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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

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MAIN REPORT

DECEMBER 1995

KOKUSAI KOGYO CO., LTD.
TOKYO, JAPAN

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JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

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

FINAL REPORT
MAIN 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,

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.

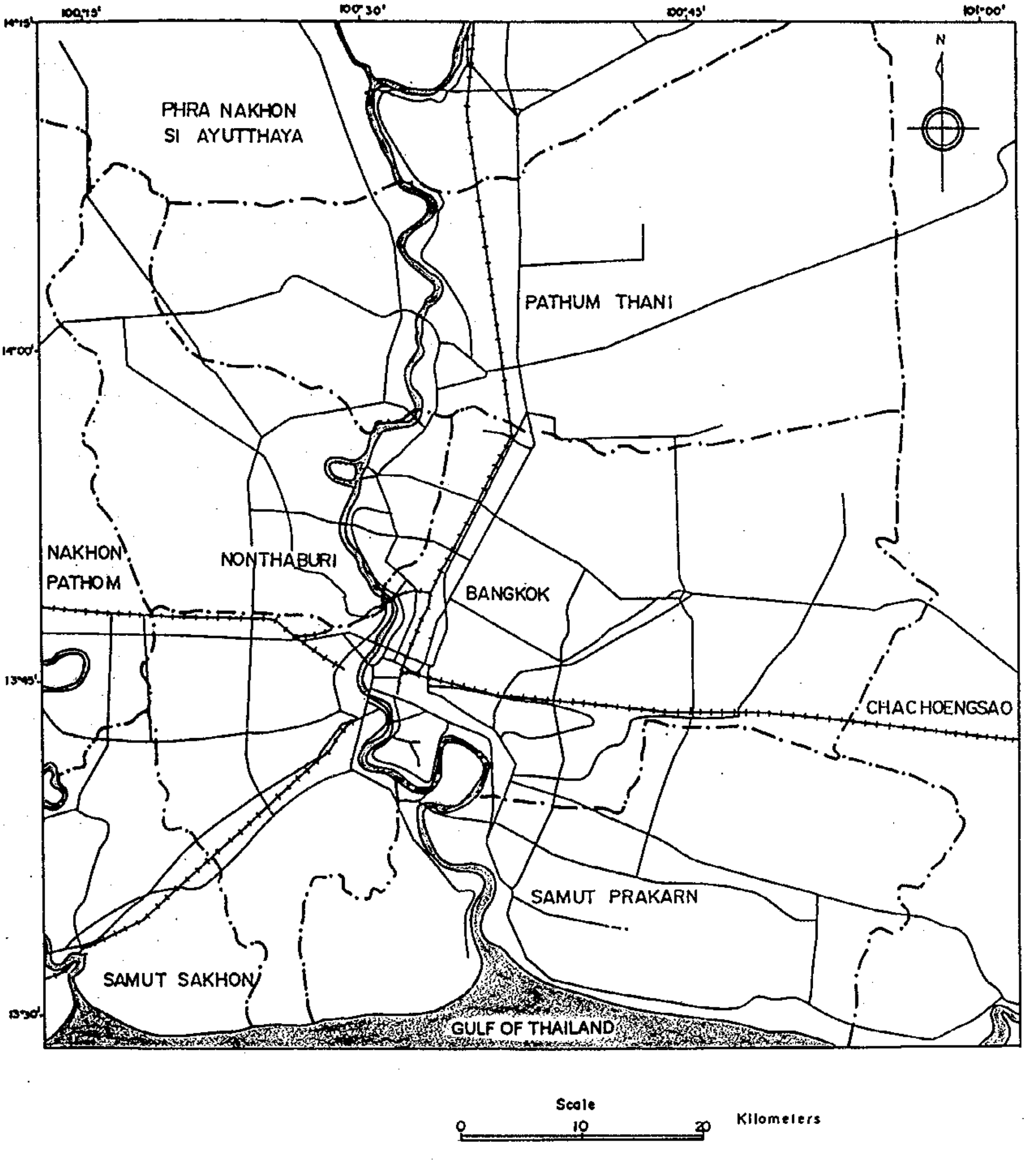
5. Recommendations

(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



	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.

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

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LIST OF ABBREVIATIONS

Organization

AAT	Airport Authority of Thailand
AIT	Asian Institute of Technology
ARD	Accelerated Rural Development Office
BMA	Bangkok Metropolitan Administration
BOI	Board of Investment
CWSD	Concession Water Supply Division
DIW	Department of Industrial Works
DLA	Department of Local Administration
DLD	Department of Land Development
DMR	Department of Mineral Resources
DOH	Department of Health
DTCP	Department of Town & Country Planning
EGAT	Electricity Generating Authority of Thailand
ETA	Expressway and Rapid Transit Authority of Thailand
EPZ	Export Processing Zone
GIZ	General Industrial Zone
IEAT	Industrial Estates Authority of Thailand
JICA	Japan International Cooperation Agency
LDD	Land Development Department
MD	Meteorological Department
MEA	Metropolitan Electric Authority
MOI	Ministry of Interior
MWA	Metropolitan Waterworks Authority
NEB	National Environmental Board
NESDB	National Economic and Social Development Board
NHA	National Housing Authority
NRCT	National Research Council of Thailand
NSO	National Statistical Office
PEA	Provincial Electric Authority
PWA	Provincial Waterworks Authority

PWD	Public Works Department
RID	Royal Irrigation Department
RTSD	Royal Thai Survey Department
SBIA	Second Bangkok International Airport
UN	United Nations
USGS	United States Geological Survey
<u>Unit etc</u>	
BGS	Below Ground Surface
CMD	Cubic Meters per Day
GDP	Gross Domestic Product
GNP	Gross National Product
GRP	Gross Regional Product
GPP	Gross Provincial Product
GWDS	Ground Water Database System
lpcd	liters per capita per day
MCM	Million Cubic Meters
MCMD	Million Cubic Meters per Day
MSL	Mean Sea Level
YBP	Years Before Present

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CHAPTER 1 INTRODUCTION

This Draft Final Report on **The Study on Management of Groundwater and Land Subsidence in the Bangkok Metropolitan Area and Its Vicinity** presents the results of the various studies on groundwater and land subsidence, their future predictions, alleviation measures for land subsidence and groundwater basin management. This report was made in accordance with the Scope of Work (SW) agreed upon between the Department of Mineral Resources (DMR) jointly with the Public Works Department (PWD) and the Japan International Cooperation Agency (JICA).

The Study was launched in mid-July 1992 and is slated for completion in end-of March 1995.

1.1 Background of the Study

The Bangkok Metropolitan Area is the seat of the Government of the Kingdom of Thailand. It occupies the southern part of the Lower Central Plain, contains an area of about 1,500 km^2, and has a total population of 6.5 million. Because of rapid urbanization, the said metropolitan area and its vicinity are confronted with serious problems in water supply, sewerage, transportation, housing, waste disposal and other related problems.

With respect to the water supply problem, two (2) aspects are discerned as prominent. One is about land subsidence while the other is the inadequacy of supply. Land subsidence resulted from heavy withdrawal of groundwater, and at the outskirts of Bangkok -- in Samut Sakhon, Rangsit and Phra Pradaeng -- where rapid industrialization is underway, it is spreading. In the said places, groundwater is excessively being withdrawn resulting in significant decline of piezometric levels. In the critical zones, land subsidence has already caused serious economic losses and triggered a host of environmental problems.

Since 1983, several initiatives had been adopted and carried out to address excessive groundwater extraction and check, if not arrest, the high rate of land subsidence. The DMR, which has the responsibility for the management of groundwater nationwide, embarked on implementing corrective measures for groundwater depletion and land subsidence. Control of the groundwater pumpage in Bangkok resulted in the recovery of water level which, in turn, decreased the rate of land subsidence. Inspite of the positive outcome of such efforts, land subsidence is still occurring in Bangkok.

The aspect about the adequacy of supply is viewed in light of the needs of the Bangkok Metropolis, the water supply of which falls under the jurisdiction of the Metropolitan Waterworks Authority (MWA). The MWA supplied in 1990 both surface water and groundwater, 2.87 MCMD and 70,000 CMD, respectively. It is currently implementing the Fifth Bangkok Water Supply Improvement Project wherein the use of surface water will be increased. With the progressively growing demand, however, and particularly for areas where rapid industrialization and urbanization have already taken place and where groundwater is the only source, supply projections are such that additional water sources have to be developed. Under the weight of such considerations, what is called for is sustained attention on mitigating the impact of land subsidence and rationally managing the groundwater resources in the Bangkok Metropolitan Area and its vicinity.

The Government of the Kingdom of Thailand, in the context of the above, requested the Government of Japan for a technical assistance on **The Study on Management of Groundwater and Land Subsidence in the Bangkok Metropolitan Area and Its Vicinity**. 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. This mission stayed in Thailand from 28 January to 12 February 1992.

An agreement was reached between the Counterpart Agencies -- the DMR and the PWD and JICA on the Scope of Work (SW) for the Study. The agreement was signed on 5 February 1992 by representatives of the three (3) agencies. As stipulated in the SW, a Study Team was finally dispatched to undertake the Study.

The Study Team stayed in the Kingdom of Thailand from 15 July to 30 September 1992 (Stage I of the Study), from 11 November 1992 to 31 March 1994 (Stage II of the Study) and from 19 May 1994 to 18 February 1995 (Stage III of the Study). The Study Team conducted basic and detailed surveys on groundwater and land subsidence during these periods in close cooperation with the DMR and the PWD counterpart-personnel.

1.2 Study Objectives and Scope

1.2.1 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

1.2.2 Study Scope

The Study is being carried out within the stipulations of the Scope of Work (SW) and covers the following major subjects:

(1) Data Collection and Review
(2) Basic Investigations

a) Comprehension of the present status of groundwater utilization, land subsidence, and saline water intrusion
b) Collection and compilation of well inventories for preparation of groundwater database
c) Review and examiantion of the previous studies concerning artificial recharge
d) Examination of the existing laws and organizaitons related to the management of groundwater and land subsidence

(3) Detailed Investigations

a) Drilling of test wells and conduct of various in-situ and laboratory tests for comprehension of hydrogeologic characteristics and soil properties

b) Observation of groundwater levels and land subsidence
c) Leveling survey
d) Water quality analysis
e) Completion of groundwater database

(4) Study and Analysis

a) Hydrogeological and hydraulic analysis
b) Prediction of groundwater behavior, land subsidence and saline water intrusion

(5) Planning and Others

a) Planning of groundwater management system
b) Planning for alleviation of land subsidence and saline water intrusion
c) Preliminary estimation of project costs
d) Social and environmental impact assessment
e) Implementation schedule
f) Project evaluation
g) Recommendations

1.3 Study Area

The Study Area covers the Bangkok Metropolis and its vicinity. As shown in Figure 1.3.1, 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

1.4 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) and Stage III (Analysis and Planning).

The Study procedure is flowcharted as shown in Figure 1.4.1.

(1) 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.

(2) Stage II: Detailed Survey

The Study in this stage included the reviews of artificial recharge, existing water supply systems, and 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.

(3) 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 establishment of groundwater management system in Bangkok Metropolitan Area and its vicinity.

1.5 Organization of the Study

In carrying out the Study, the Department of Mineral Resources (DMR) and the Public Works Department (PWD) of the Kingdom of Thailand acted as the counterpart agencies and the Japan International Cooperation Agency (JICA) acted as the official agency in technical cooperation with the Government of Japan.

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
Precha 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

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

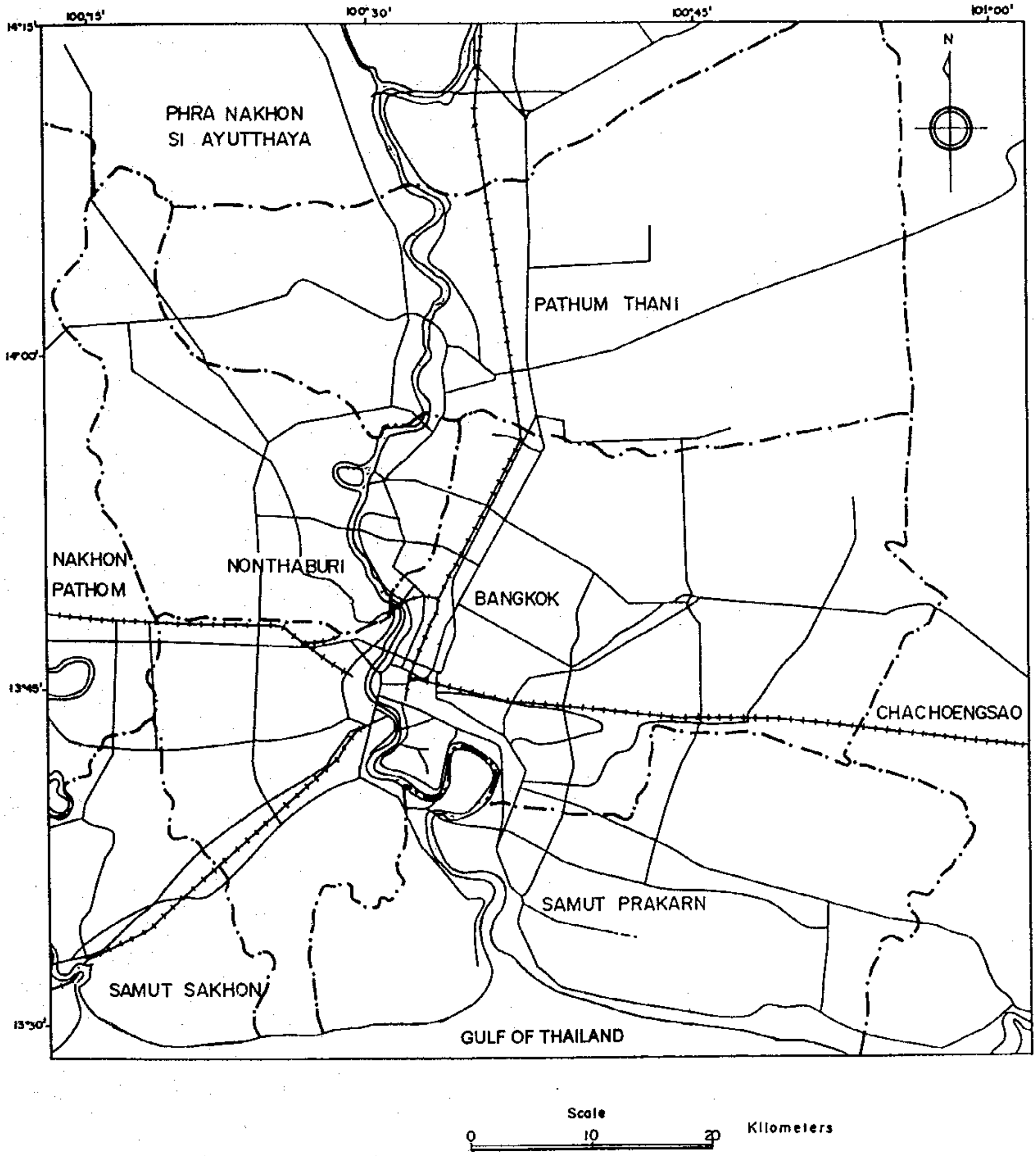

Figure 1.3.1	LOCATION MAP OF THE STUDY AREA
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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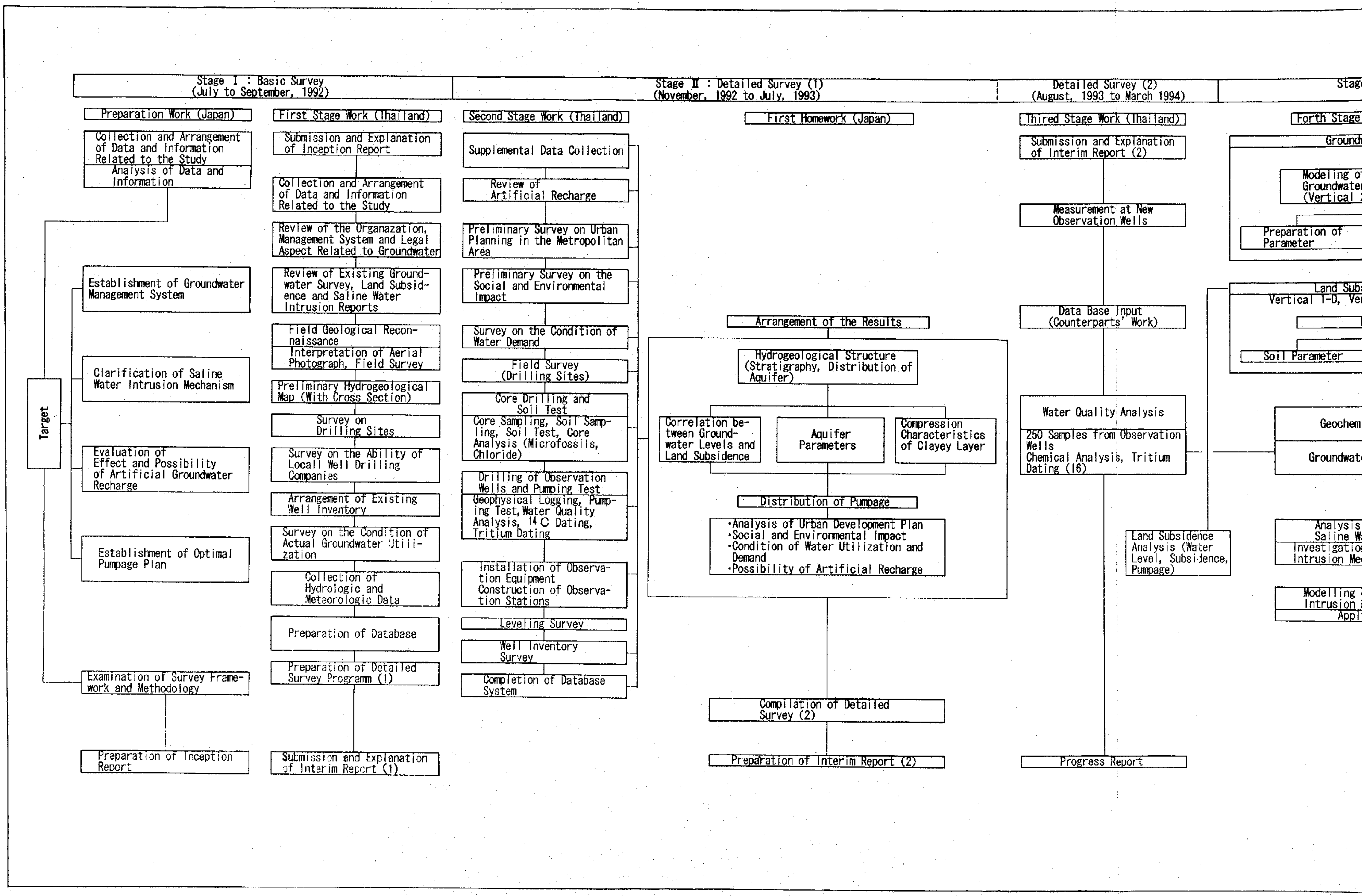

Stage I : Basic Survey (July to September, 1992)
Stage II : Detailed Survey (1) (November, 1992 to July, 1993)
Detailed Survey (2) (August, 1993 to March 1994)
Stag
Target
Preparation Work (Japan)
Collection and Arrangement of Data and Information Related to the Study
Analysis of Data and Information
Establishment of Groundwater Management System
Clarification of Saline Water Intrusion Mechanism
Evaluation of Effect and Possibility of Artificial Groundwater Recharge
Establishment of Optimal Pumpage Plan
Examination of Survey Frame-work and Methodology
Preparation of Inception Report
First Stage Work (Thailand)
Submission and Explanation of Inception Report
Collection and Arrangement of Data and Information Related to the Study
Review of the Organazation, Management System and Legal Aspect Related to Groundwater
Review of Existing Ground-water Survey, Land Subsid-ence and Saline Water Intrusion Reports
Field Geological Recon-naissance
Interpretation of Aerial Photograph, Field Survey
Preliminary Hydrogeological Map (With Cross Section)
Survey on Drilling Sites
Survey on the Ability of Locall Well Drilling Companies
Arrangement of Existing Well Inventory
Survey on the Condition of Actual Groundwater Utili-zation
Collection of Hydrologic and Meteorologic Data
Preparation of Database
Preparation of Detailed Survey Programm (1)
Submission and Explanation of Interim Report (1)
Second Stage Work (Thailand)
Supplemental Data Collection
Review of Artificial Recharge
Preliminary Survey on Urban Planning in the Metropolitan Area
Preliminary Survey on the Social and Environmental Impact
Survey on the Condition of Water Demand
Field Survey (Drilling Sites)
Core Drilling and Soil Test
Core Sampling, Soil Samp-ling, Soil Test, Core Analysis (Microfossils, Chloride)
Drilling of Observation Wells and Pumping Test
Geophysical Logging, Pump-ing Test, Water Quality Analysis, 14C Dating, Tritium Dating
Installation of Observa-tion Equipment
Construction of Observa-tion Stations
Leveling Survey
Well Inventory Survey
Completion of Database System
First Homework (Japan)
Arrangement of the Results
Hydrogeological Structure (Stratigraphy, Distribution of Aquifer)
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Chemical Analysis, Tritium Dating (16)
Land Subsidence Analysis (Water Level, Subsidence, Pumpage)
Progress Report
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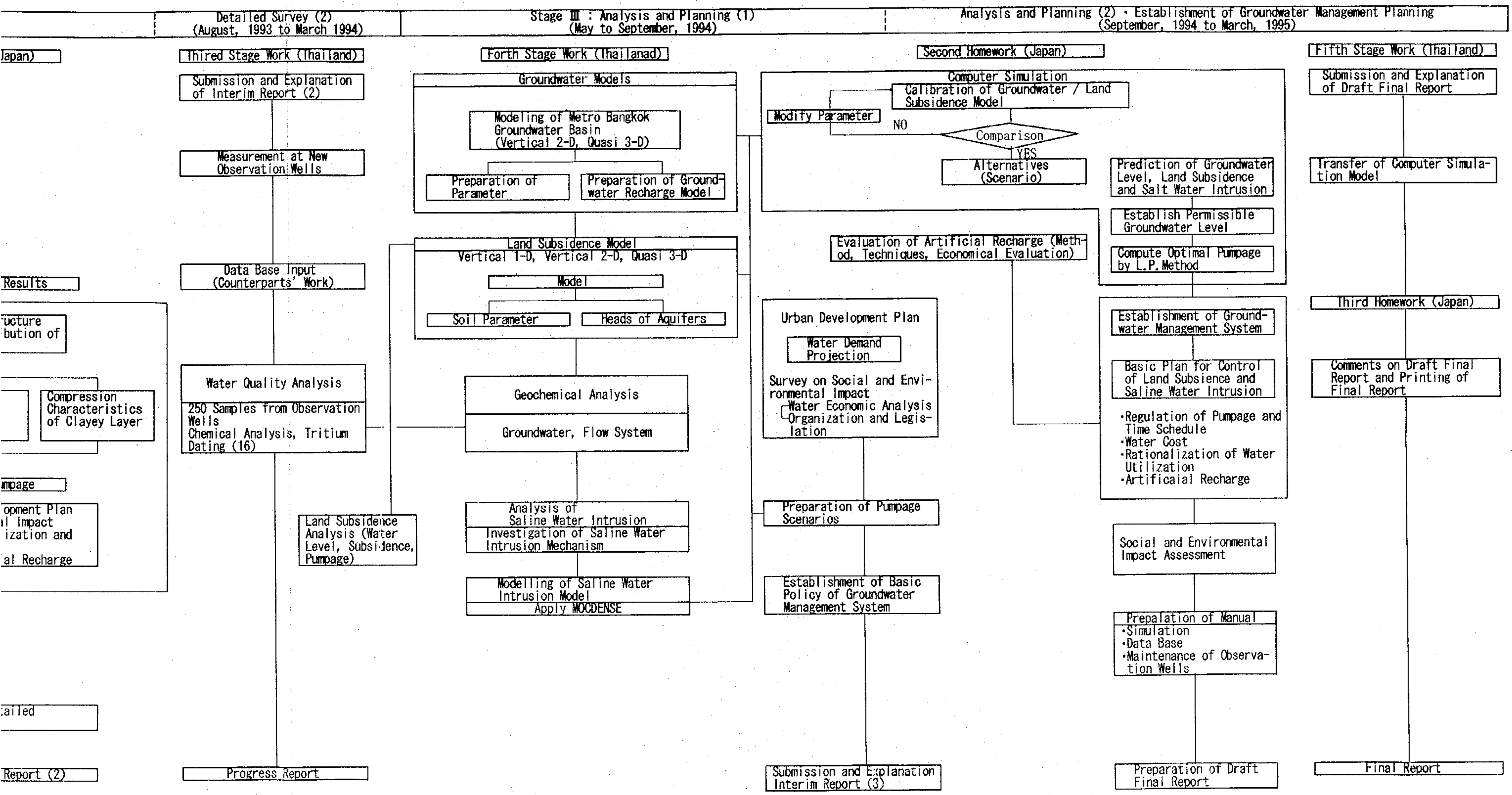

Figure 1.4.1 FLOWCHART OF THE STUDY

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

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CHAPTER 2 THE STUDY AREA

2.1 Natural Conditions

2.1.1 Topography

(1) Physiographic Regions

Thailand is situated in southeastern Asia and stretches at latitudes 5°N to 21°N. The main part of the country is bounded on the west and on the north by Burma (Myanmar) and on the east by Laos and Cambodia (Kampuchea). Peninsular Thailand extends southward to the Malaysian border and is contiguous to the Andaman Sea on the west and the Gulf of Thailand on the east.

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 2.1.1; Moormann & Rojanasoonthon, 1968).

The widest lowland area is the Central Plain that stretches from the Gulf of Thailand to as far as Uttaradit in the north. Smaller coastal plains with old and recent marine and brackish water deposits occur in many locations along the southeast of Thailand and peninsular seaboards. The rest of the country is made up of Continental Highlands and Khorat Plateau in the northeast.

The rocks underlying the mountain ranges of the country are folded and metamorphosed that in many places are intruded by igneous rocks. The dominant structural trend is approximately N-S, and this has created a general topography of N-S elongated mountain and hill ranges that are separated by intervening alluvial plains, basins and valleys.

(2) The Central Plain

The Central Plain is a strip of land over 500 km long and 100-200 km wide. It is separated from the Salaween River Basin by the Tanaosri Ranges on the west and from the Khorat Plateau by the Phetchabun Ranges on the east (Thiramongkol, 1983). On the north, the plain is bounded by mountainous regions and on the south by the Gulf of Thailand.

The Central Plain can be divided into three areas, namely, the Upper Central Plain, the Nakhon Sawan area, and the Lower Central Plain. In the Upper Central Plain, 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 typical feature in the Upper Central Plain is the combination of well defined meander belts and many scars of abandoned river courses with numerous small swamps, whereas on the higher lands, dissected terraces and peneplains with sandy ground surface predominate.

In the Nakhon Sawan area, a number of isolated mountains and mountainous groups stands out clearly from the plain, just like monadnocks. This monadnock area continues for about 50 km from Nakhon Sawan to Chai Nat in a N-S direction.

From Chai Nat, the Chao Phraya River flows south to the Gulf of Thailand traversing the Lower Central Plain. With a flat to a very slightly undulating, broad depositional surface dominating the topography of the area, the Chao Phraya River gives off many effluent branches. Among these channels, the Suphan Buri River and the Noi River and the Lop Buri River are the important ones.

Besides the Chao Phraya River, the Central Plain contains three (3) more rivers, the Mae Khlong on the west, the Pasak on the east and Bang Pakong on the southeast (Figure 2.1.2).

(3) The Lower Central Plain

The Lower Central Plain is bounded on the west by the Tanaosri Range, on the north by the Nakhon Sawan Area, on the east by the Khorat Plateau and Chanthaburi Region and on the south by the Gulf of Thailand (Figure 2.1.3). The plain covers an area of approximately 53,400 km^2. The length from north to south is roughly 200 km and the average width is about 150 km. The elevation of the central part of the Plain ranges from 20 m above MSL at Chai Nat in the north to less than 4 m at Ayutthaya and to about 2 m in the vicinity of Bangkok (Figure 2.1.4).

The Lower Central Plain is a large and flat plain consisting of young fluvial and marine deposits. Fans and terraces occupy the marginal zones of the plain. A peneplain and a structural terrace in the eastern part of the Plain are the oldest landforms of the region (Takaya & Thiramongkol, 1982 and Thiramongkol, 1983).

From Chai Nat, the Chao Phraya River has given off a few smaller branches, two (2) of them forming the Tha Chin (or Suphan Buri) River and the Noi River. 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.

(4) The Study Area

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 comprises the provinces of Bangkok Metropolis, Nonthaburi, Samut Prakan, and Pathum Thani and some parts of the provinces of Samut Sakhon, Nakhon Pathom, and Phra Nakhon Si Ayutthaya.

The 5,600-km^2 Study Area is located at latitudes 13°30'00"N to 14°13'22.2"N and longitudes 100°15'00"E to 100°53'30.6"E. It spreads on both sides of the Chao Phraya River within an extremely flat deltaic marine plain with the natural ground elevations ranging from one (1) to six (6) meters above MSL.

The area is divided into the tidal zone, the tidal flat of marine clays, the tidal flat of brackish clays and the barrier (Thiramongkol, 1983). The old meander of the Chao Phraya River can be traced in the tidal flat in addition to the tributaries and artificial Khlongs. The tidal zone is the black marsh located south of Bangkok where sea water intrudes.

Land subsidence has changed the ground elevations of the Study Area, and a zone of 0-m elevation now appears in the Bangkok area (Figure 2.1.5).

2.1.2 Climate

(1) Rainfall

Thailand is located in the monsoonal region which has a distinct dry season and a flood season caused by monsoonal rains. Over the Lower Central Plain, most of the rain is caused by the regular southwest monsoon winds but a smaller portion falls in the form of very intense torrential showers resulting from tropical storms. The average frequency of tropical storms entering Thailand is approximately two (2) storms per year which generally occur during the months of May through December.

The mean monthly rainfall values of some selected stations in the Lower Central Plain are plotted in Figure 2.1.6. As shown in this figure, monthly rainfall patterns in the basin resemble each other. About 85% of the rainfall occurs from May to October, with September generally as the month of highest rainfall. The period from November to April is distinctively dry. Annual rainfall ranges from 1,019.0 mm (as observed in Chai Nat) to 1,995.7 mm (as observed in Prachin Buri). On the other hand, monthly mean varies from 4.6 mm (as observed in Kanchanaburi) to 380.4 mm (as observed in Prachin Buri).

As shown by the isohyets of annual rainfall in the same figure, the mean annual rainfall over the Lower Central Plain is approximately 1,150 mm. The western part is considerably dryer than the eastern part. The average annual rainfall which is 900 to 1,000 mm in the western part, increases to 1,100 to 1,300 mm in the northern, central and southeastern parts and is over 1,500 mm in the eastern part of the Lower Central Plain.

Figure 2.1.7 shows the monthly rainfall variations in the stations within the Study Area. With its flat topography, very little variation exists in the rainfall regime within the Study Area and therefore, the monthly and annual rainfall data for Bangkok Metropolis may be considered representative for the entire Study Area. The mean annual rainfall in the Study Area is about 1,310.9 mm. In Figure 2.1.8 the rainfall data for Bangkok Metropolis shows that the annual fluctuation of rainfall in the Study Area is high. In a 39-year period 1952-1990, the maximum rainfall was 2,129.5 mm in 1983 and the minimum was 875.5 mm in 1967. There were five (5) dry years (1967, 1969, 1973, 1977 and 1979) and six (6) wet years (1957, 1964, 1970, 1983, 1986 and 1988) as shown by the annual rainfalls exceeding the mean ± standard deviation.

(2) Temperature, Relative Humidity and Evaporation

Figure 2.1.9 shows the mean monthly variation of temperature, relative humidity and evaporation in Nakhon Sawan, Suphan Buri and Bangkok Metropolis Stations. Nakhon Sawan is located in the northern part of the Lower Central Plain, Suphan Buri in the central part, and Bangkok in the southern part within the Study Area. As shown in this figure, the mean monthly temperature varies from 24.5°C to 31.7°C in Nakhon Sawan, 25.1°C to 31.1°C in Suphan Buri, and 25.4°C to 29.7°C in Bangkok. The data indicate that, on the average, monthly temperature ranges from a minimum of 18.1°C to a maximum of 38.0°C in Nakhon Sawan, 19.3°C to 37.0°C in Suphan Buri, and 20.6°C to 34.9°C in Bangkok. Temperature is more extreme in the northern part of the Lower Central Plain than in the southern part or in the Study Area. The coldest months are December and January while the warmest months are April and May.

The monthly average relative humidity ranges from a maximum of 83% in Bangkok to a minimum of 60% in Nakhon Sawan. The months of September and October recorded the highest relative humidity readings, while the months of March and April the lowest. Mean annual relative humidity was recorded at 70% for Nakhon Sawan, 72% for Suphan Buri and 77% for Bangkok. It is more humid in the Study Area than in the northern Lower Central Plain.

In Bangkok, mean monthly evaporation varies from a minimum of 126.0 mm in November to a maximum of 190.2 mm in April. In Nakhon Sawan and Suphan Buri, it ranges from 130.5 mm to 235.3 mm and 127.8 mm to 201.5 mm respectively. Estimated annual mean is set at 2,070.2 mm for Nakhon Sawan, 1,863.1 mm for Suphan Buri and 1,799.8 mm in Bangkok. With the above temperature and humidity conditions, evaporation is higher in the northern part than in the Study Area.

2.1.3 Hydrology

Chao Phraya River

The Chao Phraya River Basin occupies most of the northern region and the Central Plain of Thailand. The total drainage area of the Chao Phraya River Basin is about 160,000 km^2. The whole drainage area is generally divided into the Upper Chao Phraya River Basin and the Lower Chao Phraya River Basin (Figure 2.1.10; AIT, 1982; JICA, 1989). The outlet of the Upper Basin is located at Nakhon Sawan at which the rivers of the northern region -- Ping, Wang, Yom, and Nan -- emerge to become the Chao Phraya River. The drainage areas of the Upper and Lower Chao Phraya River Basins are 105,929 and 53,417 km^2, respectively (AIT, 1982).

As shown in Figure 2.1.11, the average discharge of the Chao Phraya River downstream of the confluence of the Ping and Nan Rivers at RID's Sta. C.2 in Nakhon Sawan is 683.62 m^3/sec. The drainage area above this station is 111,435 km^2. About 100 km downstream from Nakhon Sawan near Chai Nat Province, the Chao Phraya Dam was constructed to divert the river flow to irrigate an area of about 979,000 hectares located downstream along both sides of the Chao Phraya River. From a drainage area of 120,693 km^2, 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. Of these the Suphan, Noi and Lop Buri are the important ones. 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.

At the city of Ayutthaya, the Chao Phraya River joins with the fifth tributary on the east, the Pasak River. From there, the river enters the Study Area and meanders as a single channel southwards until it meets the Gulf of Thailand near Samut Prakan Province. The Study Area is located on both sides of the Chao Phraya River.

The Pasak River which drains the Central Highlands has an average annual runoff of 77.85 m^3/sec observed at Sta. S.9 downstream of the Pasak Dam at Saraburi. The drainage area above this station is 14,374 km^2.

The Tha Chin River (Suphan River) on the eastern edge of the Study Area does not rejoin the Chao Phraya River but discharges into the sea near Samut Prakan Province, 35 km west of the Chao Phraya River Mouth.

The lower stretch of the Chao Phraya River is affected by ocean tides. The tidal compartment extends up to Bang Sai in the Chao Phraya River and Rama IV Dam in the Pasak River (JICA, 1987).

In the Study Area, the maximum water levels of the Chao Phraya River measured at Memorial Bridge from 1914-1978 are shown in Figure 2.1.12.

As shown in Figure 2.1.11, 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 with a minimum of 354.1 m^3/sec in February, while the discharge in the period of September to December exceeds 1,000 m^3/sec with a maximum of 2,789.7 m^3/sec in October. 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 sometimes including the Study Area from September to November. As mentioned above, the gradient of the river ranges only from 1/10,000 to 1/50,000 for its lower course.

2.1.4 Geology

(1) Regional Geology

A simplified geological map of Thailand is shown in Figure 2.1.13 The Pre-Cambrian gneiss of amphibolite facies and the Lower Paleozoic sandstone and limestone are normally found side by side in the west from Mae Hong Son to Kanchanaburi, in the eastern Gulf and in the southern Peninsula.

The Mid-Paleozoic rocks cover large areas in both west and east. They are represented by a thick monotonous geosynclinal sequence mainly consisting of pelitic rocks and volcanic debris.

The Upper Paleozoic rocks, on the other hand, originated from a shallower marine which consists of arenaceous and calcareous rocks. In the west, they include some Triassic rocks, either conformable or unconformable.

The Early Mesozoic sequence in the western mountains is usually involved with the Upper Paleozoic rocks, but the Middle and Late Mesozoic rocks are found strongly unconformable with either the Early Mesozoic or the Upper Paleozoic. These later Mesozoic rocks are mainly non-marine red beds typically underlying the Khorat Plateau with a mild and broad folded structure.

The non-marine Cenozoic rocks are mainly found in isolated intermountain basins, and larger parts of them underlie the Chao Phraya Plain and the Gulf of Thailand.

Lithofacies change across the country suggests that the stratigraphic successions in Thailand resulted from the successive depositional evolutions of the Paleozoic-Early Mesozoic geosynclines, post-Early Mesozoic platform basins and lately, the Cenozoic basins (Bunopas, 1976).

The Gulf of Thailand was formed by rifting and a brief period of ocean spreading during the Late Cretaceous and/or Cenozoic era (Bunopas & Vella, 1983). The Chao Phraya depression (i.e., the Central Valley and the Central Plain) is thought to be a graben constituting the onshore extension of the Gulf. It may also be regarded as the largest in a series of Tertiary extensional basins in northern Thailand (Chaodumrong et al., 1973).

(2) Basement Structure of the Central Plain

Based on the interpretation of the Landsat photograph, strike-slip faults in NW-SE direction are clearly identified. These faults are accompanied with secondary faults in N-S direction and divide the basement into several blocks, in which these geological blocks constitute the grabens. (See Figure 2.1.14 and 2.1.15.) The depth to the basement is estimated to be more than 1,800 m according to the oil exploratory drilling, aero magnetic and seismic data (Achalabhuti, 1974; AIT, 1981).

In correlation with the lithologic facies in the Gulf, the sediments overlying the basement are thought to be deposits in the coastal deltaic environment from Mid-Tertiary to Quaternary (Bunopas, 1976).

(3) Quaternary Geology of the Central Plain

Quaternary geology of the Central Plain has been studied by several geologists since 1950's. Brown-Buravas et al. (1951) described three types of deposits, namely, terrace deposit, alluvium and laterite. The age of these deposits was determined mainly based on mammal fossils.

Alekseev and Takaya (1967) made the first attempt in establishing an Upper Cenozoic Stratigraphy based on the morphological expression of the deposits and fauna. As mentioned earlier, Takaya (1968) classified the Quaternary deposits in the Central Plain into four different terraces and into low-level and high-level peneplains.

Thiramongkol (1983) and Dheeradilok et al. (1983) summarized the Quaternary researches in Thailand. In 1984, Nutalaya et al. studied the surface deposits by collection and analysis of soil samples. They clarified the distribution of the content of sand, silt and clay and discussed the age of deposition and its environment.

As shown above, Quaternary geology of the Central Plain has been studied mainly from the geomorphological, paleontological and pedological points of view. The present study intends to clarify the Quaternary geology in terms of the history and the environment of sediments by means of core boring, analysis of micro-fossils, etc. Results are presented in Chapter 3 of this report.

2.1.5 Aquifer System

(1) Hydrogeologic Basement

Gneiss, sandstone, quartzite, granitic rocks, limestone of Pre-Cambrian to Cretaceous age are distributed in the periphery of the Lower Central Plain and constitute an impermeable basement. As mentioned earlier, the basement underlies the plain which is filled with clastic sediments from Tertiary to Quaternary age.

According to a previous study (Nutalaya and Rau, 1981), the top of the basement is undulated, narrow, deep and trending in the north-south direction in the area between Chao Phraya River and Tha Chin River. Details are discussed in Chapter 3.

(2) Aquifer Unit

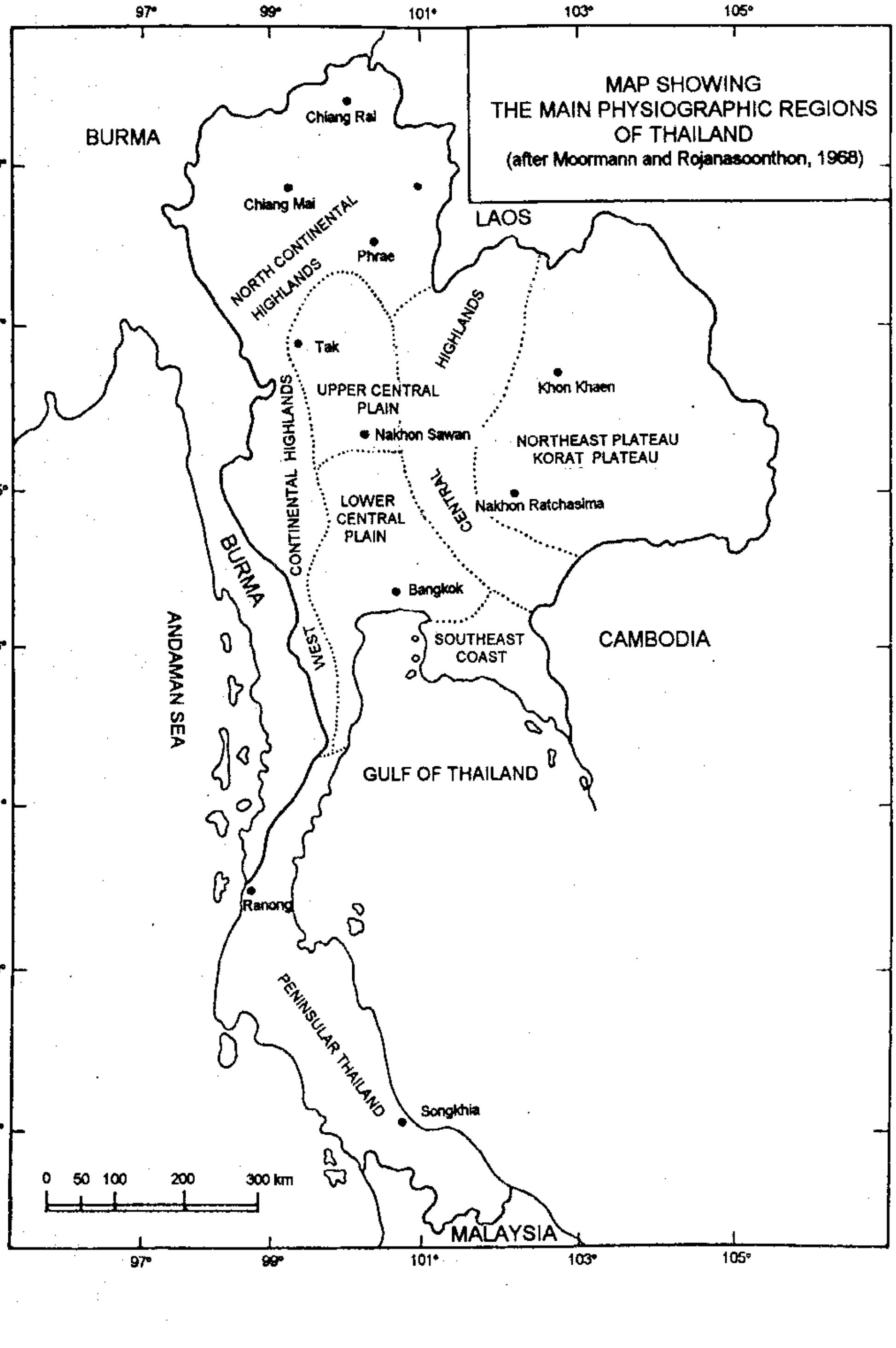
The ground surface of Bangkok is entirely underlain by blue to grey marine clay, 15 m to 30 m in thickness, known as the Bangkok Clay (Muktabhant et al., 1966). Unconsolidated and semi-consolidated sediments overlying the basement have a total thickness of about 400 m to more than 1,800 m. From a detailed study of logs of groundwater wells, the DMR identified and named eight (8) aquifers within 550 m depth (Table 2.1.1). These aquifers consist mainly of sand and gravel separated by clay beds (Figure 2.1.16).

The water in the first aquifer (Bangkok Aquifer, BK, 50 m zone) is not potable due to high salinity. The second aquifer (Phra Pradaeng Aquifer, PD, 100 m zone), the third aquifer (Nakhon Luang Aquifer, NL, 150 m zone) and fourth aquifer (Nonthaburi Aquifer, NB, 200 m zone) are very productive. Most wells in Bangkok pump water from these three (3) aquifers. The fifth aquifer (Sam Khok Aquifer, SK, 300 m zone) and the sixth aquifer (Phaya Thai Aquifer, PT, 350 m zone) are increasingly being developed in Pathum Thani Province northwest of Bangkok. The seventh aquifer (Thon Buri Aquifer, TB, 450 m zone) and the eighth aquifer (Pak Nam Aquifer, PN, 550 m zone) are used for industrial purposes in areas south and southwest of Bangkok where there is no alternative overlying potential aquifers. They are, however, too deep for domestic wells (Ramnarong & Buapeng, 1991).

Table 2.1.1 STRATIGRAPHIC SECTIONS OF BANGKOK AND ADJACENT AREAS AND THEIR WATER-BEARING PROPERTIES

AGE	AQUIFER	Thickness (meters)	Lithology	Water-bearing Properties
LATE - PLEISTOCENE TO RECENT	1 BANGKOK (50-m zone)	± 50	Topmost clay is generally dark gray to black, limonitic lateritic in the upper portion. Coarse sand, gravel and pebble are subangular to rounded, moderately to well sorted; composed mostly of various types of fragments.	Yields considerable quantity of water of poor quality, brackish to salty and highly mineralized. Normally not developed for ground water resource.
LATE - PLEISTOCENE TO RECENT	2 PHRA PRADAENG (100-m zone)	± 50	Separated from the Bangkok aquifer by a dark stiff clay bed. Gravel-sand is characteristically white to pale gray, subrounded to rounded, fairly well sorted; composed mostly of quartz, chert and other rock fragments; with carbonised woods and peats at the lower part. Clay lenses interbed in places.	Yields water of good quality only in the south and southwest of Bangkok; in other areas the aquifer yields brackish to salty water.
LOWER TO MIDDLE PLEISTOCENE ?	3 NAKHON LUANG (150-m zone)	± 50	Overlied by thick and hard clay bed. Sand-gravel layers which form the aquifer are rather thick (10-15 m). Fragments; mostly quartz, feldspar and quartzite; are subangular to subrounded, moderately to well sorted. Interbedding clays are whitish to yellowish to grayish brown, sandy and limonitic, non-plastic.	Has been heavily developed for public water supply. Yields 100-250 m^3/hr of water of exellent quality. Only in the south and southwest of Bangkok wells yield salty water due to salt water intrusion into the aquifer.
LOWER TO MIDDLE PLEISTOCENE ?	4 NONTHABURI (200-m zone)	± 50	General characteristics of the formation are the same as the Nakhon Luang aquifer. It is consisted of rather uniform thick sands and gravels with minor sandy clay lenses. The formation can be divided into three units separated by leaky clay layers.	It is one of the most productive aquifers which yield up to 200 m^3/hr of water of exellent quality. The water has been extensively used for bottled drinking water and brewerage as well as domestic supplies.
LOWER TO MIDDLE PLEISTOCENE ?	5 SAM KHOK (300-m zone)	± 100	The formation is consisted of sand, gravel and clay. Sand-gravel is yellowish brown to dirty brown, but may grade to white color, medium to very coarse grained, angular to sub-rounded, fairly well sorted, feldsparthic, calcareous due to limestone fragments in places; with interlayering clays. Both sand-gravel and clay beds are moderately to highly compacted.	Yields slightly less than those of the Nakhon Luang and Nonthaburi aquifers. Normally pennetrated by production wells in Northern Bangkok since shallower aquifers yield water of higher iron content.
LOWER TO MIDDLE PLEISTOCENE ?	6 PHAYA THAI (350-m zone)	± 50	Consisted of sand gravel and clay. Sand and gravel are dirty brown, angular, sizes ranged from medium sand to gravel size, poorly to fairly well sorted; quartz and chert being major composition. Clay is brown to dark brown, compact, calcareous and lateritic.	Wells drilled in Central and Southern Bangkok yield brackish to salty water while those in Northern Bangkok produce fresh water. The aquifer is generally not popular due to its greater depth.
LOWER TO MIDDLE PLEISTOCENE ?	7 THON BURI (450-m zone)	± 100	Separated from the upper formation by hard and compact clay. Sand and gravel beds are usually alternated layering with clay beds. Color is generally gray to brownish gray to occasional white sand layers.	No production wells ever constructed, but the packer tests of several test holes indicate that the water is fresh to slightly brackish or mineralized in places. The aquifer is not so productive as the above aquifers due to the presence of clay in many horizons.
PLIOCENE (?)	8 PAK NAM (550-m zone)	± 100	Separated from the upper formation by a leaky clay to sandy clay layer. Sand and gravel beds, generally thicker than that of the Thon Buri aquifer, are white to gray and well sorted. The clay is generally very compact, olive gray to dark gray, with carbonaceous matters.	The aquifer is very permeable and yield a considerable quantity of water of good quality. Water temperature is as high as 43°c It is, however, too deep to reach by domestic wells, except in areas where there is no alternative potential aquifer; i.e. the Southern Bangkok.

Note : Detail stratigraphic sections of Bangkok and adjacent areas and their water-bearing properties is after Chiamthaisong, 1980.



modified Thiramongkol, 1983

Figure 2.1.1	**MAIN PHYSIOGRAPHIC REGIONS OF THAILAND**
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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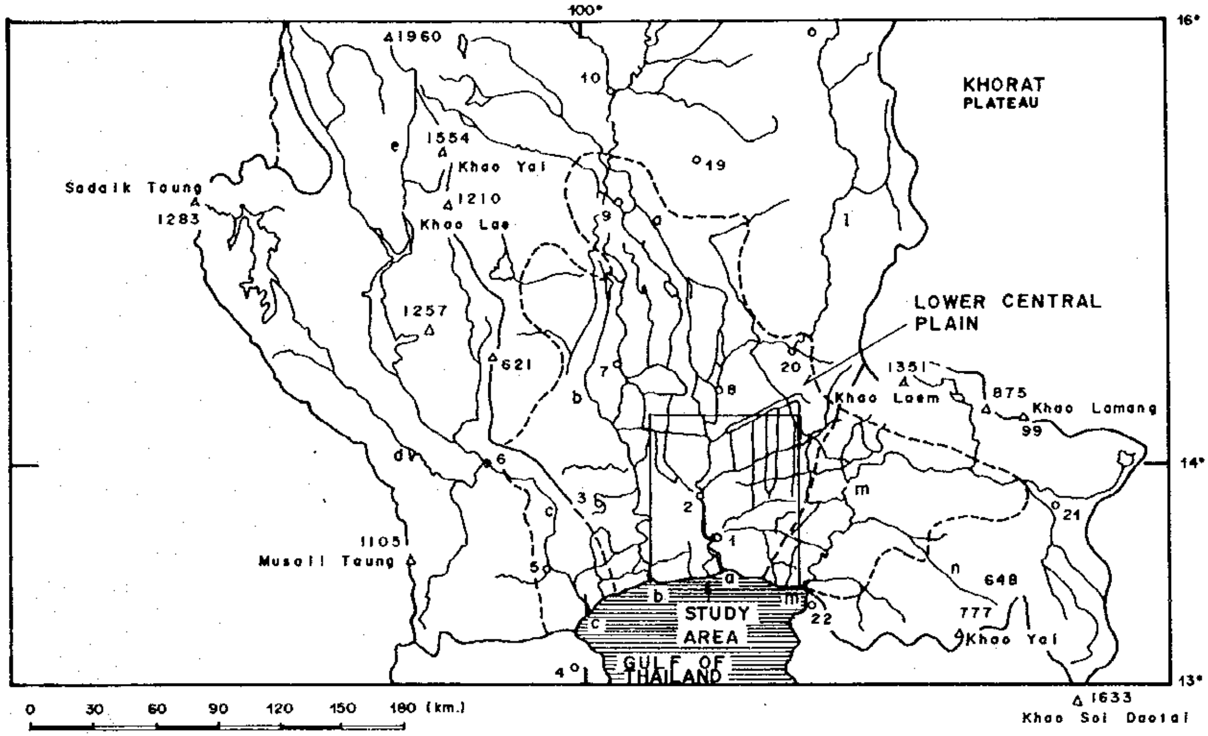

CITY				RIVER			
1.	BANGKOK	12.	CHIANG MAI	a.	MAE NAM CHAO PHRAYA	l.	MAE NAM PA SAK
2.	NONTABRI	13.	CHIANG RAI	b.	MAE NAM THA CHIN	m.	MAE NAM BANG PAKONG
3.	NAKHON PATHON	14.	LAMPANG	c.	MAE NAM MAE KLONG	n.	MAE NAM KHLPING SI YOT
4.	PHETEHABURI	15.	PHRAE	d.	MAE NAM KHWAE NOI		
5.	RATCHABURI	16.	NAM	e.	MAE NAM HUAI KHA KHAENG		
6.	KANCHANA BURI	17.	PHITSANULOK	f.	MAE NAM PING		
7.	SUPHAN BURI	18.	NONG PHAI	g.	MAE NAM WANG		
8.	AYUTTHAYA	19.	TAK FA	h.	MAE NAM YOM		
9.	CHAI NAT	20.	SARABUKI	i.	MAE NAM NAN		
10.	NAKHON SAWAN	21.	SA KAEO	j.	MAE NAM KHWAE NOI		
11.	BAN TAK	22.	CHON BURI	k.	MAE NAM WANG THONG		

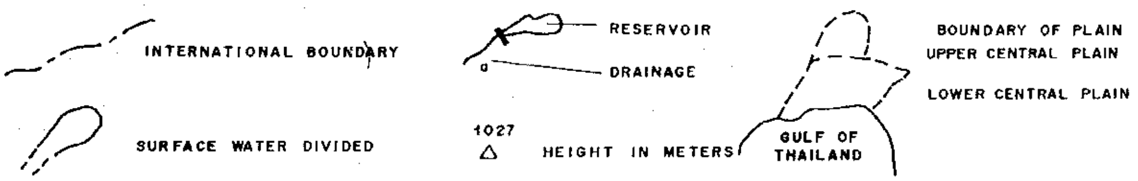

Figure 2.1.2	DRAINAGE OF THE CHAO PHRAYA RIVER
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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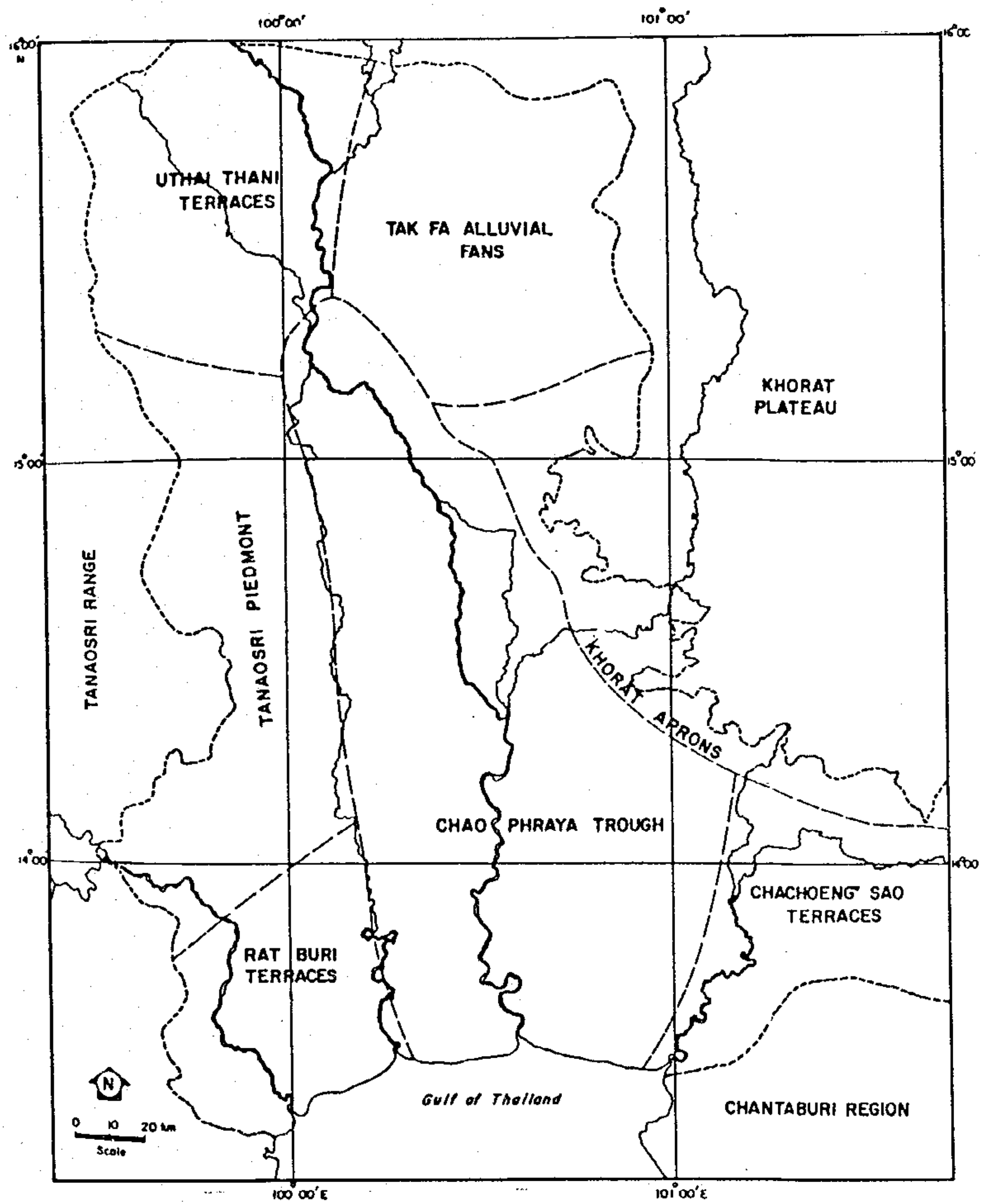

after AIT, 1978

Figure 2.1.3	SUBDIVISIONS OF GEOMORPHIC ZONES OF THE LOWER CENTRAL PLAIN OF THAILAND
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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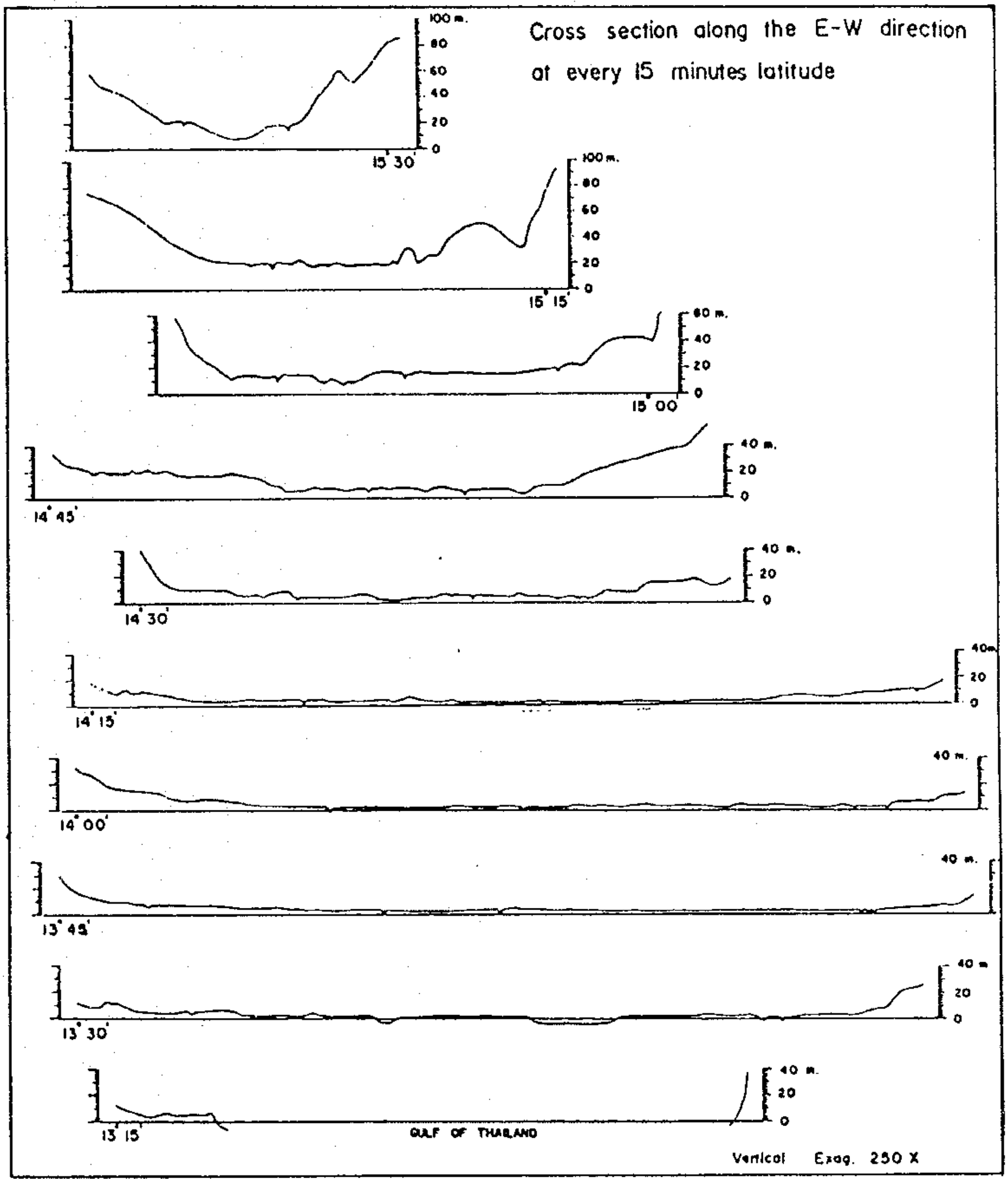

after Supajanya, 1983

Figure 2.1.4	CROSS SECTION ALONG THE E-W DIRECTION AT EVERY 15 MINUTES LATITUDE ACROSS THE LOWER CENTRAL PLAIN
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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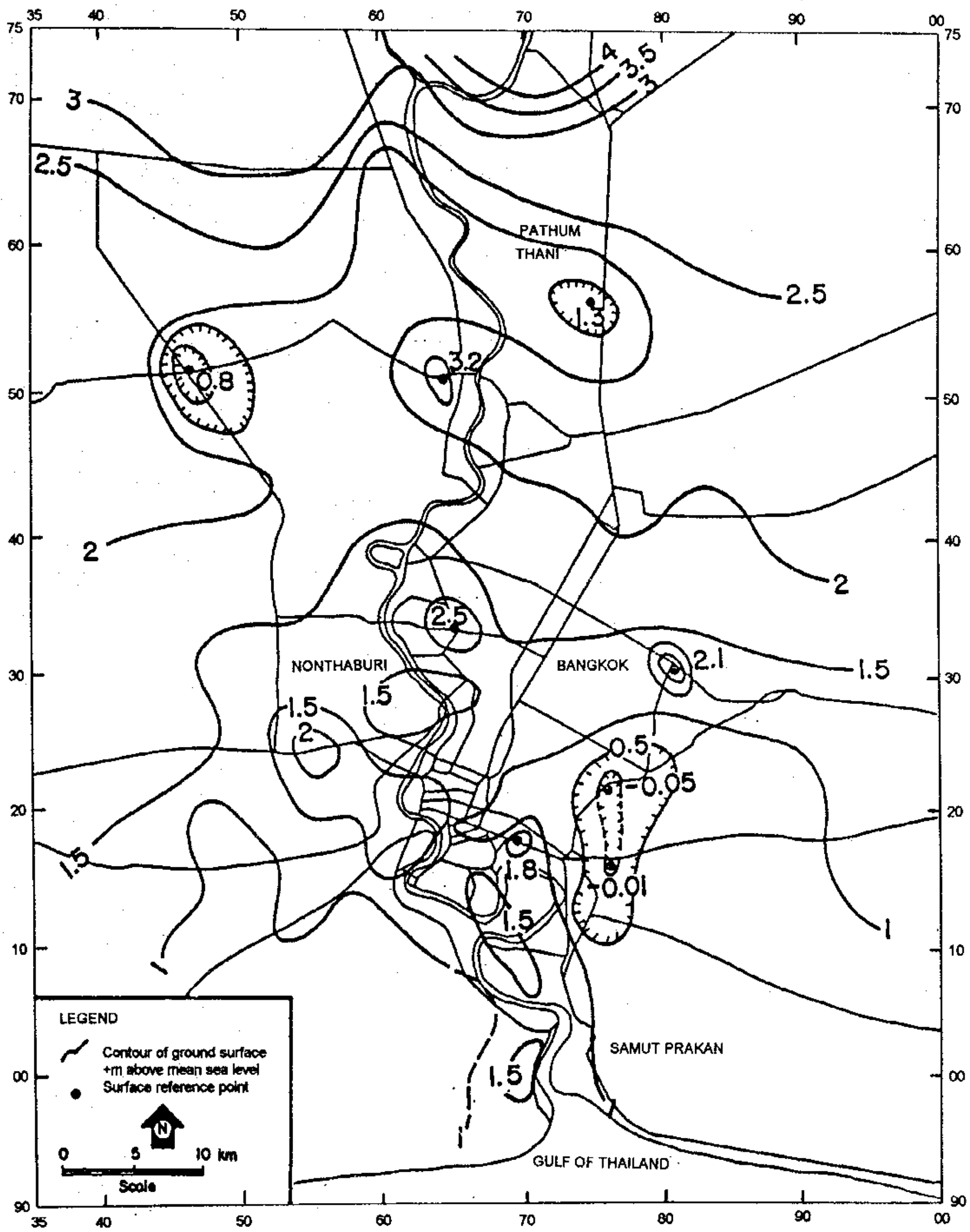

after Nutalaya, 1989

Figure 2.1.5	**GROUND ELEVATION OF BANGKOK IN 1987**
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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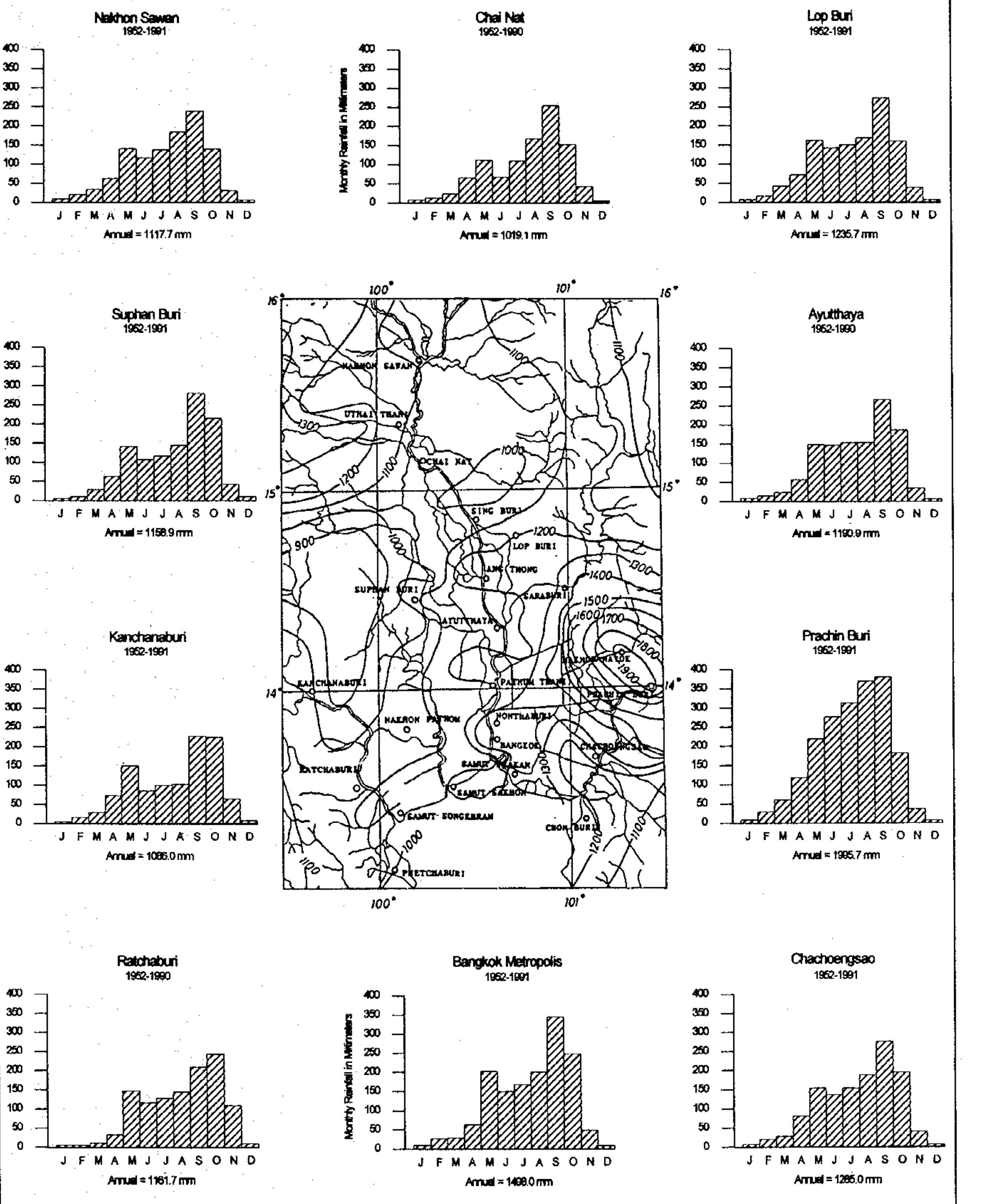

Figure 2.1.6	MEAN ANNUAL RAINFALL AND MEAN MONTHLY DISTRIBUTION OF RAINFALL IN THE LOWER CENTRAL PLAIN
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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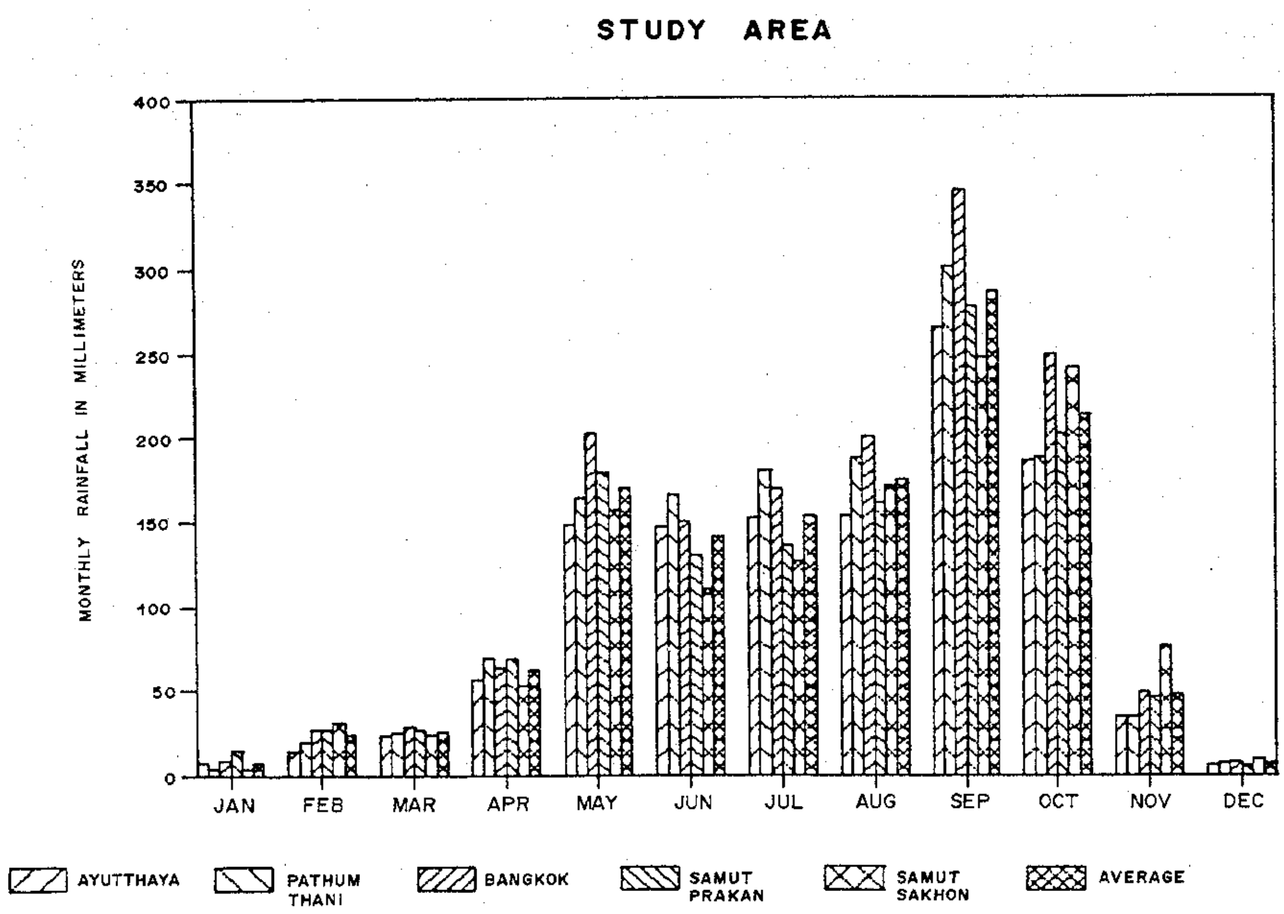

Figure 2.1.7	MONTHLY RAINFALL DISTRIBUTION IN THE STUDY AREA
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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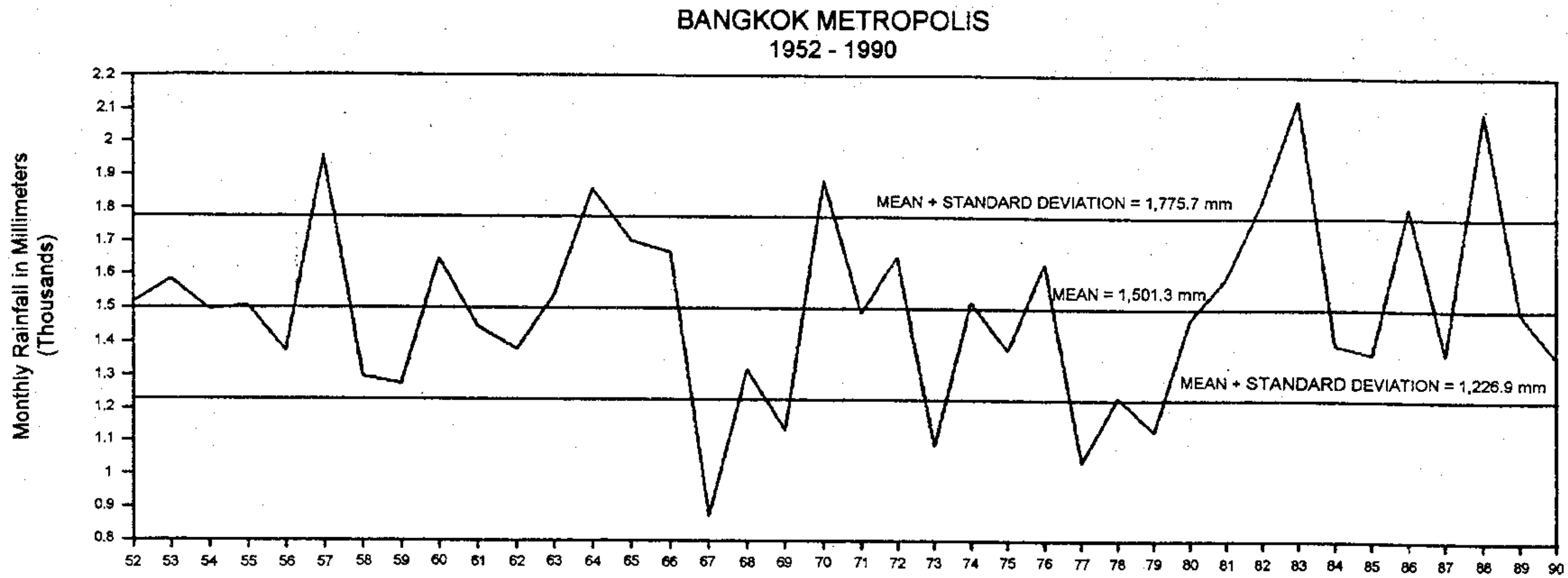

after Takaya, 1968

Figure 2.1.8	VARIABILITY OF ANNUAL RAINFALL IN THE STUDY AREA
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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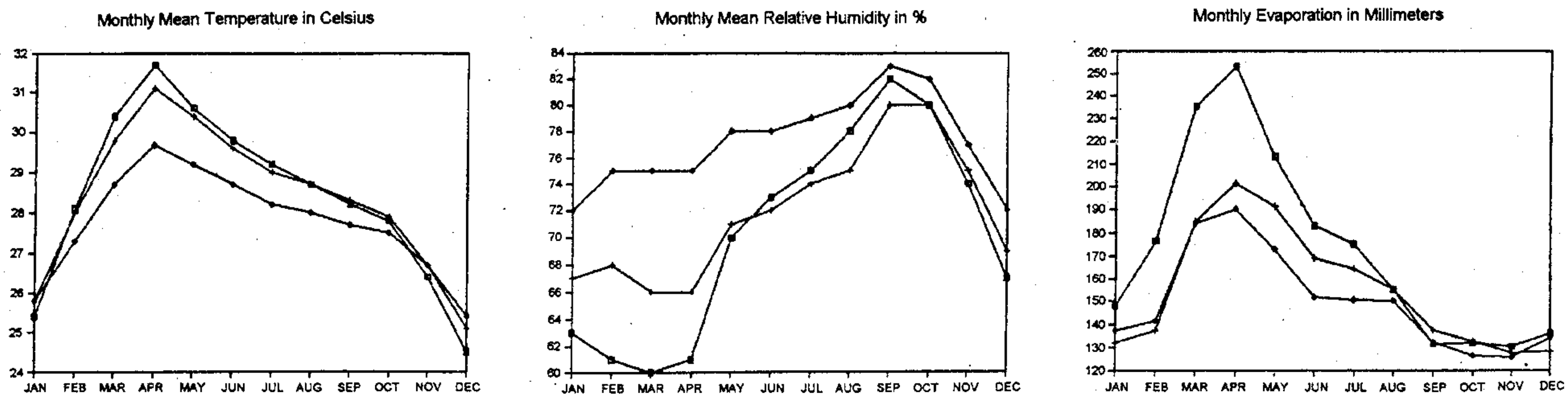
STATION NAME	PERIOD OF RECORD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Monthly Temperature in Celcius														
Nakhon Sawan	1952-1991	25.4	28.1	30.4	31.7	30.6	29.8	29.2	28.7	28.2	27.8	26.4	24.5	28.4
Suphan Buri	1952-1991	25.8	28.0	29.8	31.1	30.4	29.6	29.0	28.7	28.3	27.9	26.7	25.1	28.0
Bangkok Metropolis	1952-1991	25.8	27.3	28.7	29.7	29.2	28.7	28.2	28.0	27.7	27.5	26.7	25.4	28.0
Monthly Relative Humidity (%)														
Nakhon Sawan	1952-1991	63.0	61.0	60.0	61.0	70.0	73.0	75.0	78.0	82.0	80.0	74.0	67.0	70.0
Suphan Buri	1952-1991	67.0	68.0	66.0	66.0	71.0	72.0	74.0	75.0	80.0	80.0	75.0	69.0	72.0
Bangkok Metropolis	1952-1991	72.0	75.0	75.0	75.0	78.0	78.0	79.0	80.0	83.0	82.0	77.0	72.0	77.0
Monthly Evaporation in Millimeters														
Nakhon Sawan	1970-1991	148.1	176.4	235.3	253.1	213.1	183.2	175.0	155.4	131.7	132.1	130.5	136.3	2070.2
Suphan Buri	1963-1991	132.3	137.5	184.8	201.5	191.3	169.0	164.3	155.5	137.8	132.8	127.8	128.5	1863.1
Bangkok Metropolis	1961-1991	137.7	141.8	184.1	190.2	172.9	152.0	150.8	150.6	132.5	126.7	126.0	134.5	1799.8



□ NAKHON SAWAN + SUPHAN BURI ◇ BANGKOK

Figure 2.1.9	MEAN MONTHLY DISTRIBUTION OF TEMPERATURE, RELATIVE HUMIDITY AND EVAPORATION IN THE LOWER CENTRAL PLAIN
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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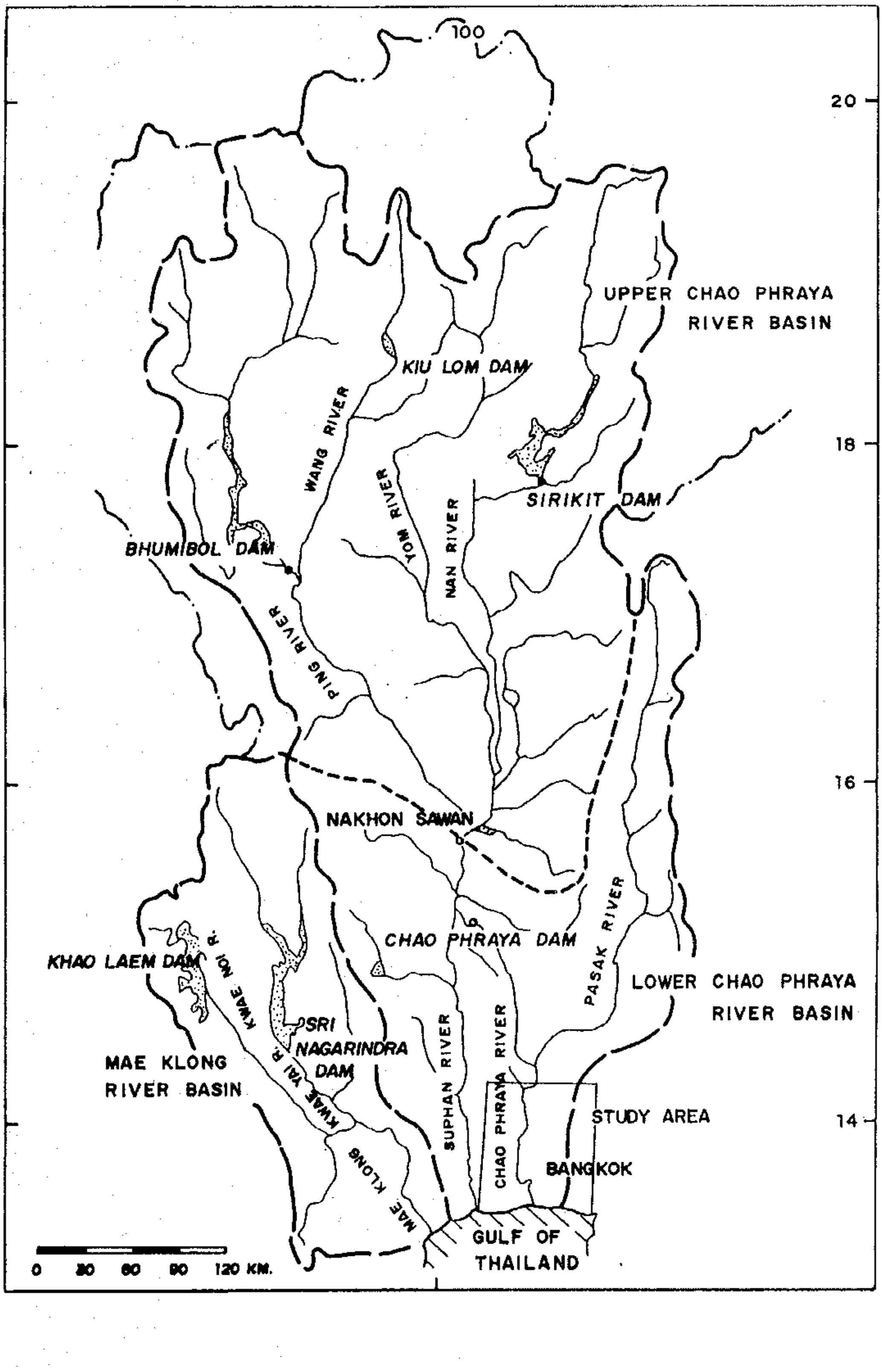

Figure 2.1.10	THE CHAO PHRAYA RIVER BASIN AND THE MAE KLONG RIVER BASIN
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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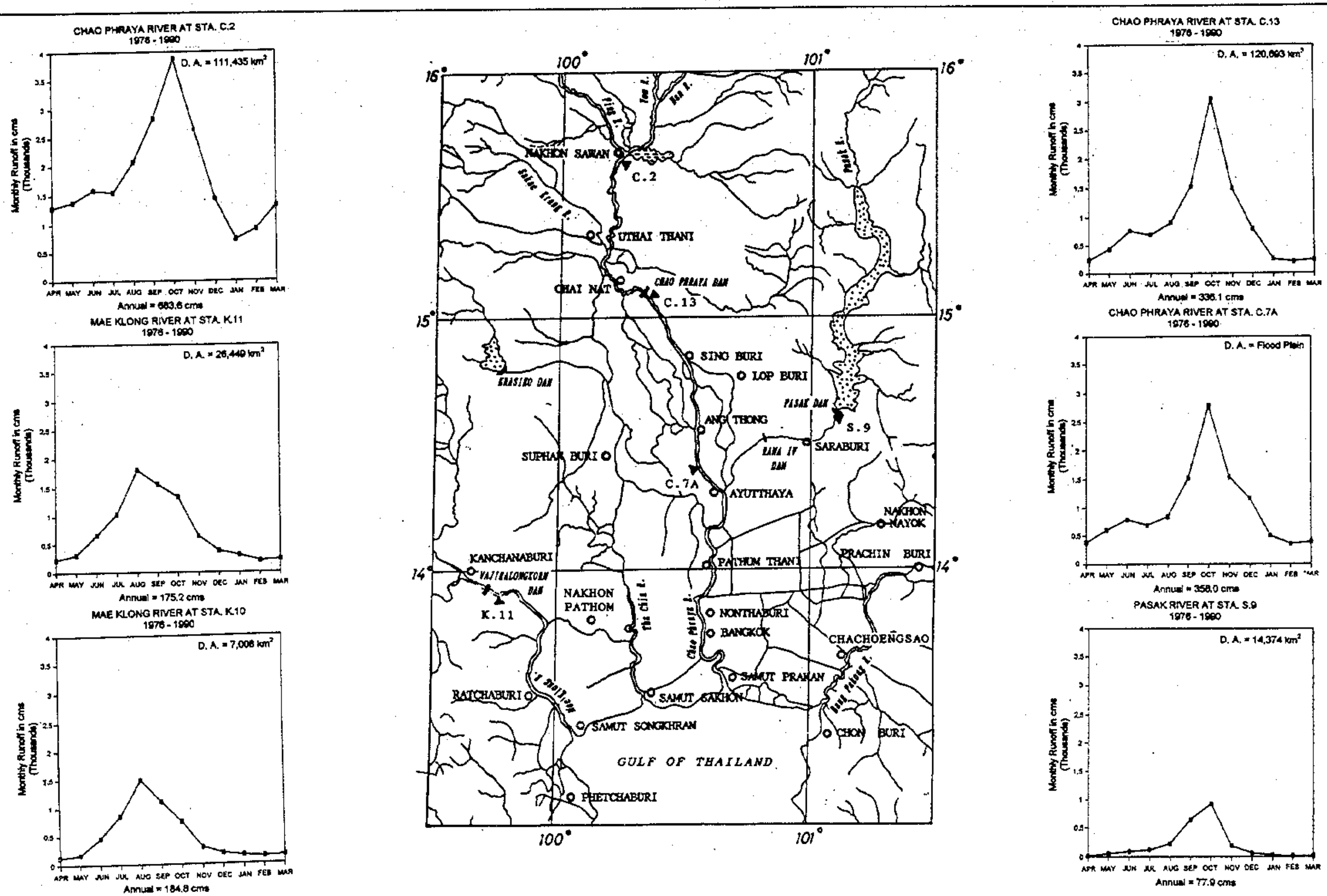

Figure 2.1.11	MEAN MONTHLY DISTRIBUTION OF RUNOFF OF THE CHAO PRAYA, PASAK AND MAE KLONG RIVERS

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

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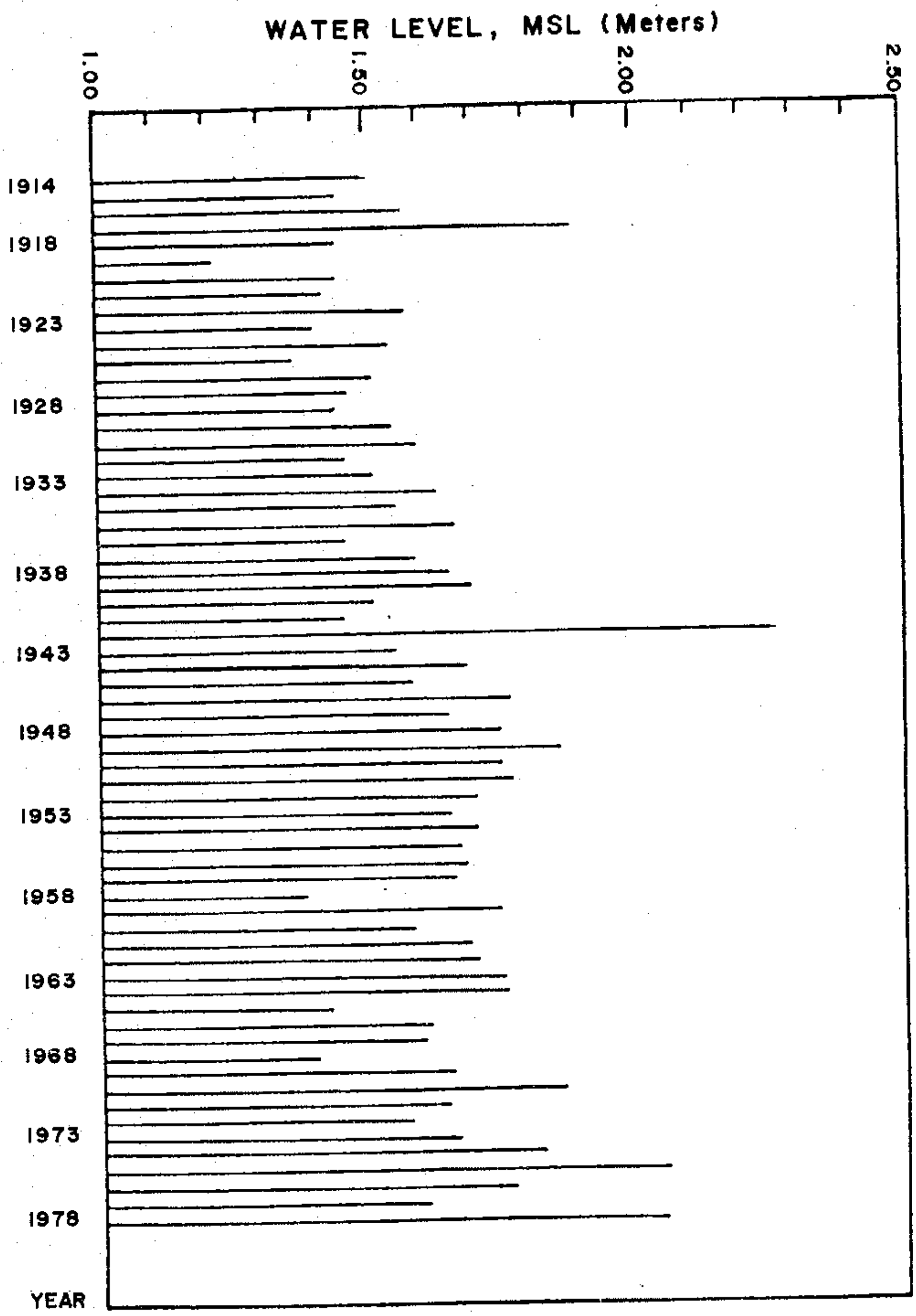

Ten Cate, 1983

Figure 2.1.12	MAXIMUM WATER LEVEL OF THE CHAO PHRAYA RIVER MEASURED AT MEMORIAL BRIDGE IN THE STUDY AREA
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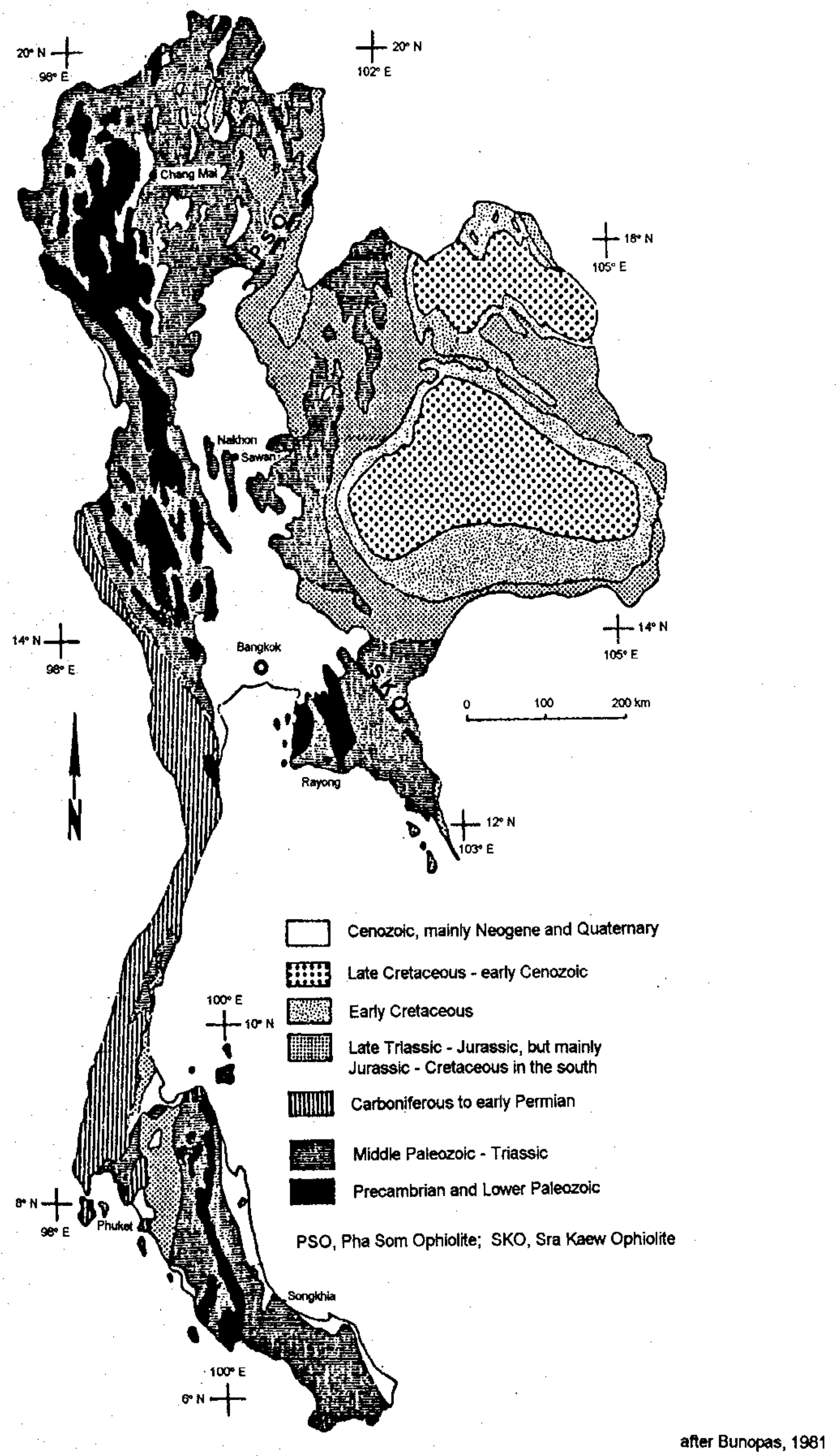

after Bunopas, 1981

Figure 2.1.13	SIMPLIFIED GEOLOGIC MAP OF THAILAND
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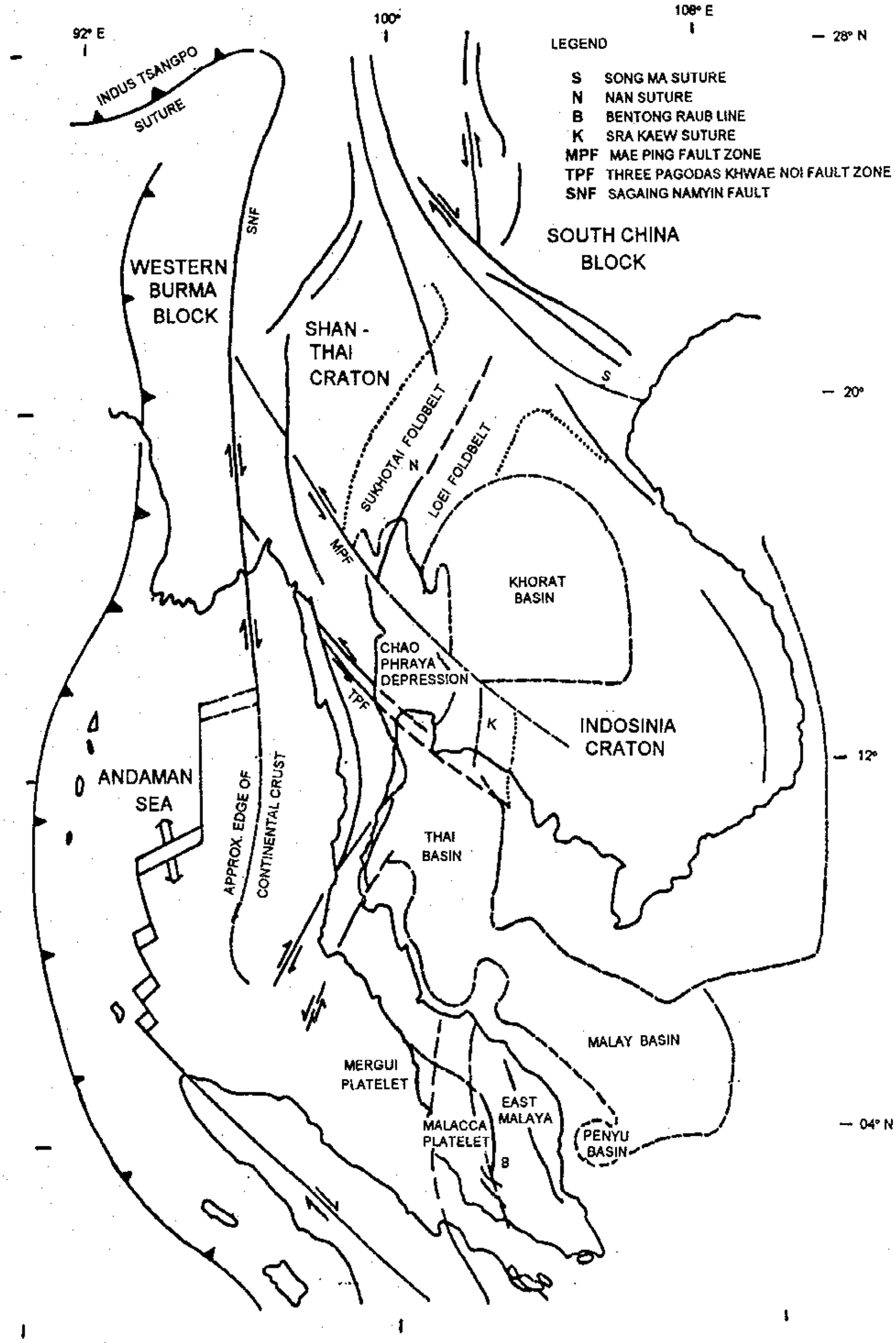

after Bunopas & Vella, 1983

Figure 2.1.14	**MAJOR TECTONIC FEATURES OF CONTINENTAL SOUTHEAST ASIA**

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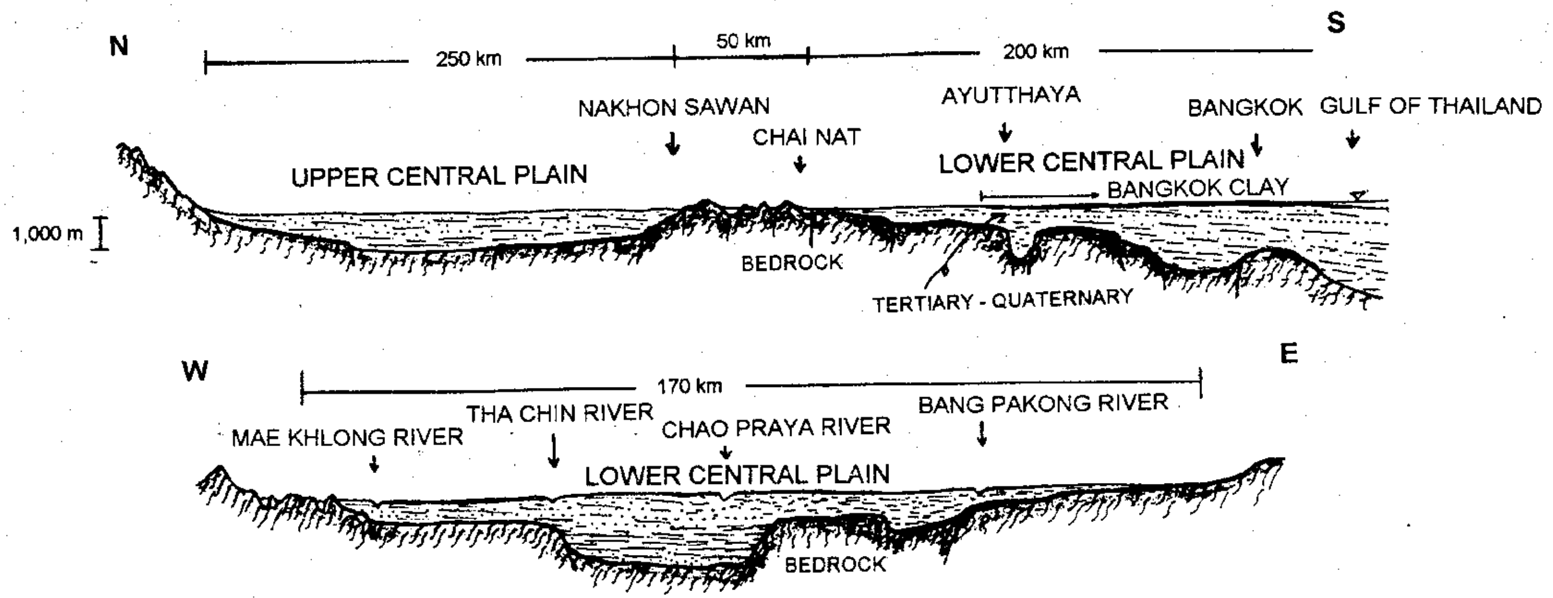

modified Nutalaya & Rau, 1981

Figure 2.1.15	SCHEMATIC PROFILES OF THE CENTRAL PLAIN
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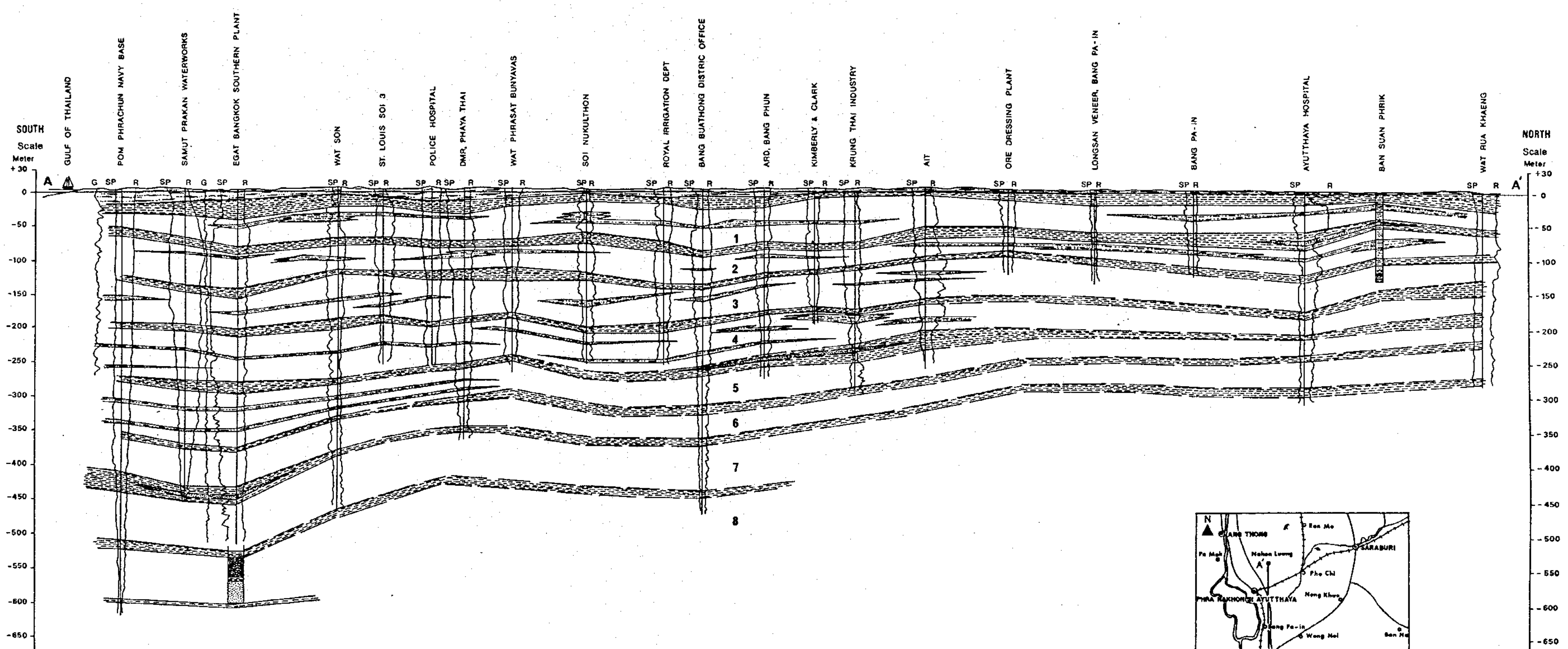


SP R

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

G

Gamma ray log (G)

Drilled log

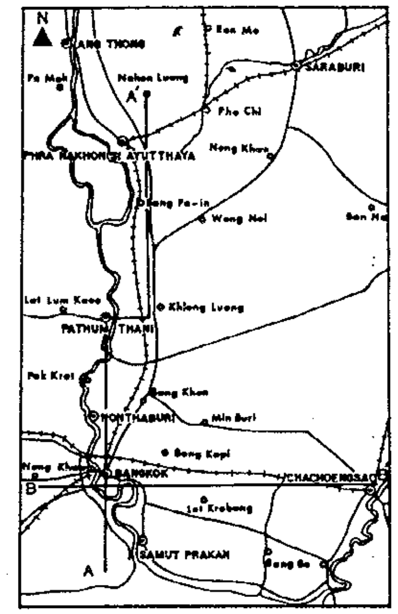
Top Clay: dark gray to black, very soft, known as "Bangkok soft clay"

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.



INDEX MAP SHOWING PROFILE-LINE

Scale 1:1,000,000

A——A' Profile-line
• Amphoe (district)
● Changwat (province)

DMR, 1979

Figure 2.1.16	HYDROGEOLOGICAL NORTH-SOUTH PROFILE OF THE LOWER CHAO PHRAYA BASIN
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