CHAPTER 7

GROUNDWATER MODELING IN HA NOI AREA

CHAPTER 7 GROUNDWATER MODELING IN HANOI AREA

7.1 Framework and Parameters

7.1.1 Purpose

In Hanoi Area, the groundwater resource has been extensively exploited in a past decade for supplying water for domestic use and industrial use. It is known that the groundwater levels have been declined not only in the well sites but also in the wide area of Hanoi City. Subsequently, it has been reported that shallow wells were dried up and a significant amount of land subsidence has occurred in many parts of the city.

The two (2) target communes of the Study, namely Dong Ngac and Xuan Dinh, are located closed to the urbanized area of Hanoi City. There are several production wells in the communes for both public and private use. Particularly, the well fields of the Hanoi Water Supply System are located near the communes, and it is planned to construct new well fields in and around the communes. Figure 7.1.1 shows locations of the major groundwater well fields and their pumping rate in Hanoi Area. According to the data collected by JICA (1997), a total groundwater pumpage in the major 8 well fields is 365,800 m^3/day in 1995. The Ngoc Ha well field, which is located about 2 km south of Xuan Dinh Commune, has 11 production wells and the total pumpage is 50,300 m^3/day in 1995. The Mai Dich well field, which is located about 3 km southwest of Xuan Dinh Commune, has 18 production wells with a total pumpage of 64,200 m^3/day in 1995.

Therefore, the Study Team decided to carry out a groundwater modeling study to evaluate present groundwater flow conditions in Hanoi, and to find an optimal and sustainable groundwater development plan for the target communes.

7.1.2 Model Structure

Groundwater flow in a groundwater basin is by nature three-dimensional. The MODFLOW program, which was developed by the U.S. Geological Survey (McDonald and Harbaugh, 1988), uses the following partial-differential equation to describe the three-dimensional movement of groundwater of constant density through porous earth material:

$$\frac{\partial}{\partial x}\left(Kxx\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(Kyy\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(Kzz\frac{\partial h}{\partial z}\right)-W=Ss\frac{\partial h}{\partial t} \qquad (7.1.1)$$

where

Kxx, *Kyy*, and *Kzz* are values of hydraulic conductivity along the *x*, *y*, and *z* coordinate axis, which are assumed to be parallel to the major axes of hydraulic conductivity (LT^{-1});

h is the potentiometric head (L);

W is a volumetric flux per unit volume and represents sources and/or sinks of water (T^{-1});

Ss is the specific storage of the porous material (L^{-1}); and

t is time (T).

In general, *Ss*, *Kxx*, *Kyy*, and *Kzz* may be functions of space (*Ss*5*Ss* (*x*,*y*,*z*), *Kxx*5*Kxx* (*x*,*y*,*z*), etc.) and *W* may be a function of space and time (*W*5*W*(*x*,*y*,*z*,*t*)); equation (7.1.1) describes groundwater flow under nonequilibrium conditions in a heterogeneous and anisotropic medium, provided the principal axes of hydraulic conductivity are aligned with the coordinate directions.

Considering the hydrogeological settings of Hanoi area, the structure of 3-D simulation model was determined. Figure 7.7.2 shows the model grid for the simulation. It is decided that the model has four (4) layers, and each model grid has 500 m3500 m in size. The modeled domain has 20 km in E-W direction and 20 km in N-S direction. Therefore, the total number of cell is (40 rows)3(40 columns)3(4 layers)56,400 cells.

The aquifer type of each model layer is assigned as follows:

Layer-1: (First aquitard):	Confined/Unconfined
Layer-2: (First Aquifer):	Confined/Unconfined
Layer-3: (Second Aquitard):	Confined
Layer-4: (Second Aquifer):	Confined

7.1.3 Boundary Conditions

Based on the hydrogeological settings of Hanoi area, constant-head boundaries are assigned at the Red River, Duong River, and West Lake as shown in Figure 7.1.3. The constant-head boundaries are set only in Layer-1. Water levels at the constant-head boundaries are given from the data of the surface water observation points. The perimeters of the modeled domain are treated as no-flow boundaries.

7.1.4 Input Parameters

The necessary parameters for the MODFLOW program were prepared based on the hydrogeological settings. Followings are the initially input data to the model:

(1) Top and bottom elevations of each layer

Top and bottom elevations of each layer were prepared from the existing lithologic data. The top elevation of Layer-1 is the elevation of ground surface, so that the nodal values of ground elevation were interpolated from the USGS digital elevation data.

Layer-1: Top: 8.1 to 30.2 masl
Bottom: 21.5 to217.3 masl
Layer-2: Top: 21.5 to217.3 masl
Bottom: 27.8 to233.9 masl
Layer-3: Top: 27.8 to233.9 masl
Bottom: 221.7 to249.4 masl
Layer-4: Top: 221.7 to249.4 masl
Bottom: 250.5 to2110.6 masl

(2) Effective porosity

0.25 is given to all layers uniformly.

(3) Specific storage or storativity (storage coefficient)

Specific storage of 0.0001 (m^{-1}) is given to all layers uniformly.

(4) Horizontal hydraulic conductivity or transmissivity

From the results of existing pumping test data, the transmissivity map of First Aquifer was prepared as shown in Figure 7.1.4. In Hanoi area, the transmissivity values are generally high, ranging from 600 to 1,500 m^2/day. The areas having higher transmissivity are located in the western part and southern part of the city. From the map, transmissivity at Dong Ngac Commune is estimated from 800 to 1,000 m^2/day, whereas transmissivity of Xuan Dinh is estimated from 800 to 1,200 m^2/day.

Values of hydraulic conductivity can be obtained from transmissivity values and the thickness of aquifer. If the well structure is known, the hydraulic conductivity of aquifer portion can be computed by (transmissivity) / (screen length). Figure 7.1.5 shows the distribution of hydraulic conductivity of Second Aquifer. The hydraulic conductivity in Hanoi area ranges from 17 to 50 m/day. The areas having more than 40 m/day are located in the western and southern parts of the city. According to the map, hydraulic conductivity of Dong Ngac and Xuan Dinh Communes is estimated from 17 to 25 m/day.

For inputting the parameter values, at first nodal values of transmissivity and thickness of Layer-2 and Layer-4 were obtained by Kriging method. The hydraulic conductivity value of each cell for Layer-2 and Layer-4 was then computed by (transmissivity) / (layer thickness). The hydraulic conductivity of Layer-1 and Layer-3 was uniformly given.

Layer-1:	0.1 m/day
Layer-2:	10.0 to 35.4 m/day
Layer-3:	0.01 m/day
Layer-4:	20.1 to 70.9 m/day

(5) Vertical hydraulic conductivity or vertical leakance

Initially, the vertical hydraulic conductivity of each layer was assumed to be 1/10 of the horizontal hydraulic conductivity, because it was taken into account that the layers consist of Quaternary sediments so that the vertical hydraulic conductivity is smaller than the horizontal hydraulic conductivity due to their sedimentary structure.

Layer-1:	0.01 m/day
Layer-2:	1.0 to 3.54 m/day
Layer-3:	0.001 m/day
Layer-4:	2.01 to 7.09 m/day

(6) Initial groundwater levels and piezometric heads

The initial groundwater levels of Layer-1 were given from the water levels measured at the surface water monitoring points. The groundwater levels of Layer-2 were given from the groundwater table measured at the observation wells of Upper Semi-confined Aquifer. The initial piezometric heads of Layer-3 and Layer-4 were given from the piezometric heads measured at the pure observation wells of Lower Confined Aquifer. The data of water levels and piezometric heads were measured in May 1991. The nodal values of each layer were interpolated by Kriging method.

Layer-1: 3.36 to 4.47 masl
Layer-2: 26.33 to 7.95 masl
Layer-3: 210.63 to 5.19 masl
Layer-4: 210.63 to 5.19 masl

(7) Recharge rate

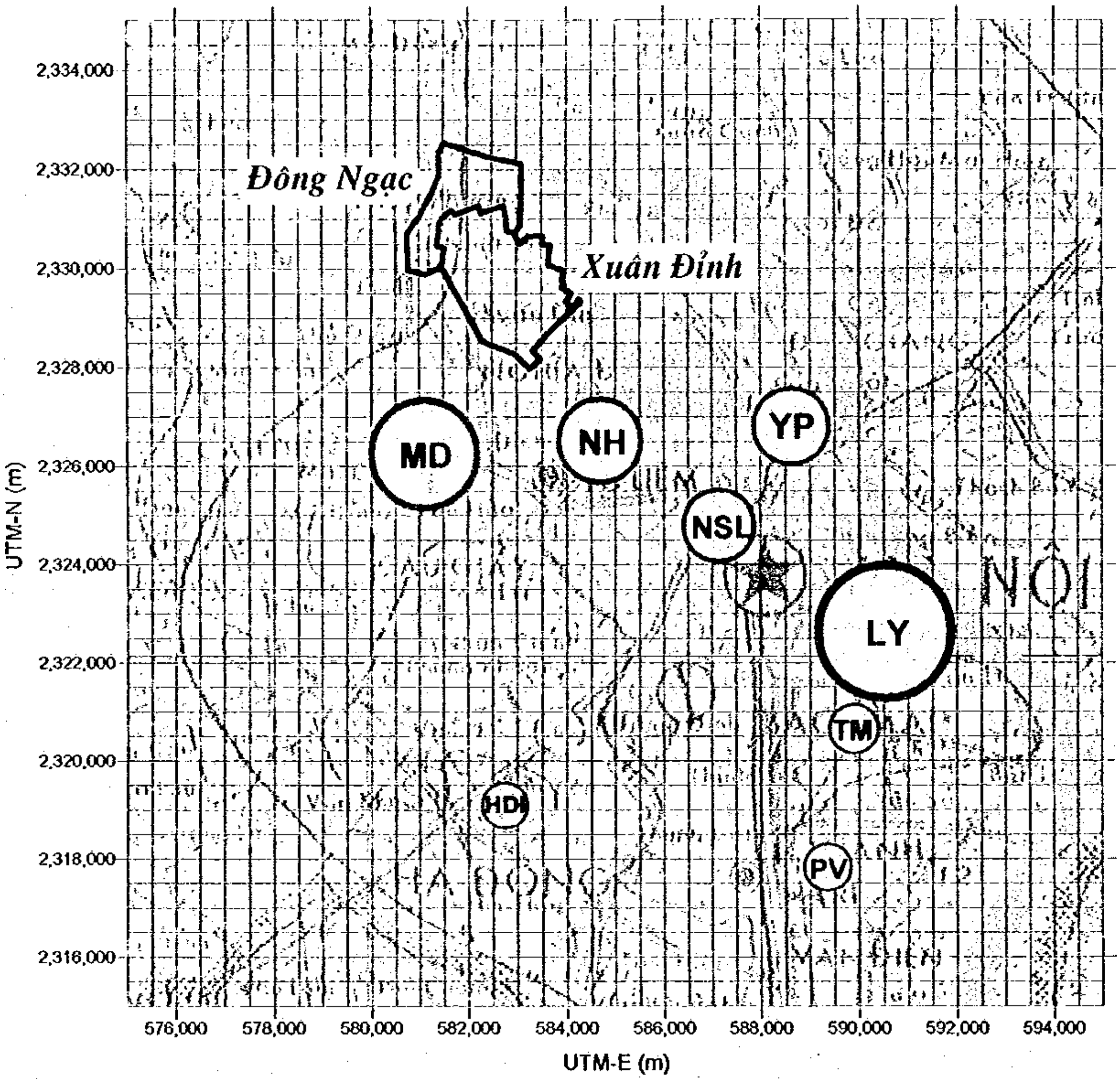
Although a detailed study of water balance in Hanoi area has not been carried out yet, a temporal recharge rate is estimated as 1.1 mm/day (5401.5 mm/year). The recharge rate was uniformly given to the active top cells of the model.

(8) Pumping rate by grid and layer

The groundwater pumpage data, that was collected by the Study Team, are mostly pumped from Lower Confined Aquifer. Therefore, the pumpage values were compiled by model cell and given to Layer-4.

The pumpage data were available from 1990 to 1996. Figure 7.1.6 shows the distribution of the average well discharge in 1991. The groundwater pumpage in 1991 was used for the steady-state model calibration mentioned in the next chapter.

Major Groundwater Well Fields in Hà Nội Area



	Name of Well Fields	Number of Wells	Pumping Rate (m^3/day)	Feasible Discharge (m^3/day)
1	Yen Phu	13	44,500	110,000
2	Ngo Si Lien	19	43,200	30,000
3	Ngoc Ha	11	50,300	30,000
4	Phap Van	9	27,700	30,000
5	Mai Dich	18	64,200	45,000
6	Ha Dinh	9	27,200	25,000
7	Luong Yen	15	79,500	80,000
8	Tuong Mai	10	29,200	30,000
	TOTAL	104	365,800	380,000

[after JICA (1997)]*

*Note:
1) Data as of 1995.
2) Number of Wells includes standby wells.
3) "Feasible Discharge" was based on FINNIDA M/P (1993) and approved by the Government of VN.

Figure 7.1.1	Major Groundwater Well Fields and Pumping Rates in Hà Nội Area
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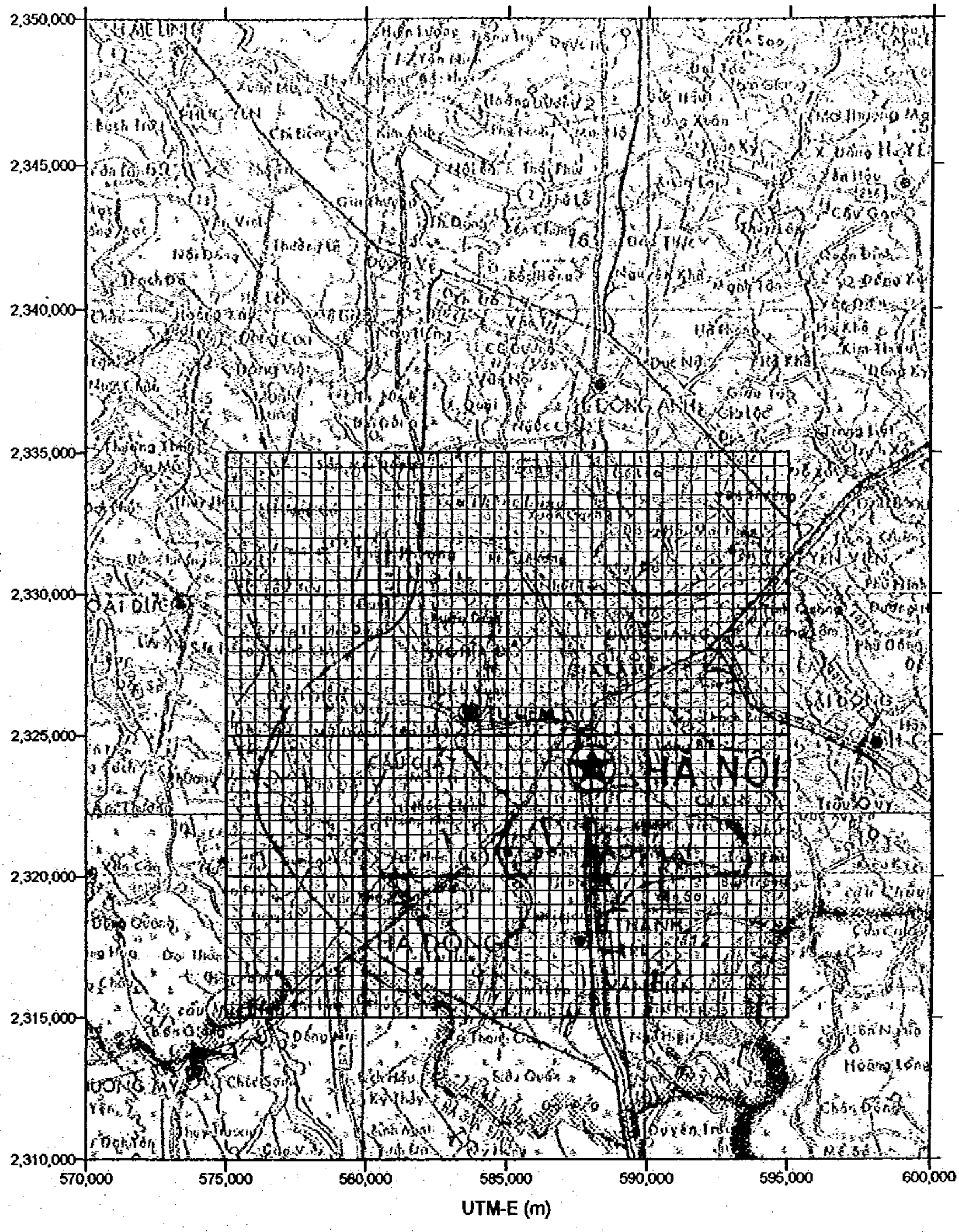

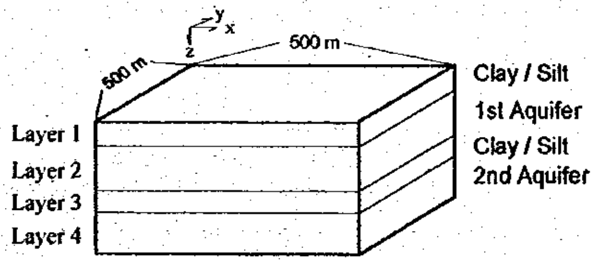

Figure 7.1.2	**Model Grid for Groundwater Simulation Applied to Hà Nội Aquifer System**

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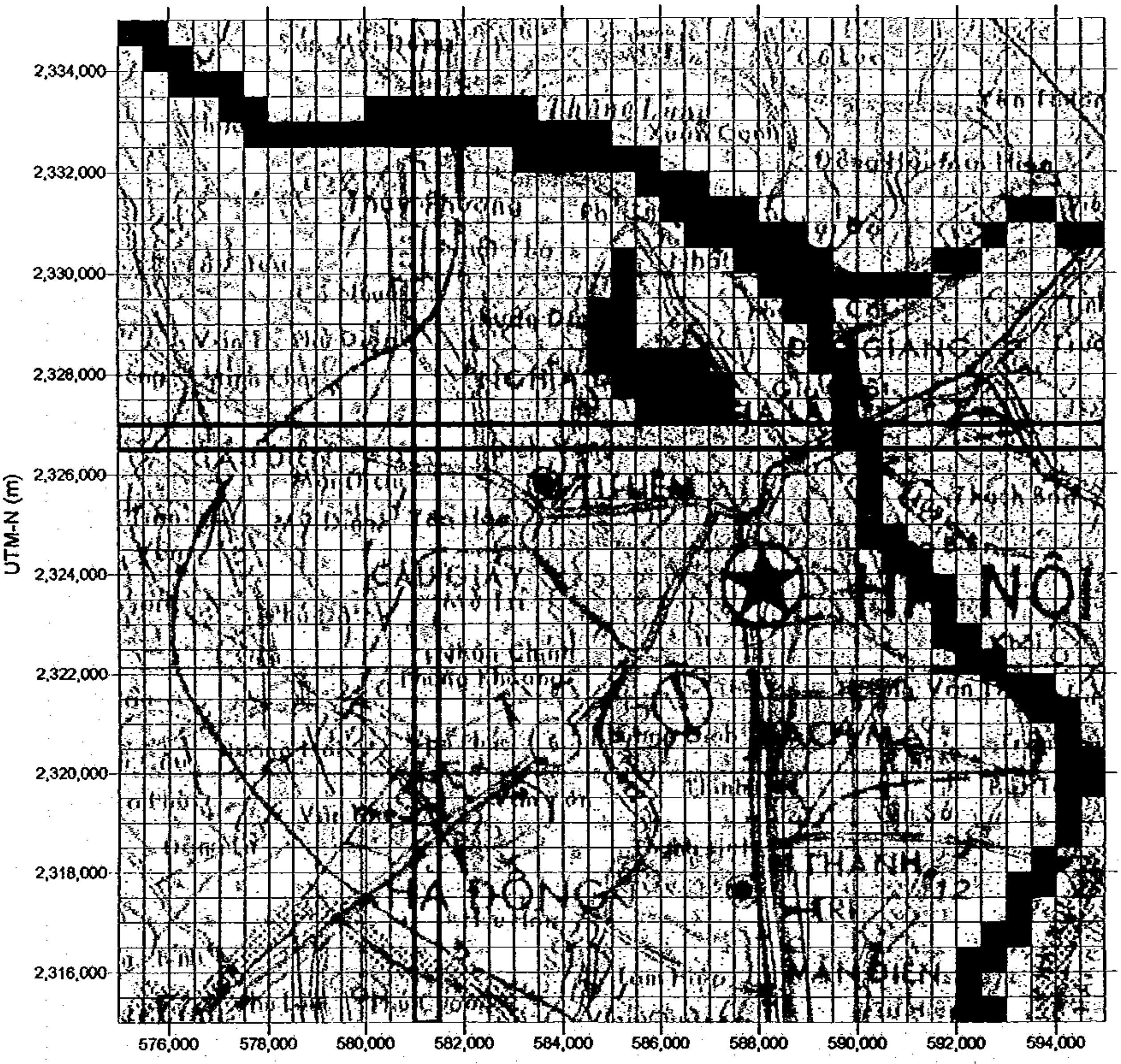
Boundary Conditions of Layer-1



■ Constant-Head Boundary

Constant-Head Boundaries are set at Red River (Sông Hồng), Duong River (Sông Đuống) and West Lake (Hồ Tây).
No Constant-Head Boundaries are set in Layer-2, Layer-3, and Layer-4.
Water levels at Constant-Head Boundaries are given from the data of Surface Water Observation Points.

Figure 7.1.3	Boundary Conditions of Hà Nội Groundwater Simulation Model
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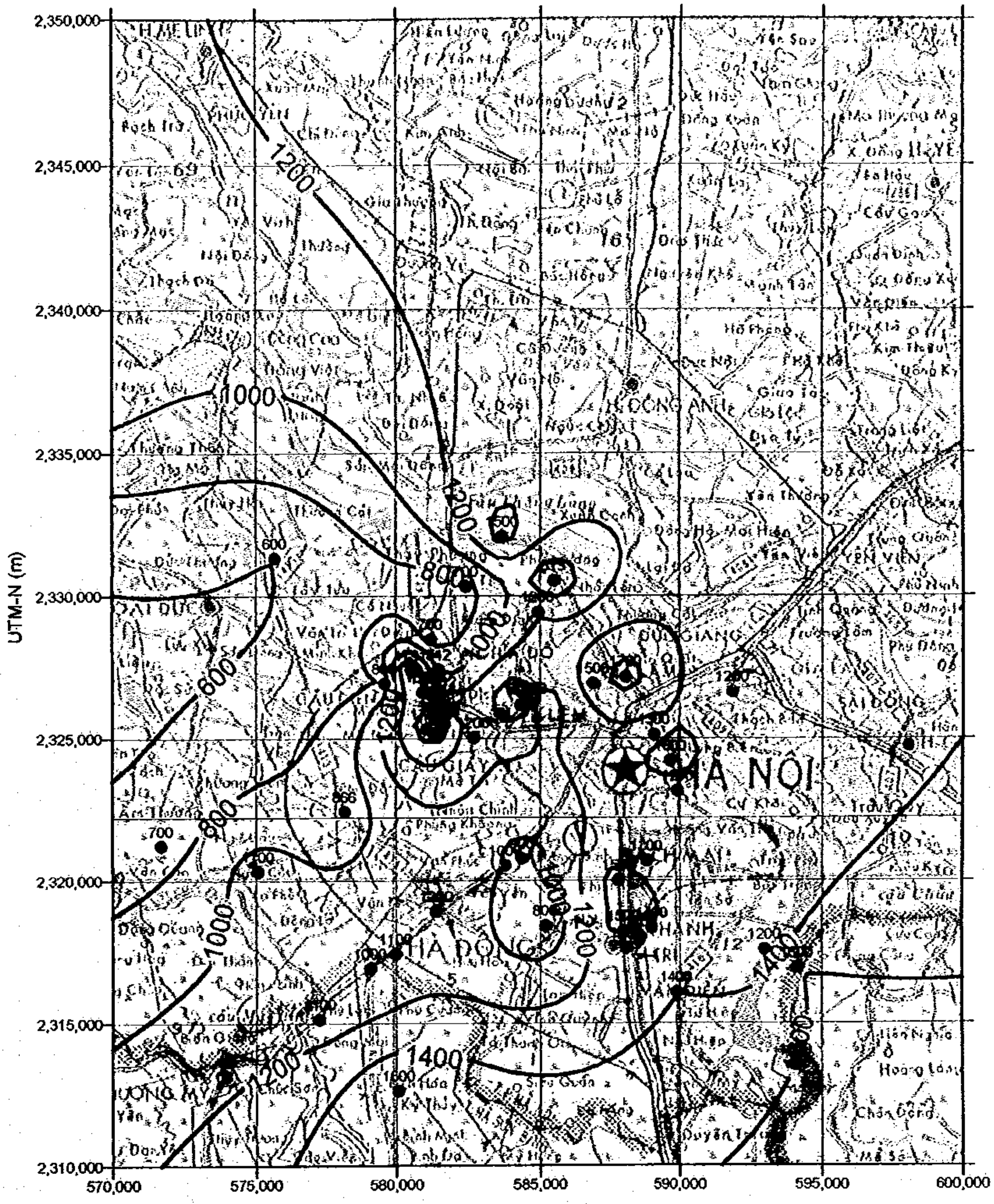

1000 Equal Line of Transmissivity, T (m^2/day)

1200 Well location with T value (m^2/day)

(Transmissivity values were determined by pumping tests.)

Figure 7.1.4	Distribution of Transmissivity in Hà Nội Area
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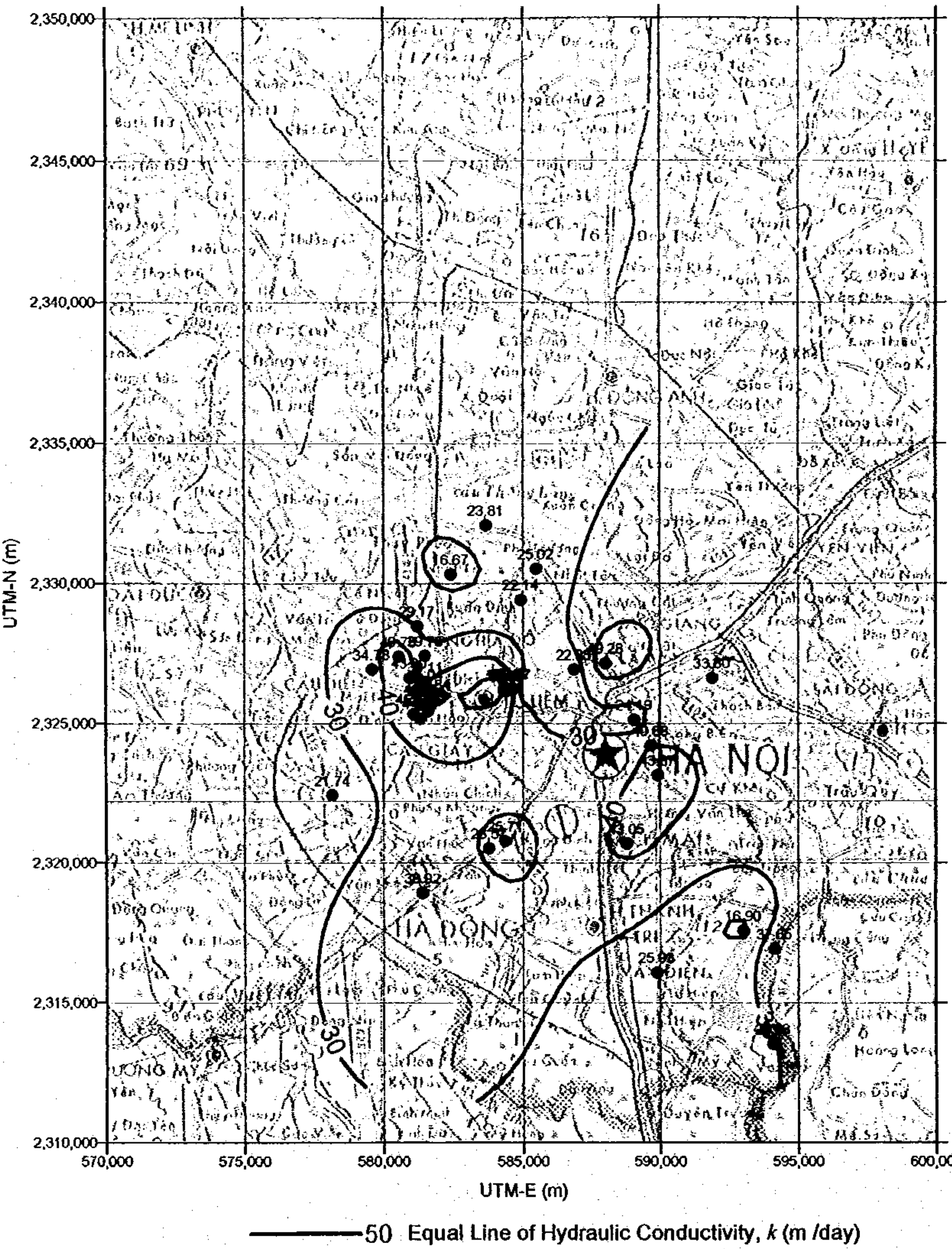

——— 50 Equal Line of Hydraulic Conductivity, *k* (m /day)

25.12 ● Well location with *k* value (m/day)

(Hydraulic Conductivity values were determined by pumping tests.)

Figure 7.1.5	Distribution of Hydraulic Conductivity in Hà Nội Area
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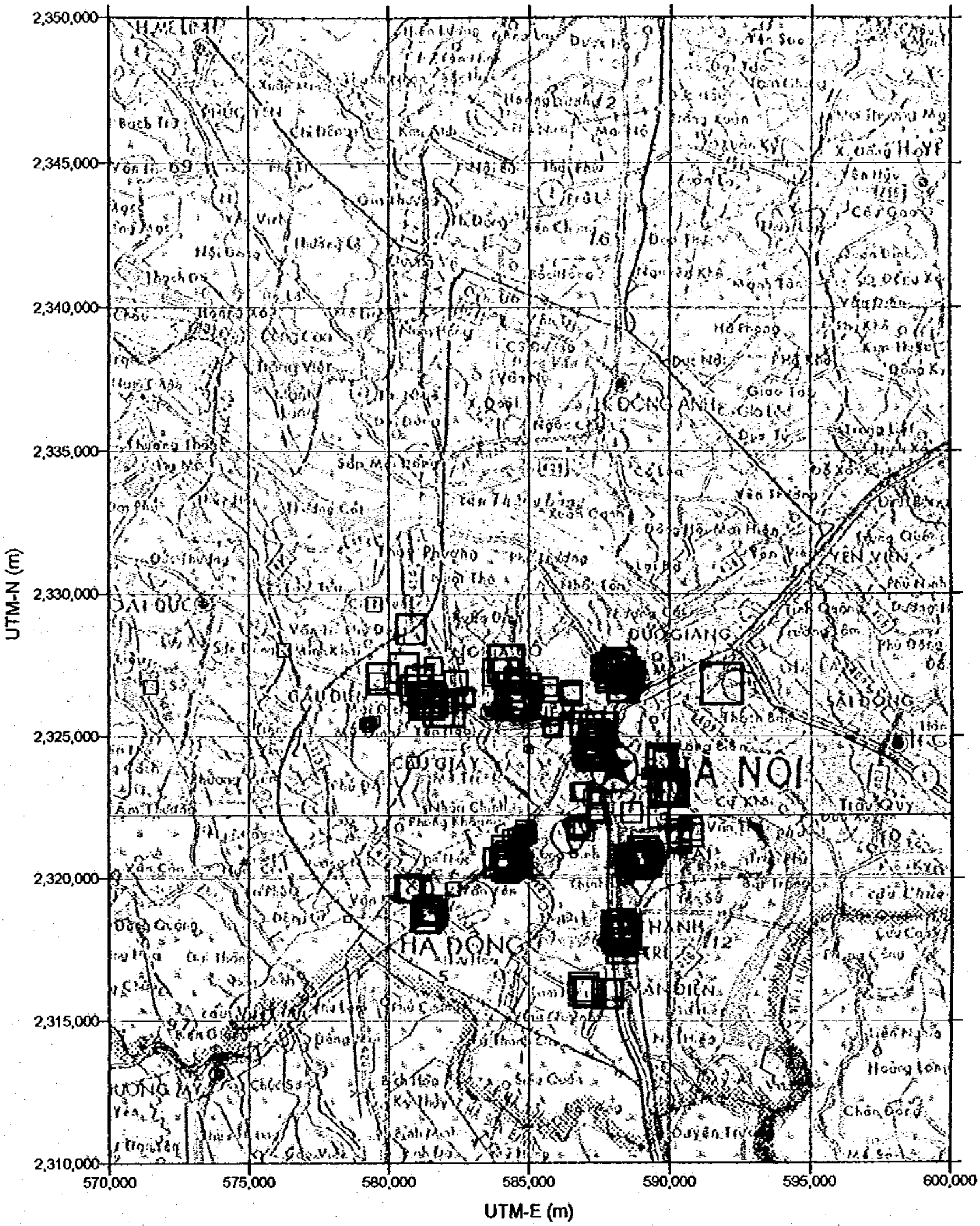

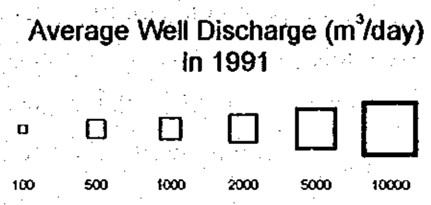

Figure 7.1.6	Distribution of Average Well Discharge in Hà Nội Area in 1991
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7.2 Model Calibration

Calibration of the simulation model is very important work for the modeling study. If the model was not calibrated properly, the results of simulation are not reliable, and the model cannot be used for future prediction.

In general, the calibration is carried out by comparing of the simulated groundwater levels with the actual groundwater levels. Therefore, monitoring of groundwater levels or piezometric heads is very essential for groundwater modeling study. At first, the created 3-D groundwater simulation model of Hanoi area was calibrated by steady-state simulation. Next, the model was calibrated by transient simulation using the pumpage data from 1990 to 1996.

7.2.1 Steady-state calibration

In the steady-state calibration, a duration of a stress period was set as 30 years, then the simulated piezometric heads were compared with the actual piezometric heads. For the calibration, model used the pumpage data of 1991 because the availability of field observation data is the best in May 1991. The actual dynamic piezometric surface map of May 1991 was prepared not only from data of pure observation wells but also data of observed production wells for the model calibration, which is shown in Figure 7.2.1. During the model calibration, vertical hydraulic conductivity of each layer was modified because the initially input data had less reliability.

As a result of the steady-state calibration, the vertical hydraulic conductivity was modified as follows:

Layer-1: 0.03 m/day
Layer-2: 1.00 to 3.54 m/day
Layer-3: 0.04 m/day
Layer-4: 2.01 to 7.09 m/day

Without modifying other parameters such as horizontal hydraulic conductivity, the model can simulate piezometric heads reasonably. Figure 7.2.2 shows the simulated piezometric surface by the steady-state simulation. Compared with the actual dynamic piezometric surface shown in Figure 7.2.1, it can be said that the shape of the depression cone as well as the values of piezometric heads by the simulation show a satisfactory agreement with the actual piezometric surface.

7.2.2 Transient calibration

The transient calibration was carried out using the simulated piezometric heads obtained by the steady-state calibration as the initial heads. In the transient simulation, yearly groundwater pumpage from 1990 to 1996 was input to the model. Table 7.2.1 summarizes the groundwater pumpage in Hanoi are from 1990 to 1996. According to the data, a total pumpage of the major well fields of the Hanoi Water Supply System has the maximum amount of 368,112 m^3/day in 1993. In 1996, the total pumpage in Hanoi area is 453,690 m^3/day, consisting of 291,480 m^3/day by the major well fields of Hanoi Water Supply System and 162,210 m^3/day by the minor well fields and private wells.

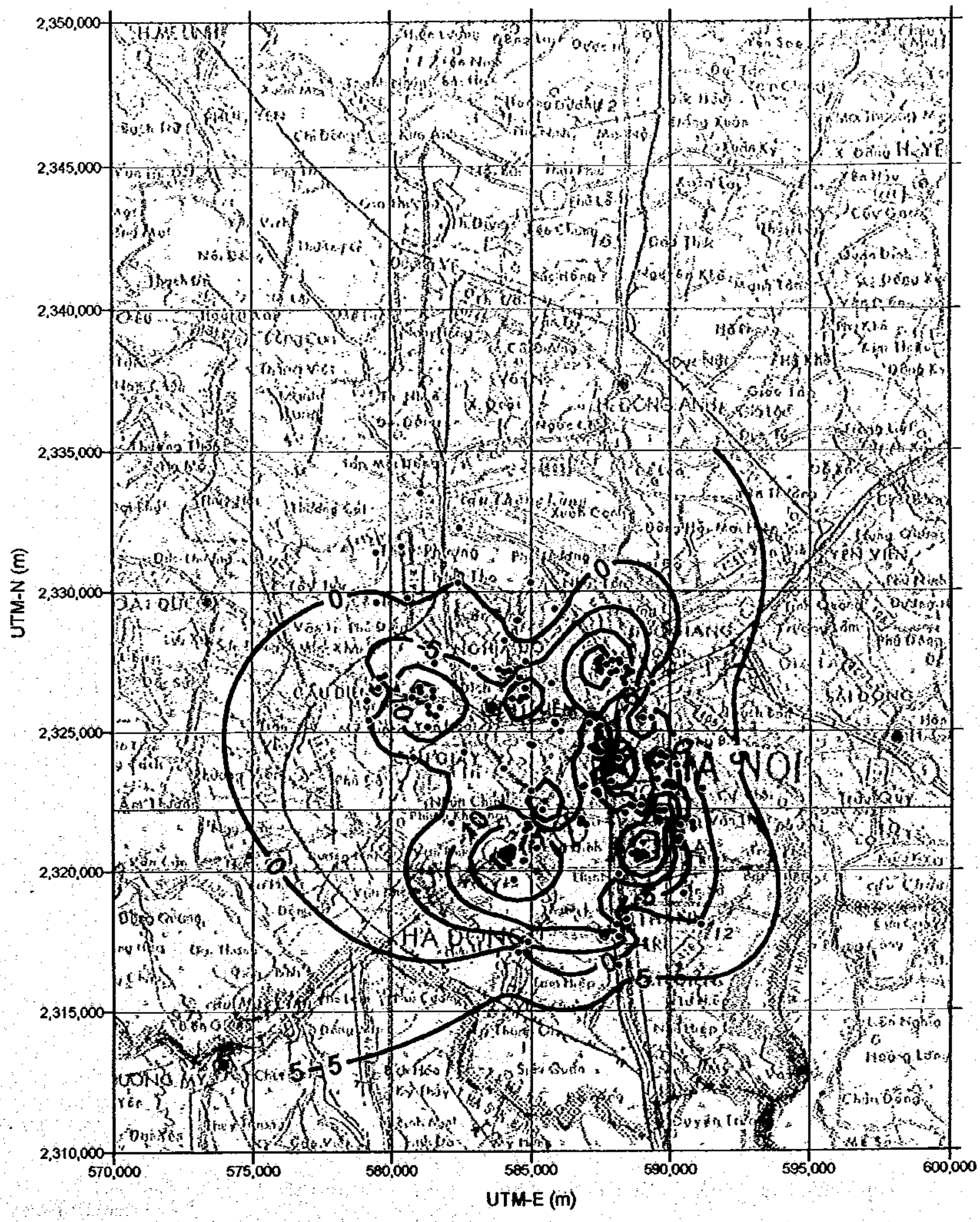
Figure 7.2.3 shows the result of the transient calibration in 1996. It can be said that the distribution of the piezometric heads in the Second Aquifer is reasonably simulated compared with the actual piezometric heads. During the transient simulation, the model parameters were not modified.

Table 7.2.1 Groundwater Pumpage in Hanoi Area from 1990 to 1996

(Unit: m^3/day)

Year		1990	1991	1992	1993	1994	1995	1996
HNWS Major Well Field								
	PHAP VAN	46,248	37,968	39,120	32,544	28,752	34,548	21,360
	MAI DICH	42,240	55,728	61,176	65,112	59,400	56,904	55,800
	NGOC HA	39,576	57,672	40,752	44,640	39,000	45,720	44,328
	LUONG YEN	-	-	25,968	79,056	77,016	74,160	57,744
	TUONG MAI	-	-	30,744	26,736	26,496	27,648	23,184
	HA DINH	-	-	30,696	27,504	30,720	31,032	29,232
	NGO SY LIEN	49,200	53,160	45,240	44,592	42,168	33,672	30,504
	YEN PHU	49,032	46,584	45,960	47,928	37,728	39,096	29,328
HNWS Major Total		226,296	251,112	319,656	368,112	341,280	342,780	291,480
Other Total		133,986	131,922	135,930	142,500	149,070	155,640	162,210
Grand Total		360,282	383,034	455,586	510,612	490,350	498,420	453,690

[Data source]
Hanoi Dept. of Sci. & Enviro. Tech. and Hanoi Univ. of Mining and Geology (1998)
Dept. of Geology and Minerals of Vietnam (1998)
Nguyen Van Hoang (1993)



-16 Equal Line of Piezometric Surface (masl)

• Observation Well and Observed Production Well

(Pure observation wells and observed production wells were used to draw dynamic piezometric surface.)

Figure 7.2.1	Distribution of Dynamic Piezometric Surface in Hà Nội Area (May 1991)
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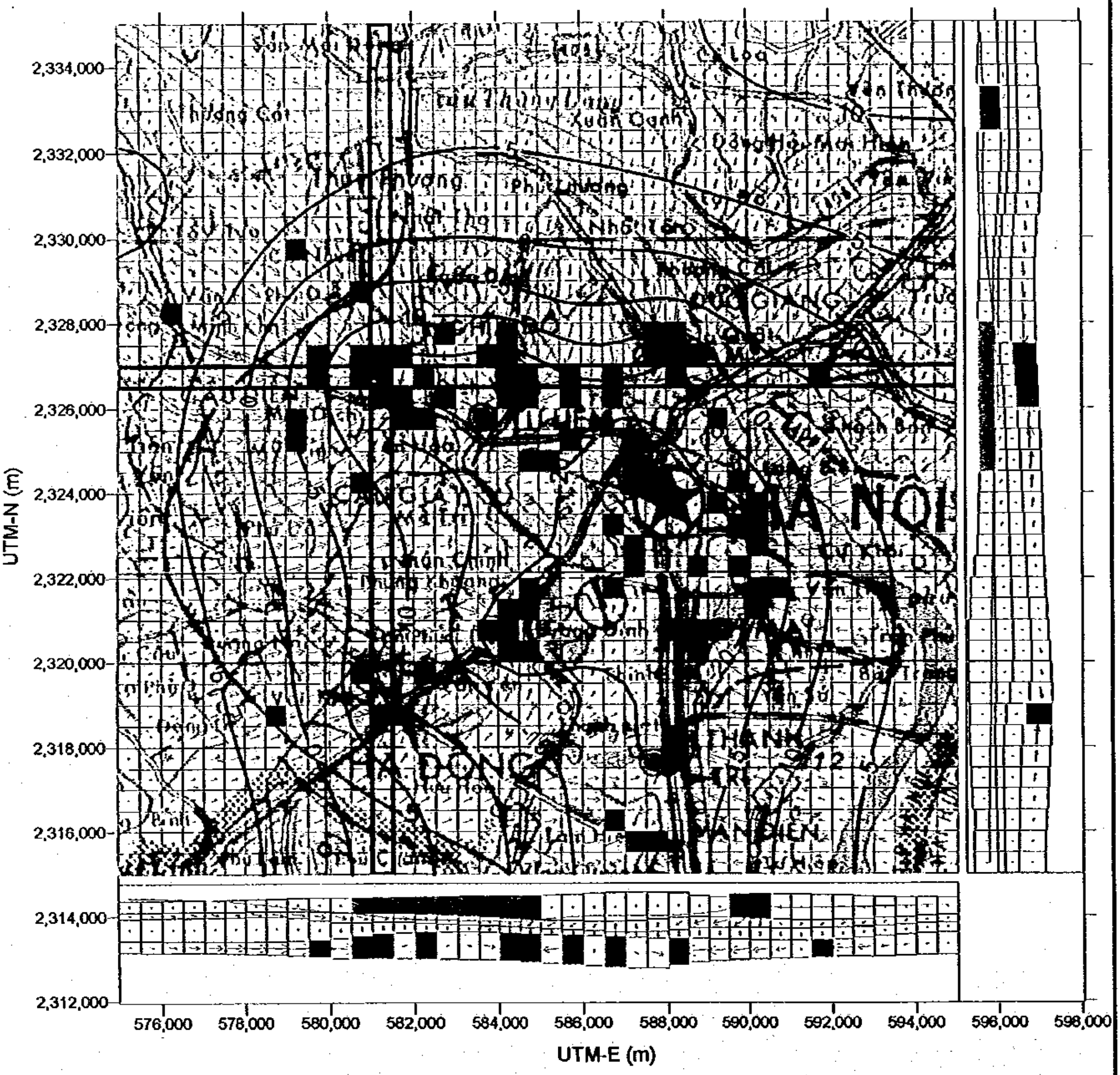
Steady-State 3-D Simulation



Top View: Layer 4 (Main Confined Aquifer)

Cross-Section
Projection Raw = 17
Projection Column = 13

Pumped Cell
Constant Head
Dried Cell
Flow Vector
Simulated Groundwater Table
-10 Equal Line of Simulated Piezometric Surface (masl)

Figure 7.2.2	**Simulated Piezometric Surface by Steady-State Calibration**

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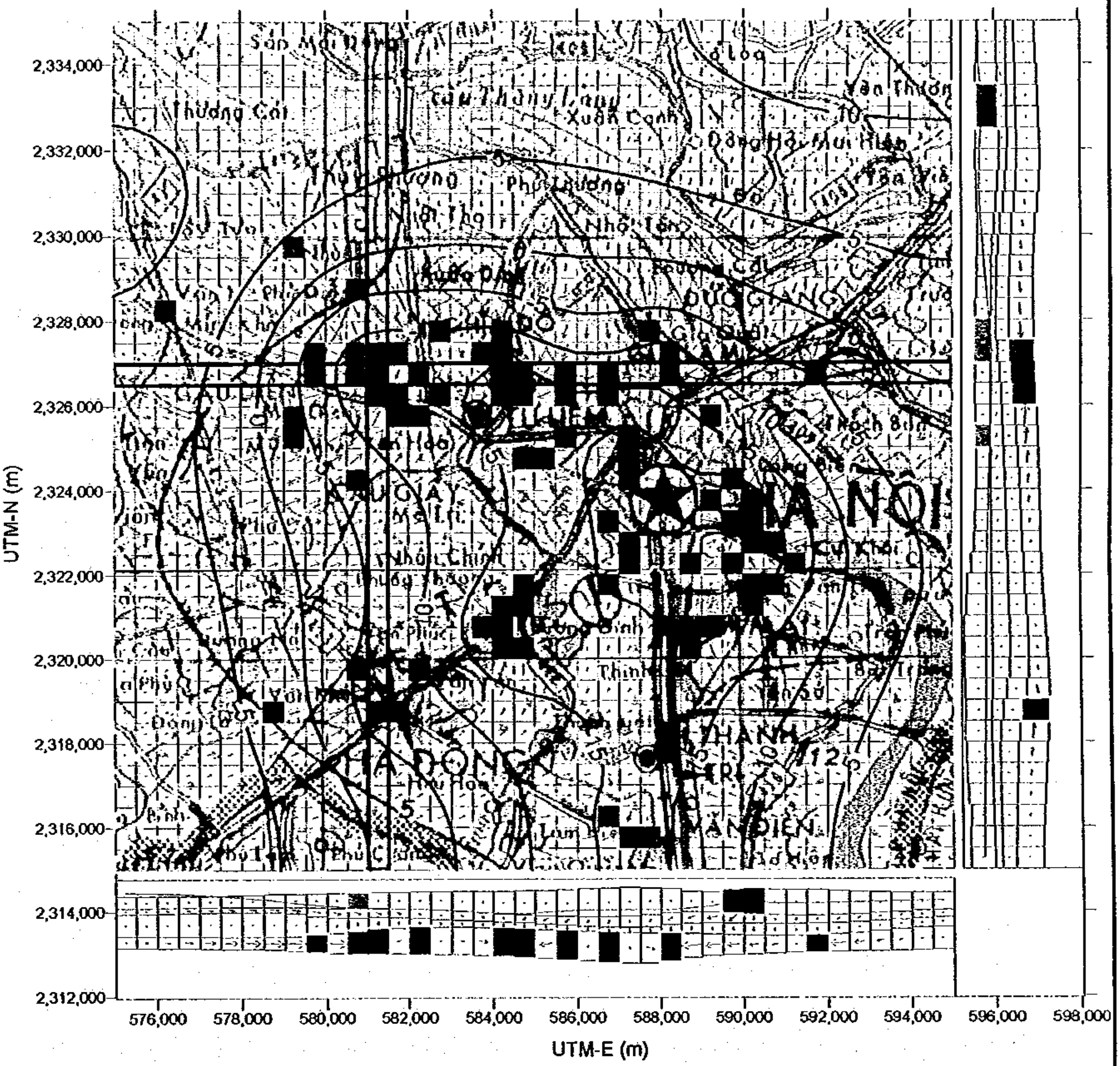
Transient 3-D Simulation



Top View: Layer 4 (Main Confined Aquifer)

Cross-Section
Projection Raw = 17
Projection Column = 13

Pumped Cell
Constant Head
Dried Cell
Flow Vector
Simulated Groundwater Table
-10 Equal Line of Simulated Piezometric Surface (masl)

Figure 7.2.3	Simulated Piezometric Surface in 1996 by Transient Calibration

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7.3 Prediction

To predict the influence of the future groundwater development in the target communes of the Study, future simulations were carried out using the calibrated model. It is assumed that one well in Dong Ngac Commune (I59, J513) and one well in Xuan Dinh Commune (I59, J514) will be constructed, and they will extract groundwater from the Second Aquifer (Layer-4).

For the future groundwater pumpage, the Hanoi Water Supply System has a plan to expand the existing well fields as shown in Figure 7.3.1. According to NHEGD-DGM (1998), Cao Dinh well field is proposed along the right side bank of the Red River. In the new well field, 26 production wells will be constructed, and a total of 97,964 m^3/day will be pumped. Yen Phu well field is also planned to be expanded along the Red River. A total of 13 production wells will be constructed additionally. The additional pumpage of Yen Phu well field will be 60,777 m^3/day. For the future simulation, it is assumed that the groundwater pumpage is the pumpage of 1996 with the planned pumpage of Cao Dinh well field and additional Yen Phu well field. Therefore, the future simulation was carried out assuming that the total groundwater pumpage in Hanoi area is 612,431 m^3/day. This pumping situation is named "Case-0".

The following two (2) cases of future pumping plan in the target communes were prepared based on the daily maximum groundwater demand designed by the Study:

Case-1: Dong Ngac	Q51,260 m^3/day,	Xuan Dinh	Q52,850 m^3/day
Case-2: Dong Ngac	Q51,890 m^3/day,	Xuan Dinh	Q54,275 m^3/day

The pumpage of Case-1 is the designed daily maximum groundwater demand. The pumpage of Case-2 is 1.5 times of Case-1 pumpage.

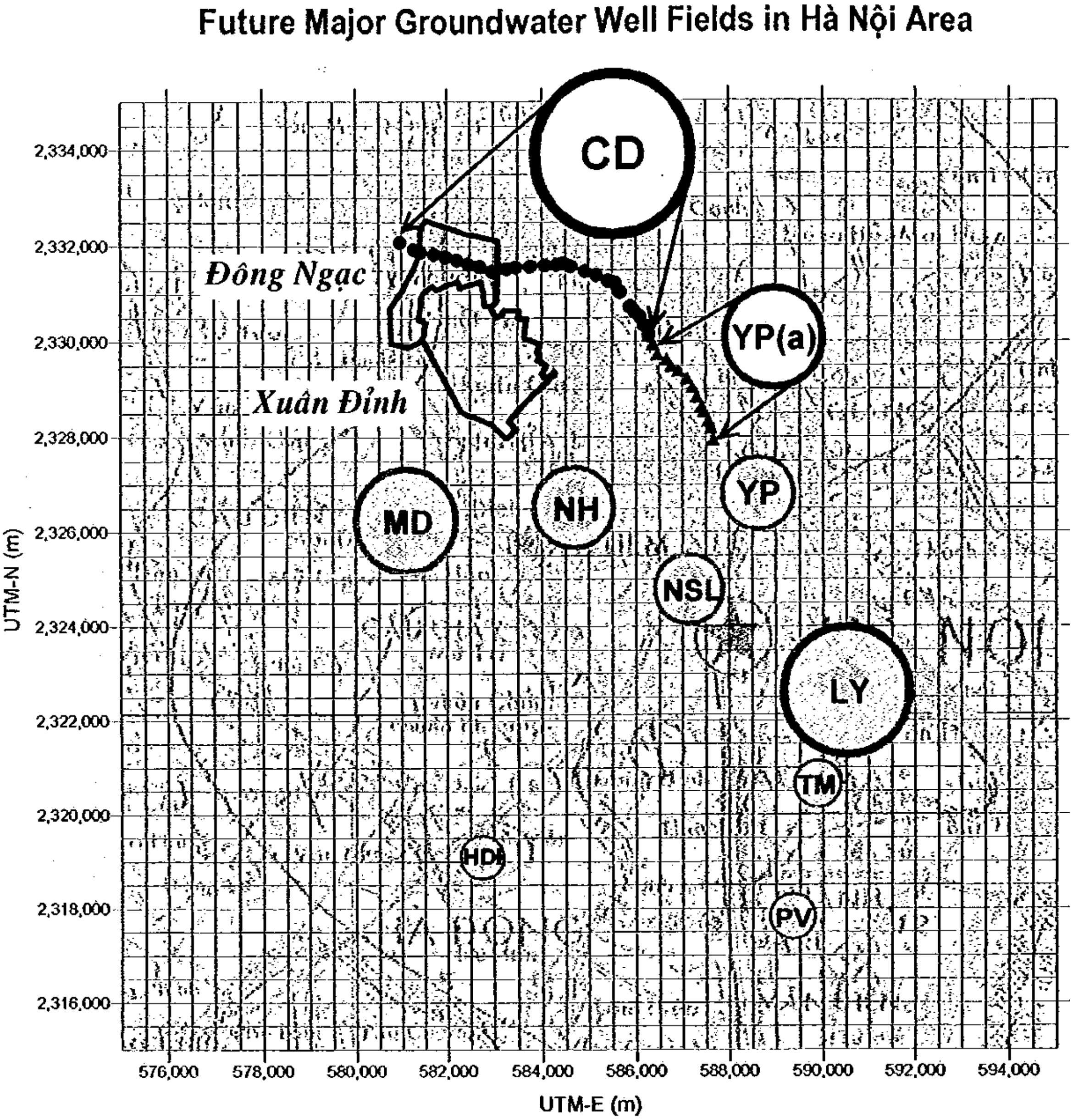
The future simulation was carried out by transient simulation. The simulation duration is 10 years, having 10 time steps. The prepared pumping plans were input to the model. The recharge was uniformly given to the top active cells of the model at a rate of 1.1 mm/day throughout the simulation period. The initial groundwater levels and piezometric heads were brought into each layer from the final simulated heads of the transient simulation from 1990 to 1996. The water levels at constant-head boundaries were the same as that of the transient simulation simulation.

In the future simulation, firstly future piezometric heads were computed without the pumpage of the target communes using Case-0 pumpage. Then, the pumpage of Case-1 and Case-2 was added to the pumpage of Case-0. The simulated piezometric drawdown of Case-1 and Case-2 after 10 years of operation was obtained by comparing the simulated piezometric heads of Case-1 and Case-2 with the simulated heads of Case-0.

Figure 7.3.2 shows the results of future simulation by Case-0. The contour lines indicate the simulated piezometric surface of Second Aquifer. The piezometric heads were lowered in the northern part of the central Hanoi by the pumpage of Cao Dinh and additional Yen Phu well fields. Due to the increase of pumpage, the piezometric surface in the target communes will be 0 to -5 masl, lowering 5 to 10 m compared with the piezometric surface in 1996.

Figures 7.3.3 shows the simulated piezometric drawdown in Case-1. The maximum drawdown is predicted as 2.36 m at the Xuan Ding pumping site. The radius of drawdown more than 10 cm is extended about 5 km to the east of the Xuan Dinh well site and about 7 km to the south. The Case-1 groundwater development plan will cause 15 to 30 cm of drawdown at existing Ngoc Ha and Mai Dich well fields.

Figure 7.3.4 shows the simulated piezometric drawdown in Case-2. The maximum drawdown is simulated as 3.54 m at the Xuan Dinh site. The radius of drawdown more than 10 cm is extended about 6 km to the east of the Xuan Dinh well site and about 8.5 km to the south. In this case, the piezometric heads at the existing well fields of the Hanoi Water Supply System near Xuan Dinh will decline 20 to 40 cm.



● Proposed Well Location of Cao Dinh Well Field

▲ Proposed Well Location of Yen Phu Well Field

	Name of Well Fields	Number of Wells	Pumping Rate (m^3/day)
1	Cao Dinh	26	97,964
2	Yen Phu (additional)	13	60,777
	TOTAL	39	158,741

[Data source: NHEGD-DGM (1998)]

Figure 7.3.1	Future Well Fields in Hà Nội Area for Future Prediction (Case-0)

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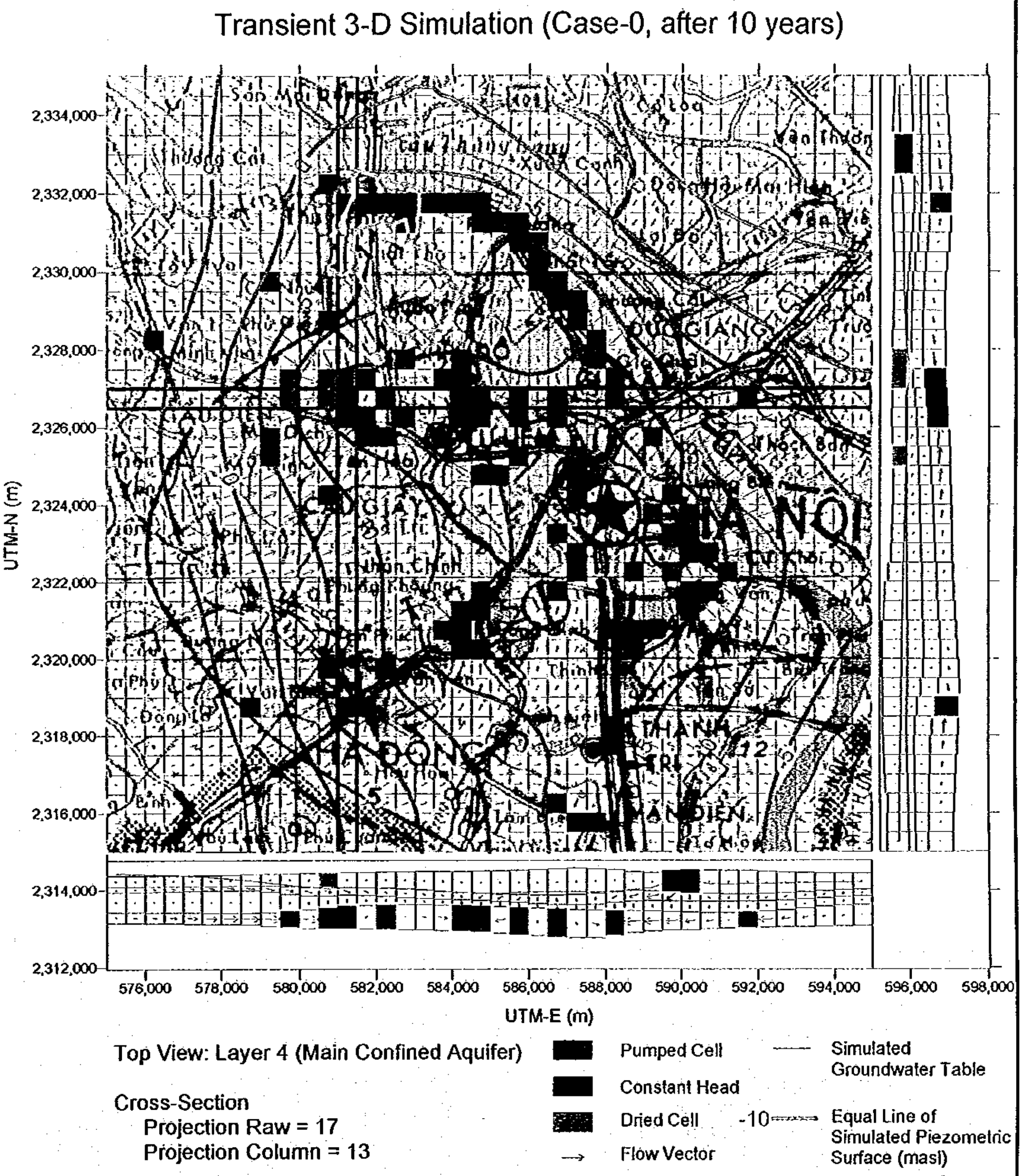

Groundwater pumpage for Case-0 is the actual pumpage in 1996 with proposed pumpage in Cao Dinh well field and additional pumpage in Yen Phu well field.

1996 Q = 453,960 m^3/day

Cao Dinh Q = 97,964 m^3/day

Additional Yen Phu Q = 60,777 m^3/day

[Data source: NHEGD-DGM(1998)]

Figure 7.3.2	Simulated Piezometric Surface by Case-0 (after 10 years)
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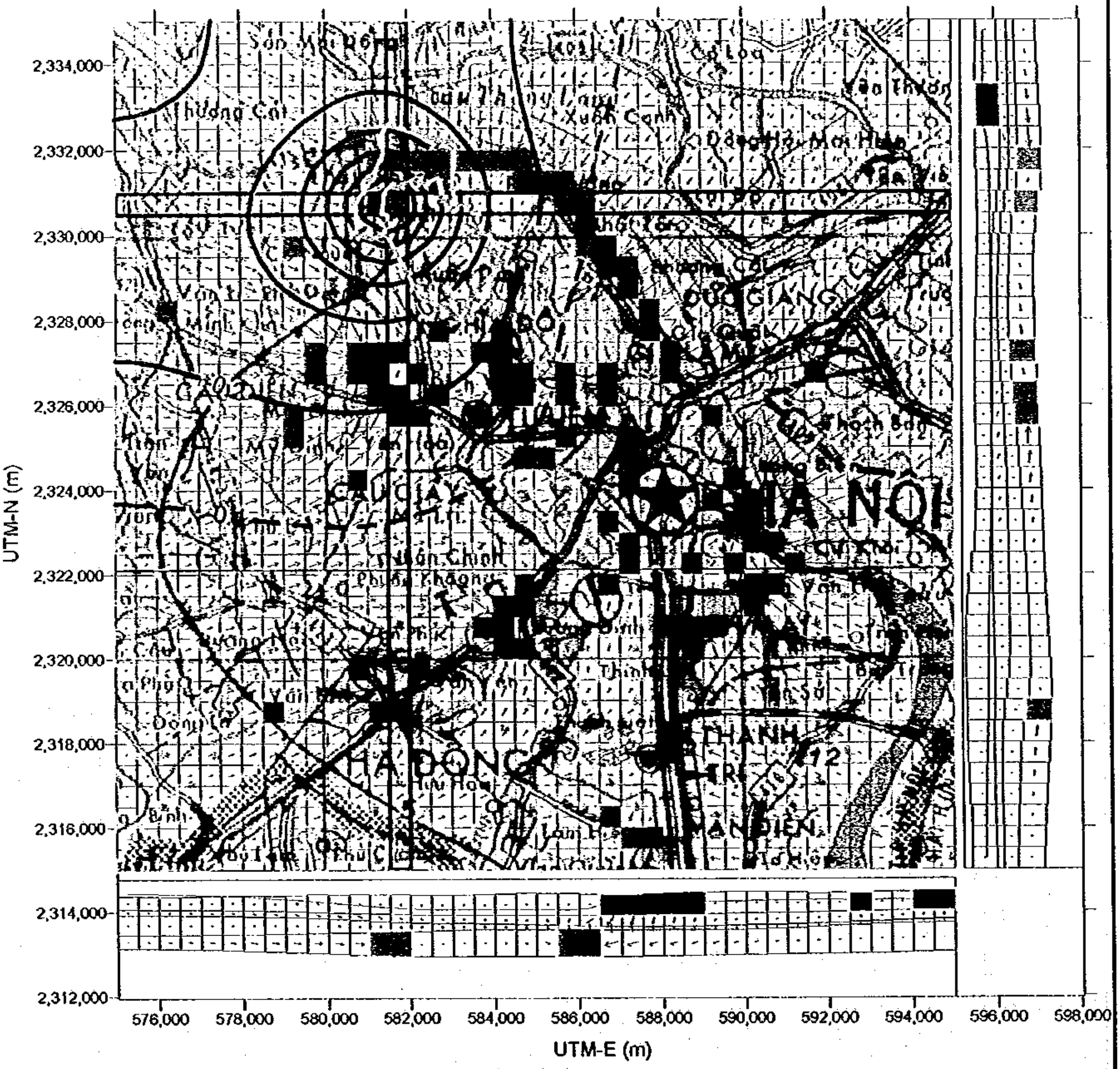
Simulated Piezometric Drawdown (Case-1, after 10 years)



Top View: Layer 4 (Main Confined Aquifer)

Cross-Section
Projection Raw = 9
Projection Column = 14

- Pumped Cell
- Constant Head
- Dried Cell
- → Flow Vector
- —— Simulated Groundwater Table
- -1.4 —— Equal Line of Simulated Piezometric Drawdown (m)

Case-1 Pumping Plan:
Pumpage of Case-0 with following pumpage:
Đông Ngạc (I=9, J=13) Q = 1,260 m^3/day
Xuân Đỉnh (I-9, J=14) Q = 2,850 m^3/day
Pumping from Layer-4.

Maximum Drawdown = 2.36 m

Figure 7.3.3	Simulated Piezometric Drawdown by Case-1 (after 10 years)

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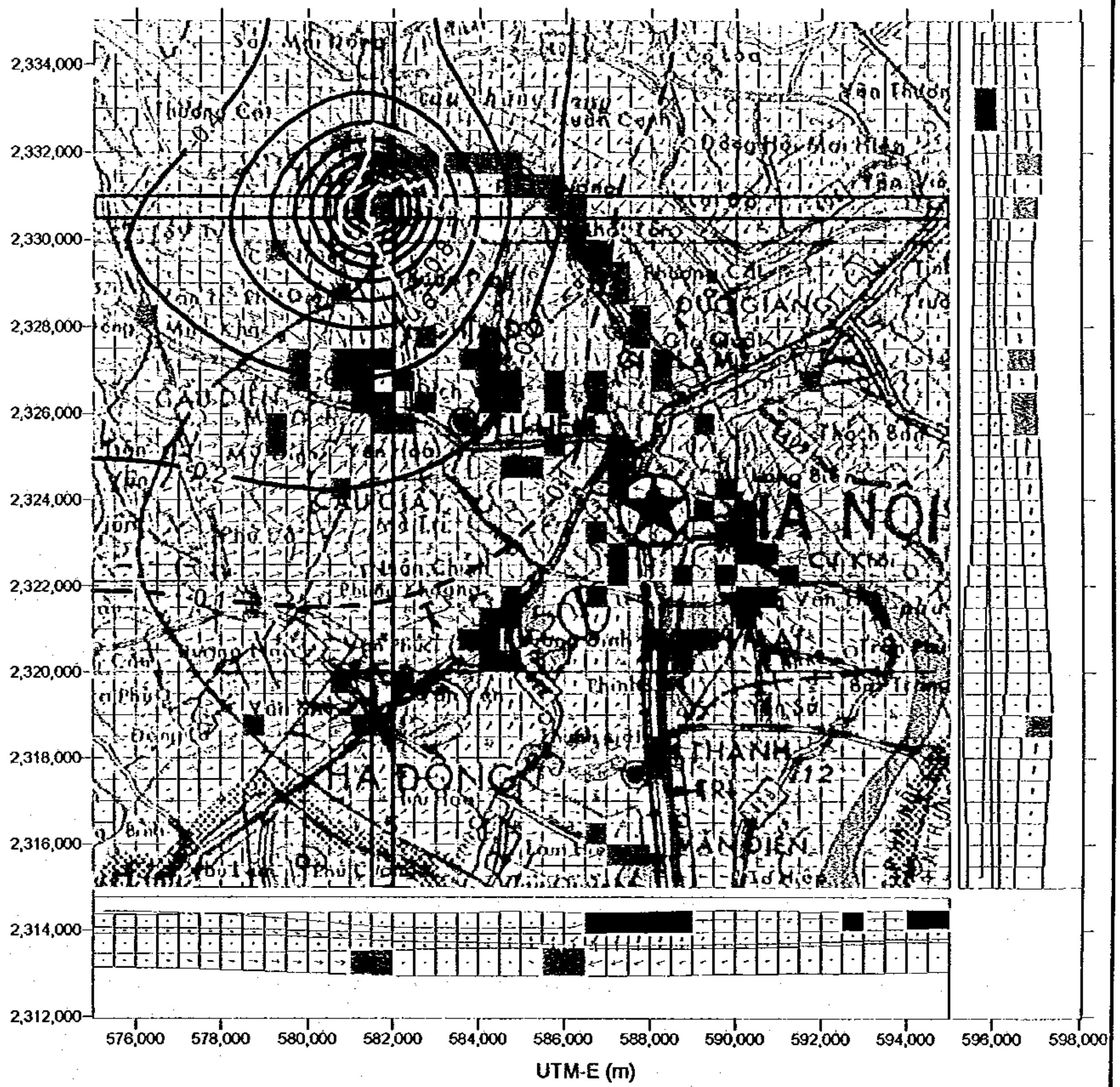
Simulated Piezometric Drawdown (Case-2, after 10 years)



Top View: Layer 4 (Main Confined Aquifer)

Cross-Section
Projection Raw = 9
Projection Column = 14

- Pumped Cell
- Constant Head
- Dried Cell
- → Flow Vector
- —— Simulated Groundwater Table
- -2.2 ▬ Equal Line of Simulated Piezometric Drawdown (m)

Case-2 Pumping Plan:
Pumpage of Case-0 with following pumpage:
Đông Ngạc (I=9, J=13) Q = 1,890 m^3/day
Xuân Đỉnh (I-9, J=14) Q = 4,275 m^3/day
Pumping from Layer-4.

Maximum Drawdown = 3.54 m

Figure 7.3.4 **Simulated Piezometric Drawdown by Case-2 (after 10 years)**

THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

7.4 Evaluation of Impact

As a result of the future simulation, it is predicted that the groundwater development plan of the target communes will cause further drawdown of piezometric heads in the northwestern part of Hanoi Area. The area having more than 10 cm of drawdown will be extended out of the target communes, including the western half of West Lake and the well fields of Ngoc Ha and Mai Dich. When the pumpage in the target communes increased 1.5 times of the designed daily maximum groundwater demand, the area having more than 10 cm of drawdown will reach to the center of Hanoi City.

While the groundwater flow system of Hanoi area has already been changed greatly from the natural conditions. A large depression of piezometric surface has been formed in the central to southern parts of Hanoi City. The groundwater of Hanoi Area flows into the center of depression formed in the Second Aquifer horizontally and vertically. The depression is formed by the groundwater pumpage from 130 production wells of the major 8 well fields of the Hanoi Water Supply System (330,000 to 390,000 m^3/day in pumpage) and about 250 private wells for industry and commercial use (about 75,000 m^3/day in 1998) (NHEGD-DGM, 1998). The designed groundwater pumpage for the target communes, which is amounted about 4,100 m^3/day, is only about 1 % of the existing pumpage. Therefore, the development of new groundwater resources would not have any significant impact on groundwater flow in Hanoi.

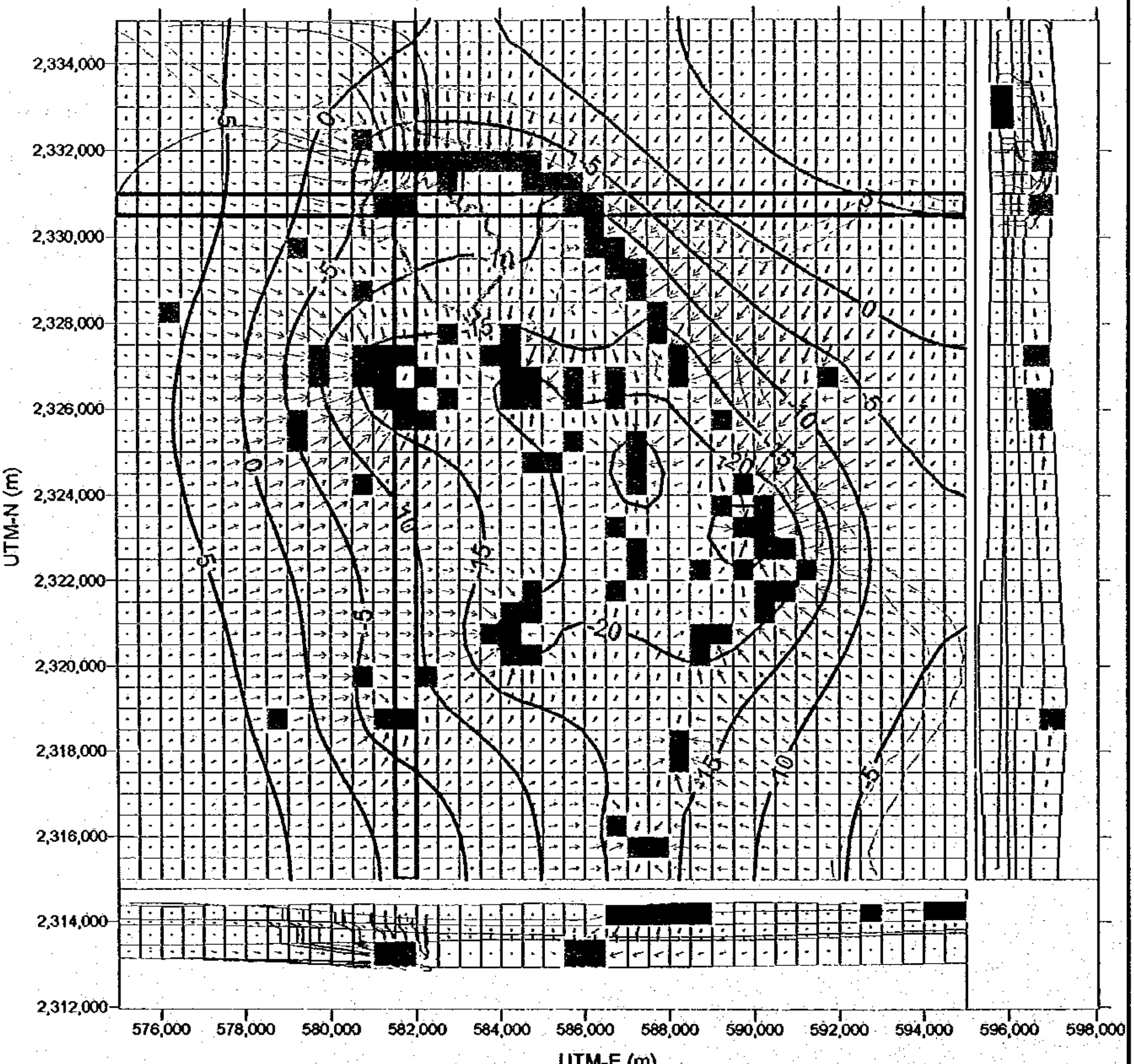
Based on the results of Case-1 future simulation, Figure 7.4.1 was made to show the simulated groundwater flow in Hanoi area and the pathlines of groundwater flow into the Dong Ngac and Xuan Dinh wells and the wells in Cao Dinh well field. The groundwater which flows into the Dong Ngac and Xuan Dinh wells will be recharged from the surface near well sites and the surface from the west. Groundwater in the Cao Dinh well field is mainly recharged by flows from the Red River.

The result of Case-1 future simulation shows that the huge pumpage in Cao Dinh well field makes deeper piezometric heads in the well field than that of Dong Ngac and Xuan Dinh. The well field will function as the barrier wells to block the direct inflow from the Red River to the wells in Dong Ngac and Xuan Dinh. It is, however, possible for Red River to directly flow into the Dong Ngac and Xuan Dinh area to recharge groundwater flow, if pumpage in the Cao Dinh well field is small.

According to JICA (1997), arsenic in the Red River in 1994 exceeds the value (0.05 mg/l) stipulated for drinking water in Vietnam at a maximum of 0.095 mg/l. The river was also observed to contain chromium, lead, and nickel levels way over the drinking water standard of Vietnam and WHO. DDT levels in the river also exceeded the drinking water standard of Vietnam.

The development of new wells in the target communes would not only necessitate particular caution regarding the groundwater amount to develop but also the quality of the recharging or target resources. It is, therefore, important that a monitoring system be established to monitor groundwater level and water quality.

Simulated Groundwater Flow and Pathlines (Case-1, after 10 years)



Top View: Layer 4 (Main Confined Aquifer)

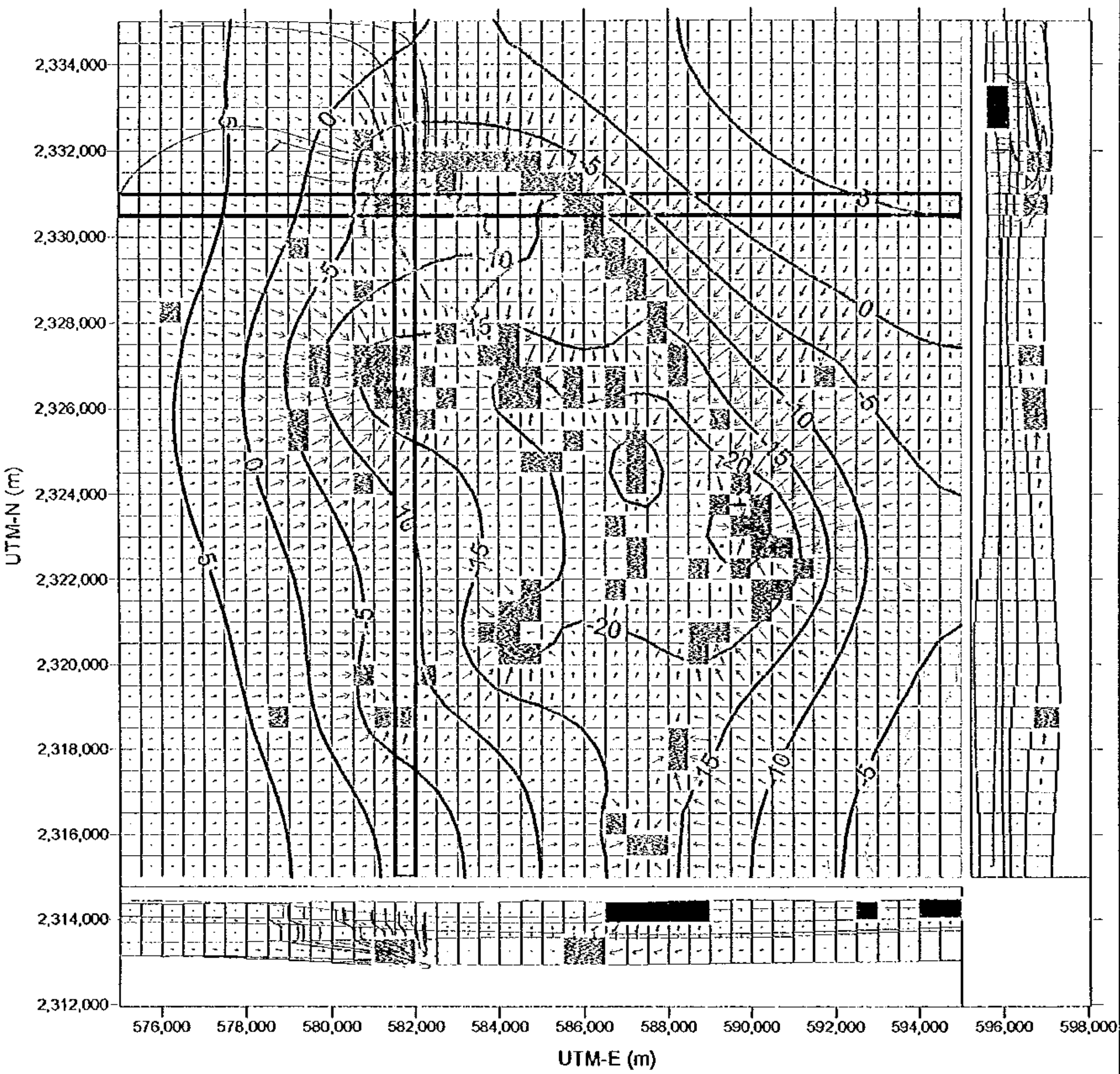
- Pathline to Cao Dinh Wells
- Pathline to Đông Ngạc and Xuân Đỉnh Wells
- Pumped Cell
- Constant Head
- Dried Cell
- → Flow Vector
- Simulated Groundwater Table
- -10 Equal Line of Simulated Piezometric Surface (masl)

Case-1 Pumping Plan:
Pumpage of Case-0 with following pumpage:
Đông Ngạc (I=9, J=13) Q = 1,260 m^3/day
Xuân Đỉnh (I-9, J=14) Q = 2,850 m^3/day
Pumping from Layer-4.

Maximum Drawdown = 2.36 m

Figure 7.4.1	Simulated Groundwater Flow and Pathlines by Case-1 (after 10 years)
THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

Simulated Groundwater Flow and Pathlines (Case-1, after 10 years)



Top View: Layer 4 (Main Confined Aquifer)

Symbol	Legend
———	Pathline to Cao Đinh Wells
- - - -	Pathline to Đông Ngạc and Xuân Đỉnh Wells
	Pumped Cell
	Constant Head
	Dried Cell
--→	Flow Vector
———	Simulated Groundwater Table
-10 ———	Equal Line of Simulated Piezometric Surface (masl)

Case-1 Pumping Plan:

Pumpage of Case-0 with following pumpage:

Đông Ngạc (I=9, J=13) Q = 1,260 m^3/day

Xuân Đỉnh (I-9, J=14) Q = 2,850 m^3/day

Pumping from Layer-4.

Maximum Drawdown = 2.36 m

Figure 7.4.1 **Simulated Groundwater Flow and Pathlines by Case-1 (after 10 years)**

THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)