CHAPTER 6 GROUNDWATER LEVELS AND LAND SUBSIDENCE

6.1 DMR Monitoring Stations

Groundwater levels in the Study Area are presently being monitored by DMR through the groundwater monitoring network of its MGL project. By end-1992, DMR has a total of 258 monitoring wells in 103 stations. The location of DMR's groundwater monitoring stations is shown in Figure 6.1.1.

A complete groundwater monitoring station consists of three (3) monitoring wells penetrating three (3) different aquifers: Phra Pradaeng (100-meter depth zone), Nakhon Luang (150-meter depth zone), and Nonthaburi (200-meter depth zone). Of the 258 monitoring wells, 60 were installed in 1978 and 1979 during the first phase of the DMR-AIT joint study. Groundwater levels in the Study Area have been monitored since 1978. At that time, only one (1) station had three (3) monitoring wells; six (6) stations had two (2) monitoring wells; and 45 stations had only one (1) monitoring well.

At present, DMR has 71 stations with three (3) wells, 12 stations with two (2) wells, and 20 stations with one (1) well. Of the 258 monitoring wells, 77 wells were installed with water level recorders. Groundwater levels in all monitoring wells are measured at least monthly.

(1) Groundwater Level Changes

Several water level records were selected to describe the temporal changes in groundwater level in the Study Area (Figure 6.1.2).

Station No.41 (Lat Krabang)

This station is located near JICA's Site-A monitoring station in Lat Krabang, Bangkok. Nonthaburi Aquifer's piezometric levels are monitored since 1980, while those of Phra Pradaeng and Nakhon Luang Aquifers are measured since 1989.

The piezometric level of Nonthaburi Aquifer has declined almost continuously from 1980 to 1992. The effect of DMR's restriction on private pumpage between 1983 and 1987 was not clear at this station. In 1980, the water level was about 30 m below ground surface (BGS) and declined by about 5 m from 1980 to 1986. A steep decline is shown from 1986 to 1989 where the groundwater level reached 40 m BGS. During the 1989-1990 period, the piezometric level was steady at the previous period's level but declined by 5 m from 1991 to 1993.

Both Phra Pradaeng and Nakhon Luang Aquifers' piezometric levels are lower than that of Nonthaburi Aquifer, and both declined from 1989 to 1993. Phra Pradaeng's groundwater level was about 45 m BGS in 1989 and declined further below 50 m BGS in the later half of 1991. Nakhon Luang's piezometric level declined from 47 m BGS in 1989 to 57 m BGS in 1993. Annually, the piezometric level drops steeply from January to July and becomes stable or recovers slightly from August to December.

Station No.19 (Pathum Thani)

This station is located about 6km southeast of JICA's Site-B monitoring station in Khlong Luang, Pathum Thani. Nakhon Luang and Nonthaburi Aquifers' groundwater levels are observed since 1979, and that of Phra Pradaeng Aquifer since 1989.

Nakhon Luang and Nonthaburi Aquifers' piezometric levels declined slightly from 1979 to 1984. Due to DMR's restriction on private pumpage, the groundwater levels recovered in 1985 and peaked in end-1986. Since then, the groundwater levels had been declining continuously. On the other hand, Phra Pradaeng Aquifer's groundwater level had been declining since 1989.

Among the three (3) aquifers, Nakhon Luang has the deepest piezometric level. In 1979, its level was about 29 m BGS and then declined by about 3 m from 1979 to 1984. Between 1985 and 1986, it rose by about 3 m. After 1986, however, it had been declining continuously. Nakhon Luang's recent piezometric level was 44.5 m BGS in February 1993. The rate of decline of Nakhon Luang's groundwater level after 1986 was greater than those of Nonthaburi and Phra Pradaeng Aquifers.

The behavior of Nonthaburi Aquifer's piezometric levels is similar to that of Nakhon Luang Aquifer. Up to 1986, the piezometric heads of Nonthaburi Aquifer were 3 m higher than those of Nakhon Luang Aquifer. After 1986, both levels declined continuously to 36 m BGS in 1993.

Piezometric level of Phra Pradaeng Aquifer declined from 28.5 m in 1989 to 33 m in 1993. Its behavior is similar to that of Nonthaburi Aquifer.

Station No.48 (Samut Sakhon)

This station is located about 3 km north of JICA's Site-C monitoring station in Samut Sakhon. Nakhon Luang Aquifer's groundwater levels are monitored since 1980, while those of Phra Pradaeng and Nonthaburi Aquifers since 1989.

Nakhon Luang Aquifer's groundwater levels declined slightly from 27.5 m in 1980 to 32.5 m BGS in 1985. From 1986, the rate of decline gradually increased, and the groundwater level bottomed at 46 m BGS in mid-1992. Since then, the groundwater level has been slightly recovering. The effect of the restriction was not observed at this station.

Between 1989 and 1991, the rate of decline of Nakhon Luang Aquifer's piezometric level was higher than that of Nonthaburi Aquifer. Nonthaburi's level was 39 m in 1989 and bottomed at 52 m BGS in 1991. In 1992, it recovered by about 7 m.

Phra Pradaeng Aquifer's groundwater level declined slightly from 18 m in 1989 to 19.5 m in 1993. Piezometric head difference between Phra Pradaeng and Nakhon Luang Aquifers was about 23 m in 1993.

(2) Groundwater Contour Map

Groundwater contour maps were prepared for analysis of temporal and spatial changes in groundwater levels in the Study Area. Monthly records of groundwater levels were provided by the DMR's Groundwater Data Center. Monitoring data were plotted on the map using the UTM coordinates given in DMR (1992).

In plotting contour lines, regularly spaced grid data were calculated using Kriging method. Grid spacing is 1km in both x- and y-directions, and grid size totals 80km by 80km. Contour lines are drawn using the calculated grid data.

1) Phra Pradaeng Aquifer

Piezometric level maps in January 1981, February 1984, January 1987, January 1990, and February 1993 were prepared as shown in Figure 6.1.3.

Piezometric Level in January 1981

The piezometric level data are available only in Bangkok Metropolis and Samut Prakan. A piezometric head depression with a maximum depth of 37.68 m BGS was observed north of Samut Prakan. Piezometric level lower than 30 m BGS occupied the central Bangkok Metropolis and Samut Prakan. Also, two small piezometric head depressions with depths below 30 m BGS were found in eastern Samut Prakan.

Piezometric Level in February 1984

Despite the slight recovery of the piezometric head from 37.68 m to 36.01 m BGS, the piezometric level below 30 m BGS extended towards east, occupying one (1) of the two (2) small depressions in eastern Samut Prakan. The other small depressions expanded and deepened from 31.72 m to 34.34 m BGS.

Piezometric Level in January 1987

Due to DMR's restriction on groundwater pumpage by private users, the piezometric levels recovered by 3 m to 5 m as compared with those in February 1984. The piezometric level below 30 m BGS contracted, divided and occupied only the central Samut Sakhon and the nearby small depression in eastern Samut Prakan. The piezometric levels from central Bangkok Metropolis to Samut Sakhon varied from 21 m to 25 m BGS.

Piezometric Level in January 1990

The monitoring network was expanded up to Pathum Thani. A new piezometric head depression deeper than 40 m BGS appeared in Lat Krabang and Bangkok. The piezometric level below 30 m BGS stretched from Samut Prakan to Lat Krabang. Also, another depression was found in Lam Luk Ka, Pathum Thani with a maximum depth of 32.2 m BGS.

Piezometric Level in February 1993

The monitoring network has covered the entire Study Area. There were two (2) major depressions in the Study Area: in Samut Prakan and in Pathum Thani. Comparing the 1990 and 1993 piezometric level maps, both depressions have expanded and deepened.

The deepest piezometric level of 53.0 m BGS was observed in Bang Phli, Samut Prakan. Below 30 m BGS piezometric levels spreaded from Phra Pradaeng, Samut Sakhon to Lat Krabang, Bangkok, Samut Sakhon and Bang Phli.

The piezometric level below 30 m BGS were also found in Lam Luk Ka and Khlong Luang, Pathum Thani. At Lam Luk Ka, the piezometric level reached 39 m BGS.

The piezometric level below 20 m BGS were distributed in the entire Bangkok Metropolis, Samut Prakan, Samut Sakhon, and central Pathum Thani. It should be noted that the piezometric levels in Krathum Baen, Samut Sakhon and Sam Phran, Nakhon Pathum were below 25 m BGS.

Changes of Piezometric Depression

The 30-m piezometric contours from January 1981 to February 1993 were drawn in one map to analyze the movement of the depressions below this contour. The deepest depression took place in Muang Samut Prakan in 1987. A new depression however appeared in Bang Phli in 1990 and expanded in 1993. In Pathum Thani, several depressions appeared since 1990.

Piezometric Change in May 1994

The piezometric levels of PD aquifer in May 1994 is shown in Figure 6.1.4. Deep piezometric level below 50 m BGS was found near Lat Krabang, Bangkok. The piezometric levels below 30 m BGS were distributed from eastern Bangkok to Samut Prakan and to Pathum Thani. Figure 6.1.4 shows the rate of piezometric level change in PD Aquifer from January 1992 to January 1994. The rate of piezometric level decline in eastern Bangkok and northeastern Pathum Thani is more than 2.0 m/year. The rate of decline in Samut Prakan where many production wells exist ranges from 1.0 to 1.5 m/year.

2) Nakhon Luang Aquifer

Piezometric level maps in January 1981, February 1984, January 1987, January 1990, and February 1993 were prepared as shown in Figure 6.1.5.

Piezometric Level in January 1981

Maximum depth of depression was 51.8 m observed in Huai Khwang, Bangkok. Peizometric levels were lower than 40 m BGS from central to eastern parts of Bangkok.

Piezometric Level in February 1984

Piezometric level depressions moved slightly towards east. Maximum depth of depression was 50.6 m measured in Bang Kapi, Bangkok. In Bang Phli, Samut Prakan and Min Buri, Bangkok, piezometric levels declined by about 1.5 m to 3.5 m as compared with 1981. The area where piezometric levels were below 30 m BGS extended to Khlong Luang, Pathum Thani. In Samut Sakhon, groundwater level was also below 30 m BGS.

Piezometric Level in January 1987

Piezometric levels in central Bangkok recovered by about 5 m to 12 m due to DMR's restriction on groundwater pumpage. The piezometric levels below 30m BGS were widely distributed in Samut Sakhon. However, the 30-m piezometric level depression at the center of the Study Area had recovered as compared with 1984.

Piezometric Level in January 1990

The center of 30-m piezometric level depression had moved to Min Buri and Lat Krabang where the maximum depth was 47.0 m BGS. This depression stretched from Bang Phli, Samut Prakan to Khlong Luang, Pathum Thani. A heavy decline of piezometric level occurred in Samut Sakhon with a maximum depth of 51.3 m BGS.

Piezometric Level in February 1993

There were two (2) major depressions in the Study Area: from eastern Bangkok to Pathum Thani and in Samut Sakhon. The maximum depths of both depressions were lower than 55m BGS.

Changes of Piezometric Depression

The 40-m piezometric contours from January 1981 to February 1993 is shown in Figure 6.1.5. From 1981 to 1984, the depression was observed in central Bangkok. In 1987, it became smaller, moved towards east and stretched from eastern Samut Prakan to Pathum Thani in the NNW-SSE direction. On the other hand, the depression in Samut Sakhon appeared in 1990 and expanded in 1993.

Piezometric Level in May 1994

The piezometric levels of NL aquifer in May 1994 is shown in Figure 6.1.6. A large piezometric level depression lower than 40 m BGS spreaded from eastern Samut Prakan to Pathum Thani through eastern Bangkok. The piezometric level at Minburi and Lat Krabang was lower than 60 m BGS. Another depression was found in Samut Sakhon where the deepest piezometric level was lower than 65 m BGS. Figure 6.1.6 also shows the rate of piezometric level change from January 1992 to January 1994. A decline of more than 5.0 m/year was found at Don Muang, Bangkok and Lam Luk Ka, Pathum Thani. The rate of decline at Bang Phli, Samut Sakhon exceeded 3.0 m/year.

3) Nonthaburi Aquifer

Piezometric level maps in January 1981, February 1984, January 1987, January 1990, and February 1993 were prepared as shown in Figure 6.1.7.

Piezometric Level in January 1981

Low piezometric levels appeared in central Bangkok Metropolis. The maximum depth was 45.5 m BGS recorded in Bang Khen, Bangkok. The piezometric level lower than 40 m were observed in the northern to eastern Bangkok.

Piezometric Level in February 1984

The piezometric level depression moved slightly towards east. Maximum depth was 52.5 m measured in Bang Kapi, Bangkok. The piezometric levels declined by about 2 m to 7 m as compared with those in 1981. The piezometric level lower than 30 m extended from south to north, i.e, from Khlong Luang , Pathum Thani to Samut Prakan.

Piezometric Level in January 1987

Piezometric levels in central Bangkok recovered by about 5 m to 10 m due to DMR's restriction on groundwater pumpage. However, piezometric levels were lower than 30m in Pathum Thani and in Samut Sakhon.

Piezometric Level in January 1990

The center of depression moved to Min Buri and Lat Krabang where the maximum depth was 41.9 m BGS. The depression extended from Bang Phli, Samut Prakan to Khlong Luang, Pathum Thani. A heavy decline of piezometric level occurred in Samut Sakhon, where the recorded maximum depth was 48.6 m BGS.

Piezometric Level in February 1993

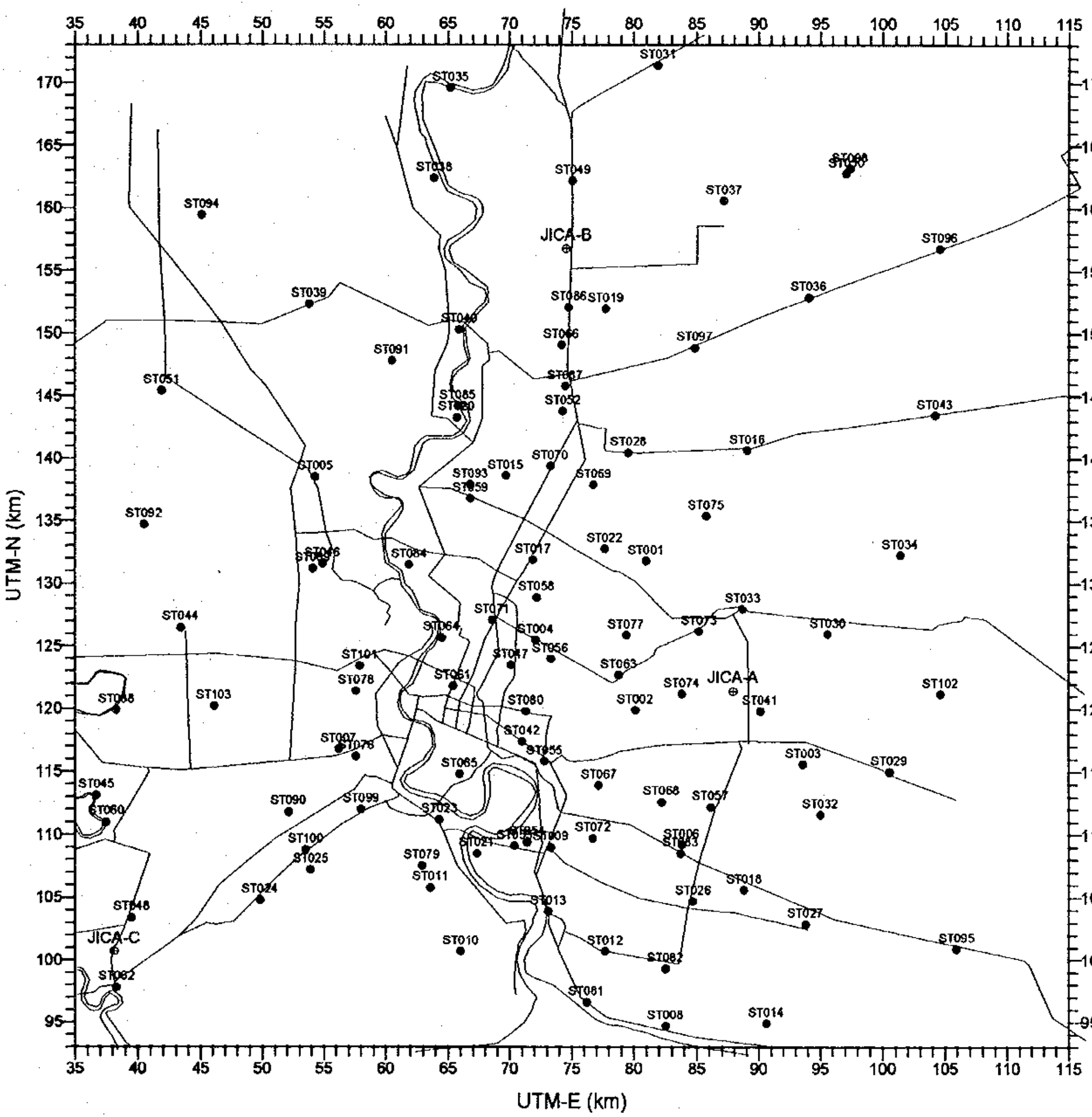
There were two (2) major depressions in the Study Area: from eastern Samut Sakhon to Pathum Thani and in Samut Sakhon. The maximum depths of depressions were 55.9 m in Min Buri and 54.8 m in Samut Sakhon.

Changes of Piezometric Depression

From 1981 to 1984, the depression appeared in central Bangkok. In 1987, the depression contracted and moved to eastern Bangkok. Almost no change occurred in 1990. In 1993, however, the depression expanded to central Pathum Thani, eastern Bangkok, and eastern Samut Prakan. On the other hand, a depression appeared in Samut Sakhon in 1990 and expanded in 1993.

Piezometric Level in May 1994

The piezometric levels of NB aquifer in May 1994 is shown in Figure 6.1.8. Depressions of piezometric levels below 40 m BGS were found from Pathum Thani to eastern Bangkok, in eastern Samut Prakan and in Samut Sakhon. Some monitoring wells in these areas show piezometric levels below 50 m. Figure 6.1.8 shows the rate of piezometric level decline from January 1992 to January 1994. The rates of more than 3.0 m/year were found in Pathum Thani, northern and eastern parts of Bangkok, and part of Nakhon Pathom.



LEGEND

⊕ Location of JICA monitoring station

• Location of DMR monitoring station with station No.

Figure 6.1.1	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.

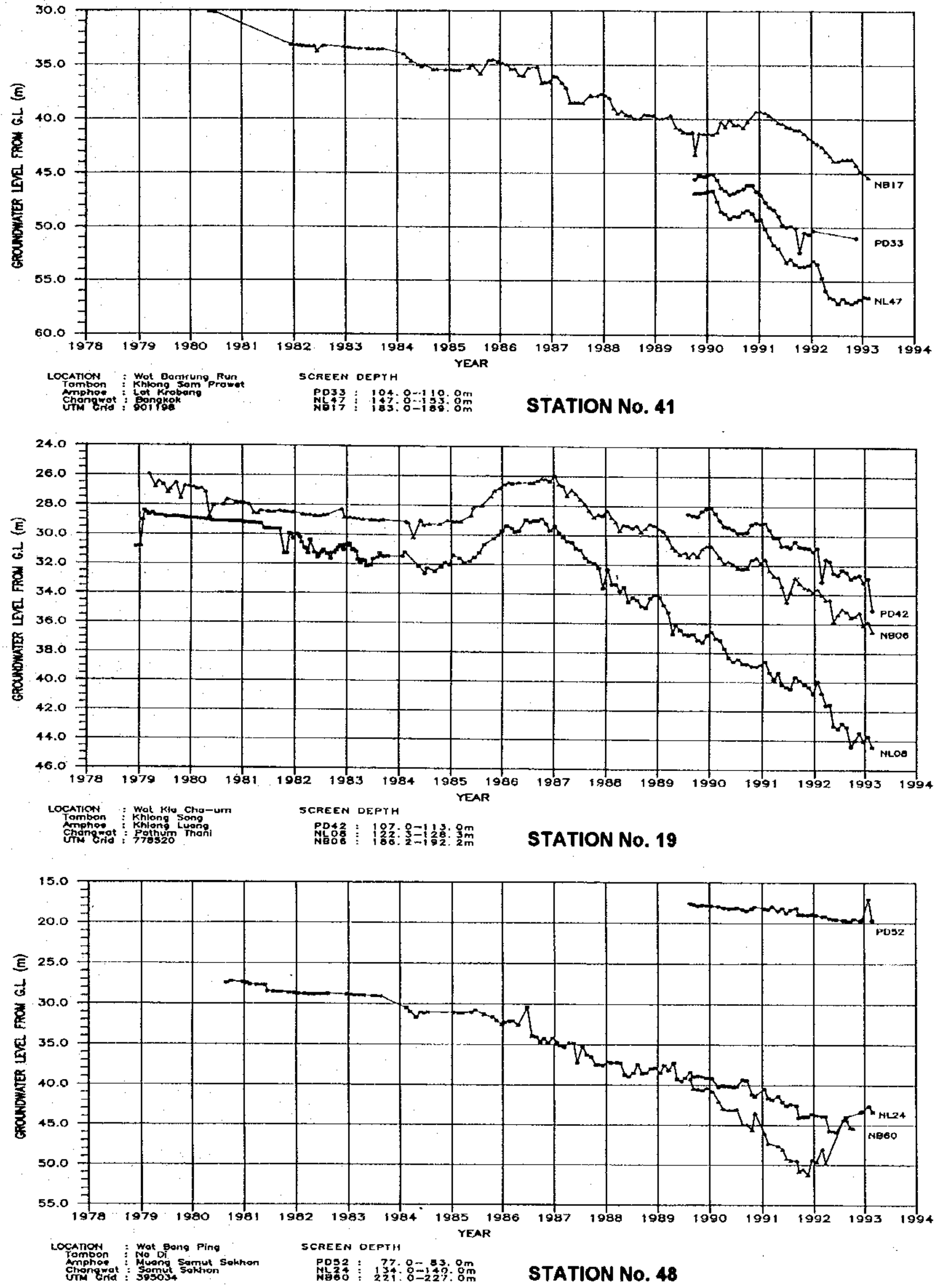
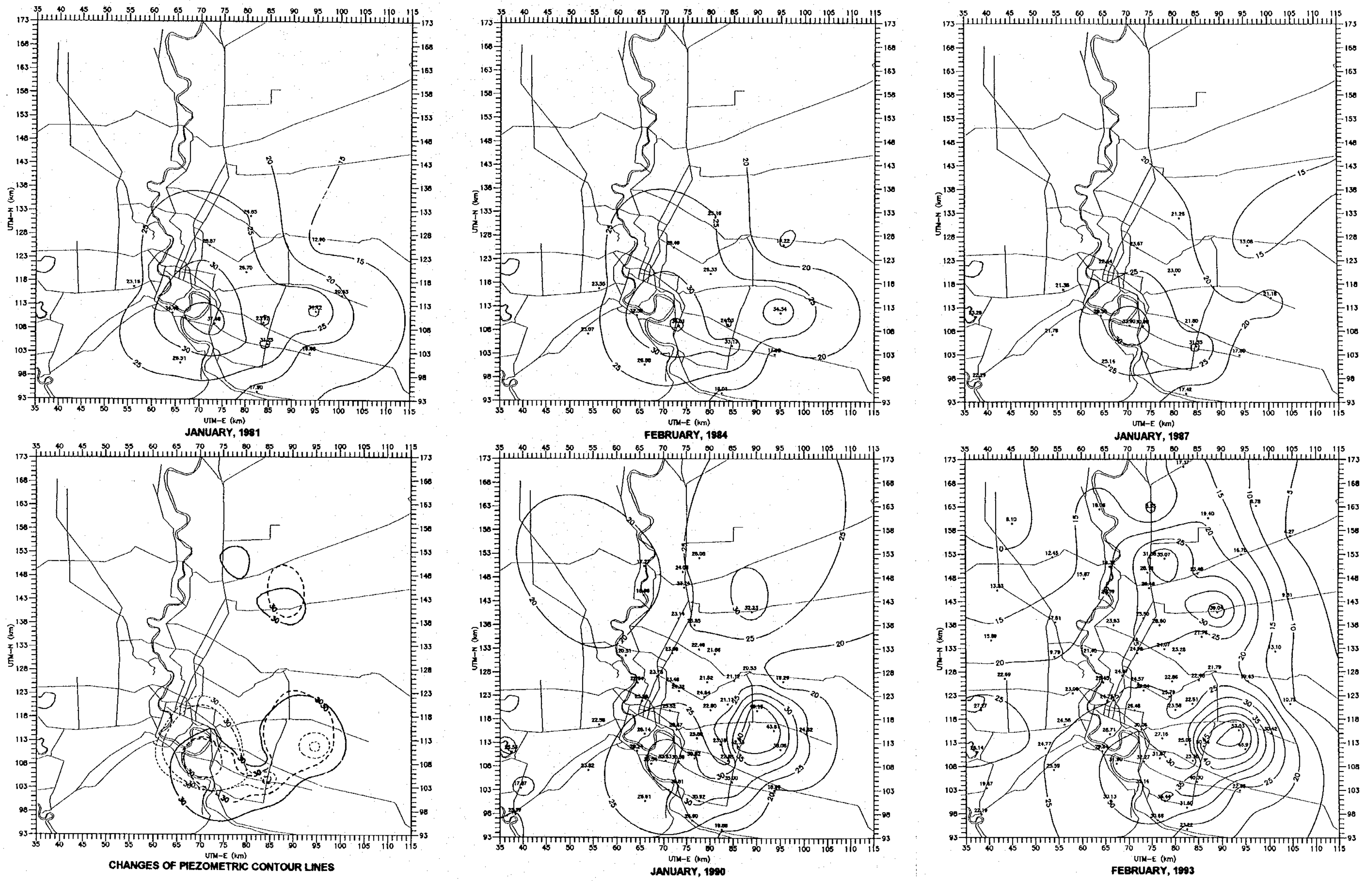


Figure 6.1.2	GROUNDWATER LEVEL CHANGES
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



LEGEND

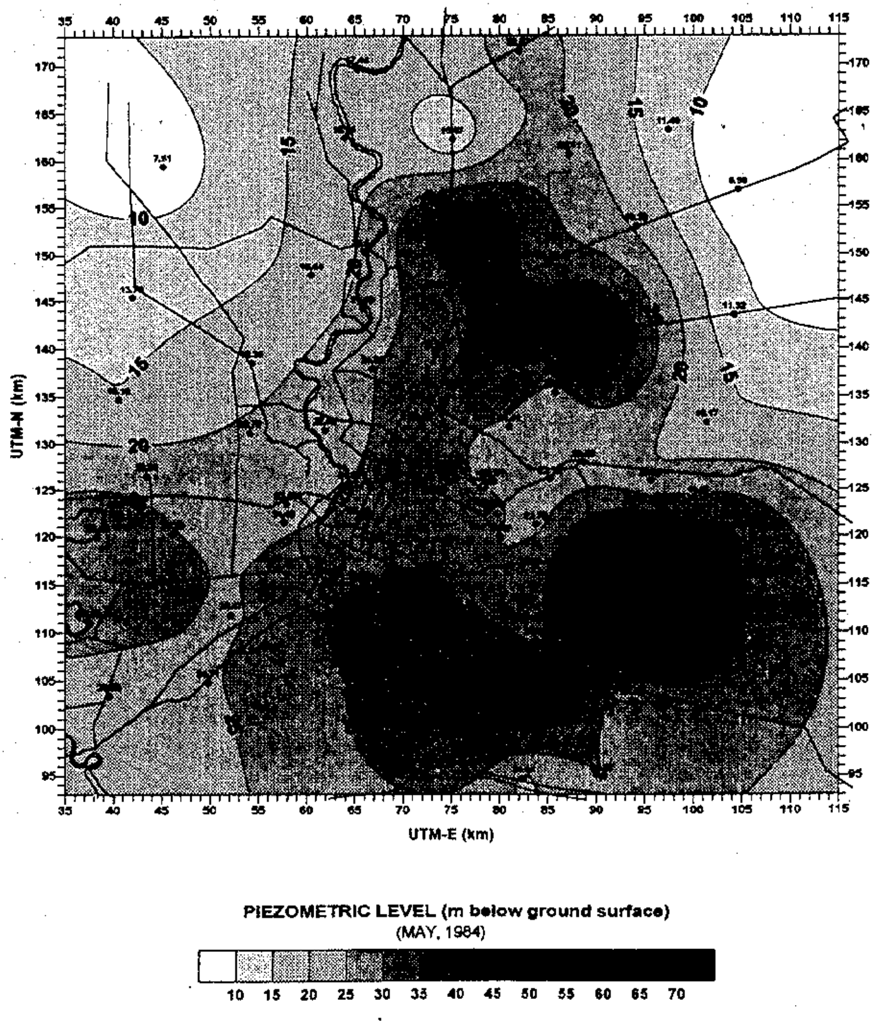
- - - - 30mbgs CONTOUR LINE IN JAN. 1981
- - - - 30mbgs CONTOUR LINE IN FEB. 1984
- - - - 30mbgs CONTOUR LINE IN JAN. 1987
- - - - 30mbgs CONTOUR LINE IN JAN. 1990
——— 30mbgs CONTOUR LINE IN FEB. 1993
(mbgs : m below ground surface)

LEGEND

——— LINE OF EQUAL PIEZOMETRIC LEVEL (m below ground surface)

25.00 DMR MONITORING WELL WITH PIEZOMETRIC LEVEL (m below ground surface)

Figure 6.1.3	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.



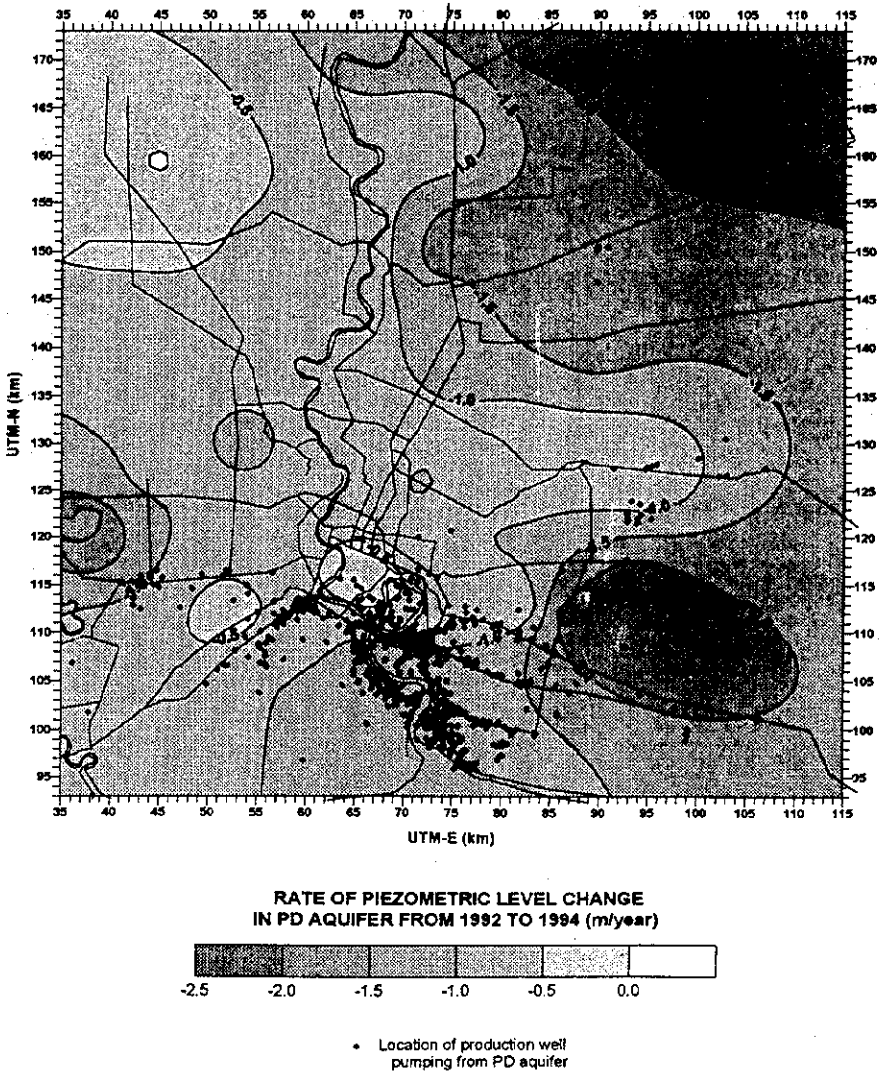
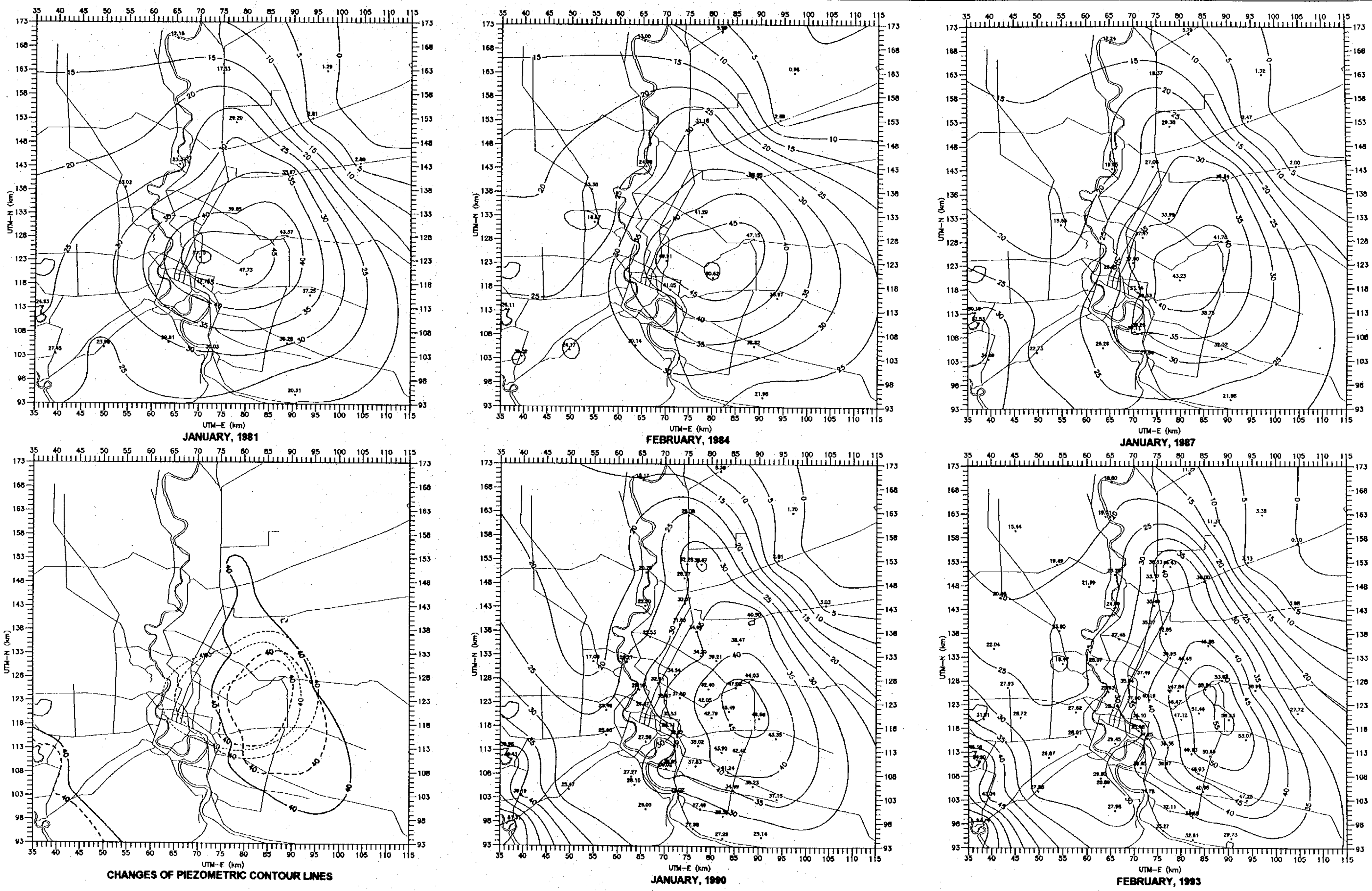


Figure 6.1.4	PIEZOMETRIC LEVELS OF PD AQUIFER
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



LEGEND

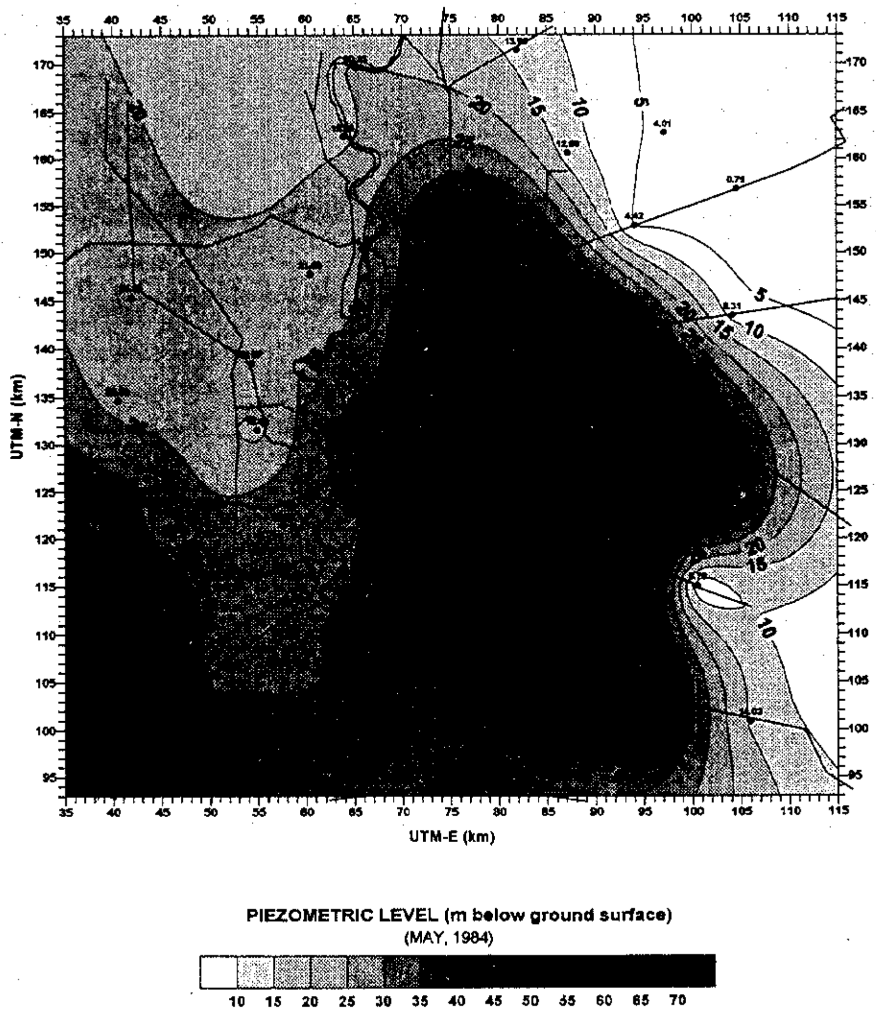
- 40mbgs CONTOUR LINE IN JAN. 1981
- 40mbgs CONTOUR LINE IN FEB. 1984
- 40mbgs CONTOUR LINE IN JAN. 1987
- 40mbgs CONTOUR LINE IN JAN. 1990
- 40mbgs CONTOUR LINE IN FEB. 1993

(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 6.1.5	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.



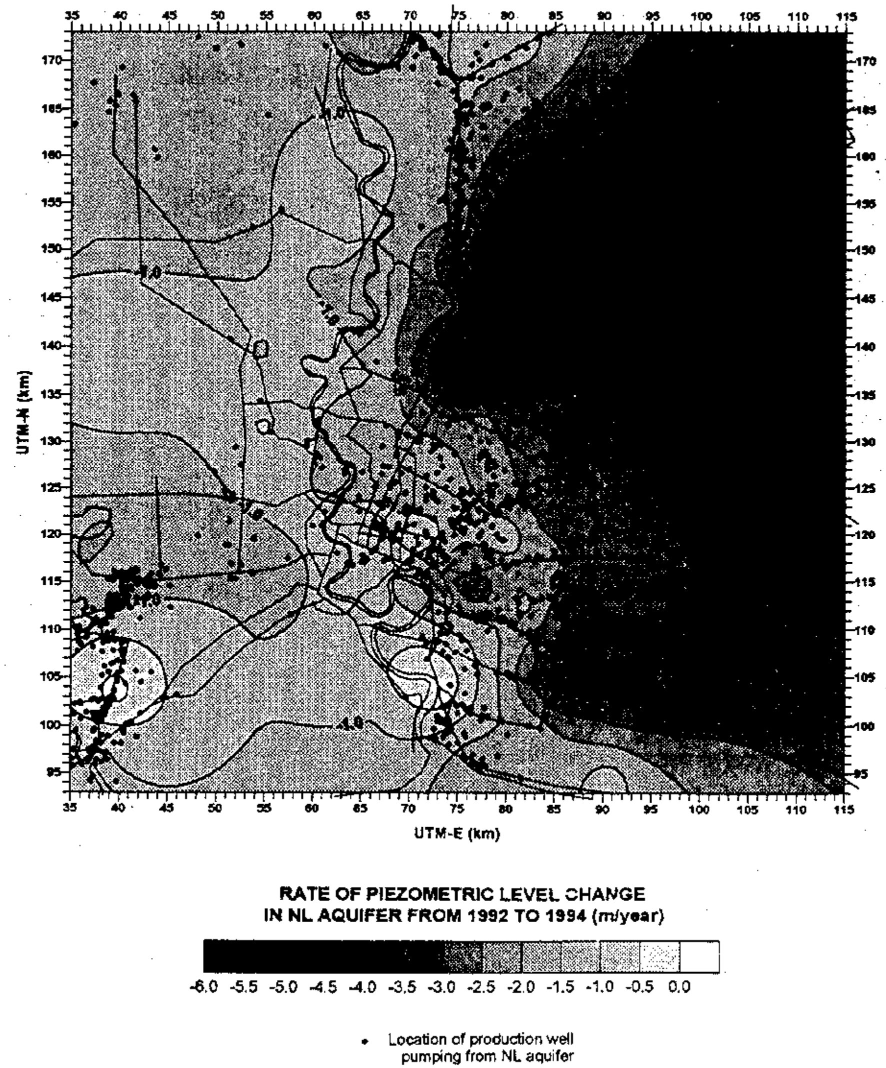
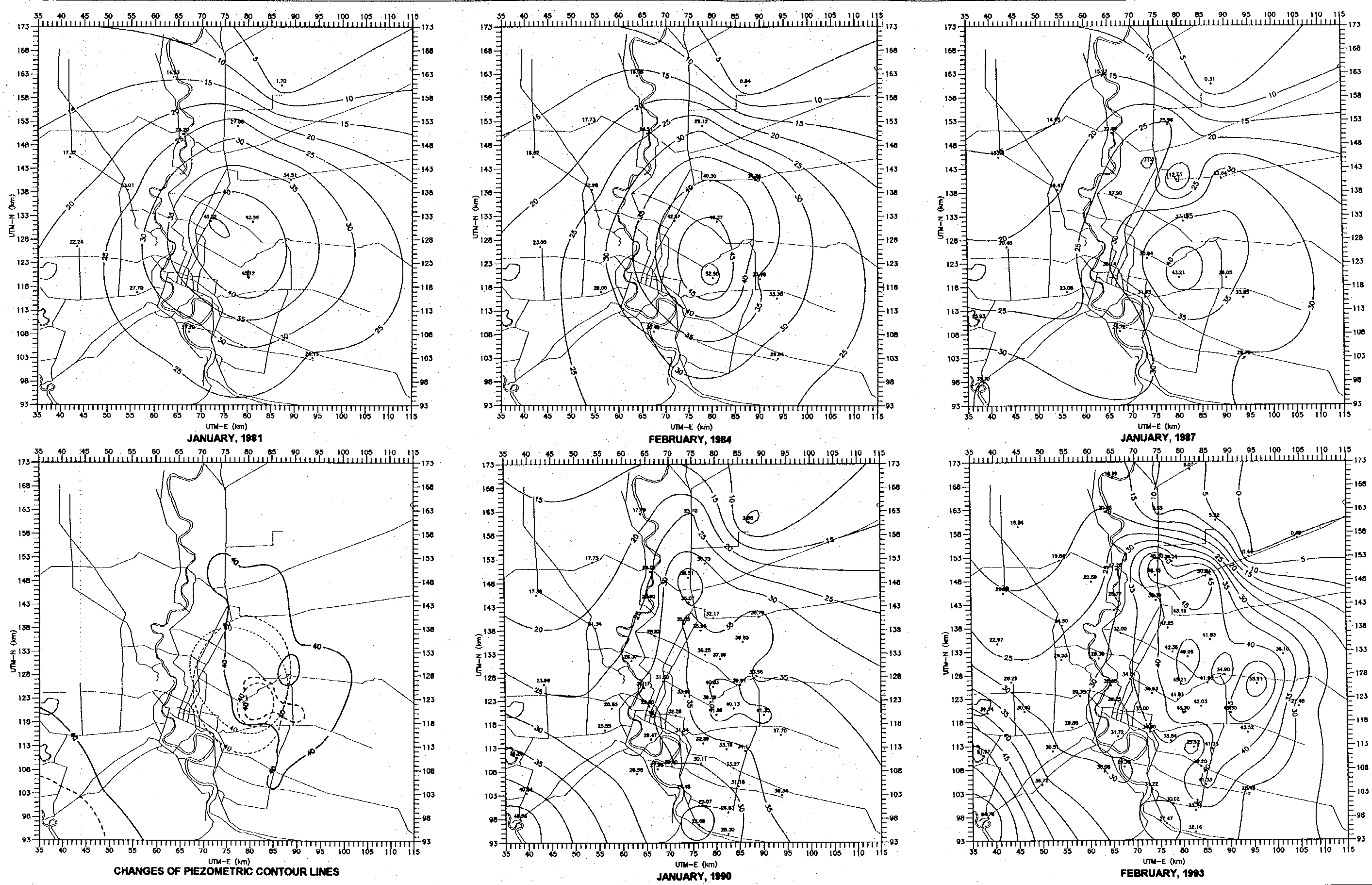


Figure 6.1.6	PIEZOMETRIC LEVELS OF NL AQUIFER
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



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 6.1.7	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.

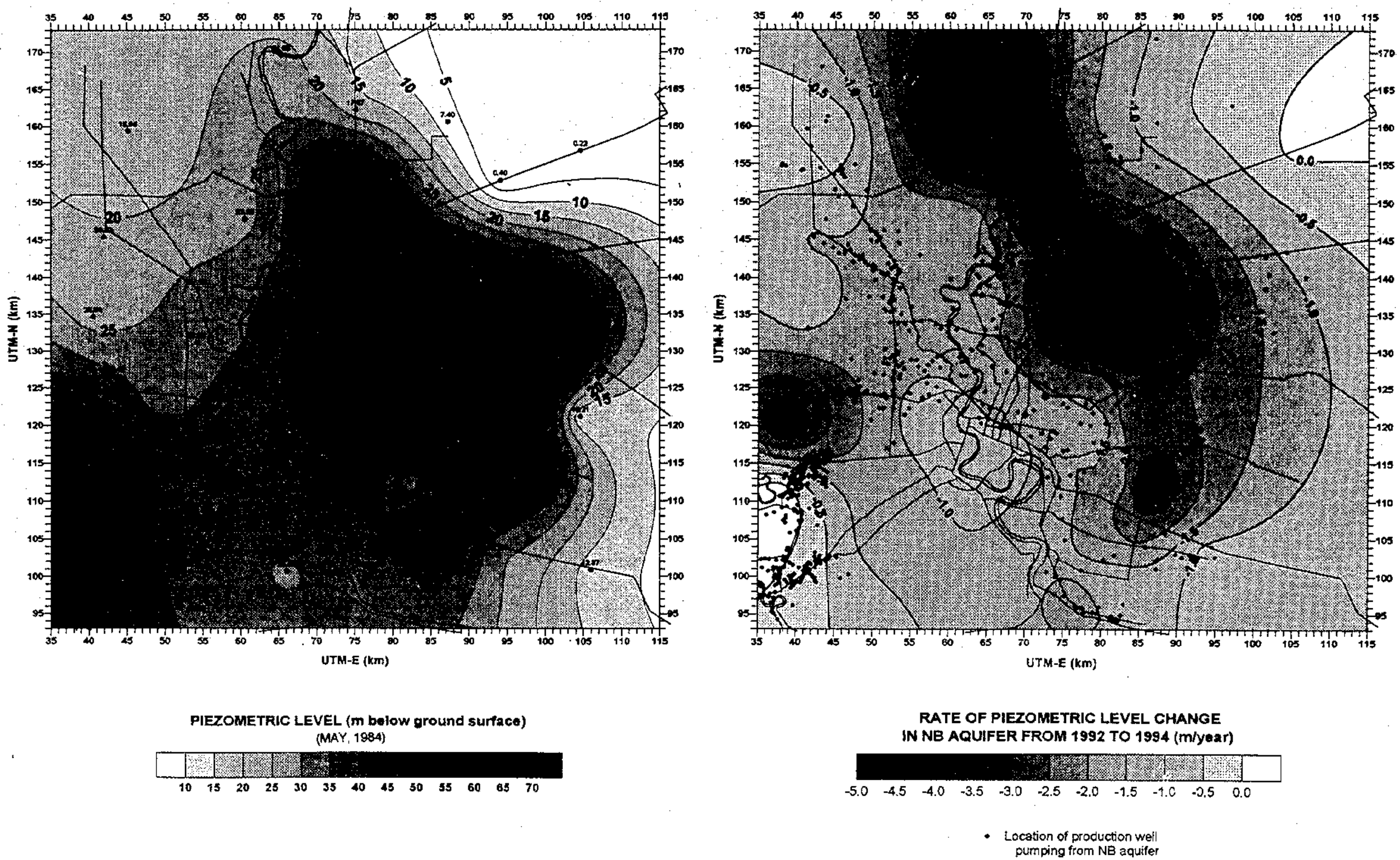


Figure 6.1.8	PIEZOMETRIC LEVELS OF NB AQUIFER

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.

6.2 JICA Monitoring Stations

Groundwater level and land subsidence are monitored at the JICA monitoring stations (see Figure 6.2.1) since July 1993. The monitoring equipment installed at the stations are recording data at an interval of one (1) hour.

(1) Site-A (Lat Krabang)

The groundwater level and land subsidence at eight (8) monitoring wells recorded for the past one (1) year are summarized in Figure 6.2.2. The groundwater level and land subsidence at each monitoring well are presented in the Supporting Report.

1) Groundwater level

The deepest groundwater levels were observed at A-6 well (depth = 145m, Nakhon Luang Aquifer) which range from -55.5 m to -61.0 m elevations. The groundwater levels at A-5 well (depth = 215 m, Nonthaburi Aquifer) and A-7 well (depth = 108 m, Phra Pradaeng Aquifer) ranged from -42.0 to -52.0 m elevations. The groundwater levels at A-2 well (depth = 437 m, Phayathai Aquifer), A-3 well (depth = 360 m, Sam Khok Aquifer), A-4 well (depth = 302 m, Sam Khok Aquifer), and A-8 well (depth = 48 m, Bangkok Aquifer) were measured between -16.0 and -26.0 m elevations. The groundwater level at A-1 well (depth = 574 m, Pak Nam Aquifer) gradually recovered; at present, the piezometric head is higher than the ground elevation in an artesian condition.

The features of groundwater level fluctuations at each monitoring well are as follows:

<u>A-1 well [depth = 574 m, Pak Nam Aquifer]</u>

The groundwater level could not be measured during the well construction due to the low permeability of the aquifer. The water level was at -6m elevation in July 1993. But it recovered and reached the mean sea level in March 1994. Now the well is in an artesian condition, with very small flow.

<u>A-2 well [depth = 437 m, Phayathai Aquifer]</u>

The groundwater level gradually declined from -19.6 m to -21.0 m elevations in one year due to sensor trouble. Erroneous water level fluctuations were recorded from September to October 1993. A new sensor was installed in December 1993.

<u>A-3 well [depth = 360 m, Sam Khok Aquifer]</u>

The groundwater level dropped from -19.9 m to -21.5 m elevations from July 1993 to July 1994. It was almost stable from August to September 1993 but started to decline from October 1993. The groundwater level was not recorded from December 1993 to May 1994 due to sensor trouble.

A-4 well [depth = 302 m, Sam Khok Aquifer]

The pattern of groundwater level changes is similar to that of A-3 well. The groundwater level declined from -24.4 m to -26.4 m elevations for the past one (1) year. The monitoring was interrupted due to sensor trouble.

A-5 well [depth = 215 m, Nonthaburi Aquifer]

The groundwater level dropped from -41.7 m to -51.8 m elevations in one (1) year. The water level was influenced by nearby production wells because similar drawdown and recovery patterns could be observed. It recovered by about 4 m in early March 1994 but dropped again from mid-March 1994.

A-6 well [depth = 145 m, Nakhon Luang Aquifer]

Since groundwater of this aquifer is heavily pumped in the area, the water level of this well is the lowest in the station. The daily fluctuations and the recoveries on holidays are clearly observed. The water level ranged between -55.5 m and -57.5 m from July 1993 to February 1994 but dropped from -57.5 m to -61.0 m from March 1994 to July 1994.

A-7 well [depth = 108 m, Phra Pradaeng Aquifer]

The groundwater levels was about -49.5 m elevation from September to December 1993. The water level recovered by about 2 m in end - February 1994 but started to drop in a stepwise pattern since March 1994. The water level in July 1994 is 1.5 m lower than that in July 1993. The records were disturbed in March 1994 due to sensor trouble.

A-8 well [depth = 48 m, Bangkok Aquifer]

The annual fluctuation of groundwater levels was only 0.5 m. But the rise from -16.3 m to -15.9 m elevations was clearly observed from September to October 1993. It remained at higher level until November 1993 but declined from December 1993 to March 1994. The water level was stable from March to July 1994. This annual fluctuation pattern may correspond to the seasonal changes in surface waters including rainfall.

2) Land subsidence

Since July 1993, the maximum recorded land subsidence which is the compression between the ground surface and the bottom of the well at A-2 well is 63 mm. Even though the subsidence rate might be affected by the well condition, it could still be seen that the subsidence rate increases with increasing well depth. If the annual total compression between the ground surface and the depth at 574 m is assumed to be 57.0 mm as measured at A-1 well, the compression between the ground surface and the depth at 48 m contributes 49% to the total compression. Similarly, the compression between 48 m and 145 m depths contributes 35% to the total compression. The subsidence rate at each well has decreased since March 1994. This phenomenon may correspond to the stoppage of groundwater level drop in the Bangkok Aquifer observed at A-8 well.

3) Elevation of benchmarks

Benchmark elevations in the monitoring station were measured by the Study Team on 05 July 1993 and 20 July 1994. The existing DMR36 benchmark at station No. 41 was used as the starting benchmark for the two leveling surveys. Besides these surveys, the DMR Surveying Division also started conducting a leveling survey on 26 November 1993.

The results of leveling survey are summarized in Table 6.2.1. It should be noted that the benchmark elevations in July 1994 were computed using the DMR36 benchmark elevation surveyed in 1993, because the 1994 DMR36 benchmark elevation was not yet known. This data could be used to know the relative difference in elevation between the starting benchmark and the benchmarks in the station. The absolute elevation of each benchmark should be recalculated after examining the movement of the starting benchmark. Further, the surveying route, origin, and date of measurement of the DMR leveling survey must be checked to compare their results with those of the Study Team.

4) Pore water pressure

Pore water pressures in shallow clayey layers are monitored in the station at one (1) week interval. The sensors were set at depths of 5 m, 10 m, 15 m, 25 m, and 34 m. The changes in pore water pressure at each measuring point are shown in Figure 6.2.3. The changes over time were small. The pore water pressures in the Bangkok Soft Clay (5 m, 10 m, and 15 m depths) were almost equal to the ideal hydrostatic pressure in which the groundwater level was assumed to be at 0 m elevation. On the other hand, the pore water pressures at depths of 25 m and 34 m were about 1.5 kgf/cm^2 smaller than the ideal hydrostatic pressures at the same depths (Figure 6.2.4).

(2) Site-B (AIT)

The groundwater level and land subsidence at five (5) monitoring wells recorded for the past one (1) year are summarized in Figure 6.2.5. The groundwater level and land subsidence at each monitoring well are presented in the Supporting Report.

1) Groundwater level

The deepest groundwater levels were observed at B-1 well (depth = 272 m, Nonthaburi Aquifer), which ranged from -34.5 m to -37.5 m elevations. The groundwater levels at B-2 well (depth = 192 m, Nakhon Luang Aquifer) and B-3 well (depth = 153 m, Nakhon Luang Aquifer) varied from -29.0 m to -33.0 m elevations. B-4 well (depth = 94 m, Phra Pradaeng Aquifer) had groundwater levels ranging from -22.2 m to -23.9 m elevations. The shallowest groundwater levels were observed at B-5 well (depth = 47m, Bangkok Aquifer), ranging from -3.8 m to -4.5 m elevations.

The features of groundwater level fluctuations at each monitoring well are as follows:

<u>B-1 well [depth = 272 m, Nonthaburi Aquifer]</u>

Groundwater level dropped from -35.0 m to -36.9 m elevations from July 1993 to July 1994. The water level was highest in August 1993 and declined gradually with moderate fluctuations. The rate of decline increased from January to March 1994. The groundwater level recovered slightly in mid-April, but dropped again from May to July 1994. The observed minor daily fluctuations had a periodicity of two (2) weeks, which perhaps were influenced by tidal movement.

B-2 well [depth = 192 m, Nakhon Luang Aquifer]

The groundwater level dropped from -30.8 m to -32.3 m during the past one (1) year. Daily and weekly fluctuations were clearly observed from the records. The water level recovered by about 2.0 m and 1.0 m during the holidays in January 1994 and April 1994, respectively.

B-3 well [depth = 153 m, Nakhon Luang Aquifer]

The pattern of water level changes was similar to that of B-2 well. Daily fluctuations were about 0.5 m. The water level clearly recovered during the holidays in January 1994 and April 1994. The base line of the hydrograph declined from -30.0m in January 1994 to -32.0m in July 1994.

B-4 well [depth = 94 m, Phra Pradaeng Aquifer]

The annual decline of groundwater level was 0.9 m from July 1993 to July 1994. The water level ranged from -22.7 m to -23.0 m elevations from July 1993 to January 1994; then it declined from -22.7 m to -23.8 m from January to July 1994.

B-5 well [depth = 47 m, Bangkok Aquifer]

The pattern of groundwater level changes was similar to that of A-8 well at Site-A. The water level recovered from -4.2 m to -3.8 m from August 1993 to October 1993 and then dropped continuously from November 1993 to March 1994. The lowest water level was recorded at -4.46 m in May 1994. The water level has recovered since June 1994. This pattern may correspond to the seasonal rainfall and surface water level changes.

2) Land subsidence

Records show that the land rebounded slightly by about 1.0 mm from July 1993 to early November 1993. But all monitoring wells recorded that subsidence occurred from mid-November 1993 when the water level of Bangkok Aquifer started to drop as monitored at B-5 well. The land subsidence graphs and the hydrograph of B-5 well were in good agreement. There was a slight rebound in March 1994, but the maximum subsidence at B-2 well reached 11.0 mm in May 1994. After this, all monitoring wells indicated a rebound until July 1994.

3) Elevation of benchmarks

Benchmark elevations in the monitoring station were measured by the Study Team on 13 July 1993 and 28 June 1994. The existing BM25 benchmark at CI station No. 25 was used as the starting benchmark for the two (2) leveling surveys. Besides these surveys, the DMR Surveying Division also conducted a leveling survey on 26 November 1993.

The results of leveling survey are summarized in Table 6.2.2. It should be noted that the benchmark elevation in July 1993 and June 1994 were computed using the BM25 benchmark elevation measured on 12 October 1993, because the latest surveyed elevation of BM25 was not available at that time. This data could be used to know the relative difference in elevations between the starting benchmark and the benchmarks in the station. The absolute elevation of each benchmark should be recalculated after examining the movement of the starting benchmark.

(3) Site-C (Samut Sakhon)

The groundwater level and land subsidence at five (5) monitoring wells recorded for the past one (1) year are summarized in Figure 6.2.6. The groundwater level and land subsidence at each monitoring well are presented in the Supporting Report.

1) Groundwater level

The deepest groundwater levels were observed at C-2 well (depth = 212 m, Nonthaburi Aquifer), which ranged from -57.5 m to -71.5 m elevations. The groundwater levels at C-3 well (depth = 140m, Nakhon Luang Aquifer) ranged from -43.0 m to -55.0 m elevations. The water levels at C-2 well and C-3 well were highly affected by nearby production wells. C-1 well (depth = 320 m, Sam Khok Aquifer) had water levels ranging between -26.3 m and -29.2 m elevations. The water levels at C-4 well (depth = 105 m, Phra Pradaeng Aquifer) and C-5 well (depth = 78 m, Phra Pradaeng Aquifer) ranged from -21.8 m to -22.9 m and -16.4 m to -17.4 m, respectively.

The features of groundwater level fluctuations at each monitoring well are as follows:

<u>C-1 well [depth = 320 m, Sam Khok Aquifer]</u>

Groundwater level dropped from -27.3 m to -29.2 m from July 1993 to July 1994. The water level at -26.3 m elevation was highest in September 1993 and declined to -28.0 m elevation from September to December 1993. The water level from January to February 1994 fluctuated between -27.3 and -27.8 m but declined to -28.8 m by April 1994. After the recovery during the holidays in April, it continued to drop until July 1994.

<u>C-2 well [depth = 212 m, Nonthaburi Aquifer]</u>

The water level changes were highly affected by nearby production wells. Daily and weekly fluctuations were about 1 m and 5 m, respectively. During the holidays in January, February and April in 1994, the water level recovered by about 6m to 8m. The groundwater level hydrograph indicated a decline from -66.0 m to -67.0 m from July 1993 to March 1994, and a steep drop from April to May 1994. The groundwater level reached -71.5 m in July 1994.

<u>C-3 well [depth = 140 m, Nakhon Luang Aquifer]</u>

The groundwater level was also affected by nearby production wells so that the daily and weekly fluctuations as well as recoveries on holidays could be clearly observed. The base line of the hydrograph was located between -49.0 m and -55.0 m elevations. The decline of the groundwater level from July 1993 to July 1994 was about 2.0 m, which was smaller than that of C-2 well.

C-4 well [depth = 105 m, Phra Pradaeng Aquifer]

The groundwater level fluctuated from -21.8 m to -22.3 m elevations from July 1993 to April 1994, dropped sharply from mid-April and reached -22.8 m elevation in July 1994. The annual decline of the groundwater level was 0.8 m.

C-5 well [depth = 78 m, Phra Pradaeng Aquifer]

The groundwater level fluctuated widely in July and August 1993 due to local pumpage. But the fluctuation decreased when the water level rose from -17.3 m to -16.5 m during the same period. The groundwater level ranged between -16.4 m and -16.8 m from October 1993 to July 1994.

2) Land subsidence

The measured land subsidence values in the station were larger than those in other stations because the ground where the station was constructed is on fill and has not yet settled. The maximum compression was recorded at C-2 well as an annual compression of 126 mm. The subsidence curves in the station can be divided into two (2) types: the curves of deeper wells (C-1 well and C-2 well) which are almost straight lines from October 1993 to July 1994 and the curves of shallower wells (C-3 to C-5 wells) which are decreasing compression rates during the same period. The true values of land subsidence should be recalculated by using the absolute elevations of benchmarks determined by leveling surveys. So far, the latest values of absolute elevations are not yet known.

3) Elevation of benchmarks

Benchmark elevations in the monitoring station were measured by the Study Team on 05 August 1993 and 30 June 1994. The existing DMR05 benchmark at station No. 48 was used as a starting benchmark for both levelings. Besides these surveys, the DMR Surveying Division also conducted a leveling survey on 09 November 1993.

The results of leveling survey are summarized in Table 6.2.3. It should be noted that the benchmark elevations in August 1993 and June 1994 were computed using the DMR05 benchmark elevations measured on 08 July 1993, because the latest elevation of DMR25 was not available yet. This data could be used to know the relative difference in elevations between the starting benchmark and the benchmarks in the station. The absolute elevation of each benchmark should be recalculated after examining the movement of the starting benchmarks.

Table 6.2.1 RESULTS OF LEVELING SURVEY AT SITE - A

Benchmark No.	ELEV. (m)	DATE (M/D/Y)	DONE BY:	ELEV. (m)	DATE (M/D/Y)	DONE BY:	ELEV. (m)	DATE (M/D/Y)	DONE BY:
DMR36	1.1292	07/02/93	DMR				1.1292	07/02/93	DMR
BM-A	0.58156	07/05/93	JICA	0.5813	11/26/93	DMR	0.59993	07/20/94	JICA
BM-B	0.57787	07/05/93	JICA	0.5781	11/26/93	DMR	0.59752	07/20/94	JICA
A-1/1	0.85032	07/05/93	JICA	0.8573	11/26/93	DMR	0.88623	07/20/94	JICA
A-1/2	0.95739	07/05/93	JICA	0.9643	11/26/93	DMR	0.99312	07/20/94	JICA
A-1/3	1.16268	07/05/93	JICA	1.1773	11/26/93	DMR	1.22650	07/20/94	JICA
A-1/4	1.48133	07/05/93	JICA	1.4793	11/26/93	DMR	1.49159	07/20/94	JICA
A-1/5	1.47864	07/05/93	JICA	1.4763	11/26/93	DMR	1.48826	07/20/94	JICA
A-2/1	0.84913	07/05/93	JICA	0.8553	11/26/93	DMR	0.88601	07/20/94	JICA
A-2/2	0.95879	07/05/93	JICA	0.9653	11/26/93	DMR	0.99569	07/20/94	JICA
A-2/3	1.15584	07/05/93	JICA	1.1713	11/26/93	DMR	1.22091	07/20/94	JICA
A-2/4	1.46131	07/05/93	JICA	1.4583	11/26/93	DMR	1.46522	07/20/94	JICA
A-2/5	1.45991	07/05/93	JICA	1.4563	11/26/93	DMR	1.46399	07/20/94	JICA
A-3/1	0.83227	07/05/93	JICA	0.8373	11/26/93	DMR	0.86769	07/20/94	JICA
A-3/2	0.93381	07/05/93	JICA	0.9393	11/26/93	DMR	0.97084	07/20/94	JICA
A-3/3	1.14117	07/05/93	JICA	1.1553	11/26/93	DMR	1.20671	07/20/94	JICA
A-3/4	1.46775	07/05/93	JICA	1.4663	11/26/93	DMR	1.47749	07/20/94	JICA
A-3/5	1.46585	07/05/93	JICA	1.4643	11/26/93	DMR	1.47498	07/20/94	JICA
A-4/1	0.85959	07/05/93	JICA	0.8653	11/26/93	DMR	0.89094	07/20/94	JICA
A-4/2	0.95194	07/05/93	JICA	0.9573	11/26/93	DMR	0.98524	07/20/94	JICA
A-4/3	1.17672	07/05/93	JICA	1.1913	11/26/93	DMR	1.24171	07/20/94	JICA
A-4/4	1.48198	07/05/93	JICA	1.4793	11/26/93	DMR	1.49534	07/20/94	JICA
A-4/5	1.47918	07/05/93	JICA	1.4763	11/26/93	DMR	1.49213	07/20/94	JICA
A-5/1	0.84981	07/05/93	JICA	0.8513	11/26/93	DMR	0.86880	07/20/94	JICA
A-5/2	0.95541	07/05/93	JICA	0.9623	11/26/93	DMR	0.98969	07/20/94	JICA
A-5/3	1.14934	07/05/93	JICA	1.1633	11/26/93	DMR	1.21079	07/20/94	JICA
A-5/4	1.46026	07/05/93	JICA	1.4573	11/26/93	DMR	1.46513	07/20/94	JICA
A-5/5	1.46090	07/05/93	JICA	1.4573	11/26/93	DMR	1.46651	07/20/94	JICA
A-6/1	0.83961	07/05/93	JICA	0.8413	11/26/93	DMR	0.86188	07/20/94	JICA
A-6/2	0.91638	07/05/93	JICA	0.9223	11/26/93	DMR	0.95049	07/20/94	JICA
A-6/3	1.12316	07/05/93	JICA	1.1343	11/26/93	DMR	1.17875	07/20/94	JICA
A-6/4	1.46939	07/05/93	JICA	1.4673	11/26/93	DMR	1.47889	07/20/94	JICA
A-6/5	1.46777	07/05/93	JICA	1.4663	11/26/93	DMR	1.47806	07/20/94	JICA
A-7/1	0.85074	07/05/93	JICA	0.8533	11/26/93	DMR	0.87481	07/20/94	JICA
A-7/2	0.95956	07/05/93	JICA	0.9643	11/26/93	DMR	0.98813	07/20/94	JICA
A-7/3	1.16313	07/05/93	JICA	1.1723	11/26/93	DMR	1.20737	07/20/94	JICA
A-7/4	1.46080	07/05/93	JICA	1.4593	11/26/93	DMR	1.46612	07/20/94	JICA
A-7/5	1.46375	07/05/93	JICA	1.4613	11/26/93	DMR	1.46798	07/20/94	JICA
A-8/1	0.83505	07/05/93	JICA	0.8353	11/26/93	DMR	0.86238	07/20/94	JICA
A-8/2	0.94036	07/05/93	JICA	0.9453	11/26/93	DMR	0.97228	07/20/94	JICA
A-8/3	1.14178	07/05/93	JICA	1.1473	11/26/93	DMR	1.17800	07/20/94	JICA
A-8/4	1.44987	07/05/93	JICA	1.4483	11/26/93	DMR	1.46028	07/20/94	JICA
A-8/5	1.45029	07/05/93	JICA	1.4483	11/26/93	DMR	1.46018	07/20/94	JICA

DMR36: Starting benchmark of leveling survey by JICA Study Team

Table 6.2.2 RESULTS OF LEVELING SURVEY AT SITE - B

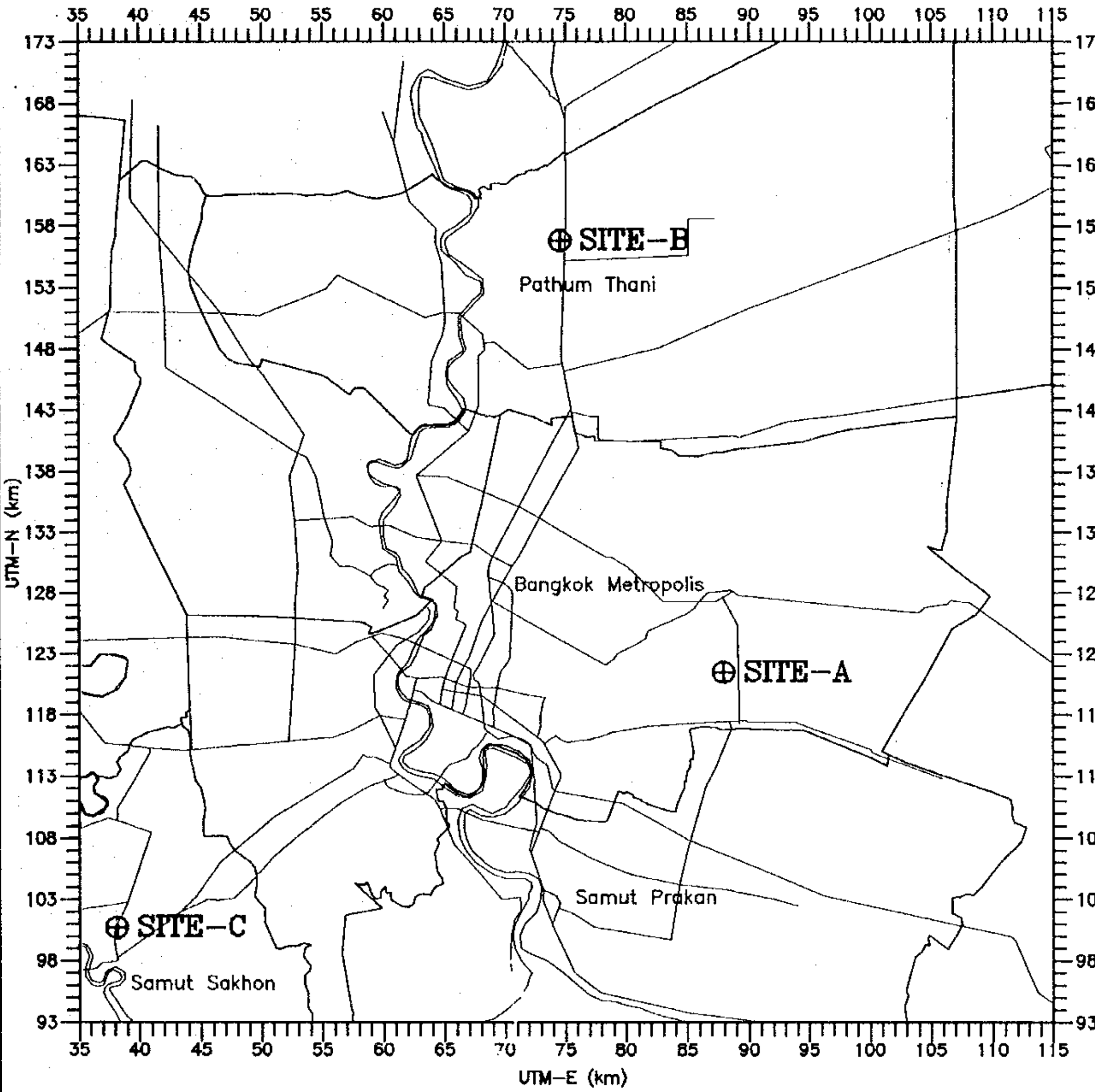
Benchmark No.	ELEV. (m)	DATE (M/D/Y)	DONE BY:	ELEV. (m)	DATE (M/D/Y)	DONE BY:	ELEV. (m)	DATE (M/D/Y)	DONE BY:
BM25	2.0107	10/12/93	DMR	2.0107	10/12/93	DMR	2.0107	10/12/93	DMR
BM-A	1.72057	07/13/93	JICA	1.7293	10/12/93	DMR	1.72778	06/28/94	JICA
BM-B	1.71828	07/13/93	JICA	1.7256	10/12/93	DMR	1.72251	06/28/94	JICA
B-1/1	2.01831	07/13/93	JICA	2.0227	11/26/93	DMR	2.02820	06/28/94	JICA
B-1/2	2.11431	07/13/93	JICA	2.1180	11/26/93	DMR	2.12393	06/28/94	JICA
B-1/3	2.36973	07/13/93	JICA	2.3732	11/26/93	DMR	2.38260	06/28/94	JICA
B-1/4	2.64157	07/13/93	JICA	2.6488	11/26/93	DMR	2.64839	06/28/94	JICA
B-1/5	2.64343	07/13/93	JICA	2.6460	11/26/93	DMR	2.65148	06/28/94	JICA
B-2/1	2.00745	07/13/93	JICA	2.0119	11/26/93	DMR	2.01497	06/28/94	JICA
B-2/2	2.11425	07/13/93	JICA	2.1187	11/26/93	DMR	2.12370	06/28/94	JICA
B-2/3	2.40343	07/13/93	JICA	2.4066	11/26/93	DMR	2.41459	06/28/94	JICA
B-2/4	2.63985	07/13/93	JICA	2.6447	11/26/93	DMR	2.64523	06/28/94	JICA
B-2/5	2.63718	07/13/93	JICA	2.6414	11/26/93	DMR	2.64187	06/28/94	JICA
B-3/1	2.01841	07/13/93	JICA	2.0227	11/26/93	DMR	2.02816	06/28/94	JICA
B-3/2	2.12518	07/13/93	JICA	2.1289	11/26/93	DMR	2.13485	06/28/94	JICA
B-3/3	2.34664	07/13/93	JICA	2.3501	11/26/93	DMR	2.35891	06/28/94	JICA
B-3/4	2.64924	07/13/93	JICA	2.6520	11/26/93	DMR	2.65496	06/28/94	JICA
B-3/5	2.64759	07/13/93	JICA	2.6539	11/26/93	DMR	2.65308	06/28/94	JICA
B-4/1	2.01173	07/13/93	JICA	2.0162	11/26/93	DMR	2.01889	06/28/94	JICA
B-4/2	2.11478	07/13/93	JICA	2.1186	11/26/93	DMR	2.12380	06/28/94	JICA
B-4/3	2.42119	07/13/93	JICA	2.4245	11/26/93	DMR	2.43101	06/28/94	JICA
B-4/4	2.64288	07/13/93	JICA	2.6479	11/26/93	DMR	2.64907	06/28/94	JICA
B-4/5	2.63624	07/13/93	JICA	2.6478	11/26/93	DMR	2.64220	06/28/94	JICA
B-5/1	2.00719	07/13/93	JICA	2.0122	11/26/93	DMR	2.01586	06/28/94	JICA
B-5/2	2.11250	07/13/93	JICA	2.1161	11/26/93	DMR	2.12161	06/28/94	JICA
B-5/3	2.36767	07/13/93	JICA	2.3709	11/26/93	DMR	2.37662	06/28/94	JICA
B-5/4	2.63958	07/13/93	JICA	2.6436	11/26/93	DMR	2.64566	06/28/94	JICA
B-5/5	2.63876	07/13/93	JICA	2.6448	11/26/93	DMR	2.64472	06/28/94	JICA

BM25: Starting benchmark of leveling survey by JICA Study Team

Table 6.2.3 RESULTS OF LEVELING SURVEY AT SITE - C

Benchmark No.	ELEV. (m)	DATE (M/D/Y)	DONE BY:	ELEV. (m)	DATE (M/D/Y)	DONE BY:	ELEV. (m)	DATE (M/D/Y)	DONE BY:
DMR05	1.3878	07/08/93	DMR				1.3878	07/08/93	DMR
BM-A	2.53832	08/05/93	JICA	2.4900	10/06/93	DMR	2.43829	06/30/94	JICA
BM-B	2.54694	08/05/93	JICA	2.5022	11/07/93	DMR	2.45417	06/30/94	JICA
C-1/1	2.84698	08/05/93	JICA	2.8163	11/09/93	DMR	2.80848	06/30/94	JICA
C-1/2	2.96564	08/05/93	JICA	2.9613	11/09/93	DMR	2.96234	06/30/94	JICA
C-1/3	3.16964	08/05/93	JICA	3.1788	11/09/93	DMR	3.20103	06/30/94	JICA
C-1/4	3.46708	08/05/93	JICA	3.4328	11/09/93	DMR	3.39080	06/30/94	JICA
C-1/5	3.46557	08/05/93	JICA	3.4322	11/09/93	DMR	3.39158	06/30/94	JICA
C-2/1	2.85967	08/05/93	JICA	2.8515	11/07/93	DMR	2.84292	06/30/94	JICA
C-2/2	2.97925	08/05/93	JICA	2.9748	11/07/93	DMR	2.97134	06/30/94	JICA
C-2/3	3.17609	08/05/93	JICA	3.1832	11/07/93	DMR	3.19906	06/30/94	JICA
C-2/4	3.45212	08/05/93	JICA	3.4089	11/07/93	DMR	3.65850	06/30/94	JICA
C-2/5	3.45138	08/05/93	JICA	3.4114	11/07/93	DMR	3.36166	06/30/94	JICA
C-3/1	2.86717	08/05/93	JICA	2.8601	11/09/93	DMR	2.85301	06/30/94	JICA
C-3/2	2.98036	08/05/93	JICA	2.9774	11/09/93	DMR	2.97627	06/30/94	JICA
C-3/3	3.18142	08/05/93	JICA	3.1833	11/09/93	DMR	3.19000	06/30/94	JICA
C-3/4	3.47558	08/05/93	JICA	3.4341	11/09/93	DMR	3.38991	06/30/94	JICA
C-3/5	3.47147	08/05/93	JICA	3.4351	11/09/93	DMR	3.39011	06/30/94	JICA
C-4/1	2.85883	08/05/93	JICA	2.8568	11/09/93	DMR	2.85460	06/30/94	JICA
C-4/2	2.96245	08/05/93	JICA	2.9604	11/09/93	DMR	2.95896	06/30/94	JICA
C-4/3	3.16952	08/05/93	JICA	3.1695	11/09/93	DMR	3.17212	06/30/94	JICA
C-4/4	3.45456	08/05/93	JICA	3.4154	11/09/93	DMR	3.37447	06/30/94	JICA
C-4/5	3.45484	08/05/93	JICA	3.4170	11/09/93	DMR	3.37157	06/30/94	JICA
C-5/1	2.82772	08/05/93	JICA	2.7869	11/09/93	DMR	2.74106	06/30/94	JICA
C-5/2	2.95357	08/05/93	JICA	2.9521	11/09/93	DMR	2.95294	06/30/94	JICA
C-5/3	3.15912	08/05/93	JICA	3.1588	11/09/93	DMR	3.16135	06/30/94	JICA
C-5/4	3.46813	08/05/93	JICA	3.4285	11/09/93	DMR	3.37563	06/30/94	JICA
C-5/5	3.47029	08/05/93	JICA	3.4238	11/09/93	DMR	3.38178	06/30/94	JICA

DMR05: Starting benchmark of leveling survey by JICA Study Team

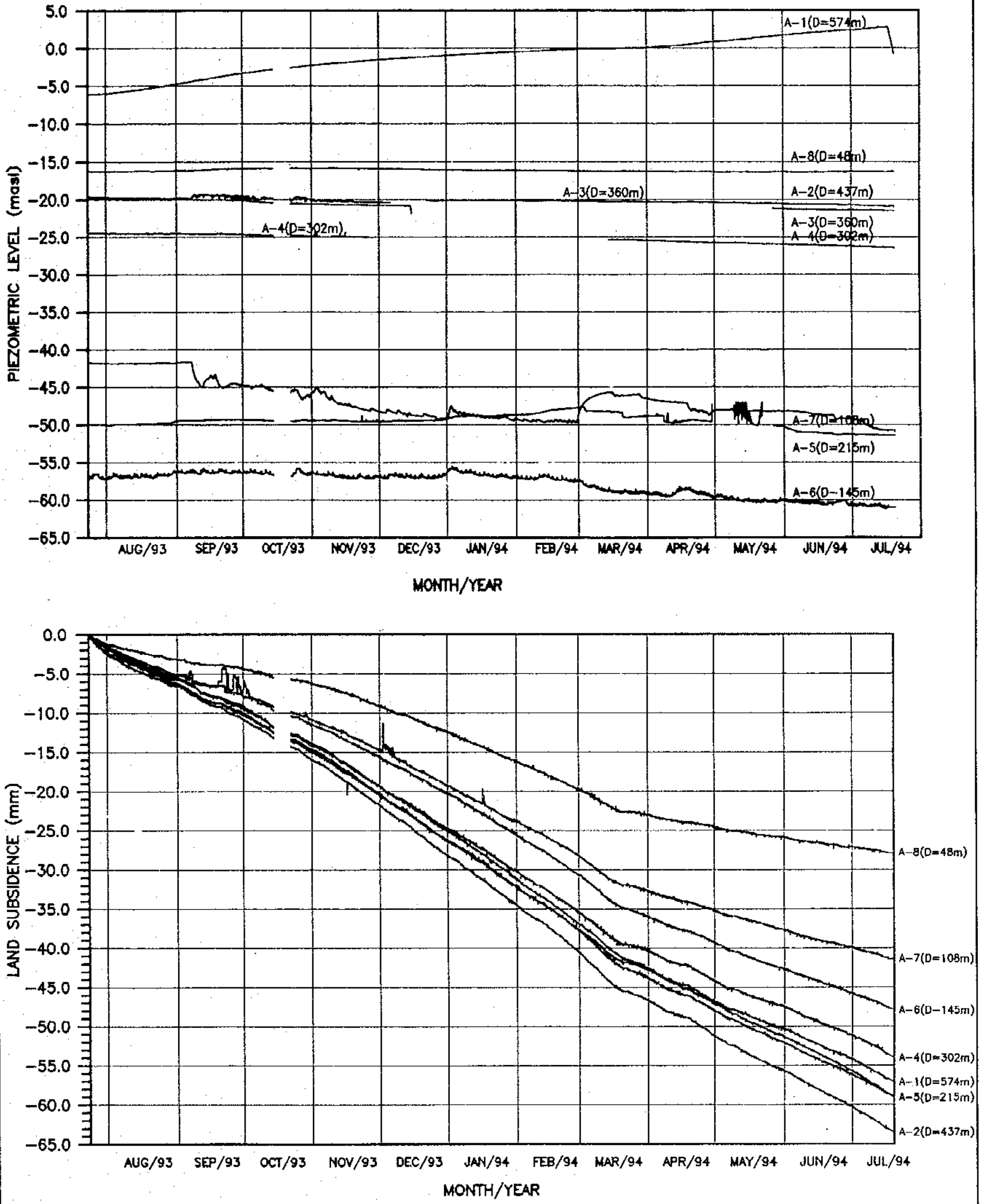


	UTM GRID	LONGITUDE	LATITUDE	LOCATION
SITE-A:	879215	100°44'17"	13°45'26"	ROM KLAO VILLAGE, NHA, LAT KRABANG
SITE-B:	746568	100°37'02"	14°04'41"	AIT CAMPUS, PATHUM THANI
SITE-C:	381007	100°16'35"	13°34'23"	RON RIAN WAT KLONG KRU, SAMUT SAKHON

Figure 6.2.1 **LOCATION OF JICA MONITORING STATIONS**

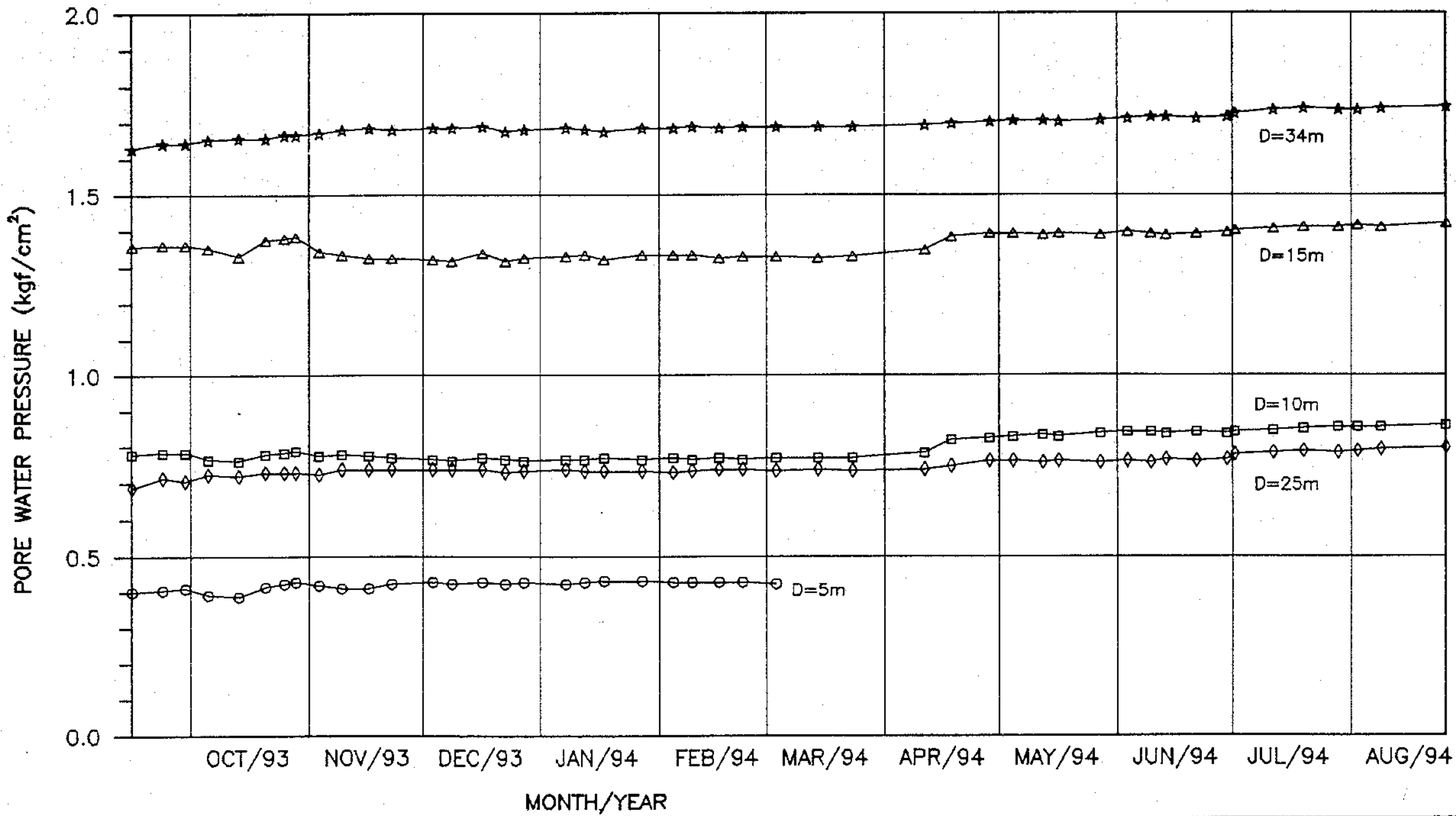
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

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



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

Figure 6.2.2	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.



LOCATION : Site–A, Lat Krabang
UTM Grid : 879215

Figure 6.2.3	CHANGES IN PORE WATER PRESSURE 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.

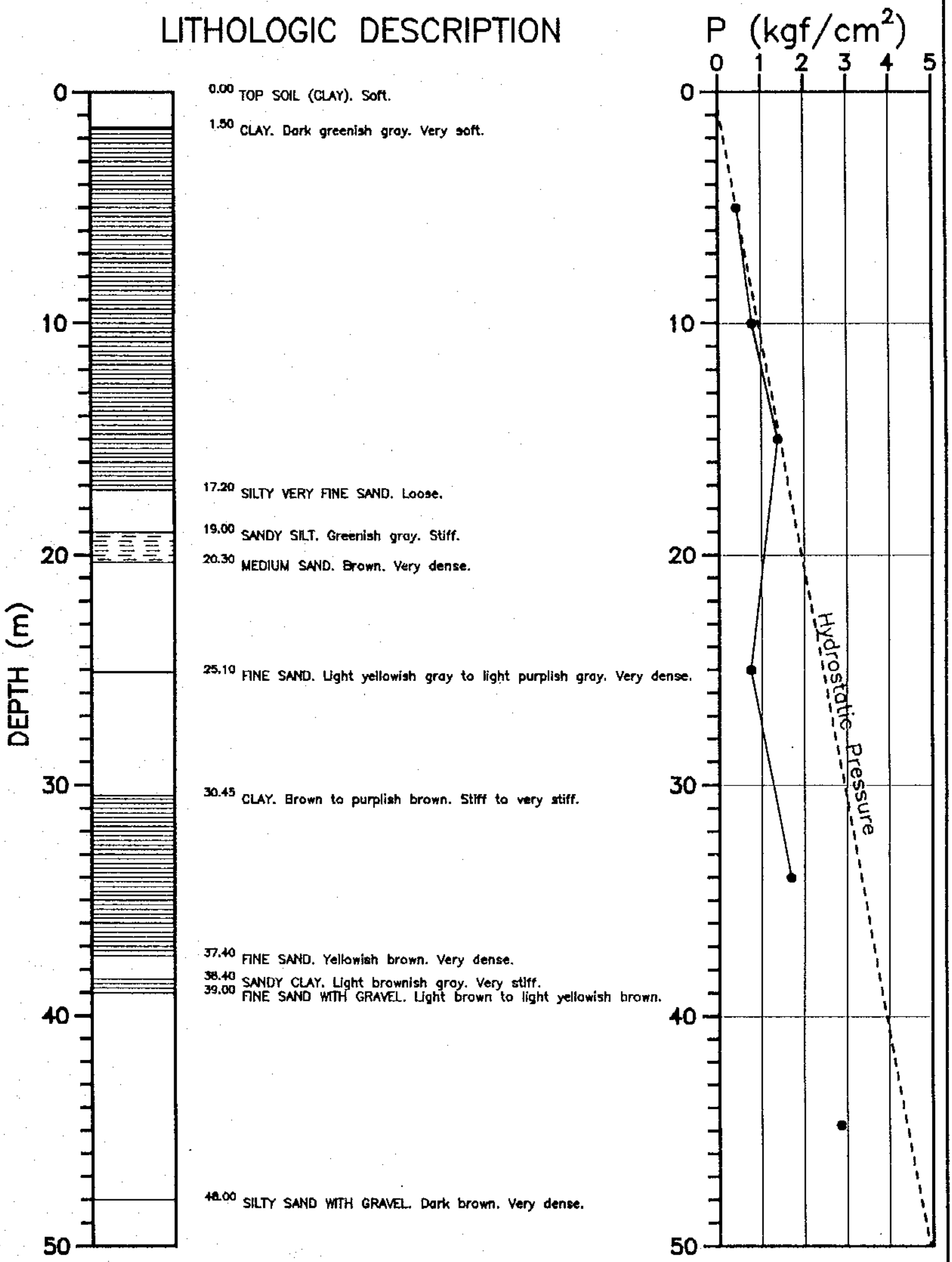
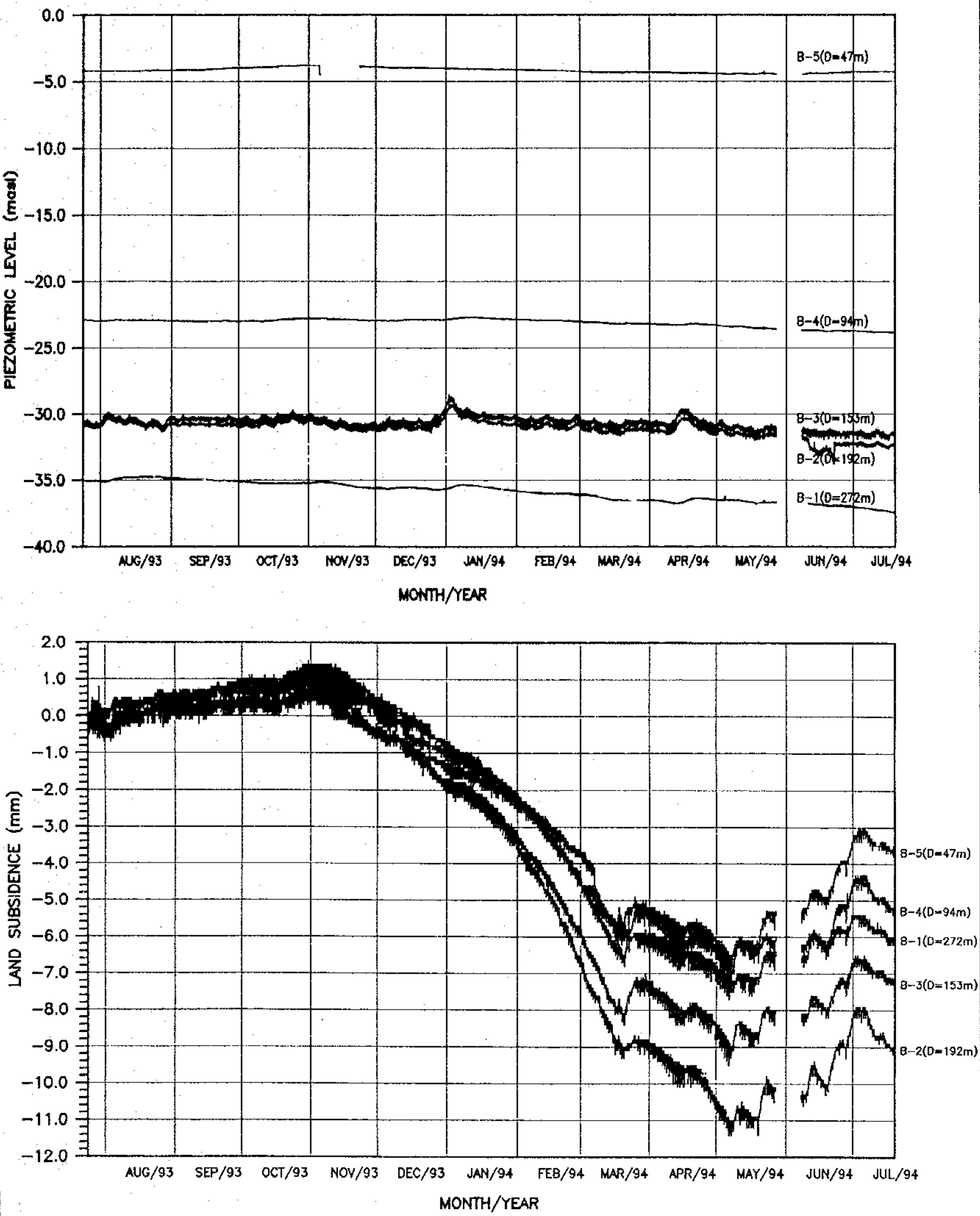
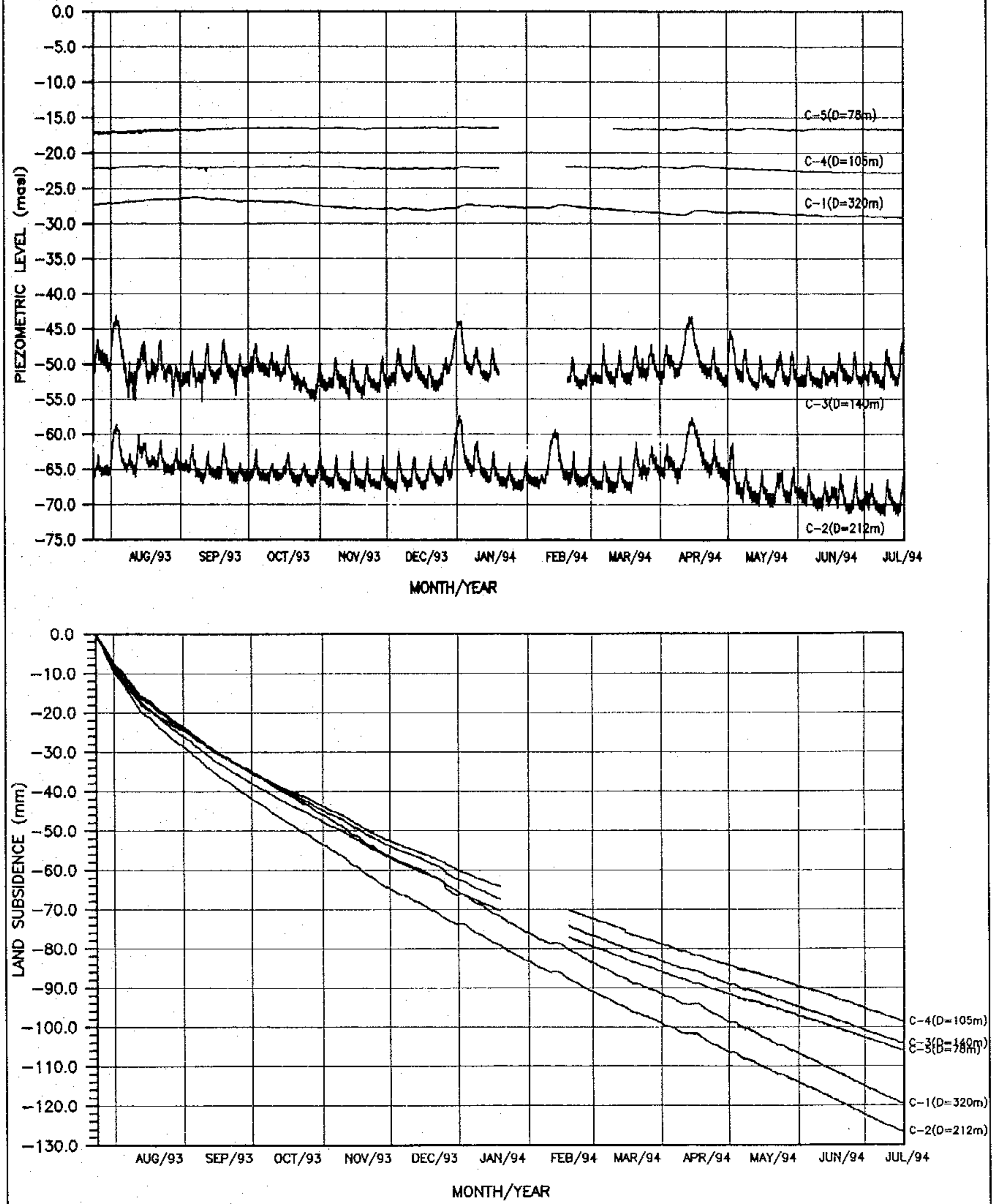


Figure 6.2.4	**DISTRIBUTION OF PORE WATER PRESSURE AT SITE - A**
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



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

Figure 6.2.5	**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.



WELL NO.: JICA C-1 to C-5
LOCATION: SAMUT SAKHON
UTM GRID: 381007

Figure 6.2.6	**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.

6.3 DMR and RTSD Benchmarks

(1) Land Subsidence Data

Several organizations constructed various types of benchmarks in the Study Area. As of 1992, a total of 1,243 benchmarks had been constructed, including those that had been destroyed or lost (see Figure 6.3.1).

NEB constructed 44 land subsidence stations which are called CI stations. In 1992, there were about 42 CI stations in the Study Area. Each CI station has 2 to 5 benchmarks of different depths:

BM benchmark	: Depth to sand layer (19-m to 35-m depths)
CI*-1	: 1-m depth
CI*-2	: 10-m depth
CI*-3	: 15-m depth
CI*-4	: 100-m to 200-m depths with automatic recorder
CI*-5	: More than 300-m depth

* denotes succeeding station numbers, about 44 in all, although some are missing.

RTSD is conducting a yearly leveling survey of the CI stations. In 1992, RTSD surveyed 140 benchmark elevations which included those of the CI stations.

RTSD itself has two (2) types of benchmarks: primary benchmarks (or BMP) and secondary benchmarks (or BMS). The BMP benchmarks were installed at the depth of 1.0 m. About 109 BMP benchmarks were constructed in the Study Area. (This number excludes CI*-1 benchmarks.) In 1992, RTSD conducted leveling survey of 87 BMP benchmarks. About 411 BMS benchmarks which are less reliable than the BMP benchmarks are maintained by RTSD in the Study Area; however, the leveling survey results of BMS benchmarks are not published by RTSD (1992).

BMA constructed 477 benchmarks in the Bangkok Metropolis and conducted leveling surveys in 1979, 1986, and 1989. Of this total, 87 are used by RTSD for its annual leveling: 43 drilled benchmarks and 44 surface benchmarks.

In 1990 and 1991, DMR constructed 86 benchmarks within or near its groundwater monitoring stations. Leveling survey is conducted by the DMR's Survey Division.

For the following discussions on land subsidence, leveling data of CI and BMP benchmarks were used due to their reliability and the availability of benchmark structure.

(2) Land Subsidence from 1980 to 1992

The displacements of 1-m depth benchmarks at CI stations and BMP-series benchmarks were assumed to represent the movement of the ground surface. Land subsidence maps were derived from the leveling data published in RTSD (1992).

Figure 6.3.2 (left hand side) shows the total land subsidence in 12 years. The maximum land subsidence of 62.6 cm was recorded at CI-14 station in Phra Khanong, Bangkok. The area from Huai Kwang to Muang Samut Prakan located east to southeast of Bangkok had subsided more than 50 cm. The area lying east of Chao Phraya river and stretching up to Don Muang, Bangkok had subsided more than 30 cm. The land subsidence in western Bangkok and Samut Sakhon ranged from 5 cm to 15 cm.

Land Subsidence from 1980 to 1986

Figure 6.3.2 (middle) shows the total land subsidence from 1980 to 1986. In this period, land subsidence occurred mainly in eastern Bangkok and Samut Prakan, where 30-cm to 45-cm subsidence were recorded. The maximum land subsidence of 46.7cm was recorded at the CI-21 station in Phra Khanong.

Land Subsidence from 1986 to 1992

Figure 6.3.2 (right hand side) shows the land subsidence after the restriction in groundwater use was implemented by the DMR. Due to this restriction, land subsidence rates in eastern Bangkok were reduced. However, areas affected by land subsidence had expanded to Samut Prakan, Pathum Thani, Nonthaburi, and western Bangkok. Large area of Samut Prakan had subsided by about 20 cm to 25 cm in this six-year period. Land subsidence in Pathum Thani and Nonthaburi ranged from 10 cm to 28 cm.

(3) Land Subsidence from 1991 to 1992

The following maps were prepared to present the land subsidence measured at different depths of benchmarks between 1991 and 1992.

1-m Depth Benchmarks

Figure 6.3.3 (left hand side) shows the recent land subsidence at ground surface. Ground surface in most parts of the Study Area had subsided. More than 20 mm of subsidence was recorded in Bangkok Metropolis, Samut Prakan, Samut Sakhon, central part of Pathum Thani, and part of Nonthaburi. In Samut Prakan, 50 mm to 60 mm of subsidence were recorded in Bang Phli and Bang Bo. Min Buri and Lat Krabang had subsided 40 mm to 55 mm, the largest in Bangkok. In Pathum Thani, 30 mm to 40 mm of subsidence were observed from Muang to Sam Khok and Khlong Luang; 30 mm to 40 mm of subsidence occurred in Samut Sakhon.

10-m Depth Benchmarks

Figure 6.3.3 (middle) shows the occurrence of land subsidence below 10-m depth. Though limited in number, the 10-m depth benchmarks located in eastern Bangkok were shown to have subsided by about 20 mm to 30 mm.

11-m to 20-m Depths Benchmarks

Available data mostly came from Bangkok Metropolis in Figure 6.3.3 (right hand side). Subsidence of 10 mm to 15 mm was recorded in eastern Bangkok, while it ranged from 0 mm to 5 mm in central Bangkok. More than 20 mm of subsidence was observed in Don Muang and Phra Samut Chedi.

21-m to 100-m Depths Benchmarks

Subsidence of more than 20 mm was recorded in Don Muang and Bang Phli in Samut Prakan. Benchmarks had subsided by about 10 mm to 15 mm in the east and less than 5mm in the west and center of Bangkok Metropolis (Figure 6.3.4(left hand side)).

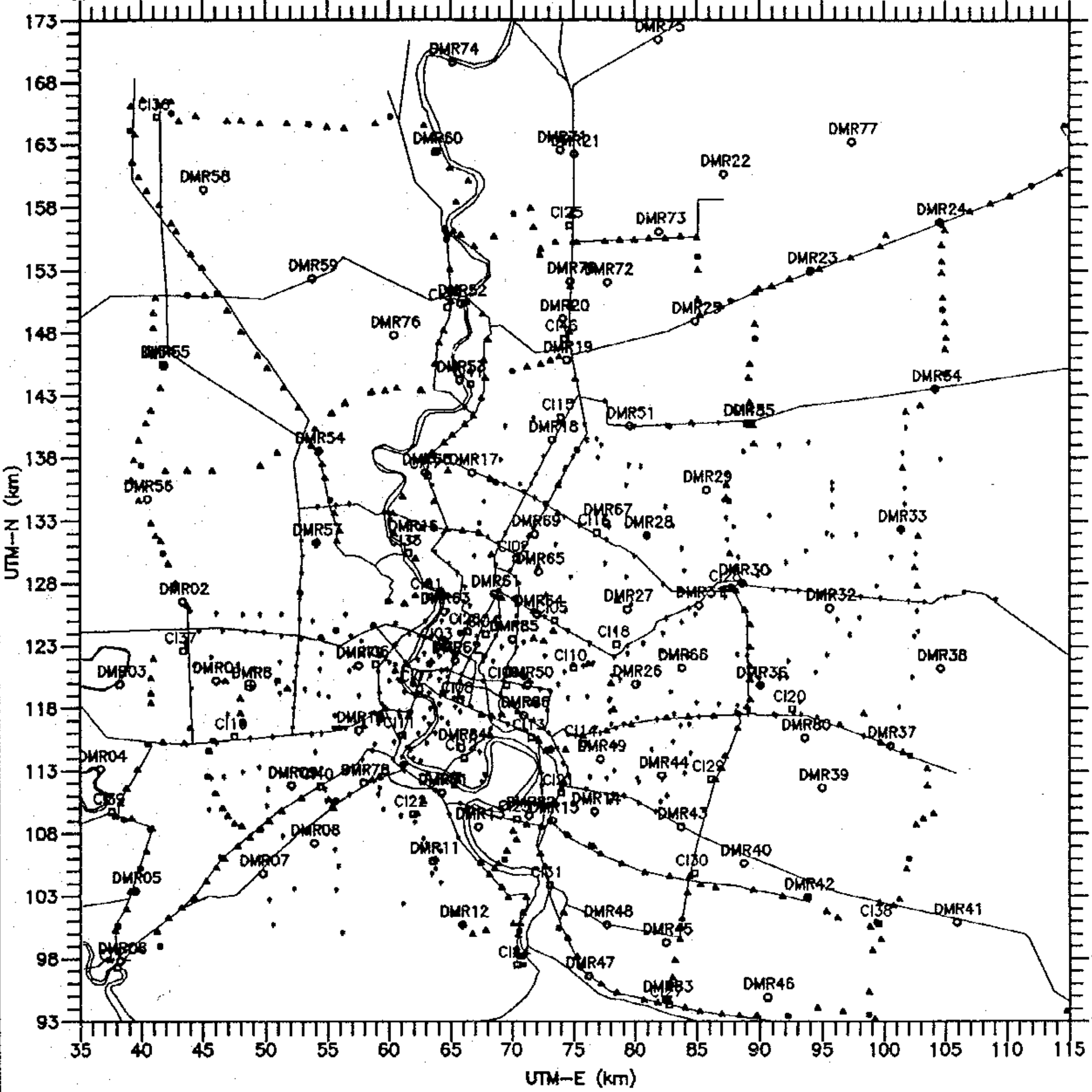
101-m to 200-m Depths Benchmarks

In central Bangkok, subsidence at these depths ranged from 2 mm to 10 mm. The benchmarks in Don Muang and Bang Phli had recorded a 25-mm subsidence (Figure 6.3.4 (right hand side)).

(4) Land Subsidence from 1992 to 1993

Figure 6.3.5 was prepared by compiling the data from the DMR and RTSD benchmarks from 1992 to 1993. The map indicates significant land subsidence areas in Samut Prakan, eastern Bangkok, Pathum Thani, and Samut Sakhon. The rate of subsidence was smaller along the Chao Phraya River.

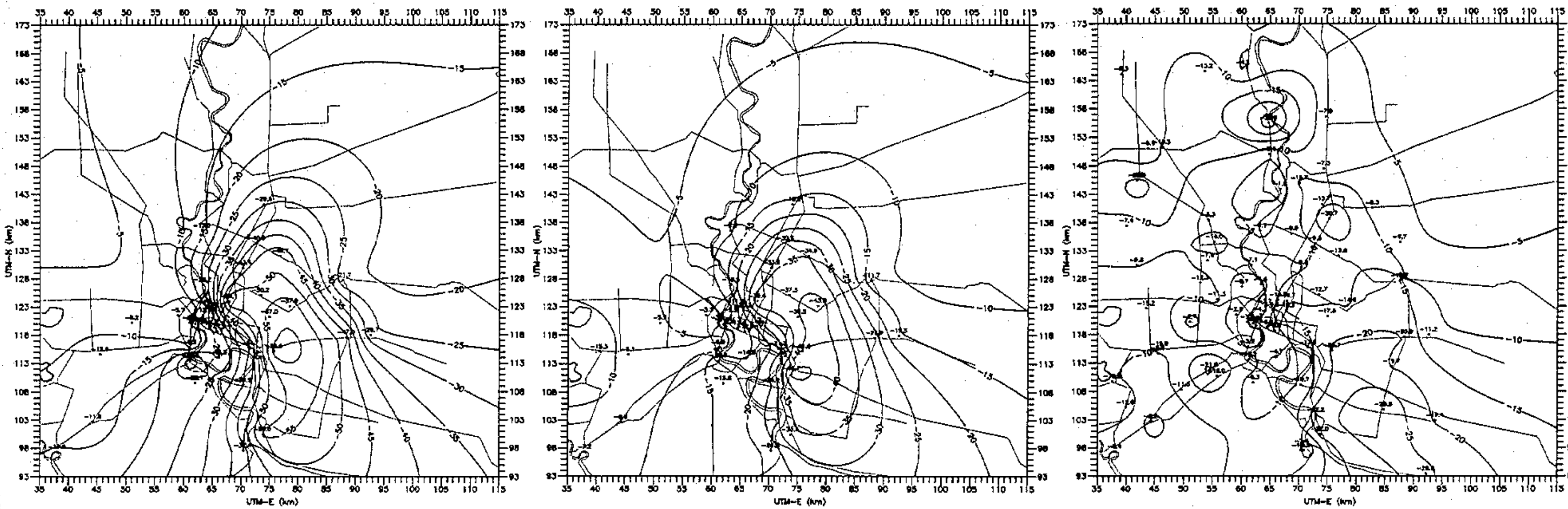
The CI stations (or AIT stations) have different depths of benchmarks as measured by the RTSD. The DMR has also been conducting leveling survey at CI stations since 1991. Figure 6.3.6a shows the land subsidence measured at AIT14 station, Wat Rajsathathum, Bangkok. This station is located near the center of the area with significant land subsidence. The subsidence measured at CI-1 benchmark (1-m depth) was 648.4 mm from 1980 to 1993. The lower graph in Figure 6.3.6a, showing the land subsidence since 1986, indicates the occurrence of about 55% of compression between 1.0 m to 10.0 m depths. Similar graphs were prepared by using the data at AIT08 station, Chulalongkorn University, Bangkok (Figure 6.3.6b). In this station, only CI-1 benchmark showed significant land subsidence since the start of measurement. The CI-4 benchmark showed rebound since 1981. The lower graph indicates that the 1.0 m to 27.1 m and 27.1 m to 196.3 m layers contributed to land subsidence 75% and 25%, respectively. The graphs at AIT25 station (Figure 6.3.6c), AIT, Pathum Thani, shows that the benchmarks of BM (depth = 19.0 m), CI-2 (depth = 10.0 m), and CI-4 (depth = 197.3 m) indicated rebound since the start of measurement. The CI-1 benchmark showed rebound from 1988 to 1990 and from 1992 to 1993.



LEGEND

- ○ DMR Land Subsidence Station
- □ NEB Land Subsidence Station (CI Station)
- • RTSD BMP-series Benchmark
- ▲ RTSD BMS-series Benchmark
- ⸱ BMA Benchmark
- ⊕ RTSD BMR Benchmark

Figure 6.3.1	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.



FROM 1980 TO 1992 | FROM 1980 TO 1986 | FROM 1986 TO 1992

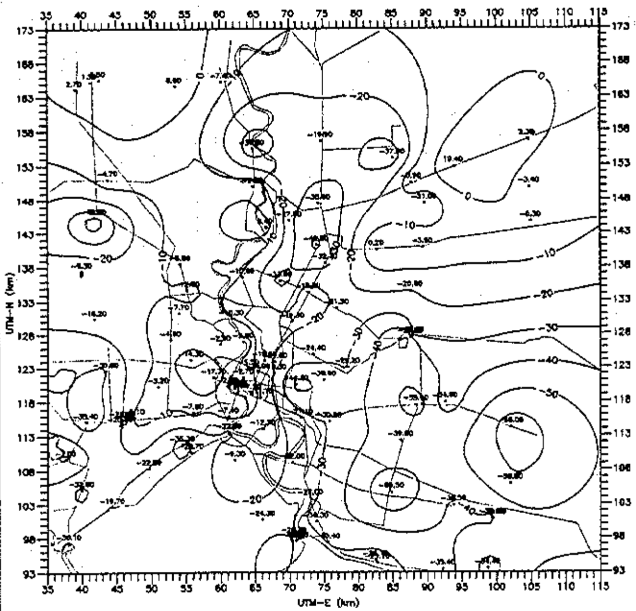
LEGEND

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

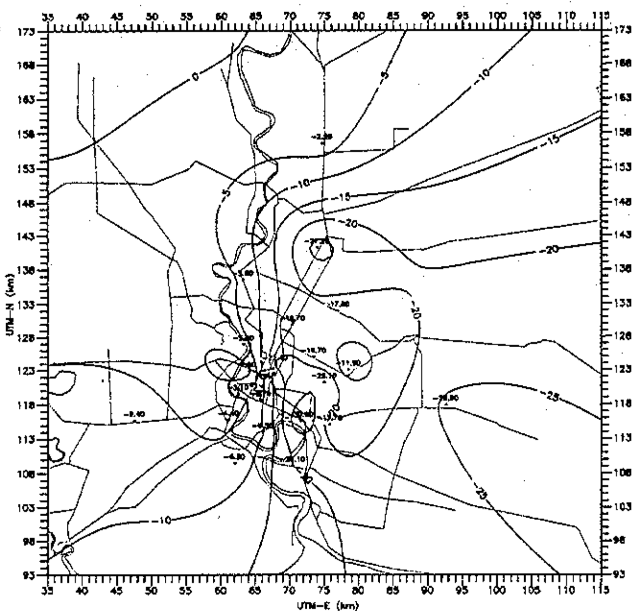
-20.0 • LAND SUBSIDENCE STATION OR BENCHMARK WITH LAND SUBSIDENCE (cm/12years)

(Negative sign represents subsidence.)

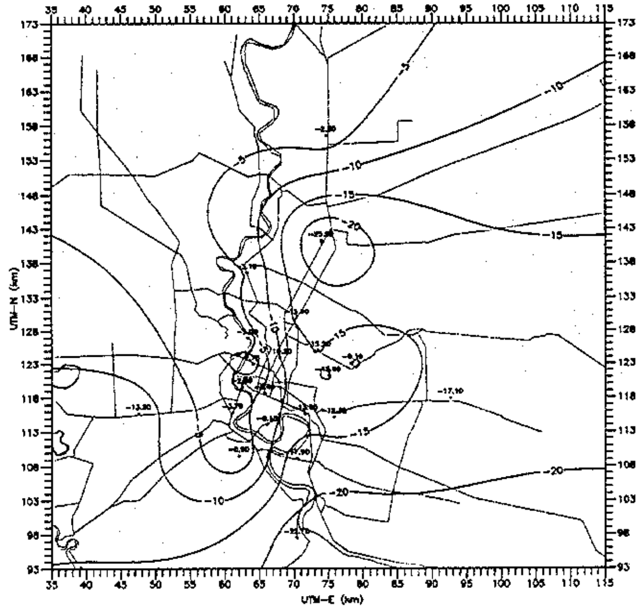
Figure 6.3.2	LAND SUBSIDENCE MEASURED AT 1 m DEPTH BENCHMARKS
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



1 m DEPTH BENCHMARKS



10 m DEPTH BENCHMARKS



11 - 20 m DEPTH BENCHMARKS

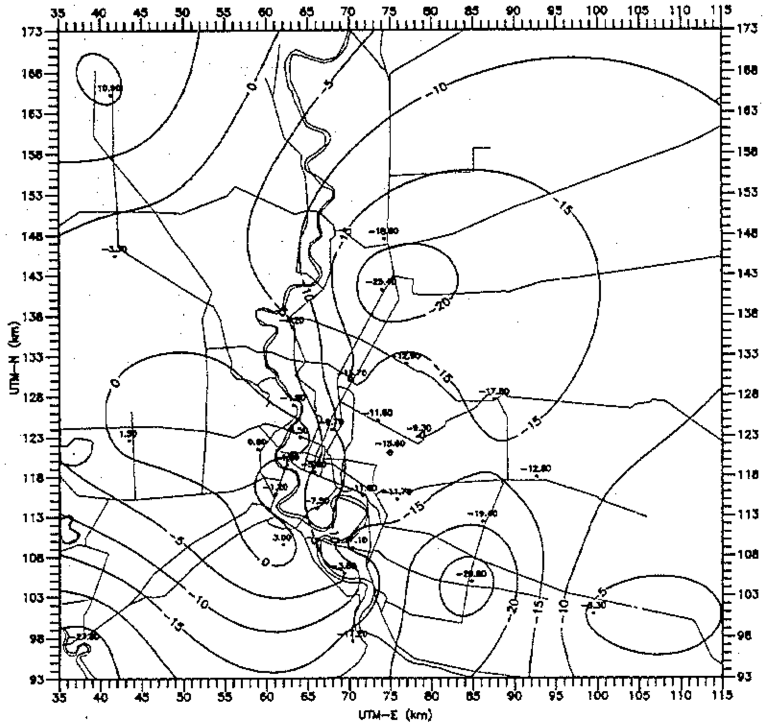
LEGEND

——— LINE OF EQUAL LAND SUBSIDENCE (mm/year)

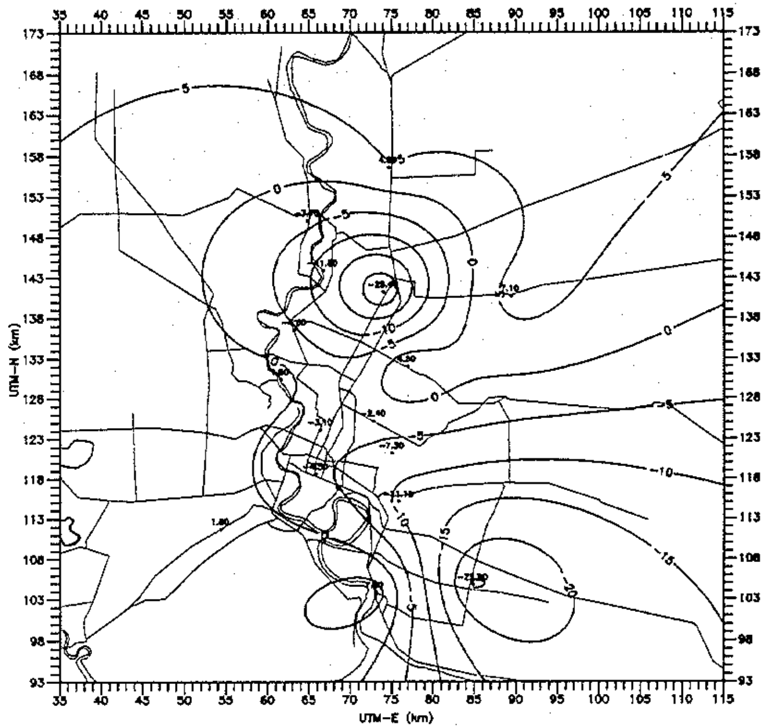
-8.00 LAND SUBSIDENCE STATION OR BENCHMARK WITH LAND SUBSIDENCE (mm/year)

(Negative sign shows subsidence.)

Figure 6.3.3	LAND SUBSIDENCE MEASURED AT VARIOUS DEPTH BENCHMARKS (FROM 1991 TO 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.



21 - 100 m DEPTH BENCHMARKS



101 - 200 m DEPTH BENCHMARKS

LEGEND

LINE OF EQUAL LAND SUBSIDENCE (mm/year)

-8.00 LAND SUBSIDENCE STATION OR BENCHMARK WITH LAND SUBSIDENCE (mm/year)

(Negative sign shows subsidence.)

Figure 6.3.4	LAND SUBSIDENCE MEASURED AT VARIOUS DEPTH BENCHMARKS (FROM 1991 TO 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.

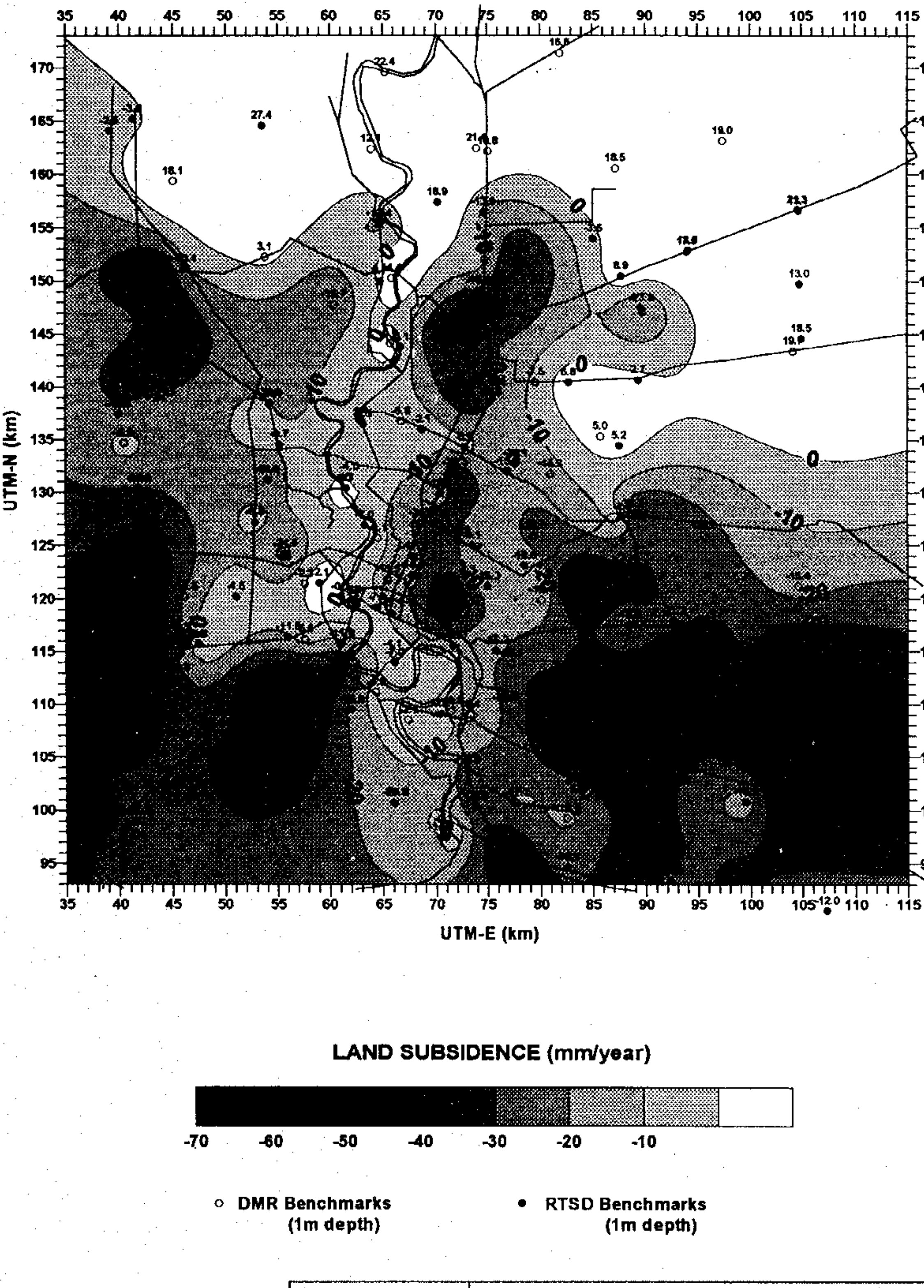


Figure 6.3.5	LAND SUBSIDENCE FROM 1992 TO 1993 MEASURED AT 1m DEPTH BENCHMARKS
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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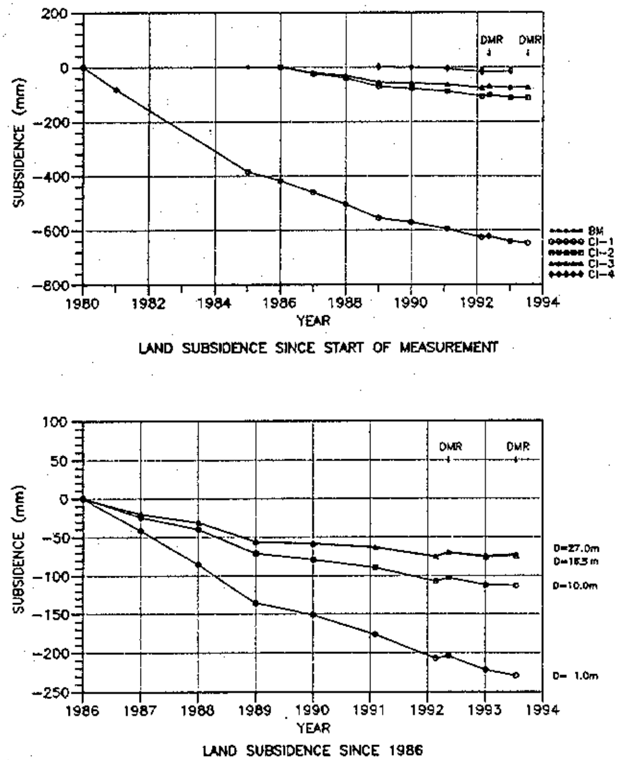
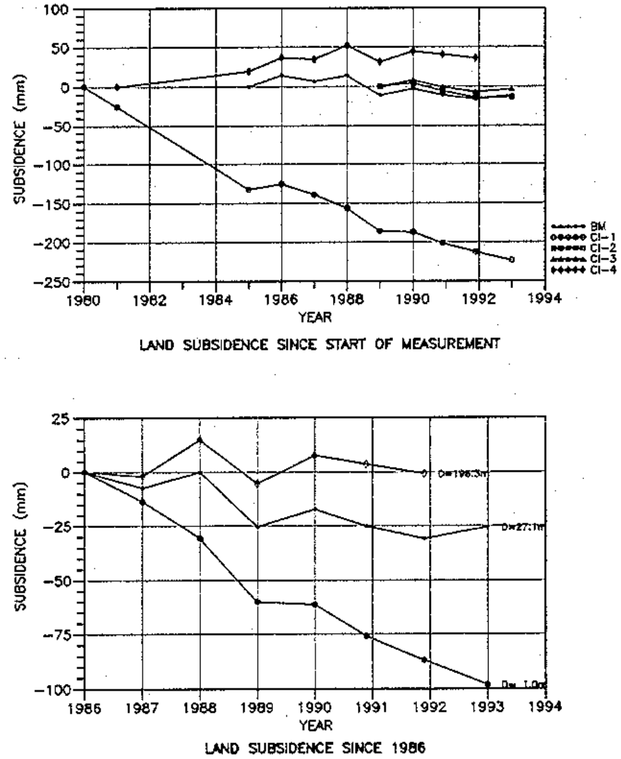
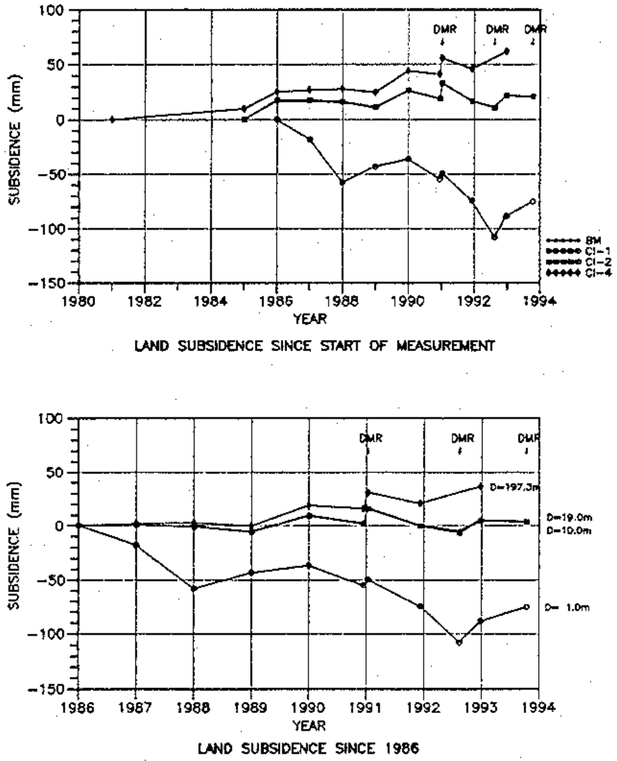


a) AIT14 STATION



b) AIT08 STATION



c) AIT25 STATION

(DMR: Measured by DMR)

Figure 6.3.6	LAND SUBSIDENCE
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
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