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JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

DEPARTMENT OF MINERAL RESOURCES
MINISTRY OF INDUSTRY
AND
PUBLIC WORKS DEPARTMENT
MINISTRY OF INTERIOR
THE KINGDOM OF THAILAND

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

SUMMARY REPORT

MARCH 1995

KOKUSAI KOGYO CO., LTD.
TOKYO, JAPAN

PREFACE

In response to a request from the Government of the Kingdom of Thailand, the Government of Japan decided to conduct a study on the Management of Groundwater and Land Subsidence in the Bangkok Metropolitan Area and Its Vicinity and entrusted the study to the Japan International Cooperation Agency (JICA).

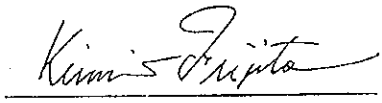
JICA sent to Thailand a study team headed by Dr.Akira KAMATA, Kokusai Kogyo Co.,Ltd., 7 times between July 1992 and February 1995.

The team held discussion with the officials concerned of the Government of Thailand, and conducted field surveys at the study area. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Kingdom of Thailand for their close cooperation extended to the team.

March 1995



Kimio Fujita
President
Japan International Cooperation Agency

March 1995

Mr.Kimio Fujita
President
Japan International Cooperation Agency

LETTER OF TRANSMITTAL

Dear Sir,

We are pleased to submit the final report of "The Study on Management of Groundwater and Land Subsidence in the Bangkok Metropolitan Area and Its Vicinity". This report has been prepared based on the field survey and the study conducted during the period from July 1992 to March 1995.

The report contains the study results on the hydrogeology, the groundwater database, the groundwater quality and the prediction of future groundwater levels and land subsidence by computer modeling as well as the details of the three new monitoring stations. A target pumpage for the management of groundwater and alleviation of land subsidence is presented based on the predictions.

We hope that the implementation of the groundwater management plan would greatly contribute to the mitigation of land subsidence in the Bangkok Metropolitan Area.

All the members of the Study Team wish to express their sincere thanks to the personnel of your Agency, the Embassy of Japan in Thailand and the officials and personnel of the Department of Mineral Resources and the Public Works Department, the Government of Thailand for the assistance extended to them.

Very truly yours,

鎌田 彰

Akira KAMATA
Team Leader
The Study on Management of Groundwater and Land Subsidence in the Bangkok Metropolitan Area and Its Vicinity

The Study on Management of Groundwater and Land Subsidence in the Bangkok Metropolitan Area and Its Vicinity

Study Period:	July 1992 to March 1995
Counterpart Agencies:	Department of Mineral Resources
	Public Works Department

Abstract

1. Background

The recent economic development of Thailand has brought about increases in water demands for industrial, commercial and domestic purposes, particularly in the Bangkok Metropolitan Area. In order to meet the growing water demands, groundwater is pumped heavily, causing increased and more widespread land subsidence and saltwater intrusion in the area. Though land subsidence has slowed down in the central part of Bangkok due to regulations undertaken in the early 80's, it is still progressing in the vicinity of the Bangkok Metropolitan Area. The land subsidence not only damages roads, bridges, buildings and canals but also causes flood in the low lands, which has brought huge economic losses. It is therefore urgently needed to establish a sound groundwater management plan and implement comprehensive measures against land subsidence.

2. Study Objectives

The Study aims at achieving the following:

(1) To establish groundwater management system
(2) To prepare alleviation plans against land subsidence and saline water intrusion
(3) Technical transfer through out the Study

3. Study Area

The 5,600-km^2 Study Area covers the Bangkok Metropolis and its vicinity, comprising wholly or partly the following eight (8) provinces, namely:

whole of BANGKOK, NONTHABURI, SAMUT PRAKAN, PATHUM THANI and parts of CHACHOENGSAO, SAMUT SAKHON, NAKHON PATHOM, PHRA NAKHON SI AYUTTHAYA

4. Study Results

The Study had established the following major pillars for the management of groundwater and land subsidence in the Bangkok Metropolitan Area and its vicinty.

1) Development and Installation of Groundwater Database System
2) Construction of Monitoring Stations at Lat Krabang, AIT and Samut Sakhon
3) Groundwater Modeling and Predictions

Based on the data collected, processed and analyzed throughout the Study, the following results were obtained.

4.1 Groundwater Use

The Study Area's total groundwater pumpage in 1992 was estimated from the well inventory database at 1.48 MCMD. Pumpage is recently increasing in Bangkok's vicinity, e.g., Lat Krabang, Pathum Thani and Samut Sakhon.

(2) Groundwater Levels

Piezometric levels of the main aquifers have declined from 30m to 60m below MSL. In the central area of Bangkok, groundwater level is again lowering because of the effect of the regional decline of groundwater level caused by overpumping in the vicinity.

(3) Land Subsidence

Land subsidence occurs widely at more than 20mm/year in the Bangkok Metropolitan Area. Subsidence of 50mm/year to 60mm/year were recorded in Samut Prakan, 40mm/year to 55mm/year in Min Buri and Lat Krabang, 30mm/year to 40mm/year in Pathum Thani and Samut Sakhon.

(4) Chloride Concentration

High chloride concentrations were observed from Samut Sakhon to Pathum Thani along the Chao Phraya River and in the coastal areas of Samut Prakan. High chloride concentrations ranging from 3,000 to 16,000 mg/L were observed in the main aquifers.

(5) Monitoring Stations

The new land subsidence and groundwater level monitoring stations were constructed in Lat Krabang, AIT and Samut Sakhon. Each observation well automatically records the groundwater level and land subsidence of the different aquifers. Together with the DMR's existing monitoring stations, the new monitoring stations would be utilized for the groundwater management, conjunctively with the database and the groundwater models.

(6) Groundwater Modeling

Groundwater flow and land subsidence models were made to predict the future groundwater levels and land subsidence. A solute transport model was also prepared to analyze saltwater intrusion. These models have shown the mechanism of land subsidence and saltwater intrusion.

(7) Prediction of Groundwater Levels and Land Subsidence

Groundwater flow and land subsidence models were used to predict the future groundwater levels and land subsidence up to year-2017 using different future pumping scenarios. Using the worst scenario, the models predicted that land subsidence would reach a maximum of

200cm by year-2017. While, using the best scenario, the models predicted that the maximum total land subsidence would be 35cm by year-2017.

(8) Tentative Permissible Yield

A tentative permissible yield was determined by giving importance to the rate of land subsidence. The response of the models was carefully reviewed and assessed. It was concluded that the tentative permissible yield for the Study Area would be 1.60 MCMD.

(9) Groundwater Basin Management

The groundwater basin management is implemented by targeting the tentative permissible yield in year-2005. The expansion of the present critical zone and the regulation of groundwater pumpage are concurrently implemented. Groundwater level, land subsidence, water quality and groundwater pumpage are monitored and used conjunctively with the database and groundwater models.

5. Recommendations

(1) Groundwater Management

Expansion of the Critical Zone
Regulation of Pumpage
Construction of New Monitoring Stations
Leveling of Benchmarks
Installation of Water Meter
Application of the Groundwater Database System
Improvement of Groundwater Models
Model Applications and Permissible Yield
Hydrogeological Investigations

(2) Comprehensive Measures

Substitutional Water Supply
Rational Use of Water
Groundwater Fee
Artificial Recharge
Strengthenning of the Technical Sub-Committee
Organization

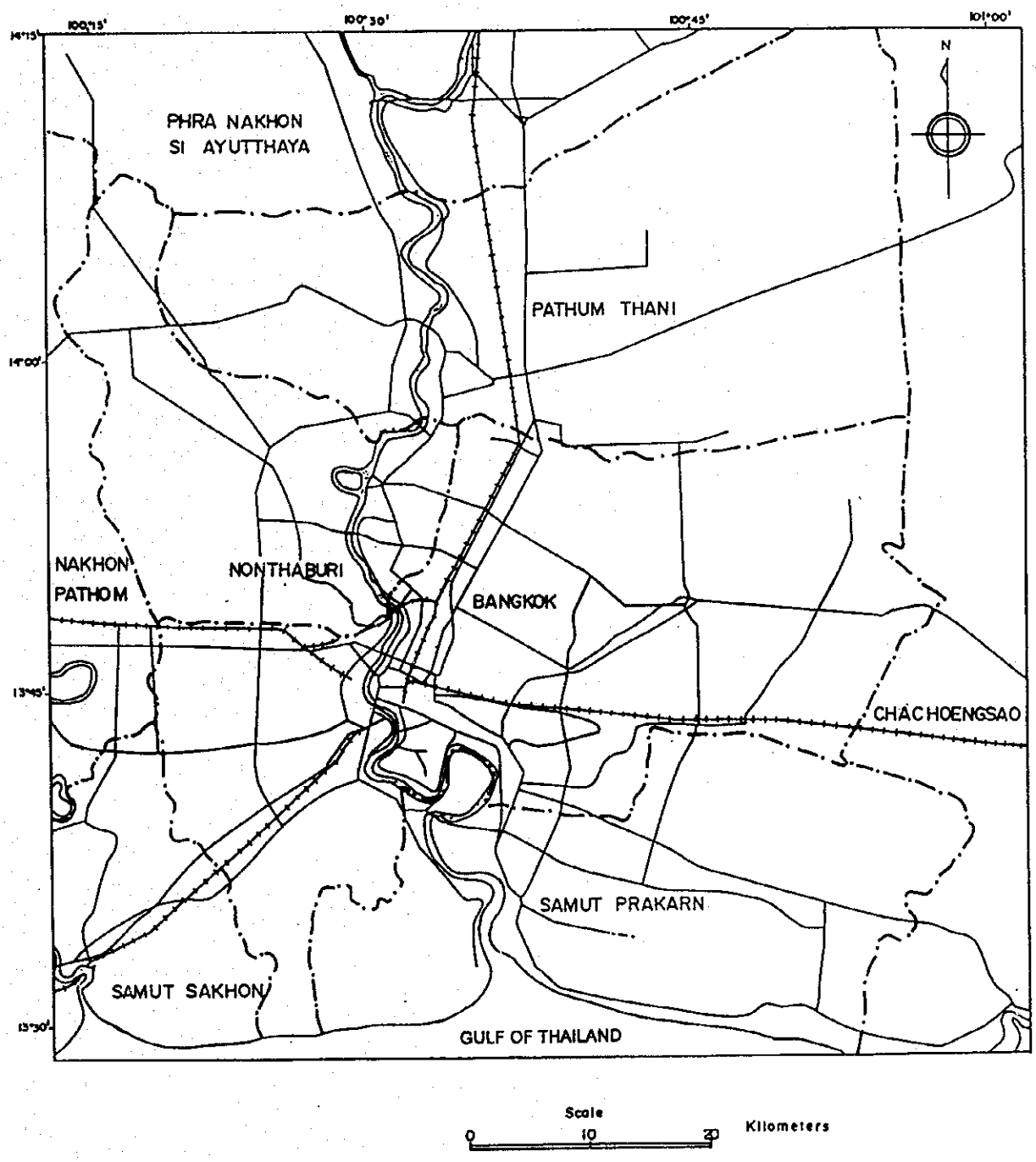


Figure 1.1	LOCATION MAP OF THE STUDY AREA
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

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CHAPTER 1 INTRODUCTION

CHAPTER 1 INTRODUCTION

1.1 Background of the Study

The Bangkok Metropolitan Area is the capital of the Kingdom of Thailand and the biggest city among the capital cities in Southeast Asia. It is situated at the southern edge of alluvial plain in the downstream of the Chao Phraya River. It has a total population of 8.2 million including its vicinity. Because of rapid urbanization, the said metropolitan area and its suburbs are confronted with serious problems in water supply, sewerage, transportation, housing, waste disposal and other related problems.

Waterworks of the Bangkok Metropolitan Area is being operated and managed by the Metropolitan Waterworks Authority (MWA). The Chao Phraya River is the main source of water supply. However, the present water supply can not meet the increasing domestic and industry water demand brought about by rapid economic growth. Areas not covered by the MWA's water supply networks resort to groundwater for their water supply.

In early 1970, uncontrolled development and excessive withdrawal of groundwater resulted in the decline of groundwater levels and land subsidence. A maximum total land subsidence was recorded at 75 cm during the 10 year period between 1978 and 1987. Land subsidence damaged various private and government infrastructures such as buildings, roads and bridges. It also caused flood in the low land and brought huge economic loss and risk of disaster.

In order to overcome such situations, the Department of Mineral Resources (DMR) and other governmental agencies initiated the investigations of groundwater and land subsidence in Bangkok in collaboration with the Asian Institute of Technology (AIT) since late 1970's. Based on these studies, the Cabinet issued a resolution on "Mitigation of Groundwater Crisis and Land Subsidence in Bangkok Metropolis" in March 1983.

In 1985, the Ministerial Regulations were issued according to the Groundwater Act, B.E.2520 which was enforced in 1978. These regulations specified "the Bangkok Groundwater Area" which covers six (6) provinces located at the downstream of the Chao Phraya River. Several initiatives were adopted and carried out such as the phase out program of MWA wells, control of groundwater use, collection of water fee, etc.

Inspite of such efforts, the decline of groundwater levels and land subsidence still continue in the industrial areas located along the main roads at the eastern, southern and western suburbs of Bangkok. However, they have been reduced in the central Bangkok area. The problem is further aggravated by groundwater salinity which is spreading to the west and south of the Bangkok Metropolitan Area.

In the light of the foregoing, the Government of the Kingdom of Thailand requested the Government of Japan for technical assistance on "The Study on Management of Groundwater and Land Subsidence in the Bangkok Metropolitan Area and Its Vicinity" in October 1989 and March 1990.

The request was favorably considered and a preliminary survey mission was sent by the Government of Japan to clarify the background and specifics of the request. An agreement was reached between the Counterpart Agencies -- the DMR and the Public Works Department (PWD) and JICA on the Scope of Work (SW) for the Study.

1.2 Study Objectives and Area

Study Objectives

The Study aims at achieving the following:

(1) To establish groundwater management system
(2) To prepare alleviation plans against land subsidence and saline water intrusion

Study Area

The Study Area covers the Bangkok Metropolis and its vicinity. As shown in Figure 1.1, the Study Area comprises wholly or partly the following eight (8) provinces, namely:

whole of BANGKOK, NONTHABURI, SAMUT PRAKAN, PATHUM THANI and parts of CHACHOENGSAO, SAMUT SAKHON, NAKHON PATHOM, PHRA NAKHON SI AYUTTHAYA

1.3 Study Framework

The Study commenced in July, 1992 and lasted for 33 months until March, 1995. The Study period is divided into three (3) stages:

Stage I - Basic Survey
Stage II - Detailed Survey
Stage III - Analysis and Planning

Stage I: Basic Survey

This stage involved the review and analysis of existing studies and data, field geological reconnaissance, arrangement of existing well inventories, questionnaire survey on groundwater utilization, preparation of the groundwater database, and appraisal survey on the availability and capability of local drilling contractors.

Stage II: Detailed Survey

The Study in this stage included the reviews of artificial recharge, existing water supply systems, urban planning, preliminary environmental impact survey, core drilling and soil testing, construction of observation stations, survey on groundwater utilization and completion of well inventories and groundwater database. After the construction of new observation stations, long-term measurements of groundwater level and land subsidence were conducted. Groundwater samples were collected and analyzed. The various data obtained throughout Stage II were arranged for Stage III.

Stage III: Analysis and Planning

The Study at Stage III concerned the prediction of land subsidence and saltwater intrusion, the planning for the mitigation of land subsidence, and the groundwater management system in Bangkok Metropolitan Area and its vicinity.

1.4 Organization of the Study

The Study was carried out jointly by the JICA Study Team, the DMR Team and the PWD Team:

JICA STUDY TEAM

Akira KAMATA	Team Leader/Hydrogeologist
Shoichi OHMORI	Geologist
Reynaldo R. MEDINA	Hydrologist
Mutsuo ASANO	Soil Engineer
Yoshinao MIURA	Drilling Supervisor
Chujiro TAKAHASHI	Drilling Supervisor
Naoaki SHIBASAKI	Hydrogeologist
Masaharu KINA	Urban Planner
Eiji TAKEMORI	Water Supply Engineer
Hajime TAKAHASHI	Socio-economist
Presha CHUNTAKORN	Coordinator

DMR Team

Vachi RAMANARONG	Research Expert, Director of the Mitigation of Groundwater Crisis and Land Subsidence in Bangkok (MGL Project)
Somkid BUAPENG	Chief of Groundwater Data Center, Groundwater Division
Samrit CHUSANATHAS	Hydrogeologist
Aranya FUANGSWASDI	Hydrogeologist
Suchai SHINPOOL-ANANT	Hydrogeologist
Paisal LAKANANURAK	Hydrogeologist
Oranuj LORPHENSRI	Hydrogeologist
Sanguansak SUNGKABUN	Hydrogeologist

PWD Team

Nathanwuth USOMBOON	Chief, Deep Well Drilling and Development Division
Posit NIPPITAWASIN	Senior Hydrogeologist
Roongroj KIATPANICHKIT	Hydrogeologist
Chaiporn SIRIPORNPIBUL	Hydrogeologist

CHAPTER 2 THE STUDY AREA

CHAPTER 2 THE STUDY AREA

2.1 Natural Conditions

(1) Topography

The main physiographic features of Thailand can be divided into seven (7) regions, namely, the Central Plain, the West Continental Highlands, the North Continental Highlands, the Central Highlands, the Northeast Plateau, the Southeast Coast and the Peninsular Thailand (Figure 2.1). The widest lowland area is the Central Plain which stretches from the Gulf of Thailand to as far as Uttaradit in the north, over 500 km long and 100 to 200 km wide.

Three (3) big rivers, namely, the Ping, the Yom and the Nan, whose source lies in the northern mountainous regions traverse the plain and join together at Nakhon Sawan to form the Chao Phraya River. The Central Plain is divided into two (2) plains, namely, the Upper Central Plain and the Lower Central Plain at Nakhon Sawan area, where the width of the plain narrows.

The Lower Central Plain is a large and flat plain consisting of young fluvial and marine deposits. From Chai Nat, the Chao Phraya River branches out to smaller rivers, two (2) of which are the Tha Chin (or Suphan Buri) River and the Noi River which flow southward joining the Pasak River on the way. The Mae Klong River, draining the mountainous areas in the west, flows southeast and south through the plain. The Bang Pakong River enters the Lower Central Plain from the east and flows southward to the Gulf of Thailand.

The Study Area is situated in the Lower Central Plain and is bounded on the west by Tha Chin River, on the east by Bang Pakong River, and on the south by the Gulf of Thailand. It has an area of about 5,600 km^2 and geomorphologically comprises the fan, the delta and the tidal zone (Figure 2.2) with the natural ground elevations ranging from one (1) to three (3) meters above MSL. Recently, land subsidence caused certain areas to be below MSL.

(2) Climate

The Study Area is located in the monsoonal region which has a distinct dry season from December to April and a rainy season from May to November. About 85% of the rainfall occurs in the rainy season. The mean annual rainfall is about 1,500 mm in Bangkok and averages 1,300 mm in the Study Area (Figure 2.3). The mean monthly temperature varies from 25.4°C to 29.7°C and the average monthly minimum and maximum temperature are 20.6°C and 34.9°C in Bangkok, respectively.

(3) Hydrology

The Chao Phraya River is a big river which has a total drainage area of 160,000 km^2. The annual mean flow of the Chao Phraya River at RID's Sta. C.2 in Nakhon Sawan is 683.62 m^3/sec. About 100 km downstream from Nakhon Sawan near Chai Nat Province, the Chao Phraya Dam was constructed to divert the river flow for irrigation. The flow of the Chao Phraya River downstream of this dam at RID's Sta. C.13 has decreased to 336.10 m^3/sec.

Downstream of Chai Nat Province many effluent branches come off from the main river. The discharge of the Chao Phraya River before it reaches the city of Ayutthaya as observed at RID's Sta. C.7A averages 358.02 m^3/sec.

River flow fluctuates sharply according to the season. For instance, the discharge of the Chao Phraya River at Sta. C.7A varies from 495.8 to 835.3 m^3/sec in the period from January to August, while the discharge in the period from September to December exceeds 1,000 m^3/sec. The capacity of the river is only 1,500 m^3/sec near Ayutthaya and the excess water will overflow and flood the low-lying areas including the Study Area (Figure 2.4).

(4) Hydrogeology

Pre-Cambrian, Paleozoic and Triassic rocks are distributed in the highlands west and north of Thailand and southern Peninsula. The highlands on the east and south consist of Triassic rocks. In the plateau situated in the northeast of Thailand, Mesozoic rocks from Jurassic to Cretaceous ages are extensively distributed. The Central Plain consists mainly of Neogene and Quaternary sediments.

The basement of Neogene and Quaternary sediments in the Central Plain is divided into several blocks which constitute the grabens. The basement depth was estimated to be more than 1,800 m according to the oil exploratory drilling, aero-magnetic and seismic data. Geology of Neogene sediment is still not clarified yet. Quaternary sediment consists of the terrace deposit, the alluvium and the laterite.

The hydrogeology of the Study Area was investigated using lithologic logs of production wells and shallow borings. The ground surface of Bangkok is entirely underlain by blue to grey marine clay, 15 m to 30 m in thickness, known as the Bangkok Clay. Unconsolidated and semi-consolidated sediments underlying the Bangkok Clay consist of sand, gravel and clay of Pleistocene to Pliocene ages. From a detailed study of electrical logs, the DMR identified and named eight (8) aquifers within 550 m depth. These aquifers consist mainly of sand and gravel separated by clay beds.

1. Bangkok Aquifer (BK, 50 m zone)
2. Phra Pradaeng Aquifer (PD, 100 m zone)
3. Nakhon Luang Aquifer (NL, 150 m zone)
4. Nonthaburi Aquifer (NB, 200 m zone)
5. Sam Khok Aquifer (SK, 300 m zone)
6. Phaya Thai Aquifer (PT, 350 m zone)
7. Thon Buri Aquifer (TB, 450 m zone)
8. Pak Nam Aquifer (PN, 550 m zone)

Among the eight (8) aquifers, Phra Pradaeng, Nakhon Luang and Nonthaburi Aquifers are the most developed and extensively used for water supply (Figure 2.5).

2.2 Socio-Economy

(1) Economic Development in Thailand

Economic growth in Thailand over the past decade was one of the highest and steadiest among the developing countries. Beginning 1986, the economy began a period of very rapid growth brought about by increase in exports, capital inflows, as well as tourism. The growth in GDP during the last three (3) years had been remarkable, averaging over 10 percent per annum (Table 2.1).

The Bangkok Metropolitan Area and its Vicinity and the Central Region served as the core of Thailand's economy and contributed one half of the country's GDP. Recently, the annual growth rate of the Bangkok Metropolitan Area exceeded 20% .

The concentration of economy in the Bangkok Metropolitan Area lured the rural populace to migrate to the urban areas. The heavy influx to the metropolis caused severe environmental problems, such as traffic congestion, shortage of housing facilities and water supply systems, air and water pollution, etc.

(2) Population

According to Thailand's population census, the population of Thailand was 56.3 million in 1990 with Bangkok having 5.62 million. The population of Bangkok and the adjoining 7 provinces reached 9.98 million. Considering the number of unaccountable migrants, Bangkok's population may exceed 8 million (Table 2.2).

(3) Transportation and Electric Power Supply

Thailand's transportation network is characterized mainly by highways and roads. These highways and roads are well consolidated. However, the present rate of construction of new highways can not meet the demand of rapid mobilization in the Bangkok Metropolitan Area. Serious and chronic traffic congestion hinders daily urban activities. Alternate means of transportation, such as the subways and the elevated rail road projects have been planned but are yet to be implemented.

Almost 100% of the Bangkok Metropolis and 90% of its adjoining provinces have electricity.

2.3 Water Supply

(1) Water Supply Organizations

In the Study Area, the MWA supplies water to the Bangkok Metropolis and the provinces of Samut Prakan and Nonthaburi. The PWA serves the Pathum Thani Province through its Regional Office III in Bangkok. Groundwater is used for domestic purpose in areas not covered by the MWA and PWA water distribution networks.

Four (4) goverment agencies, namely, the Office of Accelerated Rural Development (ARD), the Public Works Department (PWD), the Department of Mineral Resources (DMR) and the Department of Health (DOH) are involved in well constructions for the use of groundwater in the rural areas. The Industrial Estate Authority of Thailand (IEAT) supplies water from its own deep wells to the factories located in its industrial estates.

More than 10,000 private deep wells were constructed in the Study Area mainly for domestic and industrial consumptions. Drilling of these private wells and use of groundwater are controlled by the DMR.

(2) MWA

The MWA's water supply service in 1991 covered an area of 710 km^2 which is about 22% of the MWA's total service area (3,195 km^2) and 5.6 million of the service population which is about 78% of the total population (7.2 million) (Figure 2.6). The total water production in 1991 was 1,143.4 MCM (3.13 MCMD). About 97% of the total production, 1,109.2 MCM (or 3.04 MCMD), came from the Chao Phraya River. The rest, which amounted to about 34.2 MCM (or 93,000 CMD), about 3% of the total , came from groundwater pumped from its 41 deep wells. The total pumpage of the MWA wells amounted to 142.4 MCM (390,000 CMD) in 1983 (Table 2.3). However, since then, the MWA is phasing out its wells according to the Cabinet Resolution in order to alleviate land subsidence.

(3) PWA (Pathum Thani)

Pathum Thani Province is located north of Bangkok Metropolis. The PWA Regional Office III in Bangkok manages the waterworks system in Pathum Thani province. This system relies on 20 deep wells. In 1992, PWA's service area covered about 180 km^2 and about 6.27 MCM of groundwater was produced. About 98,000 people were served, which is about 21% of the province's total population.

(4) Private and Public Wells

Private wells are registered at the DMR as required by the Groundwater Act of Thailand. At present, the DMR charges water fee at 3.5 baht/m^3 for these wells.

Public wells numbering about 12,600 have been constructed by government agencies, such as PWD, DOH, ARD and DMR. Pumpage from these wells is estimated at 1.4 MCMD (see Chapter 5).

(5) IEAT

There are presently nine (9) industrial estates in the Study Area. The total pumpage from the eighty (80) deepwells located in these estates amounted to 33 MCM in 1992 (Figure 2.7).

2.4 Review of Land Subsidence in Bangkok

(1) Brief History

In 1969, land subsidence in Bangkok caught public attention when its evidence, such as protrusions of well casings and foundations of buildings, were observed in many places. A seminar organized in 1979 recognized the major cause of land subsidence as due to

excessive withdrawal of groundwater. Consequently, the DMR and the AIT started research projects on the management of groundwater and mitigation of land subsidence in Bangkok. The ground surface leveling revealed that Lat Phrao, Bang Kapi, Hua Mak, Phra Khanong and Bang Na areas subsided more than 10 cm/year and the center of land subsidence coincided with the center of depression of artesian pressure.

(2) Groundwater Use

Groundwater is used as supplemental source of the MWA water supply systems. Groundwater is used mainly for residential, commercial and industrial water supplies in areas not covered by the MWA distribution networks. The Groundwater Act requires groundwater users to secure permit for drilling of wells and usage. Likewise, installation of water meter was required since 1985. As a result, groundwater pumpage can be estimated. The total estimated pumpage of groundwater of the private wells and MWA's wells increased from 1.12 to 1.48 MCMD in the Study Area (see Chapter 5).

(3) Groundwater Level and Land Subsidence

Groundwater levels in the Phra Pradaeng (PD), the Nakhon Luang (NL), and the Nonthaburi (NB) Aquifers declined through late 60's to 70's. They declined to a maximum of between 40 m to 50 m in each aquifer in early 80's. However, groundwater level recovered at the central area of Bangkok since 1985 due to the control of groundwater pumpage by the Ministerial Regulations. On the other hand, groundwater levels continued to decline in the vicinity of Bangkok, such as Lat Krabang, Pathum Thani and Samut Sakhon areas. Groundwater pumpage in these areas increased yearly due to continuous construction of factories and housing. This has caused the steep decline of groundwater levels.

Leveling surveys for land subsidence have been conducted by the Royal Thai Survey Department (RTSD), Bangkok Metropolitan Authority (BMA), and DMR. Based on the RTSD's data, a maximum subsidence of 75 cm occurred during the 10 year period between 1978 and 1987. It can be estimated that a maximum subsidence of over 160 cm had occurred in 45 years based on the old leveling survey data.

As mentioned above, land subsidence rate in early 80's was 5 to 10 cm/year in central Bangkok. It decreased to less than 2 cm/year accompanied with a recovery of groundwater level. Meanwhile, Bang Phli, Samut Prakarn and Samut Sakhon, located at the east, at the south and at the southwest of Bangkok Metropolitan Area, respectively, suffered from extreme land subsidence at the rate of over 5 cm/year.

(4) Legal Aspect

To conserve groundwater and minimize land subsidence, the Government of Thailand enforced the Groundwater Act B.E. 2520 in 1978. Under this Act, permits for drilling of groundwater, for use of groundwater and for disposal of water into wells must be secured by the user.

As a result of the promulgation of said law, Bangkok and five (5) adjoining provinces were designated as the Bangkok Groundwater Area and users of wells in these areas were charged groundwater fee.

(5) Mitigation of Groundwater Crisis and Land Subsidence

Based on the DMR and AIT joint study on "Groundwater Resources in Bangkok Area: Development and Management", the Cabinet issued a resolution on the "Mitigation of Groundwater Crisis and Land Subsidence in Bangkok Metropolis" in March 1983. The resolution aimed at controlling the groundwater pumpage to recover the piezometric levels in the three (3) heavily used aquifers to as high levels as possible and to slow down the rate of land subsidence .

In this resolution, a control area of groundwater use was designated and the area was divided into three (3) critical zones according to the rate of subsidence, rate of water level decline and water levels. The MWA wells were planned to be phased out. The rate of private pumpage was regulated in the critical zones by the target year (Figure 2.8).

From 1983 to 1987, groundwater recovery was observed and the rate of land subsidence was reduced in the central area of Bangkok due to the instituted control measures. Unfortunately, annual private pumpage kept on increasing since 1988 because of the unexpected rapid national economic growth. This phenomenon caused an upsurge in water demand and hastened the decline of water levels as well as the rate of land subsidence. It is in this light that groundwater control and management programs should be reassessed to be more responsive to the present situation.

Table 2.1 Growth of Real GDP and Per Capita GNP

Year	Real GDP	Agricul–ture	Industry	Services	Real per Capita GNP
60 – 65	7.2	4.8	11.5	7.2	–
65 – 70	8.6	6.0	10.4	9.5	–
70 – 75	5.6	3.8	7.3	5.6	2.9
75 – 80	7.9	4.0	10.6	8.2	5.3
80 – 85	5.6	4.9	5.0	6.3	3.5
86	4.5	0.2	7.1	4.6	2.6
87	9.5	–0.2	12.8	11.1	7.7
88	13.2	10.2	17.4	11.6	11.4
89	12.0	6.6	16.2	11.1	10.5
90	10.0	–1.8	15.8	10.0	8.5

Source : National Economic and Social Development Board (NESDB)

Table 2.2 NUMBER OF POPULATION BY PROVINCE 1980-1991

PROVINCE	1980	1981	1982	1983	1984	1985
WHOLE KINGDOM	44,824,540	47,875,002	48,846,927	49,515,094	50,583,105	51,795,651
Bangkok	4,697,071	5,331,402	5,468,286	5,018,327	5,174,682	5,363,378
Nonthaburi	369,777	403,809	422,392	456,588	478,199	504,424
Pathum Thani	319,674	332,111	341,336	357,809	366,767	384,713
Samut Prakarn	484,829	557,292	585,320	623,514	640,316	662,612
Samut Sakhon	247,168	270,744	278,949	296,714	301,631	315,373
Ayutthaya	602,021	626,590	631,285	630,799	637,845	652,977
Nakhon Pathom	525,906	569,649	590,588	585,931	596,257	609,316
Chachoengsao	445,000	498,092	507,422	503,184	510,308	525,717
TOTAL	7,691,446	8,589,689	8,825,578	8,472,866	8,706,005	9,018,510

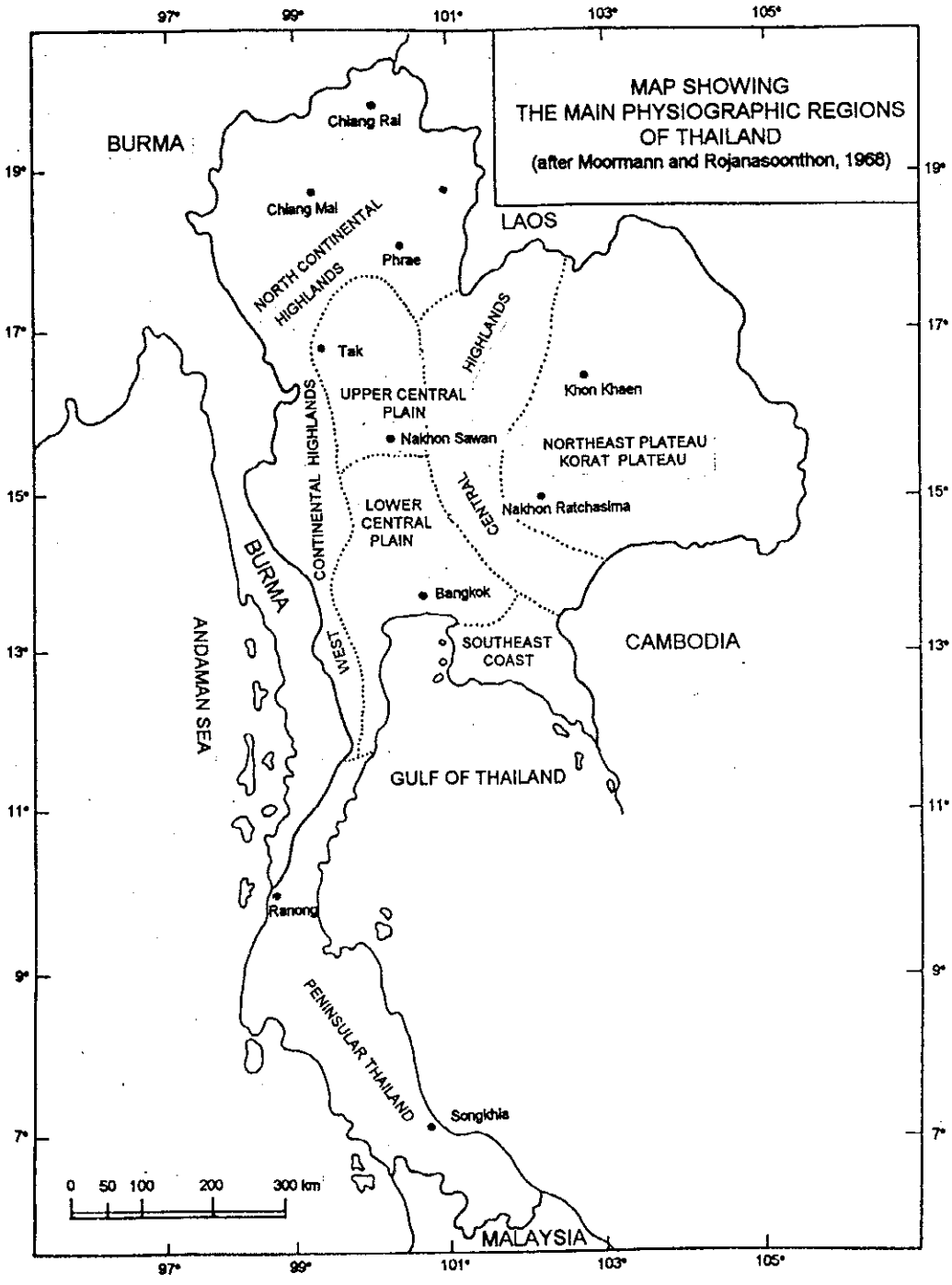
PROVINCE	1986	1987	1988	1989	1990	1991	Av.Annual Grow.Rate 1980.1991
WHOLE KINGDOM	52,969,204	53,873,172	54,960,917	55,888,393	56,303,273	56,961,030	2.20
Bangkok	5,468,915	5,609,352	5,716,779	5,832,843	5,546,937	5,620,591	1.65
Nonthaburi	525,475	571,871	596,381	627,667	668,760	703,187	6.02
Pathum Thani	402,080	415,193	435,409	441,930	452,693	465,968	3.48
Samut Prakarn	689,631	741,905	789,060	829,412	854,883	882,164	5.59
Samut Sakhon	327,677	334,170	340,952	349,680	358,155	365,274	3.61
Ayutthaya	664,245	668,611	677,626	680,100	685,394	691,075	1.26
Nakhon Pathom	617,596	619,518	630,805	646,803	657,182	664,190	2.14
Chachoengsao	540,864	550,787	569,411	575,731	582,783	589,829	2.59
TOTAL	9,236,483	9,511,407	9,756,423	9,984,166	9,806,787	9,982,278	2.40

Source : Department of Local Administration

Table 2.3 WATER SUPPLY ACHIEVEMENT OF MWA

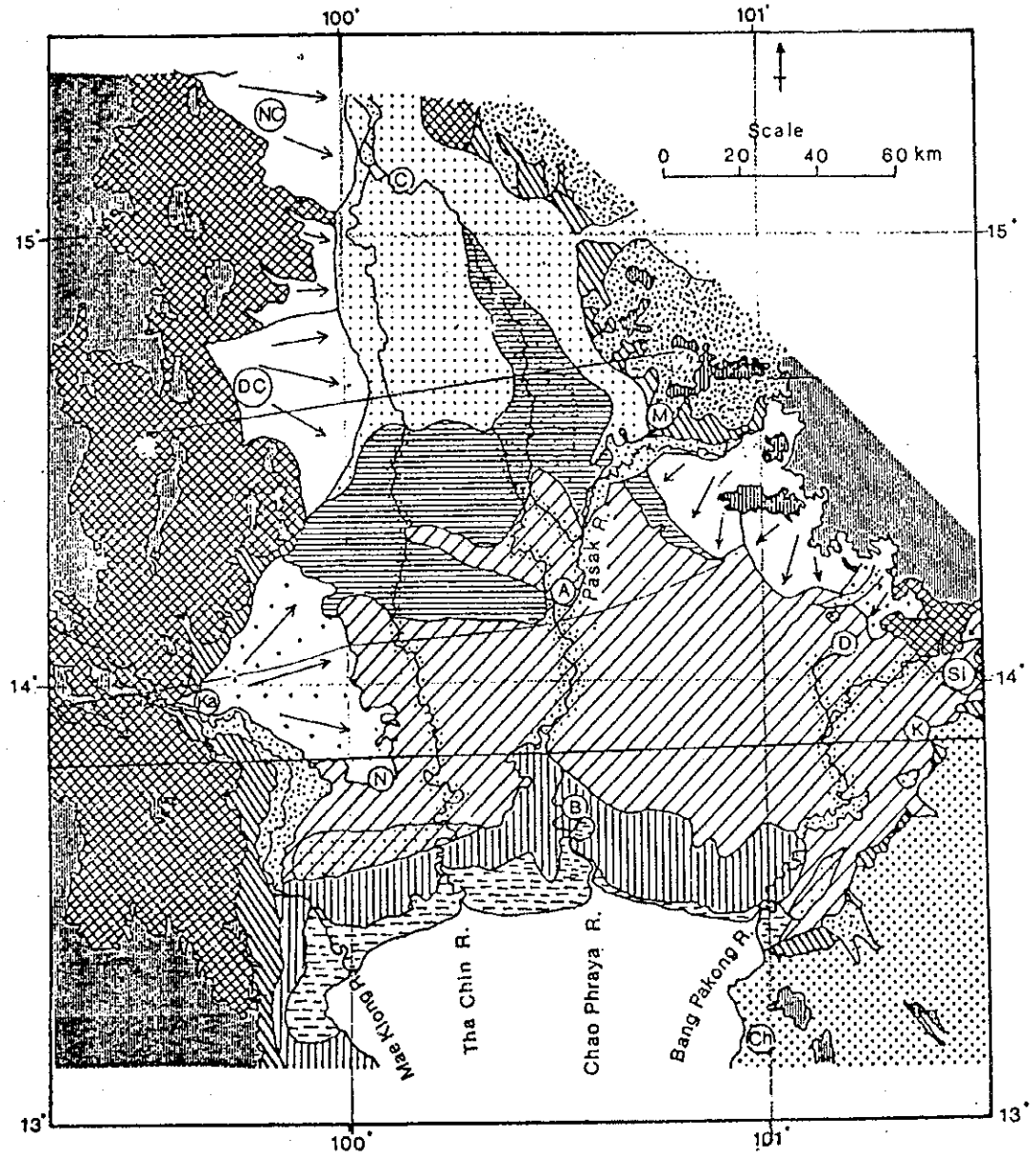
Description	Unit	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
A. Total Water Production (Include Groundwater) B + Water Loss + I	M. m3	624 .7	630 .3	626 .5	731 .2	801 .8	820 .8	841 .3	859 .6	934 .3	1049 .3	1109 .2
B. Water Sales 1) +2)	M. m3	334 .2	340 .8	360 .7	423 .4	477 .4	485 .0	523 .0	570 .3	628 .2	718 .7	781 .5
1) Residence	M. m3	191 .1	194 .6	205 .0	239 .4	280 .4	280 .0	305 .2	328 .5	328 .0	369 .4	391 .7
2) Business, Gove. Agencies	M. m3	143 .1	144 .3	162 .3	182 .7	195 .4	204 .0	216 .2	240 .3	298 .7	347 .9	377 .7
C. Water Sales %, B/A	%	53.5	54.2	59.0	57.9	59.5	59.1	62.2	66.4	67.4	68.5	70.5
D. Total Customers, No.	1000	423	445	468	520	602	660	721	790	867	949	1028
E. Population Responsible Area, Person	1000	6292 .5	6476 .0	6098 .4	6293 .2	6530 .4	6684 .0	6923 .2	7102 .2	7289 .9	7070 .6	7205 .9
F. Water Consumption Ratio, ℓ/Person/day	ℓ	148	142	148	163	178	169	172	172	164	188	190
G. Service Area	km2	315	330	350	390	430	475	520	580	625	680	710
H. Water Supply Ratio	%	56	58	62	64	66	68	70	74	75	76	78
I. Groundwater Supply Volume	M. m3	186 .2	163 .4	143 .4	130 .8	109 .9	71 .3	76 .7	72 .6	59 .3	28 .7	34 .2
J. Groundwater Supply Ratio, I/A	%	29.8	25.9	22.8	17.9	13.7	8.6	9.1	8.4	6.3	2.8	3.1

Source : MWA M. m3 =Million m3 Note: MWA service area is BKK Metropolis, Nonthaburi and SamutPrakarn.



modified Thiramongkol, 1983

Figure 2.1	MAIN PHYSIOGRAPHIC REGIONS 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.



After Narong Thiramongkol (1983)

Figure 2.2	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.

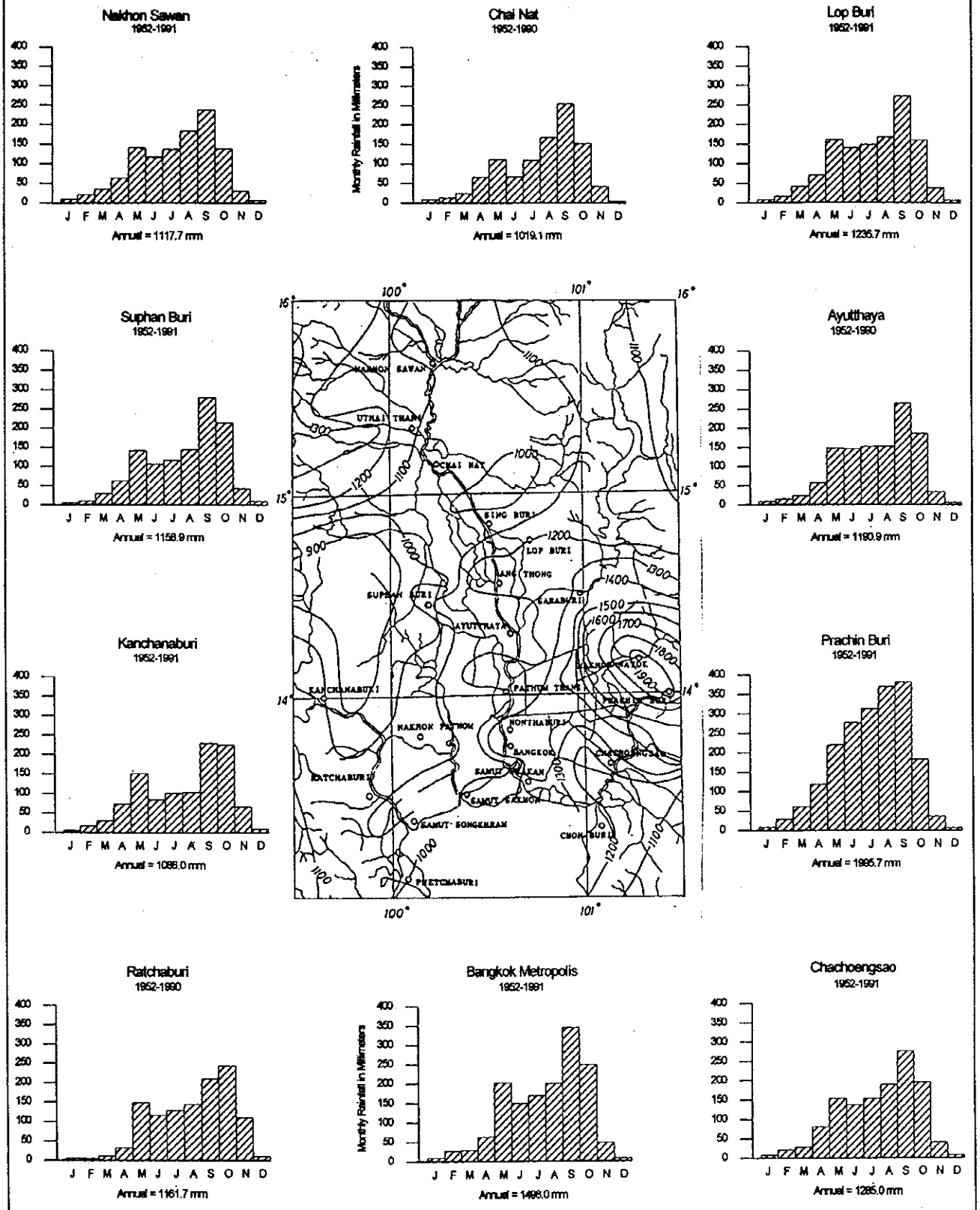
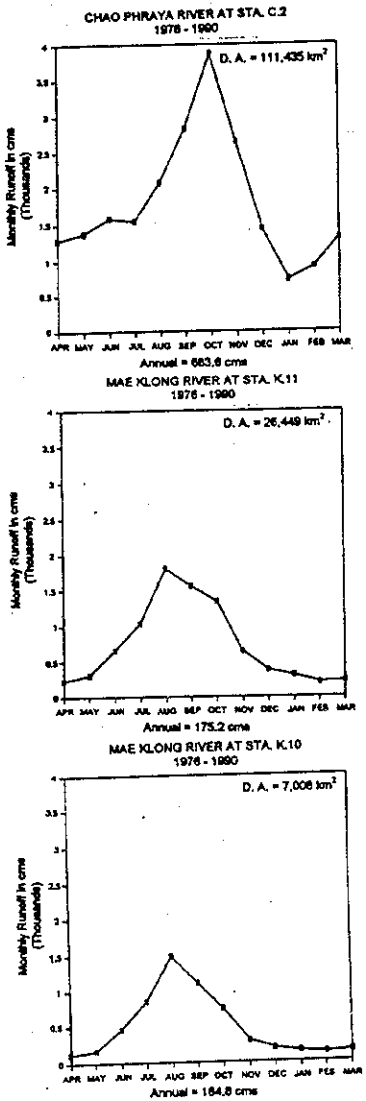
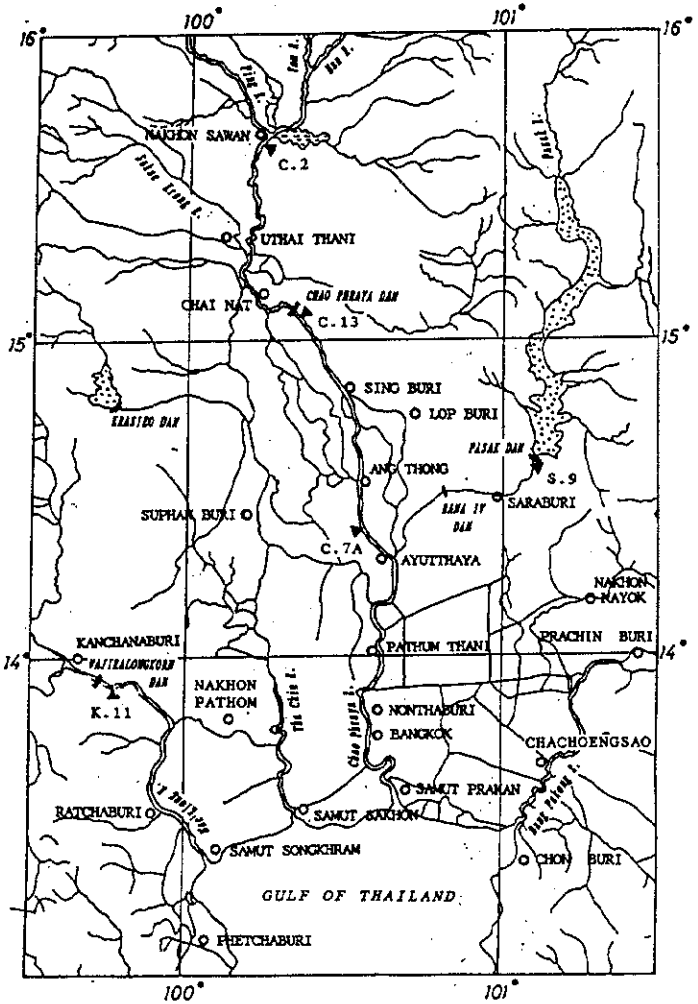


Figure 2.3	MEAN ANNUAL RAINFALL AND MEAN MONTHLY DISTRIBUTION OF RAINFALL IN THE LOWER CENTRAL PLAIN
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.





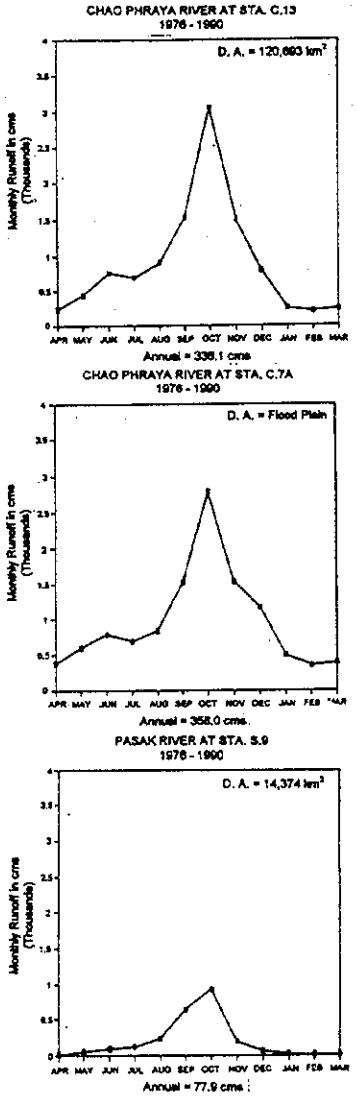
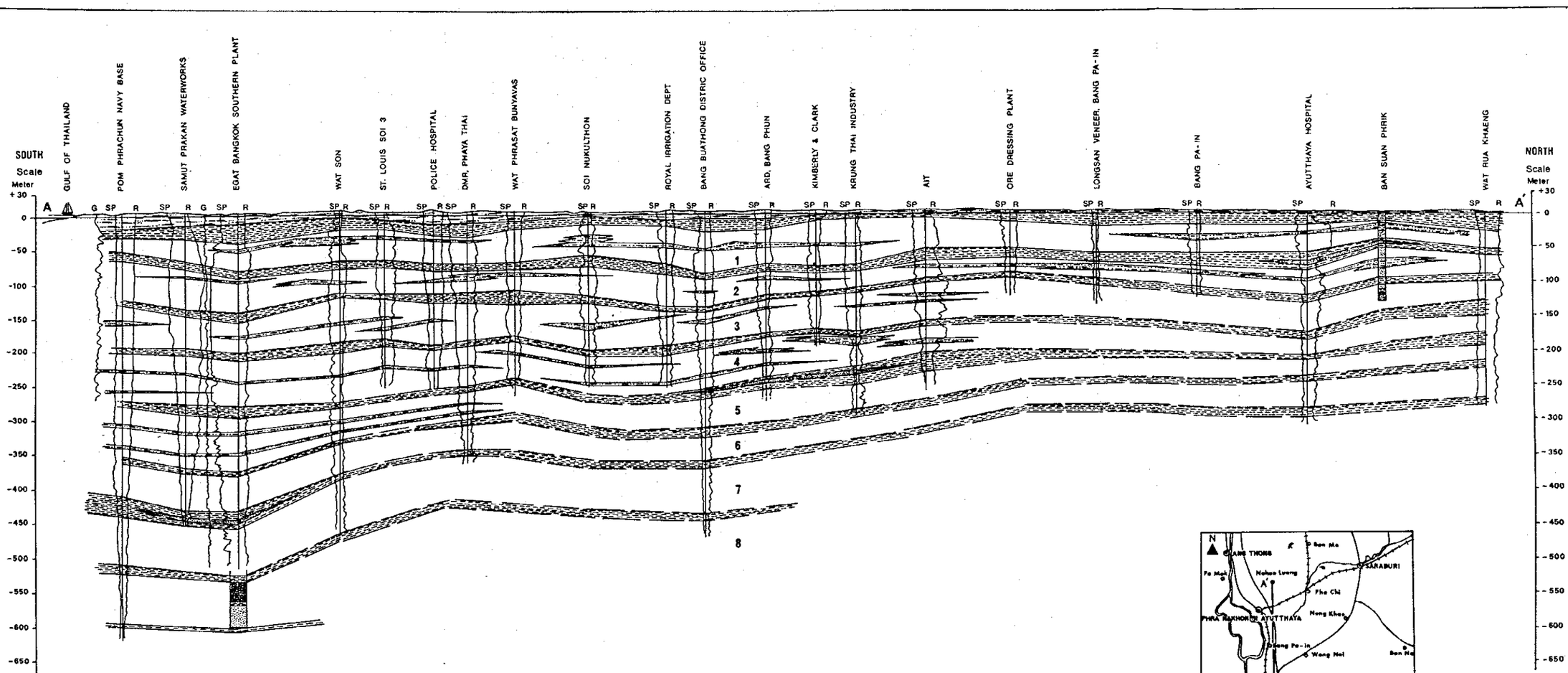
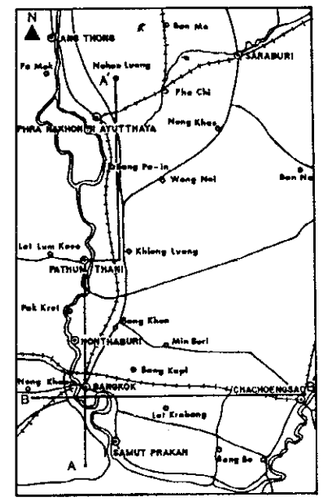


Figure 2.4	MEAN MONTHLY DISTRIBUTION OF RUNOFF OF THE CHAO PRAYA, PASAK AND MAE KLONG RIVERS
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.





INDEX MAP SHOWING PROFILE-LINE

Scale 1:1,000,000

A——A' Profile-line

● Amphoe (district)

● Changwat (province)

SP R — Electrical log, SP curve on the left, Resistivity (R) curve on the right

G — Gamma ray log (G)

Drilled log

Top Clay: dark gray to black, very soft, known as "Bangkok soft clay"

Clay (confining bed) : consisted predominantly of stiff clay, with localized sandy clay or fine sand layers or lenses. Boundaries are correlated through electrical logs, and dashed where approximate.

Sand and gravel (aquifer) : consisted of sand and gravel of various sizes and colors, moderately to well sorted, subangular to rounded. The aquifers are commonly interbedded by clay layers and lenses.

Clay layer: intercalating in the sand and gravel aquifer.

Sand layer: intercalating in the confining clay bed.

DMR, 1979

Figure 2.5 — **HYDROGEOLOGICAL NORTH-SOUTH PROFILE OF THE LOWER CHAO PHRAYA BASIN**

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.

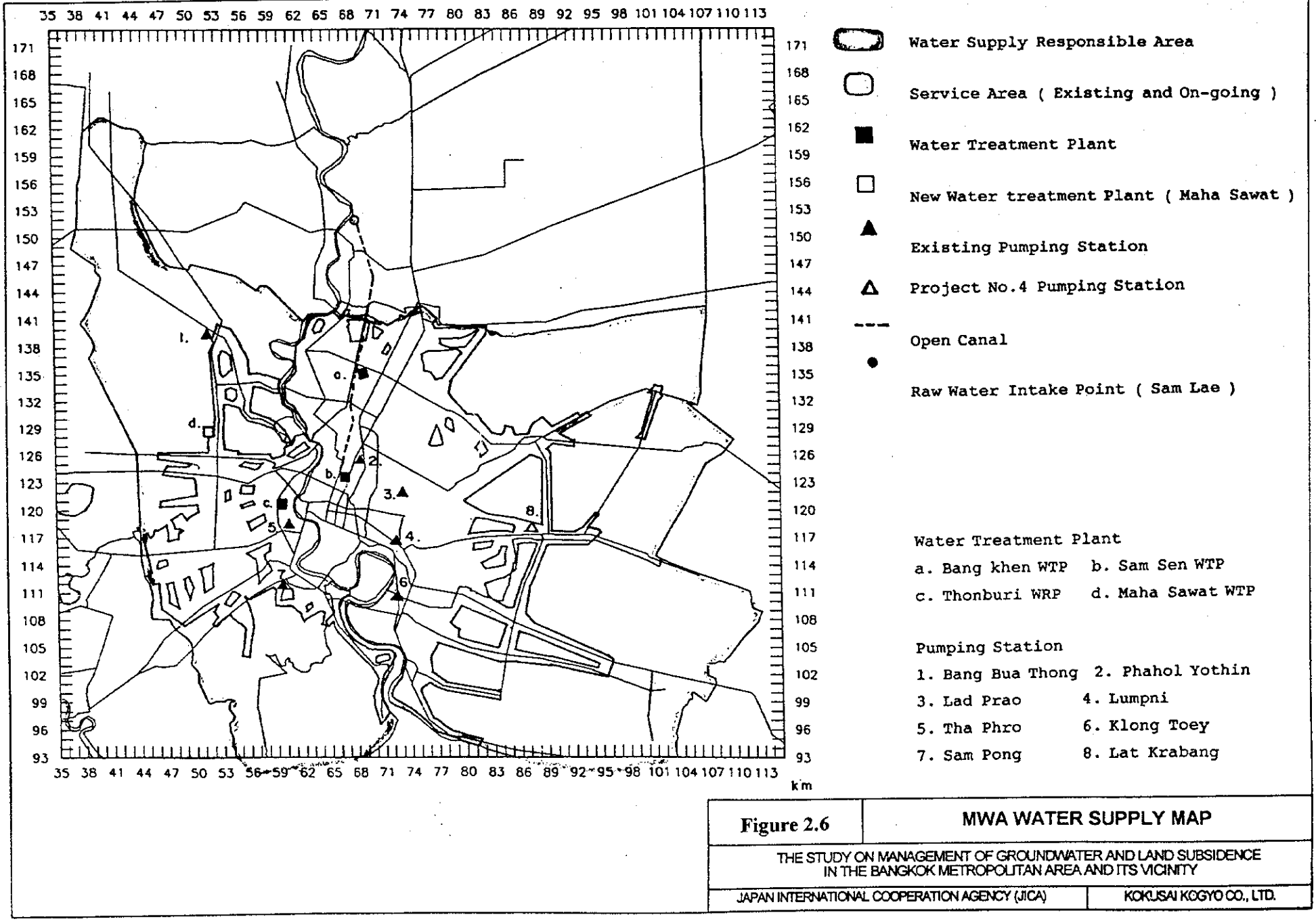
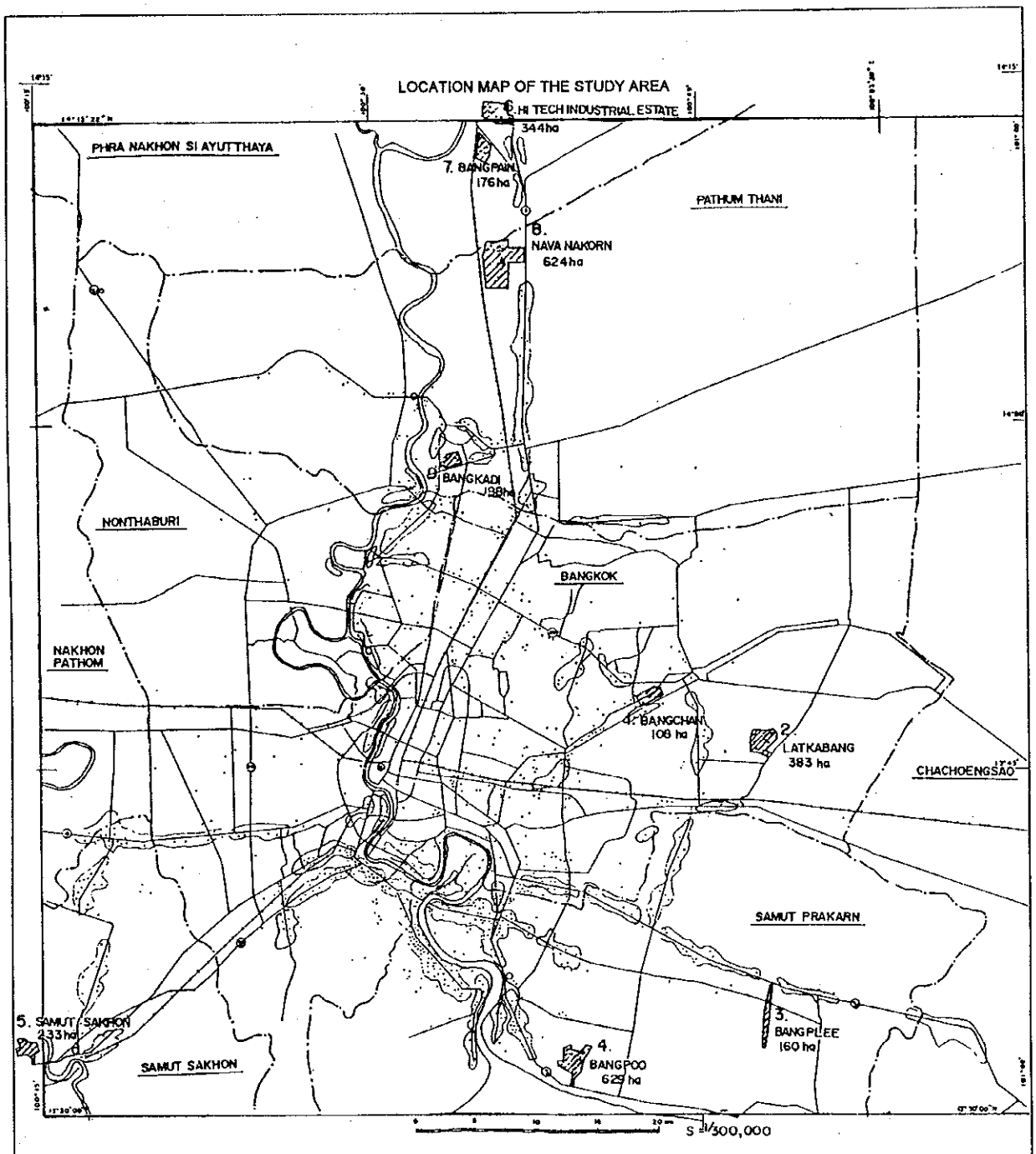


Figure 2.6 MWA WATER SUPPLY MAP

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.



REMARKS

- WELL POINT OF REGISTERED UNDER THE DMR
- IEAT and PRIVATE INDUSTRIAL ESTATE
- INDUSTRY AREA OF PRIVATE SECTOR, AND RESIDENTIAL TOWN

Figure 2.7	MAIN INDUSTRIAL ESTATES AND INDUSTRIAL AREAS
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.

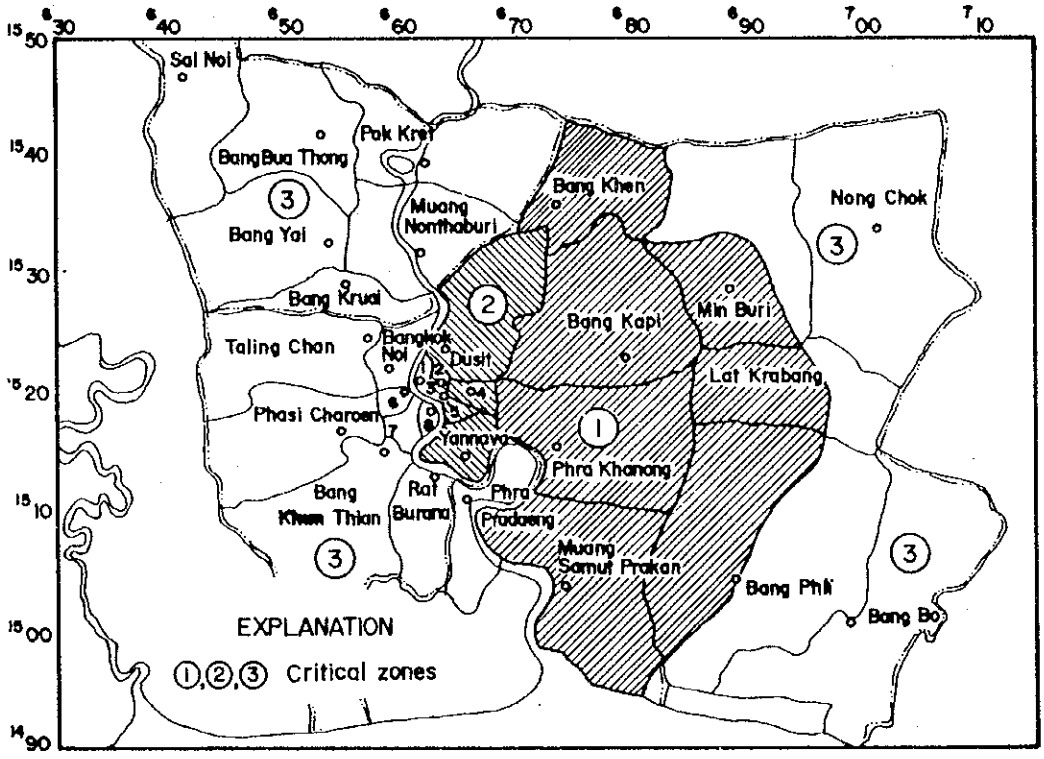


Figure 2.8 Present Critical Zones of Bangkok Metropolitan Area

CHAPTER 3 HYDROGEOLOGIC STRUCTURE

CHAPTER 3 AQUIFER SYSTEM

3.1 Topography and Geology

A schematic topographical and geological map of the Lower Central Plain is shown in Figure 3.1. Mountains are situated in the west and the east of the plain. High and middle terraces are distributed from the mountain foot to the plain. Old and young alluvial fans are located at the outlet of the rivers from the mountain. The plain consists of delta and tidal zone. The delta is composed of fluviatile sediments in the vicinity of Chai Nat and brackish sediments in Ayutthaya. Marine to brackish delta underlain by Bangkok Clay and tidal zone are distributed in the Bangkok Metropolitan Area. As the ^{14}C age of Bangkok Clay (soft clay) indicates 4,000 to 7,000 Y.B.P., the clay was deposited during the Holocene Transgression. Overlain by Bangkok Clay, Pleistocene to Pliocene sediments overlay the basement at the thickness of 500 to 1,800 m.

3.2 Core Borings

Core borings were conducted to investigate subsurface hydrogeological conditions as well as to collect core samples for core analyses and soil tests. Three (3) sites were selected to perform core borings and to construct observation wells.

Site-A: Rom Klao Village of NHA, Lat Krabang	: depth 600 m
Site-B: AIT Campus, Pathum Thani	: depth 300 m
Site-C: Ron Riang Wat Klong Kru, Samut Sakhon	: depth 325 m

(1) Hydrogeologic Classification

Site-A

Sixteen (16) facies units were identified based on the detailed lithologic logs and the results of geophysical loggings. Hydrogeological classification at Site-A is summarized as follows (Figure 3.2):

Hydrogeological Classification	Depth
Bangkok Clay (soft clay)	1.50 m to 17.20 m
Bangkok Clay (stiff clay)	17.20 m to 20.30 m
Bangkok Aquifer	20.30 m to 57.80 m
Phra Pradaeng Aquifer	57.80 m to 121.50 m
Nakhon Luang Aquifer	121.50 m to 178.28 m
Nonthaburi Aquifer	178.28 m to 280.80 m
Sam Khok Aquifer	280.80 m to 361.40 m
Phayathai Aquifer	361.40 m to 440.00 m
Thonburi Aquifer	440.00 m to 482.00 m
Pak Nam Aquifer	482.00 m to 600.00 m+

Site-B

Eleven (11) facies units were identified based on the detailed lithologic logs and the results of geophysical loggings. The hydrogeological classification at Site-B is summarized as follows:

Hydrogeological Classification	Depth
Bangkok Clay (soft clay)	2.00 m to 9.20 m
Bangkok Clay (stiff clay)	9.20 m to 15.80 m
Bangkok Aquifer	15.80 m to 49.00 m
Phra Pradaeng Aquifer	49.00 m to 126.25 m
Nakhon Luang Aquifer	126.25 m to 193.40 m
Nonthaburi Aquifer	193.40 m to 281.13 m
Sam Khok Aquifer	281.13 m to 300.00 m+

Site-C

Thirteen (13) facies units were identified based on the detailed lithologic logs and the results of geophysical loggings. The hydrogeological classification at Site-C is summarized as follows:

Hydrogeological Classification	Depth
Bangkok Clay (soft clay)	1.40 m to 14.50 m
Bangkok Clay (stiff clay)	14.50 m to 19.45 m
Bangkok Aquifer	19.45 m to 43.45 m
Phra Pradaeng Aquifer	43.45 m to 108.00 m
Nakhon Luang Aquifer	108.00 m to 170.00 m
Nonthaburi Aquifer	170.00 m to 281.00 m
Sam Khok Aquifer	281.00 m to 325.00 m+

(2) Analysis of Core Samples

Core samples were analyzed for the following items.

- ^{14}C dating
- Microfossils (Diatom and Foraminifera)
- Salt content

^{14}C Dating

The age of Bangkok Clay (soft clay) was estimated by ^{14}C dating. The results of dating ranged from 1,110±100 to 8,620±340 Y.B.P. at Site A (Lat Krabang) and Site B (AIT) indicating the deposits of the Alluvial Transgression.

Environments of Deposition

A few diatom and foraminifera are contained in the Bangkok Clay. Results of microfossil analysis indicated that the Bangkok Clay is deposited in a marginal sea environment.

Salt Content Analysis

Salt contents in the core samples showed high concentration at depth of 30 m to 90 m at Site A and 30 m to 50 m at Site B. These results indicated the salinity of the Bangkok Aquifer.

Soil Test

Undisturbed samples were taken by thin wall sampler and tested for physical properties and consolidation. Pleistocene sediments may also be consolidated. Therefore, core samples were taken at depth from 50 to 600 meter by wire line method and tested for physical properties and consolidation (some samples for high stress consolidation). Future land subsidence was predicted by using parameters obtained by the soil tests. Bangkok Clay is a consolidated bed which affects land subsidence.

3.3 Basement Structure

Based on previous studies and results of the core borings, the basement structure of the Lower Central Plain was delineated as shown in Figure 3.3. The depth of the basement was estimated at more than 1,000 m in the right bank of the Chao Phraya River. The depth of the basement is 385 m and 412 m at two (2) existing boreholes in the left bank near the river mouth. However, the core boring at Site A did not reach the basement at depth of 600m. Therefore, the depth of the basement of the entire left bank was estimated at 500 to 1,000 m.

3.4 Aquifer Unit

Based on the core boring data and the existing lithologic logs, the geology and hydrogeology of the Study Area were interpreted and analyzed. Figure 3.4 shows a representative profile of the Study Area. Eight (8) aquifer units were classified according to DMR's definition. The isodepth maps of main aquifers were prepared as shown in Figures 3.5.1, 3.5.2 and 3.5.3.

3.5 Construction of Monitoring Stations

Monitoring wells were drilled at Site A (Lat Krabang), B (AIT) and C (Samut Sakhon) for measurement of land subsidence and groundwater levels at different depths. Number of wells and their depths are shown in Figure 3.6. The set of subsidence equipment and water level recorders were installed at each monitoring well (Figure 3.7). Pumping tests were conducted to obtain aquifer parameters.

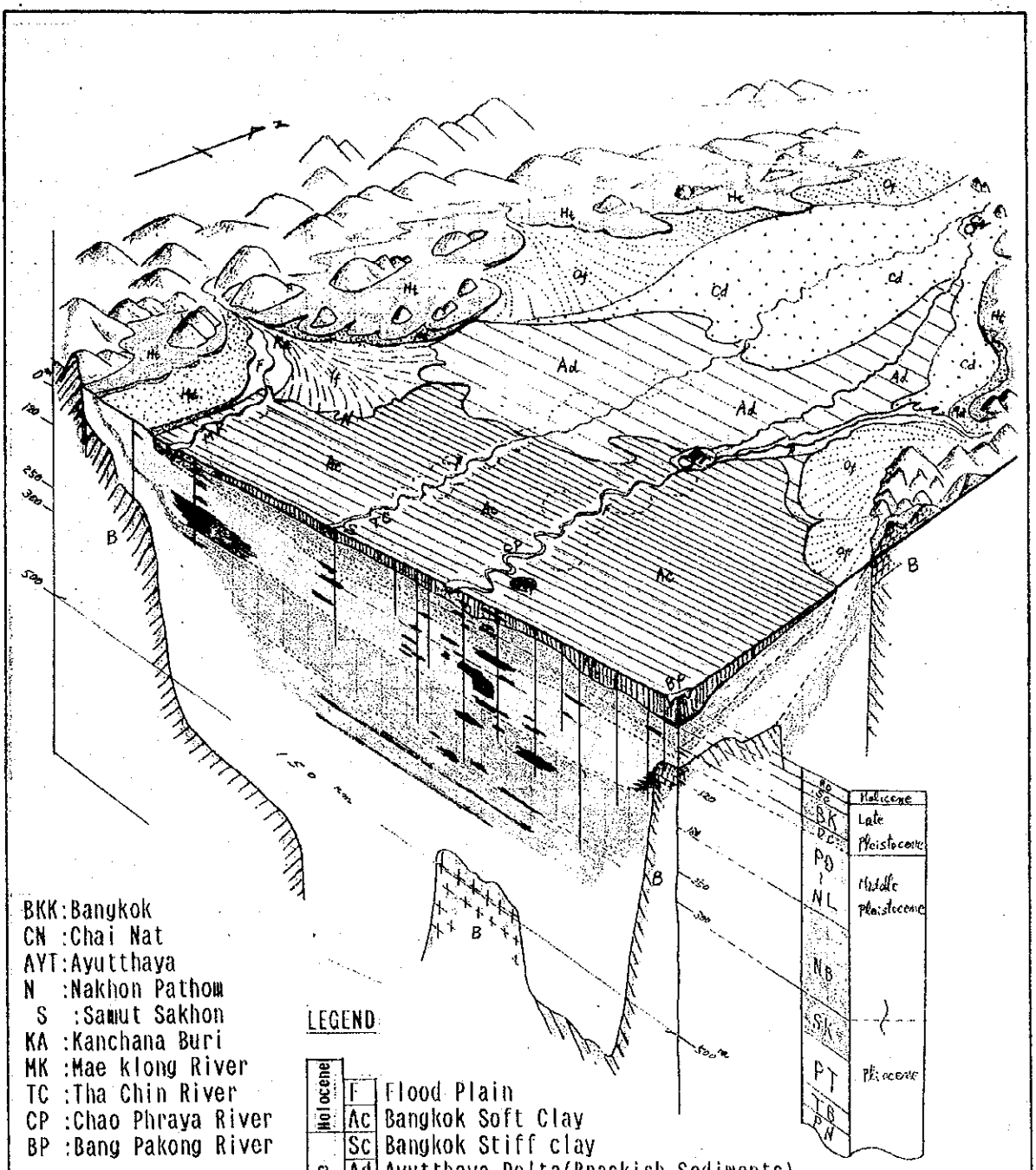


Figure 3.1	SCHEMATIC DIAGRAM OF THE LOWER CENTRAL PLAIN
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

JICA – A LOGGING

Age	Depth (m)	Facis Units	Facies	Aquifer Unit	Aquifer Name
Holocene		1 (17.2)	Dark greenish gray clay Bangkok top clay		
		2	Gray silty stiff clay	20	
		20.3 3 34.5	Fine to medium sand	1	
		4	Brown stiff clay	30	
		38.4 5 59.0	Fine to medium sand with gravel	38 2 59	BK
	50	6 (122.0)	Brown reddish brown yellowish brown silt clay sand alt calcareous nodule	70.2 3 75.5	
		7 (149.0)	Brownish gray fine to medium sand with granule	90 93.5 4 102 105 5 118 122 6	PD
	100	8 (165.0)	Yellowish to reddish brown clay with calcareous nodule	127 7 149	NL upper / Lower
		9 (178.0)	Brown to yellowish brown fine to medium sand with silt	172 8 178	
Pleistocene		10 (230.0)	Brownish gray dark gray fine to coarse sand with silt with gypsum Mn.Fe nodule	186 9 198 205 10 222	NB upper / Lower
	200	11 (280.0)	Yellowish brown gray purplish gray very fine to very coarse sand and gray brownish gray silt alt with consolidated silt calcareous nodule	237 11 248 255 12 273	
	250			280 289 13 303	SK
	300		Upper consolidated clay		
		12 (362.0)	Lower darkgray brownish gray very fine to medium sand	333 14 352 362	
	350				

Sp(mV): 0

R(ρ)(Ω-m): 0 — 50

γ(cps): 0

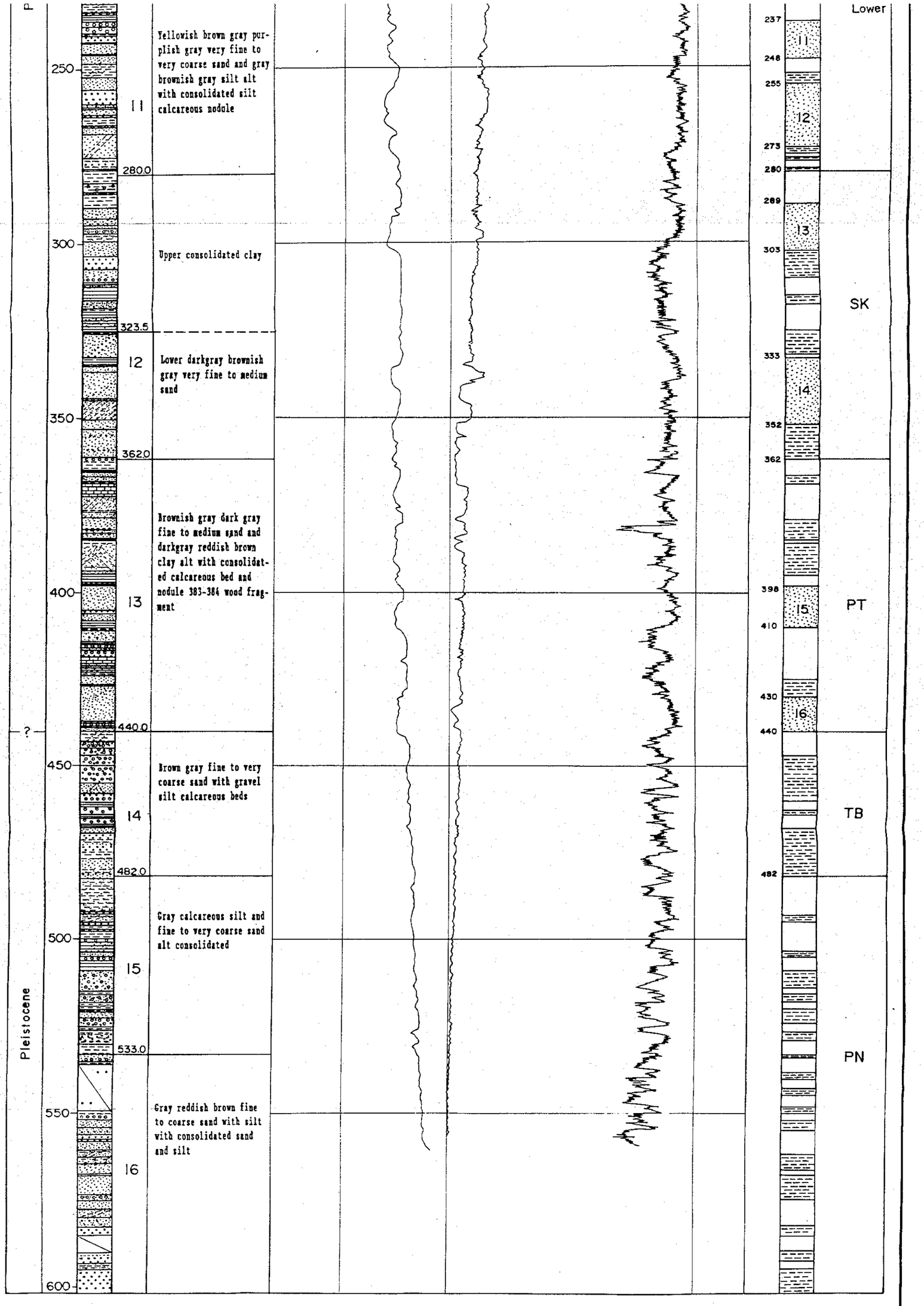


Figure 3.2	JICA - A Logging and Aquifer
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

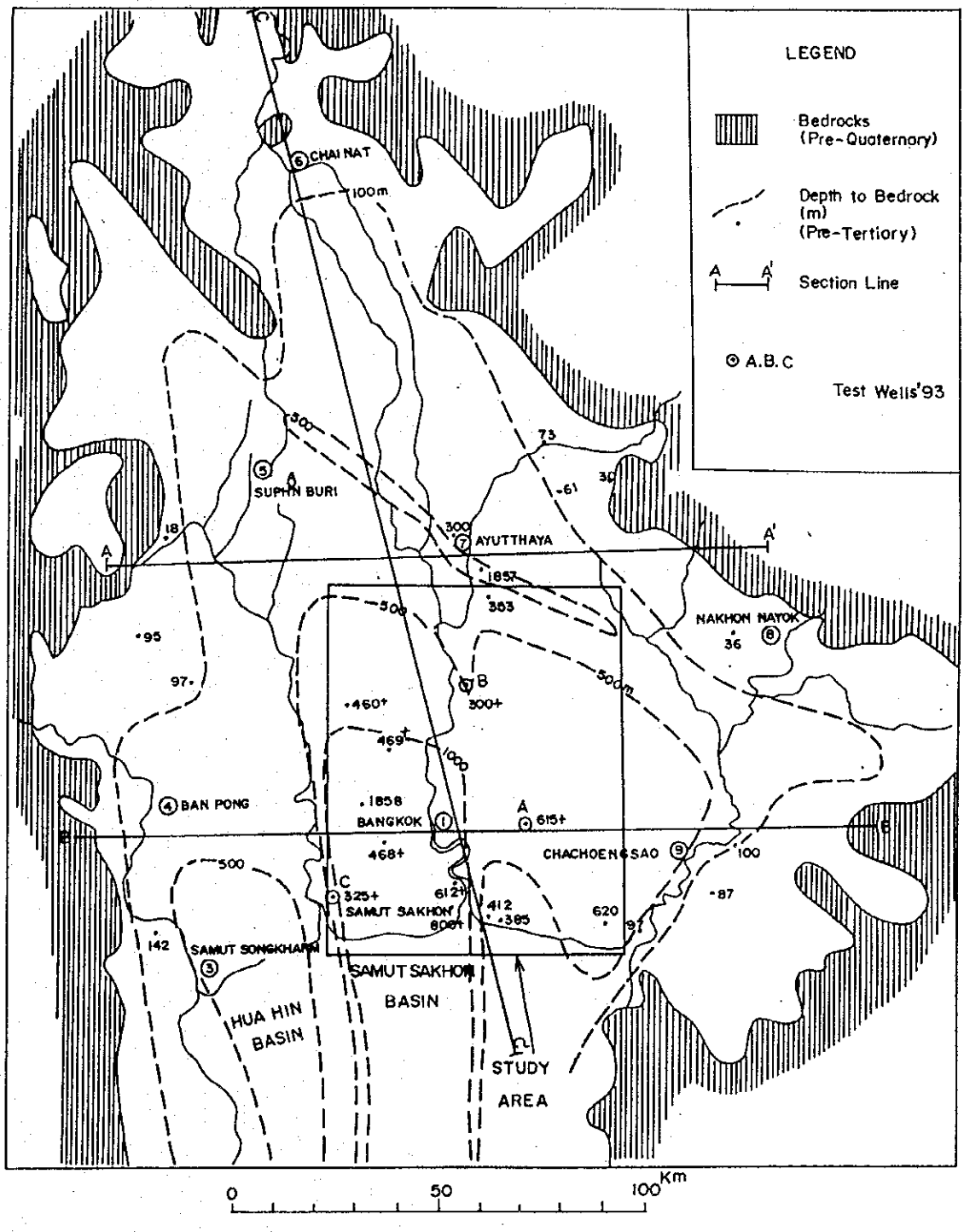
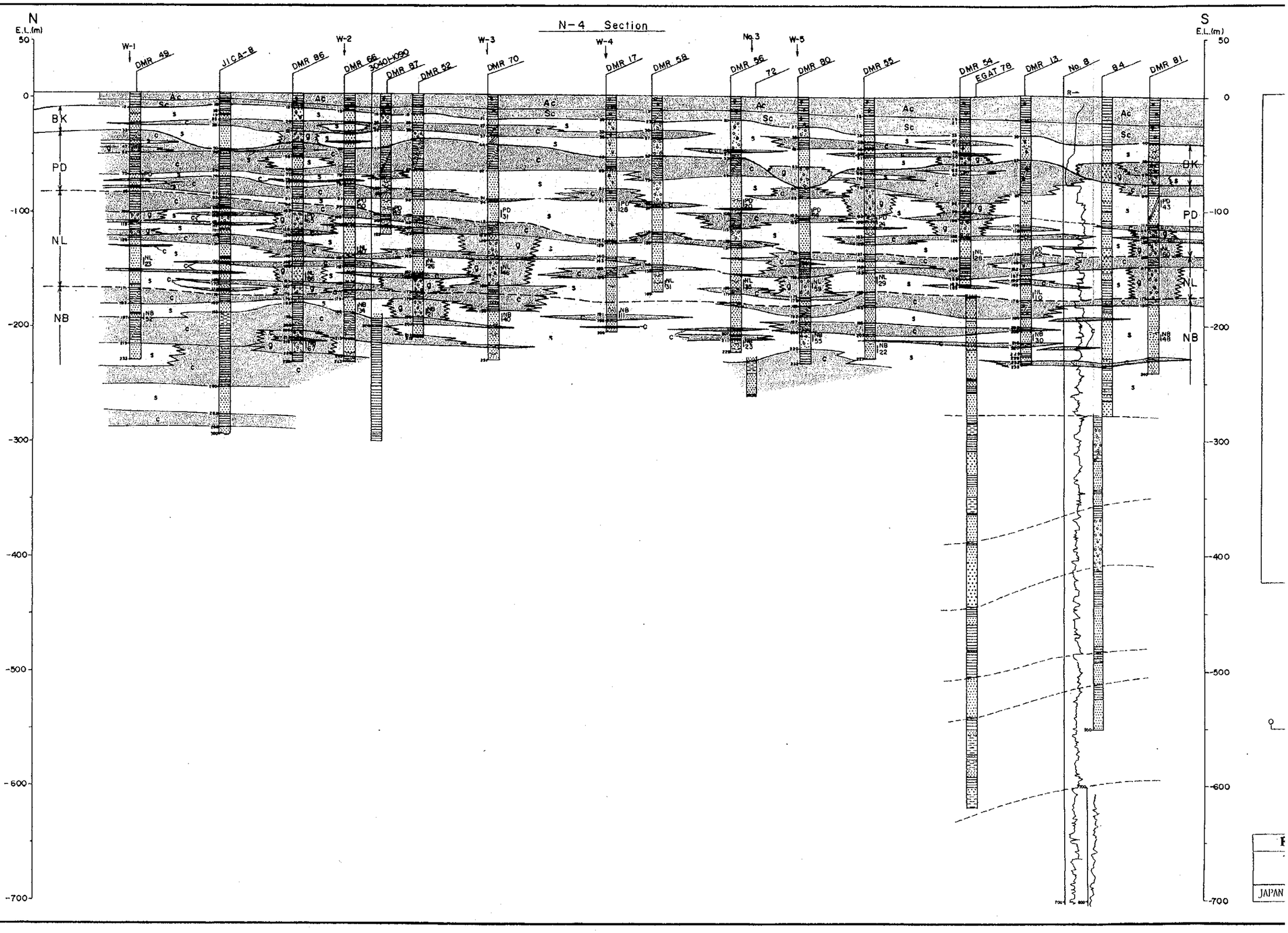


Figure 3.3	SEDIMENTARY BASIN OF THE LOWER CENTRAL PLAIN
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

N-4 Section


N
E.L.(m)
S
E.L.(m)
W-1
W-2
W-3
W-4
No.3
W-5
DMR 49
JICA-8
DMR 86
DMR 66
3040+1090
DMR 87
DMR 52
DMR 70
DMR 17
DMR 58
DMR 56
72
DMR 90
DMR 55
DMR 54
EGAT 78
DMR 13
No. 8
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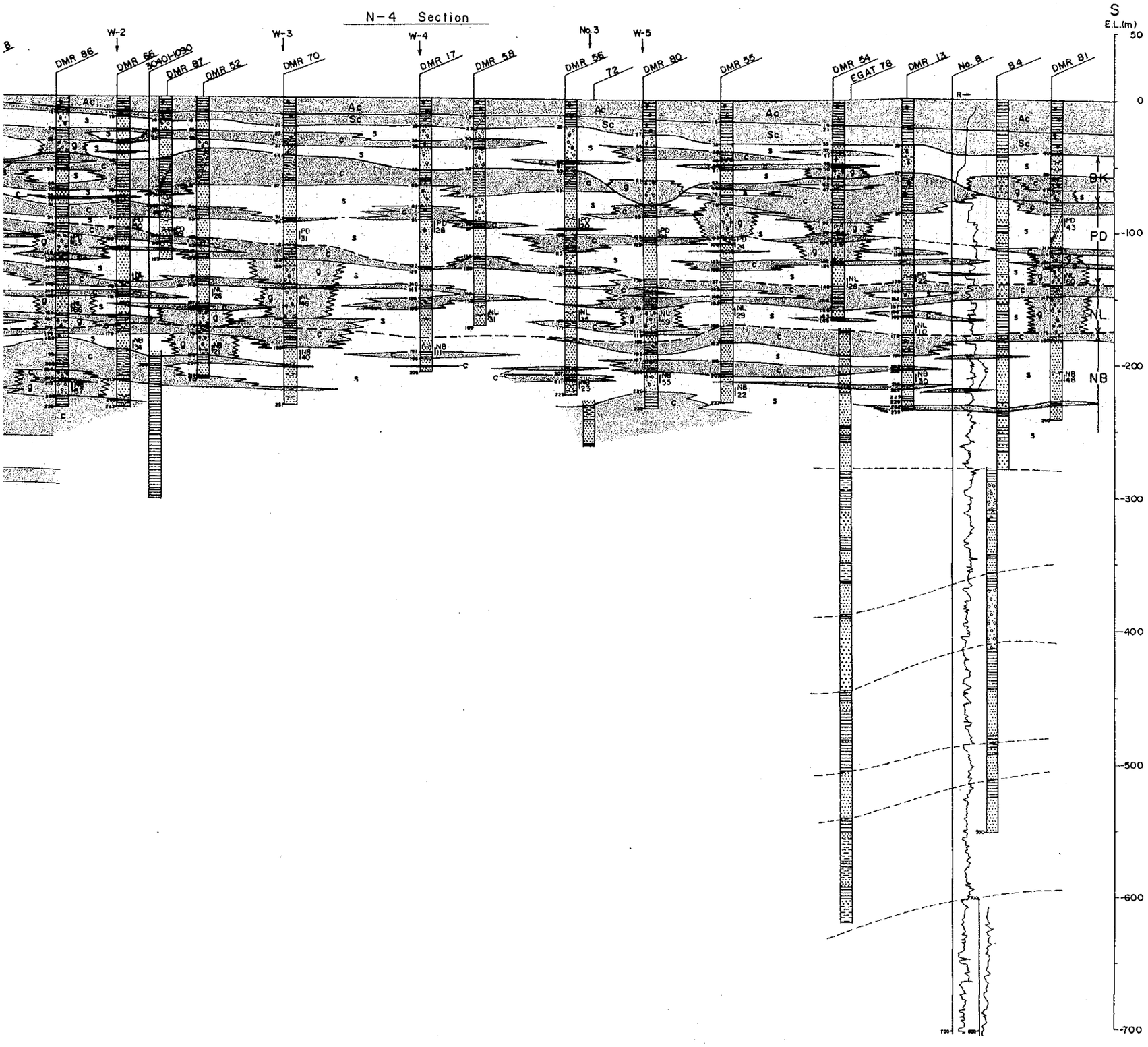
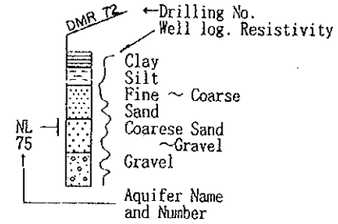


LEGEND

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

Aquifer Boundary

Facies Boundary
Sequence Boundary



Aquifer Name

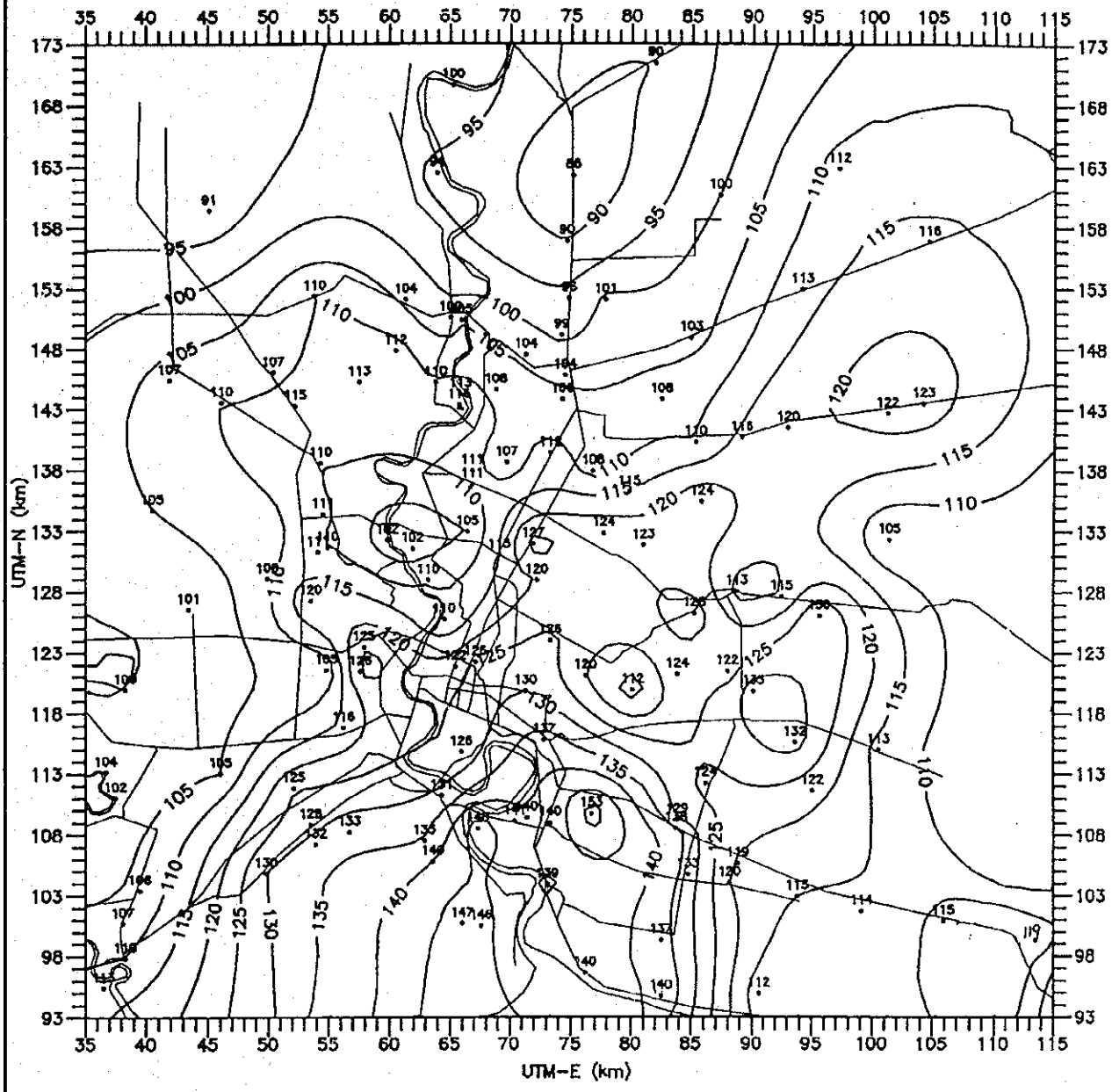
BK :	Bangkok	SK:	Sam Khok
PD :	Phra Phradaeng	PT:	Phaya Thai
NL :	Nakhon Luang	TB:	Thon Buri
NB :	Nonthaburi	PN:	Pak Nam

0 3 6 9 12 15 km

Figure 3.4 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.

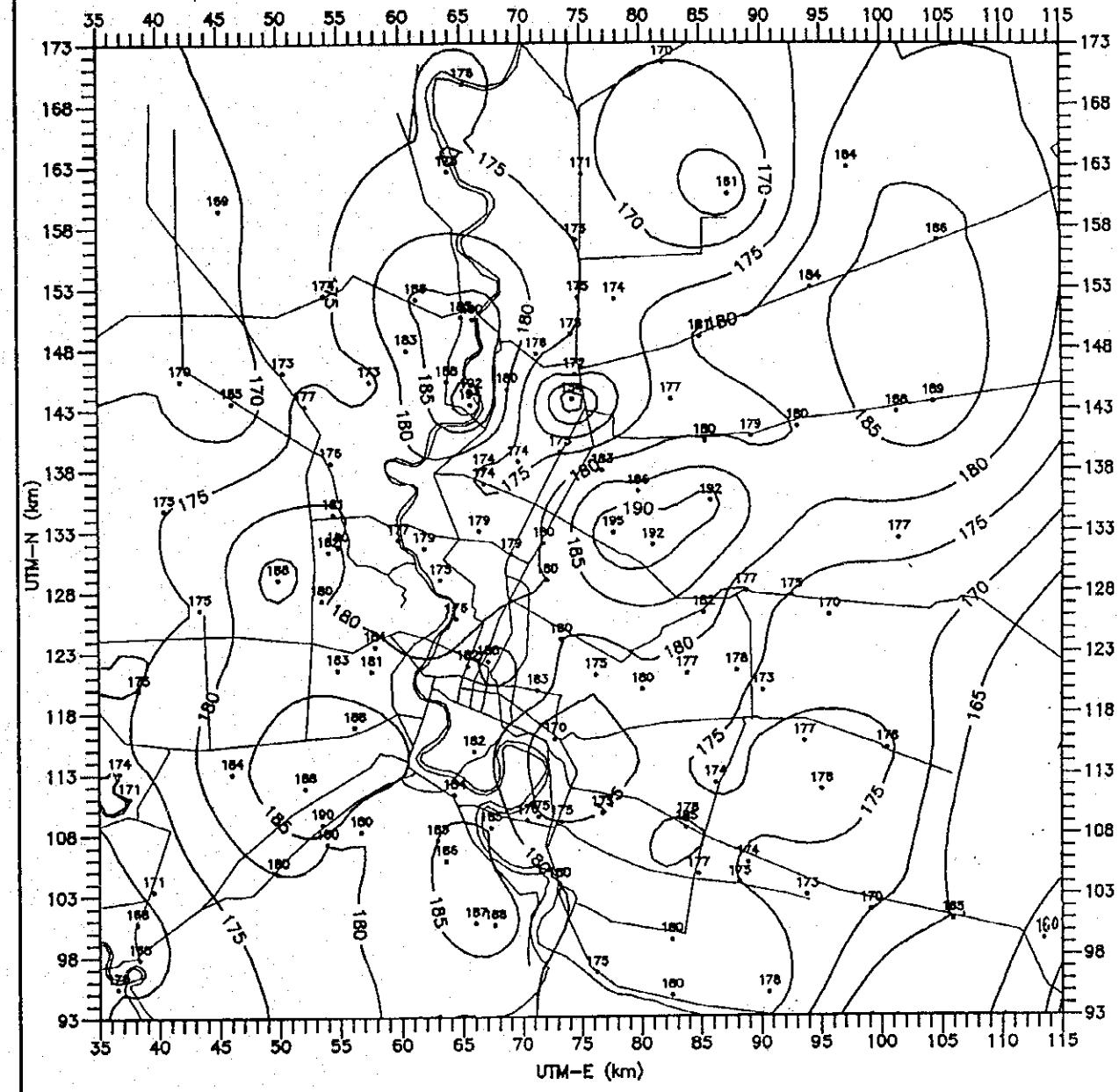


LEGEND

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

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

Figure 3.5.1	**DEPTH TO THE BOTTOM OF PHRA PRADAENG AQUIFER (PD)**
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.

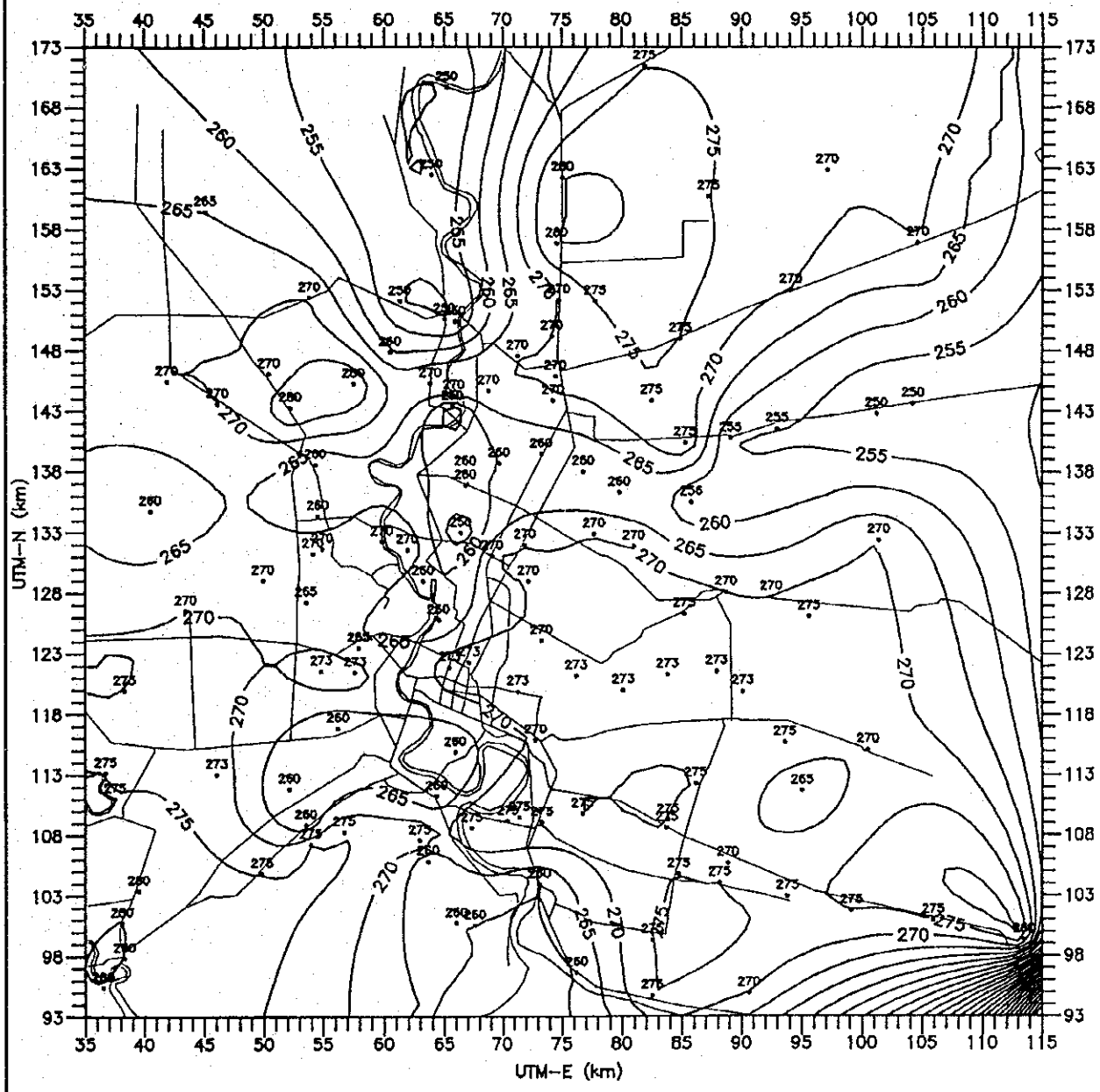


LEGEND

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

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

Figure 3.5.2	**DEPTH TO THE BOTTOM OF NAKHON LUANG AQUIFER (NL)**
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)

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

Figure 3.5.3	DEPTH TO THE BOTTOM OF NONTHABURI AQUIFER (NB)
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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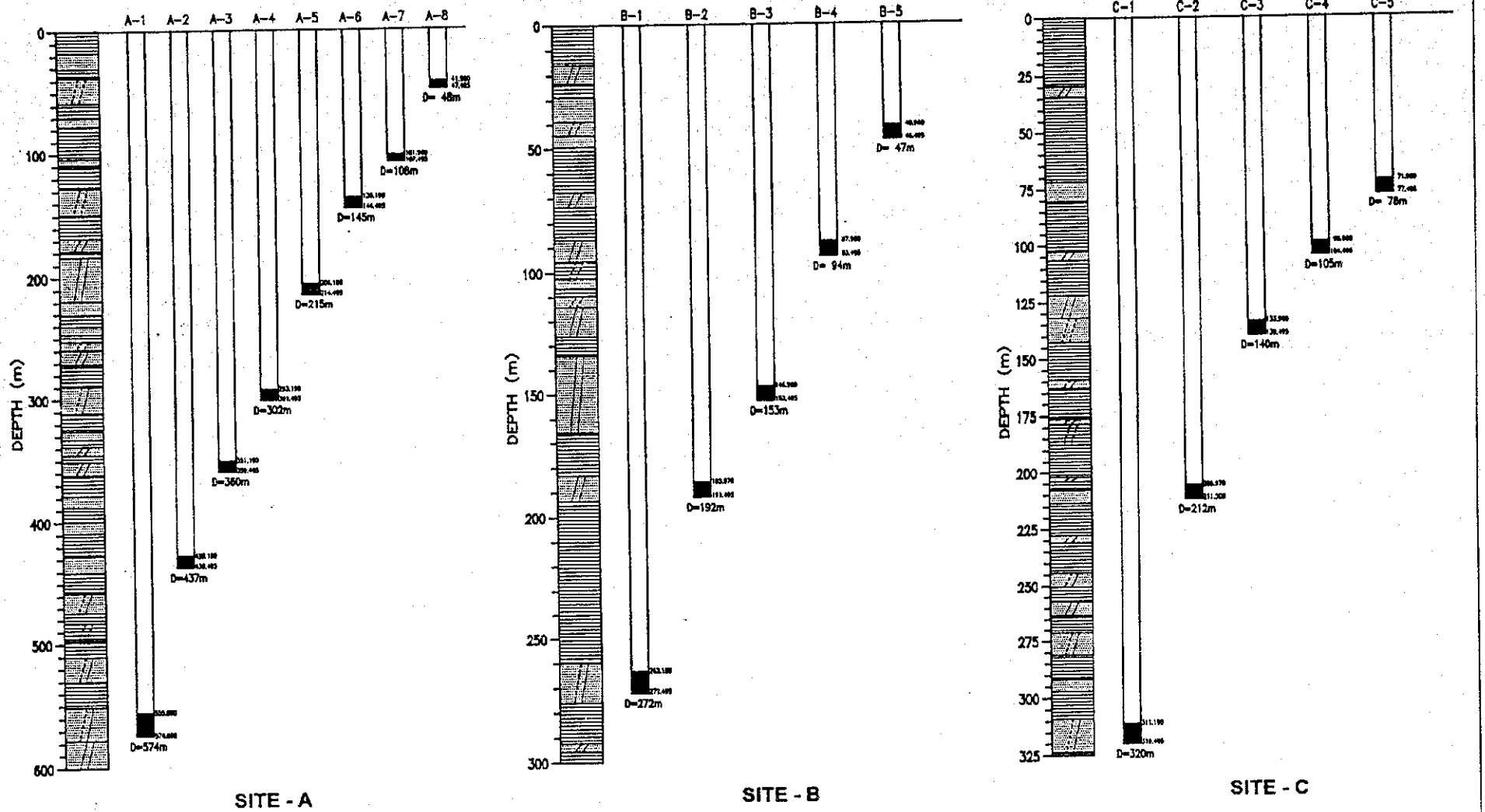

Figure 3.6 SCHEMATIC DIAGRAM OF MONITORING WELLS

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

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Figure 3.7 SCHEME DRAWING OF THE OBSERVATION UNIT