**(4) Scenario 3**

The decline of piezometric levels in the present critical zones 1 and 2 will stabilize from 1998 to 2008 as shown in Figure 7.2.77. However, the piezometric levels at Site-B and Site-C straightly drop because these areas are not covered by the present critical zone. It is noted that the piezometric levels at Site-A will again drop after 2008 even the pumpage is maintained at the constant amount. This is due to the expansion of the piezometric level's depression at Pathum Thani where the pumpage increases as mentioned in Scenario 1.

The land subsidence graphs at Site-A and the DMR office in Figure 7.2.78 show the subsidence rates become gentle from 1998 to 2008, however, the rates increase again from 2009. The subsidence at Site-B and Site-C will straightly continue until 2017.

Figure 7.2.79 shows that most parts of the present critical zones 1 and 2 will subside more than 50 cm by 2017. The severe subsidence ranging from 50 cm to 190 cm is predicted in Pathum Thani and Samut Sakhon.

**(5) Scenario 4**

The piezometric levels at Site-A clearly recover from 2002 as shown in Figure 7.2.80 due to the reduction of pumpage at the present critical zones 1 and 2. The piezometric levels of the main aquifers will be higher than those at present. However, the piezometric levels of NL aquifer at Site-B and Site-C will straightly drop by -187 masl and by -170 masl, respectively in the year 2017.

The land subsidence at Site-A and the DMR office will stop from the year 2001 then slight rebound can be observed for a period from 2001 to 2012 as shown in Figure 7.2.81. However, the subsidence at Site-B and Site-C will straightly continue like Scenario 1.

The simulated land subsidence distribution by the year 2017 is shown in Figure 7.2.82. The scenario is effective in the present critical zone. The subsidence by 2017 will be around 25 cm in the area. But in Pathum Thani and Samut Sakhon, more than 100 cm of severe subsidence is predicted.

**(6) Scenario 5A**

The scenario can control decline of the piezometric levels in the Study Area after the year 2000. As shown in Figure 7.2.83, the piezometric levels at Site-A will slightly recover from 2000, whereas the declining rates of piezometric levels at Site-B and Site-C become small after 2000. The piezometric levels of NL aquifer at Site-A, Site-B, and Site-C in 2017 are -59 masl, -114 masl, and -111 masl, respectively.

The rates of land subsidence at the observation points decrease from the year 2001 as shown in Figure 7.2.84, however, the scenario cannot stop land subsidence. The subsidence by the end 2017 is predicted as 96 cm at Site-C, 58 cm at the DMR office, 56 cm at Site-B, and 30 cm at Site-A.

The area subsided more than 100 cm by 2017 no longer exists in Pathum Thani and Samut Sakhon as shown Figure 7.2.85. However, more than 50 cm of land subsidence is widely distributed even in the new critical zone.

**(7) Scenario 5B**

The recovery of piezometric levels from the year 2001 is clearly observed at the JICA monitoring stations (Figure 7.2.86). The simulated piezometric heads of NL aquifer in 2017 are -33 masl at Site-A, -65 masl at Site-B, and -62 masl at Site-C, respectively.

Figure 7.2.87 shows the subsidence at the observation points stop in 2001 then slightly rebound until 2011 to 2013 due to the recovery of the piezometric heads. The subsidence by the end of 2017 is 66 cm at Site-C, 36 cm at Site-B, 32 cm at the DMR office, and 18 cm at Site-A.

The area subsided more than 50 cm by 2017 is sporadically distributed in Bangkok, Pathum Thani, Samut Prakan, and Samut Sakhon (Figure 7.2.88). In the new critical zone, subsidence more than 50 cm by 2017 will occur only in Samut Sakhon.

**(8) Scenario 5C**

The recovery of piezometric heads from 2001 to 2010 is smaller than that of Scenario 5B due to the small pumpage reduction rate (Figure 7.2.89). The simulated piezometric head of NL aquifer at Site-A is -60 masl in 2001 and -47 masl in 2017. Similarly, the head of NL aquifer at Site-B drops to -116 masl in 2001 and then recovers to -90 masl in 2017. At Site-C, the head of NL aquifer drops to -103 masl in 2001, then recovers to -88 masl in 2017.

The simulation results show that the subsidence at Site-A will stop from 2001 to 2011 (Figure 7.2.90). At Site-B, Site-C, and the DMR office, the rates of subsidence become within 0.5 cm/year from 2001 to 2010, then the rates range from 0.5 cm/year to 1.0 cm/year from 2011 to 2017.

The land subsidence more than 50 cm by 2017 is predicted in Samut Prakan, western Bangkok, part of Pathum Thani, and central Samut Sakhon as shown in Figure 7.2.91.

**(9) Scenario 6**

The scenario reduces the pumpage increasing rate from 1995 to 2000 so that the drawdown for the period becomes smaller than that in Scenario 5C as shown in Figure 7.2.92. The simulated piezometric head of NL aquifer at Site-A is -57 masl in 2001 and -41 masl in 2017. Similarly, the head of NL aquifer at Site-B drops to -87 masl in 2001 and then recovers to -73 masl in 2017. At Site-C, the head of NL aquifer drops to -88 masl in 2001, then recovers to -72 masl in 2017.

As a result, the simulated land subsidence by the year 2001 decreases comparing with that of Scenario 5C. Figure 7.2.93 shows the subsidence at Site-C by the end of 2001 is 42 cm, then it will be 48 cm by the end of 2017. The subsidence at Site-A, Site-B, and the DMR office can be controlled within 20 cm in 2000 by the scenario.

The future subsidence map by the year 2017 (Figure 7.2.94) shows the area subsided more than 50 cm no longer exists in the new critical zone.

**(10) Scenario 7**

The scenario is more effective to reduce drawdown by the year 2000 in the new critical zone, as shown in Figure 7.2.95. The simulated piezometric head of NL aquifer at Site-A is -55 masl in 2001 and -38 masl in 2017. Similarly, the head of NL aquifer at Site-B drops to -80 masl in

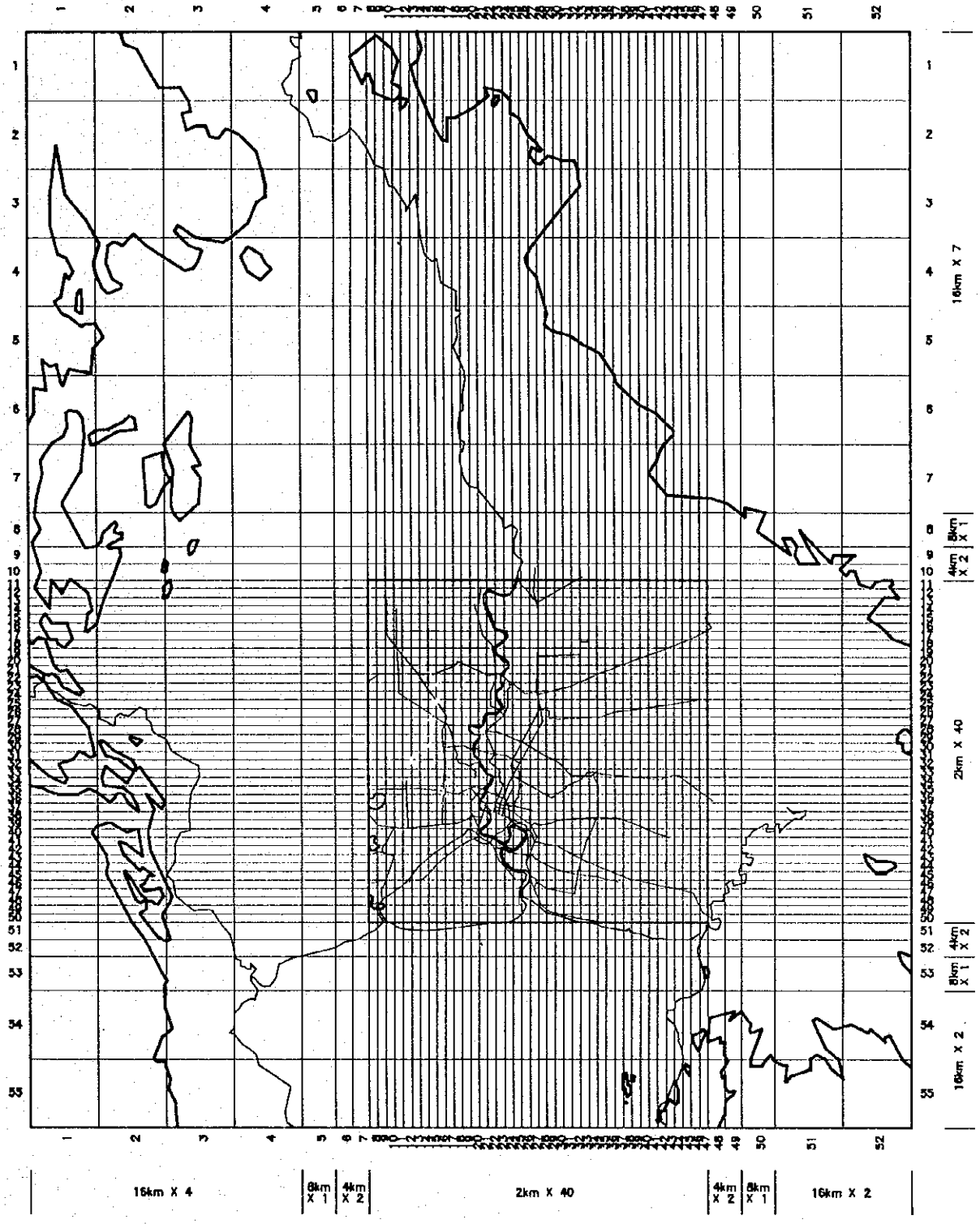
2001 and then recovers to -68 masl in 2017. At Site-C, the head of NL aquifer drops to -80 masl in 2001, then recovers to -66 masl in 2017.

As a result, the simulated land subsidence by the year 2001 further decreases comparing with that of Scenario 6. Figure 7.2.96 shows the subsidence at Site-C by the end of 2001 is 31 cm, then it will be 36 cm by the end of 2017. The subsidence at Site-A, Site-B, and the DMR office can be controlled within 30 cm in 2017 by the scenario.

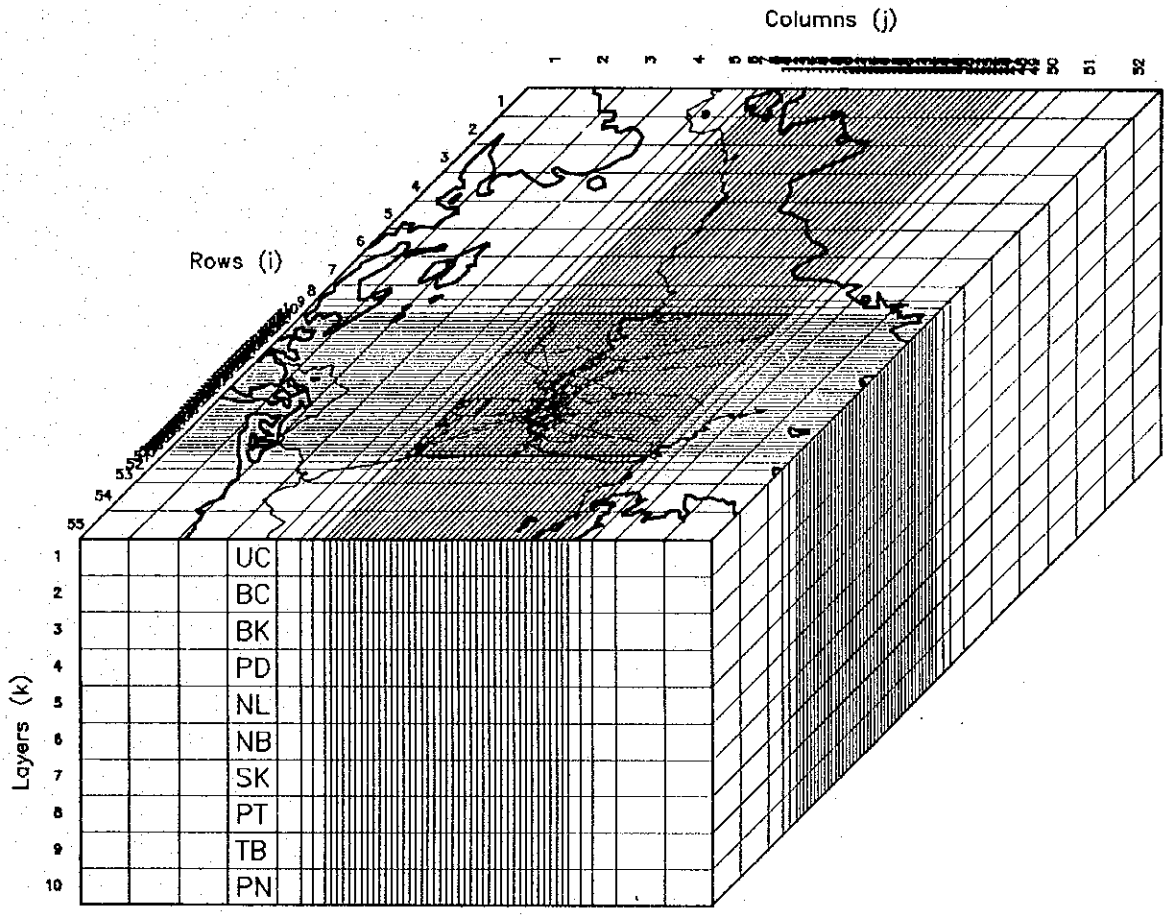
Figure 7.2.97 indicates that the subsidence in most parts of the Study Area can be controlled within 30 cm in 2017. The area having more than 30 cm of subsidence by 2017 can be seen at western Samut Prakan, western Bangkok, central Bangkok, part of Pathum Thani, and part of Phra Nakhon Si Ayutthaya.

## Table 7.2.3 SUMMARY OF FUTURE PUMPAGE SCENARIOS

| SCENARIO | ASSUMPTION |
|---|---|
| Scenario 1 | Private wells and public wells (except IEAT and MWA wells)<br>= Past 5 years trend extrapolated to the future.<br>IEAT wells<br>= Each industrial estate's plan.<br>MWA wells<br>= Stepwise phased out by 2007 from 1993. |
| Scenario 2 | MWA responsible area (BKK, NTB, SPK)<br>= MWA wells stepwise phased out by 2007 from 1993.<br>Decrease private pumpage by MWA Master Plan.<br>Pathum Thani<br>= PWA wells phased out by 2001 from 1997.<br>Supply surface water by PWA's plan.<br>IEAT wells<br>= Each industrial estate's plan.<br>SSK, AYT, and NPT<br>= Same as Scenario 1. |
| Scenario 3 | Present Critical Zones 1&2 (in BKK and SPK)<br>= Regulate all types of pumpage (except MWA) from 1998 at 1997's amount.<br>MWA wells<br>= Same as Scenario 1.<br>Outside of Present Critical Zones 1&2<br>= Same as Scenario 1. |
| Scenario 4 | Present Critical Zones 1&2 (in BKK and SPK)<br>= Regulate all types of pumpage (except MWA) from 1998 to 2001 at 1997's amount.<br>Stepwise reduction from 2002, 50% in 2007, 35% in 2012.<br>Maintain 35% of 1997's pumpage from 2013 to 2017.<br>Present Critical Zone 3 (BKK, NTB, and SPK)<br>= Regulate all types of pumpage (except MWA) from 2001 at 2000's amount.<br>MWA wells<br>= Same as Scenario 1.<br>Outside of Present Critical Zones<br>= Same as Scenario 1. |
| Scenario 5A | New Critical Zone (in BKK, NTB, PTM, SPK, and SSK)<br>= By 2000: Same as Scenario 1<br>From 2001 to 2017: Regulate all types of pumpage (except MWA) at 2000's amount.<br>MWA wells<br>= Same as Scenario 1.<br>Outside of New Critical Zone<br>= Same as Scenario 1. |
| Scenario 5B | New Critical Zone (in BKK, NTB, PTM, SPK, and SSK)<br>= By 2000: Same as Scenario 1<br>From 2001 to 2010: Reduce all types of pumpage (except MWA) from 100% to 50 % of 2000's amount.<br>From 2011 to 2017: Maintain 50% of 2000's amount.<br>MWA wells<br>= Same as Scenario 1.<br>Outside of New Critical Zone<br>= Same as Scenario 1. |
| Scenario 5C | New Critical Zone (in BKK, NTB, PTM, SPK, and SSK)<br>= By 2000: Same as Scenario 1<br>From 2001 to 2010: Reduce all types of pumpage (except MWA) from 100% to 50 % of 2000's amount.<br>From 2011 to 2017: Maintain 75% of 2000's amount.<br>MWA wells<br>= Same as Scenario 1.<br>Outside of New Critical Zone<br>= Same as Scenario 1. |
| Scenario 6 | New Critical Zone (in BKK, NTB, PTM, SPK, and SSK)<br>= From 1993 to 1994: Same as Scenario 1.<br>From 1995 to 2000: Reduce pumpage increasing rate at 50% of Scenario 1.<br>From 2001 to 2010: Reduce all types of pumpage (except MWA) from 100% to 75% of 2000's amount.<br>From 2011 to 2017: Maintain 75% of 2000's amount.<br>MWA wells<br>= Same as Scenario 1.<br>Outside of New Critical Zone<br>= Same as Scenario 1. |
| Scenario 7 | New Critical Zone (in BKK, NTB, PTM, SPK, and SSK)<br>= From 1993 to 1994: Same as Scenario 1.<br>From 1995 to 2000: Regulate all types of pumpage (except MWA) at 1994's amount.<br>From 2001 to 2010: Reduce all types of pumpage (except MWA) from 100% to 75% of 2000's amount.<br>From 2011 to 2017: Maintain 75% of 2000's amount.<br>MWA wells<br>= Same as Scenario 1.<br>Outside of New Critical Zone<br>= Same as Scenario 1. |




| Figure 7.2.1 | GRID FOR 3-D MODFLOW MODEL |
|---|---|
| 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. |




## AQUIFER UNITS

UC: Unconfined (constant head)
BC: Bangkok Soft Clay
BK: Bangkok Aquifer
PD: Phra Pradaeng Aquifer
NL: Nakhon Luang Aquifer
NB: Nonthaburi Aquifer
SK: Sam Khok Aquifer
PT: Phayathai Aquifer
TB: Thonburi Aquifer
PN: Pak Nam Aquifer

| Figure 7.2.2 | STRUCTURE OF 3-D MODEL |
|---|---|
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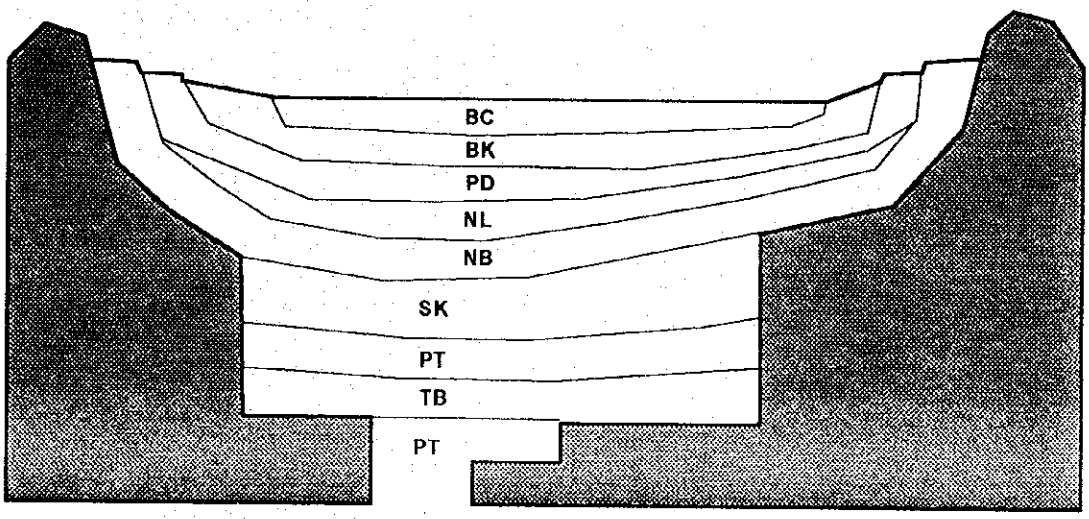
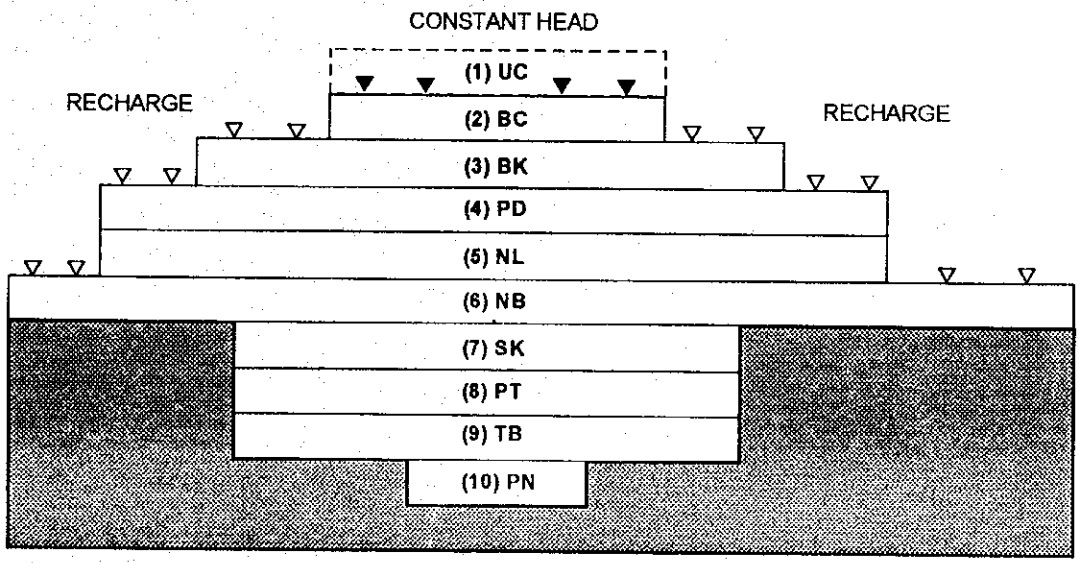



(a) Schematic Profile of Bangkok Aquifer System




(b) 3-D Groundwater Model Applied to Bangkok Aquifer System

| Figure 7.2.3 | CONCEPT OF 3-D MODEL APPLIED TO BANGKOK AQUIFER SYSTEM |
|---|---|
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY | |
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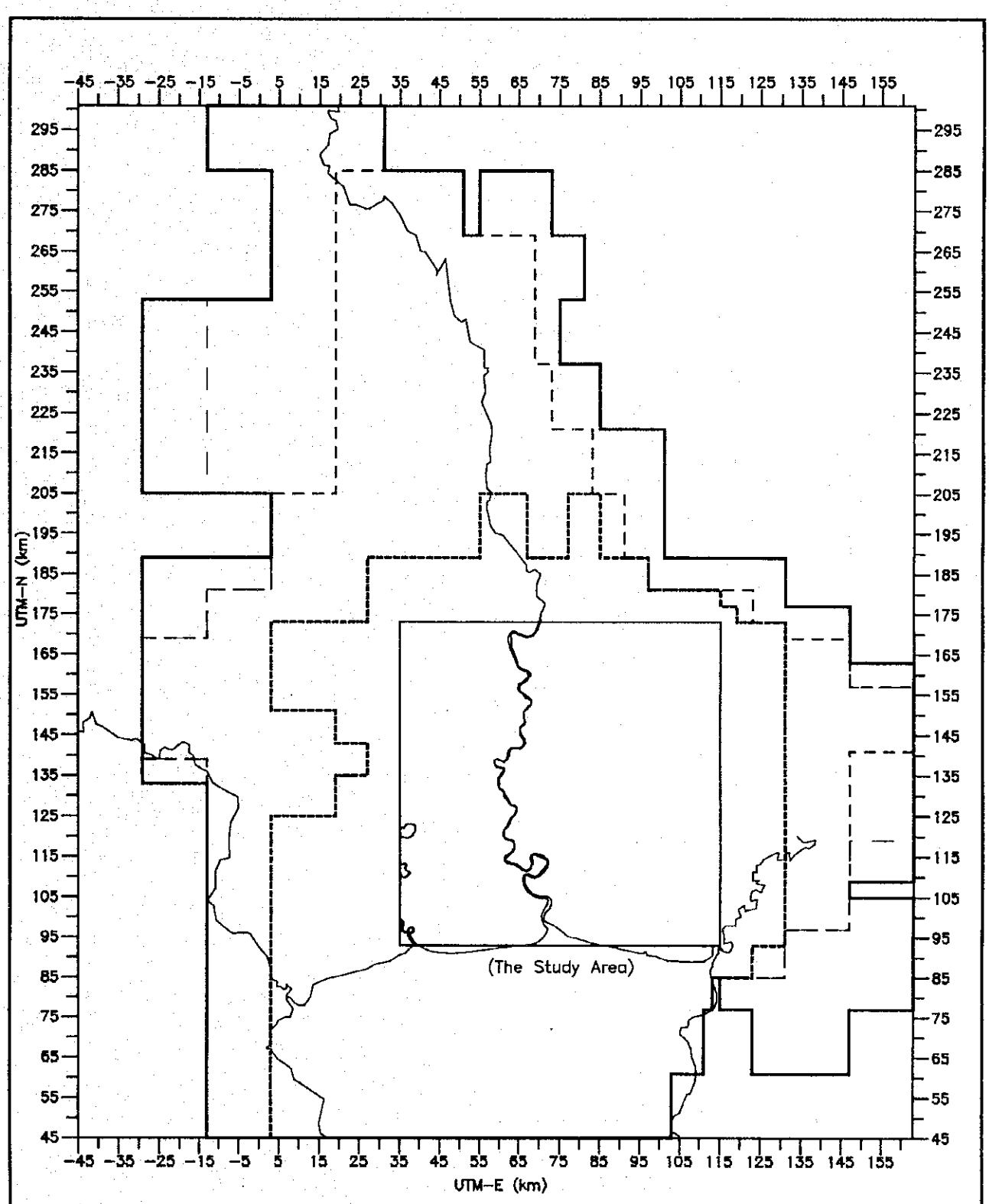


| Figure 7.2.4 | BOUNDARIES OF AQUIFER UNITS (BC TO NB) FOR MODFLOW 3-D MODEL |
|---|---|
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY | |
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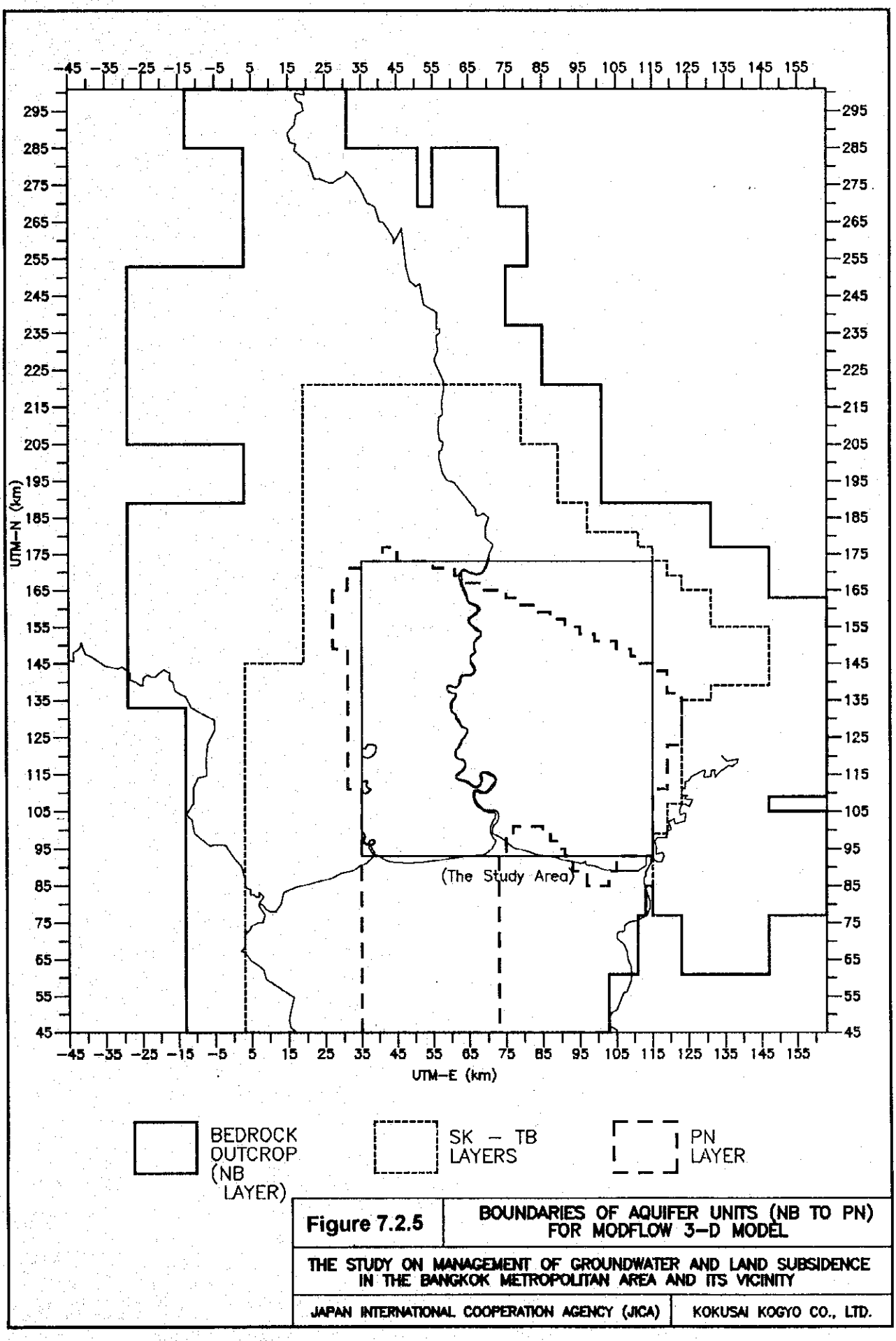


| | |
|---|---|
| **Figure 7.2.5** | BOUNDARIES OF AQUIFER UNITS (NB TO PN) FOR MODFLOW 3-D MODEL |
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY | |
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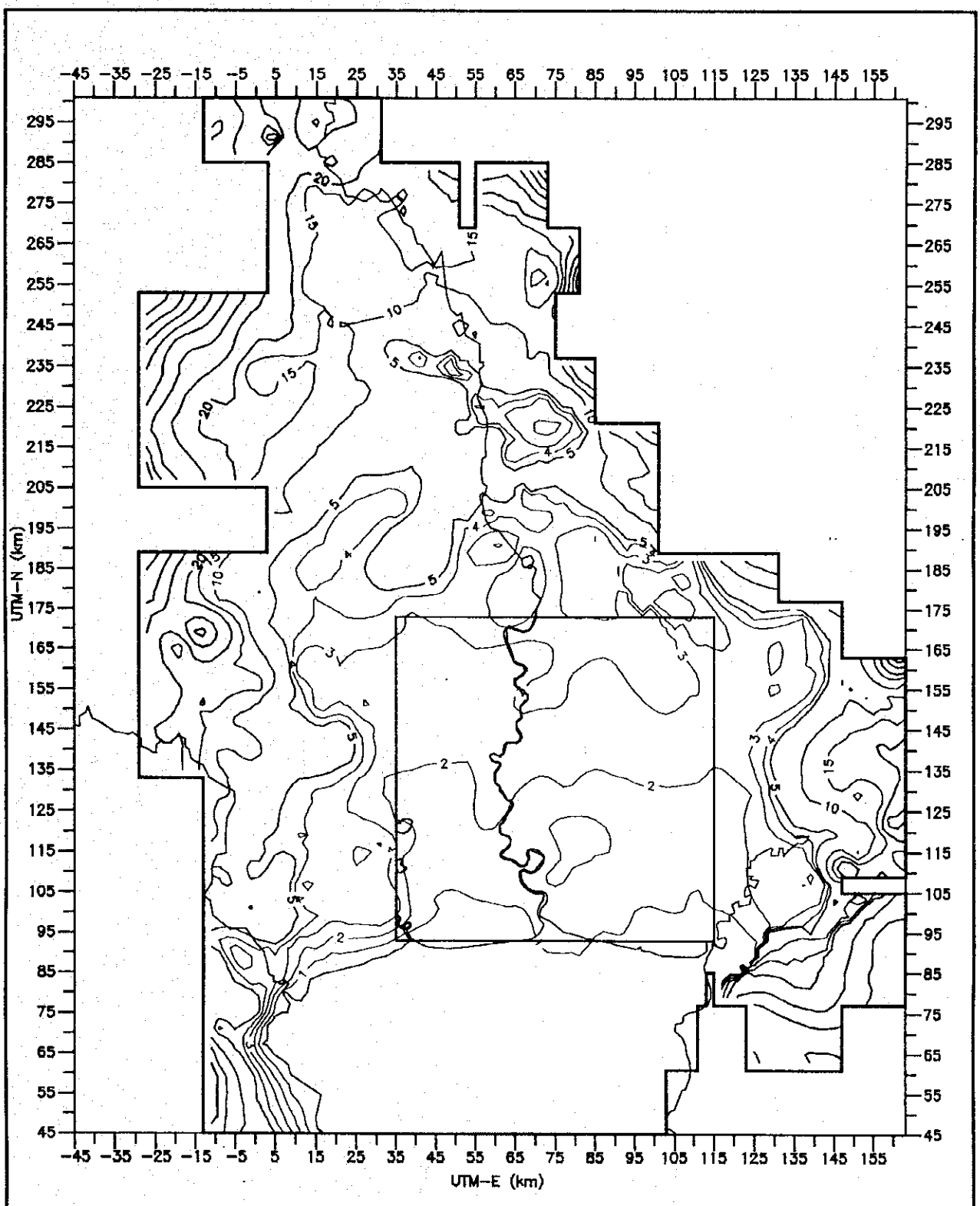


(Unit: m above sea level)

| Figure 7.2.6 | ELEVATION OF GROUND SURFACE |
|---|---|
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY | |
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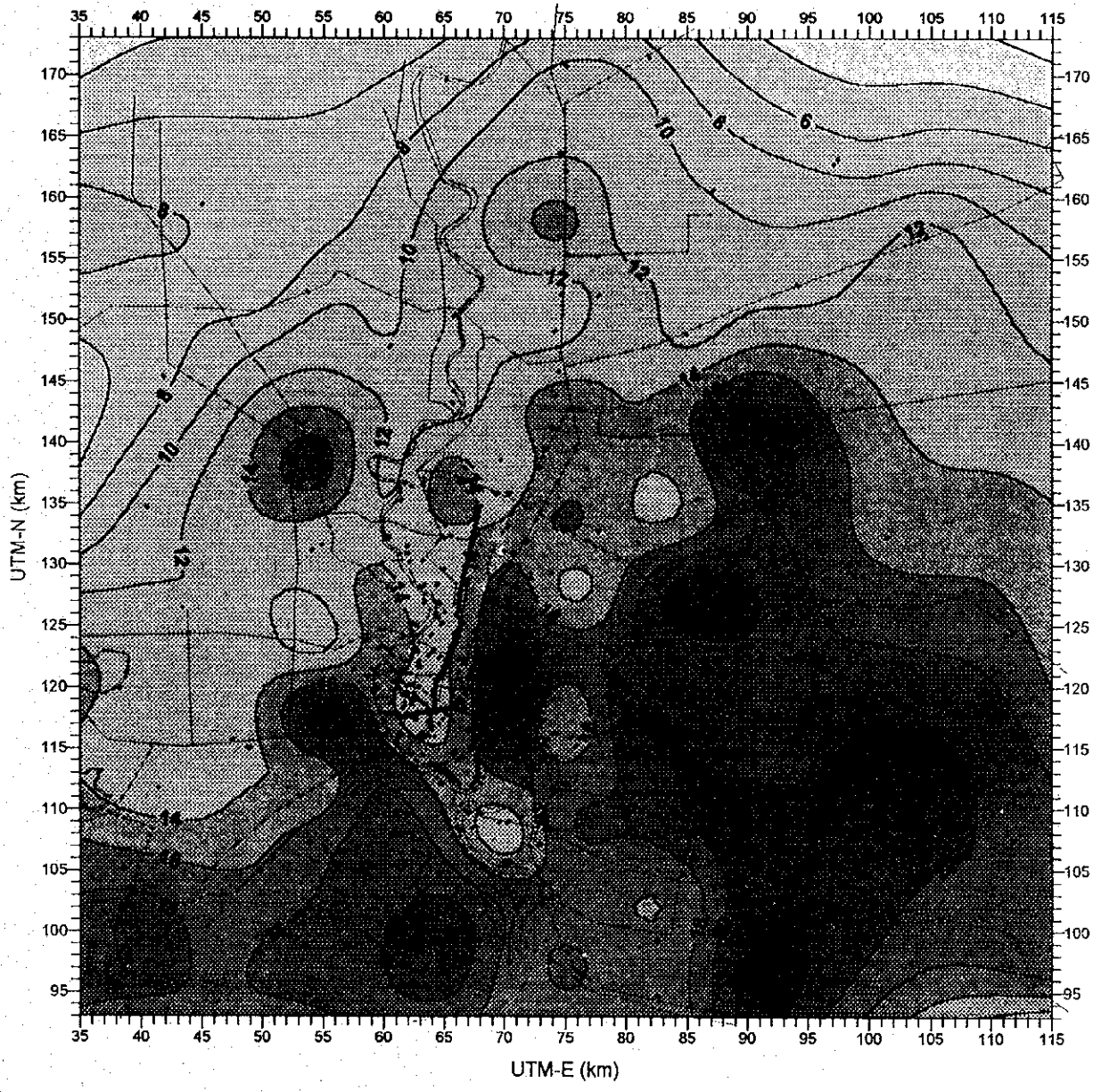


**LEGEND**

Isopach of Bangkok Soft Clay (m)

10 12 14 16 18 20 22

Location of borehole/well used to compile the map

| Figure 7.2.7 | ISOPACH MAP OF BANGKOK SOFT CLAY |
|---|---|
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY | |
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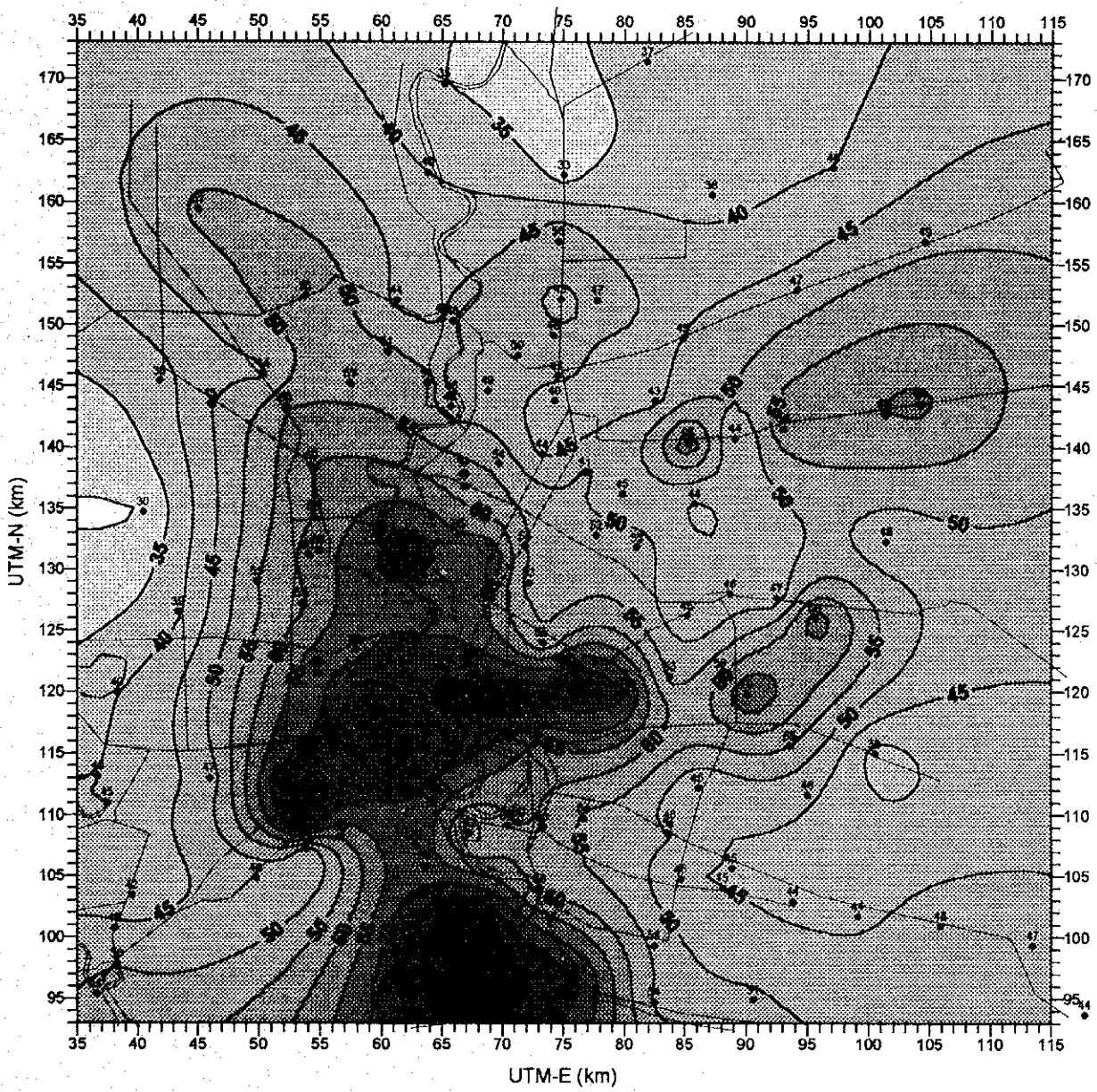


**LEGEND**

Depth to Aquifer Bottom (m below ground surface)

25 30 35 40 45 50 55 60 65 70 75 80 85 90

55 Well location used to compile the map with depth to aquifer bottom (m below ground surface)

| Figure 7.2.8 | DEPTH TO THE BOTTOM OF BK AQUIFER |
|---|---|
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY | |
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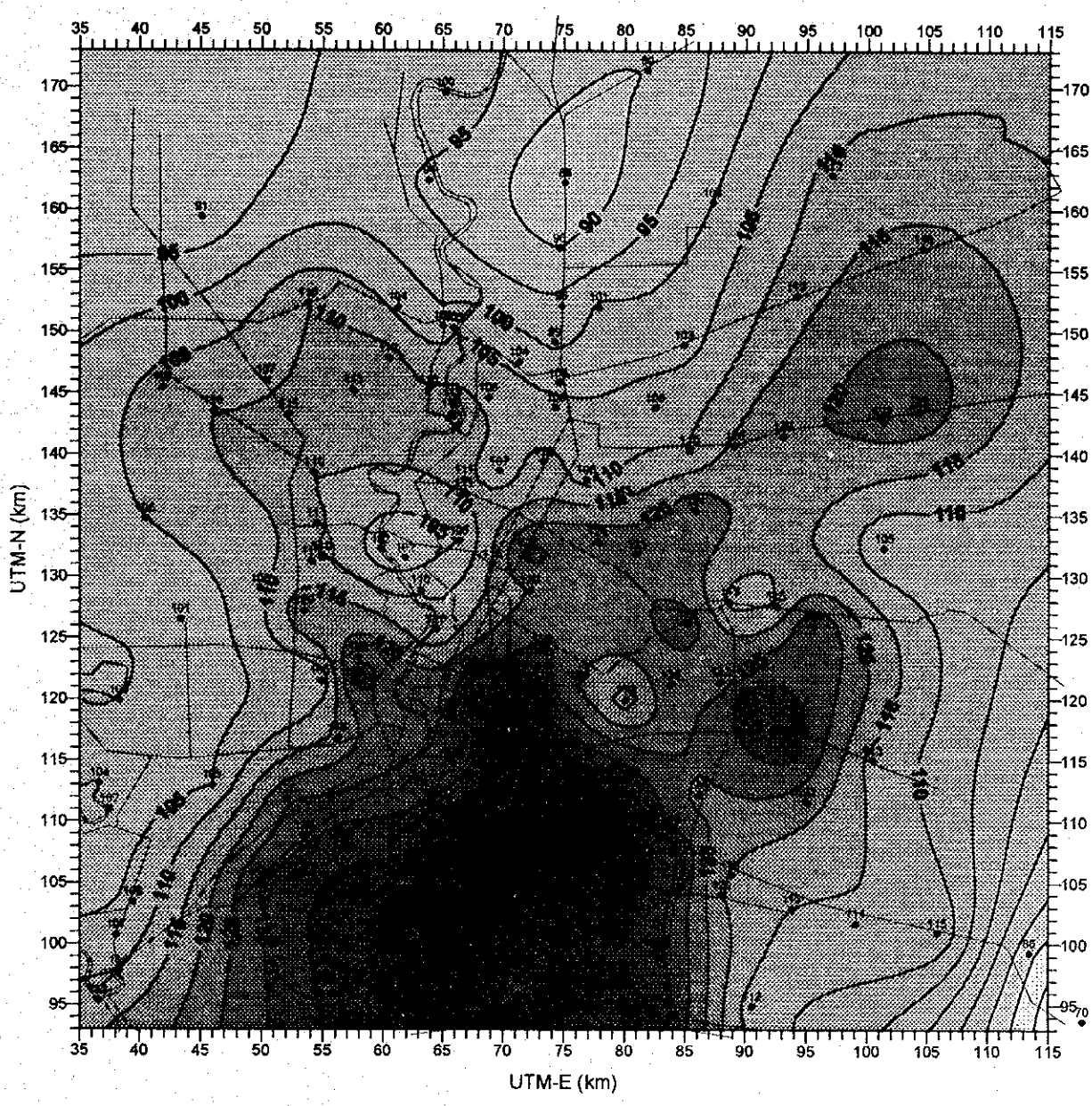


**LEGEND**

Depth to Aquifer Bottom (m below ground surface)

75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150

115 Well location used to compile the map with depth to aquifer bottom (m below ground surface)

| Figure 7.2.9 | DEPTH TO THE BOTTOM OF PD AQUIFER |
|---|---|
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY | |
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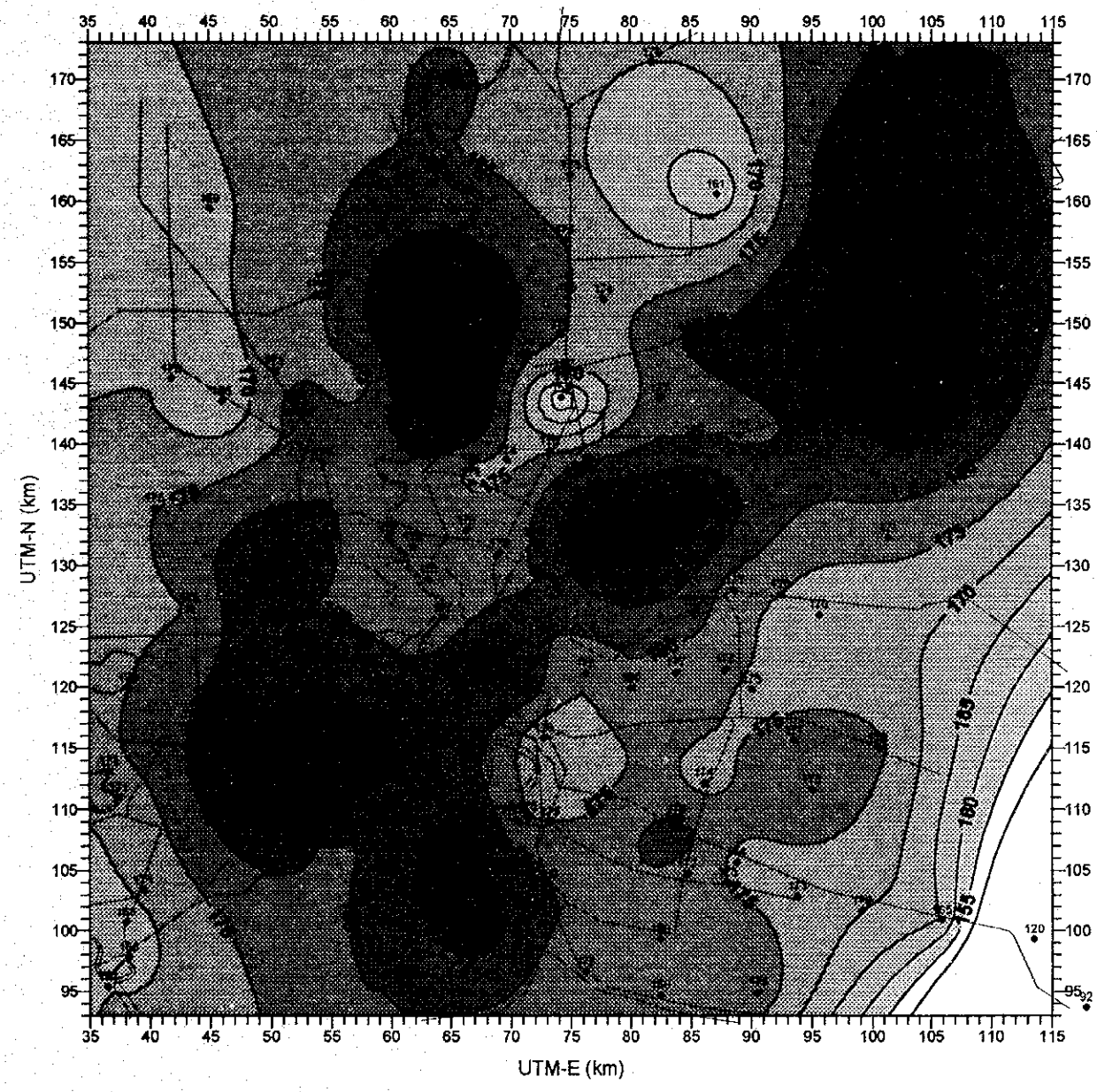


**LEGEND**

Depth to Aquifer Bottom (m below ground surface)

150 155 160 165 170 175 180 185 190

175 Well location used to compile the map with depth to aquifer bottom (m below ground surface)

| Figure 7.2.10 | DEPTH TO THE BOTTOM OF NL AQUIFER |
|---|---|
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY | |
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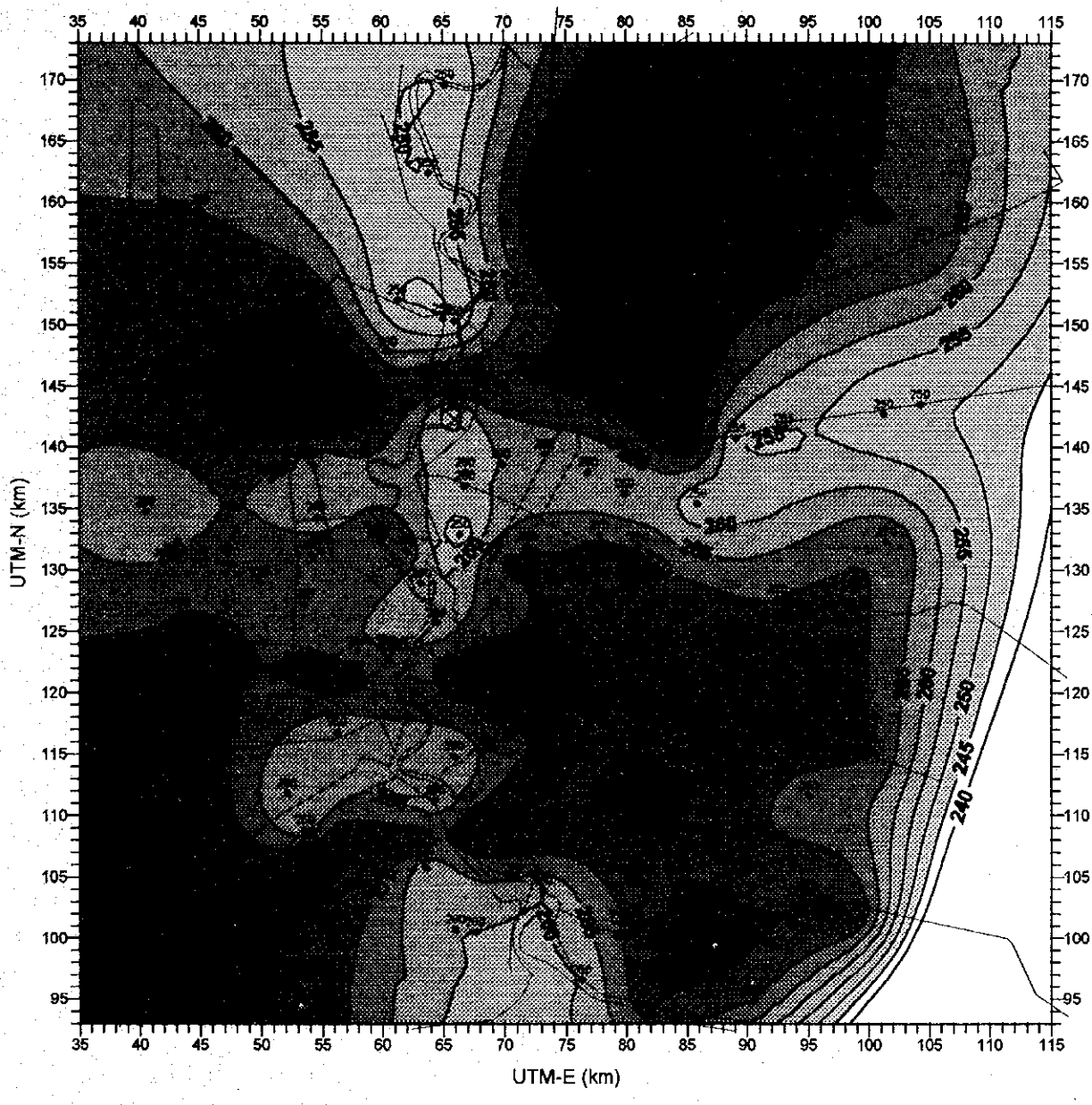


**LEGEND**

Depth to Aquifer Bottom (m below ground surface)

240 245 250 255 260 265 270 275 280

265 • Well location used to compile the map with depth to aquifer bottom (m below ground surface)

| Figure 7.2.11 | DEPTH TO THE BOTTOM OF NB AQUIFER |
|---|---|
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY | |
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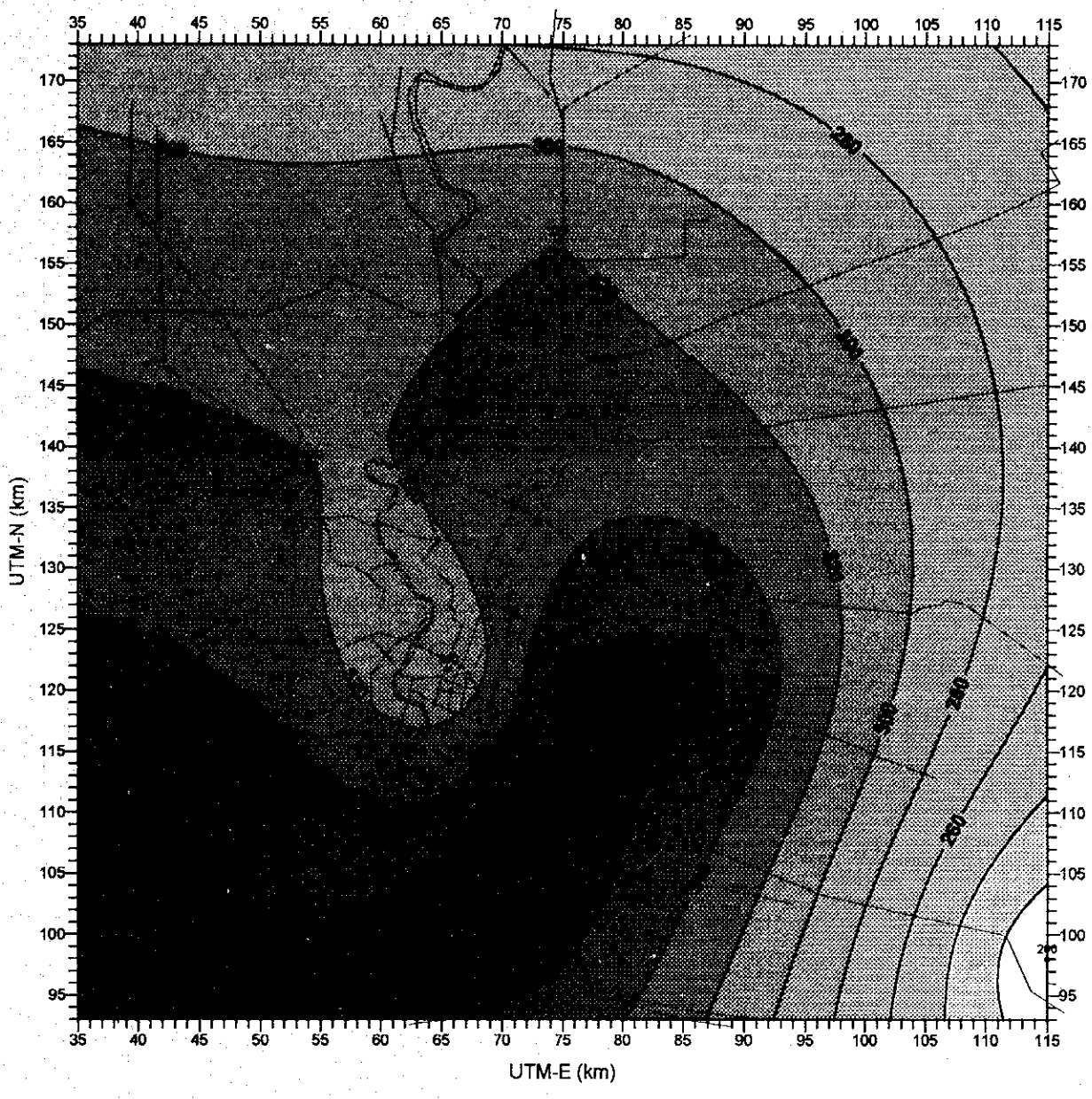


**LEGEND**

Depth to Aquifer Bottom (m below ground surface)

200 220 240 260 280 300 320 340 360 380

325 Well location used to compile the map with depth to aquifer bottom (m below ground surface)

| Figure 7.2.12 | DEPTH TO THE BOTTOM OF SK AQUIFER |
|---|---|
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY | |
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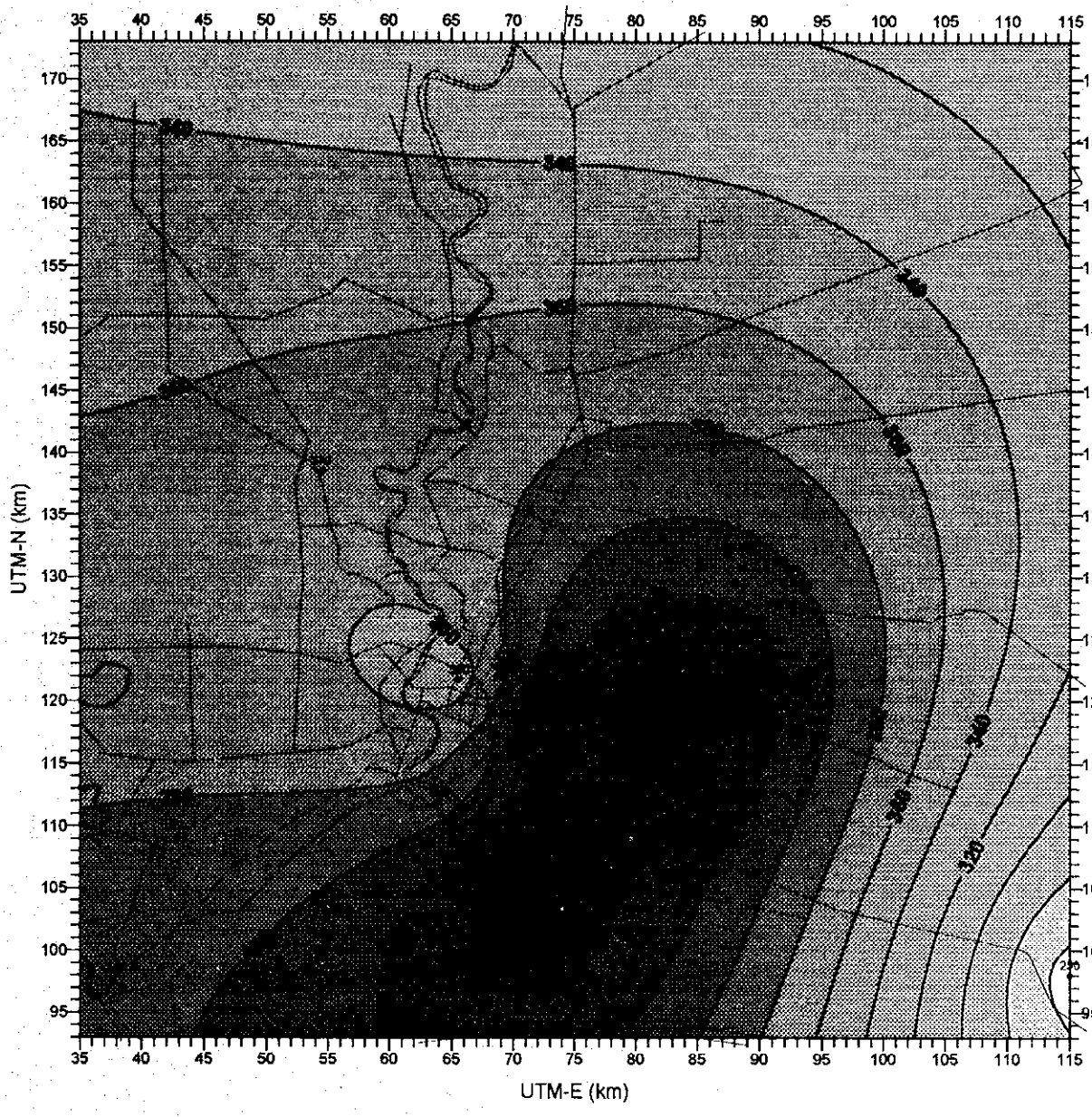


**LEGEND**

Depth to Aquifer Bottom (m below ground surface)

240 260 280 300 320 340 360 380 400 420 440 460

365 Well location used to compile the map with depth to aquifer bottom (m below ground surface)

| Figure 7.2.13 | DEPTH TO THE BOTTOM OF PT AQUIFER |
|---|---|
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY | |
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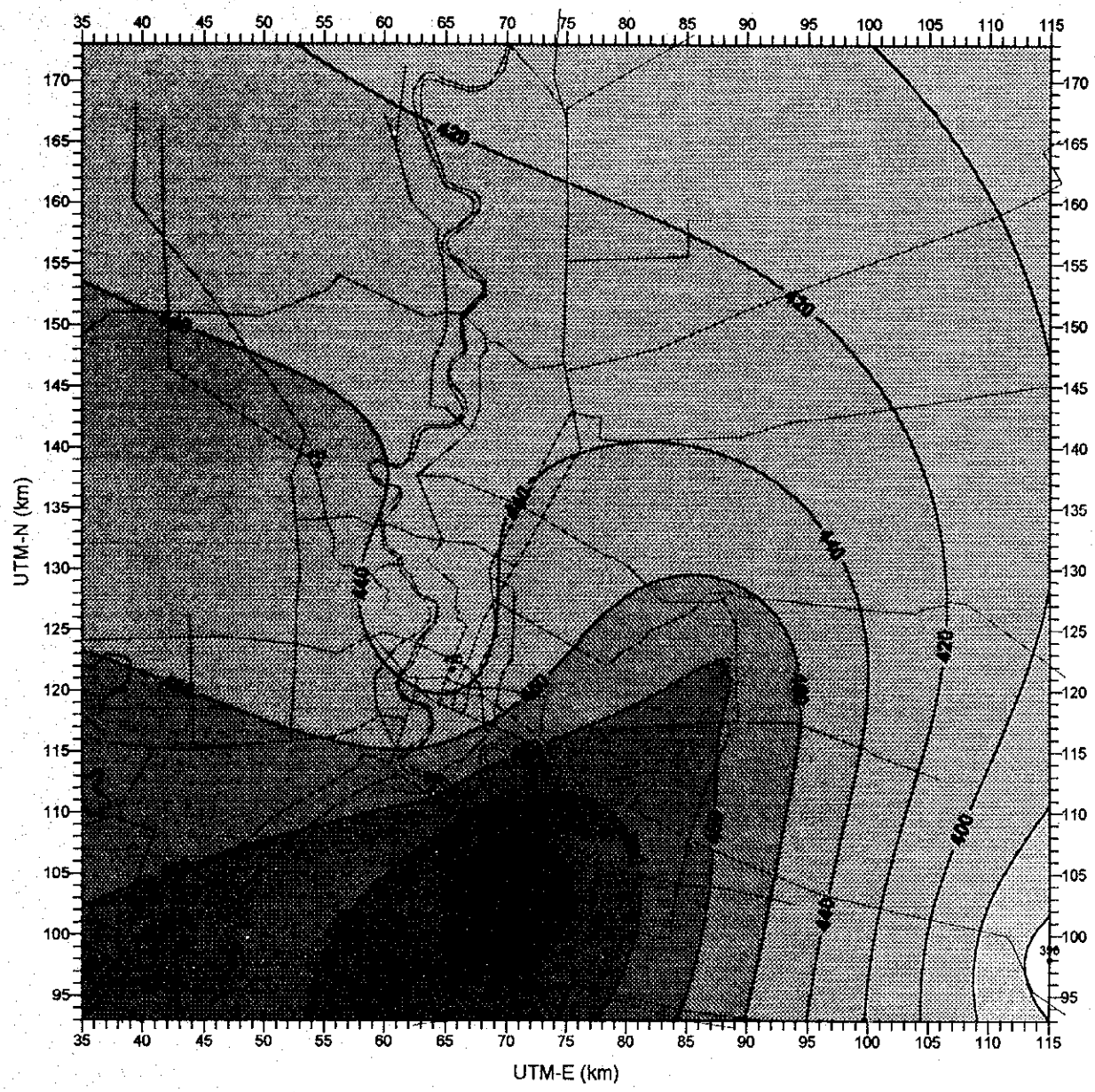


**LEGEND**

Depth to Aquifer Bottom (m below ground surface)

340 360 380 400 420 440 460 480 500 520 540

415 ◆ Well location used to compile the map with depth to aquifer bottom (m below ground surface)

| Figure 7.2.14 | DEPTH TO THE BOTTOM OF TB AQUIFER |
|---|---|
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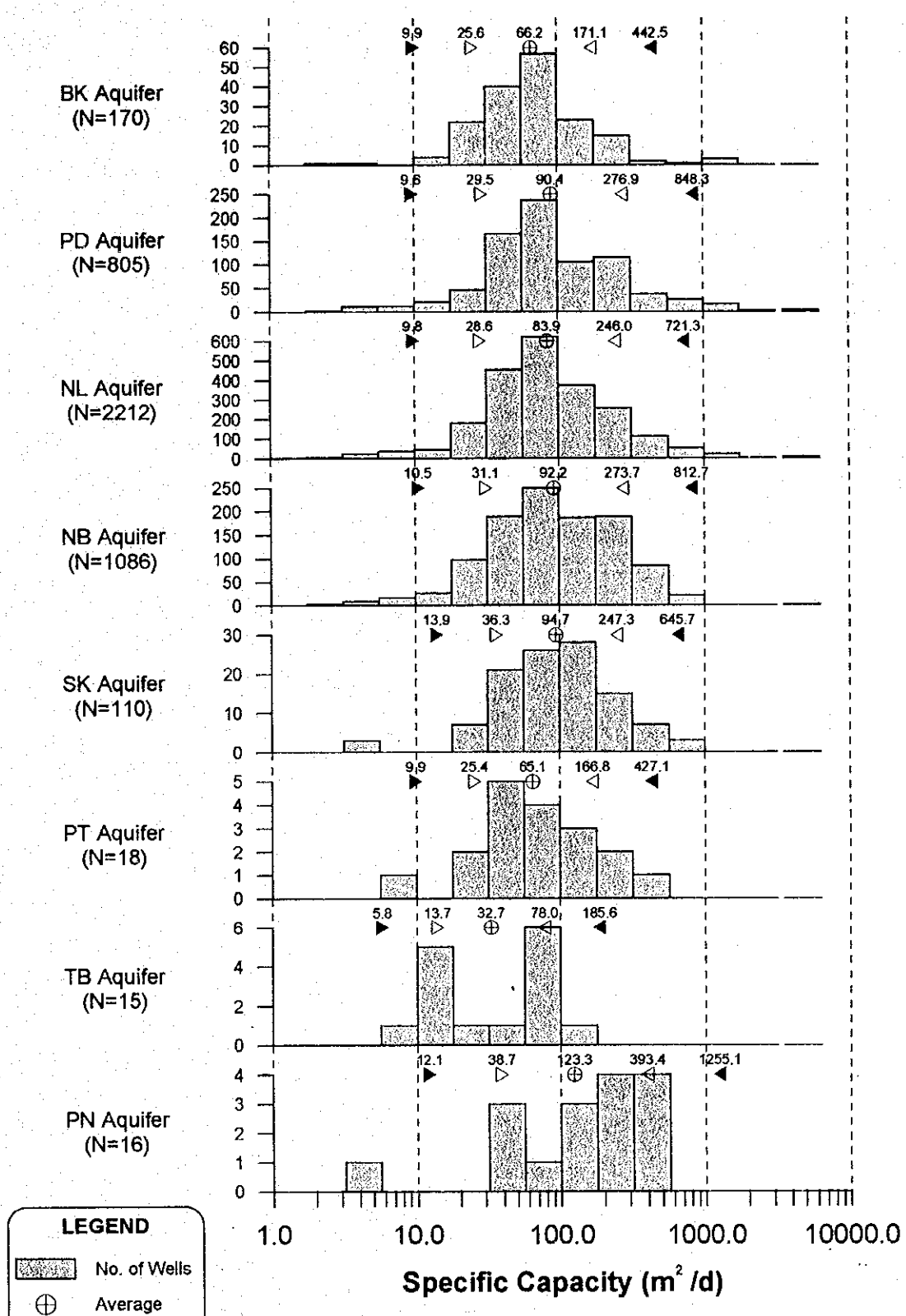


**Figure 7.2.15** DISTRIBUTION OF SPECIFIC CAPACITY VALUES OBTAINED FROM PRODUCTION WELLS DATA

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

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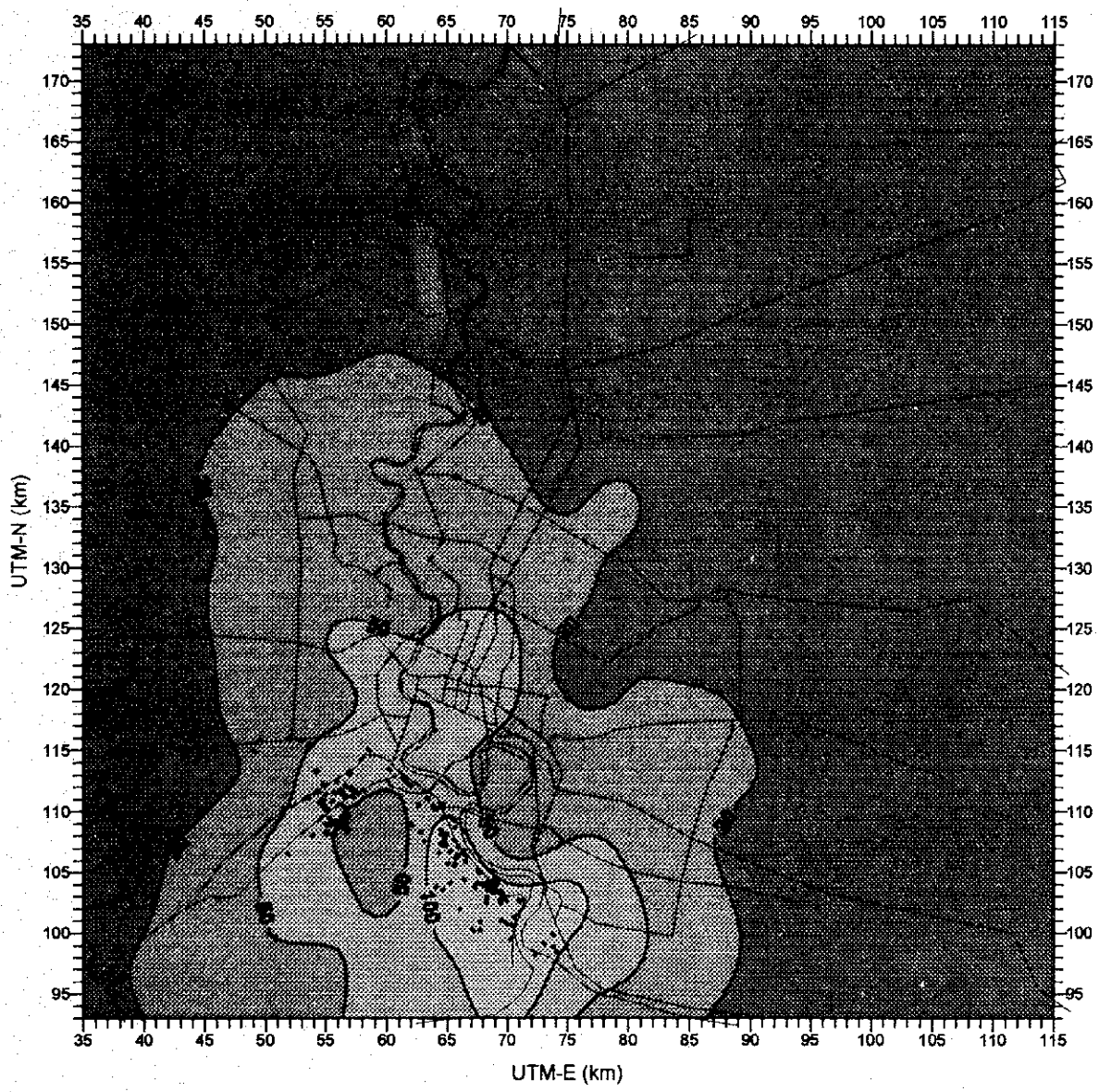


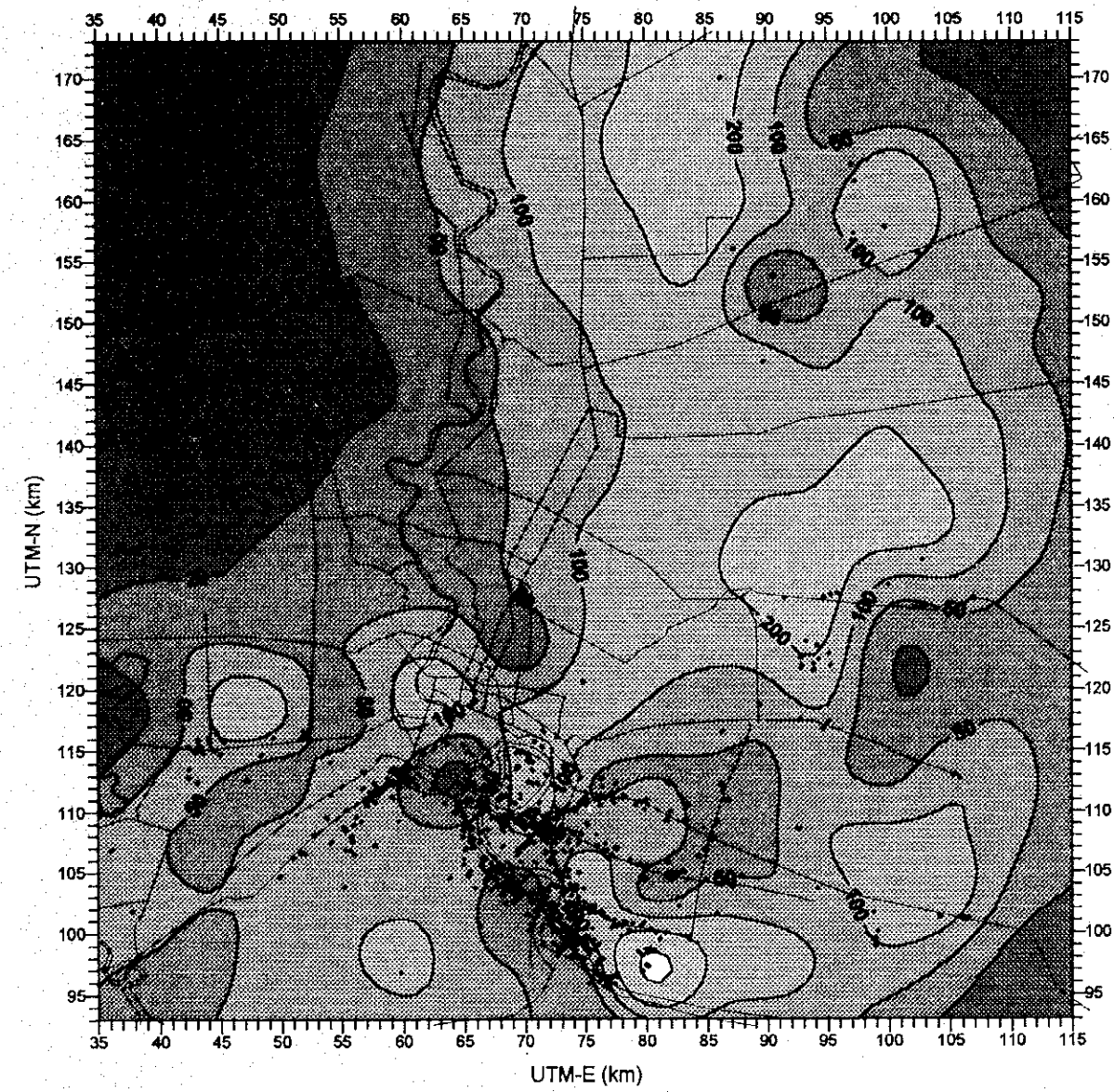

**LEGEND**

Specific capacity ($m^2$ /d)

20 50 100 200 500

• Location of production well having specific capacity value

| Figure 7.2.16 | DISTRIBUTION OF SPECIFIC CAPACITY IN BK 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**

Specific capacity ($m^2$ /d)

20 50 100 200 500

• Location of production well having specific capacity value

| Figure 7.2.17 | DISTRIBUTION OF SPECIFIC CAPACITY IN PD AQUIFER |
|---|---|
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY | |
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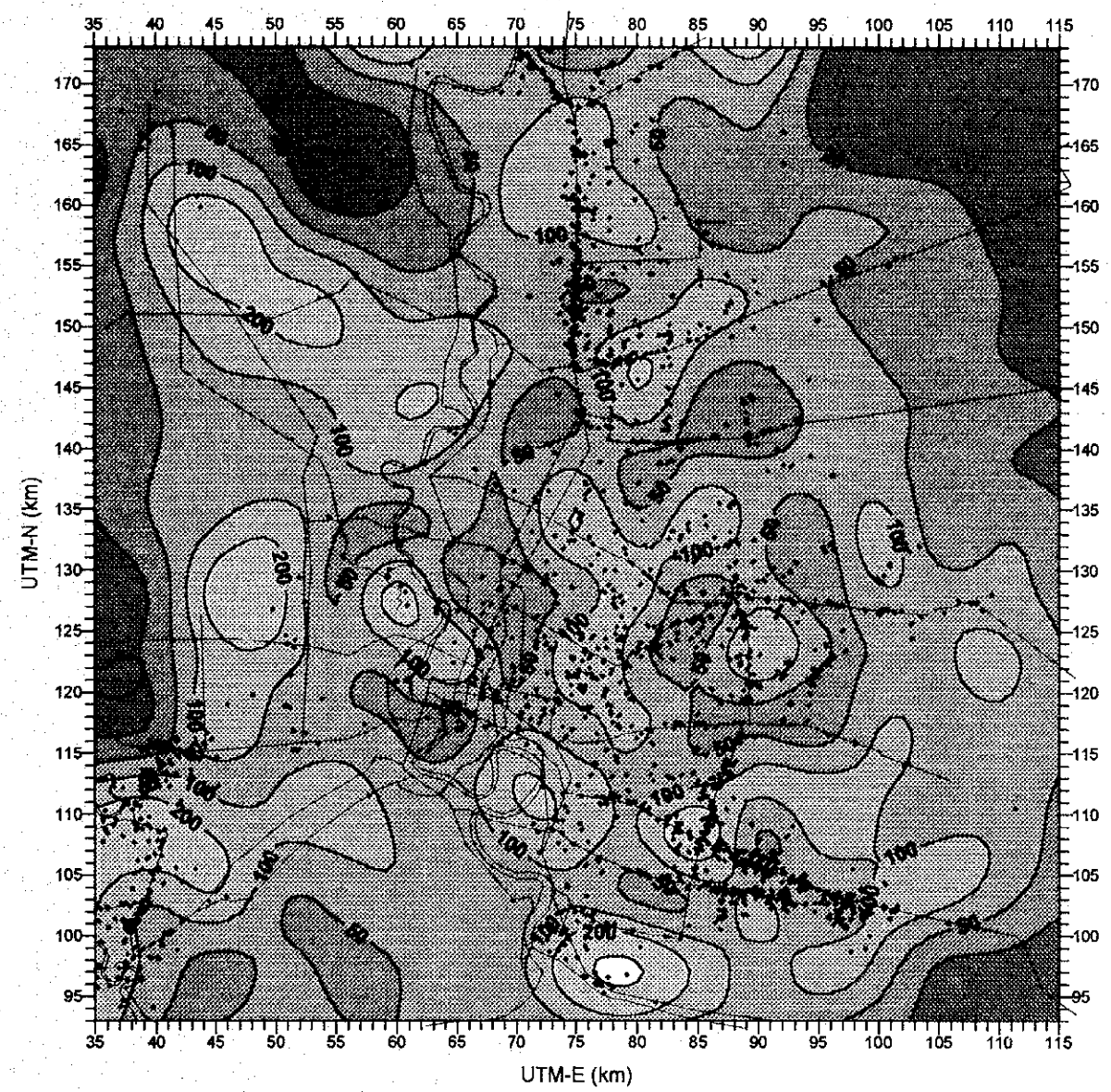


**LEGEND**

Specific capacity ($m^2$ /d)

20 50 100 200 500

• Location of production well having specific capacity value

| Figure 7.2.18 | DISTRIBUTION OF SPECIFIC CAPACITY IN NL AQUIFER |
|---|---|
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY | |
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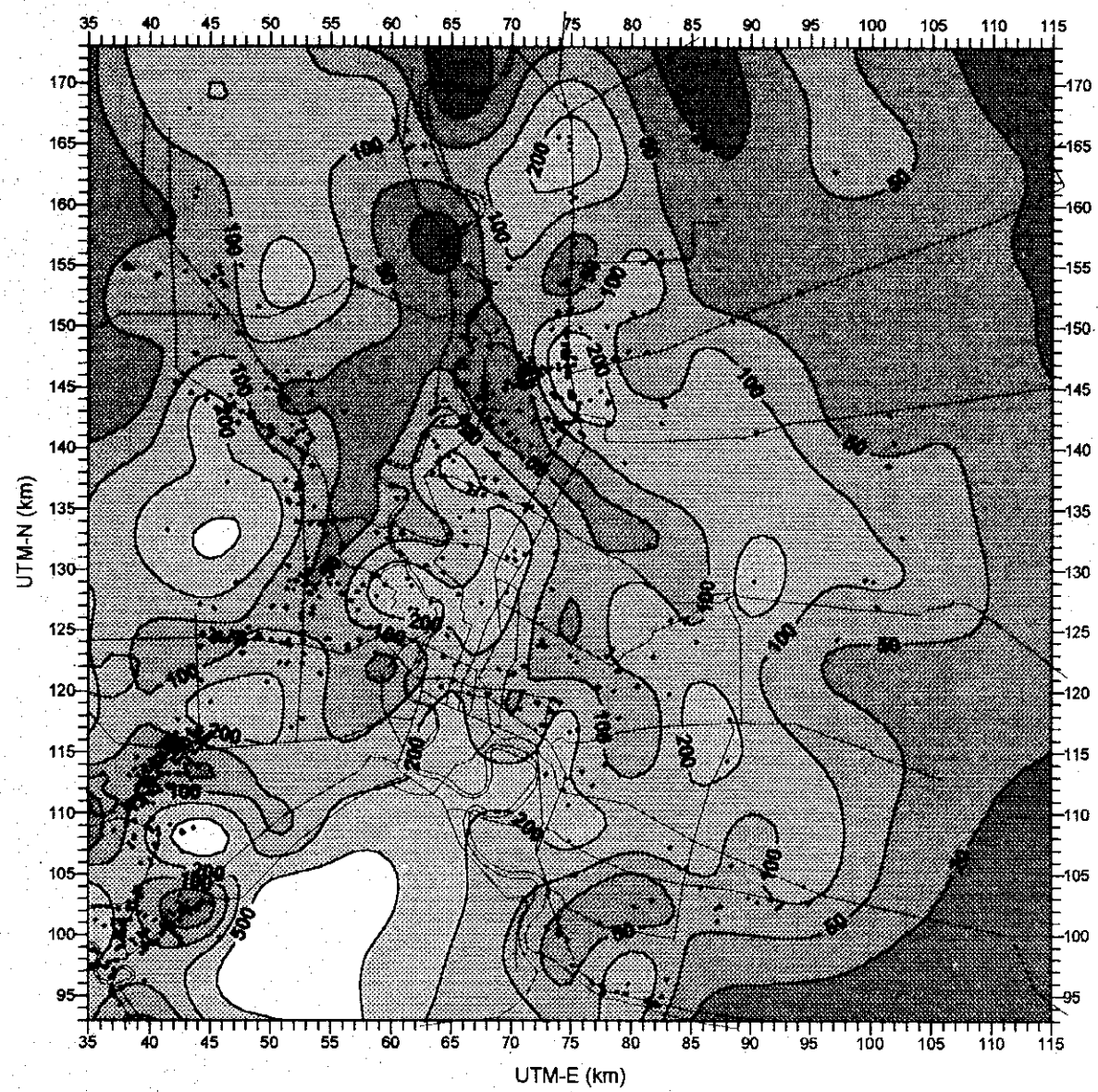


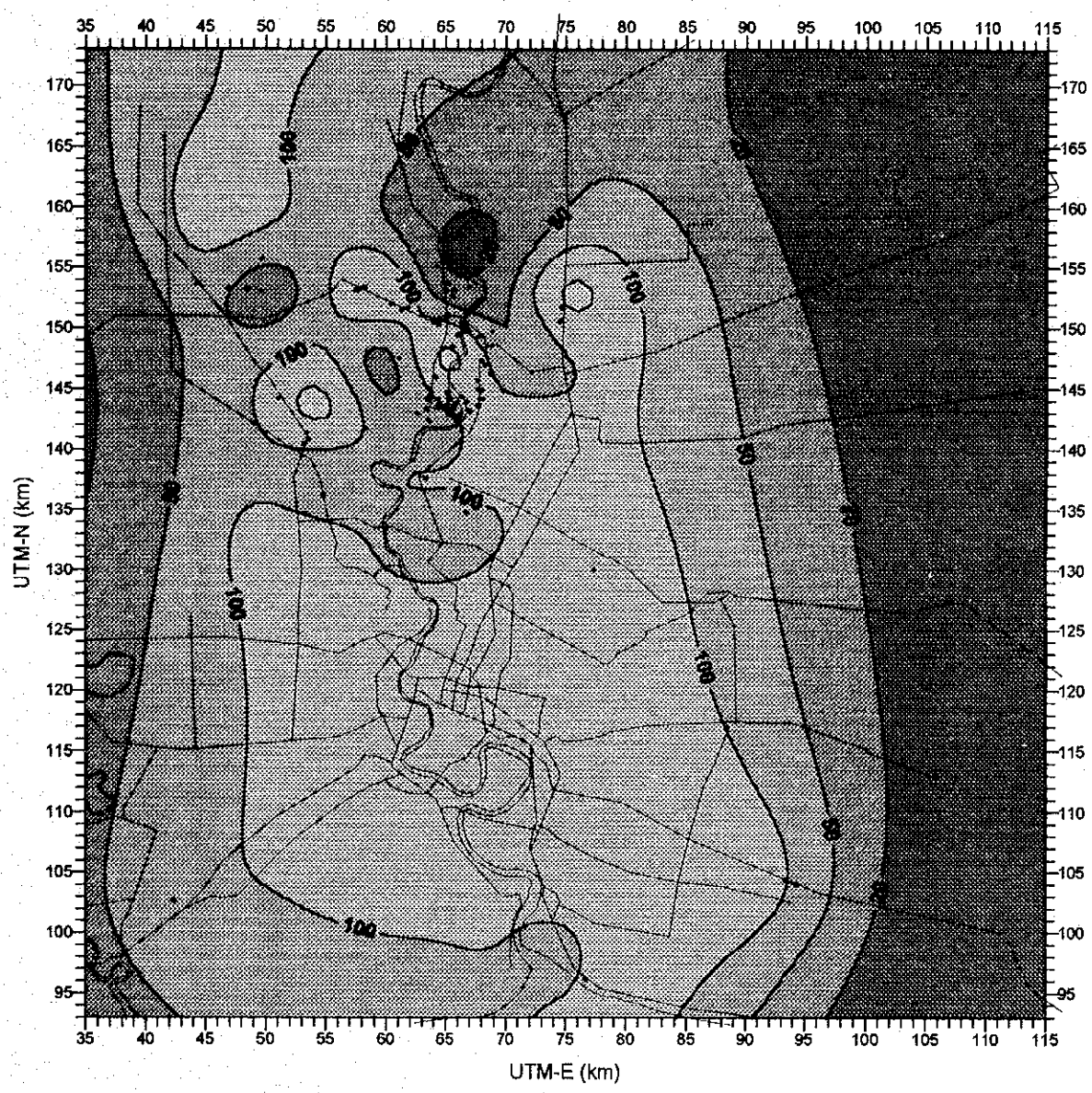

**LEGEND**

Specific capacity ($m^2$/d)

20 50 100 200 500

• Location of production well having specific capacity value

| Figure 7.2.19 | DISTRIBUTION OF SPECIFIC CAPACITY IN 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. |



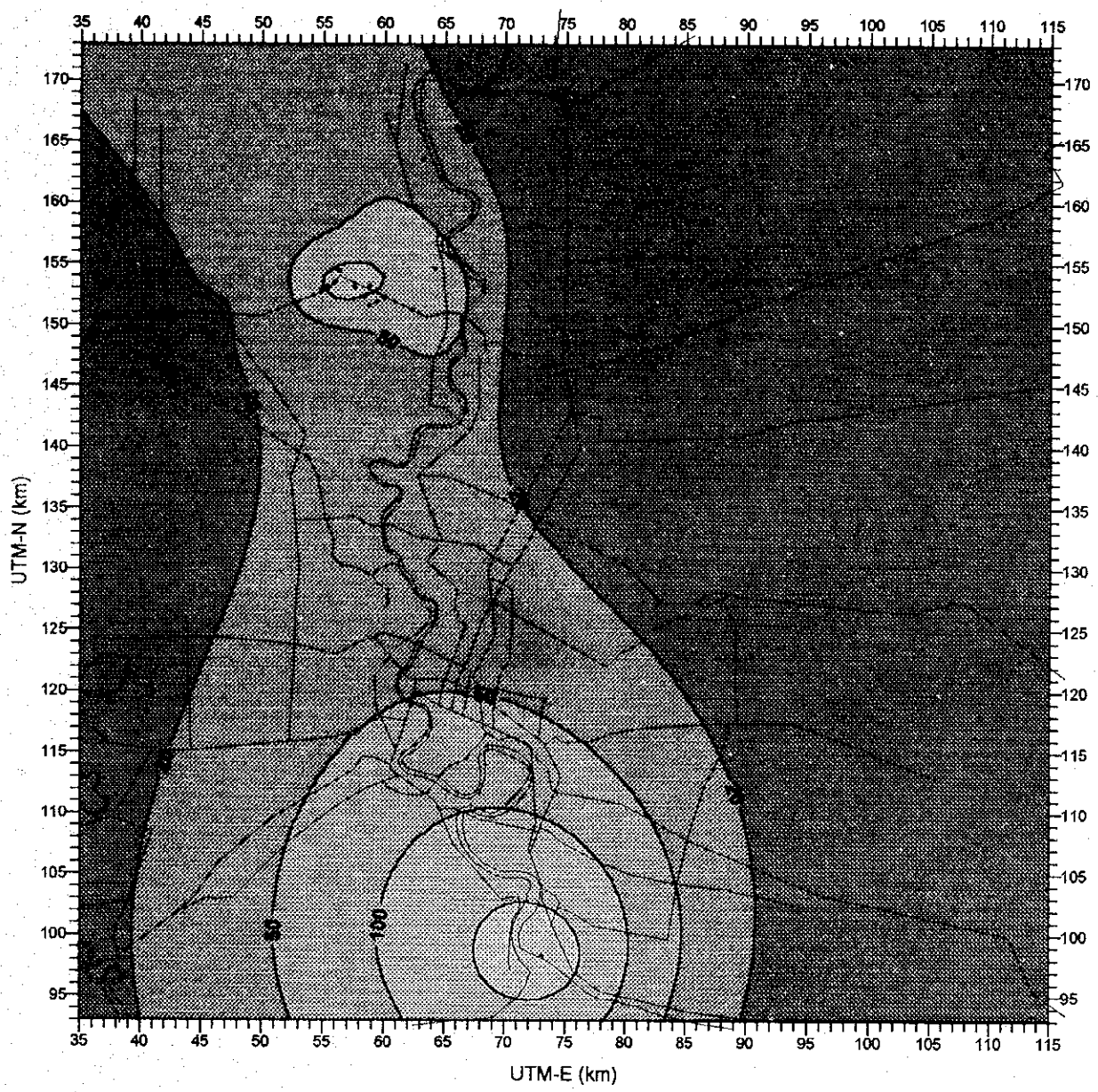

**LEGEND**

Specific capacity ($m^2$ /d)

20 50 100 200 500

• Location of production well having specific capacity value

| Figure 7.2.20 | DISTRIBUTION OF SPECIFIC CAPACITY IN SK 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**

Specific capacity ($m^2$ /d)

20 50 100 200 500

• Location of production well having specific capacity value

| Figure 7.2.21 | DISTRIBUTION OF SPECIFIC CAPACITY IN PT AQUIFER |
|---|---|
| THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY | |
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