CHAPTER 4 GROUNDWATER QUALITY

CHAPTER 4 GROUNDWATER QUALITY

4.1 Water Quality of DMR Monitoring Wells

(1) Method of Sampling

A total of 237 groundwater samples from the DMR monitoring wells and 16 samples from production wells were collected and analyzed in the laboratory. The submersible pump was used to remove stagnant water from the well so as to collect reliable samples. Pumping was done for at least one (1) hour. Water level, discharge rate, electric conductivity, pH, and temperature were measured at an interval of 10 minutes during pumping.

(2) Distribution of Water Quality

DMR monitoring wells tapped three (3) major aquifers, i.e, Phra Pradaeng (PD), Nakhon Luang (NL) and Nonthaburi (NB) Aquifers. Groundwater of these aquifers were interpreted from the geochemical point of view.

Trilinear Diagram Analysis

The results of analysis were plotted on the trilinear diagram. The central diamond-shape area of the diagram was divided into 5 domains.

Domain I	$Ca(HCO_3)_2$ type
Domain II	$NaHCO_3$ type
Domain III	$CaSO_4$ or $CaCl_2$ type
Domain IV	Na_2SO_4 or NaCl type
Domain V	the middle

Groundwater chemically evolved along the path from domain III(V) to domain I, and from domain I to II(V). Most of PD Aquifer samples were plotted on domain III, IV and V. A few samples were plotted on domain I and II. NL Aquifer samples were also located in domain III, IV and V. More NL Aquifer samples were plotted on domain I and II than PD Aquifer samples. NL Aquifer samples were divided into two (2) groups: one at domain III and IV and the other at domain II and V. Fresh water was generally represented on domain I,II and V. Groundwater at domain IV was affected by sea water or fossil water (Figures 4.1.1 to 4.1.3).

Pattern Diagram Analysis

PD Aquifer samples were classified into two (2) groups: one was characterized by dominance of (Na+K) and the other was characterized by almost the same contents of (Na+K) and (Ca). The former group is in Samut Prakan and western Bangkok, while the latter group is distributed in northern Bangkok, Pathum Thani, and Nonthaburi.

NL Aquifer samples taken from the coastal area had high content of chloride and (Na+K) which could have originated from sea water. Samples taken from the inland area had higher content of calcium as well as (Na+K) in cations. This may indicate that the source of saline water in the inland area may be different from that in the coastal area.

NB Aquifer samples taken from the southern part of the Study Area were rich in chloride and (Na+K), similar to the water quality of NL Aquifer. The cause of salinity of the NB Aquifer may be the same as that of the NL Aquifer (Figures 4.2.1 to 4.2.3).

4.2 Water Quality of JICA Monitoring Wells

The results of analysis of groundwater collected from the 18 monitoring wells are summarized in Figure 4.3 and Table 4.1. BK Aquifer samples were plotted on domain IV or III because of high chloride concentration. Groundwater of PD and NB Aquifers were plotted on domain IV at Site A (Lat Krabang) and Site B (AIT), however, in Site C (Samut Sakhon), PD and NB groundwater not affected by salinity yet were plotted at domain V and I, respectively.

NL groundwater which was affected by salinity was plotted on domain IV at Site C (Samut Sakhon). At Site A (Lat Krabang) and B (AIT), it was plotted on domain IV to V and was not affected by salinity yet.

Groundwater of deep SK, PT and PN Aquifers at Site A (Lat Krabang) was moved to domain IV. At Site C (Samut Sakhon), it was still on domain I indicating fresh water.

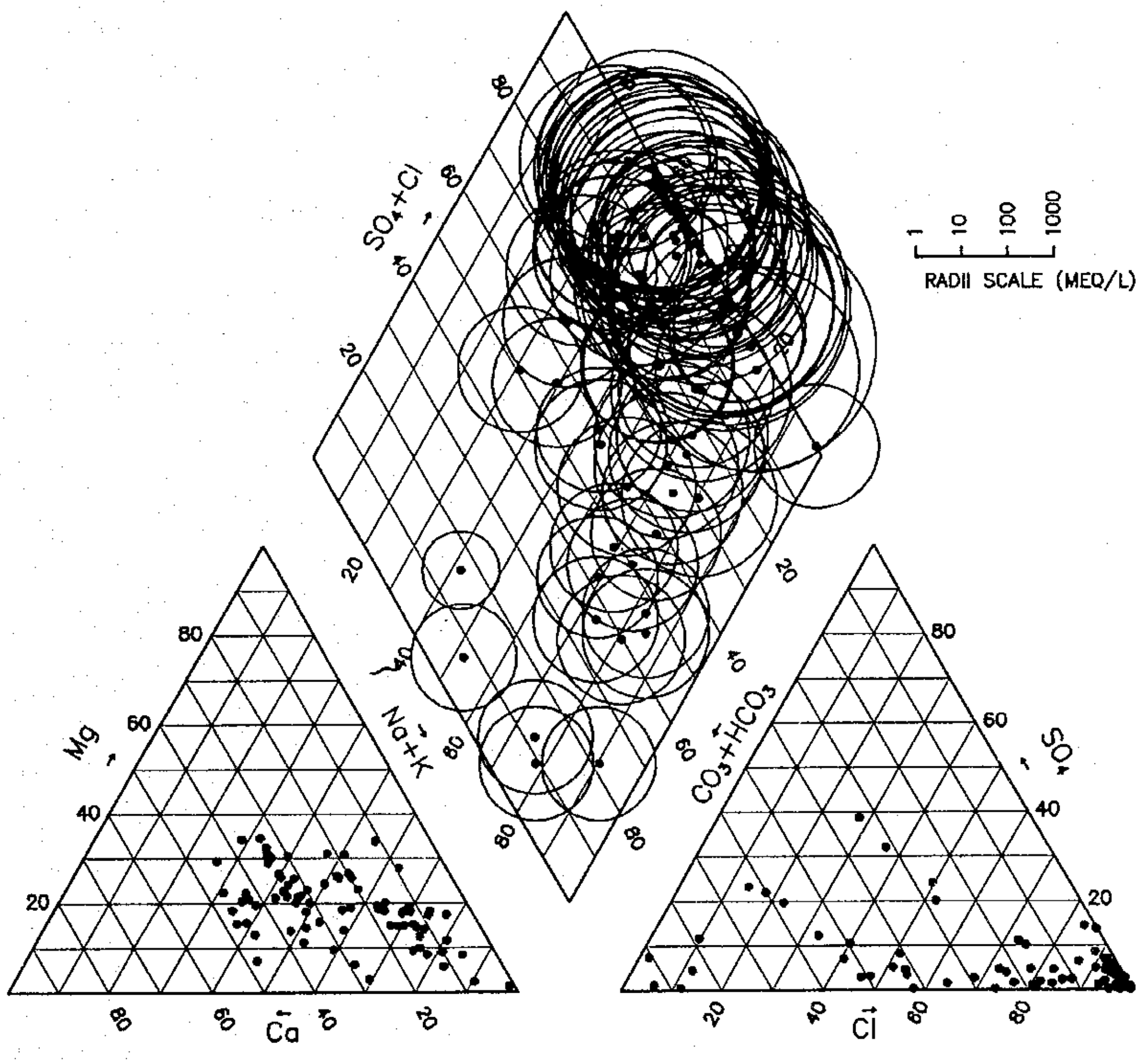
4.3 Salinity of Groundwater

In PD Aquifer, the area of high chloride concentration spread over the entire Study Area except the eastern part. On the other hand, in NL Aquifer, the area of concentration laid along the coast from Samut Sakhon to Samut Prakan and right bank of the Chao Phraya River. NB Aquifer showed more than 5,000 mg/l of chloride concentration in the areas at the mouth of the Chao Phraya River, Samut Sakhon, Samut Prakan and Pathum Thani (Figures 4.4.1 to 4.4.3).

Spatial distribution of chloride concentration suggested that the salinity of groundwater was brought about by downward leakage of fossil water from shallow BK Aquifer to deep aquifers. Leakage occurred due to depletion of the deep aquifer's artesian head which was heavily pumped. Aquifers deeper than PD Aquifer are possible to crop out at the bottom of the Gulf of Thailand. However, they may crop out several hundred kilometers far from the mouth of the Chao Phraya River. In addition, aquifers are overlain by Bangkok Clay in the coastal area. This indicates low possibility of direct sea water intrusion.

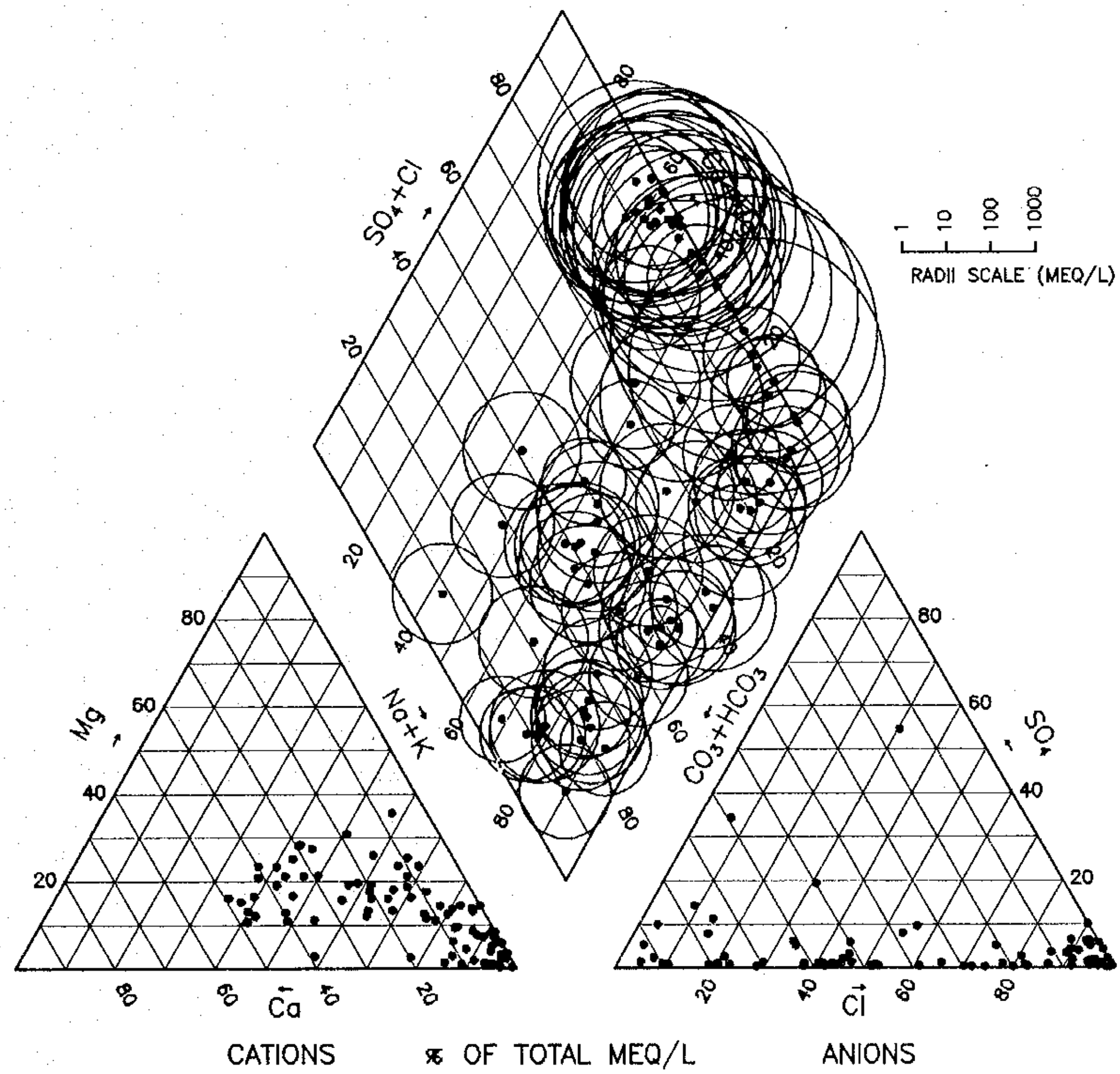
Table 4.1 CHEMICAL ANALYSES OF GROUNDWATER FROM MONITORING WELLS

Well No.	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	B-1	B-2	B-2	B-3	B-4	B-5	C-1	C-1	C-2	C-3	C-4	C-5
Well Depth (m)	574	437	215	302	215	145	108	48	272	192	192	153	94	47	320	320	212	140	105	78
Sampling Date	20-Jul-93	27-May-93	23-May-93	29-May-93	07-Jun-93	05-Jun-93	09-Jun-93	02-Jun-93	22-Feb-93	23-Mar-93	08-May-93	23-Apr-93	29-Apr-93	29-Apr-93	15-Mar-93	08-May-93	29-Jun-93	20-Jun-93	18-Jun-93	23-Jun-93
pH	9.04	8.45	8.13	7.96	8.57	7.65	7.55	5.67	7.88	7.71	7.60	7.64	7.59	6.35	7.50	7.34	7.45	7.89	7.89	7.48
Temperature (deg.C)		39.0	26.0	36.0	30.6	26.7	27.6	30.0	39.0	35.0	34.4	33.3	33.3	31.7	40.0	40.5	37.7	37.6	30.8	29.1
Electric Conductivity (us/cm)	1160	1540	975	1500	1180	749	1860	28400	981	865	858	783	1450	21900	477	486	580	1570	767	3000
Calcium Ion (ppm)	4.20	5.15	8.34	1.50	15.92	55.40	99.80	1519.70	24.13	27.13	26.10	30.50	71.20	76.50	40.21	45.00	39.60	21.70	11.70	41.80
Magnesium Ion (ppm)	0.79	0.27	0.31	0.03	3.10	6.78	24.21	39.75	4.43	5.49	6.06	21.38	15.06	122.60	14.18	15.19	3.85	51.49	22.00	131.45
Sodium Ion (ppm)	22.10	552.98	134.77	177.19	414.80	323.94	202.22	1910.40	46.40	303.14	110.63	95.22	212.78	329.70	29.44	37.57	50.63	180.56	190.16	236.70
Potassium Ion (ppm)	4.13	1.89	1.32	1.67	2.36	2.00	3.16	40.76	2.77	2.08	1.86	1.47	2.41	45.19	17.69	7.03	4.87	6.75	6.64	9.93
Manganese Ion (ppm)	0.17	ND	ND	0.16	0.17	0.06	0.45	198.73	0.02	<0.02	0.08	0.06	0.35	1.22	<0.02	0.06	0.07	ND	<0.02	0.67
Ammonium Ion (pmm)	0.56	ND	ND	ND	ND	ND	ND	1.74	ND	ND	0.25	0.17	0.17	1.54	ND	0.08	0.22	ND	ND	0.22
Bicarbonate Ion (ppm)	31.70	212.30	222.00	119.60	100.00	209.80	173.20	28.10	90.30	179.30	201.30	206.20	195.40	242.20	146.40	151.28	168.40	153.70	205.00	174.50
Sulfate Ion (ppm)	69.60	326.00	34.50	69.30	85.10	35.60	161.00	403.00	36.05	70.70	60.14	46.21	162.30	1923.00	7.24	6.33	16.00	34.30	61.40	17.84
Iron Ion (ppm)	1.64	0.12	0.16	0.17	1.60	0.13	0.10	2.23	0.02	<0.02	0.17	0.07	0.13	6.60	ND	0.07	0.01	0.10	0.21	0.43
Chloride Ion (ppm)	193.0	47.5	69.5	283.7	205.5	40.1	332.7	9686.4	203.0	80.7	78.3	34.2	210.4	7631.7	10.8	7.6	11.5	347.3	14.4	792.5
Bromide Ion (ppm)	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	1.09	1.10	1.80	1.20	1.80	0.60	<0.3	1.60	1.30	<0.3	ND	ND	0.09
Iodide Ion (ppm)	0.17	0.58	0.17	0.46	0.39	<0.1	ND	0.14	<0.2	<0.2	<0.2	<0.2	0.20	0.50	<0.2	<0.2	0.10	1.35	0.26	0.06
Nitrate Ion (ppm)	12.00	0.15	1.70	2.41	0.88	1.41	0.10	14.78	<1	<1	2.74	2.88	ND	7.73	<1	1.97	0.92	0.85	0.82	ND
Nitrite Ion (ppm)	40.80	5.30	NIL	NIL	10.40	NIL	NIL	20.80	<6	<6	8.90	11.80	20.80	26.10	ND	<6	10.20	11.90	8.90	11.90



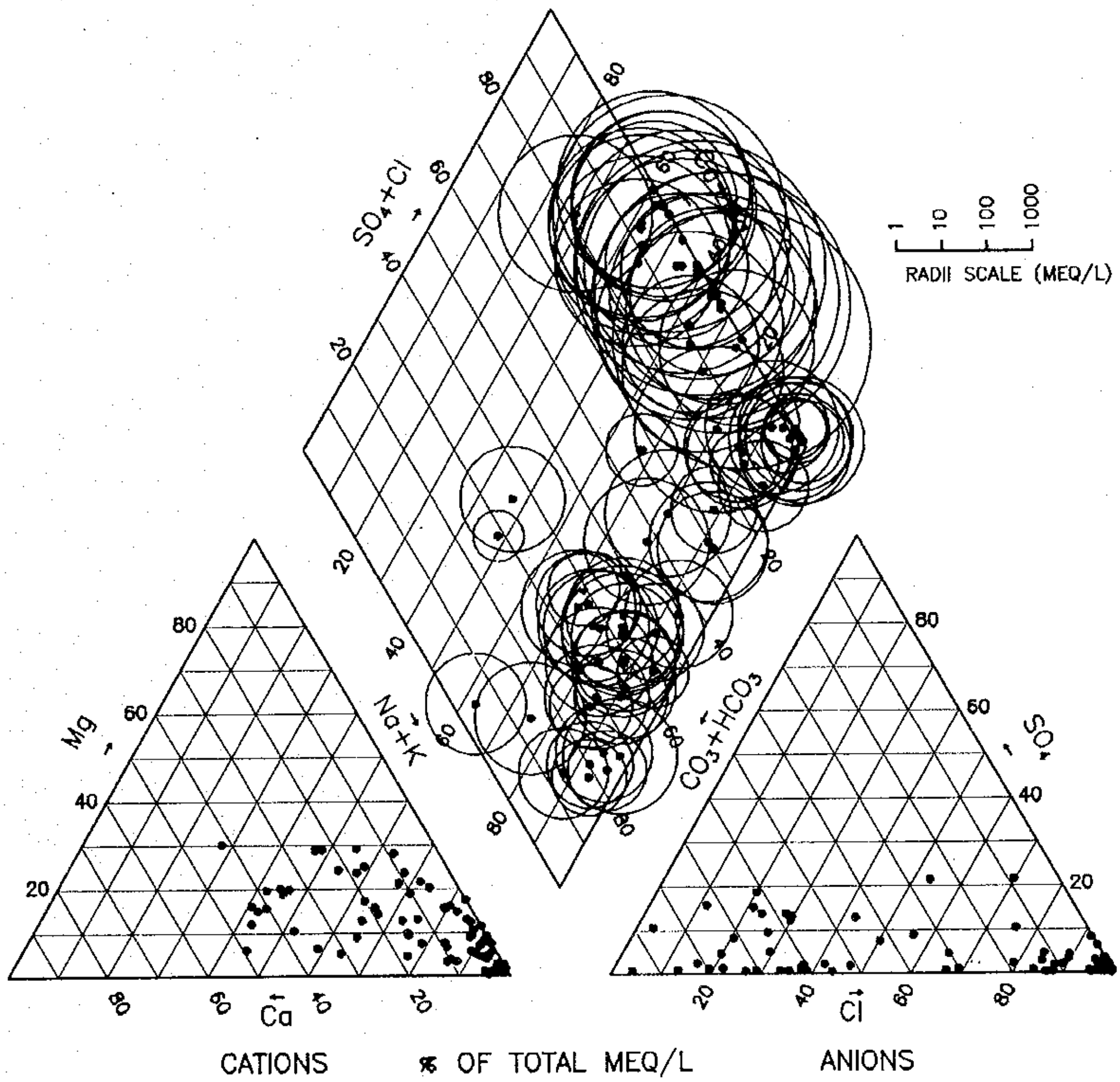
(Water samples were collected by the Study Team in 1993.)

Figure 4.1.1	TRILINEAR DIAGRAM OF PHRA PRADAENG AQUIFER
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



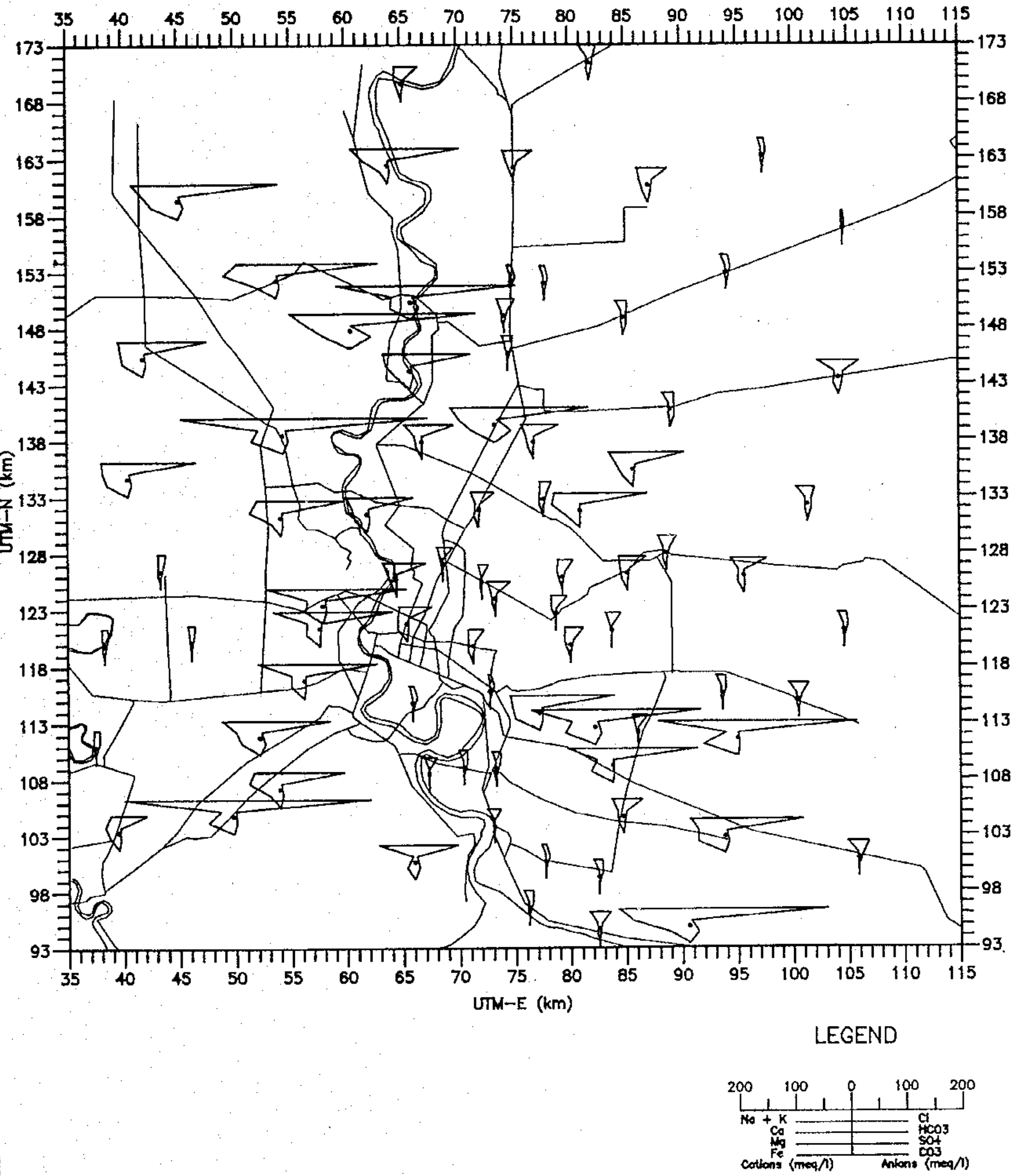
(Water samples were collected by the Study Team in 1993.)

Figure 4.1.2	TRILINEAR DIAGRAM OF NAKHON LUANG AQUIFER
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



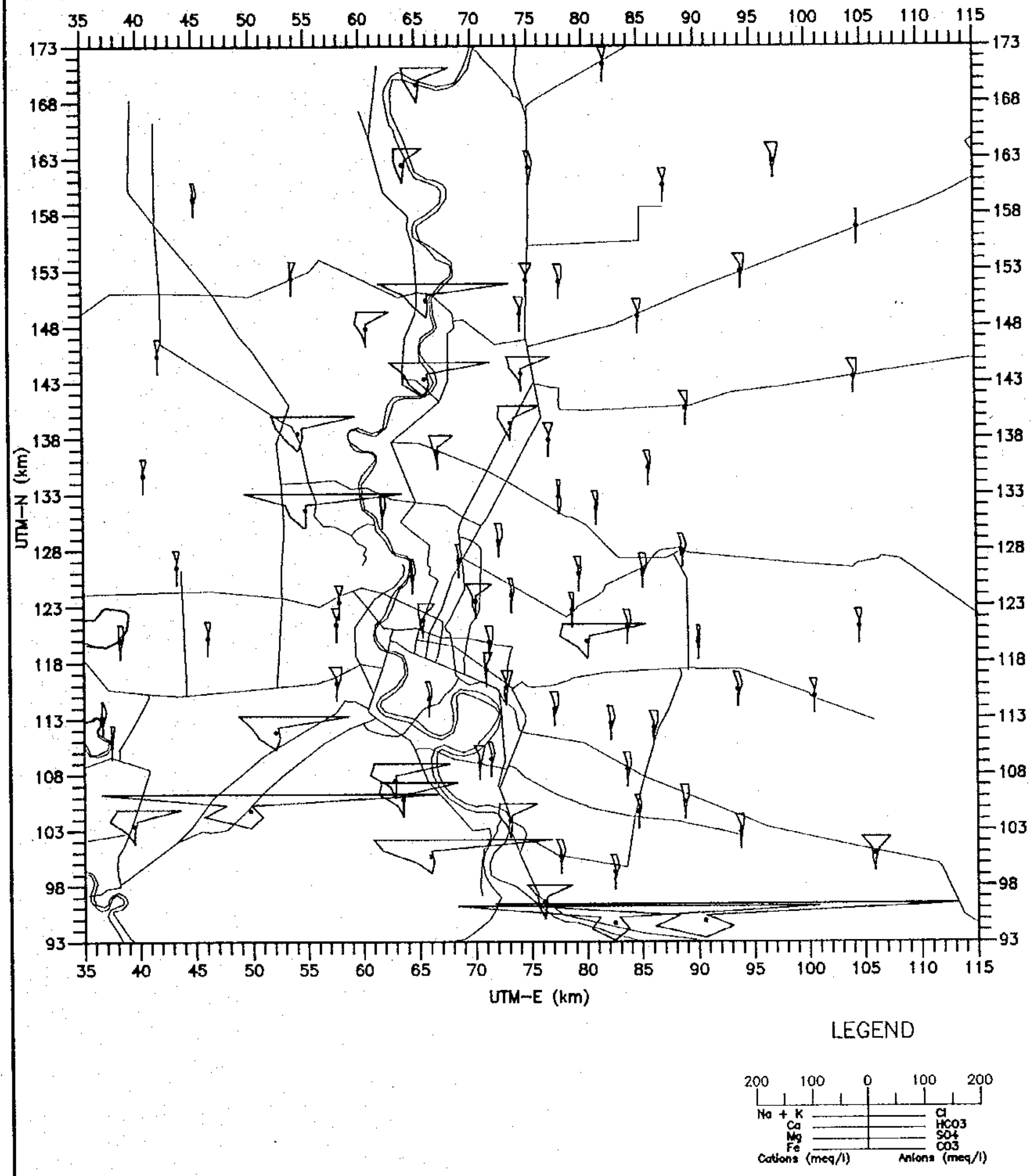
(Water samples were collected by the Study Team in 1993.)

Figure 4.1.3	**TRILINEAR DIAGRAM OF NONTHABURI AQUIFER**
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	**KOKUSAI KOGYO CO., LTD.**



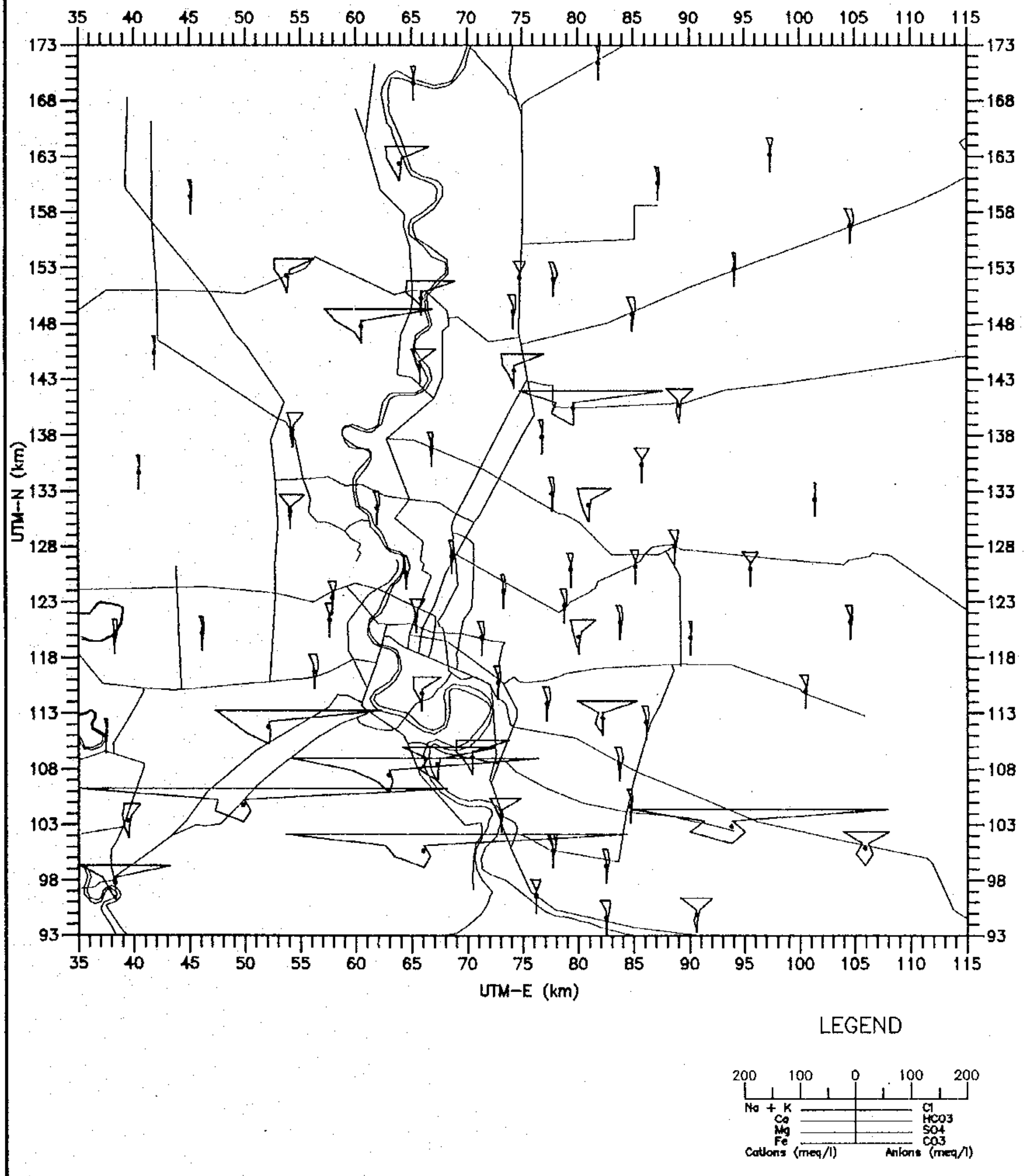
(Water samples were collected by the Study Team in 1993.)

Figure 4.2.1	STIFF DIAGRAMS OF PHRA PRADAENG AQUIFER
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



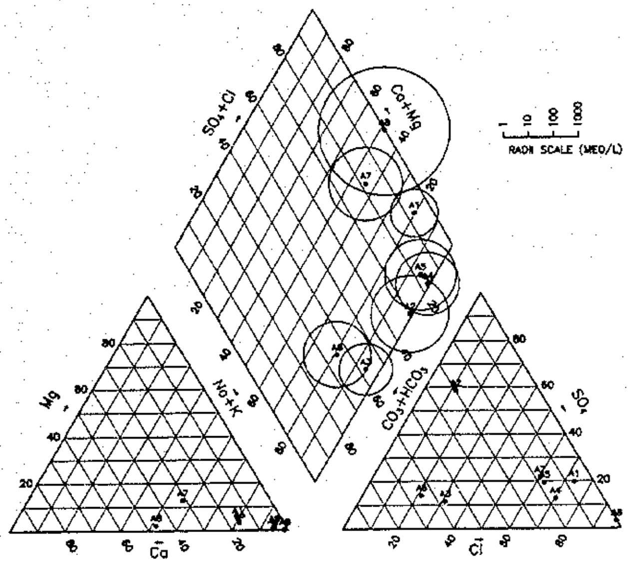
(Water samples were collected by the Study Team in 1993.)

Figure 4.2.2	STIFF DIAGRAMS OF NAKHON LUANG AQUIFER
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



(Water samples were collected by the Study Team in 1993.)

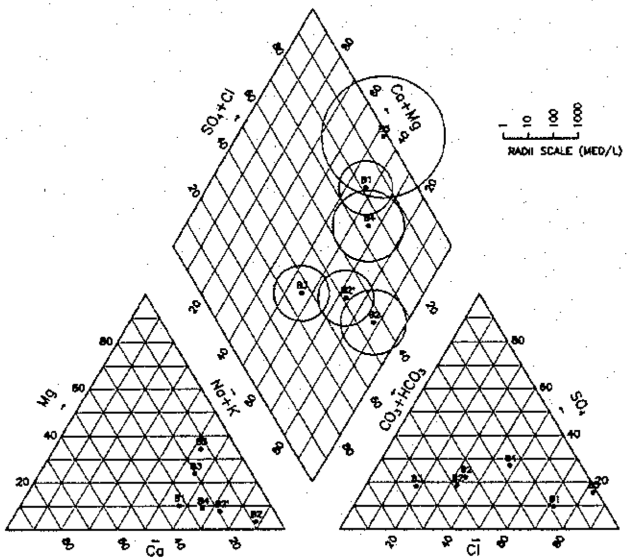
Figure 4.2.3	STIFF DIAGRAMS OF NONTHABURI AQUIFER
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



CATIONS % OF TOTAL MEQ/L ANIONS

Label	Well No.	Well Depth (m)	Aquifer	Sampling Date
A1	A-1	574	PK	20-07-1993
A2	A-2	437	PT	27-05-1993
A3	A-3	360	SK	23-05-1993
A4	A-4	302	SK	29-05-1993
A5	A-5	215	NB	07-06-1993
A6	A-6	145	NL	05-06-1993
A7	A-7	108	PD	09-06-1993
A8	A-8	48	BK	02-06-1993

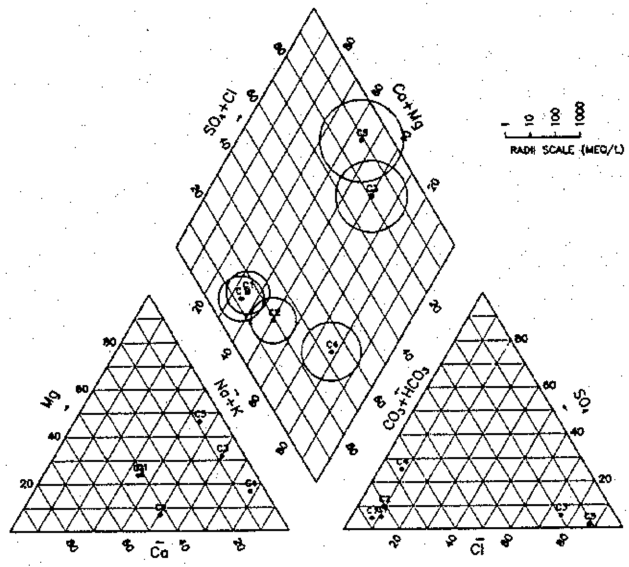
SITE - A



CATIONS % OF TOTAL MEQ/L ANIONS

Label	Well No.	Well Depth (m)	Aquifer	Sampling Date
B1	B-1	272	NB	22-02-1993
B2	B-2	192	NL	23-03-1993
B2'	B-2	192	NL	08-05-1993
B3	B-3	153	NL	23-04-1993
B4	B-4	94	PD	29-04-1993
B5	B-5	47	BK	29-04-1993

SITE - B



CATIONS % OF TOTAL MEQ/L ANIONS

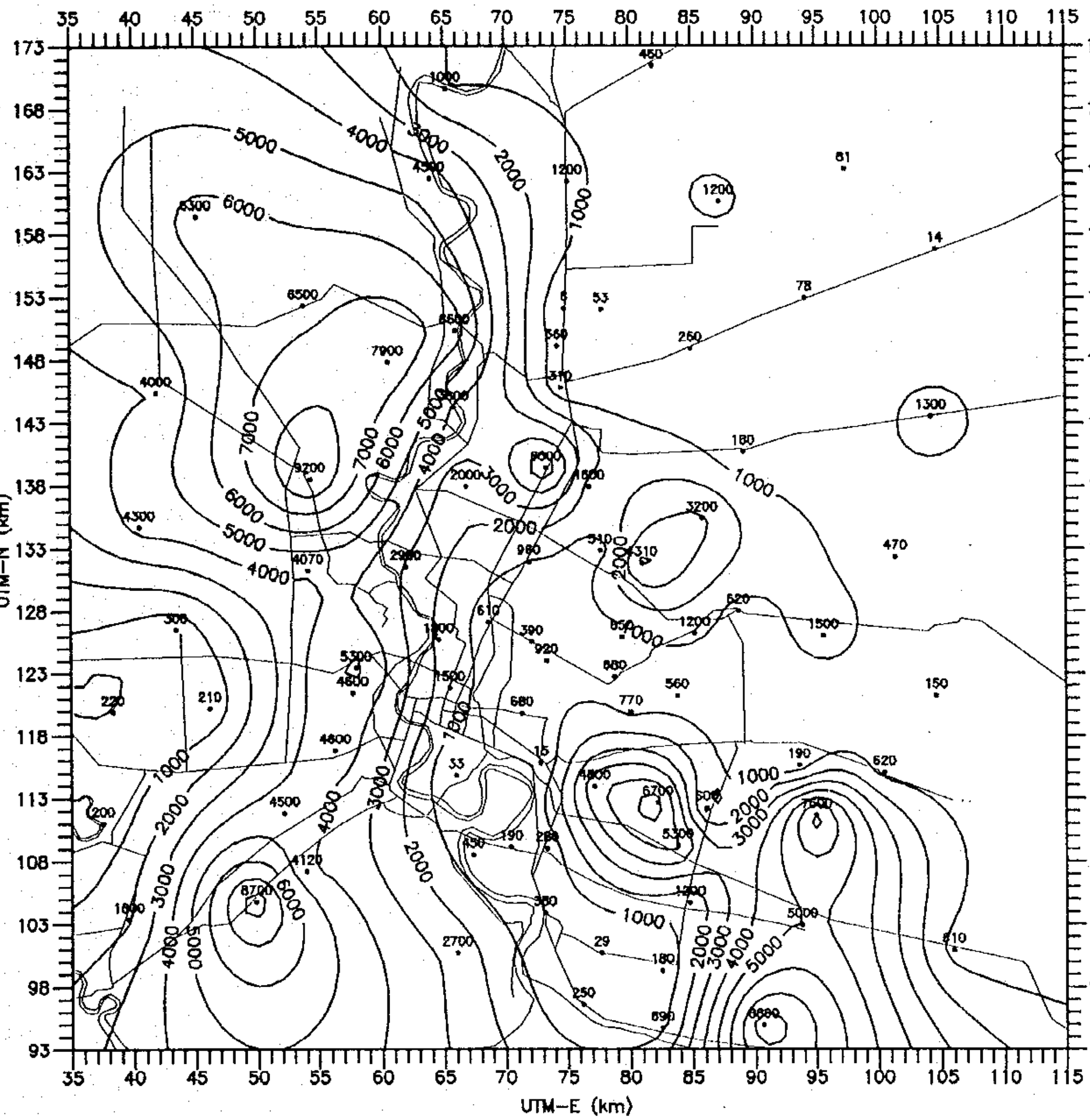
Label	Well No.	Well Depth (m)	Aquifer	Sampling Date
C1	C-1	320	SK	15-03-1993
C1'	C-1	320	SK	08-05-1993
C2	C-2	212	NB	29-06-1993
C3	C-3	140	NL	20-06-1993
C4	C-4	105	PD	18-06-1993
C5	C-5	78	PD	23-06-1993

SITE - C

Figure 4.3 **TRILINEAR DIAGRAMS OF GROUNDWATER AT SITES - A, B & C**

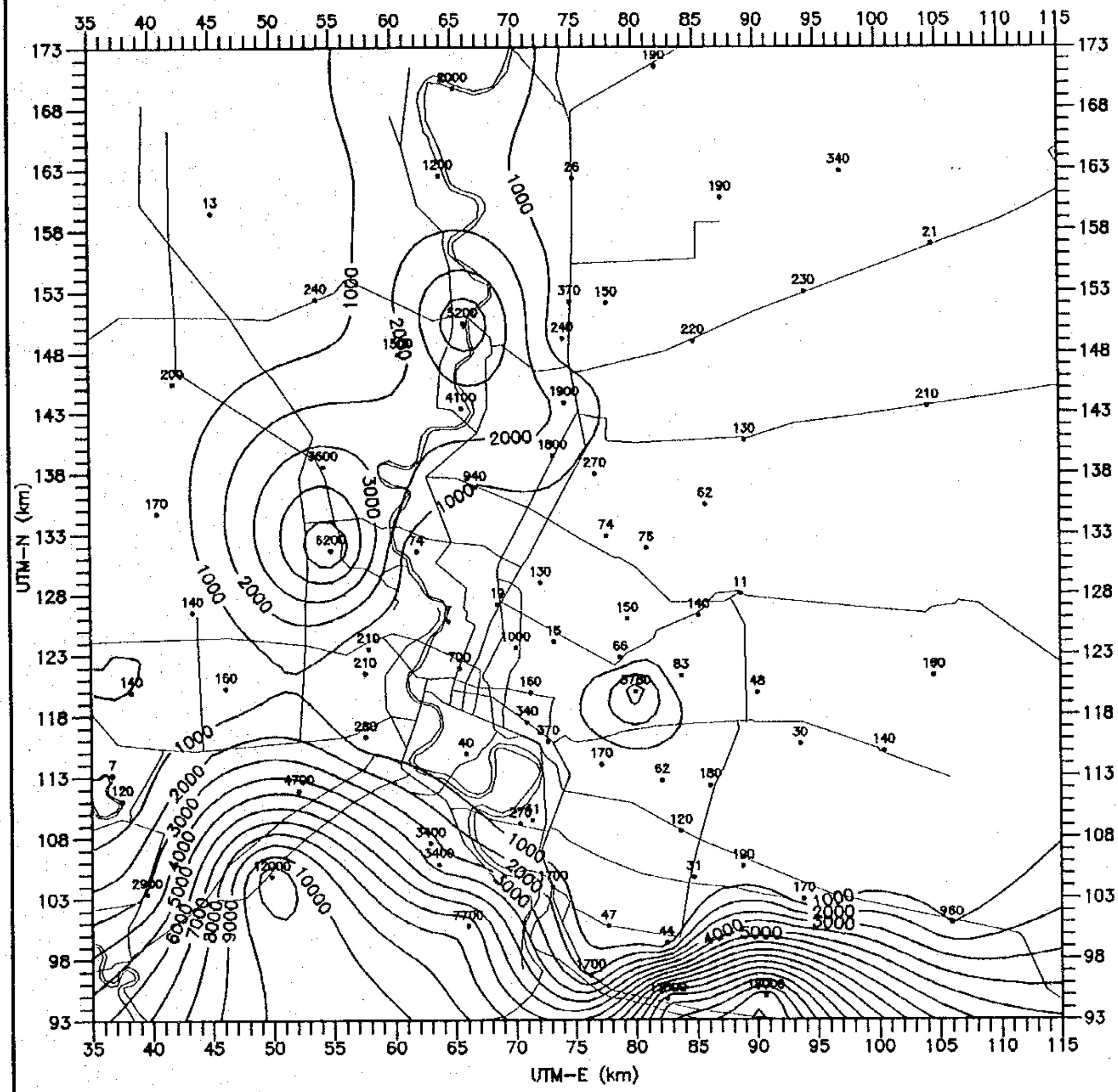
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

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



(Water samples were collected by the Study Team in 1993.)

Figure 4.4.1	CHLORIDE CONCENTRATION OF PHRA PRADAENG AQUIFER
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



LEGEND

——— LINE OF EQUAL Cl^- CONCENTRATION (mg/L)

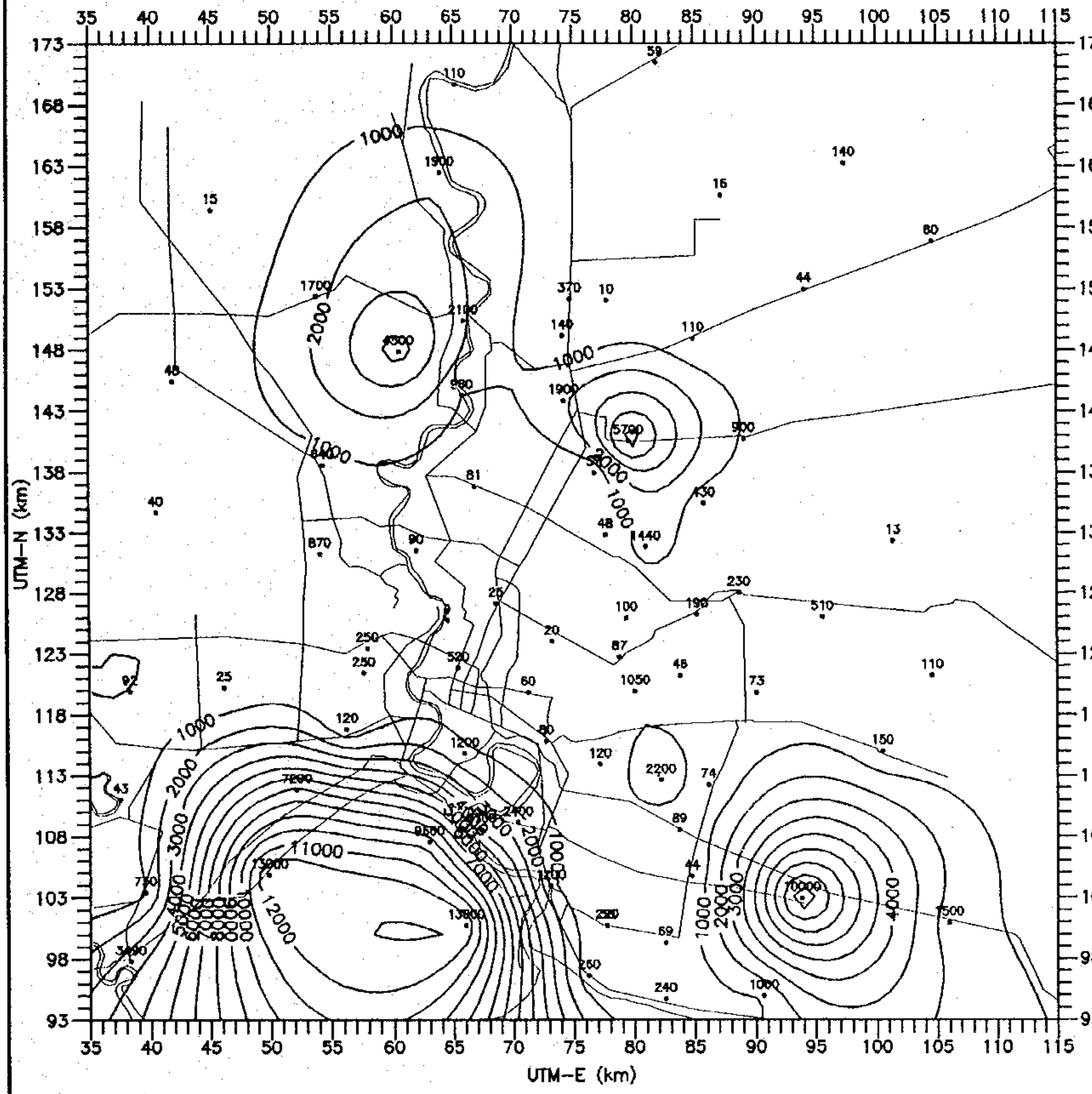
1500 • DMR MONITORING WELL WITH Cl^- CONCENTRATION (mg/L)

(Water samples were collected by the Study Team in 1993.)

Figure 4.4.2	CHLORIDE CONCENTRATION OF NAKHON LUANG AQUIFER

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

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



LEGEND

LINE OF EQUAL Cl⁻ CONCENTRATION (mg/L)

1500 DMR MONITORING WELL WITH Cl⁻ CONCENTRATION (mg/L)

(Water samples were collected by the Study Team in 1993.)

Figure 4.4.3	CHLORIDE CONCENTRATION OF NONTHABURI AQUIFER
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

CHAPTER 5 GROUNDWATER PUMPAGE

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5.1 Background

This chapter presents the results of the estimations of year-1992 groundwater abstractions and historical groundwater pumpage records (1983-1992) based on the compilation of well inventories of both private and public wells in the Bangkok Metropolitan Area and its vicinity.

Private wells are those wells registered at DMR for water rights, while **public wells** are those wells constructed or managed (or both) by DMR, PWD, MWA, PWA, DOH, ARD and IEAT. Meanwhile, the **Whole Area** shall include wholly the eight provinces containing the 11,222 private wells and 2,475 public wells. Inside the Whole Area is the **Study Area** which covers wholly Bangkok, Nonthaburi, Pathum Thani, and Samut Prakan and partly Samut Sakhon, Ayutthaya, Nakhon Pathum and Chachoengsao, i.e., between 35°E and 115°E and between 93°N and 173°N, and locates the 10,772 private wells and 884 public wells.

5.2 Well Inventory

The groundwater pumpage estimations basically relied on the Groundwater Database System prepared by the Study Team, specifically on the system's well inventory database which stores all the different well inventories collected from the said agencies during the Study. These well inventories contain 11,222 private wells, 2,475 public wells and 258 groundwater observation wells for a total of 13,955 wells as of 1992, encompassing active, inactive and abandoned wells.

As shown in Figure 5.2.1, of the 11,222 inventoried private wells, more than 75% of the private wells are located in Bangkok (4,853 wells) and Samut Prakan (3,669 wells), and more than 45% (5,140 wells), 37% (4,189 wells) and 14% (1,667 wells) are tapping Nakhon Luang, Phra Pradaeng and Nonthaburi Aquifers, respectively. Nakhon Luang Aquifer is giving out groundwater to 52.5% of the wells in Bangkok, 57.2% of the wells in Pathum Thani, 52.9% of the wells in Samut Sakhon and 72.4% of the wells in Ayutthaya. In Samut Prakan, 62.2% of the wells are tapping Phra Pradaeng Aquifer. More than 72.4% of the wells in Nonthaburi province are withdrawing from a deeper aquifer, Nonthaburi.

Around 45.3% (5,088 wells) of the 11,222 private wells are for domestic consumption. The distributions of the rest consist of 4.2% (478 wells) for institutional use; 10.6% (1,186 wells) for commercial use; and 39.8% (4,470 wells) for industrial use. Around 47% of the 5,088 domestic wells are abstracting from Nakhon Luang Aquifer, and 39.3% from Phra Pradaeng Aquifer. The largest number of industrial wells, 1,129, are pumping from Phra Pradaeng Aquifer in Samut Prakan. The second largest number (645 wells), which is also situated in Samut Prakan, is withdrawing groundwater from Nakhon Luang Aquifer.

As shown in Figure 5.2.2, of the 2,475 public wells, 1,019 (41.2%) were constructed by DMR, 932 (37.7%) by PWD, 157 (6.3%) by MWA, 111 (4.5%) by PWA, 83 (3.4%) by DOH, 93 (3.7%) by ARD, and 80 (3.2%) by IEAT. Wells constructed or managed (or both) by DMR, PWD, PWA, DOH, and ARD are specifically for domestic use. MWA well productions are largely for domestic consumption, while IEAT wells are utilized for industries.

More than 6.6% (163) of the 2,475 public wells are located in Bangkok, 3.2% (79) in Nonthaburi, 8% (198) in Pathum Thani, 7.1% (175) in Samut Prakan, 12.2% (303) in Samut

Sakhon, 34.3% (847) in Ayutthaya, 14.3% (355) in Nakhon Pathum and 14.3% (355) in Chachoengsao. There are 1,110 (44.8%) pumping out from Nakhon Luang Aquifer, 602 (24.3%) from Phra Pradaeng Aquifer, and 534 (21.6%) from Nonthaburi Aquifer.

Of the 11,222 private wells gathered from the DMR's Groundwater Division, 10,772 are located in the Study Area. More than 60.6% of the 884 inventoried public wells in the Study Area are located in Bangkok, Pathum Thani and Samut Prakan, and more than 46.4% were constructed by PWD. The combined total of the inventoried number of private and public production wells in the Study Area is 11,656. Of this total, public wells represent only 7.6%.

On the other hand, the number of private wells with active water permits was estimated at 4,141 for the year-1992 based on the years of the issuance, expiration and extension of water permits. Of this total, 4,132 wells are located in the Study Area.

5.3 Historical Groundwater Pumpage Estimations

The 1983-1992 historical groundwater pumpage records were estimated to provide basic data for groundwater simulation studies, i.e. for the calibration and verification of groundwater model, and also for generation of future pumpage scenarios.

Two (2) cases of historical daily groundwater pumpage estimates were considered for private wells:

Case 1: Assumes that all private wells with permits that have expired and have not been extended shall become inactive or abandoned. daily pumpage Estimates are based on the years of issuance, expiration and extension of water rights and the volume permitted stipulated in the water rights multiplied by the GPC. This GPC is the average ratio of the actual pumpage to the volume permitted.

Case 2: Considers that well owners shall continue using groundwater even after the expiration of their water rights for there is still an inadequate supply of surface water. Estimates are based on either the year of issuance of water permit or the year of completion of well construction and the volume permitted multiplied by the GPC.

For public wells, monthly discharge records stored in the well inventory database were used for the computation of historical groundwater pumpage. In the absence of actual pumpage records, historical daily pumpage was estimated using the well yield data obtained during pumping test, the number of hours of operation per day, and the year the well was constructed.

The results of estimations are as follows.

Private Wells ***Case 1***: The year-to-year pattern of groundwater withdrawals for the Study Area is similar to that for the Whole Area, as shown in Figure 5.3.1. The groundwater withdrawals for the Whole Area increased steadily from 640,375 CMD (630,619 CMD for the Study Area) in 1980, peaked to 838,610 CMD (821,952 CMD) in 1988, started declining in 1989, and decreased abruptly between 1989 and 1990 by 22.1% (23.4% for the Study Area) mainly due to the supposed abandonment of wells with expired water permits. By the year-1992, the groundwater pumpage was estimated at 645,053 CMD for the Whole Area and 603,588 CMD for the Study Area.

Private Wells *Case 2*: The historical records of groundwater pumpage as calculated using *Case 2* for both Whole Area and Study Area had patterns similar to the one shown in Figure 5.3.2. The rate of increase in the total groundwater withdrawal is higher after 1987 (about 7.5%) than before 1987 (about 5%). This phenomenon after 1987 can be attributed to the fact that Thailand experienced an unexpected high economic growth.

The total groundwater withdrawals for the Whole Area increased from 640,375 CMD in 1983 to 1,171,321 CMD in 1992. In the Study Area, the total use of groundwater had increased 177.8% (or by 490,685 CMD) from 630,620 CMD to 1,121,305 CMD for the same period.

In Table 5.3.1, these statistics have shown that groundwater withdrawal is continuously increasing as assumed in *Case 2*. Since it was also in good agreement with the results of the groundwater simulation studies, *Case 2* therefore was considered as the most probable historical pattern of groundwater withdrawal in the Study Area.

Public Wells: For both the Whole Area and Study Area, the groundwater pumpage estimates for DMR, PWD, PWA, IEAT, DOH, and ARD showed a year-to-year increasing pattern, while MWA showed a historical decreasing trend. This is shown in Figure 5.3.3. Combined withdrawals of all public wells reflected the historical trend of that of MWA because its withdrawals as compared with those of other agencies were much larger. The historical decline of MWA pumpage was due to the Cabinet Resolution of March 1983 directing MWA to phase out all public wells in the defined Critical Zones 1 and 2 by the end of 1987.

Combined total groundwater pumpage of both private and public wells: The combined total historical groundwater withdrawals of both private and public wells were generated using *Case 2*. They are shown in Table 5.3.2 and Figure 5.3.4.

The historical patterns for the Whole Area and the Study Area showed a drop in groundwater withdrawal between 1985 and 1986 as influenced by the abrupt decline of MWA extraction in the same period for the reason mentioned above.

The total groundwater withdrawals for the Whole Area increased from 1,277,499 CMD in 1983 to 1,799,596 CMD in 1992. In the Study Area, the total use of groundwater had increased 132.6% from 1,117,028 CMD to 1,481,061 CMD for the same period.

5.4 Year-1992 Total Groundwater Pumpage in the Study Area

The combined year-1992 total pumpage of both private and public wells shows the approximate picture of the year-1992 groundwater pumpage in the Study Area.

The year-1992 pumpage level generated by private wells in the Study Area was 1,121,305 CMD as computed using *Case 2* in Table 5.4.1. Figure 5.4.1 shows the distributions of this total pumpage as 23.8% for domestic supplies, 4.3% for institutional uses, 6.9% for commercial purposes and 65% for industries. Around 728,755 CMD, which represented 65% of the total average daily pumpage in the Study Area, were used by industries. Of this amount of pumpage, textile industry got the biggest share at 30.6%, followed by food processing industry with 11.5%. The share of chemical industry amounted to 7% or 50,709 CMD and paper industry shared 5.9% or 42,739 CMD to the total industrial pumpage. On the other hand, the high pumpage shares of Samut Prakan, Bangkok and Pathum Thani could be attributed to the concentration of industries in these areas.

As presented in Table 5.4.1, the year-1992 groundwater production of public wells in the Study Area totaled 359,756 CMD. In Figure 5.4.1, this total was divided into 78.7% for domestic use and 21.3% for industrial use. For domestic use, public wells produced more groundwater than private wells (283,153 CMD against 267,570 CMD). While abstraction for industrial use by public wells represented only 10.5% of the total industrial production of private wells.

Combined total of the estimated groundwater withdrawals of private and public wells in the Study Area amounted to 1,481,061 CMD. Of this total, public wells used 24.3%.

The combined total withdrawals were distributed as: 550,723 CMD for domestic uses; 47,944 CMD for institutional uses; 77,036 CMD for commercial uses; and 805,358 CMD for industrial uses. Combined distributions were 37.2% for domestic supplies, 3.2% for institutional uses, 5.2% for commercial supplies and 54.4% for industries. This is shown in Figure 5.4.1. Figure 5.4.2 plots the spatial distribution of pumpage in the Study Area in year-1992.

Table 5.3.1 **GROUNDWATER LEVEL STATISTICS FROM 84 DMR MONITORING STATI**

Changwat	Recover* in 1990-91	Decline after 1987	Neither Recover nor Decline* after 1987	Total
Bangkok	14 (41%)	13 (38%)	7 (21%)	34 (100%)
Nonthaburi		5 (100%)		5 (100%)
Pathum Thani		15 (94%)	1 (6%)	16 (100%)
Samut Prakan	1 (5%)	17 (77%)	4 (18%)	22 (100%)
Samut Sakhon		1 (50%)	1 (50%)	2 (100%)
Ayutthaya		3 (100%)		3 (100%)
Nakhon Pathom		2 (100%)		2 (100%)
Total	15 (18%)	56 (67%)	13 (15%)	84 (100%)

*Decline after 1991

Table 5.3.2 COMBINED HISTORICAL PUMPAGE ESTIMATES FOR PRIVATE (USING CASE 2) AND PUBLIC WELLS

Changwat	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Bangkok	595,922	566,283	540,192	491,247	504,187	483,409	439,486	409,567	435,201	458,729
Nonthaburi	81,191	88,060	77,369	46,210	49,296	52,163	56,427	62,422	66,940	69,729
Pathum Thani	96,888	105,918	115,955	125,360	137,731	159,293	196,442	223,842	263,734	289,979
Samut Prakan	269,940	308,389	327,221	330,583	353,731	368,664	382,223	421,692	460,615	474,118
Samut Sakhon	89,145	104,795	117,434	129,061	144,421	156,876	172,497	186,303	205,009	220,611
Ayutthaya	121,149	133,866	139,696	154,469	173,394	185,921	195,609	208,334	238,179	249,583
Nakhon Pathom	22,568	23,294	23,282	24,467	24,036	24,206	25,988	27,554	29,096	31,478
Chachoengsao	697	992	1,387	2,171	2,545	2,901	3,092	3,787	4,559	5,367
WHOLE AREA	1,277,499	1,331,597	1,342,536	1,303,567	1,389,340	1,433,434	1,471,765	1,543,501	1,703,334	1,799,596
Bangkok	595,799	566,160	540,069	491,124	504,065	483,286	439,362	409,445	435,078	458,607
Nonthaburi	80,918	87,788	77,096	45,936	49,022	51,889	56,153	62,149	66,667	69,456
Pathum Thani	96,824	105,918	115,955	125,360	137,675	159,238	196,156	223,083	261,849	287,304
Samut Prakan	269,938	308,388	326,219	330,581	353,728	368,661	382,170	421,638	460,560	473,973
Samut Sakhon	61,470	69,234	77,246	85,377	94,516	102,518	115,533	128,542	144,165	154,231
Ayutthaya	10,717	12,182	14,470	17,250	17,167	18,475	21,743	25,950	32,042	35,425
Nakhon Pathom	1,362	1,362	1,471	1,638	1,629	1,624	1,624	1,756	1,863	1,979
Chachoengsao	0	5	66	66	66	66	77	77	86	86
STUDY AREA	1,117,028	1,151,037	1,152,592	1,097,332	1,157,868	1,185,757	1,212,818	1,272,640	1,402,310	1,481,061

UNITS: PUMPAGE IN CUBIC METERS PER DAY (CMD)

Table 5.4.1 YEAR-1992 COMBINED GROUNDWATER PUMPAGE ESTIMATES FOR PRIVATE AND PUBLIC WELLS IN THE STUDY AREA

Changwat	Type of User	Private Total	DMR	PWD	MWA	PWA	DOH	ARD	IEAT	Public Total	Combined Total
Bangkok	Domestic	141,628	2,516	4,110	79,937	0	0	0	0	86,563	228,191
	Institutional	34,318								0	34,318
	Commercial	42,867								0	42,867
	Industrial	134,755							18,476	18,476	153,231
	TOTAL	353,568	2,516	4,110	79,937	0	0	0	18,476	105,039	458,607
Nonthaburi	Domestic	22,542	750	20,300	5,197	0	0	0		26,247	48,789
	Institutional	2,211								0	2,211
	Commercial	2,270								0	2,270
	Industrial	16,186							0	0	16,186
	TOTAL	43,209	750	20,300	5,197	0	0	0	0	26,247	69,456
Pathum Thani	Domestic	41,902	2,391	19,765	0	19,487	0	0		41,643	83,545
	Institutional	5,373								0	5,373
	Commercial	12,431								0	12,431
	Industrial	157,355							28,600	28,600	185,955
	TOTAL	217,061	2,391	19,765	0	19,487	0	0	28,600	70,243	287,304
Samut Prakan	Domestic	47,020	2,699	33,945	20,892	0	0	0	0	57,536	104,556
	Institutional	4,300								0	4,300
	Commercial	13,256								0	13,256
	Industrial	322,734							29,127	29,127	351,861
	TOTAL	387,310	2,699	33,945	20,892	0	0	0	29,127	86,663	473,973
Samut Sakhon	Domestic	10,609	459	43,510	0	9,871	0	0	0	53,840	64,449
	Institutional	1,676								0	1,676
	Commercial	4,550								0	4,550
	Industrial	83,556								0	83,556
	TOTAL	100,391	459	43,510	0	9,871	0	0	0	53,840	154,231
Ayutthaya	Domestic	3,869	3,375	10,810	0	956	0	118		15,259	19,128
	Institutional	66								0	66
	Commercial	1,662								0	1,662
	Industrial	14,169							400	400	14,569
	TOTAL	19,766	3,375	10,810	0	956	0	118	400	15,659	35,425
Nakhon Pathom	Domestic		1632	0	0	211	136	0	0	1,979	1,979
	Institutional									0	0
	Commercial									0	0
	Industrial									0	0
	TOTAL	0	1,632	0	0	211	136	0	0	1,979	1,979
Chachoengsao	Domestic		86							86	86
	Institutional									0	0
	Commercial									0	0
	Industrial									0	0
	TOTAL	0	86	0	0	0	0	0	0	86	86
Study Area	Domestic	267,570	13,908	132,440	106,026	30,525	136	118	0	283,153	550,723
	Institutional	47,944	0	0	0	0	0	0	0	0	47,944
	Commercial	77,036	0	0	0	0	0	0	0	0	77,036
	Industrial	728,755	0	0	0	0	0	0	76,603	76,603	805,358
	TOTAL	1,121,305	13,908	132,440	106,026	30,525	136	118	76,603	359,756	1,481,061

Note: No private well was inventoried in Nakhon Pathom and Chachoengsao.

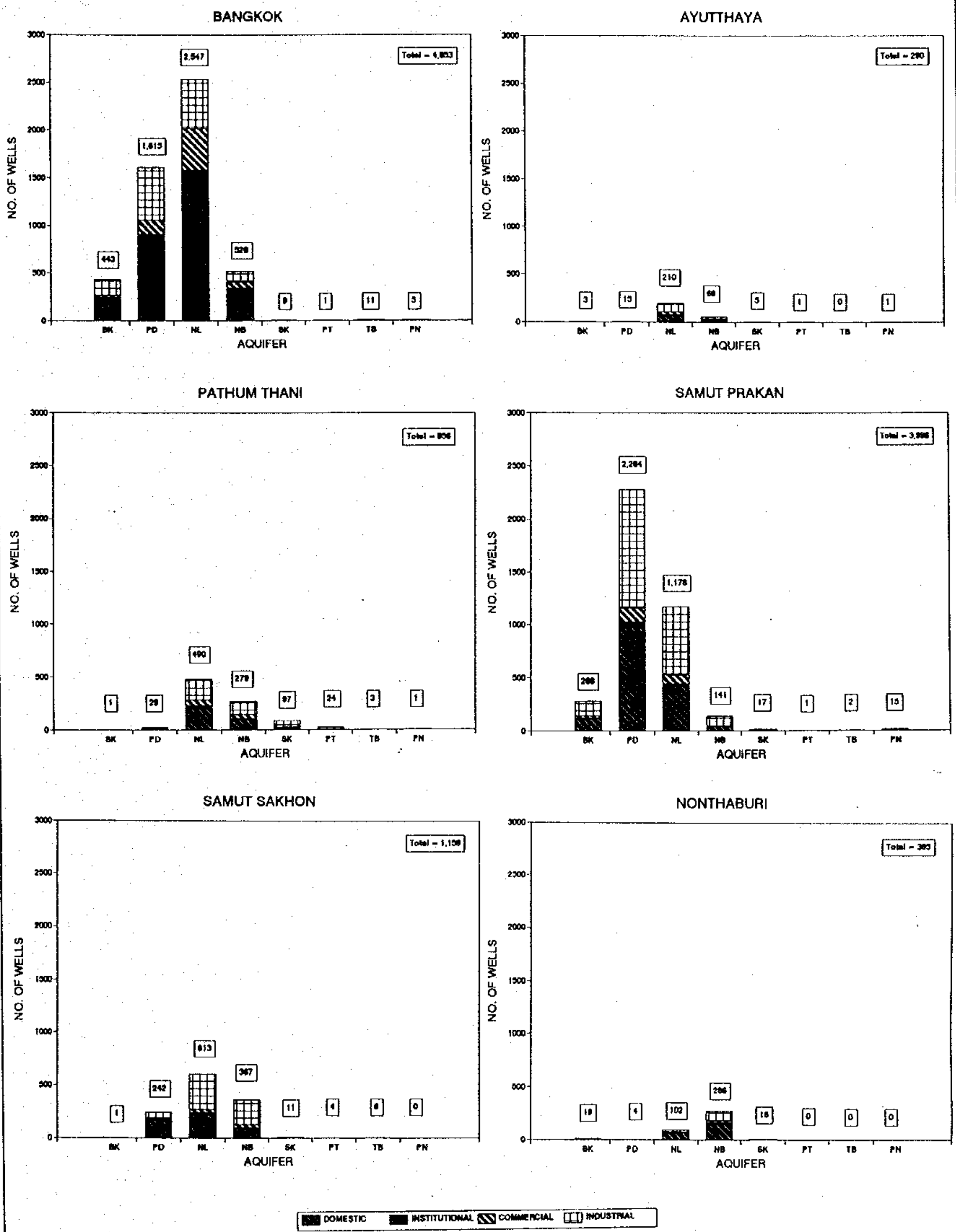


Figure 5.2.1	DISTRIBUTION OF PRIVATE WELLS IN THE WHOLE AREA
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

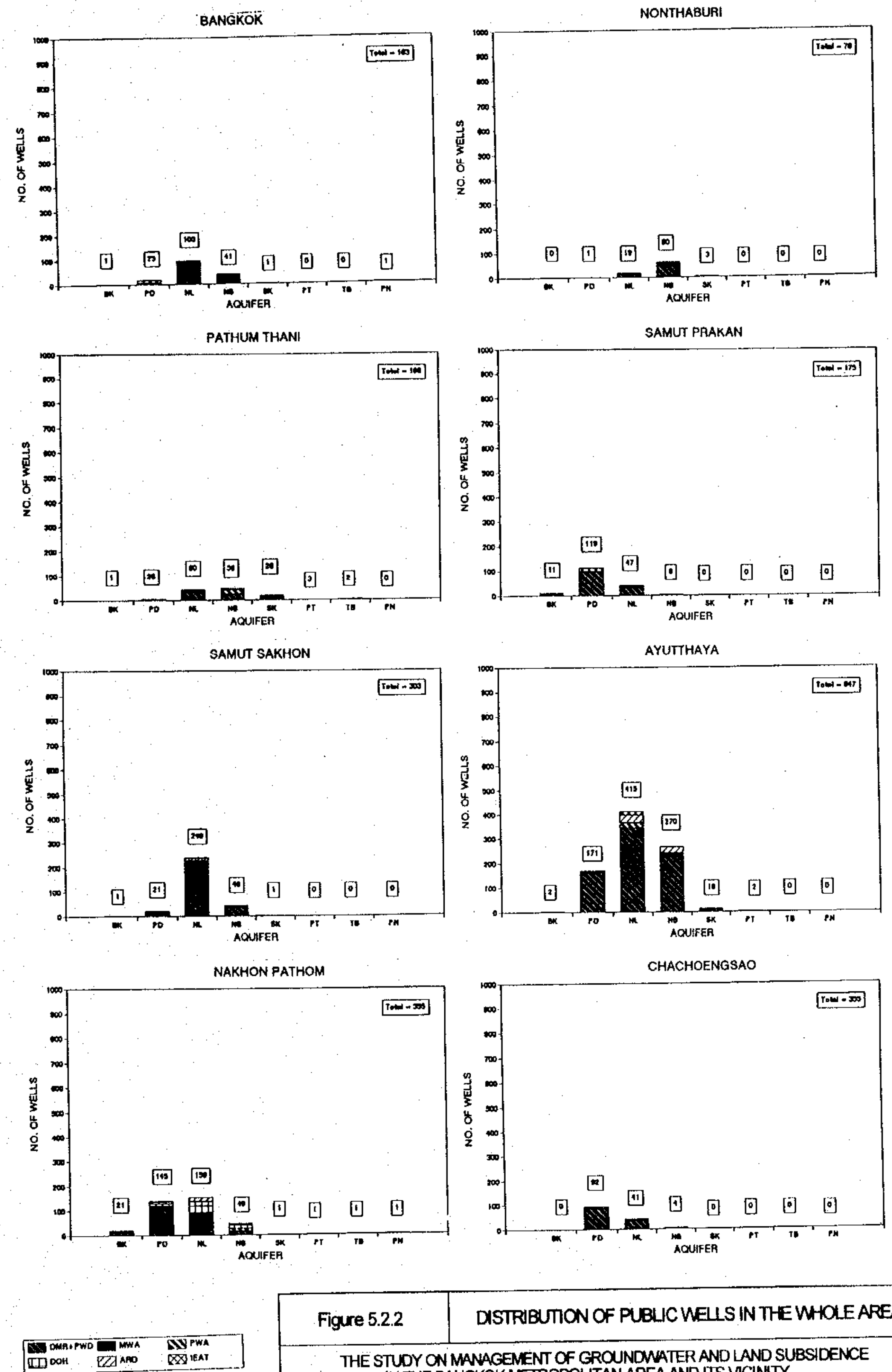


Figure 5.2.2	DISTRIBUTION OF PUBLIC WELLS IN THE WHOLE AREA
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

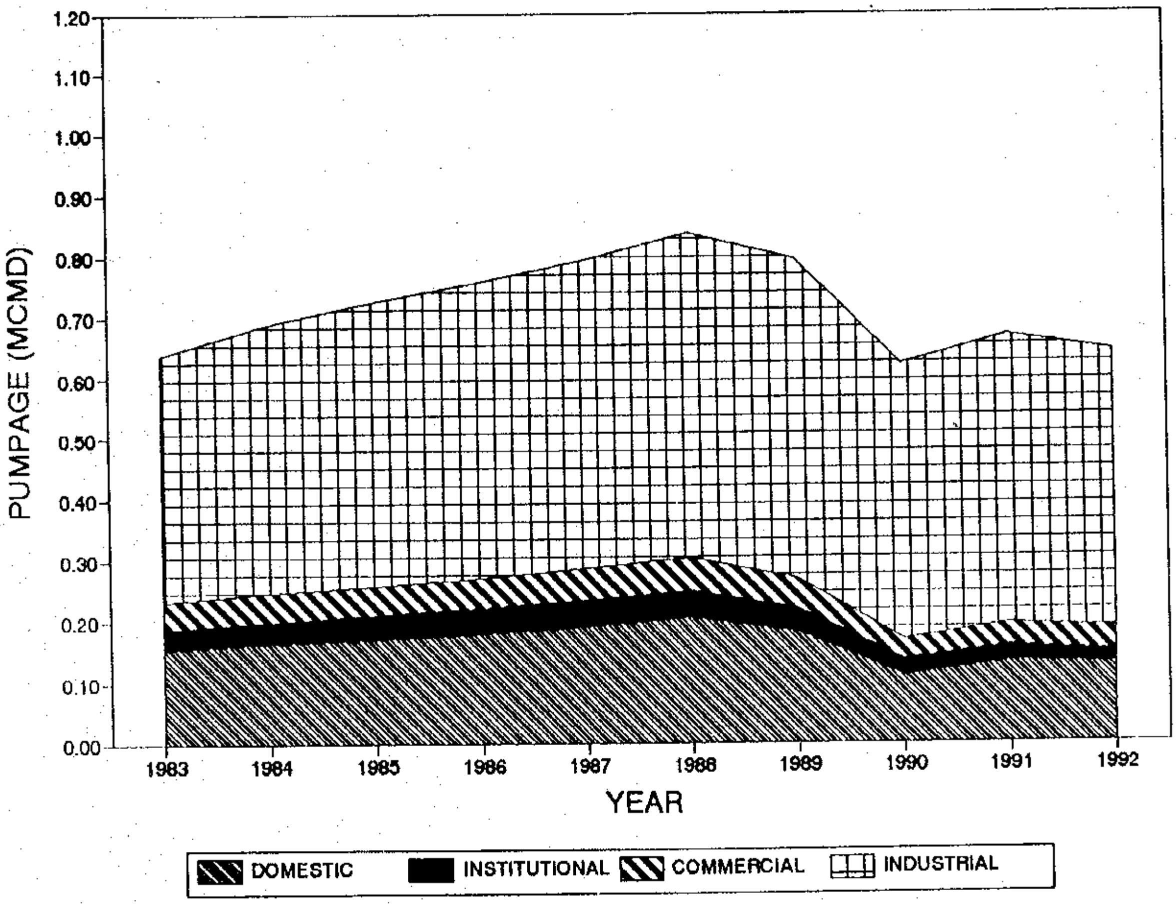


Figure 5.3.1	CASE 1 HISTORICAL PUMPAGE ESTIMATES FOR PRIVATE WELLS IN THE WHOLE AREA
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

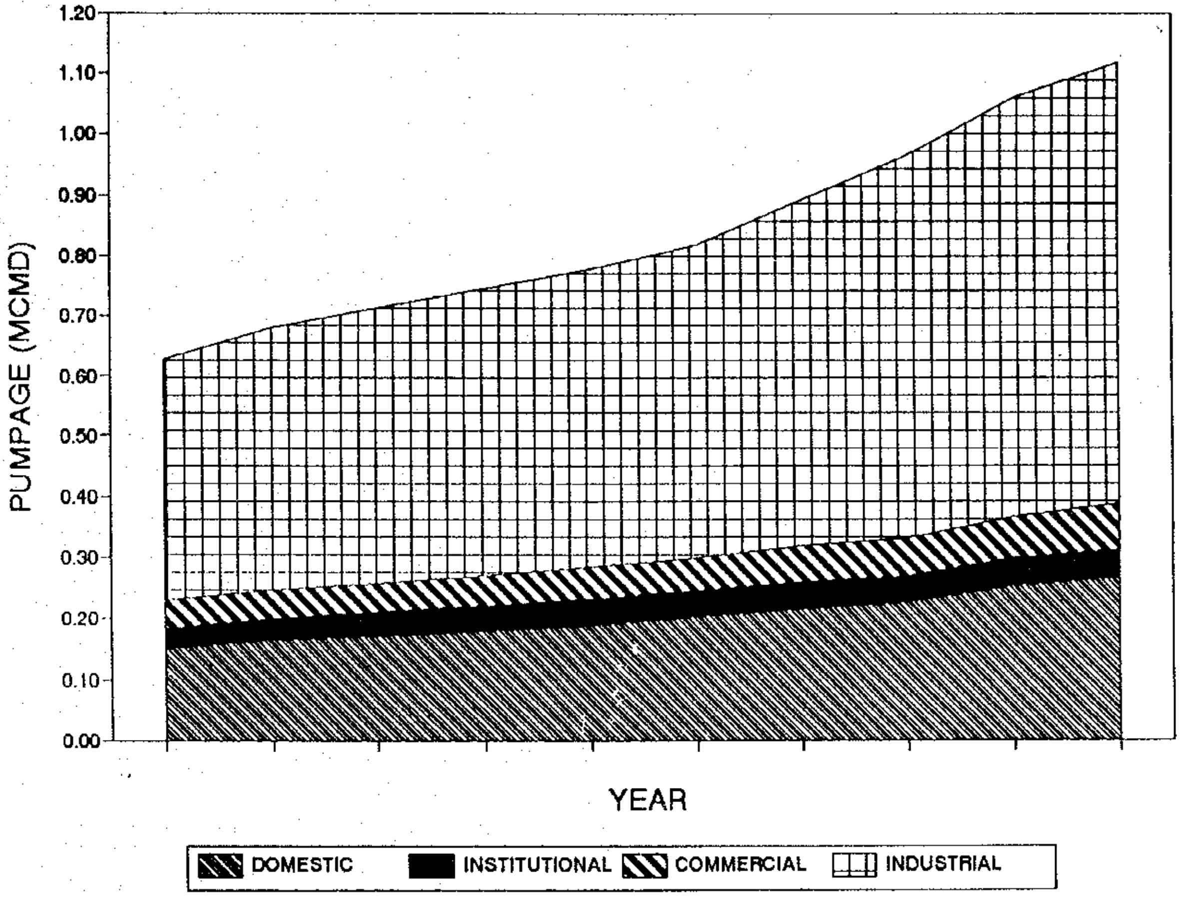


Figure 5.3.2	CASE 2 HISTORICAL PUMPAGE ESTIMATES FOR PRIVATE WELLS IN THE STUDY AREA
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

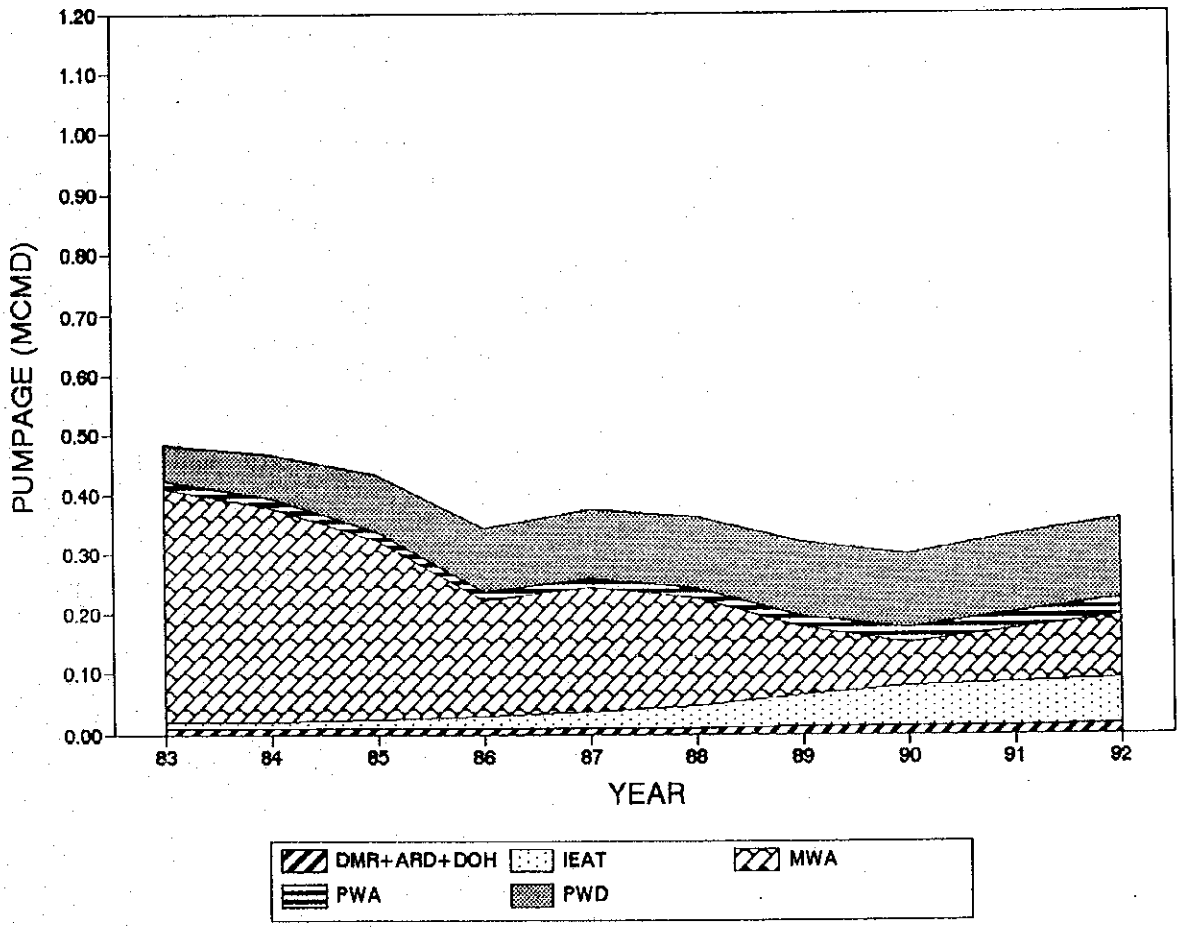


Figure 5.3.3	HISTORICAL PUMPAGE ESTIMATES FOR PUBLIC WELLS IN THE STUDY AREA
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

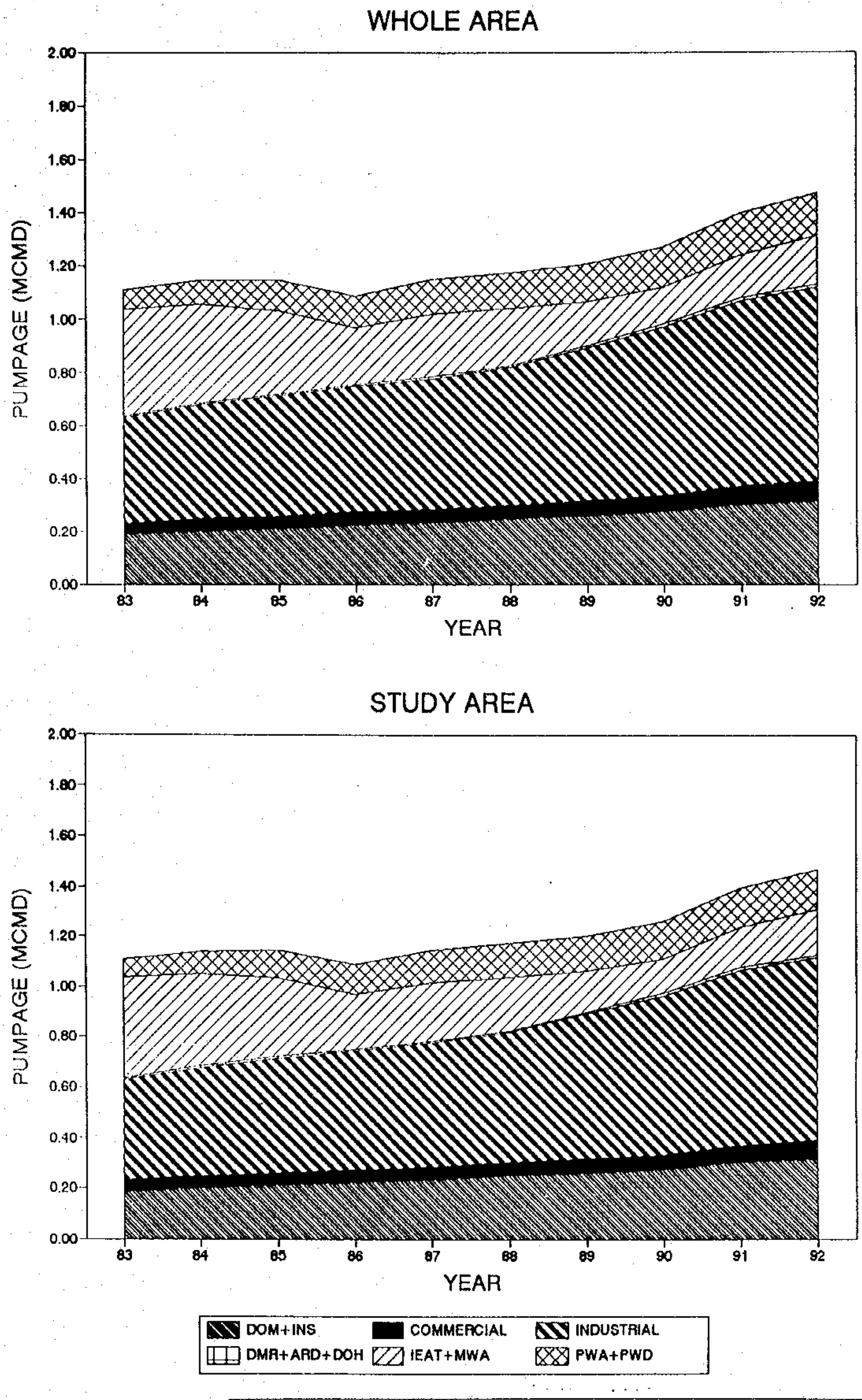


Figure 5.3.4	CASE 2 COMBINED HISTORICAL PUMPAGE ESTIMATES FOR PRIVATE AND PUBLIC WELLS
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

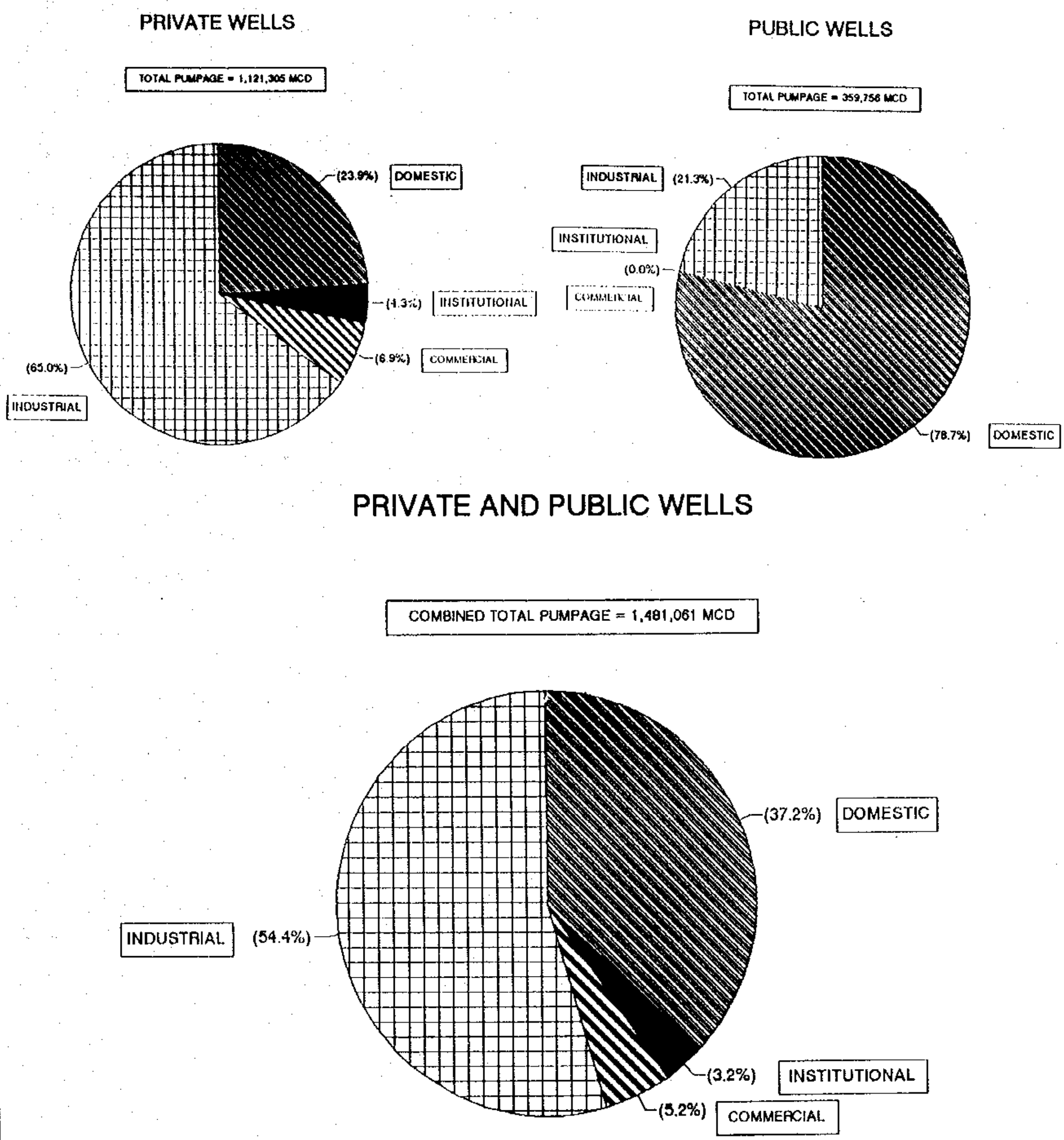
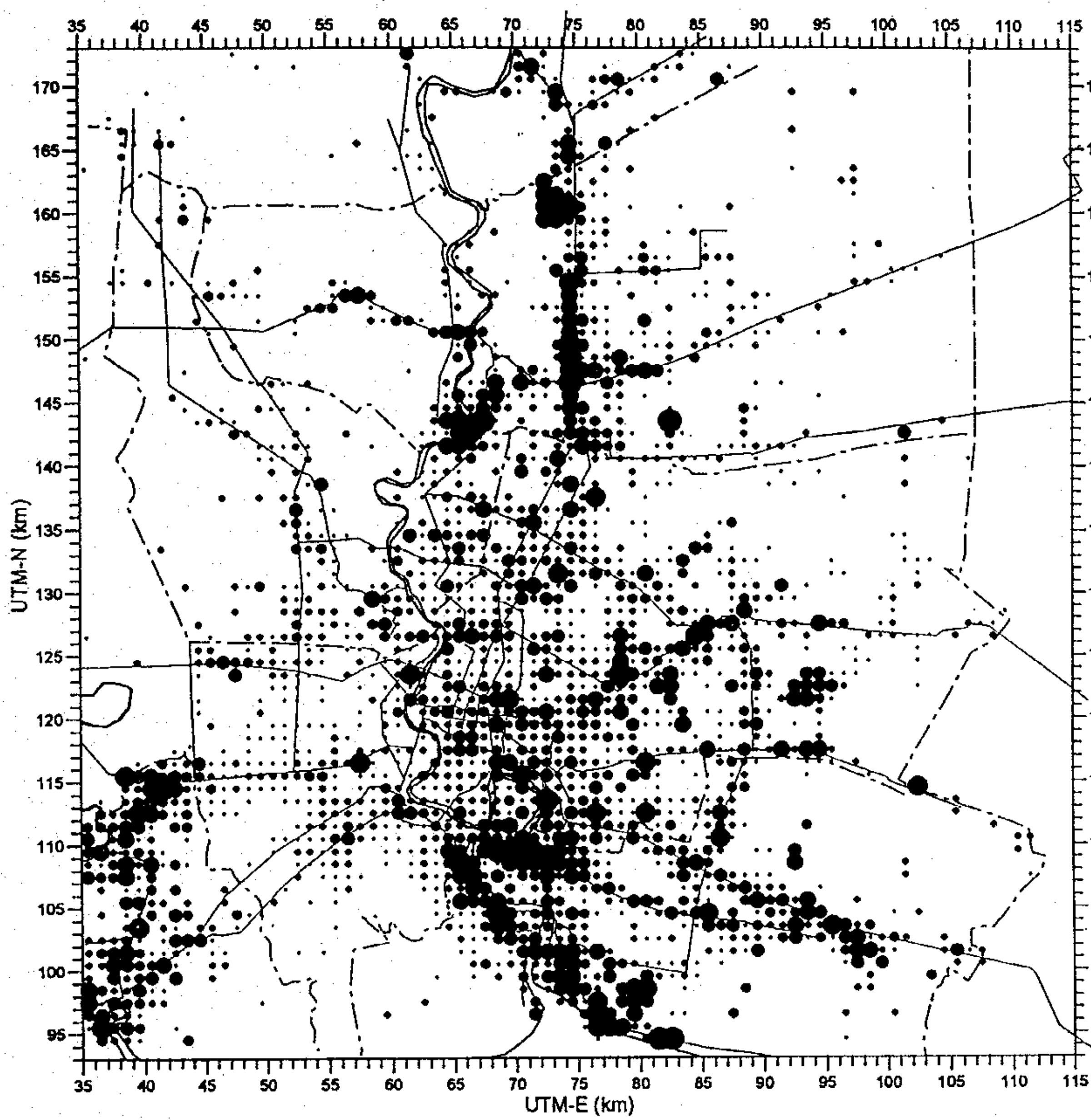


Figure 5.4.1	YEAR-1992 GROUNDWATER USE DISTRIBUTIONS OF PRIVATE AND PUBLIC WELLS IN THE STUDY AREA

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

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



LEGEND

Groundwater Pumpage (m^3 /day)
per 1km x 1km grid

- 1 to 99
- 100 to 499
- 500 to 999
- 1,000 to 1,999
- 2,000 to 4,999
- 5,000 to 9,999
- More than 10,000

Total Pumpage in Study Area in 1992 = 1,481,061 m^3/day

Figure 5.4.2	DISTRIBUTION OF GROUNDWATER PUMPAGE IN THE STUDY AREA IN 1992
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.

CHAPTER 6 GROUNDWATER LEVELS AND LAND SUBSIDENCE

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6.1 DMR Monitoring Stations

Groundwater levels in the Study Area are monitored by DMR through the groundwater monitoring network consisting of 258 observation wells in 103 stations. Of the 258 monitoring wells, 77 wells were installed with water level recorders. Groundwater levels in all monitoring wells are measured at least monthly (Figure 6.1).

(1) Groundwater Level Changes

The annual piezometric changes of main aquifers in the past 15 years in Lat Krabang, PathumThani, and Samut Sakhon are presented in Figure 6.2. Recent decline of groundwater levels and land subsidence were noticeable in these areas. In Pathum Thani, the piezometric levels declined almost continuously, though the levels temporarily recovered from 1985 to 1987 due to DMR's restriction on private pumpage. The annual decline of water levels were also significant in the other two (2) areas.

(2) Groundwater Contour

Phra Pradaeng Aquifer

From 1981 to 1985, piezometric level lowered yearly in the central Bangkok Metropolis but recovered slightly in 1987 due to restriction of pumpage. The cone of depression extended to the east and the deepest piezometric level of 53.0 m was observed in Bang Phli, Samut Prakan in 1993. The piezometric levels below 20 m were distributed in the entire Bangkok Metropolis, Samut Prakan, Samut Sakhon, and central Pathum Thani. The cone of depressions deeper than 30 m appeared isolately (Figure 6.3).

Nakhon Luang Aquifer

Peizometric levels lower than 40-50 m were observed from central to eastern portion of Bangkok in the beginning of 1980. The center of the depression moved toward east every year. The 1994 groundwater contour shows an elliptical depression zone extending from north to south at maximum depth of 60 m. The center of Bangkok is at the western edge of the depression zone showing 30 m to 35 m water level (Figure 6.4).

Nonthaburi Aquifer

The piezometric contour of Nonthaburi aquifer is similar to those of the above mentioned two (2) aquifers. From 1980 to 1984, the cone of depression was observed in the central Bangkok but moved gradually toward the east. A wide depression zone of 40 m to 50 m stretching from Pathum Thani, Samut Sakhon and Samut Prakarn appeared in 1994 (Figure 6.5).

6.2 JICA Monitoring Stations

Groundwater levels and land subsidence are monitored at the JICA monitoring stations in Lat Krabang (Site A), AIT (Site B) and Samut Sakhon (Site C) since July 1993. These monitoring wells measure groundwater levels and land subsidence at different depths, record data on the chart continuously and store them in the magnetic card every hour. These data are collected every month and processed on the micro-computer at DMR.

(1) Lat Krabang (Site-A)

The deepest groundwater level was observed at A-6 well (Nakhon Luang Aquifer) showing 63.0 m in July 1994. The decline since the beginning was about 5 m. The groundwater levels at A-5 well (Nonthaburi Aquifer) and A-7 well (Phra Pradaeng Aquifer) were lower than 50 m. Those at the deep monitoring wells, i.e., A-2 well (Phayathai Aquifer), A-3 well (Sam Khok Aquifer), A-4 well (Sam Khok Aquifer) and at the shallowest A-8 well (Bangkok Aquifer) ranged from 20 m to 27 m. The water level of the deepest A-1 well (Pak Nam Aquifer) has gradually recovered since its construction, and the present piezometric head is slightly higher than the ground elevation indicating an artesian condition.

The maximum land subsidence of 6.5 cm was recorded at A-2 well in July 1993. The subsidence rate which was evaluated considering the compaction of land fill was almost the same as the recorded subsidence rate based on the nearby benchmark. The annual compression from the surface to the bottom of A-8 well (48 m) which was considered subsidence of the shallow formations including Bangkok Clay represented only 40% of the total compression measured at A-1 well (574 m). The rest, 60% of the compression, occurred at deeper formations (Figure 6.6).

(2) AIT (Site-B)

Groundwater level was lowest at B-1 well (Nonthaburi Aquifer) and gradually increased as the depth decreased in the order of B-2, B-3 (both Nakhon Luang Aquifers), B-4 (Phra Pradaeng Aquifer) and B-5 (Bangkok Aquifer). The groundwater levels declined to 37 m, 32 m and 32 m at B-1, B-2 and B-3, respectively. The daily and weekly fluctuations of water levels were observed at B-2 and B-3 wells. These fluctuations were caused by the pumping of the industrial wells in the vicinity.

Slight land subsidence occurred at the above monitoring wells. A maximum subsidence was only 1.1 cm since the beginning. However, records showed the land slightly rebounded since May 1994. A rhythmic daily cycle of compression and rebound was observed. This corresponded with the daily fluctuation of the groundwater level (Figure 6.7).

(3) Samut Sakhon (Site -C)

The deepest groundwater levels were observed at C-2 well (Nonthaburi Aquifer) recorded at 71 m elevation and at C-3 well (Nakhon Luang Aquifer) recorded at 53 m elevation (July, 1994). The groundwater levels were affected by the pumping of wells in the vicinity and a rhythmic daily and weekly fluctuations were observed. C-4 and C-5 (both Phra Pradaeng Aquifers) and the deepest C-1 well (Sam Khok Aquifer) ranged from 17 m to 29 m in water levels. Fluctuations of groundwater levels were not observed.

A maximum subsidence of 12.6 cm was recorded at C-2 well (212 m) for about 1 year. C-4 well (105 m) recorded a minimum subsidence of 10 cm. The deepest C-1 well (320 m) also recorded about 12.0 cm and the shallowest C-5 (78 m) was 10.6 cm. Most of the compression occurred at the shallow formations. The site was excavated and filled with soil when it was constructed because it was situated at a low soft ground. A much longer time for evaluation of land subsidence on each well was necessary in view of the anticipated settlement of the land fill (Figure 6.8).

(4) Benchmarks

Two (2) kinds of benchmarks were constructed at each monitoring station in order to measure ground subsidence. One benchmark's foundation was placed at the depth of 1 m BGS without support. The other benchmark's foundation was supported by 3 m long concrete piles. The elevations of these benchmarks were determined by reliable leveling conducted by the Study Team in July 1993 and June 1994 using nearby existing DMR benchmarks as reference benchmark. The latest elevation of existing DMR benchmarks were not available at that time and so, their subsidence were calculated.

(5) Pore Water Pressure

Five (5) pore water pressure meters were buried from 5 m to 34 m depths at Lat Krabang (Site A). The pore water pressure of Bangkok Clay was measured once a month. The results indicated the hydrostatic pressure distribution up to a depth of 15 m. It was noted that the pressure lowered to 0.8kgf/cm^2 and 1.8 kgf/cm^2 at 25 m and 34 m depths, respectively.

6.3 DMR and RTSD Benchmarks

A total of 1,243 benchmarks were constructed by DMR, RTSD, BMA and related agencies as of the year-1992. Some of these benchmarks were destroyed or lost (see Figure 6.9). There was no established standard date and time of leveling among these agencies. The following is discussed according to the RTSD and the DMR data:

(1) Subsidence at Representative Benchmarks

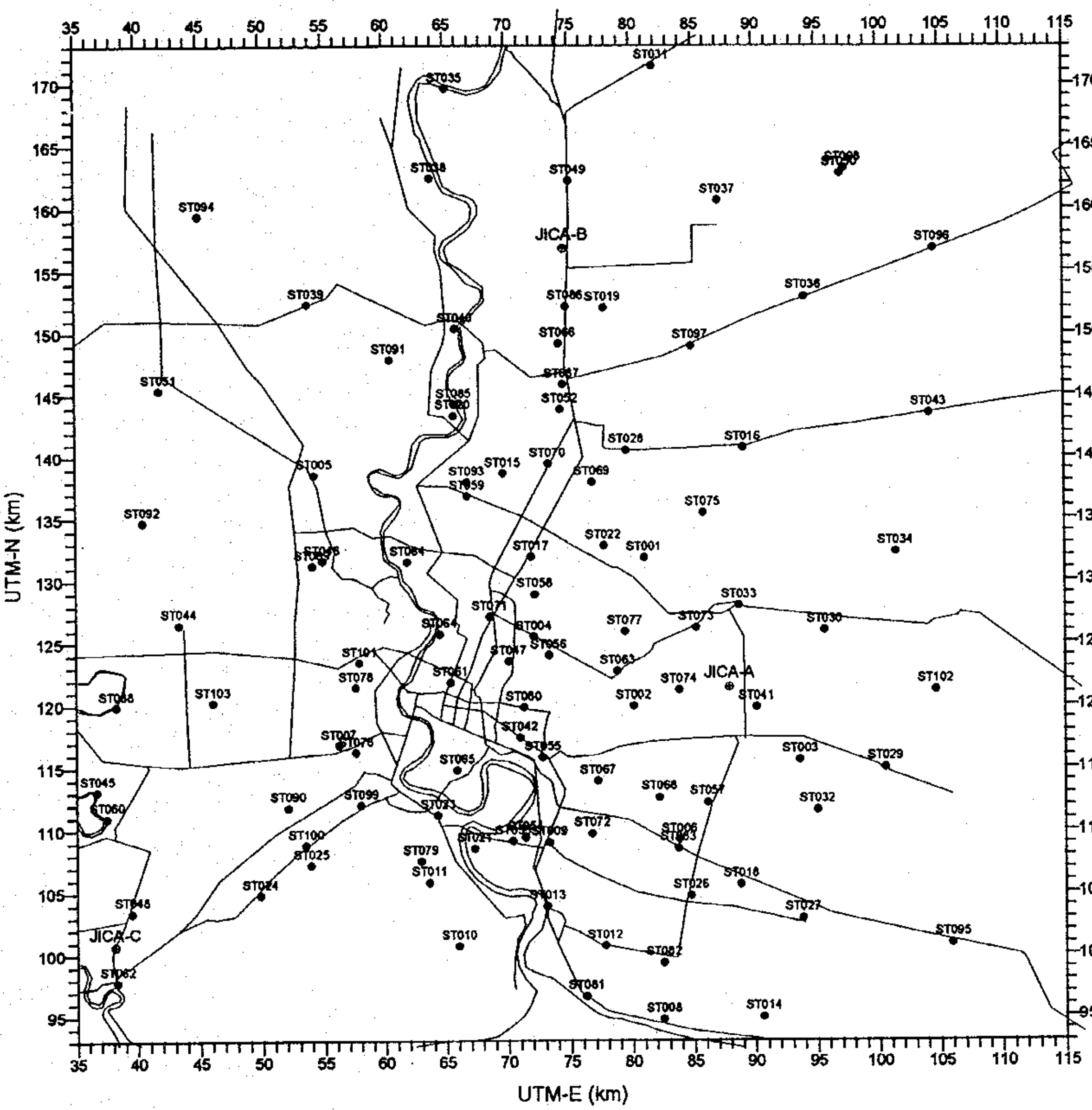
The land subsidence recorded at AIT-14 station's CI-1 benchmark (1 m depth) in Phra Khanong, Bangkok was 648.8 mm in 13 years from 1980 to 1993. AIT-08 station's CI-1 showed 225 mm in the same period. It is located at Chulalongkorn University in the center of Bangkok. AIT-25 station's CI-1 in Pathum Thani also recorded 75 mm in 8 years since 1986, however, it rebounded in 1990 and 1992 (Figure 6.10).

(2) Total Land Subsidence

Figure 6.11 shows the total subsidence distribution in twelve (12) years from 1980 to 1992 (1 m depth). A subsidence cone was located in the center of Bangkok indicating 62.6 cm maximum. The land subsidence area extends north-south direction from this center of the cone. The Study Area entirely subsided more than 10 cm. The total subsidence before 1986 formed the subsidence cone in the center of Bangkok, however, the cone gradually moved toward the east since 1986. The total subsidence in the southern and eastern areas, Samut Prakan and Lat Krabang, showed 20 to 25 cm in 6 years, while in the center of Bangkok was less than 15 cm.

(3) Land Subsidence Rate from 1992 to 1993

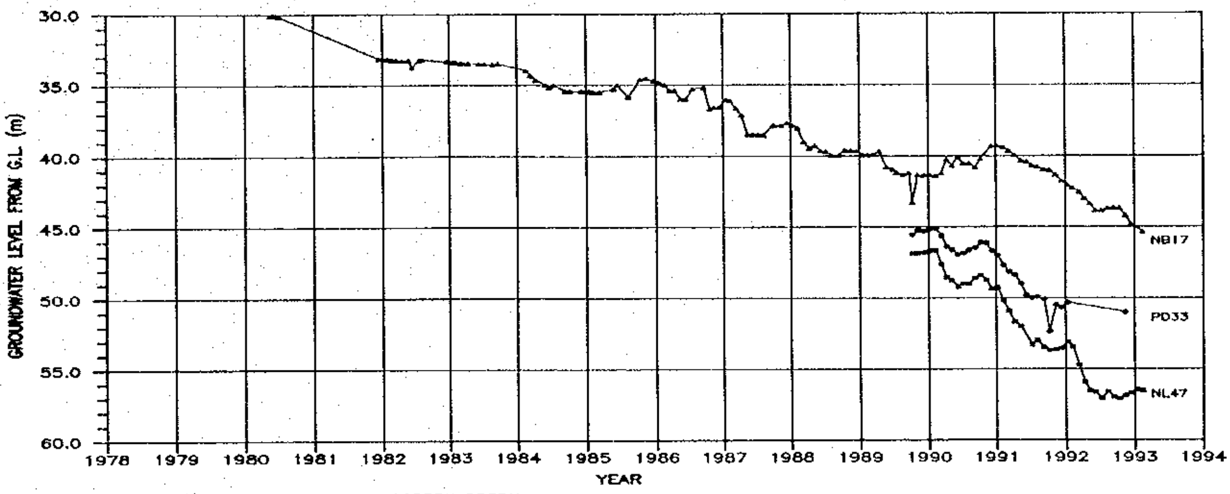
Figure 6.12 shows the annual rate of subsidence from 1992 to 1993. The map indicates significant land subsidence at more than 3 cm/year which occurred in Samut Prakan and Lat Krabang, south and east of Bangkok, respectively. The subsidence cone of 4-5 cm/year was observed locally in these areas. On the other hand, 1-2 cm/year of subsidence was observed at the center of Bangkok. It was less than 1 cm/year in the area along the Chao Phraya River.



LEGEND

- Location of JICA monitoring station
- Location of DMR monitoring station with station No.

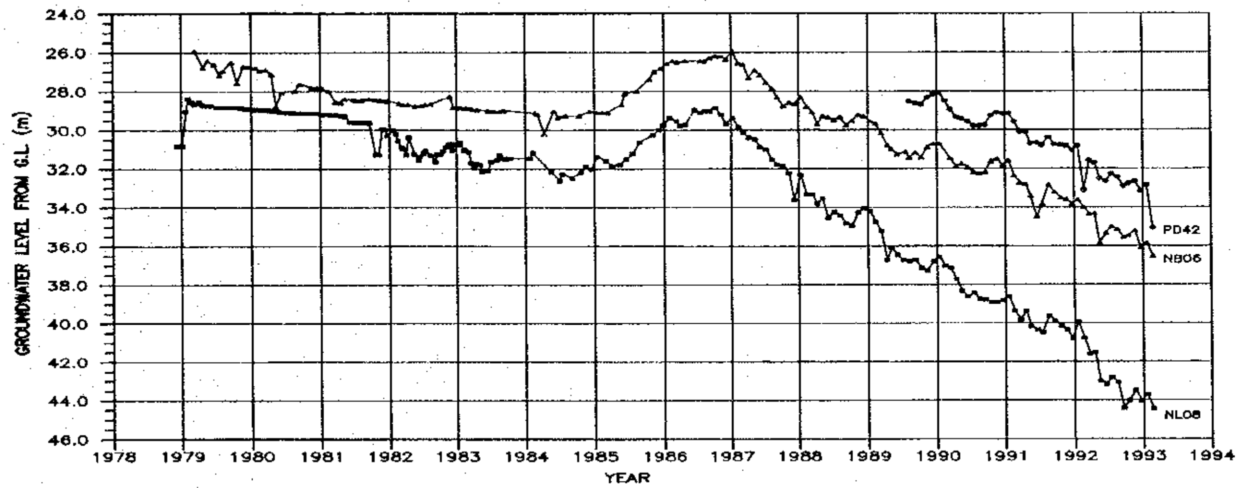
Figure 6.1	**LOCATION OF DMR MONITORING STATIONS**
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



LOCATION : Wat Bamrung Run
Tambon : Khlong Sam Prawet
Amphoe : Lat Krabang
Changwat : Bangkok
UTM Grid : 901198

SCREEN DEPTH
PD33 : 104.0–110.0m
NL47 : 147.0–153.0m
NB17 : 183.0–189.0m

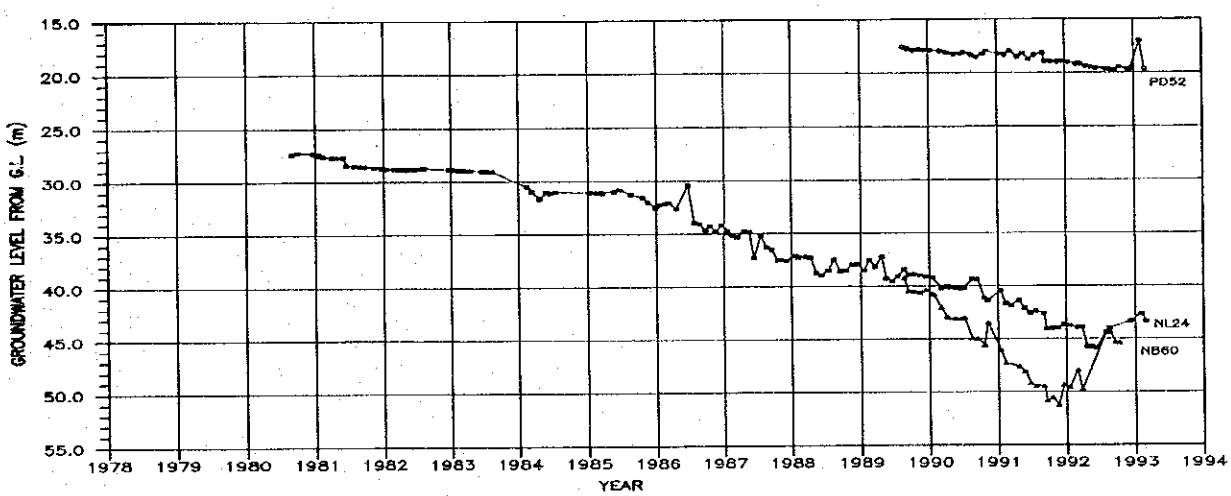
STATION No. 41



LOCATION : Wat Kla Cha-um
Tambon : Khlong Song
Amphoe : Khlong Luang
Changwat : Pathum Thani
UTM Grid : 778520

SCREEN DEPTH
PD42 : 107.0–113.0m
NL08 : 122.3–128.3m
NB06 : 186.2–192.2m

STATION No. 19

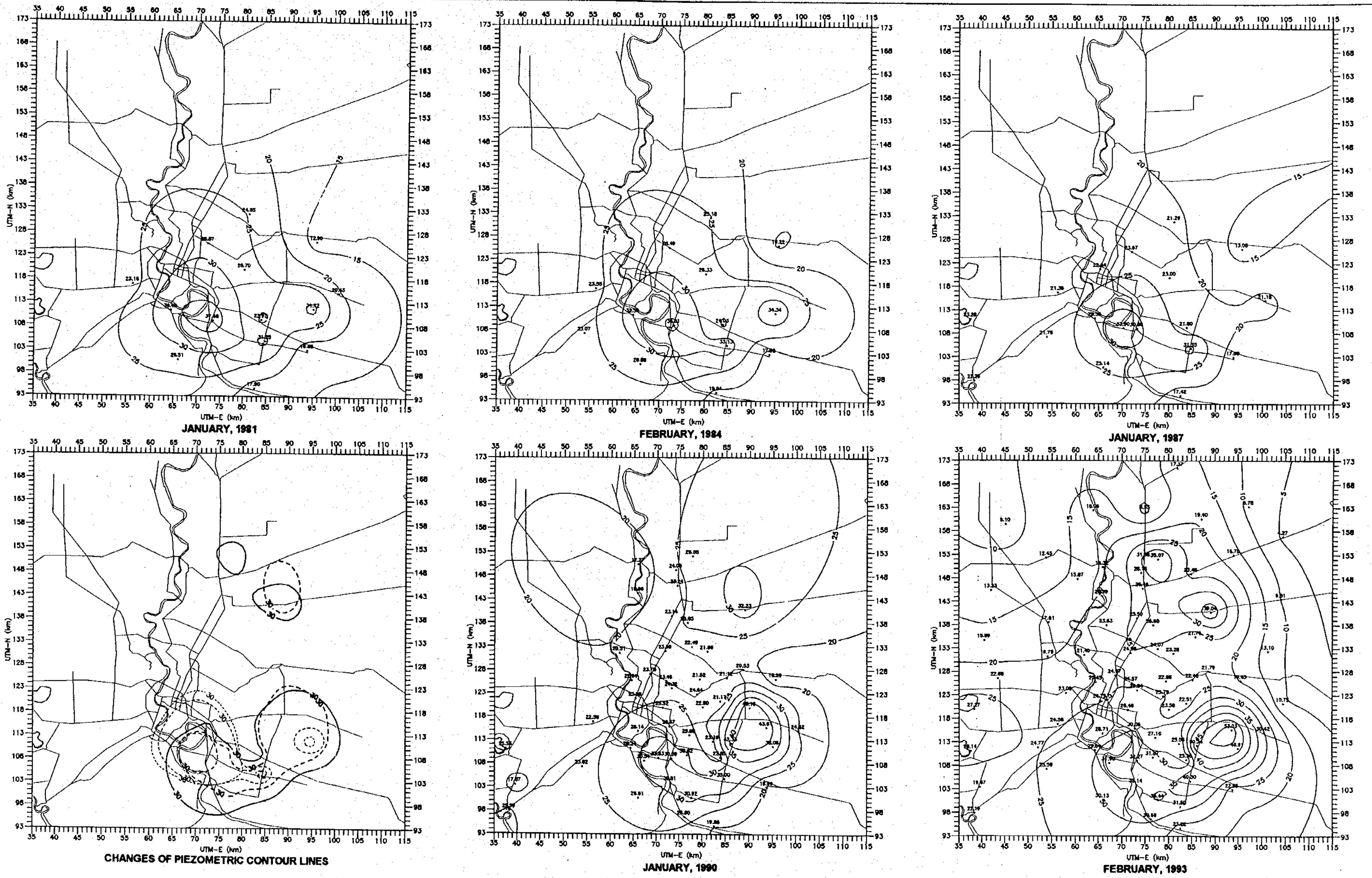


LOCATION : Wat Bang Ping
Tambon : Na Di
Amphoe : Muang Samut Sakhon
Changwat : Samut Sakhon
UTM Grid : 395034

SCREEN DEPTH
PD52 : 77.0– 83.0m
NL24 : 134.0–140.0m
NB60 : 221.0–227.0m

STATION No. 48

Figure 6.2	**GROUNDWATER LEVEL CHANGES**
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



LEGEND

- 30mbgs CONTOUR LINE IN JAN. 1981
- 30mbgs CONTOUR LINE IN FEB. 1984
- 30mbgs CONTOUR LINE IN JAN. 1987
- 30mbgs CONTOUR LINE IN JAN. 1990
- 30mbgs CONTOUR LINE IN FEB. 1993

(mbgs : m below ground surface)

LEGEND

- LINE OF EQUAL PIEZOMETRIC LEVEL (m below ground surface)
- 25.00 DMR MONITORING WELL WITH PIEZOMETRIC LEVEL (m below ground surface)

Figure 6.3	PIEZOMETRIC LEVEL OF PHRA PRADAENG AQUIFER
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

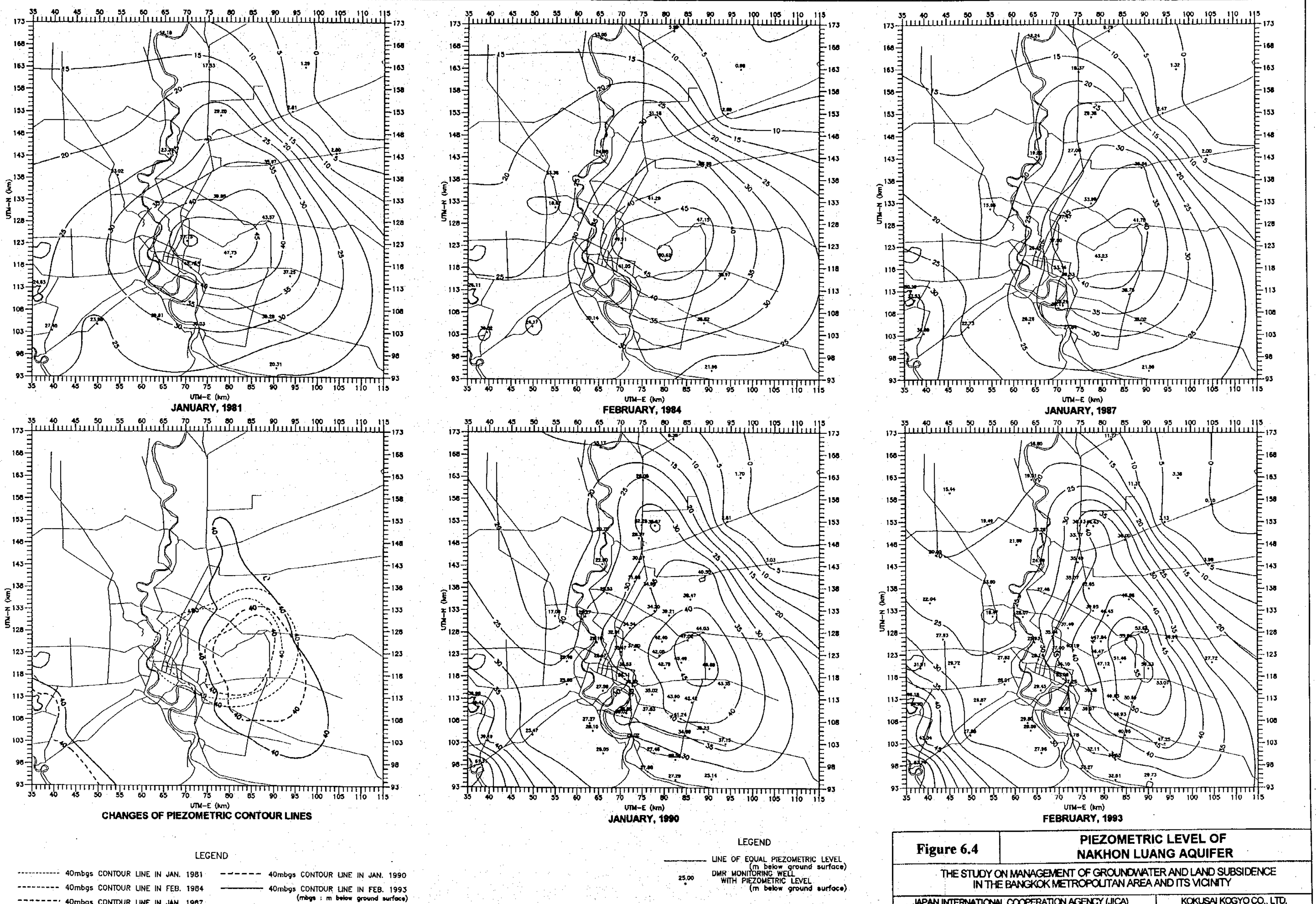
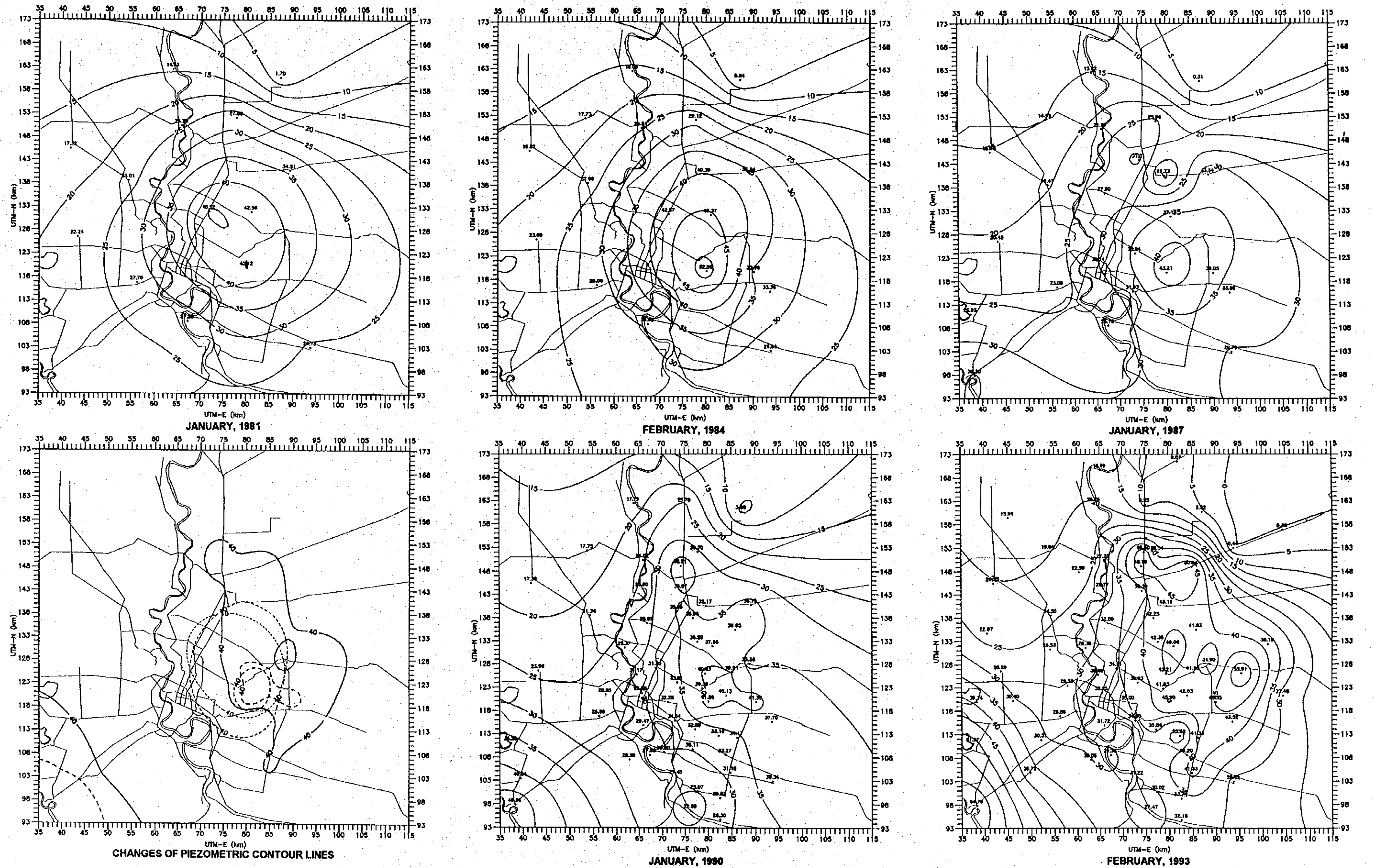


Figure 6.4 PIEZOMETRIC LEVEL OF NAKHON LUANG AQUIFER

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

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



LEGEND

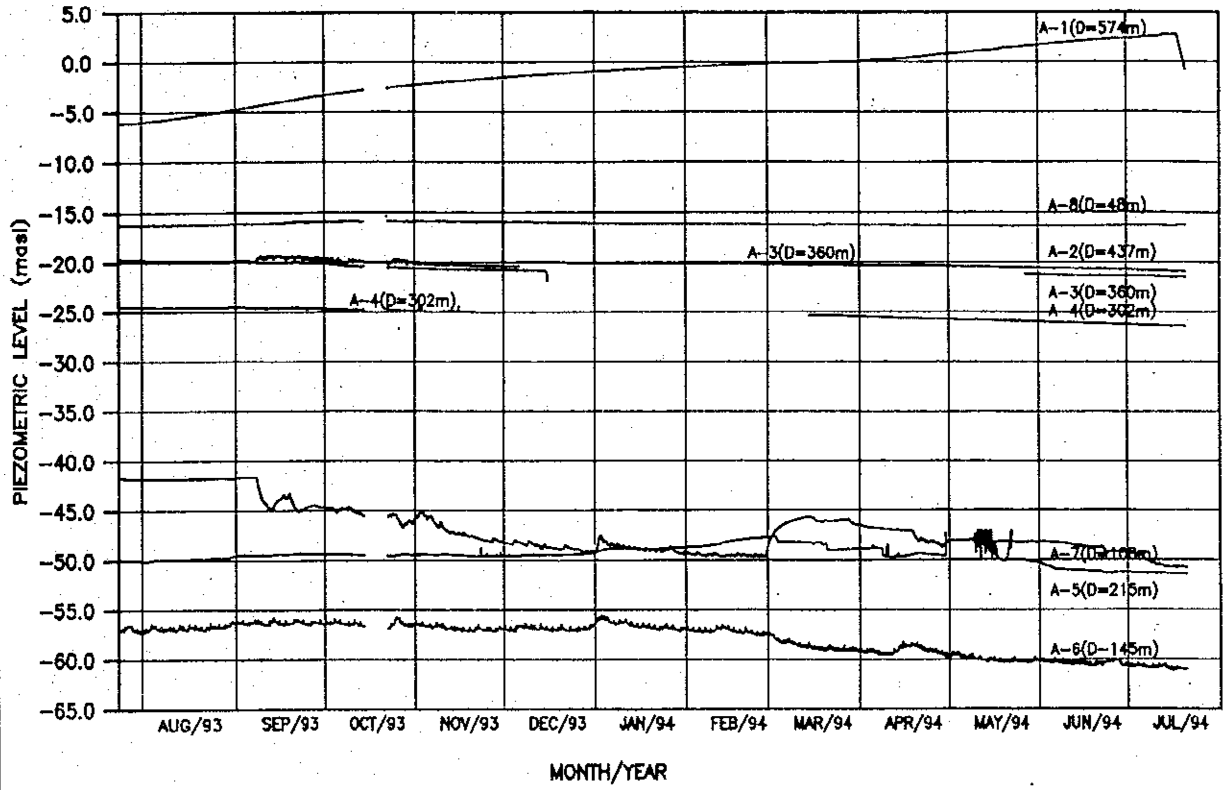
- .... 40mbgs CONTOUR LINE IN JAN. 1981
- – – – – – 40mbgs CONTOUR LINE IN FEB. 1984
- — — — — 40mbgs CONTOUR LINE IN JAN. 1987
- –·–·–·– 40mbgs CONTOUR LINE IN JAN. 1990
- ———— 40mbgs CONTOUR LINE IN FEB. 1993

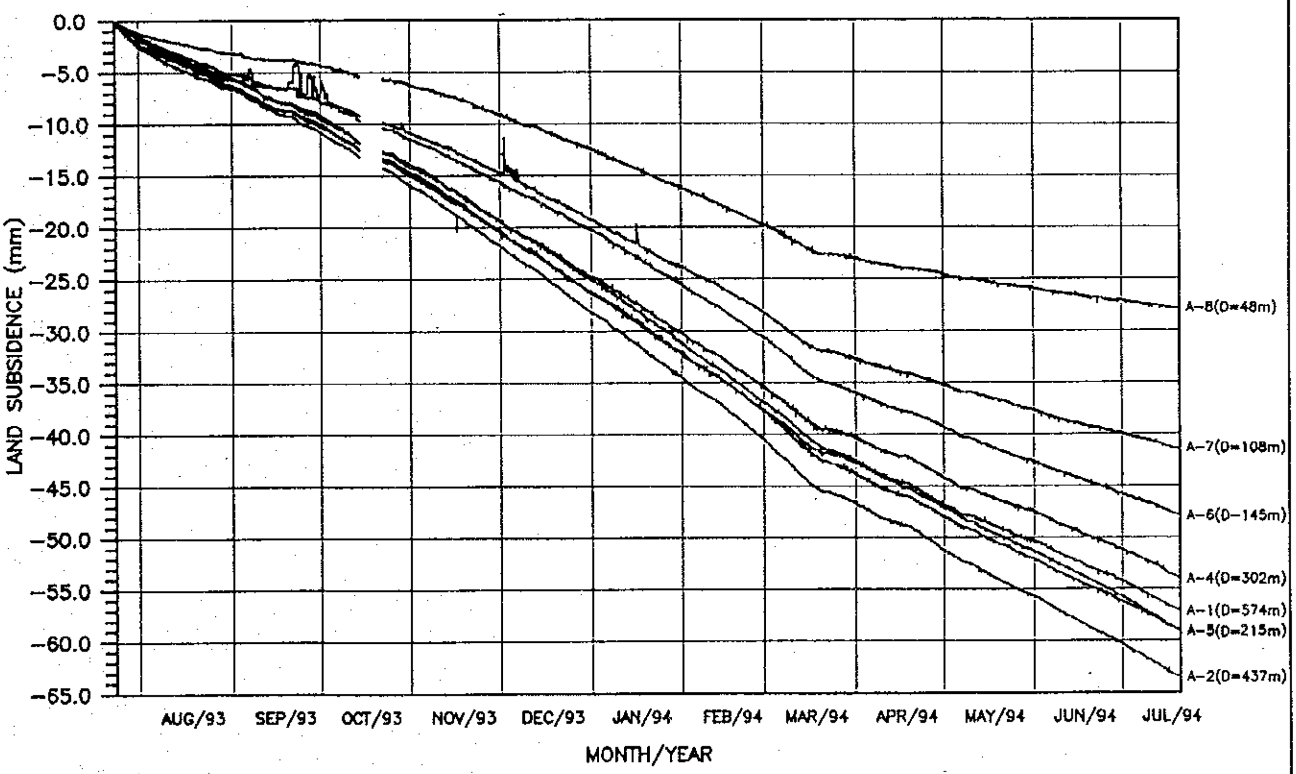
(mbgs : m below ground surface)

LEGEND

- ———— LINE OF EQUAL PIEZOMETRIC LEVEL (m below ground surface)
- 25.00 • DMR MONITORING WELL WITH PIEZOMETRIC LEVEL (m below ground surface)

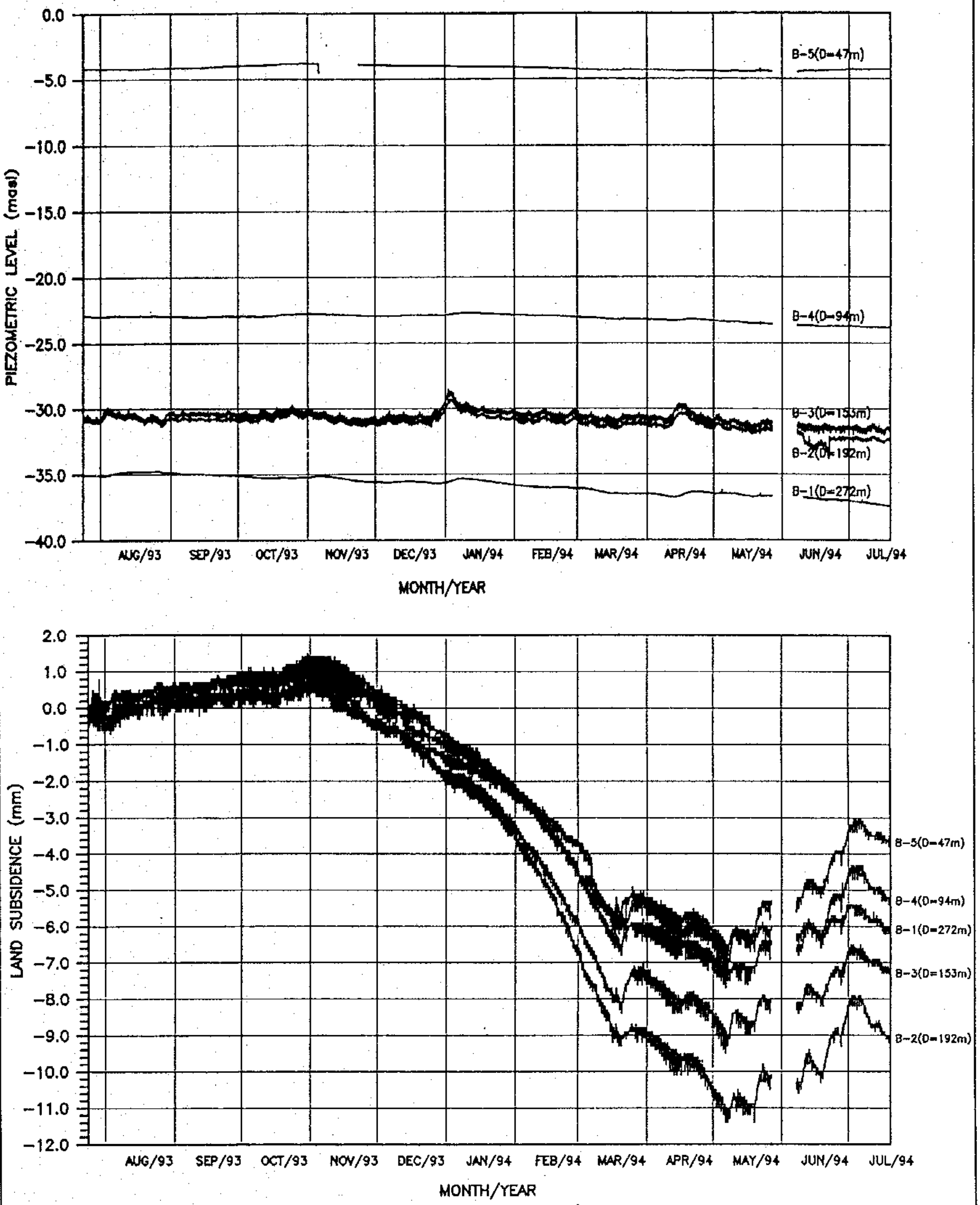
Figure 6.5	PIEZOMETRIC LEVEL OF NONTHABURI AQUIFER
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.





WELL NO.: JICA A-1 to A-8
LOCATION: LAT KRABANG
UTM GRID: 879215

Figure 6.6	PIEZOMETRIC LEVELS AND LAND SUBSIDENCE AT SITE - A
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.



WELL NO.: JICA B-1 to B-5
LOCATION: AIT
UTM GRID: 746568

Figure 6.7	PIEZOMETRIC LEVELS AND LAND SUBSIDENCE AT SITE - B
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

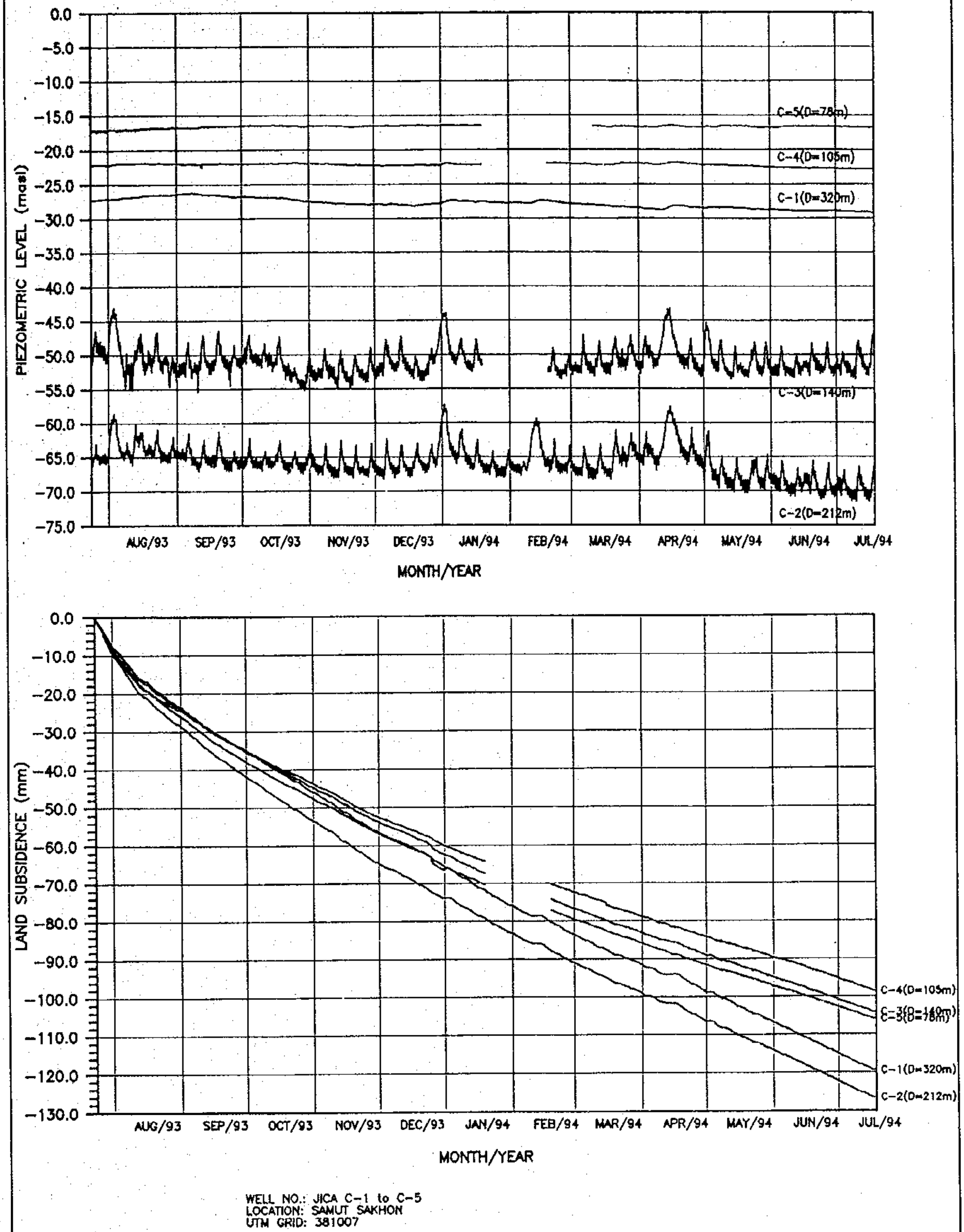


Figure 6.8	PIEZOMETRIC LEVELS AND LAND SUBSIDENCE AT SITE - C
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

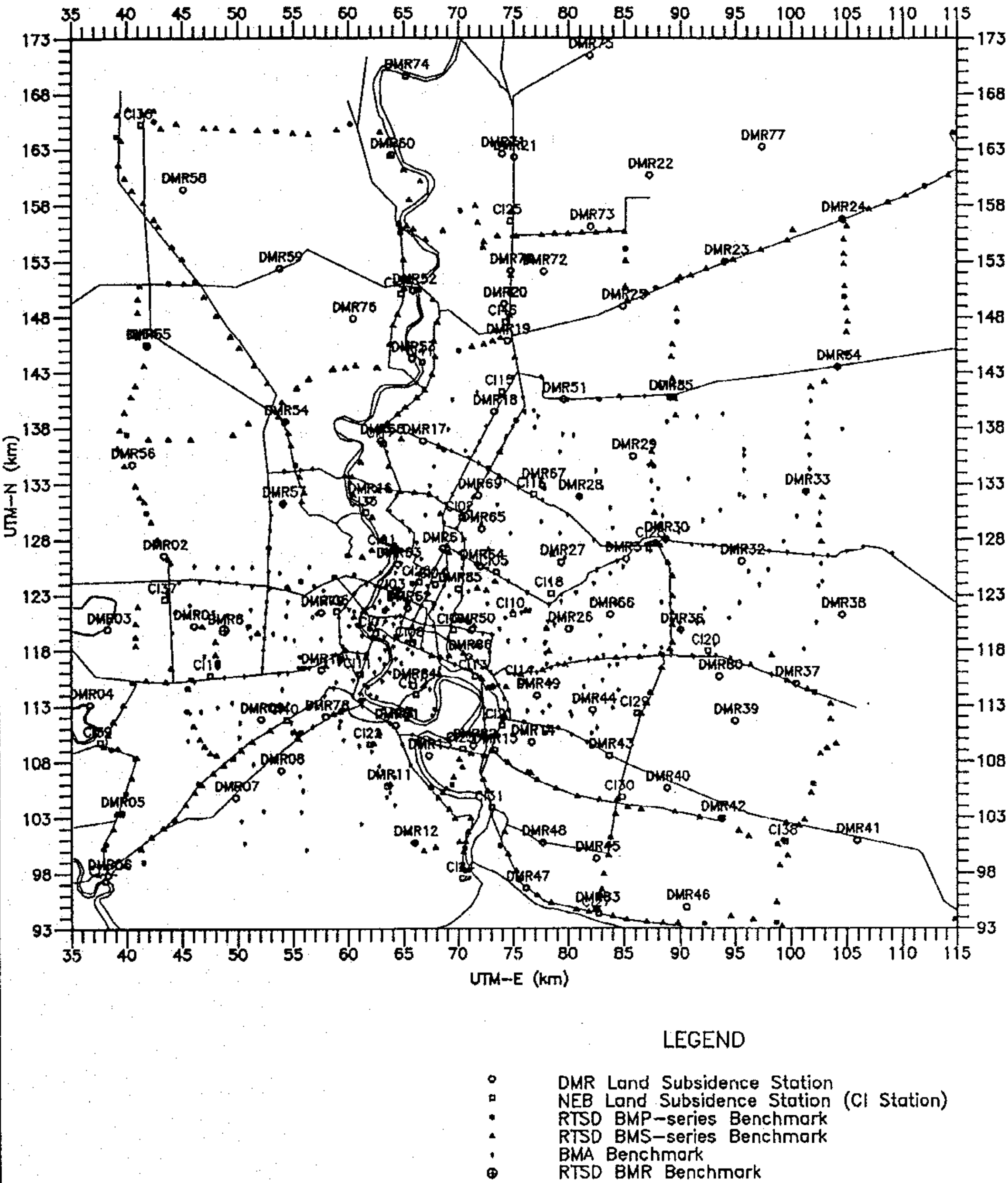
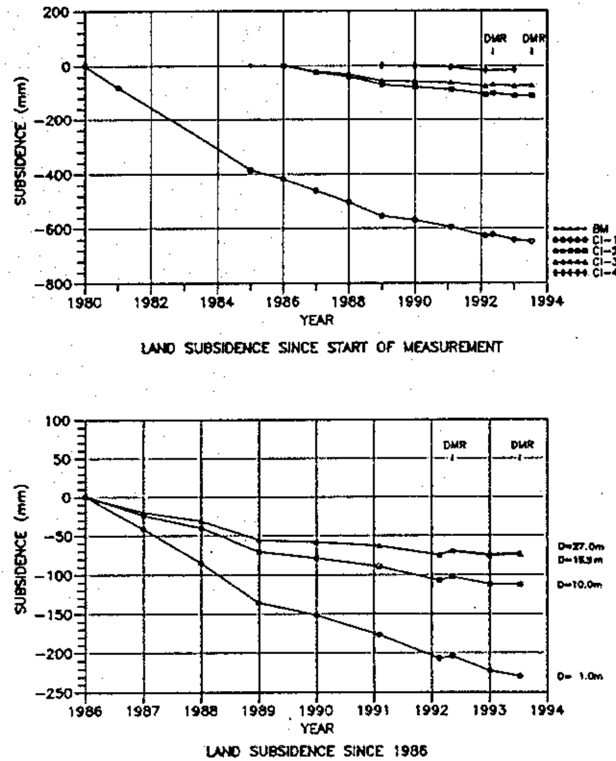
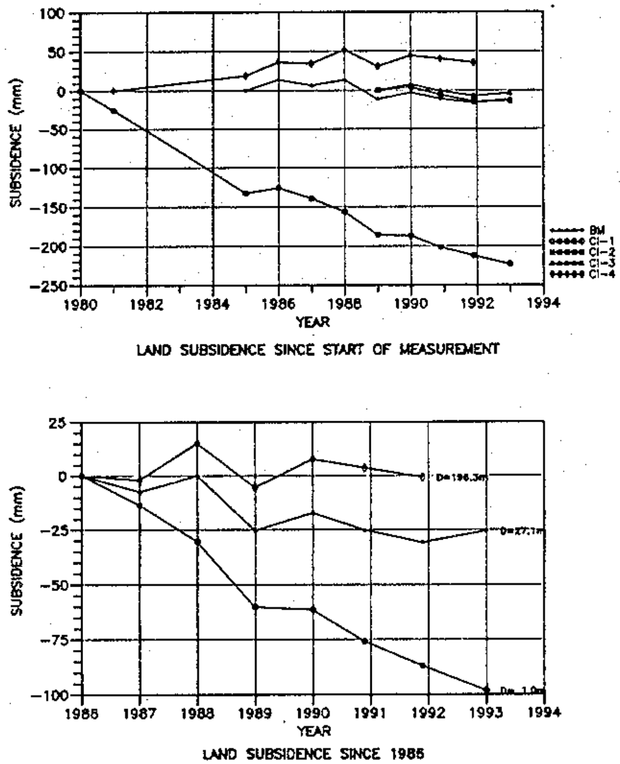


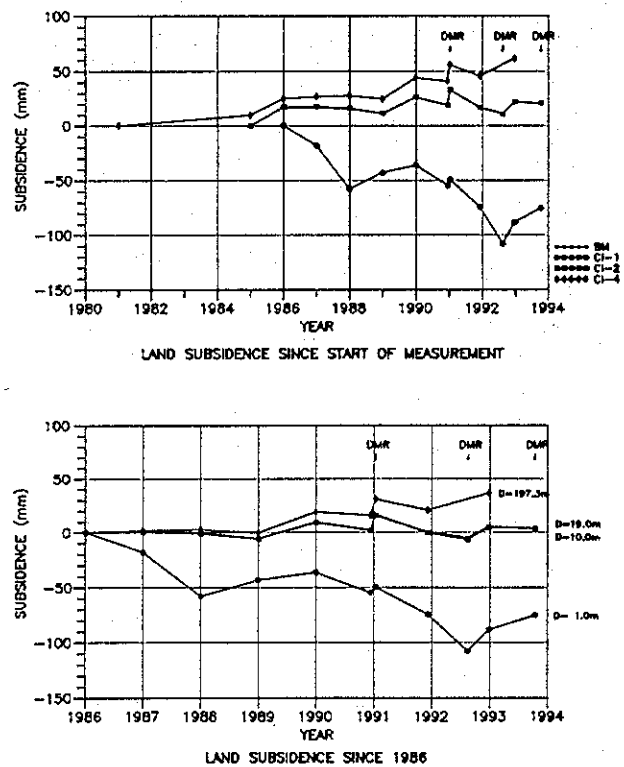
Figure 6.9	LOCATION OF LAND SUBSIDENCE STATIONS AND BENCHMARKS
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



a) AIT14 STATION



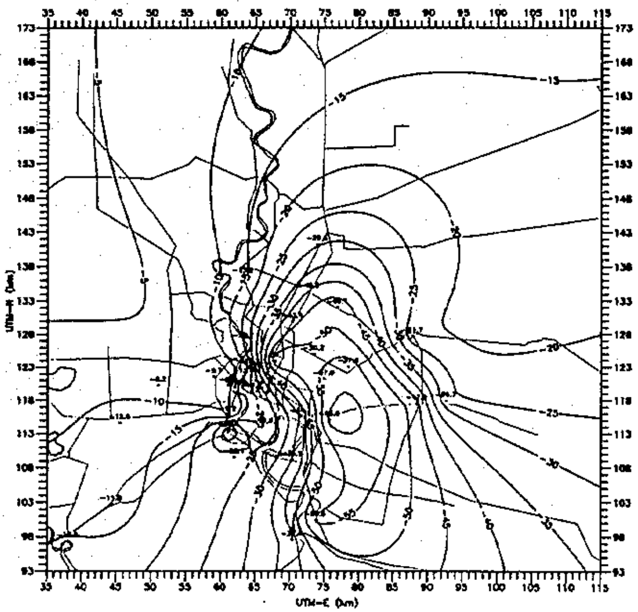
b) AIT08 STATION



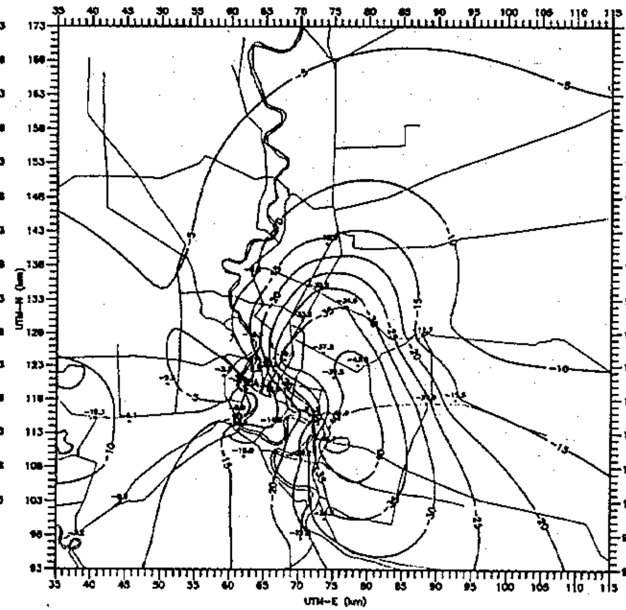
c) AIT25 STATION

(DMR: Measured by DMR)

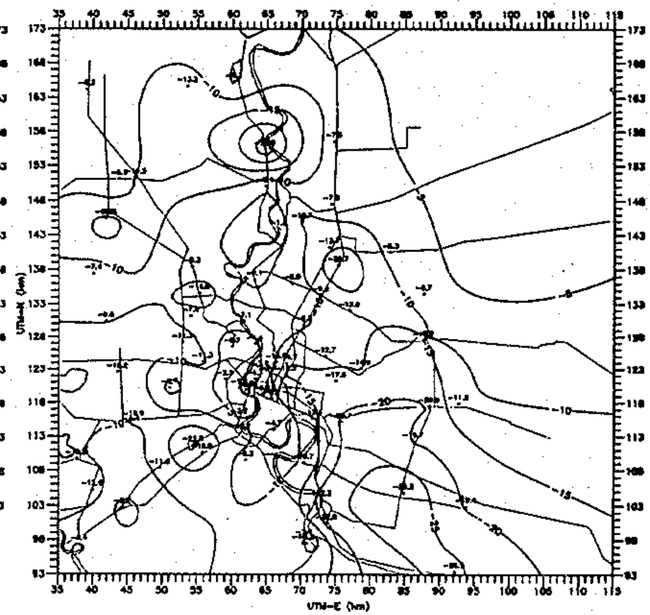
Figure 6.10	LAND SUBSIDENCE
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



FROM 1980 TO 1992



FROM 1980 TO 1986



FROM 1986 TO 1992

LEGEND

——— LINE OF EQUAL LAND SUBSIDENCE (cm/12years)

-20.0 LAND SUBSIDENCE STATION OR BENCHMARK WITH LAND SUBSIDENCE (cm/12years)

(Negative sign represents subsidence.)

Figure 6.11	LAND SUBSIDENCE MEASURED AT 1 m DEPTH BENCHMARKS
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

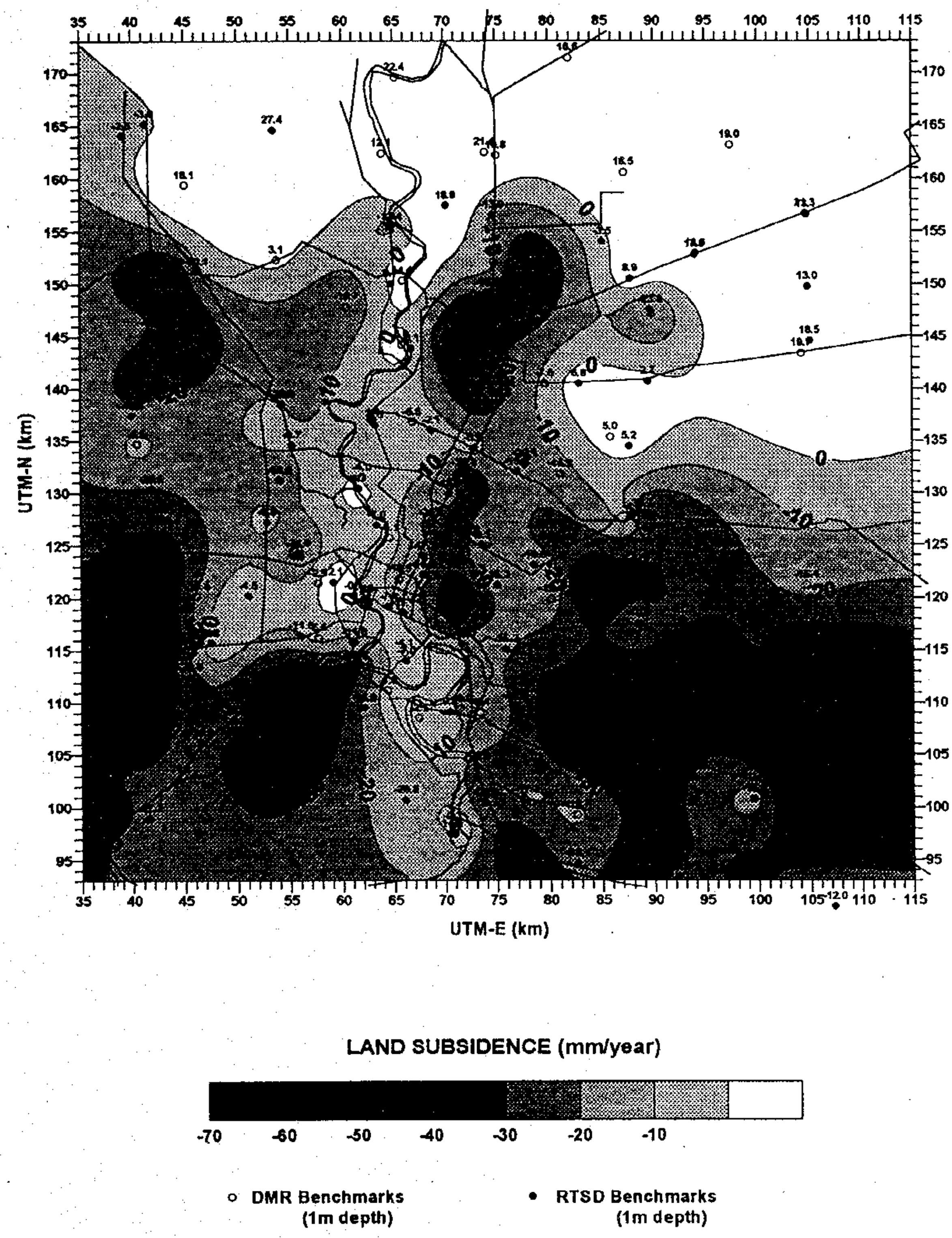


Figure 6.12	LAND SUBSIDENCE FROM 1992 TO 1993 MEASURED AT 1m DEPTH BENCHMARKS
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.