2.2 Socio-Economy

2.2.1 National Development Policy

(1) Economic Development in Thailand

Economic growth in Thailand over the past decade has been one of the highest and steadiest of the developing countries.

Between 1960 and 1980, the average rate of real gross domestic product (GDP) growth was above 7 percent annually. Dividing the period from 1960 to 1985 into five-year intervals, the economic growth was lowest during the periods of the two oil shocks: 1970-75 and 1980-85. The impact of the oil shock was cushioned by a boom in commodity prices during the same period. This helped increase farm income and reduced poverty in rural areas. However, after the second oil shock, all the main agricultural commodities of the Kingdom suffered from price reductions. While Thailand still maintained a satisfactory growth rate, the impact on agricultural income was severe. After 1986, the economy began a period of very rapid growth, which was driven by increases in the manufacture of exports, capital inflows, as well as tourism. Growth in GDP reached 13.2 percent in 1988, falling to 10 percent in 1990. The growth in GDP during the last three (3) years has been remarkable, averaging over 10 percent per annum (see Table 2.2.1).

Thailand is presently experiencing a rapid transformation from an agrarian society to an industrialized one.

(2) Seventh National Economic and Social Development Plan (1992-1996)

The formulation of the Seventh Plan was intended to be a consensus-building exercise which relied on the cooperative effort of all sectors that included not only government agencies, state enterprises and universities but also private sector and non-governmental organizations. With a broad-based participation, the substance of the Seventh Plan reflects a liberalization process in many aspects. It encourages the revision of existing legislations and the formulation of new laws and regulations for the conservation of natural resources and the protection of the environment.

The three (3) main development objectives of the Seventh Plan as set out are as follows:

1. Maintain economic growth rates at appropriate levels to ensure sustainability and stability.
2. Redistribute income and decentralize development to the regions and rural areas more widely.
3. Accelerate the development of human resources and upgrade the quality of life and management of environment and natural resources.

Table 2.2.2 shows the major development targets of the Seventh Plan as compared with the outcomes of the Sixth Plan. In the Seventh Plan, the economic growth for the period from 1992 to 1996 is expected to be 8.2 percent per year at constant prices, which will be distributed as follows: 3.4% for agriculture, 9.5% for industry, 8.9% for construction, and 8.1% for services and others.

The investment of the public sector, however, is expected to achieve a growth rate of 8.5 percent per annum as compared with the 6.5 percent per annum for the Sixth Plan. Furthermore, the Seventh Plan is designed to maintain a low 1.2 percent per annum population growth rate and also a low 0.5 percent per annum unemployment rate.

The commencement of the Seventh Plan is a promising move towards more sustainable development, i.e., by keeping a balance between growth and income distribution, between industrialization and protection of environmental quality, and between urbanization and support for the rural population.

2.2.2 Economic Structure

(1) General

During the Sixth Plan period from 1986 to 1991, the Thai economic growth has skyrocketed with the gross domestic product (GDP) expanding at an average of 10.5 percent per year, which is twice the Plan's target; and it represented the highest average growth rate in the past 25 years. The economic structure has become more outward-oriented and internationalized, as indicated by the increase in the proportion of international trade to GDP, from 60 percent in 1986 to 80 percent by 1991.

The key factors that brought high economic growth rates were the increase in exports, investments and tourism; all of which had gone up considerably faster than the projected rates.

On the macroeconomic level, cautious fiscal and monetary policies, together with political stability were also instrumental in boosting business confidence, propelling Thai economy to grow and making Thailand the fastest-growing economy in the world during the past (5) five years.

Although the high economic growth has had significant beneficial effects on the overall economy, the pattern of growth has led to several structural imbalances, which may become long-term development issues for the country, such as:

- Income disparities among households of different socio-economic status and between rural and urban areas: regional disparities have been on the rise as Bangkok Metropolis and its surrounding provinces continue to play a dominant role and have rapid economic growth rates. In 1981, Bangkok contributed about 42 percent to GDP. By 1989, this share increased to 48 percent, while the shares of most of the other regions had actually declined. During the same period, for instance, the share of the Northeastern Region declined from 14.7 percent to 12.9 percent, the Northern Region from 13.5 percent to 11.4 percent and the Southern Region from 10 percent to 9 percent.

- Infrastructure bottlenecks: virtually all types of basic infrastructure services are inadequate to meet the strong demands resulting from the rapidly growing economy. The policy to promote private sector provision of infrastructure services has not been implemented in an effective and timely manner, impeding both current and future development efforts.

(2) Gross National Product (GNP) and Gross Domestic Product (GDP)

In 1990, Thailand's GDP and GNP amounted to about 2,051,208 million bahts and 2,030,064 million bahts at current market prices, respectively, while the per capita GNP was about 36,032 bahts (see Table 2.2.3). In the same year, the contribution of each economic sector to the GDP was 26.10% for the manufacturing/industrial sector, 15.25% for the wholesale and retail trade, 13.58% for the services sector and 12.41% for the agricultural sector. Their contributions came to about 1,381,287 million bahts which corresponded to 67.34% of the GDP (see Table 2.2.4).

In recent years, Thailand's economy showed a high growth rate brought by the increases in the production of upland crops other than rice, the development of light manufacturing industries, the growth of the export sector, the growth of investments, etc. From 1986 to 1990, the annual growth rate of Thailand's economy averaged 11.29% for GDP and GNP and 9.54% for per capita GNP (see Tables 2.2.5 and 2.2.6).

Located in the lower reaches of the Chao Phraya River, the Bangkok Metropolitan Area and its Vicinity (or BMA) and the Central Region have served as the core of Thailand's economy and have contributed one half of the country's GDP. Of the 557,960 million bahts in 1986, for example, 509,033 million bahts were contributed by the BMA and 48,927 million bahts by the Central Region. From 1986 to 1988, the annual growth rates of the BMA at 21.8% and the Central Region at 15.2% averaged 18.5% which was more than the country's 17.3% average annual growth rate of the gross regional product (GRP) (see Table 2.2.7).

In 1986, however, the per capita GRP was about 61,544 bahts in the BMA and about 18,724 bahts in the Central Region. This per capita GRP in the BMA was three (3) times the national average. Compared with the 15.3% national average for the per capita GRP in the 1986-1988 period, the yearly growth rates for the BMA averaged 18.9% and for the Central Region 14.2% (see Table 2.2.8).

Tables 2.2.9 and 2.2.10 indicate the gross provincial product (GPP) and the per capita GPP of the provinces in the Study Area. The Study Area's GPP in 1988 amounted to about 785,886 million bahts which corresponded to 52.1% of the Kingdom's GDP (1,506,977 million bahts). The GPP of Bangkok Metropolis in the same year amounted to 609,924 million bahts which was 77.6% of the Study Area's GPP or 40.5% of the Kingdom's GDP. The 21.4% average growth rate of the Study Area's GPP for the 1986-1988 period was greater than the average growth rate of the country's GDP.

In the same period, the three (3) provinces of Nonthaburi, Samut Prakan and Samut Sakhon in the Study Area achieved a fairly high growth rate in GPP at 24.3%, 28.4% and 20.8% per annum, respectively (see Table 2.2.9).

The Study Area's average per capita GPP in 1988 was estimated at about 50,642 bahts or 1.8 times more than the country's average. At the province level, Bangkok, Samut Prakan, Pathum Thani and Samut Sakhon showed high per capita GPP of 104,475 bahts, 92,555 bahts, 60,931 bahts and 48,224 bahts, respectively (see Table 2.2.10).

(3) Government Budget

The economy of Thailand grew very rapidly at an average rate of 10.5 percent per year, and the government revenue collection had been significantly higher than estimated, having a 15.1% (in 1986) to 19.7% (in 1990) increase in GDP. On the contrary, the public finance of Thailand during the past two (2) decades was yearly in the red. However, this financial deficit had decreased since 1987. In the 1988-1990 period, the revenue grew higher than expenditure as shown in Table 2.2.11.

In 1990, the public revenue was 394,514 million bahts against a public expenditure of 336,508 million bahts, yielding a profit of 58,006 million bahts (see Table 2.2.12).

Eighty eight percent (88%) of the total revenue, amounting to 348,591 million bahts, came from taxes and duties.

Among the 1990 expenditures, the debt service payment was the largest at 69,574 million bahts. Other expenditures in the order of amounts were 68,966 million bahts for economic services, 59,962 million bahts for education, 54,759 million bahts for defense, 42,507 million bahts for public health and utilities, and 14,889 million bahts for internal security.

(4) Household Income

Based on the NSO data, the average monthly income per household in the country was 5,621 Bahts in 1990. By region, Bangkok Metropolis was reported to have the highest household income of 11,344 bahts per month. Next was the Central Region with 6,060 bahts, followed by the Southern Region with 5,023 bahts and the Northern Region with 4,553 bahts. The Northeastern Region had the lowest average monthly income of 3,563 bahts.

Thailand's average household income has increased by 66.4 percent from 1981 to 1990. Among the regions, the BMA had the highest rate of increase at 91.9%, followed by the Central Region at 65.3%, the Northern Region at 57.8%, the Southern Region at 54.3%, and the Northeastern Region at 41.8%.

Table 2.2.13 shows the average monthly income per household and the rate of increase by region.

2.2.3 Population and Household

(1) Population

The population estimates presented in this Chapter were obtained from the National Statistical Office (NSO) and the Department of Local Administration under the Ministry of Interior.

Thailand's population census is conducted every 10 years since 1960. The population was 26.258 million in 1960, 34.397 million in 1970 and 44.825 million in 1980. The NSO data shows the 1990 population at 56.303 million (see Table 2.2.14).

Like other developing countries, Thailand went through a period of high population growth. Between 1960 and 1970, an annual growth rate of 2.74% was observed. With intensive family planning campaigns, the population growth rate was reduced to 2.68% between 1970 and 1980 and to 2.31% between 1980 and 1990 (see Table 2.2.14).

By region, Bangkok Metropolis had a remarkable growth rate of 3.72% in the 1960-1970 period and 4.32% in the 1970-1980 period. This was mainly due to the increase in migrants from rural areas and the high birth rate. This growth rate had gradually decreased in the 1980-1990 period due to a lesser number of migrants, which probably resulted from the effects of rapid urbanization such as congestion and high cost of land.

Based on the data collected from the NSO and the Department of Local Administration, the 1991 population of the BMA was nearly 5.621 million which was about 68.6% of the Study Area's total population (see Table 2.2.17 and Figures 2.2.1 and 2.2.2), and the BMA's growth rate was 1.65% per annum during the 1980-1991 period. (See Table 2.2.15)

The Study Area's population had risen from 6.266 million in 1980 to 8.197 million in 1991 (see Table 2.2.16). From 1980 to 1991, the population growth rate averaged 2.47% per annum. In the same period, the Study Area's provinces of Nonthaburi, Pathum Thani, Samut Prakan and Samut Sakhon had shown high annual growth rates of 6.02%, 3.48%, 5.59% and 3.61%, respectively. These high growth rates were also caused by the increasing number of migrants from the rural areas (see Table 2.2.16).

The country's population density in 1991 was estimated at an average of 111 persons per square kilometer, and that of the Study Area was 1,289 persons per square kilometer.

Among the Study Area's provinces, Bangkok was the most densely populated at 3,583 persons/sq. km. It is followed by Nonthaburi at 1,130 persons/sq. km., Samut Prakan at 879 persons/sq. km. and Samut Sakhon at 706 persons/sq. km. (see Table 2.2.17).

(2) Household

The NSO data show that Thailand had about 11.719 million households in 1991 with an average size of 4.9 persons per household, while the Study Area had reached about 1.857 million households (about 15.85% of Thailand's total) with an average size of 4.4 persons per household.

The Study Area's provinces of Ayutthaya and Chachoengsao had an average size of over five persons per household, followed by Bangkok, Nonthaburi, Pathum Thani, Samut Prakan and Nakhon Pathom with about 4.3 persons per household. Samut Sakhon has the smallest size at 3.7 persons per household (see Table 2.2.17).

2.2.4 Infrastructure

(1) Transportation

Thailand's transportation network is characterized mainly by highways and roads. These highways and roads are classified into seven (7) categories: special highway, national highway, provincial highway, concession highway, rural road, municipal road and sanitary road. The first four (4) categories of highways are administered by the Department of Highways, while the remaining three (3) categories of roads are managed by the respective provincial administrative organizations through the Municipal Public Works.

Table 2.2.18 shows the yearly total lengths of national and provincial highways between 1985 and 1991. The total length of national highways increased by 2.76% from 15,218 km in 1985 to 17,920 km in 1991, while that of provincial highways by 4.98% from 21,017 km to 28,127 km in the same period. Hence the provincial highway has lengthened most among the four (4) categories of highways in the said period.

Railway network is less consolidated than the road network. As of 1982, the State Railway of Thailand was operating a total length of only 3,735 km of railway lines and had not been constructing any new lines since 1970.

The railway networks are radially constructed from Bangkok leading off to the north (to Chiang Mai), northeast (to Ayutthaya and other connecting lines), east (to Prachin Buri) and south (to Suhai Kolok) directions.

The inland water transportation serves a distance of about 3,000 km. Chao Phraya River's canal network is the Thailand's largest and the Study Area's original means of transportation. This canal network has been used in transporting gravel, cement, maize, etc. All year round navigation, however, is impossible due to changing canal water depths, and high costs are involved in dredging these canals.

(2) Electric Power Supply

Two (2) agencies are responsible for electric power supply in the Study Area: the Metropolitan Electric Authority (MEA) and the Provincial Electric Authority (PEA). Both agencies get their power supplies from the Electricity Generating Authority of Thailand (EGAT) and distribute electricity to their respective service areas. MEA serves Bangkok, Nonthaburi, Samut Prakan and some parts of Pathum Thani, while PEA is responsible for Nakhon Pathom, Samut Sakhon and the rest of Pathum Thani.

Table 2.2.19 illustrates that about 10,919,500 households or 89.3 percent of the country's total have electricity. Around 2,295,100 households or 98.6 percent of the municipal areas' total are using electricity. In non-municipal areas, households using electricity number around 8,624,400, which is 87.2 percent of its total number of households; only 12.8 percent are not served by electricity.

About 99.4% of the Bangkok Metropolis, 92.6% of the Central Region, 87.9% of the Northeastern Region, 85.7% of the Northern Region, and 84.4% of the Southern Region have electricity.

Table 2.2.1 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 2.2.2 MAJOR DEVELOPMENT TARGETS OF ECONOMIC AND SOCIAL DEVELOPMENT DURING THE SEVENTH PLAN (1992-1996)

	Sixth Plan (1987-1991)	Seventh Plan targets (1992-1996)
1. Economic growth (% per year at constant prices)	10.5	8.2
1.1 Agriculture sector	3.4	3.4
1.2 Non-agriculture sector	12.1	8.6
- Industry	13.7	9.5
- Construction	18.7	8.9
- Services and others	11.0	8.1
2. Per capita income (baht/year) 1/	41,000	71,000
3. Expenditures (% per year at constant prices)		
3.1 Private sector		
- Consumption	9.1	5.7
- Investment	26.0	8.8
3.2 Public sector		
- Consumption	2.0	3.3
- Investment	6.5	8.5
4. Export of goods		
4.1 Average (billion baht)	496.0	1,063.0
4.2 Aver. growth rate per year (%)	24.5	14.7
5. Import of goods		
5.1 Average value (billion baht)	664.3	1,358.0
5.2 Aver. growth rate per year (%)	32.6	11.4
6. Trade balance		
6.1 Average value	(168.0)	(313.0)
6.2 Trade balance/GDP (%)	(8.4)	(9.4)
7. Current account balance		
7.1 Average Value (billion baht)	(99.0)	(170.3)
7.2 Current account balance/GDP(%)	(4.9)	(5.2)
8. Inflation (%)	4.7	5.6
9. Number of population (million)	56.9	61.0
Population growth rate (%)	1.4	1.2
10. Employment (million persons)	32.0	34.9
Unemployment rate (%)	0.6	0.5
11. Proportion of people under poverty line (%)	23.7	20
12. Reserve forest (% of total)	18.4	25

Source : The Seventh National Economic and Social Development Plan (1992 - 1996)
National Economic and Social Development Booard

Table 2.2.3 GROSS DOMESTIC PRODUCT AND GROSS NATIONAL PRODUCT AT CURRENT MARKET PRICES (1986-1990)

(Unit : Million Baht)

INDUSTRIAL ORIGIN	1986	1987	1988	1989	1990
Agriculture	178,140	205,592	250,384	266,379	254,523
Mining and Quarrying	34,607	38,491	47,657	60,648	73,500
Manufacturing	258,644	299,327	373,326	453,258	535,396
Construction	56,572	66,097	84,791	112,283	146,817
Electricity and Water Supply	27,300	31,266	34,315	41,499	47,367
Transportation and Communication	85,368	92,943	106,696	123,047	138,752
Wholesale and Retail Trade	171,035	195,696	240,080	272,748	312,738
Banking, Insurance and Real Estate	37,208	50,366	64,979	87,845	124,527
Ownership of Dwellings	44,842	48,802	52,697	58,430	64,355
Public Administration and Defense	50,580	52,700	56,397	64,326	74,603
Services	151,072	171,867	195,655	235,515	278,630
GROSS DOMESTIC PRODUCT (GDP)	1,095,368	1,253,147	1,506,977	1,775,978	2,051,208
Plus: Net Factor Income Payment from the Rest of the World	(22,437)	(22,394)	(24,770)	(23,404)	(21,144)
GROSS NATIONAL PRODUCT (GNP)	1,072,931	1,230,753	1,482,207	1,752,574	2,030,064
National Income (NNP)	852,451	977,857	1,160,715	1,372,921	1,574,649
PER CAPITA GNP (Baht)	20,377	22,960	27,179	31,608	36,032

Source: National Income of Thailand, 1990,
Office of the National Economic and Social Development Board

Table 2.2.4 CONTRIBUTION OF INDUSTRIAL SECTOR TO GDP (1986.1990)

(Unit : Percent)

INDUSTRIAL ORIGIN	1986	1987	1988	1989	1990
Agriculture	16.26	16.41	16.61	15.00	12.41
Mining and Quarrying	3.16	3.07	3.16	3.42	3.58
Manufacturing	23.61	23.89	24.77	25.52	26.10
Construction	5.16	5.27	5.63	6.32	7.16
Electricity and Water Supply	2.49	2.49	2.28	2.34	2.31
Transportation and Communication	7.79	7.42	7.08	6.93	6.76
Wholesale and Retail Trade	15.61	15.62	15.93	15.36	15.25
Banking, Insurance and Real Estate	3.40	4.02	4.31	4.95	6.07
Ownership of Dwellings	4.09	3.89	3.50	3.29	3.14
Public Administration and Defense	4.62	4.21	3.74	3.62	3.64
Services	13.79	13.71	12.98	13.26	13.58
GROSS DOMESTIC PRODUCT (GDP)	100.00	100.00	100.00	100.00	100.00

Source: National Income of Thailand, 1990
Office of the National Economic and Social Development Board
Percentages, arranged by the Study Team

Table 2.2.5 GNP, GDP AND PER CAPITA GNP AT THE 1972 PRICES BY INDUSTRIAL ORIGIN

(Unit : Million Baht)

ORIGIN	YEAR					AVER. ANNUAL GROWTH RATE 1986-1990 (%)
	1986	1987	1988	1989	1990	
GROSS DOMESTIC PRODUCT	413,489	452,635	512,467	574,195	631,610	11.17
GROSS NATIONAL PRODUCT	406,935	446,249	505,756	568,470	626,970	11.41
PER CAPITA GNP (Baht)	7,728	8,325	9,274	10,252	11,128	9.54

Source: National Income of Thailand, 1990
Office of the National Economic and Social Development Board

Table 2.2.6 ANNUAL GROWTH RATES OF GDP, GNP AND PER CAPITA GNP (1986-1990)

(Unit : Percent)

ORIGIN	1986	1987	1988	1989	1990
GROSS DOMESTIC PRODUCT	-	9.46	13.22	12.04	10.00
GROSS NATIONAL PRODUCT	-	9.66	13.33	12.40	10.29
PER CAPITA GNP	-	7.72	11.40	10.54	8.54

Source : National Income of Thailand, 1990
Office of the National Economic and Social Development Board

Table 2.2.7 GROSS REGIONAL PRODUCT (GRP) AT CURRENT MARKET PRICES AND AVERAGE ANNUAL GROWTH RATE BY REGION (1986-1988)

REGION	CURRENT MARKET PRICES (Million Baht)			AV. ANNUAL GROWTH RATE (%) 86-88
	1986	1987	1988	
Whole Kingdom	1,095,368	1,253,148	1,506,977	17.3
Bangkok Metropolitan and Vicinity	509,033	611,496	754,651	21.8
Bangkok Metropolis	414,075	495,107	609,924	21.4
Central Region	48,927	53,566	64,984	15.2
Eastern Region	100,023	103,542	67,719	-17.7
Western Region	57,497	63,991	72,132	12.0
Northeastern Region	143,407	152,842	179,500	11.9
Northern Region	126,196	141,618	171,799	16.7
Southern Region	110,285	126,095	146,196	15.1

Source : Statistical Yearbook, Thailand, 1991
National Statistical Office

Table 2.2.8 PER CAPITA (GRP) AT CURRENT MARKET PRICES AND AVERAGE GROWTH RATE BY REGION (1986-1988)

REGION	PER CAPITA (in Baht)			AV. ANNUAL GROWTH RATE (%) 86-88
	1986	1987	1988	
Whole Kingdom	20,803	23,377	27,632	15.3
Bangkok Metropolitan and Vicinity	61,544	72,315	87,032	18.9
Bangkok Metropolis	71,074	82,905	104,475	21.2
Central Region	18,724	20,275	24,412	14.2
Eastern Region	30,700	32,037	20,558	-18.2
Western Region	18,988	20,192	22,499	8.9
Northeastern Region	7,825	8,208	9,494	10.1
Northern Region	12,210	13,503	16,156	15.0
Southern Region	16,168	18,024	20,381	12.3

Source : Statistical Yearbook, Thailand, 1991
National Statistical Office

Table 2.2.9 GROSS PROVINCIAL PRODUCT (GPP) AT CURRENT MARKET PRICES BY PROVINCES IN THE STUDY AREA (1986-1988)

PROVINCE	CURRENT MARKET PRICES (Million Baht)			AV. ANNUAL GROWTH RATE (%) 86-88
	1986	1987	1988	
Bangkok Metropolis	414,075	495,107	609,924	21.4
Nakhon Pathom	10,505	11,827	13,604	13.8
Nonthaburi	8,776	10,409	13,565	24.3
Pathum Thani	19,228	23,842	26,688	17.8
Samut Prakarn	44,989	57,062	74,136	28.4
Samut Sakhon	11,460	13,249	16,734	20.8
P. N. Si Ayutthaya	9,738	9,976	11,697	9.6
Chachoengsao	14,602	16,478	19,538	15.7
TOTAL	533,373	637,950	785,886	21.4

Source : Statistical Yearbook, Thailand, 1991
National Statistical Office

Table 2.2.10 PER CAPITA (GPP) AT CURRENT MARKET PRICES BY PROVINCES IN THE STUDY AREA (1986-1988)

PROVINCE	PER CAPITA (in Baht)			AV. ANNUAL GROWTH RATE (%) 86-88
	1986	1987	1988	
Bangkok Metropolis	71,074	82,905	104,475	21.2
Nakhon Pathom	17,655	20,183	21,091	9.3
Nonthaburi	17,552	20,018	22,533	13.3
Pathum Thani	50,335	61,608	60,931	10.0
Samut Prakarn	68,581	84,162	92,555	16.2
Samut Sakhon	36,732	42,328	48,224	14.6
P. N. Si Ayutthaya	15,239	15,467	17,967	8.6
Chachoengsao	28,244	32,246	37,357	15.0

Source : Statistical Yearbook, Thailand, 1991
National Statistical Office

Table 2.2.11 GOVERNMENT ACTUAL REVENUE AND EXPENDITURE (1981-1990) (Thousands Baht)

Fiscal year	Actual revenue (1)	Budget expendit. (2)	Difference (1)-(2)
1981	110,391,930	140,000,000	-29,608,070
1982	113,847,788	161,000,000	-47,152,212
1983	136,607,836	177,000,000	-40,392,164
1984	147,871,822	192,000,000	-44,128,178
1985	159,199,939	209,000,000	-49,800,061
1986	166,123,227	211,650,000	-45,526,773
1987	193,524,953	225,032,058	-31,507,105
1988	245,031,256	243,500,000	1,531,256
1989	309,534,113	285,500,000	24,034,113
1990	394,514,362	336,507,500	58,006,862

Source: Statistical Yearboook Thailand, 1991
National Statistical Office

Table 2.2.12 BREAKDOWN OF THE GOVERNMENT FINANCE: FISCAL YEARS 1987-1990

(Thousands Baht)

ITEM	1987	1988	1989	1990
REVENUE	193,524,953	245,031,256	309,534,113	394,514,362
Taxes and duties	171,313,785	219,403,979	273,325,778	348,591,497
Direct taxes	36,553,718	50,144,074	65,713,773	98,078,680
General sales tax	34,249,295	48,947,336	65,636,657	87,545,238
Specific sales tax	56,834,206	59,900,438	69,492,165	69,961,037
Consumption goods tax	54,886,270	57,362,155	66,648,212	67,107,923
Natural resource tax	1,947,936	2,538,283	2,843,953	2,853,114
Import - export duties	38,429,722	55,211,189	68,079,725	87,906,586
Fees and permits	5,246,291	5,200,119	4,402,826	5,099,956
Other taxes and duties	553	823	642	
Sales of goods and services	5,808,872	9,082,589	11,958,749	18,104,514
State enterprices	9,504,478	10,227,386	13,585,337	18,620,416
Miscellaneous	6,897,818	6,317,302	10,664,239	9,197,936
BUDGET EXPENDITURE	227,500,000	243,500,000	285,500,000	336,507,500
Economic services	35,902,000	38,088,500	46,292,600	68,966,000
Education	41,111,000	43,860,700	47,358,100	59,962,100
Public health and utilities	24,405,000	25,334,500	31,238,300	42,506,800
Defence	41,057,700	42,985,100	46,427,400	54,758,900
Internal security	10,922,200	11,634,900	12,500,000	14,889,000
General administration	6,208,300	6,693,200	8,053,100	11,038,800
Debt services	56,097,200	59,746,700	66,500,800	69,574,200
Others	11,796,600	13,156,400	27,129,700	14,811,700

Source: Statistical Yearboook Thailand, 1991
National Statistical Office

Table 2.2.13 AVERAGE MONTHLY INCOME PER HOUSEHOLD AND INCREASE RATE BY REGION 1981-1990

REGION	AVERAGE MONTHLY HOUSEHOLD INCOME			INCREASE RATE (%)		
	1981 (2)	1988	1990	1981-88	1988-90	1981-90
WHOLE KINGDOM	3,378	4,106	5,621	21.6	36.9	66.4
Bangkok Metropolitan Area	5,912	7,877	11,344	33.2	44.0	91.9
Central (1)	3,665	4,220	6,060	15.1	43.6	65.3
Southern	3,256	3,959	5,023	21.6	26.9	54.3
Northern	2,886	3,400	4,553	17.8	33.9	57.8
Northeastern	2,512	3,067	3,563	22.1	16.2	41.8

(1) Excludes Bangkok Metropolis, Nonthaburi, Pathum Thani and Samut Prakarn

Source: (2) Report of 1981 Socio-Economic Survey, Whole Kingdom
National Statistical Office
Statistical Handbook of Thailand 1992
National Statistical Office

Table 2.2.14 POPULATION AND GROWTH RATE BY REGION : 1960, 1970, 1980, 1990

REGION	POPULATION				AVERAGE ANNUAL GROWTH RATE (%)		
	1960	1970	1980	1990	1960-1970	1970-1980	1980-1990
WHOLE KINGDOM	26,257,916	34,397,374	44,824,540	56,303,273	2.74	2.68	2.31
BANGKOK METROPOLIS	2,136,435	3,077,361	4,697,071	5,546,937	3.72	4.32	1.68
CENTRAL /1	2,101,492	2,465,932	3,069,408	4,511,841	1.61	2.21	3.93
EASTERN	1,809,808	2,373,600	3,181,565	4,182,000	2.75	2.97	2.77
WESTERN	2,223,567	2,694,984	3,475,299	4,127,000	1.94	2.58	1.73
NORTHEASTERN	8,991,543	12,025,140	15,698,878	19,828,941	2.95	2.70	2.36
NORTHERN	5,723,106	7,488,683	9,074,103	10,993,792	2.73	1.94	1.94
SOUTHERN	3,271,965	4,271,674	5,628,216	7,112,762	2.70	2.80	2.37

Note : /1 Excluding Bangkok Metropolis
Source : 1960 Population Census and 1970, 1980 and 1990 Population and Housing Census
National Statistical Office
Department of Local Administration

Table 2.2.15 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 2.2.16 NUMBER OF POPULATION OF THE STUDY AREA 1980-1991

PROVINCE	1980	1981	1982	1983	1984	1985
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	148,860	163,059	168,001	178,700	181,661	189,937
Ayutthaya	85,710	89,208	89,877	89,807	90,811	92,965
Nakhon Pathom	69,830	75,639	78,419	77,801	79,172	80,906
Chachoengsao	89,764	100,473	102,355	101,500	102,937	106,046
TOTAL	6,265,515	7,052,993	7,255,986	6,904,046	7,114,545	7,384,981

PROVINCE	1986	1987	1988	1989	1990	1991	Av.Annual Grow.Rate 1980.1991
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	197,348	201,258	205,343	210,599	215,703	219,991	3.61
Ayutthaya	94,569	95,191	96,474	96,826	97,580	98,389	1.26
Nakhon Pathom	82,005	82,260	83,759	85,883	87,261	88,192	2.14
Chachoengsao	109,101	111,103	114,859	116,134	117,557	118,978	2.59
TOTAL	7,569,124	7,828,133	8,038,064	8,241,294	8,041,374	8,197,460	2.47

Source : Department of Local Administration

Table 2.2.17 STUDY AREA POPULATION, HOUSEHOLD, DENSITY, 1991

PROVINCE	AREA (km2)	POPULATION	HOUSEHOLD	DENSITY (pers/km2)	Person per household
Bangkok	1,568.737	5,620,591	1,239,475	3,583	4.5
Nonthaburi	622.303	703,187	165,229	1,130	4.3
Pathum Thani	1,525.856	465,968	110,927	305	4.2
Samut Prakarn	1,004.092	882,164	223,044	879	4.0
Samut Sakhon /1	311.800	219,991	60,124	706	3.7
Ayutthaya /1	477.500	98,389	18,224	206	5.4
Nakhon Pathom /1	282.350	88,192	20,053	312	4.4
Chachoengsao /1	527.000	118,978	20,356	226	5.8
Gulf	38.862			0	0.0
TOTAL	6,358.500	8,197,460	1,857,432	1,289	4.4

Source: Department of Local Administration
National Statistical Office
/1 by the Study Team based on DLA & NSO data

Table 2.2.18 LENGTH OF HIGHWAYS AND ROADS IN THAILAND

(unit: Km)

Category	1985	1987	1988	1989	1990	1991	1985-90 (%)
National Highway	15,218	15,664	15,899	16,815	17,482	17,920	2.76
Primary	7,305	7,278	7,314	7,323	7,536	7,802	1.10
Secondary	7,913	8,386	8,585	9,492	9,950	10,118	4.18
Provincial Highway	21,017	24,500	25,895	27,595	27,959	28,127	4.98
Total	51,453	55,828	57,693	61,225	62,927	63,967	3.69

Source: Statistical Yearbook, Thailand, 1991
Statistical Handbook of Thailand, 1992
National Statistical Office

Table 2.2.19 PERCENTAGE OF PRIVATE HOUSEHOLD BY SOURCE OF WATER SUPPLY AND LIGHTING

WATER SUPPLY / LIGHTING	WHOLE KINGDOM			REGION				
	TOTAL	MUNIC. AREA	NON-MUNIC. AREA	Bangkok Metrop.	Central Region (Excl. Bangkok Metrop.)	Northern Region	North-eastern Region	Southern Region
WATER SUPPLY								
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Tap Water	29.6	84.6	16.8	92.1	35.3	22.9	14.2	17.9
Well Water	58.3	11.4	69.3	3.4	39.8	67.9	76.3	75.8
Rain Water	1.7	0.4	2	0.4	2.9	1	1.6	2.1
River, Canal, Stream, Waterfall	9.7	3.1	11.2	3.7	21.2	7.5	7.3	3.5
Others	0.4	0.3	0.4	0.3	0.5	0.3	0.3	0.4
Unknown	0.3	0.2	0.3	0.1	0.3	0.4	0.3	0.3
LIGHTING								
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Electricity	89.3	98.6	87.2	99.4	92.6	85.7	87.9	84.4
Pressure Lamp	0.4	0.2	0.4	0.1	0.5	0.4	0.4	0.5
Oil Lamp	9.4	0.9	11.4	0.3	6	12.6	10.9	14.3
Others	0.5	0.1	0.6	0.1	0.5	0.9	0.4	0.5
Unknown	0.4	0.2	0.4	0.1	0.4	0.4	0.4	0.3

Source : National Statistical Office

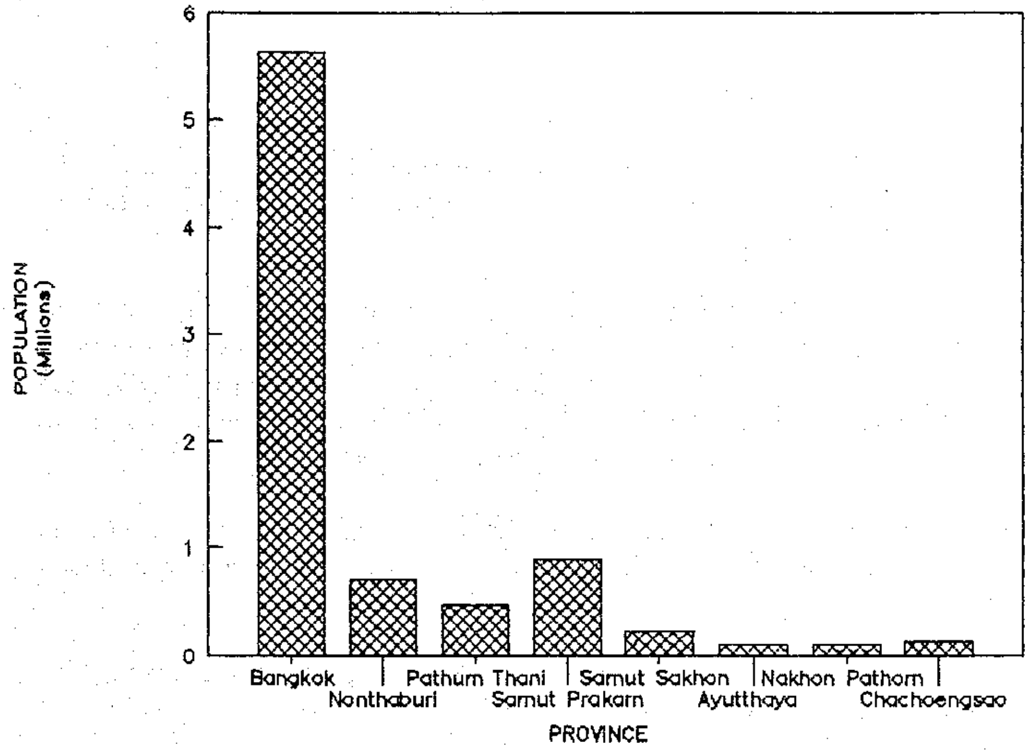


Figure 2.2.1 STUDY AREA POPULATION, 1991

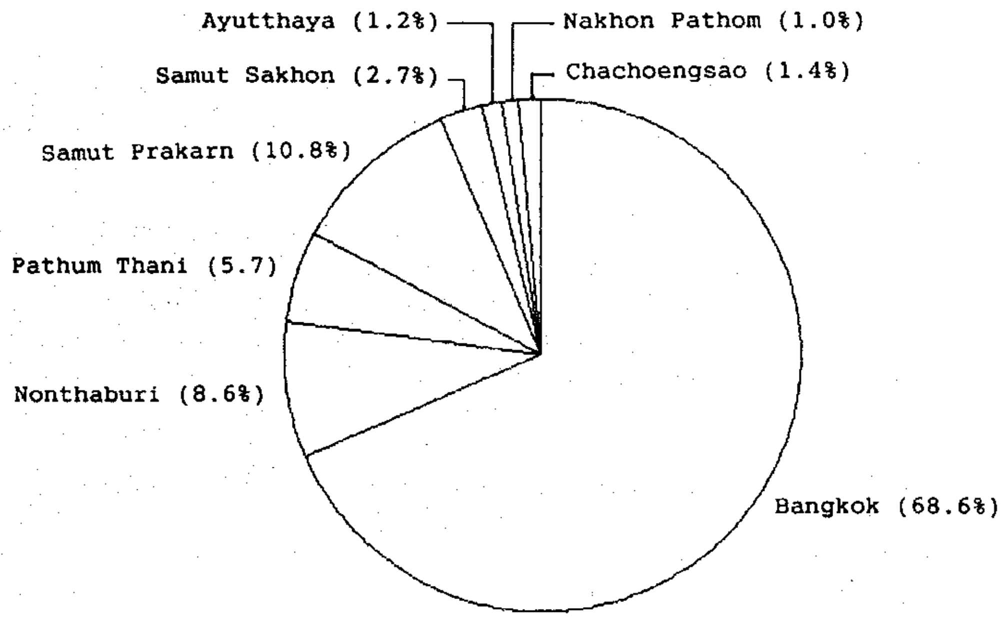


Figure 2.2.2 STUDY AREA POPULATION BY PERCENTAGE, 1991

2.3 Water Supply

2.3.1 Water Supply Organizations

In the Study Area, the MWA supplies water to the Bangkok Metropolitan Area and the provinces of Samut Prakan and Nonthaburi. The PWA serves the Pathum Thani Province through its Region Office III in Bangkok.

Groundwater is being exploited for domestic purpose in areas not covered by the MWA and PWA water distribution networks. Four (4) government 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 those areas.

The Industrial Estate Authority of Thailand (IEAT) develops land into industrial estates and manages them. Using its own deep wells, the IEAT supplies water to the factories located in its industrial estates.

In addition, more than 10,000 private deep wells have been 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.

2.3.2 MWA Water Supply

The MWA was established in 1967, and its water supply service in 1991 covered an area of 710 km^2. However, MWA's total service area is about 3,195 km^2 with a total population of about 7.2 million (Figure 2.3.1). At present, MWA supplies potable water to some 1,027,600 customers or approximately 5.6 million people or 78% of its service area's total population.

About 96.9% (or 1,109.2 MCM) of MWA's water production in 1991 came from Chao Phraya River. The rest, which amounted to about 3.1% (or 34.2 MCM) of MWA's total, came from groundwater.

In 1991, MWA delivered about 36 m^3/sec of raw water from Chao Phraya River. The intake is located at Sam Lae in Pathum Thani Province, about 95 km upstream from the mouth of the Chao Phraya River. Raw water is pumped up at Sam Lae and conveyed to Bang Khen Water Treatment Plant through an 18-km long canal. Portion of the raw water at Bang Khen is conveyed to Sam Sen Water Treatment Plant through a 12-km long canal and then excess raw water at Sam Sen is piped to Thonburi Water Treatment Plant.

Present water production capacity at each water treatment plant (WTP) is as follows:

Bang Khen WTP:	2.10 MCMD
Sam Sen WTP :	0.60 MCMD
Thonburi WTP:	0.20 MCMD

Chao Phraya River's lowest discharge at 61 m^3/sec was observed at Sam Lae between 1975 and 1988. In the Master Plan prepared by Thai DCI in 1990 is shown an almost equal amount (60 m^3/sec) of raw water to be diverted from Chao Phraya River in the year-2017. Hence, future raw water requirements have to be secured from Mae Klong River and Tha Chin River.

In addition to the surface water being diverted from Chao Phraya River, MWA is presently abstracting groundwater from 41 deep wells (29 in Bangkok Metropolis, 3 in Nonthaburi and 9 in Samut Prakan). Since 1983, MWA is phasing out some of its wells in accordance with the Groundwater Act.

Before its phase-out program in 1983, MWA was withdrawing groundwater at the rate of about 390,000 CMD. The use of groundwater was gradually reduced and replaced by surface water. However, the phase-out program has not yet been completed at present, and the groundwater pumpage in 1992 was about 122,000 CMD from 41 wells.

MWA's water supply achievement is summarized in Table 2.3.1; MWA's water tariff is shown in Table 2.3.2; and MWA's water consumption in 1992 is detailed in Table 2.3.3.

2.3.3 Pathum Thani Province's Water Supply

Pathum Thani Province is located in the north of Bangkok Metropolis. Along with the expansion of the Bangkok Metropolis , Pathum Thani area is presently experiencing a rapid urbanization and industrialization.

The PWA Regional Office 3 in Bangkok manages the waterworks system in Pathum Thani province. This system relies on 20 deep wells (280-350 m) with a total pumping capacity of 0.15 m^3/sec in 1992. The total area of Pathum Thani Province is 1,497 km^2, and as of 1992, PWA's service area was about 180 km^2. About 6.27 MCM of groundwater was produced and 4.90 MCM was sold to 10,049 customers or approximately 98,000 people which is about 21% of the province's total population in 1991.

Table 2.3.4 shows the water supply achievement of Paw's Pathum Thani Waterworks, and Table 2.3.5 presents the PWA's water tariff.

In the Study Area, PWA had 35 active wells as of 1992 (see Chapter 5).

2.3.4 Pumpage of Private Wells

Based on the Groundwater Act of Thailand (B.E. 2520), Bangkok Metropolis (1,550 km^2) and its five adjoining provinces, namely, Nakhon Si Ayutthaya (2,480 km^2), Nonthaburi (622 km^2), Pathum Thani (1,497 km^2), Samut Prakan (934 km^2) and Samut Sakhon (840 km^2) were designated as the Bangkok Groundwater Area (7,923 km^2)(see Figure 2.4.12 in the following section).

According to this Act, permits for drilling and for use of groundwater must be secured by any person who wishes to engage in groundwater activities. A permit for use of groundwater is valid only for 10 years from the day of its issuance. In addition, the

Ministerial Regulation (1984) entitled the DMR to levy a water charge on private groundwater users in the Bangkok Groundwater Area.

Groundwater tariff being implemented by the DMR is as follows. In rural areas, groundwater use of less than 25 m^3/day for irrigation and domestic use is exempted from water charges; more than 25 m^3/day is charged with 0.75 baht/m^3. All well owners in urban areas are charged with 1.0 baht/m^3. Groundwater charges are determined by multiplying the amount of water used per day by 25 days per month and by one baht (i.e., water used in m^3/day x 25 days x 1 baht). The DMR is presently considering a new rate of 3.0 baht/m^3(see Table 2.4.2).

In recent years, the DMR had been requiring well owners to install water meters; as of 1992, a total of about 2,500 water meters had already been installed.

The number of wells registered at DMR and the groundwater pumpage in the Study Area is described in Chapter 5 of this report.

2.3.5 Water Supply for Industrial Estates

The Industrial Estate Authority of Thailand (IEAT) was established in 1972 as a semi-public government agency existing under the jurisdiction of the Ministry of Industry. The IEAT is also authorized to carry out the government's industrial development policy.

At present, there are three (3) types of industrial estates in the Study Area.

Type 1 The IEAT plans and constructs industrial zones and, after completion, controls and manages the zones independently (e.g., Bangchan and Lat Krabang Industrial Estates).

Type 2 Private enterprises develop and sell the lands in the industrial estates. The management of the industrial estates is under the IEAT (e.g., Bang Phli, Bang Poo, Samut Sakhon, Ban Pa-in and Hi-Tech Industrial Estates) .

Type 3 Private enterprises develop industrial estates, control and manage them independently (e.g., Nava Nakhon and Bangkadi Industrial Estates)

These industrial estates are completely equipped with infrastructures, such as groundwater supply, waste water treatment plant, electricity, road network and residential areas for workers.

The IEAT and the private sectors are currently planning and developing more industrial estates in order to meet the demand for tenant factories. The new industrial estates, however, have to be established in areas outside of the rapidly expanding Bangkok Metropolis.

The industrial estates located in the Study Area are detailed and summarized in Table 2.3.6 and their locations are shown in Figure 2.3.2. In 1992, the total number of factories in both IEAT and private industrial estates was 934 .

Water supply for the industrial estates relies on groundwater. Presently, 80 deep wells are being operated in the nine (9) industrial estates and in the year-1992 total groundwater pumpage was estimated at about 30,338,800 m^3 (See Chapter 5).

Table 2.3.7 summarizes the average water consumption of each type of factory in the industrial estates. The water consumption data were obtained from 432 factories in Bangchan, Lat Krabang, Bang Phli, and Bang Poo Industrial Estates. The average water consumption of factories engaged in textile, soft drink, paper products, plastic products is 190 m^3/day to 240 m^3/day, while other factories, such as those engaged in wearing apparel, leather product , wood product etc. is less than 100 m^3/day .

Table 2.3.1 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.

Table 2.3.2 WATER TARIFF OF MWA

1991

CATEGORY 1 : Residence		CATEGORY 2 :Business, State Enterprise, Government Agency and Others		CATEGORY 3 : Industrial	
Volume (m3)	Rates (Baht/m3)	Volume (m3)	Rates (Baht/m3)	Volume (m3)	Rates Baht/m3)
0 - 30	4.00 Not less than 20 B	0 - 10	50 Baht Package Rate	0 - 10	50 Baht Package Rate
31 - 40	4.25	11 - 20	6.20	11 - 20	6.20
41 - 50	4.50	21 - 30	6.45	21 - 30	6.45
51 - 60	4.75	31 - 40	6.70	31 - 40	6.70
61 - 70	5.00	41 - 50	6.95	41 - 50	6.95
71 - 80	5.25	51 - 60	7.20	51 - 60	7.20
81 - 90	6.15	61 - 80	7.45	61 - 80	7.45
90 - 100	6.40	81 - 100	7.70	81 - 100	7.70
101 - 120	6.65	101 - 120	7.95	101 - 120	7.95
121 - 160	6.90	121 - 160	8.20	121 - 160	8.20
161 - 200	7.15	161 - 200	8.45	161 - 200	8.45
201 over	7.65	201 over	8.70	201 - 2000	8.60
				2001- 4000	8.40
				4001- 6000	8.00
				6001-10000	7.50
				10001-20000	7.00
				20001-30000	6.50
				30001-40000	6.00
				40001-50000	5.50
				50001 over	5.00

Table 2.3.3 MWA WATER CONSUMPTION IN DETAIL (1)

1. Small User 1992 (Unit m3)

Mounth	Residence	Govern. Office	Commercial	Enterprise	Distributer	Industrial	Total
Jan.	29,674.427	115,251	16,499,560	40,508	4,376	9,295	46,343,417
Feb.	30,093,061	108,368	16,573,892	36,720	5,168	37,106	46,854,315
Mar.	29,829,449	97,231	16,032,420	33,346	4,415	8,453	46,005,314
Apr.	33,678,504	106,310	17,614,866	37,810	6,991	10,562	51,455,043
May.	34,538,994	195,035	17,978,092	39,295	5,476	8,094	52,674,986
Jun.	31,296,894	98,009	17,046,297	28,198	5,239	8,231	48,482,868
Jul.	31,317,002	116,383	17,194,487	29,146	3,692	7,265	48,667,975
Aug.	31,820,660	99,777	17,520,279	34,555	2,642	8,834	49,486,747
Sep.	30,247,668	95,002	16,905,116	31,944	3,251	8,409	47,291,390
Oct.	29,844,767	104,070	17,085,680	36,739	4,418	9,288	47,084,962
Nov.	30,284,024	95,640	17,115,736	39,484	11,184	9,724	47,555,792
Dec.	29,452,499	99,667	16,288,876	37,196	4,378	15,087	45,897,703
Sum	372,077,949	1,240,743	203,855,301	424,941	61,230	140,348	557,800,512

2. Large User 1992 (Unit m3)

Mounth	Residence	Govern. Office	Commercial	Enterprise	Distributer	Industrial	Total
Jan.	5,653,459	3,417,942	9,426,376	666,421	114,710	884,345	20,163,253
Feb.	5,790,010	3,713,827	9,563,449	660,115	128,891	1,038,127	20,894,419
Mar.	5,268,552	3,315,158	9,122,547	659,737	132,115	1,016,118	19,514,227
Apr.	6,093,779	3,971,360	9,857,679	672,981	131,751	931,136	21,658,686
May.	5,676,295	3,673,145	10,130,164	694,358	143,047	1,194,570	21,475,579
Jun.	5,751,234	3,480,973	9,729,351	686,690	140,149	988,499	20,776,896
Jul.	6,029,157	4,217,517	9,946,236	659,722	120,957	895,097	21,868,686
Aug.	6,252,927	3,865,699	10,489,177	673,536	116,577	1,212,073	22,609,989
Sep.	5,412,023	2,818,639	9,956,695	651,433	126,161	1,092,931	20,057,882
Oct.	5,732,743	3,705,154	8,993,564	644,779	130,534	907,612	20,114,386
Nov.	5,709,972	3,809,326	9,653,112	638,643	112,493	926,862	20,850,408
Dec.	5,778,221	3,724,202	8,887,134	660,496	118,808	1,021,277	20,190,138
Sum	69,148,372	43,676,942	115,755,484	7,968,911	1,516,193	12,108,647	250,174,549

Table 2.3.3 MWA WATER CONSUMPTION IN DETAIL (2)

1. Water Consumption Total 1992 (Unit m3)

Mounth	Residence	Govern. Office	Commercial	Enterprise	Distributer	Industrial	Total
Jan.	35, 327, 886	3, 533, 193	25, 925, 936	706, 929	119, 086	893, 640	66, 506, 670
Feb.	35, 883, 071	3, 883, 195	26, 137, 341	696, 835	134, 059	1, 075, 233	67, 748, 734
Mar.	35, 098, 001	3, 412, 389	25, 154, 967	693, 083	136, 530	1, 024, 571	65, 519, 541
Apr.	39, 772, 283	4, 077, 670	27, 472, 545	710, 791	138, 742	941, 698	73, 113, 729
May.	40, 215, 289	3, 742, 180	28, 108, 256	733, 653	148, 523	1, 202, 664	74, 150, 565
Jun.	37, 048, 128	3, 578, 982	26, 775, 648	714, 888	145, 388	996, 730	69, 259, 764
Jul.	37, 346, 159	4, 333, 900	27, 140, 723	688, 868	124, 649	902, 362	70, 536, 661
Aug.	38, 073, 587	3, 965, 476	28, 009, 456	708, 091	119, 219	1, 220, 907	72, 096, 736
Sep.	35, 659, 691	2, 913, 641	26, 861, 811	683, 377	129, 412	1, 101, 340	67, 349, 272
Oct.	35, 577, 510	3, 809, 224	26, 079, 244	681, 518	134, 952	916, 900	67, 199, 348
Nov.	35, 993, 996	3, 904, 966	26, 768, 646	678, 127	123, 677	936, 586	68, 406, 200
Dec.	35, 230, 720	3, 823, 869	25, 176, 010	697, 692	123, 186	1, 036, 364	66, 087, 841
Sum	441, 226, 321	44, 917, 685	319, 610, 785	8, 393, 852	1, 577, 423	12, 248, 995	827, 975, 061

Source : MWA   Small User = Meter Diameter 0.5 ～ 1.25 ins.
Large User = Meter Diameter 1.5 ～ over 2 ins.

2. Total Customer 1992 (Unit Number)

	Residence	Govern. Office	Commercial	Enterprise	Distributer	Industrial	Total
Small	791, 773	792	262, 094	290	10	25	1, 054, 984
Large	3, 826	1, 354	6, 608	341	34	131	12, 294
Sum	795, 599	2, 146	268, 702	631	44	156	1, 067, 278

Table 2.3.4 WATER SUPPLY ACHIEVEMENT OF PATHUM THANI WATERWORKS

(PWA Regional Office - 3 in Bangkok)

Description	Unit	1983	1984	1985	1986	1987	1988	1989	1990	1991
A. Total Water Production	1000m3	1099.9	1597.5	2155.3	2238.6	2236.3	2281.2	3421.5	5420.1	6266.5
B. Water Sales	1000m3	523.7	869.0	1107.2	1151.2	1277.9	1441.7	2333.5	3941.3	4900.2
C. Water Sales Ratio, B/A	%	47.6	54.4	51.4	51.4	57.1	63.2	68.2	72.7	78.2
D. Total Customer	No.	1229	2181	2475	2741	3180	5019	5901	7120	10049
E. Population of Responsible Area	1000 Person	357.8	366.8	384.7	402.0	415.2	435.4	441.9	452.7	465.9
F. Water Consumption Ratio, ℓ/Person/day		42	65	66	56	57	53	54	65	72
G. Service Area	km2	30	36	45	50	80	140	161	172	180
H. Water Supply Ratio	%	2.1	2.5	3.5	4.2	5.7	10.2	11.5	12.2	12.8

Source : PWA

Table 2.3.5 WATER TARIFF IN 1991

Water Consumption (m^3/month)	Tariff (Baht/m^3)
0 - 10	3.75
11 - 20	4.50
21 - 30	6.50
31 - 50	7.50
51 - 80	8.00
81 - 100	8.50
101 - 300	9.00
300 - 1000	9.25
1000 - 2000	9.50
2000 - 3000	9.75
3000 over	10.00

Table 2.3.6 INDUSTRIAL ESTATES IN THE STUDY AREA

Name	Industy Opening	Industy Area	Groundwater supply Volume m3/d	Water Charge Baht/m3	Total of Workers & NO. of Factorie	NO. of Wells & Well Depth	Land Sub-sidence & Water Quality
1. Bangchan Industrial Estate (IEAT)	GIZ:1972	108 ha Minburi Dist. BKK	7,000m3/day	4.0 Baht/m3	11,000 92	4 Wells 66-78m	1-3cm/year Good
2. Lat Krabang Industrial Estate (IEAT)	GIZ:1990 EPZ:1990	383 ha Lat Krabang Dist. BKK	38,000m3/day	5.0 Baht/m3	54,000 183 Max. 233	10 Wells 150-160m	None Good
3. Bangplee Industrial Estate (IEAT)	GIZ:1984 GIZ:1989 GIZ:1991	160 ha Bangplee Dist. Samut Prakarn	5,400m3/day	5.0 Baht/m3	14,000 136	4 Weels 180-200m	2-4cm/year Good
4. Bangpoo Industrial Estate (IEAT)	GIZ:1977 EPZ:1987	629 ha Muang Dist. Samut Prakarn	20,000m3/day	5.5 Baht/m3	53,600 293 Max. 390	19 Weels 150-170m	7-8cm/year Good
5. Samut Sakhon Industrial Estate (IEAT)	GIZ:1992	233 ha Samut Sakhon	20,000m3/day	5.0 Baht/m3	(1,000) Max. 220	15 Weels 200-250m	None Good
6. Hi-Tech Industrial Estate	GIZ:1992 EPZ:1992	344 ha Bang Pra In Dist.	17,600m3/day	5.0 Baht/m3	(1,800) Max. 66	8 Weels 150-180m	None Good
7. Bang Pain Industrial Estate	GIZ:1994 EPZ:1994	174 ha Bang Pra In Dist.	6,500m3/day	5.0 Baht/m3	(1,400) Max. 50	9 Weels 150-160m	None Good
8. Navanakhon Co., LTD	GIZ:1987	624 ha Pathum Thani	27,000m3/day	5.0 Baht/m3	47,000 188	9 Weels 150-180m	1cm/year Good
9. Bang Kadi Industrial Park Co., LTD	GIZ:1988	188 ha Bang Kadi Pathum Thani	3,600m3/day	5.0 Baht/m3	12,200 30	2 Weels 170-180m	1-2cm/year Good

Source : IEAT GIZ : General Industrial Zone EPZ : Export Processing Zone

Table 2.3.7 CLASSIFICATION OF INDUSTRIAL ACTIVITIES AND WATER CONSUMPTION IN IEAT

Description	Type of Industry	Water Consumption
1) Soft Drink:	Canned Juice, Fruits Juice	190 m^3/day
2) Food Products:	Vegetable Oil, Frozen Food Snack, Instant Noodle,etc.	168 m^3/day
3) Textile Industry:	Textile, Wool, Weaving	240 m^3/day
4) Wearing Apparel:	Table Sheets, Underwear Apparel, Artificial Wool,etc.	89 m^3/day
5) Leather Products:	Bag,Leather Goods, Shoes,etc.	42 m^3/day
6) Wood Products:	Rattan Furniture, Wood Products	91 m^3/day
7) Paper Products:	Paper Core, Paper Box, etc.	194 m^3/day
8) Printing:	Printing House	51 m^3/day
9) Chemical Industry:	Tooth Paste, Medicine, Chemicals	123 m^3/day
10) Rubber Products:	Rubber Goods, Car Tire, Gloves,etc.	88 m^3/day
11) Plastic Products:	Clay, Roof/Floor Tiles, Toys	198 m^3/day
12) Non-Metal Products:	Transformer, Watch Parts	108 m^3/day
13) Metal Products:	Car & Bicycle Parts	126 m^3/day
14) Machine & Electrical Appliance:	Car Engine, Motor, Electronics	111 m^3/day
15) Vehicles & Repairing:	Car Production & Repair	171 m^3/day
16) Others:	Umbrella,Photographic, Carbon case	61 m^3/gay

Note : The factories data from Bangchan, Lat Kabang, Bang Plee and Bang Poo Industrial Estates, and the water consumption data are collected from 432 factories.

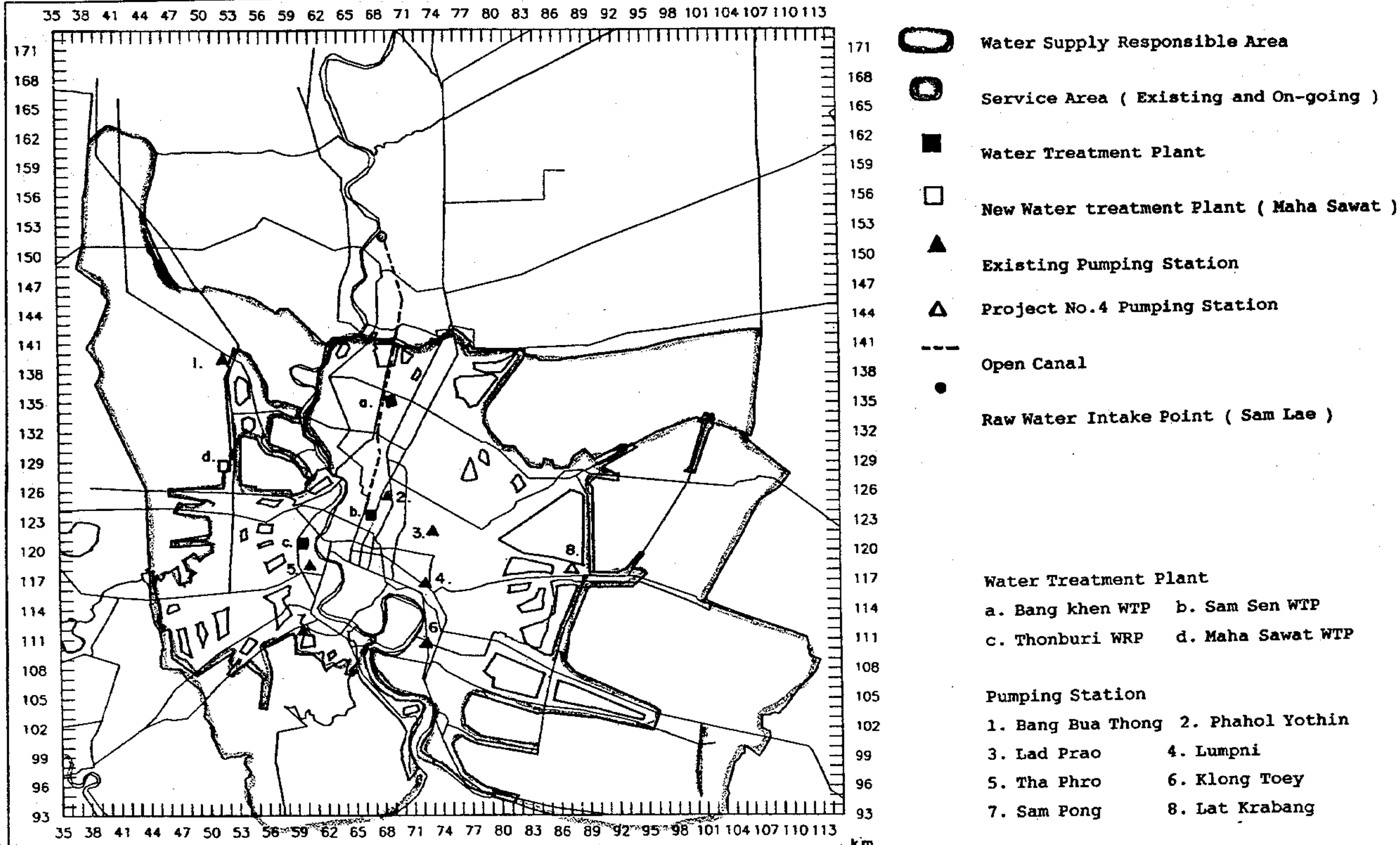
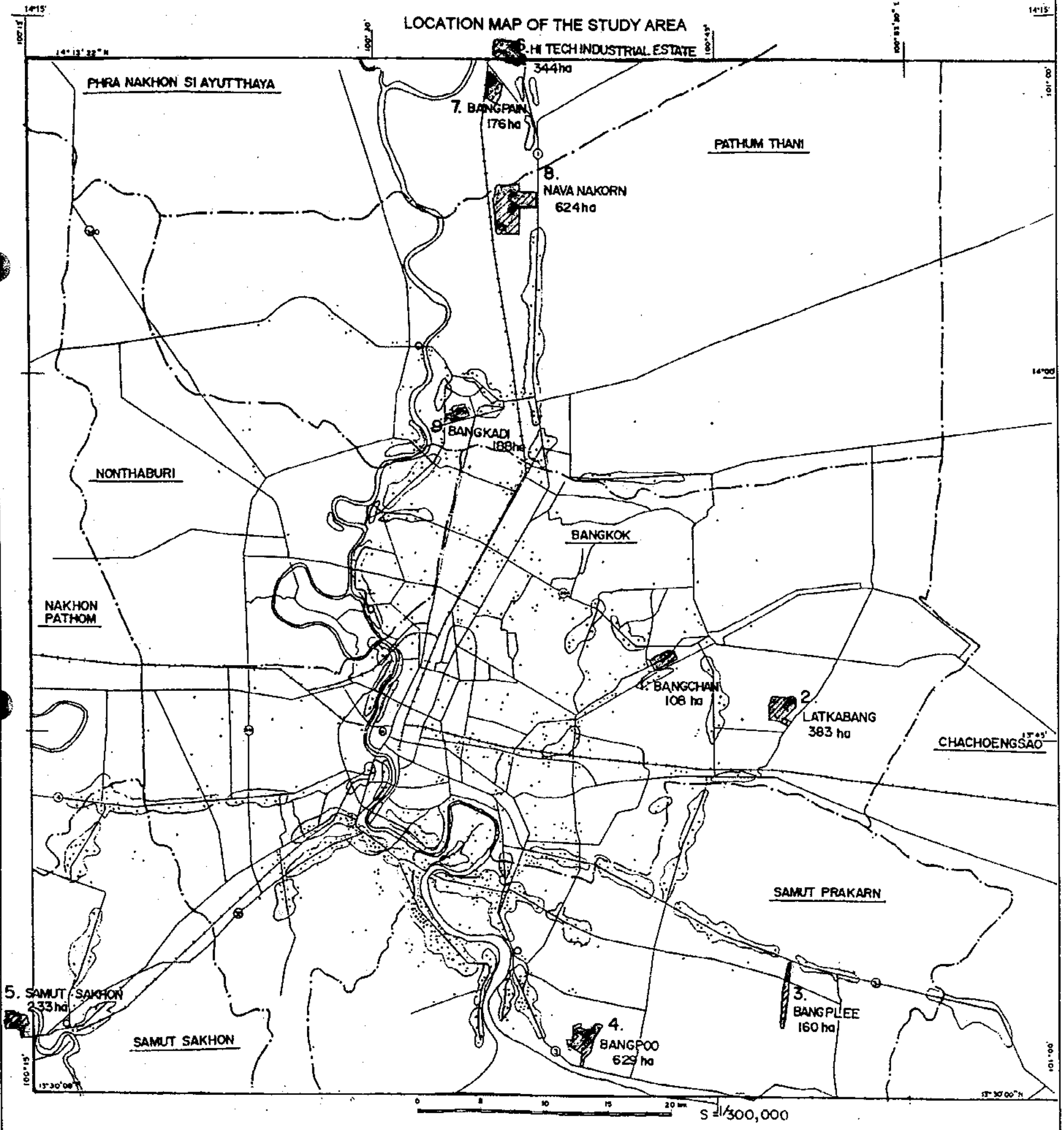


Figure 2.3.1 MWA WATER SUPPLY MAP

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 RESIDENTIALTOWN

Figure 2.3.2	MAIN INDUSTRIAL ESTATES AND INDUSTRIAL AREAS
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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2.4 Review of Land Subsidence in Bangkok

2.4.1 Brief History

In 1969, land subsidence in Bangkok was given public attention for the first time when its evidence was pointed out in the newspapers. Many indications, such as protrusions of well casing and foundation of the building, were observed in many places.

The major cause of land subsidence was recognized in a seminar organized in 1979 on this subject. After that seminar, research projects on the management of groundwater and mitigation of land subsidence in Bangkok were started and undertaken by the DMR and the AIT. Other related research and investigation projects mostly commenced in 1978.

The first ground surface leveling in Bangkok was run by the RTSD in 1930. The next one was conducted in mid-1978. The leveling was carried out by using the existing benchmarks.

Between 1978 and 1981, 51 new benchmarks were installed in addition to the 25 existing benchmarks belonging to the BMA. Levelings were run every 3 months to measure the actual rate of subsidence.

The center of land subsidence coincides with the center of depression of artesian pressure in the east to southeast of Bangkok at Lat Phrao, Bang Kapi, Hua Mak, Phra Khanong and Bang Na. Since 1978, the rate of subsidence in these places was estimated at more than 10cm/year, and as much as 1.14m subsidence occurred between 1940 and 1980 (Ramnarong, 1983). Between 1978 and 1992, the annual rates of subsidence at Dusit, Phaya Thai, Phra Nakhon, and Yan Nawa in Central Bangkok ranged from 5cm to 10cm, and subsidence rate at Thonburi in Western Bangkok was estimated at less than 5cm/year.

2.4.2 Groundwater Use

Groundwater use in the Bangkok area started in 1954 to supplement the requirement of the Metropolitan Waterworks Authority (MWA) for public water supply. Over the years, the pumpage steadily increased with additional private use as the public water supply facility could not cope with the demand. Historical record of pumpage for public water supply by the MWA was available, but for private pumpage, only estimates were provided by the DMR since there was no law regulating the use till 1978. After the promulgation of the Groundwater Act in 1978, statistics of the total number of private wells and the total rate of withdrawal were available (estimation of the number of wells and groundwater pumpage of the Study Area are described in Chapter 5 of this report).

Groundwater utilization in Bangkok and adjacent areas is summarized in the following types of use:

Domestic use

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

Industrial use

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

Agricultural use

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

2.4.3 Groundwater Level and Land Subsidence

(1) Groundwater Level

As shown in Figures 2.4.1, 2.4.2 and 2.4.3, groundwater levels in the Phra Pradaeng (PD), the Nakhon Luang (NL), and the Nontha Buri (NB) Aquifers have been declining since late 60's due to increasing groundwater withdrawals. The total decline reached a maximum of over 40m to 50m in each aquifer. Groundwater surface depression appeared first in the central area of Bangkok in late 60's and then spread over the entire Bangkok Metropolis in the 70's.

Because of the implementation of the Groundwater Act in 1983, groundwater level in the central area of Bangkok recovered. For the NL Aquifer, the water level in the monitoring well NL25 at Wat Kunnathi Ruttharam, Khet Huai Klawang was recorded at 54m BGS in early 1982. Thereafter, a recovery was observed. And in early 1987, the water level was as high as 37m BGS, which means a recovery of 17m in five (5) years.

Figure 2.4.4 shows the annual changes in the groundwater levels in the east-west profile at grid 20. Groundwater surface depression spread towards Bang Kapi and Minburi and reached its lowest point in 1982. As a result of the regulation enforced by the Act, groundwater recovered in the central area, but kept on declining in the western and eastern ends. Although groundwater level recovered in Minburi in 1985, it declined again in 1986. As shown in Figure 2.4.5, the groundwater levels particularly in the NL Aquifer continue to decline thereafter in Bang Phli district southeast of Bangkok and in Samut Sakhon where rapidly growing housing and industrial activities are now taking place.

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

Type A Water level is rapidly declining

Type B	Water level is rapidly declining with a short period of recovery between 1984 and 1987
Type C	Water level has recovered since 1984
Type D	Water level is slowly declining
Type E	Water level is stable or not changing

Figure 2.4.6 shows the temporal distribution of the five (5) types of patterns of groundwater level changes. Figure 2.4.7 shows the spatial distribution of each type of groundwater level change. As shown in the latter figure, the central area of Bangkok belongs to Type C and is surrounded by Type B areas. Existing and newly developed industrial and housing districts are in Type A areas. This spatial distribution of patterns of behavior of groundwater level change clearly displays the effect of the measures adopted in the critical zones of Bangkok since 1983 and delineates areas of increasing groundwater withdrawals.

(2) Land Subsidence

The land subsidence phenomenon was widely recognized in Bangkok since 1970's. Though there were several opinions on the cause of this phenomenon, two (2) studies, namely, AIT (1982) and AIT & DMR (1982), and the surface leveling conducted by RTSD in 1978 clarified the cause and extent of land subsidence happening in Bangkok Metropolis.

As shown in Figure 2.4.8, a maximum subsidence of 85.6cm between 1933 and 1978 was located in the southeastern part of Bangkok as a result of the RTSD's surface leveling survey. Subsequent surveys of RTSD revealed a maximum subsidence of 75cm between 1978 and 1987. Therefore, a total subsidence of over 160cm in 45 years occurred in Bangkok.

Soil layer compressions in the top zone (up to 50m BGS) and in the deeper zone (50m-200m below ground surface) contributed to 40% and 60% respectively of the total land surface subsidence between 1978 and 1981 (AIT & DMR, 1982).

Figure 2.4.9 shows that land subsidence rates in 1979 and 1981 were over 10cm/year in the eastern suburbs and 5 to 10 cm/year in Central Bangkok. As mentioned earlier, after the introduction of the measures for controlling groundwater pumpage in 1983, a recovery of groundwater level was observed particularly in the Type C area. This recovery has contributed in slowing down the subsidence rate in this area. Table 2.4.1 and Figure 2.4.9 illustrate this observation by comparing the land subsidence rates before and after 1983. However, the 1987 land subsidence distribution shown in Figure 2.4.9 reveals the fact that land subsidence rate is increasing in the areas southeast, northeast and northwest of Bangkok (shadowed areas in the figure), where major industrial areas are located.

Discernible from Figure 2.4.10, the annual subsidence rates in 1988 and 1989 were 3 to 5cm/year in the eastern suburbs and 2 to 3 cm/year in central Bangkok. In 1990, the subsidence rates decreased to 2 to 3 cm/year in the eastern suburbs and 1 to 2 cm/year in the Central Bangkok (Ramnarong & Buapeng, 1991).

Figure 2.4.11 which was plotted using the RTSD's leveling data of the CI-Stations of NEB shows the 1991 land subsidence rate distribution in the Study Area. The following were discerned from this figure:

1) Subsidence rates of less than 2 cm/year existed in most parts of Bangkok.

2) In Central Bangkok, subsidence rate of more than 2cm/year was observed.

3) Subsidence rates of 2 to more than 5 cm/year were observed in Samut Prakan on the south, Bang Phili on the southeast and Samut Sakhon on the southwest.

4) Recently subsiding areas almost coincided with the new groundwater depression zones shown in Figures 2.4.5 to 2.4.7.

5) Although the groundwater water level went up in Bangkok, land subsidence is still occurring.

Goundwater levels in Bangkok area were affected by a regional decline of groundwater levels caused by heavy withdrawals in the surrounding areas. This resulted in the continuous occurrence of land subsidence in the Metropolis. Serious land subsidence may now take place in the surrounding areas unless groundwater withdrawals are strictly regulated.

2.4.4 Legal Aspect

(1) Groundwater Act

The uncontrolled and excessive pumping of groundwater caused the widespread decline of water level and land subsidence in the Bangkok Metropolis and its vicinity since 1970's.

As a legal measure against land subsidence, the Government enforced the Groundwater Act B.E. 2520 in July of 1978. The underlying principle of the Act is the government control of groundwater activities.

Under the provisions of the Act, groundwater utilization, exploitation, development, conservation and protection shall be subject to the control and regulation of the government through the DMR.

The need for a water permit is stipulated in Chapter 2 of the Act. It can be briefly stated as "No one shall engage in any activity relating to the groundwater in any groundwater area without securing an official permit".

Permits for drilling and groundwater use are not required for government organizations which are responsible in providing water for agricultural, domestic or industrial purposes. However, government organizations are not exempted from the Ministerial Regulations concerning drilling, well development or abandonment, controlled extraction of groundwater, public health and environmental protection.

At present, the water permit is the principal method of managing groundwater resources in the Kingdom of Thailand. Three (3) kinds of permits are prescribed in Section 18 of the Act.

1) A permit for drilling for groundwater

2) A permit for use of groundwater
3) A permit for disposal of water into wells

Permits are issued for one (1) year for drilling purposes, for five (5) years to facilitate disposal of water into wells, and for ten (10) years for groundwater use.

Since the Minister of Industry is the custodian of this Act, the Ministry's DMR is the body responsible for implementing the same.

In the nationwide management of groundwater resources, the DMR's functions include the control of well drilling, the abstraction of groundwater, the data collections, the regulations, the inter-agency agreements and the registration of wells. The DMR's Groundwater Division deals mainly with these matters.

The DMR investigates and assesses the water permit applications. It allows a certain amount of pumpage or withdrawal to the applicants based on the evaluation of the current groundwater condition in the locality

The Act requires the Groundwater Committee which is chaired by the DMR's Director-General to advise the Minister in establishing regulations and in making recommendations. This committee is composed of the heads of the departments and line agencies involved in the exploitation of groundwater resources and three experts appointed by the Minister. These government agencies are the PWD, the RID, the Public Health Department and the MWA.

(2) Implementation of the Act

In the implementation of the Act, the Minister issued a directive containing the following main points (Sritrakul, 1983).

1) Bangkok and five (5) adjoining provinces were designated as the Bangkok Groundwater Area (Figure 2.4.12). Groundwater occurring at depths exceeding 15 meters below ground surface in this area is subject to administration under the Act

2) Specifications for drilling and construction of wells are provided under the Act. Standard forms for daily drilling reports, well records and other information were prescribed

3) Methods of groundwater extraction and conservation were outlined.

4) Technical measures to protect groundwater from pollution were described and drinking water standards were issued.

5) Technical principles were given for disposal or injection of water or liquids into the aquifers through wells.

6) Pricing of water use rate was considered

This directive was later adopted by the Ministerial Regulations effective on February 3, 1985. The Regulations entitled the DMR to levy a charge on private users of groundwater in the Bangkok Groundwater Area.

After enforcing the Act in 1978, detailed data on water wells and their uses have been collected.

2.4.5 Mitigation of Groundwater Crisis and Land Subsidence

From 1978 to 1982, the DMR and AIT jointly conducted a study entitled "Groundwater Resources in Bangkok Area: Development and Management". The study aimed at the prediction of future groundwater levels and land subsidence due to groundwater pumpage.

Based on the results of the study, 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 (Ramnarong, 1991).

In this resolution, a control area of groundwater use was designated. The control area covers the four provinces of Bangkok Metropolis, Nonthaburi, Pathum Thani and Samut Prakan. Furthermore, Bangkok Metropolitan Area was divided into three (3) critical zones defined as follows (Figure 2.4.13).

Critical Zone 1 the the area where subsidence rate is greater than 10 cm/year and/or water level declines rapidly

Critical Zone 2 the area where subsidence rate is 5-10cm/year and/or water level declines rather rapidly.

Critical Zone 3 the area where subsidence rate is less than 5 cm/year and/or water level declines slowly.

This resolution directed the MWA to phase out all public wells in the Critical Zones 1 and 2 by end-1987. The MWA implemented the phase-out-in-steps program of public wells from 1983 to 1987. Although the program was extended, the MWA was able to reduce the pumpage from 446,343 CMD in 1982 to 73,000 CMD in 1990 (Table 2.4.3). During this period, groundwater source was replaced by surface water. In addition, the resolution allowed an annual increase in private pumpage of less than 5% from 1983 to 1987. From 1988 to 1992, private pumpage would be reduced at a rate of 5% annually.

As the MWA expanded its distribution network, the DMR was able to restrict the average yearly increase in private pumpage from 1983 to 1987 to only 2.3%. This resulted in a net decrease of 9.4% in the total pumpage as compared to that of 1983 (Table 2.4.2 and Figure 2.4.14).

Meanwhile, annual private pumpage has kept on increasing since 1988 because of the unexpected rapid national economic growth. This has caused a rising water demand due to the expansion of housing and industry in the suburban areas of Bangkok. Groundwater is the only source of water supply in such a newly developed area. Instead of decreasing, the private pumpage increased by 6.1% on the average during the past three years from 1988 to 1990. A reassessment of the groundwater control program of the government is therefore necessary to cope up with the rapid economic growth of the country.

TABLE 2.4.1 COMPARISON OF LAND SUBSIDENCE IN THE EIGHT (8) MOST SERIOUS STATIONS

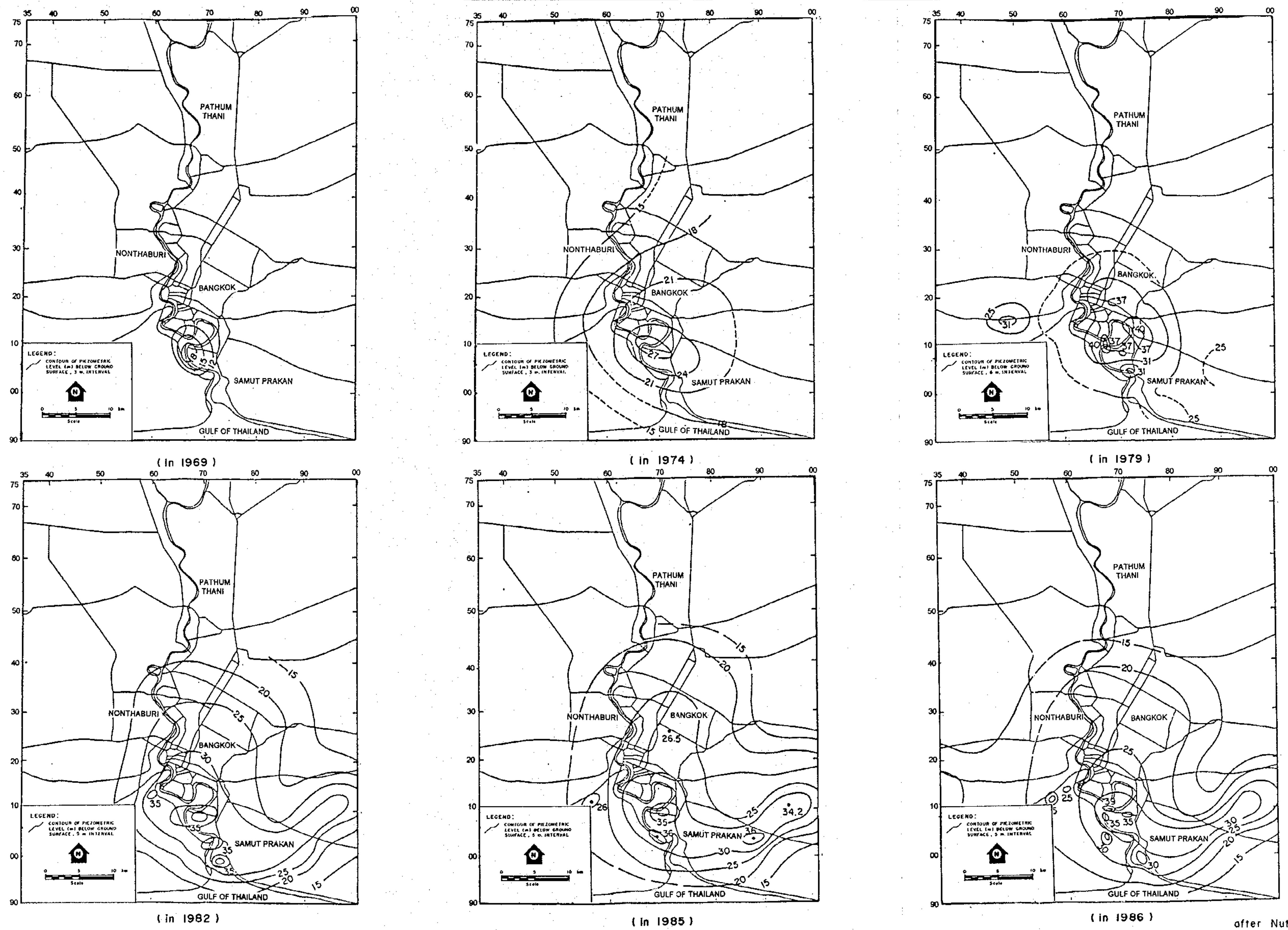
STATION, CI	LAND SUBSIDENCE 1979 - 1983		LAND SUBSIDENCE 1984 - 1989		LAND SUBSIDENCE 1979 - 1989	
	TOTAL (cm)	AVERAGE (cm/y)	TOTAL (cm)	AVERAGE (cm/y)	TOTAL (cm)	AVERAGE (cm/y)
2. Land Development Department	45.5	9.1	14.3	2.4	59.8	5.4
4. Post & Telegraph Department	52.0	10.4	18.0	3.0	70.0	6.4
5. Khuru Sapha Printing	50.0	10.0	14.8	2.4	64.8	5.9
10. Ramkamhaeng University	56.0	11.2	17.0	2.8	73.0	6.6
14. Wat Rajsathathum	50.0	10.0	23.5	3.9	73.5	6.7
16. Aviation Division, Police Department	46.8	9.3	16.9	2.8	63.7	5.8
18. National Housing Authority, Khlong Chan	57.8	11.5	17.0	2.8	74.8	6.8
21. Meteorological Department, Bang Na	52.0	10.4	22.4	3.7	74.4	6.8
AVERAGE		10.2		2.9		6.3

(modified from NEB 1990)

TABLE 2.4.2 THE AMOUNT OF GROUNDWATER USED IN THE CONTROL AREA OF THE REMEDIAL MEASURES, IN CMD (Ramnarong, 1990)

Year	MWA		Private		Total Groundwater Use	% Increase or Decrease
	Pumpage	% Increase or Decrease	Pumpage	% Increase or Decrease		
1982	446,343		944,305		1,390,648	
1983	391,311	-12.0	3,993,842	+5.2	1,385,153	-0.4
1984	356,765	-8.8	1,066,029	+7.2	1,422,794	+2.7
1985	299,721	-16.0	1,014,433	-4.8	1,314,154	-7.6
1986	193,642	-35.4	1,005,192	-0.9	1,198,834	-8.7
1987	207,470	+7.1	1,052,496	+4.7	1,259,966	5.1
1982-1987				ave. +2.3		
1988	181,900	-12.3	1,102,000	+4.7	1,283,910	+1.9
1989	110,423	-39.3	1,183,407	+7.4	1,293,830	+0.8
1990	73,000	-33.9	1,257,710	+6.3	1,330,710	+2.8

Note: Control area covers Bangkok, Samut Prakan, Nonthaburi, and Prathum Thani.



after Nutalaya et al., 1989

Figure 2.4.1	AREAL DISTRIBUTION OF PIEZOMETRIC LEVEL CHANGE IN PHRA PRADAENG AQUIFER, 100M ZONE
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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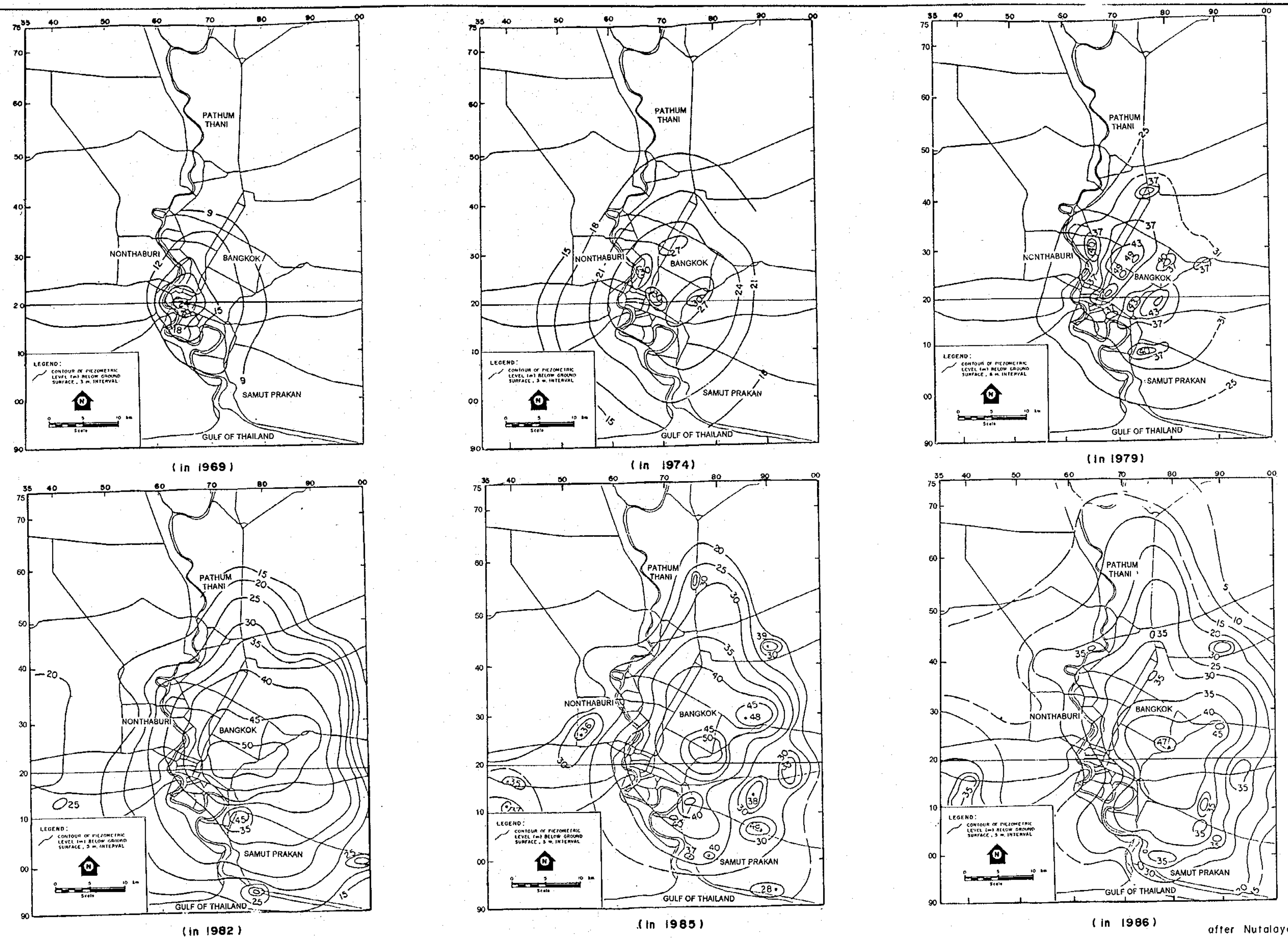

after Nutalaya et al., 1989

Figure 2.4.2	AREAL DISTRIBUTION OF PIEZOMETRIC LEVEL CHANGE IN NAKHON LUANG AQUIFER, 150M ZONE
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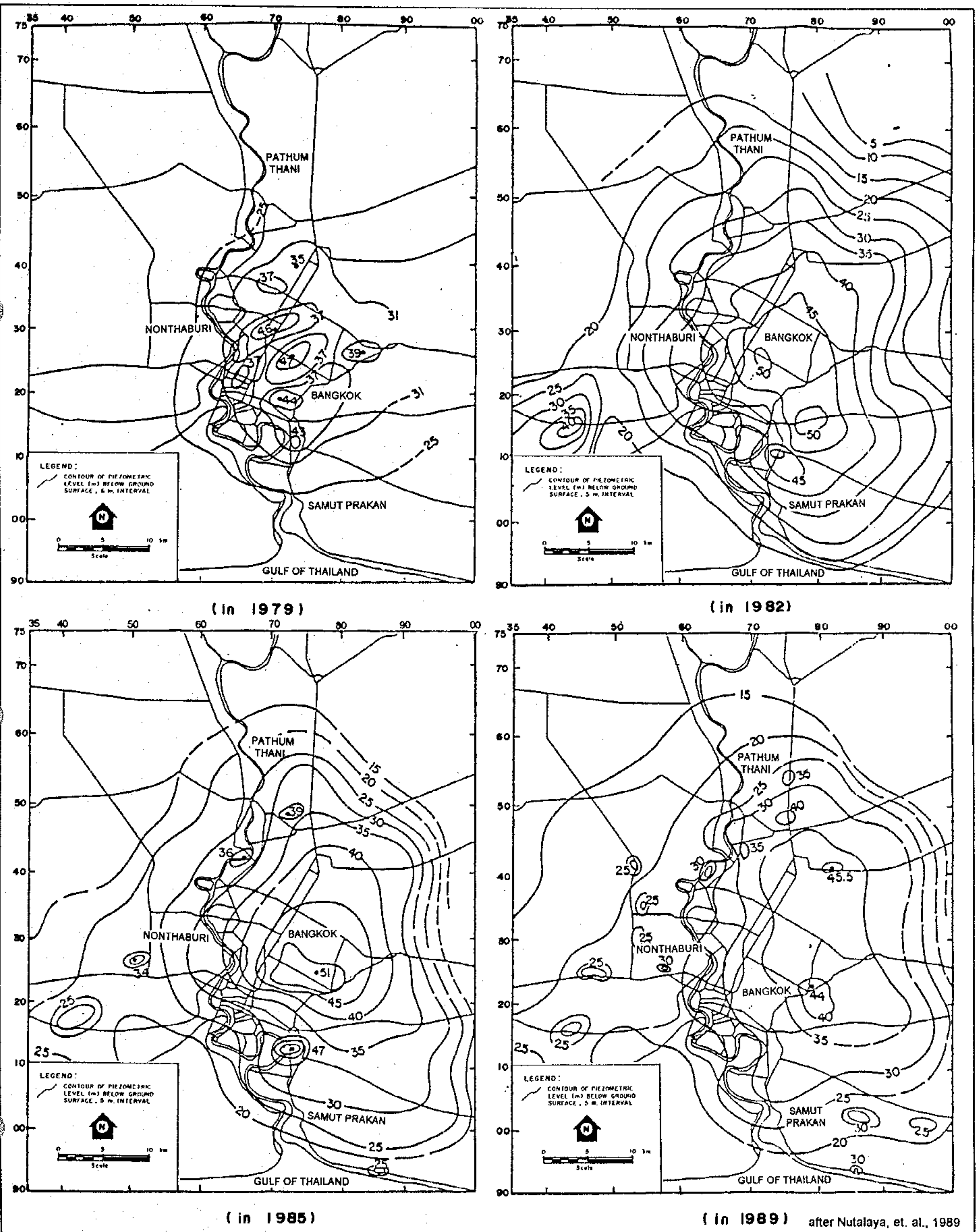

after Nutalaya, et. al., 1989

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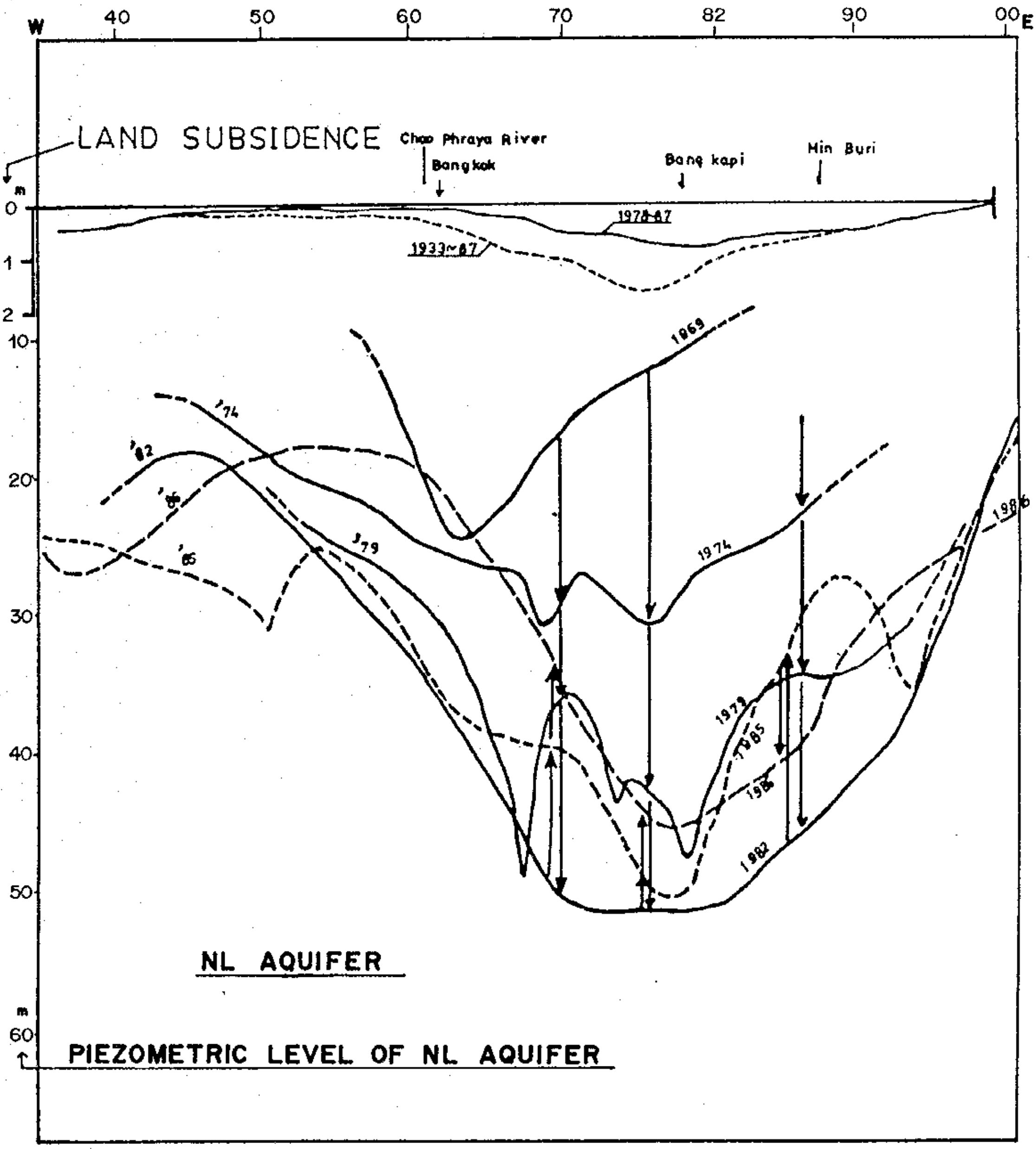

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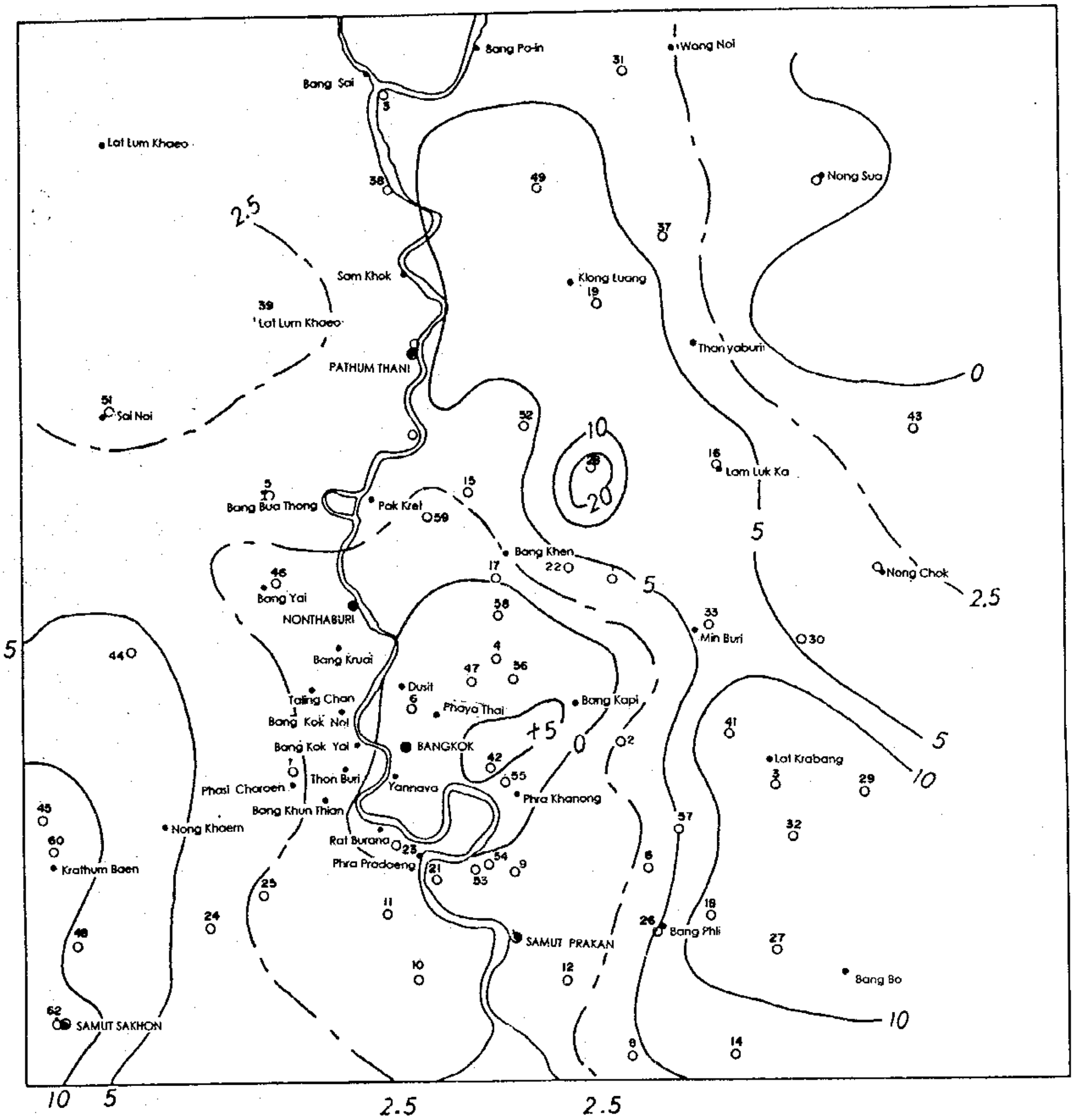

5 — CONTOURS ARE LINES OF EQUAL DECLINE IN METERS FOR THE PERIOD JAN 1987 - DEC. 1991

○ DMR OBSERVATION WELLS

Data Source DMR

Figure 2.4.5	DECLINE OF THE PIEZOMETRIC LEVEL OF NAKHON LUANG AQUIFER (1987-1991)
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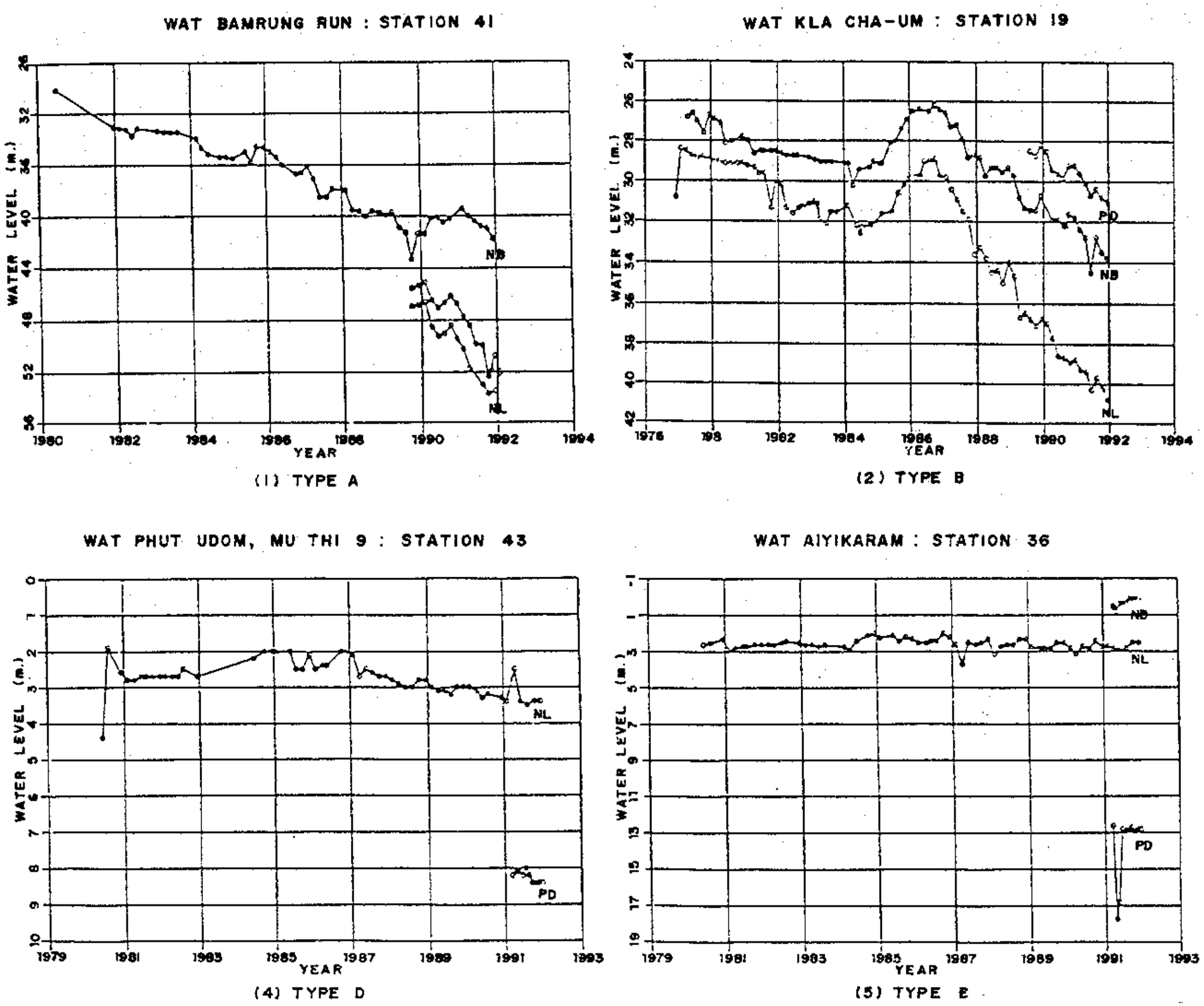

Data Source DMR

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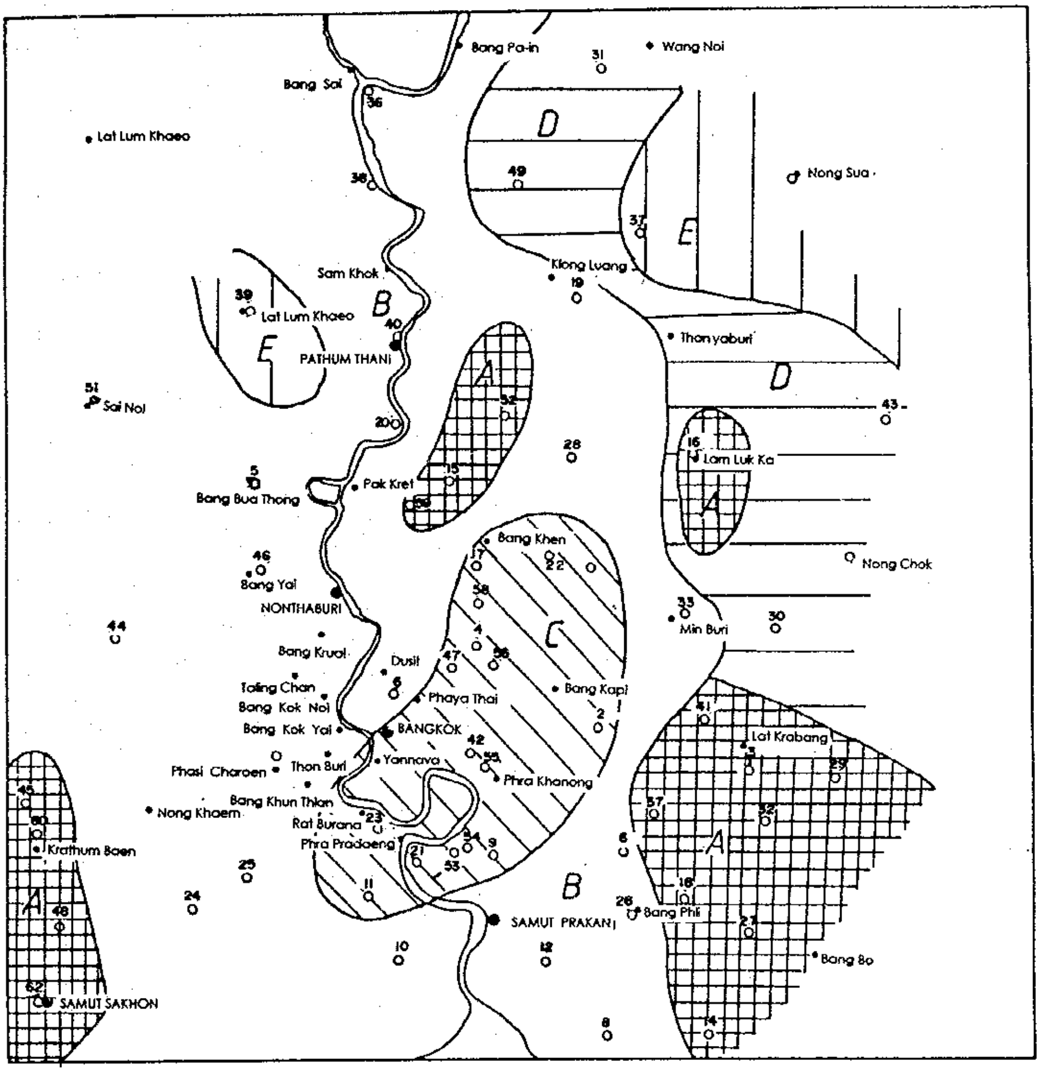

LEGEND:

TYPE A : WATER LEVEL IS RAPIDLY DECLINING

TYPE B : WATER LEVEL IS RAPIDLY DECLINING WITH A SHORT PERIOD OF RECOVERY BETWEEN 1984 AND 1987

TYPE C : WATER LEVEL HAS RECOVERED SINCE 1984

TYPE D : WATER LEVEL IS SLOWLY DECLINING

TYPE E : WATER LEVEL IS STABLE OR NOT CHANGING

DMR OBSERVATION WELLS

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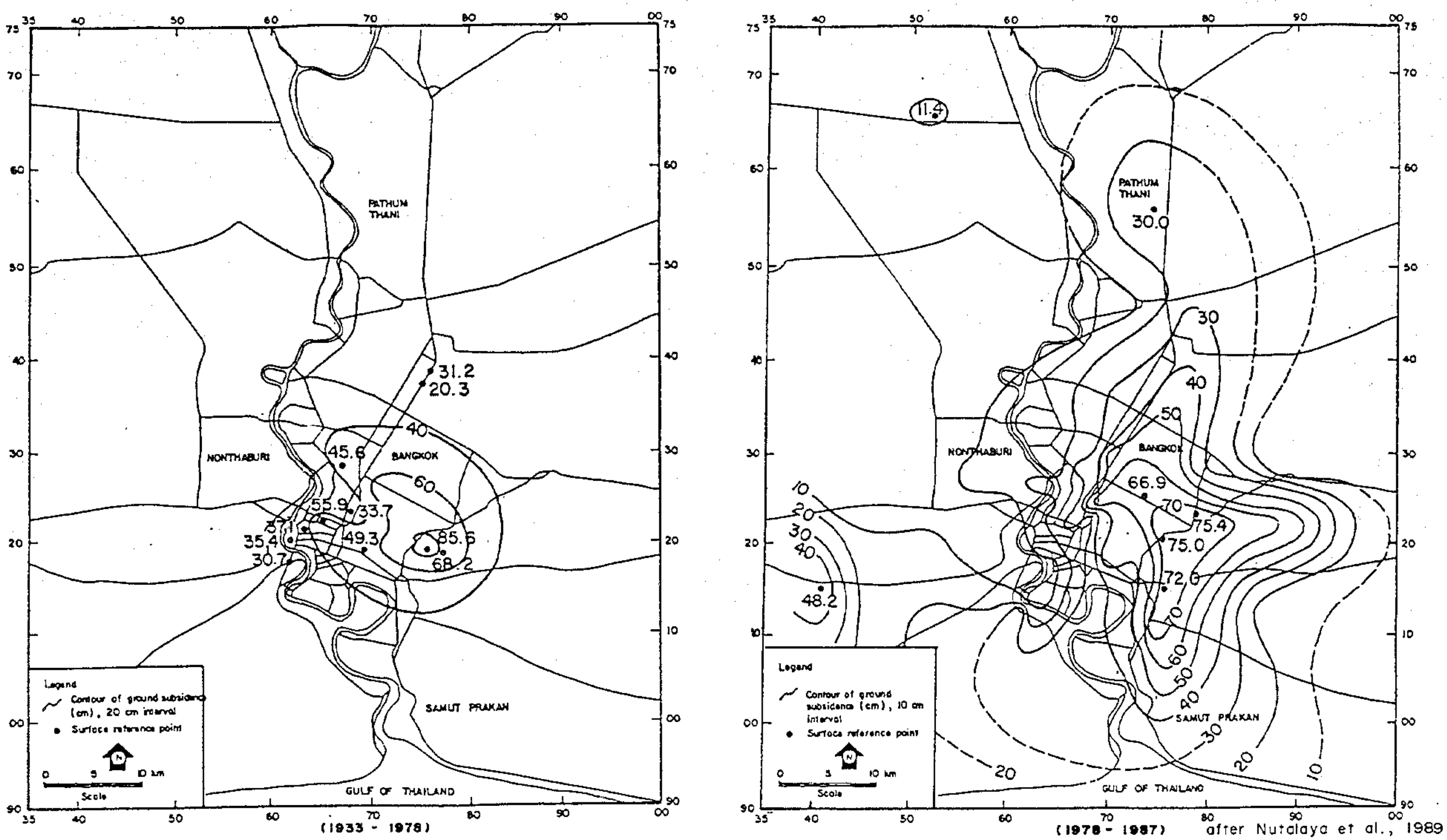

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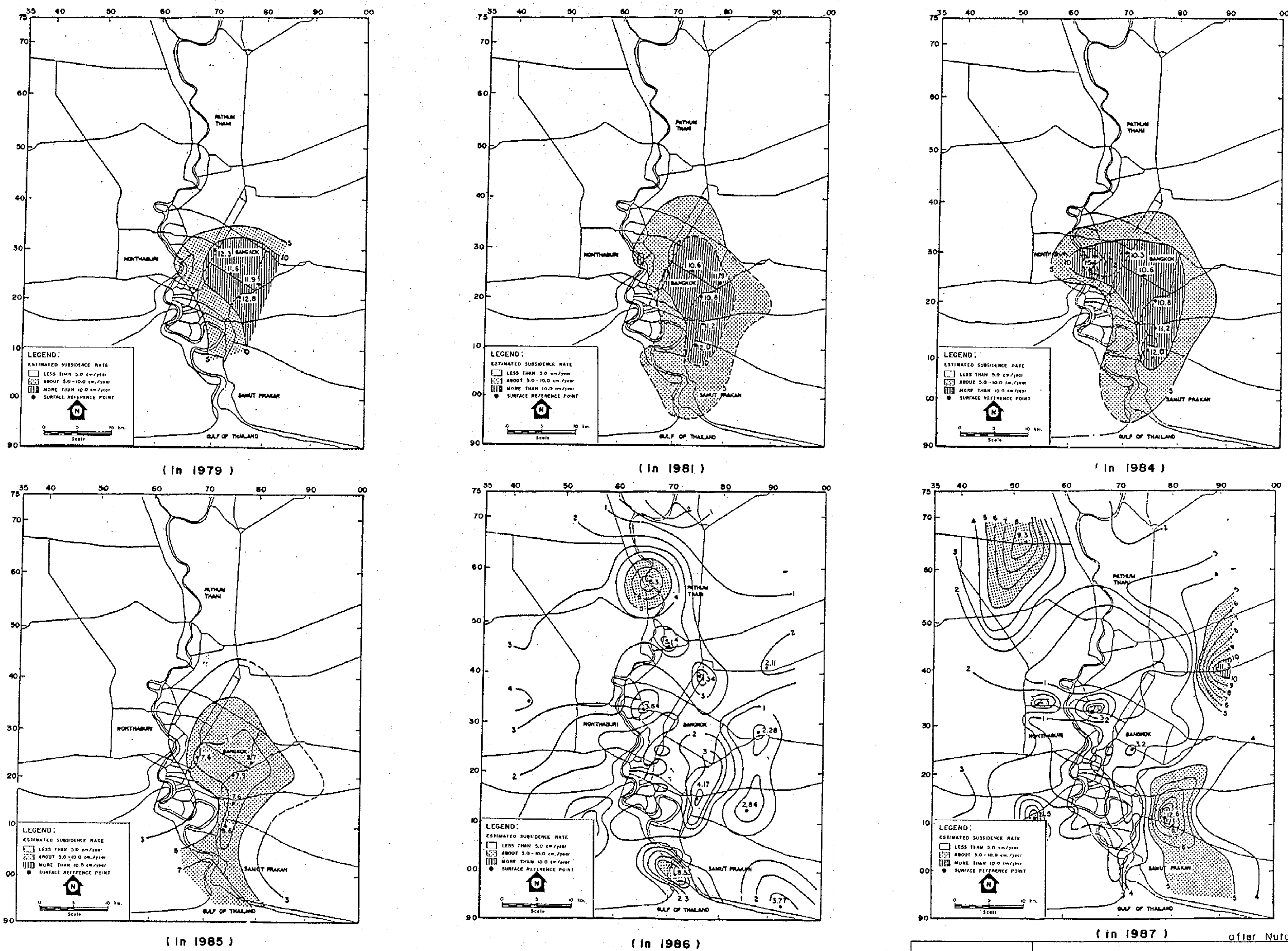

after Nutalaya et al., 1989

Figure 2.4.9	TOTAL LAND SUBSIDENCE IN BANGKOK

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

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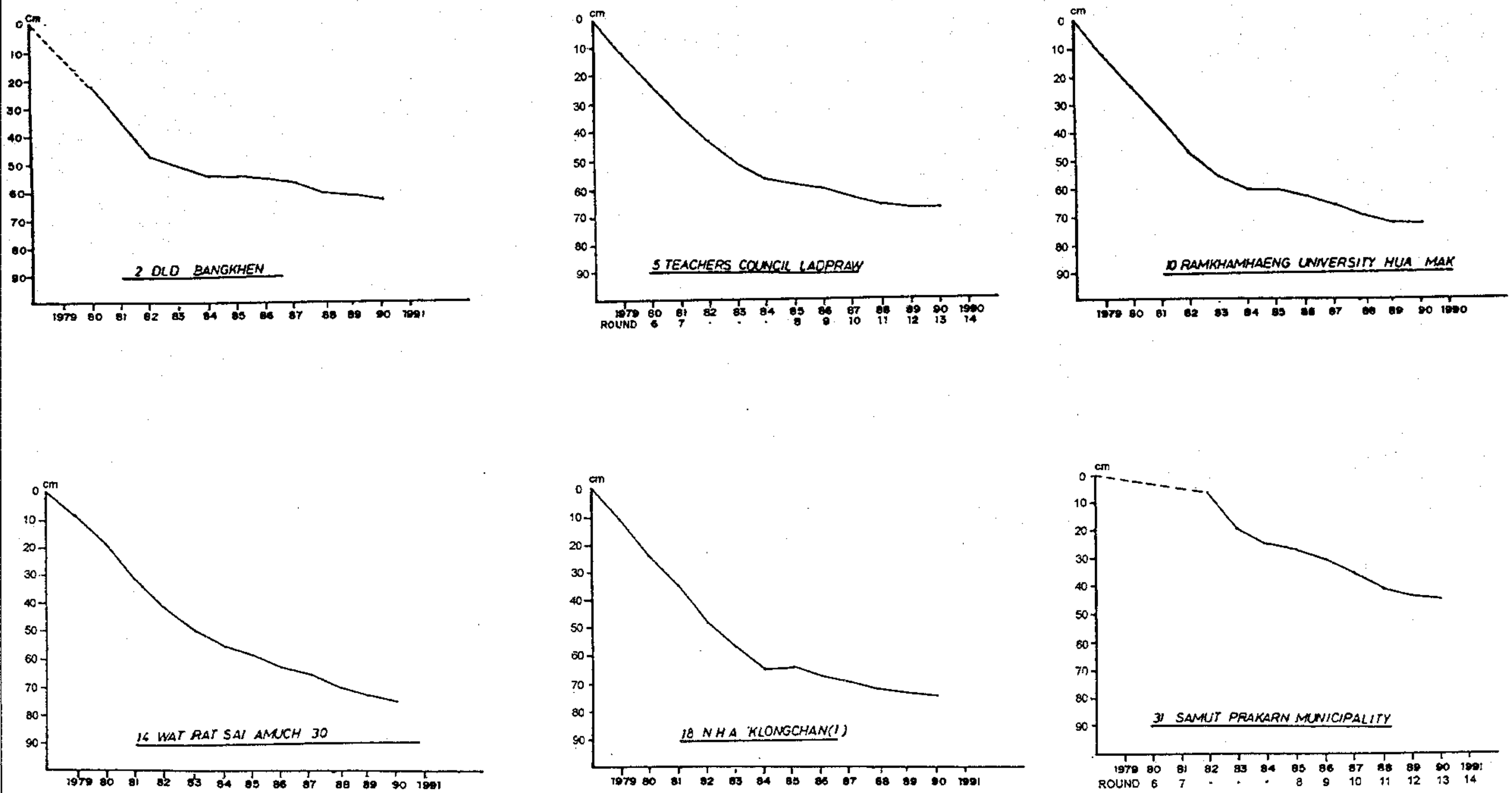

after NEB, 1990

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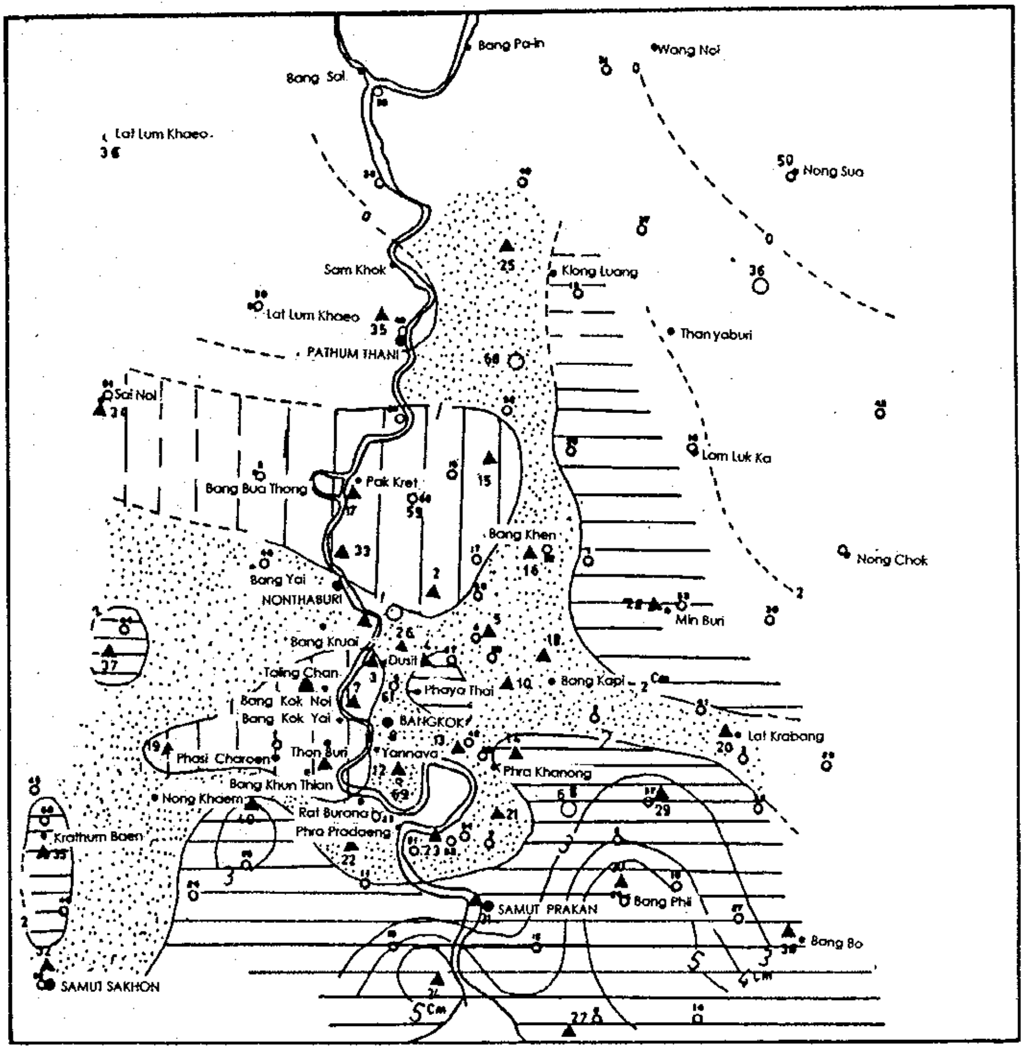


LEGEND

Scale

+ - 0 cm

0.0 - 1.0 cm

1.0 - 2.0 cm

2.0 cm -

NEB CI Land Subsidence Station

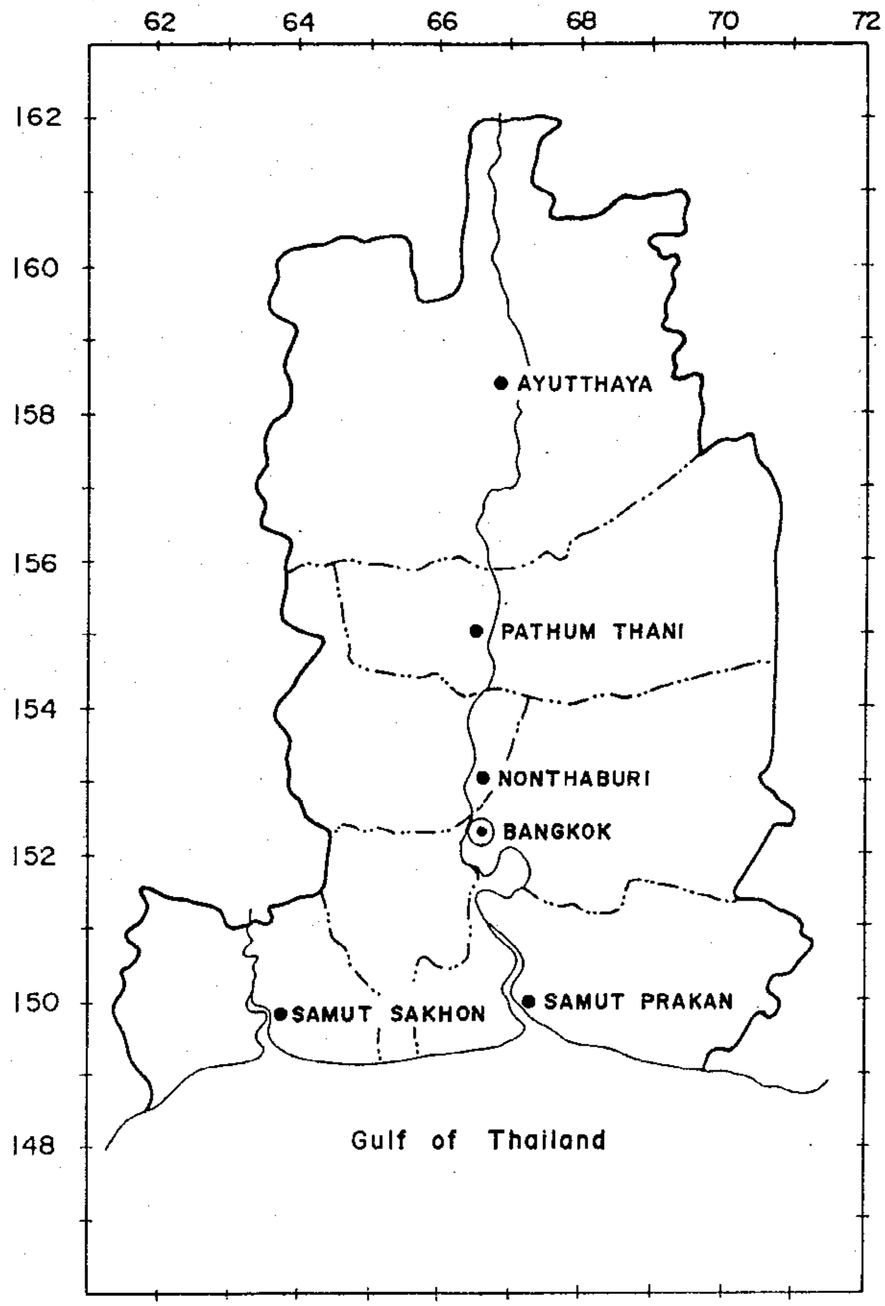
DMR Observation Wells

RTSD. report, 1991

Figure 2.4.11	1991 LAND SUBSIDENCE DISTRIBUTION IN THE STUDY AREA (RTSD, CI-1, 1M BM)

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.



AYUTTHAYA	2,480	km^2
BANGKOK	1,550	"
NONTHABURI	622	"
PATHUM THANI	1,497	"
SAMUT PRAKAN	934	"
SAMUT SAKHON	840	"
	7,923	km^2

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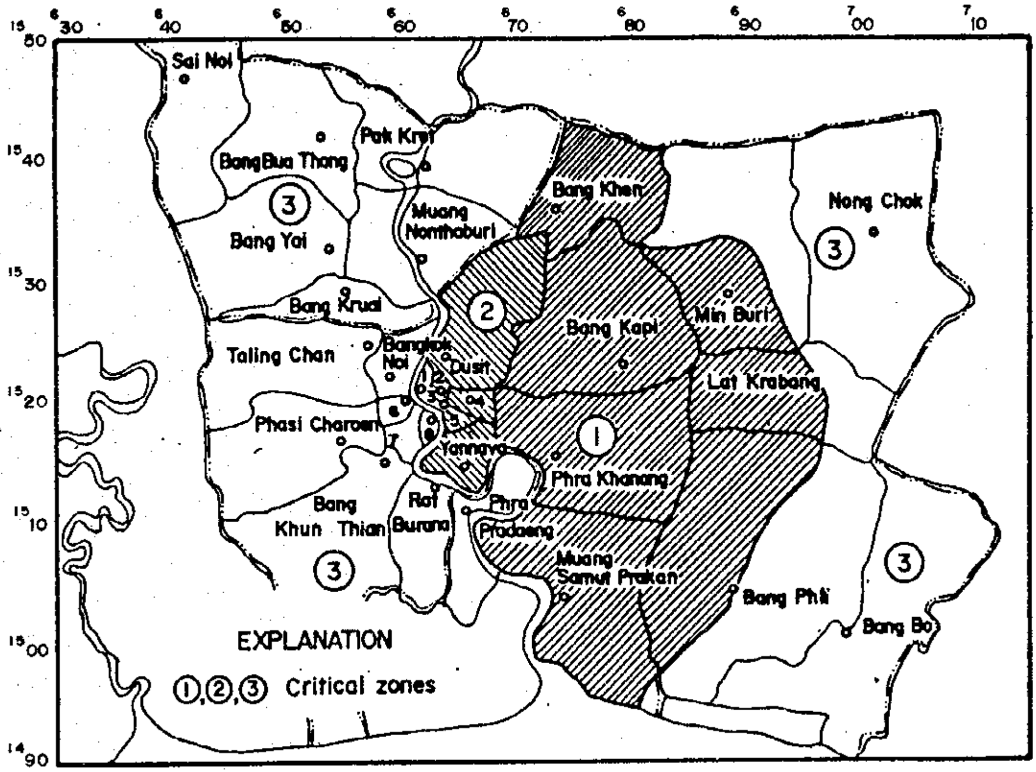

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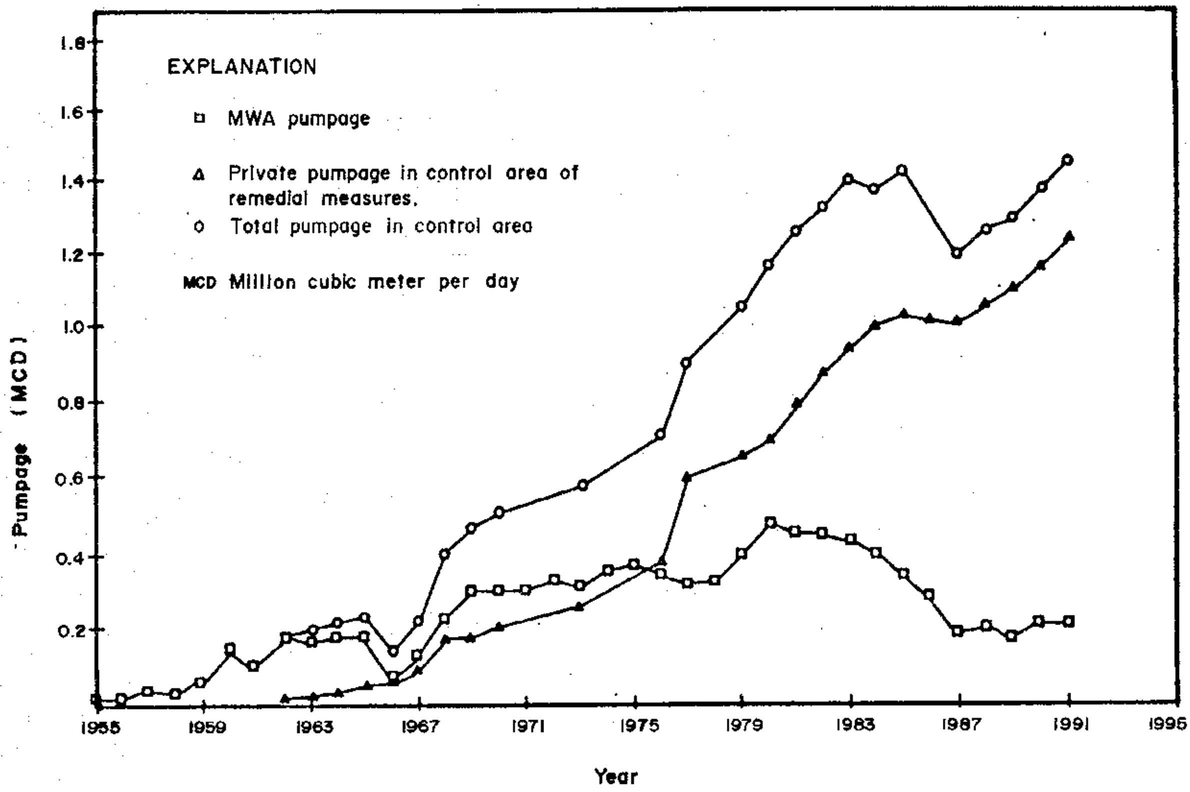

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JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

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CHAPTER 3 AQUIFER SYSTEM

3.1 Topography and Geology

The Lower Central Plain stretches 150 km from east to west and 200 km from north to south and forms a flat plain with elevations ranging from 0 m to 20 m above MSL.

Previous studies (Takaya, 1968, 1972 and Thiramongkol, 1983), classified the plain into the following landforms: mountain, hill, middle terrace, high terrace, old and young alluvial fans, delta, tidal flat and flood plain, etc. (Figure 3.1.1).

Table 3.1.1 presents the geologic facies and correlations; Figure 3.1.2 shows a schematic geologic model of the plain.

Structural Terrace in Marl is distributed in the inter-mountain valleys, forming a gentle slope. Mountains consisting of Palaeozoic limestone are located in the northeastern part of the plain. Terrace deposit is composed of white massive marl of lacustrine of the Miocene to Pliocene age.

Peneplain is distributed east of Bang Pakong River, ranging in altitude from 10 m to 100 m. The partly consolidated deposits consist of laterite, weathered granite, etc. The age of these deposits is thought to be of the Pliocene to Early Pleistocene.

The 40 km wide High Terrace stretches in the N-S direction in the western part of the plain. The terrace height which inclines to the east varies from 30 m to 150 m. Monadnocks consisting of Palaeozoic to Mesozoic rocks are distributed within the terrace. The terrace deposits consisting of laterite, sand, silt and granular sand were formed in the Pliocene to Early Pleistocene age. The laterite has a honeycomb structure.

Middle Terrace is distributed narrowly between the High Terrace and the Peneplain. Its height ranges from 3 m to 40 m, with the northern and western parts slightly higher. Its clay, sand and gravel deposits are partly intercalated with laterite. This laterite bed contains pisolitic or iron oxide botryoidal concretion. Mammal fossils, such as Hippopotamus and Stegodon, are found in the laterite bed located near Nakhon Sawan. The deposit is thought to be of the Middle Pleistocene (Von Koeningswald, 1959).

Old Alluvial Fans are distributed in the west, as Non Chang Fan (with elevations of 20 m-100 m) and Don Chedi Fan (with elevations of 5 m-45 m), and in the east, as Pasak Fan (with elevations of 5 m-40 m). Composed of clay, silt, sand and gravel, the fan deposit is intercalated with laterite. Believed to be a deposit of the Middle Pleistocene age, this laterite also contains iron oxide pisolitic botryoidal concretion.

Young Alluvial Fan which is called Mae Klong Fan has elevations ranging from 5 m to 20 m, inclining gently towards east. The deposit consists of alternating beds of sand, clay, silt and gravel. Upper parts of the sandy and clayey beds contain iron-oxide pisolitic nodules. Total thickness of the deposit is estimated to be more than 80 m, and its geologic age is thought to be of the Middle to Late Pleistocene (Nanthaphisarm, 1976).

Delta of Fluviatile Sediments is formed in the 60 km wide and 80 km long zone located between the fan and the structural terrace. Its elevations range from 6 m to 18 m and inclines 3° towards the south. The deposit is composed of silty clay and sandy loam and also contains pisolitic concretion and iron oxide. High concentration of manganese oxide can be observed in the deposit. Many outcrops show that this bed covers another bed that contains high concentration of calcareous nodules. The deposit which is believed to be of the Late Pleistocene age was formed in the shallow sea and deltaic environment of the high sea level (Monastirian Stage) from 8 m to 15 m above MSL. The deposit may be correlated with the facies of the bed distributed at the depth of about 60 m in the Study Area.

Delta of Brackish Sediments is distributed in the north of Ayutthaya. The delta's elevations range from 4 m to 12 m above MSL and inclines 3° towards the south. Its deposit is composed mainly of clay with dark or black grayish color. Clay with yellow or brown color is seen in the weathered part of the deposit. The deposit also contains manganese and iron pisolitic nodules and thought to be formed in the Late Pleistocene. This bed can be correlated with the Bangkok Stiff Clay.

Tidal Flat of Brackish Clay stretches in the south of the plain. It is 120 km wide and 80 km long and 2 m to 3 m high. Its deposit is composed of clay with dark or black color. No concentration of nodule is observed in the deposit. But, it contains shell and crab fossils. Thickness of the deposit is about 2 m to 3 m in Ayutthaya and 20 m in Bangkok. The ^{14}C dating results in ages of 4030+120 YBP to 7440+150 YBP, which means that the clay was deposited during the Holocene Transgression. This clay deposit can be correlated with the Bangkok Soft Clay.

Barrier is distributed in the south and southeast of the plain. Its elevations are 1 m to 3 m higher than those of the surrounding areas. The ^{14}C of shell fragment contained in the deposit indicates an age of 3670+125 YBP. It might be supposed that the deposit was formed at a temporal stagnant stage of the sea level when the regression was followed by the maximum Holocene Transgression.

Tidal Flat of Marine Clay is distributed along the coast and its elevations range from 0 m to 3 m. The deposit consists of dark to black clay and brown to blue clay; and, ^{14}C dating indicates its age at 2250+100 YBP and 3650+120 YBP. This deposit can be correlated with the upper part of the Bangkok Clay (Top Clay).

3. 2 Results of Core Borings

Core borings were conducted to investigate subsurface hydrogeologic 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

The locations of these sites are shown in Figure 3.2.1.

Undisturbed samples were taken by thin wall sampler, while disturbed samples were collected by SPT sampler up to a depth of 50 meters. Core samples at depth from 50 to 600 meter were taken by using wireline core barrel. All core samples were gathered to AIT site for lithologic description, photographs, and selection of samples for soil tests and core analyses. The results of soil tests are presented in the Supporting Report.

3.2.1 Hydrogeological Classification

Hydrogeological classification at the three (3) sites was made based on the results of core observations, standard penetration tests (SPT), and geophysical loggings. To determine the aquifer names based on the hydrogeological classification in DMR (1992), the lithologic logs and geophysical logs were compared with those of the DMR monitoring wells located near the sites.

Site-A (refer to Figure 3.2.2)

Sixteen (16) facies units were identified based on the detailed lithologic logs and the results of geophysical loggings. Geophysical logging results were generally in good agreement with the facies. The geophysical logs indicated changes of geologic materials at depths of 20 m, 60 m, 150 m, 300 m, 400 m, and 500 m, where these boundaries could be unconformities.

The resistivity log provided useful information about facies changes from depths of 60 m to 400 m, but low resistivity values were measured in the shallow portion up to a depth of 60 m due to the occurrence of saline water. The resistivity values were also low, below 400-m depth, due to the occurrence of dense mud water.

The SP-logs which were in good agreement with the resistivity logs could identify aquifers.

The natural gamma log showed a clear boundary of gamma ray patterns at 300-m depth. Above this boundary, a relatively low but stable gamma ray was detected; below this boundary, the log indicated higher levels of radioactivity. This high gamma ray which was detected at a depth of 385 m was due to the occurrence of carbonized wooden fragments.

As demonstrated in Figure 3.2.2, the detailed correlation of the lithologic log with the geophysical logs shows that the facies units can be divided into small aquifer units. The formations from the ground surface to the depth of 600 m were hydrogeologically categorized into the aquifer units in DMR (1992). For this purpose, several hydrogeological profiles were made and the continuities of geologic formation were examined. The top clay usually referred to as the Bangkok Clay was divided into soft clay and stiff clay. The hydrogeological classification at Site-A is summarized as follows:

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+

It is also possible to subdivide Nakhon Luang and Nonthaburi Aquifers into upper and lower portions based on the sedimentary cycle.

Site-B (refer to Figure 3.2.3)

Eleven (11) facies units were identified based on the detailed lithologic logs and the results of geophysical loggings. Geophysical logging results were generally in good agreement with the facies.

The resistivity log provided useful information about facies changes from depths of 87 m to 209 m, but low resistivity values were measured in the shallow portion up to a depth of 87 m due to the occurrence of saline water. The resistivity values were also low between depths of 209 m and 260 m due to occurrence of clay and silt.

The SP-logs which were in good agreement with the resistivity logs could identify the aquifers even in the portion where the saline water occurred.

High gamma ray was detected up to a depth of 209 m at clayey formations. From depths of 209 m to 260 m, the natural gamma log showed a relatively low gamma ray. This pattern could be seen usually at sandy formations. However, said layer consisted of partly lateritic clay and silt with calcareous nodules and botryoidal oxidized iron. Also, geophysical logging results showed that it was composed of loose fine materials and had a high conductance. It was presumed that the sediments were under high temperature and in a dry environment. The formations from 163 m to 170 m had the same sediments. At about 123-m depth, thin intercalated clay beds emitted high gamma ray intensity.

As shown in Figure 3.2.3, the detailed correlation of the lithologic log with the geophysical logs shows that the facies units can be divided into 13 aquifer units. The formations from the ground surface to the depth of 300 m were hydrogeologically categorized into the aquifer units in DMR (1992). For this purpose, several hydrogeological profiles were made and the continuities of geologic formations were examined. The top clay usually referred as the Bangkok Clay was divided into soft clay and stiff clay. 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+

It is possible to subdivide Phra Pradaeng and Nakhon Luang Aquifers into upper and lower portions based on the sedimentary cycle.

Site-C (refer to Figure 3.2.4)

Thirteen (13) facies units were identified based on the detailed lithologic logs and the results of geophysical loggings. Geophysical logging results were generally in good agreement with the facies.

The resistivity log provided useful information about facies changes from depths of 60 m to 325 m, but low resistivity values were measured above the 60-m depth due to the occurrence of saline water.

The SP-logs which were in good agreement with the resistivity logs could identify clearly both sandy and clayey formations even in the portion where the saline water occured.

The natural gamma log also indicated clayey formations. The Bangkok clay occurring at shallow depths was characterized by a low gamma ray intensity.

As shown in Figure 3.2.4, the detailed correlation of the lithologic log with the geophysical logs shows that the facies units can be divided into 29 aquifer units. The formations from the ground surface to the depth of 325 m were hydrogeologically categorized into the aquifer units in DMR (1992). For this purpose, several hydrogeological profiles were made and the continuities of geologic formations were examined. The top clay usually referred as the Bangkok Clay was divided into soft clay and stiff clay. 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+

It is possible to subdivide Phra Pradaeng, Nakhon Luang and Nonthaburi Aquifers into upper and lower portions based on the sedimentary cycle.

3.2.2 Analysis of Core Samples

Core samples were analyzed for the following items.

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

(1) ^{14}C Dating

The radiocarbon dating (^{14}C dating) was used to determine the absolute age of a sample by measuring the proportion of the isotope ^{14}C in the carbon it contained. The method was suitable for determining ages up to a maximum of about 50,000 years.

Results of ^{14}C dating is shown as follows:

LOCATION NO.	DEPTH in Meter	LITHOLOGY	Age
Minburi A-1	1.00-1.45	Clay,dark gray	1,110±100
Minburi A-2	8.00-8.45	Clay,dark greenish gray	4,850±140
Minburi A-3	11.00-11.45	Clay ,dark gray	7,170±550
Minburi A-4	17.00-17.45	Clay ,dark gray	8,620±340
Minburi A-5	385	Silt, black, peaty	>37,840
AIT B-1	3.00-3.45	Clay, dark greenish	5,730±470
AIT B-2	4.00-4.45	Clay, dark greenish	8,040±380
AIT B-3	7.00-7.45	Clay,dark greenish	8,400±140
AIT B-4	9.00-9.45	Clay,dark greenish	7,550±140
AIT B-5	11.00-11.45	Shell fossil	3,510±200

*Age in Year since 1950.

It was considered that the inversion of age in AIT B-4 was caused by mixing of younger ^{14}C from groundwater.

(2) Diatom Analysis

Most samples did not contain diatom fossils. At Site-A, five (5) out of 39 samples contained diatom fossils; at Site-B, only one (1) out of 21 samples contained diatom fossils; and at Site-C, only two (2) out of 19 samples contained diatom fossils.

The samples containing diatom fossils are as follows:

Site	Sample No.	Depths
Site-A	D-A1	4.00- 4.45 m
	D-A2	10.00-10.45 m
	D-A3	16.00-16.45 m
	D-A4	18.00-18.45 m
	D-A5	20.00-20.45m
Site-B	D-B1	2.00- 2.45 m
Site-C	D-C1	8.00- 8.45 m
	D-C2	14.00-14.45 m

The diatoms found in the above samples were presented in the Supporting Report.

(3) Foraminifera Analysis

Clayey or silty sediments are suitable samples for the foraminifera analysis. Foraminifera analysis can also estimate the sedimentary environment and can be used for stratigraphic correlation.

After thorough examinations, it was found that only a few samples, representing the uppermost parts at Site-A and Site-C, contained foraminifera. No foraminifera fossil was detected at Site-B.

All samples that contained fossils came from the uppermost part of the borehole section. Hence, it was reasonable to assume that they were of the same age.

Planktonic foraminifera, which is a very good and widely used tool in age determination, was completely absent in the samples. Although the degree of reliability was not so high, age determination from the foraminiferal point of view was therefore based only on the occurrence of benthonic forms. However, the occurrence of nannofossil species at Site-C (depths: 14.00 m-14.45 m) provided a good dating tool, hence a more conclusive result could be made.

Billman et al. (1980) recorded the stratigraphic range of Asterorotalia milletti in the Indopacific region as Pleistocene (N.22-N.23, Blow, 1969). The occurrence of the nanno-fossil specie *Gephyrocapsa oceanica* in abundance and the absence of species *Pseudoemiliania lacunosa, Emiliania huxley* and *Gephytocapsa caribbeanica* (in F-C2 sample) suggested that an age of Pleistocene of Billman *et al.* (1980), Zone CN 14b of Okada and Burky (1980) or Zone NN 20 of Martini (1971) could be assigned to the sample. It meant that the uppermost sections at Site-A and Site-C were stratigraphically higher than the Brunhes/Matsuyama paleomagnetic epoch boundary or younger than 0.73Ma. These nannofossil zones could be correlated partly with Zone N 23 in terms of planktonic foraminiferal biostratigraphy.

3.2.3 Environments of Deposition

Samples from the three (3) boreholes which were barren of foraminifera were interpreted as continental deposits (river or fluvial deposits). There were at least two (2) distinct extreme types of roundness, i.e., angular and rounded, shown by the sand grain composition of the sediments. Euhedral bipyramidal quartz grains were also found in many samples. These observations suggested that the sediments were continental deposits (fluvial) having at least two (2) different sources of materials; one was located relatively much farther from the site than the other. Also, the carbonate material that was often found in the sediments might represent caliche.

The depositional environments of samples containing foraminifera and other fossils are discussed as follows. These samples have one thing in common: planktonic foraminiferal species are totally lacking. This suggests that the environments in which they were deposited were poorly connected with the open sea, which resulted also in a poor circulation of water among them. It is concluded therefore that the samples might have been deposited in a marginal sea environment.

The depositional environments of the foraminifera-bearing samples are described in detail in the following discussions:

Site-A

The deepest sample containing foraminifera in this site comes from the depth of 20.45m where rare specimens of *Ammonia beccarii* and *Pseudorotalia schroeteriana* are found and accompanied by some shell fragments, echinoid spines, etc. This association indicates a shallow marine environment, probably very near the shore. This condition persisted up to the time of the deposition of the sample from 18.45-m depth, which contains rare *A. beccarii* and a few shell fragments.

The maximum marine condition in this area was achieved during the deposition of sample F-A1 (depths: 16.00 m-16.45 m) which contains quite a number of specimens of *A. trisspinosa*, *A. subtrispinosa*, and *Pararotalia sp.* Also, this sample contains echinoid spines and molluscan shell fragments. This paleontological association might probably indicate a shallow bay environment.

Site-C

The deepest sample containing foraminifera comes from the depth of 25.6 m where only a single specimen of *Spiroloculina* and molluscan shell fragments are found. This suggests that the sample was deposited probably in a littoral environment.

Sample from 16.45-m depth contains more foraminifera and echinoid spines and some shell fragments. The depositional environment was more or less the same (littoral) but probably a slight deepening had taken place.

Further deepening of the sea is interpreted based on the paleontological evidence of the sample from depths of 14.00 m-14.45 m. This sample is characterized by dominant association of *Ammonia beccarii*, *Asterorotalia trispinosa*, and *Elphidium advenum*. Other important species occurring in this sample are *Spiroloculina terquemiana*, *Quinqueloculina sp*, *Textularia foliacea*, and *Pseudorotalia schroeteriana*. Molluscs and ostracoda are abundant. The sample also contains echinoid spines and abundant nannofossil specie *Gephyrocapsa oceanica.*

Ammonia beccarii and *Elphidium* are both euryhaline (tolerant to a wide range of salinity) and shallow water species. The association of the two are common in the marginal seas (bay, lagoon, etc.) and shallow shelf seas. The occurrence of *A. trispinosa*, *P. schroeteriana*, *Quinqueloculina sp*, and *T. foliacea* suggests that the salinity was very close to a normal marine condition. This is supported by the occurrence of the marine molluscan species. *Gephyrocapsa oceanica* is very abundant in the marginal sea and inland sea environments (Okada, 1984 in: Perch-Nielsen, 1985).

Based on the lithological and paleontological data, it is concluded that the depositional environment of the sample from depths of 14.00 m-14.45 m was the outer part of the bay where the salinity was close to a normal marine condition. The depth was probably around 40 m and the bottom was muddy.

Paleontologically, the sample from 8.00-m to 8.45-m depths resembles the sample from depths of 14.00 m to 14.45 m. However, *A. beccarii* is very dominant and extremely abundantly. At the same time, *Elphidium* is much less dominant than in the sample from

8.00-m to 8.45-m depths. This may indicate a regression of the sea although the depositional environment of the sample is still a bay.

3.2.4 Salt Content Analysis

Salt contents in the samples helped in analyzing the occurrence of saline water and the mechanism of saline water intrusion as well as the sedimentary environment.

Preparation of Samples

Clayey or silty sediments are suitable samples for the salt content analysis. Samples are prepared using the following procedure. Break the sample into granule-size pieces and then dry them under a temperature of 110°C for 48 hours; grain the sample into the size finer than the 32-mesh; take 10 grams of the sample and put it into a 140-cc test bottle; add 120cc of pure water, stir it for 3 minutes and leave it for one hour; and finally analyze the turbid water.

Method of Analysis

Measure the chloride concentration and electric conductivity of the turbid water; keep the water samples for five days without evaporation; and finally measure again the chloride content and electric conductivity. Unless there is a significant difference, the latter measured values are adopted. The chloride concentration in mg/l is converted into chloride content in g/kg. Also, the measured value of electric conductivity is corrected for temperature of 25°C.

Results of Analysis

Figure 3.2.5 shows that the three (3) sites have high salt content in the shallow portion up to a depth of about 50 m and low in the deeper portions. It is also shown that the changes in the electric conductivity are similar to those in the chloride content.

At Site-A, chloride content is 1.71g/kg at 31.0-m depth and 1.28g/kg at 59.8-m depth. The chloride contents from 89.0-m to 200.1-m depths range correspondingly from 0.14g/kg to 0.37g/kg, while the electric conductivities vary respectively from 115mS/cm to 141mS/cm. The samples from 240.0-m to 550.4-m depths have chloride contents of 0.10g/kg or lesser and electric conductivities ranging from 47.2mS/cm to 57.8mS/cm.

At Site-B, the sample from 27.0-m depth has the highest salt content: chloride content is 2.18g/kg and electric conductivity is 1,980mS/cm. The chloride contents from 149.5-m to 265.4-m depths are 0.10g/kg or lesser. On the other hand, the electric conductivities decrease from 300mS/cm at 50.1-m depth to 28.5mS/cm at 149.5-m depth. But they are relatively higher at deeper layers, ranging from 107mS/cm at 180.3-m depth to 147mS/cm at 208.4-m depth.

At Site-C, the sample from 17.0-m depth has the highest chloride content at 3.51g/kg and the highest electric conductivity at 1,190mS/cm. Between 17.0-m depth and 69.9-m depth, salt content decreases; from 89.0-m to 314.9-m depths, chloride content is less than 0.10g/kg.

As shown by the results discussed above, the shallow portions at the three (3) sites, up to around 50-m depth, are affected by salinity. The occurrence of high salt content in the shallow portions may be explained considering the results of microfossil analyses and hydrogeologic investigations. Also, the soil content analysis showed that no fossil water occurred in the deeper portions

3.3 Basement Structure

Previous studies conducted through airborne magnetic survey and drilling show that the basement rocks are composed of granite, gneiss, sandstone and limestone and that the depth of the basement is estimated at 400 m to more than 1,800 m (Achalabuch 1974) (see Figure 3.3.1). The top of the basement is undulated and gradually deepens towards the south to the Gulf of Thailand (Figures 3.3.2 and 3.3.3). The deepest part can be located between the Chao Phraya River and the Tha Chin River. This part is called Samut Sakhon Basin (CCOP, 1991).

Granitic basement rock was found at depths of 385 m to 412 m on the left bank of the mouth of the Chao Phraya River, which may be contiguous to the granite exposed in Chon Buri. Core boring in JICA's Site-A monitoring station (JICA-A) at Lat Krabang did not encounter the granitic rock at 615-m depth. However, arkose sandstone cores taken from this depth indicate that the basement rock is already close.

In the east-west section, the basement is deepest in the central part of the plain. However, in the north-south section, it deepens from Chai Nat, the northern edge of the plain, towards the south to the Gulf of Thailand. On the left bank of the Chao Phraya River, the basement is shallow; thus, the sedimentary basin inland below 400-m depth is closed.

Since the basement depth has a large scale and basement shape has a high relief, the Central Plain can be considered as a Structural Basin formed by diastrophism of the post-Palaeogene.

Based on the data obtained from oil and gas exploration in the Gulf of Thailand, it is estimated that the deposit overlying the basement rock of the Central Plain is composed of coastal deltaic sediments of the Post-Oligocene (Archalabuch, 1974 and Bunopas, 1976). JICA Study's drilling data also supports this idea. Particularly, the transition of meander and distributary of the river after the Pleistocene period can be identified by analyzing the gravel beds at less than 300-m depth (Figures 3.1.2 and 3.3.5). The facies and sedimentary structure may be regulated by the change in sea level under coastal and deltaic environments.

Figure 3.3.3 illustrates the idea of the continuity of the sediments at the bottom of the sea. The bottom of the BK (Bangkok Aquifer) may be contiguous to the sea floor at 75-m below sea level. The NL (Nakhon Luang Aquifer) and other deeper aquifers may not be exposed at the sea floor.

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 3.3.4 shows the location of the said core drillings and the wells with existing drilling data.

Figure 3.3.5 shows a representative profile of the Study Area.

Boundaries of each formation were determined based on the sequence of the facies; however, the boundaries of the deep formation could not be defined clearly because of the scarcity of data (see Figure 3.3.6). Formation name defined in the MGL Project (DMR, 1992) was used for the present Study.

Based on the boundaries of the sequence, aquifer boundaries were defined at the upper surface of the clay beds that are the most widely distributed in the Study Area (see Figures 3.3.5 and 3.3.6). Therefore, the aquifer units proposed in the present Study has no discrepancy with those of DMR; the concept is also the same. However, isodepth contour maps of some aquifers were drawn based on the analysis of the geologic profiles of the Study Area (see Figure 3.3.7). These maps were never made in the previous studies.

PT (Phaya Thai), TB(Thon Buri) and PN (Pak Nam)

The facies of these formations are alternating beds of brown and brownish grey fine sand, coarse sand and clay (JICA-A). The thickness of each single bed is only a few centimeters. If facies change frequently, it indicates a deltaic sedimentary environment. The clay bed generally intercalated with calcareous and consolidated bed. The sand bed below 400-m depth is also cemented by siliceous or calcareous matrix.

Boundaries of the aquifers were interpreted using the gamma log, resistivity log and the lithologic facies. The boundary-depths of these aquifers are 360-430 m for PT, 430-480 m for TB and 480-600 m for PN (see Figure 3.3.5).

Productive artesian aquifer zones are prominently composed of sand beds, and they are found at depths of around 400 m in PT, 450 m in TB and 550 m in PN.

The deposits of PT, TB and PN may be correlated with the Peneplain and High Terrace deposits of the Pliocene to Late Pleistocene.

SK (Sam Khok)

This formation is mainly composed of fine to medium sand and intercalated with calcareous clay bed. Clay bed contains calcareous nodules and hard consolidated layer. Facies changes are moderate; however, the occurrence of gypsum suggests that the deposition experienced a dry epoch in its history.

The formation is at depths of 280 m to 360 m. Sand and gravel are prominent at depths of 330 m to 350 m and constitute an artesian aquifer.

Its deposits may be correlated with the Pliocene to Early Pleistocene.

NB (Nonthaburi)

The formation consists mainly of fine to coarse sand and is intercalated with calcareous clay bed which contains manganese, iron oxide and calcareous nodules. Thicknesses of sand and clay vary horizontally.

This formation is at depths of 180 m to 280 m, and it can be divided into upper and lower formations. The boundary may be placed at the clay bed which is horizontally distributed at 230-m depth. This clay bed may be correlated with the High Terrace deposit, and its age is estimated to be of the Early Pleistocene. The lower formation is classified as SK in DMR (1992). Gravels in the lower NB are widely distributed, while gravels in the upper NB concentrate in the central part of the Study Area. Productive aquifers are located at depths of 200 m to 250 m.

NL (Nakhon Luang)

The formation is composed of the alternating beds of brown to brownish grey fine to coarse sand, gravel and calcareous clay containing nodules. Thickness of clayey beds varies horizontally from place to place. Gravels consist mainly of granules and occur discontinuously like the shape of a lens (see Figure 3.3.6). The gravel bed is distributed everywhere in the plain. Thick gravel bed occurs particularly in the marginal zone of the plain (see Figures 3.1.2 and 3.3.5).

NL is at 120-m to 180-m depths. This formation may be divided into 4 to 5 layers in terms of gravel bed depositions. However, gravel beds are discontinuous in the horizontal direction. The clayey bed at the 140-m depth spreads continuously and can be traced widely in the plain. Thus, the formation can be divided into upper and lower beds at this clayey layer (see Figure 3.3.6).

Sand and gravel beds constitute good aquifers at depths of 140 m to 150 m. Compared with the lower formations, gravel and sand beds are distributed continuously in the horizontal direction. In the upper NL, a clayey bed separates NL from PD (Phra Pradaeng). This bed discontinuously spreads.

The NL deposition's age may be of the Middle Pleistocene, and the deposition can be correlated with the Middle Terrace and Old Fan in terms of landforms and facies.

PD (Phra Pradaeng)

The formation is composed of alternating beds of thin calcareous clay, thin fine sand and gravel. The clayey bed contains manganese and iron oxide nodules and veins and calcareous nodules. Thick gravel bed is distributed particularly in the east of the Chao Phraya River.

The PD formation is at depths of about 60 m to 120 m. Considering the occurrence of gravel beds, this formation can be divided into 3 to 4 layers. This Study however divides this formation into two (2) layers only, namely, upper bed and lower bed, based on the clay bed distributed at depth of about 100 m (see Figure 3.3.6).

Gravel and sand constitute good aquifers at depths of 90 m to 100 m.

The upper most clay bed, named "Dc", separates this formation from the BK (Bangkok) formation and spreads continuously in the Study Area. This clay bed was deposited maybe during the epoch of high sea level at the Early Pleistocene. Accordingly, PD may be correlated with the Middle to Late Pleistocene.

BK (Bangkok)

The formation is composed mainly of fine to coarse sand and intercalated with brown to black calcareous clay. Gravel is distributed in some places along the Chao Phraya River and Minburi (see Figure3.3.6). Gravel does not occur in the upper part of the formation, i.e., at depths of about 30 m to 40 m. Bangkok Clay widely covers this formation.

BK's gravel and sand beds occur continuously in the horizontal direction and have properties of a good aquifer. However, groundwater is entirely salinized.

Considering the facies and the depths of distribution and also the age of the Bangkok Clay, the formation might have been deposited between the epochs of low sea level (Würm maximum, 20,000 YBP) and high sea level (12,000 YBP) of the Late Pleistocene.

Since the gradient of the sedimentary area was reduced due to the rise in sea level, the gravel beds might be lacking in the upper part of the formation. The salinity of groundwater originated perhaps during the transgression. Since BK was sealed by the Bangkok Clay during the Holocene age, fresh water could not completely replace the saline water.

Bangkok Clay

Thickness of the Bangkok Clay is about 15 m to 30 m. The formation is divided into lower Stiff Clay and upper Soft Clay (the top most clay).

Stiff Clay (SC) is composed of well consolidated brown sandy silt and clay. Soft Clay (AC) is a very soft black clay containing shell fragments. The formation is locally intercalated with fine sand along the Chao Phraya River. It is also covered locally by sand beds that originated from floods. These sand beds constitute the local unconfined aquifers.

The ^{14}C dating of Bangkok Soft Clay at Site A (Minburi) and Site B (AIT) showed ages from 1,000 YBP to 8,000 YBP, which indicates that the formation was deposited during the Holocene period.

Considering its well consolidated facies, the Stiff Clay was not deposited in a similar sedimentary environment of the Soft Clay. Unconformity may exist at the boundary of the two (2) clay layers. After the deposition of Stiff Clay during the period of high sea level, the regression occurred, and the SC was exposed, dried, and weathered. And the Holocene transgression followed.

The ^{14}C dating conducted by AIT (1981) showed the age of the Stiff Clay within the range of 14,700 YBP to 45,000 YBP. Data of BH 4 obtained at Post and Telegraph Department and BH 10 obtained at Ramkamheng University showed the age at about 17,000 YBP