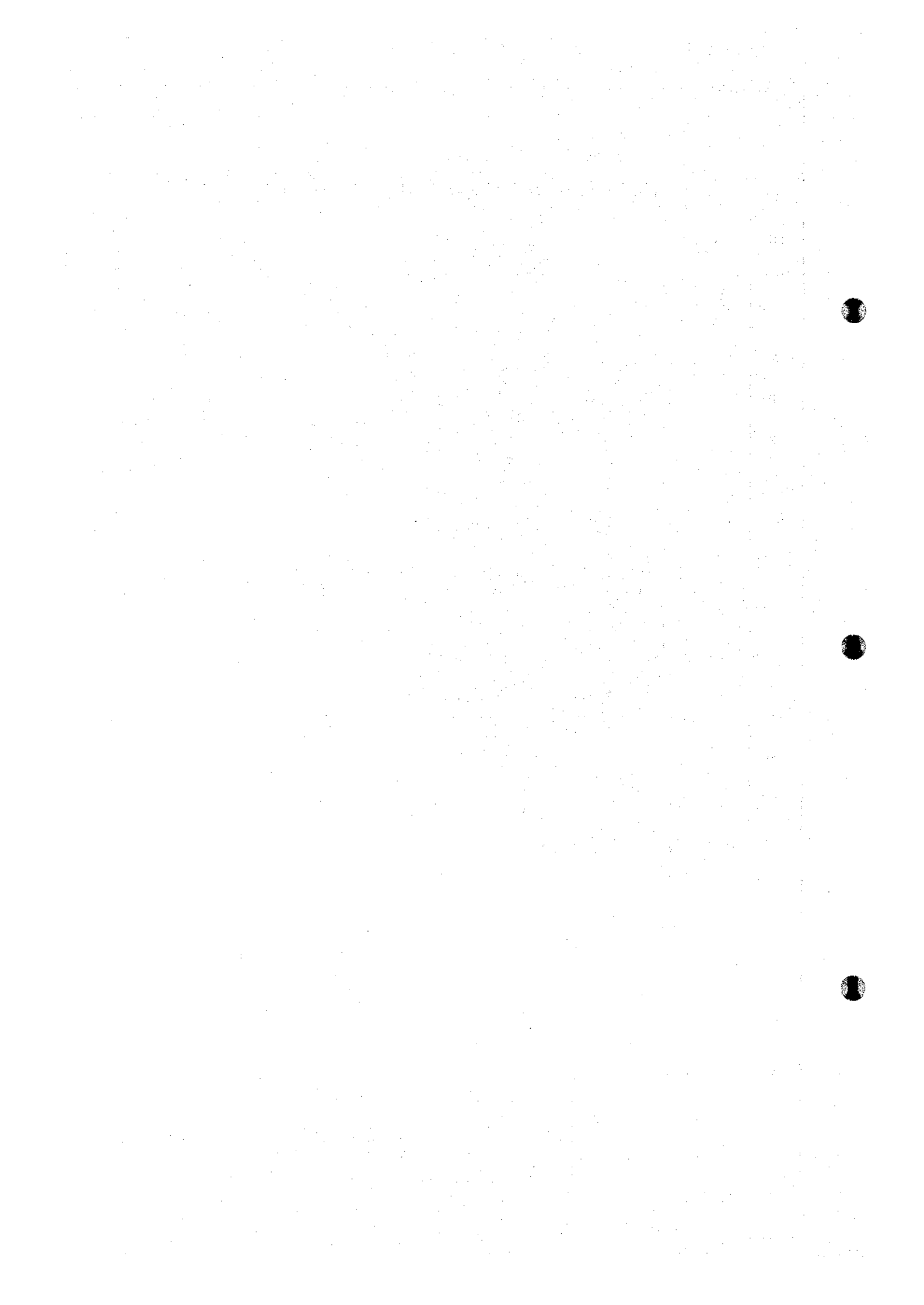


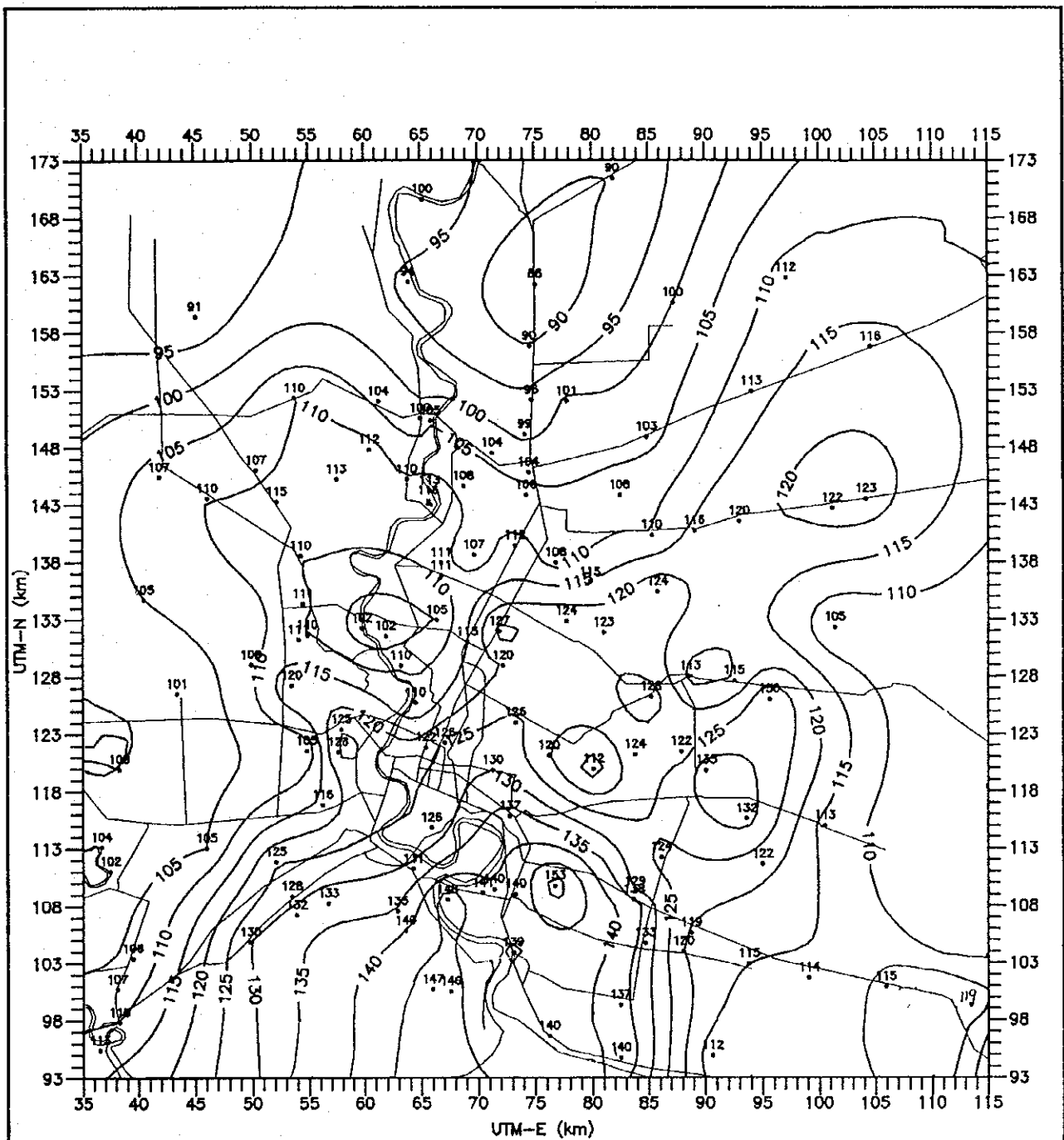
LEGEND

———— LINE OF EQUAL DEPTH TO AQUIFER BOTTOM  
(m below ground surface)

50 • INVESTIGATED WELL  
WITH DEPTH TO AQUIFER BOTTOM  
(m below ground surface)

|                                                                                                                 |                                                        |
|-----------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|
| Figure 3.3.7<br>(1)                                                                                             | <b>DEPTH TO THE BOTTOM OF<br/>BANGKOK AQUIFER (BK)</b> |
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE<br>IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY |                                                        |
| JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)                                                                   | KOKUSAI KOGYO CO., LTD.                                |



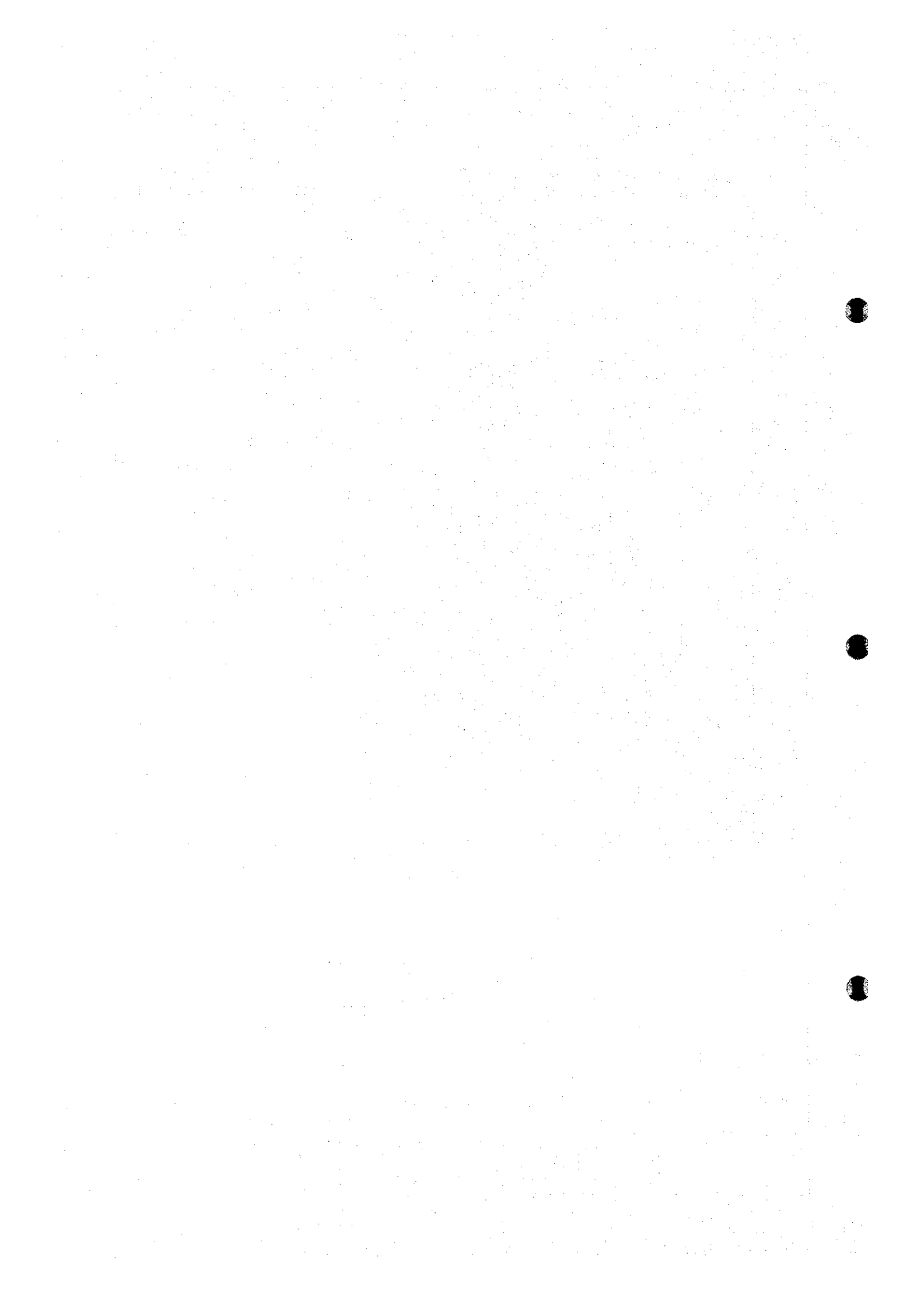


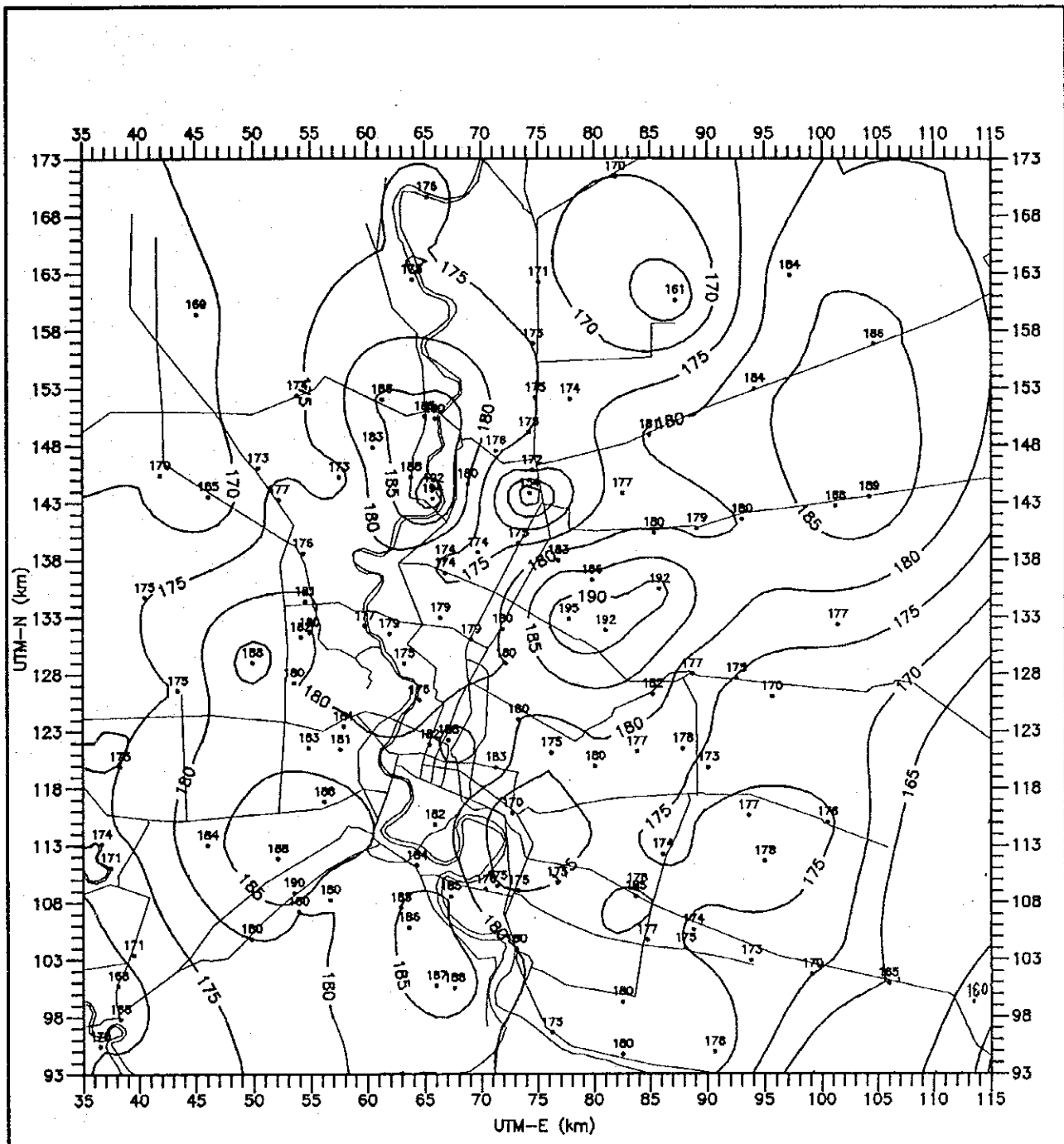
LEGEND

— LINE OF EQUAL DEPTH TO AQUIFER BOTTOM  
(m below ground surface)

120 • INVESTIGATED WELL  
WITH DEPTH TO AQUIFER BOTTOM  
(m below ground surface)

|                                                                                                                 |                                                              |
|-----------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| Figure 3.3.7<br>(2)                                                                                             | <b>DEPTH TO THE BOTTOM OF<br/>PHRA PRADAENG AQUIFER (PD)</b> |
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE<br>IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY |                                                              |
| JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)                                                                   | KOKUSAI KOGYO CO., LTD.                                      |

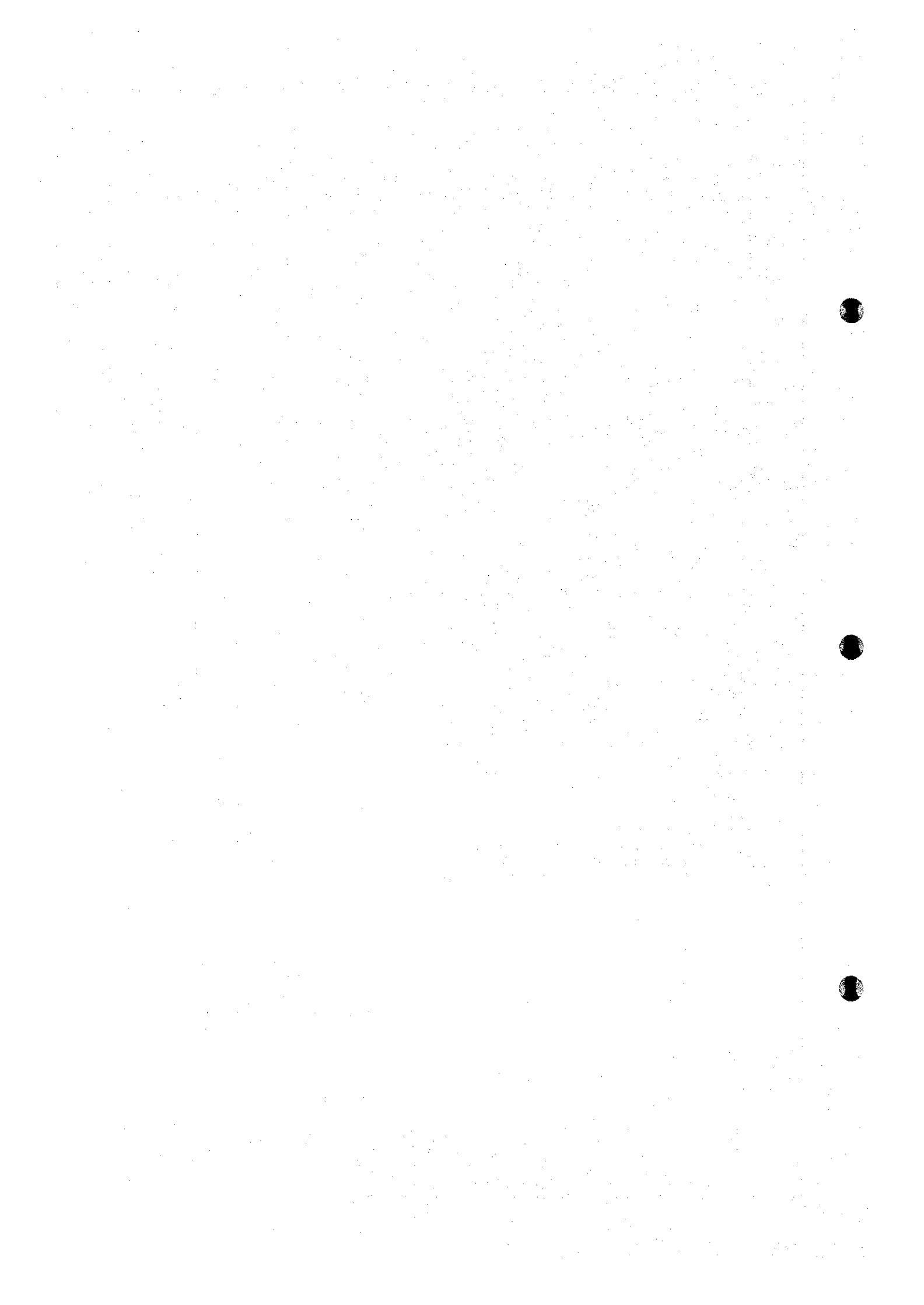


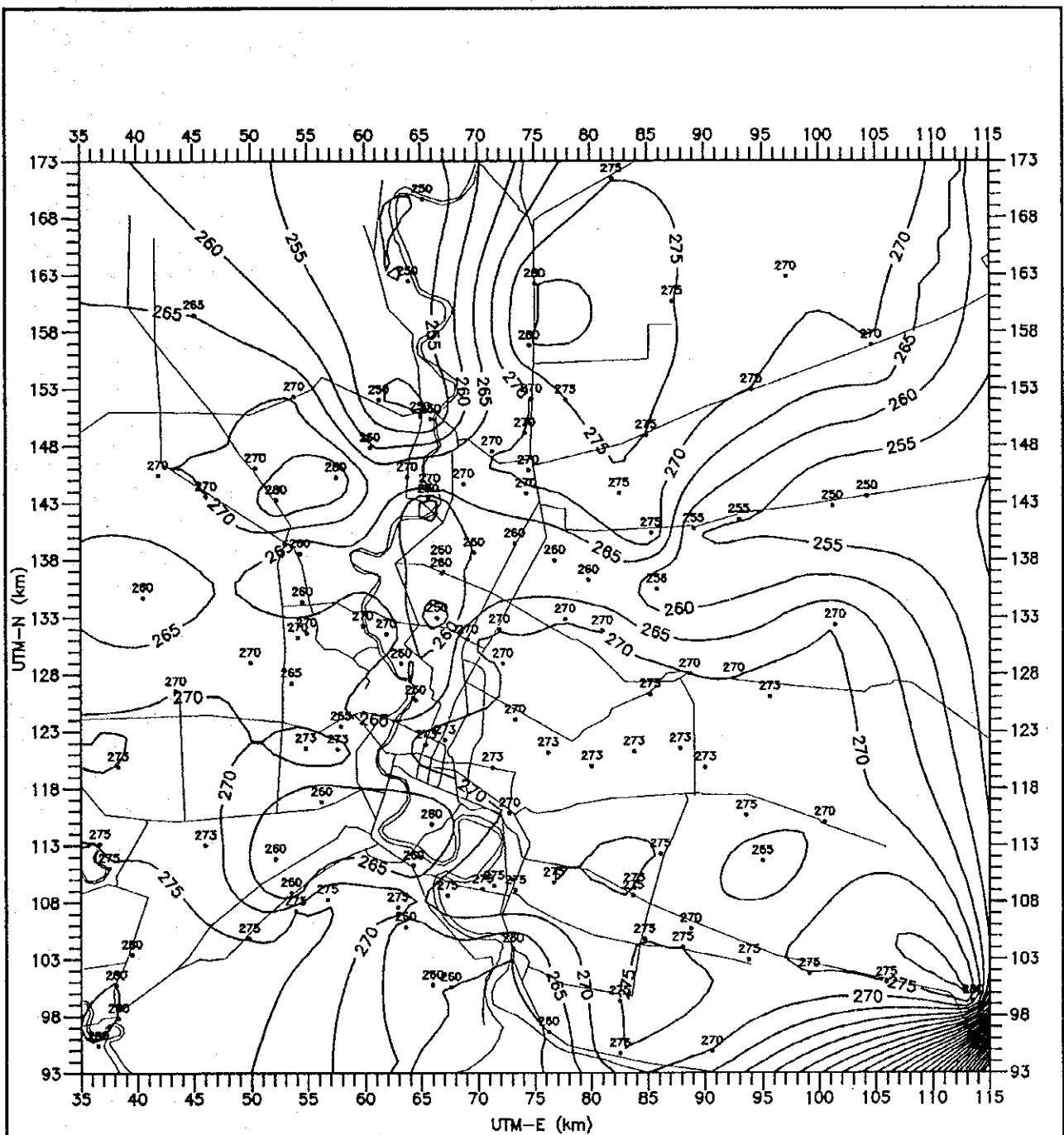


**LEGEND**

- LINE OF EQUAL DEPTH TO AQUIFER BOTTOM  
(m below ground surface)
- 120 INVESTIGATED WELL  
WITH DEPTH TO AQUIFER BOTTOM  
(m below ground surface)

|                                                                                                                 |                                                             |
|-----------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------|
| Figure 3.3.7<br>(3)                                                                                             | <b>DEPTH TO THE BOTTOM OF<br/>NAKHON LUANG AQUIFER (NL)</b> |
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE<br>IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY |                                                             |
| JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)                                                                   | KOKUSAI KOGYO CO., LTD.                                     |



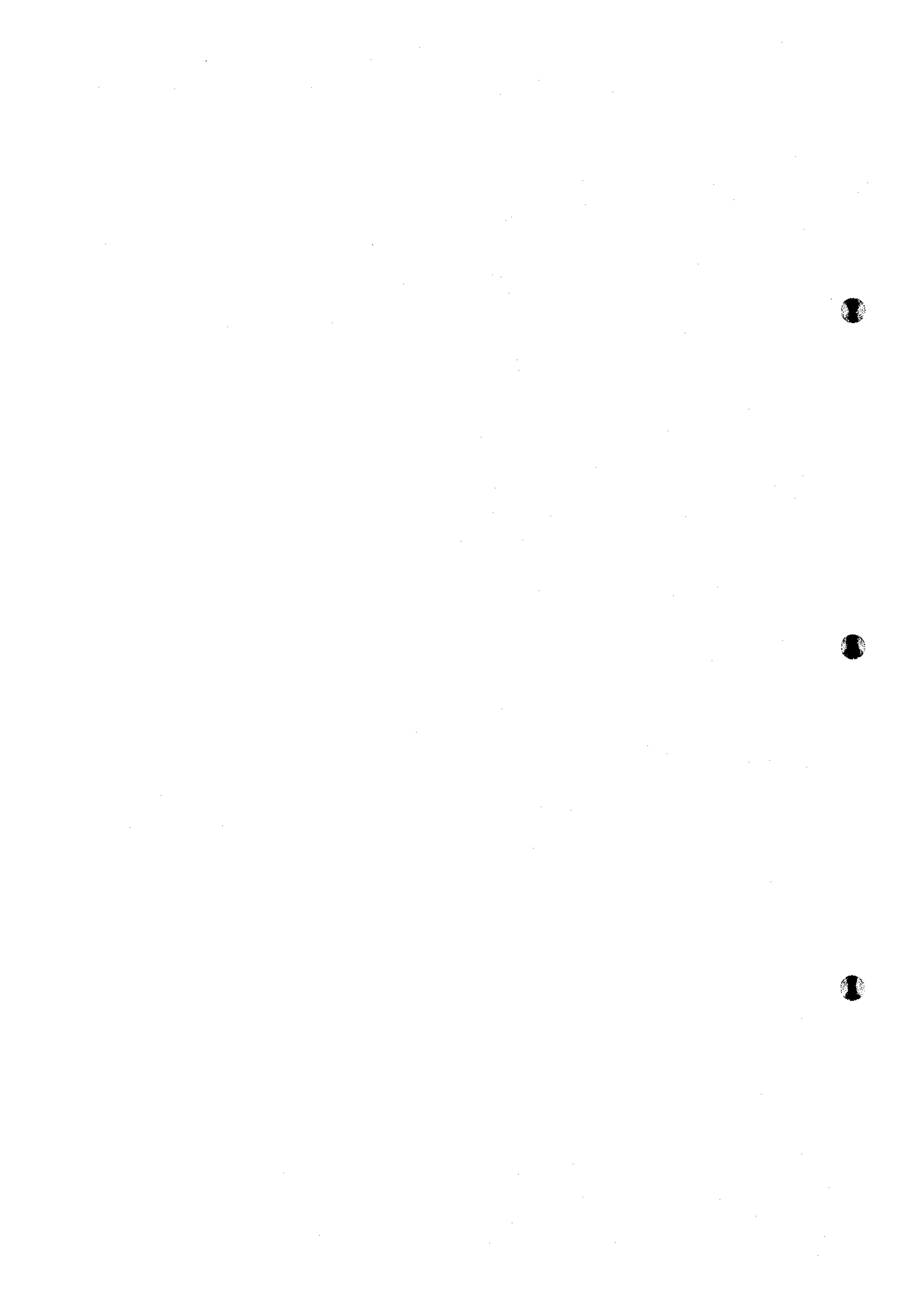


LEGEND

- LINE OF EQUAL DEPTH TO AQUIFER BOTTOM  
(m below ground surface)
- 120 INVESTIGATED WELL  
WITH DEPTH TO AQUIFER BOTTOM  
(m below ground surface)

|                                                                                                                 |                                                           |
|-----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|
| Figure 3.3.7<br>(4)                                                                                             | <b>DEPTH TO THE BOTTOM OF<br/>NONTHABURI AQUIFER (NB)</b> |
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE<br>IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY |                                                           |
| JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)                                                                   | KOKUSAI KOGYO CO., LTD.                                   |





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## **CHAPTER 4 GROUNDWATER QUALITY**

### **4.1 Groundwater Sampling**

A total of 237 groundwater samples from the DMR monitoring wells and 16 samples from production wells were collected from September 1993 to December 1993. The submersible pump was used to remove stagnant water from the well so as to collect reliable samples. The method of sampling is as follows:

- a) Remove existing monitoring unit from the well.
- b) Measure static groundwater level.
- c) Install a submersible pump into the well.
- d) Pump up stagnant water from the well for at least one (1) hour.
- e) Measure water level, discharge rate, electric conductivity, pH, and temperature at an interval of 10 minutes during pumping.
- f) Collect sample from pumped water at the final stage of pumping and keep it in sampling bottles.
- g) Write the necessary information on the label pasted on the bottles: sample no., well no., sampling date, electric conductivity, pH, and temperature.
- h) Transport samples to the laboratory on the same day.
- i) Reinstall monitoring unit to the well.

### **4.2 Results of Analysis**

The samples together with the results of chemical analysis are listed in Table 4.2.1. Trilinear diagrams, Stiff diagrams, and chloride concentration maps were prepared to interpret the results.

#### **4.2.1 Trilinear Diagram Analysis**

The trilinear diagrams of Phra Pradaeng (PD) Aquifer, Nakhon Luang (NL) Aquifer, and Nonthaburi (NB) Aquifer were prepared as shown in Figures 4.2.1 to 4.2.3, respectively.

##### **(1) Phra Pradaeng (PD) Aquifer (Figure 4.2.1)**

Most samples are plotted on the upper-right part of the diamond-shape diagram. The elements of (Na+K) and (Ca) occupy 25% to 98% and 2% to 48% of the total cations, respectively. Most samples are chloride-rich in anion composition. However, several samples are rich in bicarbonate. Sulfate content is higher in PD Aquifer than in NL Aquifer or NB Aquifer.

##### **(2) Nakhon Luang (NL) Aquifer (Figure 4.2.2)**

Samples are plotted on the upper-right to lower-right portions of the diamond-shape diagram. The element of (Na+K) occupies 30% to 99% of the total cations. For anions, sulfate is less than 10% except for a few samples.