The groundwater discharge data in the modeled area were prepared from the groundwater use survey by the Study Team. There are ten (10) MWSS wells and twenty-six (26) private wells in the area. Figure 8.4.12 shows the annual groundwater production from 1981 to 1990, based on the monthly production reports of MWSS wells and field investigations of the private wells. Total groundwater production has increased from 11,419 CMD in 1981 to 19,456 CMD in 1990.

The discharge data were arranged for computer simulation. Figures 8.4.13 (1) to 8.4.13 (10) show the year-wise distribution from 1981 to 1990 of discharge which were inputted to the model.

Throughout the nonsteady-state simulation, the storage coefficient was modified through comparison of computed heads with actual heads. Further, the Q3P model was arranged to simulate changes of piezometric heads in 1990 using estimated 3-day recharge and discharge data for the identification of storage coefficient. Figure 8.4.14 shows actual 3-day rainfall, with computed groundwater hydrograph using final storage coefficient ranging from 0.05 to 0.1. The general trends of piezometric changes are reasonably simulated.

Figure 8.4.15 shows the simulated piezometric contours in 1990. The difference between the simulated heads and bottom elevations of the aquifer is shown in Figure 8.4.16. The piezometric heads, which since 1981 have been declining, reached a maximum depth of 16.4m due to the increase of discharge (Figure 8.4.17).

8.4.3 Optimal Pumpage

(1) Future Pumpage Plans

The Antipolo groundwater flow model simulated future piezometric heads for the design of optimal pumpage in the area. The simulated future period is up to the year 2010. Thus piezometric heads of 30 time-steps (30 years) from 1981 to 2010 were simulated continuously.

The following three (3) cases were prepared for future simulation based on the well design of new MWSS wells and the rehabilitation plan.

(a) The discharge of MWSS wells in 1990 will continue up to 2010.

(b) New MWSS wells will be constructed and will pump from years 1991 to 2010 at a rate of 830 CMD per well. The discharge of existing MWSS wells will not change.

(c) New MWSS wells will be constructed and will pump from years 1991 to 2010 at a rate of 830 CMD per well. The discharge of existing MWSS wells will be augmented 207 CMD per well from 1991 by well rehabilitation.

It is assumed in the above cases that the discharge of existing private wells will be the same as that in 1990 and no new private wells will be constructed. It is also assumed that future recharge will be uniform from 1991 to 2010.

(2) Future Recharge Evaluation

The recharge from rainfall is the most important parameter in evaluating the future groundwater potential in the area. As mentioned before, a 10-year recharge estimation was carried out using daily rainfall and daily pan-evaporation data. The estimated recharge takes a wide range from 337.9mm/year to 1310.8mm/year, depending on the amount of precipitation and rainfall pattern.

The long-term statistical analysis of rainfall and recharge aids the evaluation of groundwater recharge. The meteorological data at the Sumulong and Antipolo stations were used for this kind of analysis. Sixty-two (62) years data from 1911 to 1972 were collected and arranged for annual recharge estimation. The annual rainfall and estimated annual recharge are shown in Figure 8.4.18. The average, maximum and minimum recharge for the 26-year period are 636.0mm/year, 223.3mm/year and 1682.6mm/year, respectively.

A probability analysis using the Thomas method was done. The results are shown in Table 8.4.1.

TABLE 8.4.1 RESULTS OF DROUGHT PROBABILITY ANALYSIS OF RECHARGE (26-YEARS DATA OF SCIENCE GARDEN)

Drought Probability	Recharge (mm/year)	Recharge to the Basin (CMD)
(Simple average)	636.0	42,799
2 years	589.9	39,697
3 years	495.1	33,318
5 years	418.8	28,183
10 years	350.2	23,567
20 years	302.0	20,323

For the future simulation, the recharge value of a 5-year drought probability was employed on the safe side. The recharge value of 28,183 CMD is the maximum groundwater potential from the water balance point of view.

(3) Future Simulation

(a) Case (a)

The evaluated recharge and the discharge of 1990 were inputted to the model. Figure 8.4.19 shows that the simulated piezometric heads will decline even though the discharge is the same as that for 1990. The simulated piezometric contours and the heights from the aquifer bottom are shown in Figure 8.4.20 and 8.4.21, respectively. The maximum drawdown from 1991 to 2010 is expected as 52.4m.

(b) Case (b)

The exploitable groundwater potential and possible number and locations of new MWSS wells have been examined under different recharge conditions. The discharge of existing MWSS wells and existing private wells in 1990 will continue up to 2010. The following are the criteria for locating new wells:

i) New wells should be located where the simulated piezometric heights of Case (a) in year 2010 (Figure 8.4.21) are more than 30m because the drawdown of new wells are estimated to be 20m to 21m from static level.

ii) Existing pumping grids should be avoided for the new wells' location.

iii) The total discharge of existing wells and new wells should not exceed the recharge to the basin.

iv) Simulated piezometric heights up to the year 2010 using the new discharge data involve the new wells' discharge. The simulated piezometric heights at the sites of new wells should be more than 21m.

The possible number and locations of new wells were identified under several discharge conditions and are given in Table 8.4.1. Evaluation results are given in Table 8.4.2.

TABLE 8.4.2 AVAILABLE NUMBER OF NEW WELLS AND EXPLOITABLE DISCHARGE UNDER DIFFERENT RECHARGE CONDITIONS

Drought Probability	Recharge (CMD)	Total Discharge (CMD)	Available New Wells	Exploitable Discharge (CMD)
2 years	39,697	36,056	20	16,660
3 years	33,318	30,246	13	10,790
5 years	28,183	27,756	10	8,300
10 years	23,567	22,776	4	3,320
20 years	20,323	20,286	1	830

In this case, the construction of ten (10) new wells may be optimal for future groundwater development in the area.

(c) Case (c)

The plan for the construction of new wells, as well as the augmentation of existing MWSS wells by well rehabilitation, is examined in this case. The discharge of each existing MWSS well will be aug-mented by 207 CMD. So, the total augmentation of existing MWSS wells is:

207 CMD x (10 MWSS existing wells) = 2,070 CMD

Under the recharge conditions of a 5 years drought probability, the total recharge to the basin is estimated as 28,183 CMD. The existing wells were pumping 19,456 CMD in 1990, so that the maximum available water from the new wells is estimated as:

28,183 CMD - 19,456 CMD - 2,070 CMD = 6,657 CMD

The simulation study was carried out to make an optimal plan of groundwater development in the area. Firstly, the piezometric heads in 2010 are computed using the increased discharge of existing wells. The number and location of new wells are determined using the same criteria as Case (b).

As a result, seven (7) new MWSS wells are found to satisfy the criteria. The optimal distribution of future discharge is shown in Figure 8.4.22. Figure 8.4.23 and Figure 8.4.24 show the piezometric contours and piezometric heights from aquifer bottom in 2010, respectively. The piezometric heads will be lower than 100m at the central part of the basin, but the piezometric heights at the new sites will be more than 21m. Figure 8.4.25 shows the piezometric heads will almost be stabilized by the year 2010.

The total discharge in the basin is:

19,456 CMD +2,070 CMD +5,810 CMD (7 new wells) = 27,334 CMD

Figure 8.4.26 shows the estimated discharge and recharge of the optimal plan.

(4) Optimal Plan for Groundwater Development

Under the conditions mentioned above, the optimal groundwater development plan in Antipolo basin is summarized as follows:

i) Rehabilitate existing ten (10) MWSS wells
ii) Construct seven (7) new MWSS wells

However, it should be noted that this optimal plan was made under various assumptions. The most important and problematic assumption is the remaining constant of the future pumpage of private wells. Actually there are many unknown factors to consider to predict future pumpage of privately-owned wells. Although this pumpage may be correlated with population growth, many assumptions will still have to be made.

The optimal plan was carefully examined from the water balance and hydrogeological conditions in the basin. The groundwater potential also was evaluated on the safe side.

From the maximum groundwater potential of 29,287 CMD, existing wells are already pumping 19,456 CMD. So the maximum available water in the future is estimated only as 10,000 CMD.

Some problems may occur during the lowering of piezometric heads as reactions to the groundwater development. One of these problems is the decreasing yield from existing wells because some of these wells are so shallow that they may not be able to yield water at the same rate at present. Some wells may have to install higher capacity pumps.

Since the groundwater potential and source of groundwater recharge are limited in the area, a countermeasure for groundwater conservation should also be taken into account to better utilize the groundwater resources.

8.5 METRO MANILA GROUNDWATER BASIN MODEL

The quasi three-dimensional groundwater flow model (Q3P model) was applied to the aquifer system in the Metro Manila groundwater basin.

The Guadalupe formation and Alluvium comprise a complex confined aquifer system in the Metro Manila groundwater basin.

The eastern margin of the basin is bounded by a hilly area consisting of Pre-Quaternary formations. The aquifer system continues across northern and southern boundaries. The western and southeastern margins are bounded by Manila Bay and Laguna de Bay, respectively.

The hydrogeologic basement in the basin is of Pre-Quaternary formations, but detailed information on basement rocks have not been collected because these are overlain by the thick Guadalupe formation. The thickness of the Guadalupe aquifer system may be more than 1,000m in Manila Bay, but detailed structures about the basement of the Guadalupe formation have yet to be known.

A number of conceptualization and quantification have been made in the representation of the groundwater regime in order to analyze the dynamic behavior of groundwater flow. The aquifer system up to a depth of 300m was modeled as a main confined aquifer because most of the wells in the area extract groundwater at a depth of 300m. The main aquifer is hydraulically connected to the overlying phreatic aquifer through a confining layer.

The finite-element grid used in the model is shown in Figure 8.5.1. The model domain has an area of 1404.7km^2 and is divided into 754 rectangular elements of 1350m x 1380m in size, which correspond to 45 seconds of longitude and latitude. The number of elements in the x and y coordinates are 28 and 35, respectively. The number of nodes in the domain where heads are computed is 829.

8.5.1 Model Parameters and Boundary Conditions

(1) Model Parameters

Input parameters used in the model were collected/measured by the Study Team during Stage I to III. After data processing was completed, input data for the Q3P model were prepared. These parameters were inputted to the model, and then modified and identified through model calibration. The period of model calibration is the ten (10) years from 1981 to 1990.

Model parameters used in the model are as follows.

(a) Transmissivity

Transmissivity was estimated from specific capacity of existing wells data and pumping tests results compiled by the Study Team. The methodology of the estimation was as mentioned in Chapter 4. Figure 8.5.2 shows the inputted transmissivity values which were discretizated from the transmissivity map shown in Figure 3.6.6.

(b) Storage coefficient

The values of storage coefficient were initially and uniformly assigned as $1x10^{-3}$ because of the lack of actual data. During the steady-state and nonsteady-state calculation, the values were modified by comparison of model results with field observations of piezometric heads. The final distribution of storage coefficient is shown in Figure 8.5.3.

(c) Aquitard thickness and permeability

The thickness (b') and permeability (k') of aquitard control the leakage recharge to the confined aquifer as leakance (k'/b'). The aquitard thickness is obtained from the clay content map. The clay content map was prepared from the well columnar sections collected by the Study Team. Figure 8.5.4 shows the discretizated aquitard thickness in the area.

The permeability of aquitard is one of the unknown parameters in the area. Thus, initial values of the permeability were uniformly assigned as $1x10^{-3}$m/d, and then modified and identified throughout the model calibrations. Figure 8.5.5 shows the labels of identified aquitard permeability which were inputted to the model. Figure 8.5.6 shows computed leakance values from the thickness and permeability of aquitard.

(d) Phreatic water level and initial heads

The phreatic water level is an important leakage recharge parameter. This was estimated through geomorphological analysis. A river level map was first made from topographic maps using the same grid to model the area. The phreatic water level was then assumed at 10m below the river level. The obtained phreatic water levels are shown in Figure 8.5.7. The model assumes that the phreatic water levels are invariant during the simulation.

The initial piezometric heads for the steady-state simulation were estimated using the same method mentioned. The initial piezometric heads in 1981 for the nonsteady-state simulation were prepared from the data of MWSP II (1983). Figure 8.5.8 shows the initial heads in 1981.

(e) Direct recharge

The direct recharge area was demarcated as shown in Figure 8.5.9. This area is based on the results of groundwater leveling mentioned in Chapter 5. The model assumes that leakage recharge does not occur at the direct recharge area.

The values of direct recharge were obtained from the water balance study mentioned in Section 3.5 of the Main Report. The input average recharge is 183.1mm/year, which is about 8% of annual rainfall.

(2) Boundary Conditions

Three (3) different boundary conditions were specified based on the hydrogeologic interpretations (Figure 8.5.10). The boundary of the eastern margin of the basin was treated as a no-flow boundary. The northern and southern perimeters of the modeled area where the aquifer extends out were assigned as constant-flow boundaries. Constant-head boundaries were assigned to Manila Bay and Laguna de Bay, at the points where the distance from coastlines is about 5km. The area between constant-head boundaries and actual coastlines can be regarded as cushion zone.

8.5.2 Verification of the Model

(1) Steady-state Simulation

The calibration of the model was initially carried out in steady-state conditions to identify initial heads, storage coefficient, leakance and boundary conditions of the model. The simulated piezometric heads were observed at the selected points shown in Figure 8.5.11. By using a constant year-1981 pumping rate (see Figure 8.5.12) throughout the 30-year period (30 time-steps), groundwater heads were computed on a trial and error basis until the difference between the computed heads and the actual heads in 1981 becomes approximately zero. Figure 8.5.13 shows the changes of piezometric heads at observation points during the steady-state simulation. The simulated piezometric contours after the 30-year steady-state calculation are shown in Figure 8.5.14.

(2) Nonsteady-state Simulation

The nonsteady-state simulation from 1981 to 1990 was carried out to simulate transient groundwater flow and decline of piezometric heads due to groundwater pumpage. The actual piezometric heads in 1981 shown in Figure 8.5.8 were used as initial heads in the model. The leakance and storage coefficient were modified and identified throughout the simulation. The simulation period is divided into 10 time-steps, each time-step having 1 year (365 days).

The groundwater discharge data in the modeled area were prepared from the groundwater use survey by the Study Team. Figure 8.5.15 shows the annual groundwater production from 1981 to 1990 in the modeled area. Total groundwater production decreased from 333.1MCM/year in 1981 to 310.5MCM/year in 1990, but the production of MWSS wells increased from 18.2MCM/year in 1981 to 29.0MCM/year in 1990.

The above discharge data were arranged for computer simulation. Figures 8.5.16 (1) to 8.5.16 (10) show the total discharge maps from 1981 to 1990 which were used in the model. Figure 8.5.17 shows the discharge distribution in 1990.

Throughout the nonsteady-state simulation, leakance and storage coefficient were modified and identified by comparison of computed heads with actual heads. As leakance is the most sensitive parameter in the model, more than hundred times of test simulation was carried out to determine it.

Figure 8.5.18 shows simulated piezometric contours in 1990. The changes of piezometric heads at the observation points are shown in Figure 8.5.19. Recovery of the piezometric heads in the northern part to the center part of Metro Manila (Caloocan, Valenzuela, Manila, the western part of Quezon city, San Juan, Mandaluyong and western part of Pasig) and the Cavite area is reasonably simulated due to decreases of the discharge. However, the piezometric heads in the southern part of Metro Manila (Taguig, Parañaque, Muntinlupa, Las Piñas, Bacoor, Imus, Kawit, Noveleta and Rosario) went down because the discharge increased in those areas.

8.5.3 Prediction of Future Groundwater Levels

The model can simulate future piezometric heads using future recharge and discharge plans. The duration of future simulation is the 20 years from 1991 to 2010. The future piezometric heads are computed based on the simulated piezometric heads of 1990. The model thus computed piezometric heads at 30 time-steps (30 years from 1981 to 2010).

The evaluation of the future recharge to the basin is contained in the water balance study in Section 3.6. Future piezometric heads were predicted using the calibrated model for the following five (5) future groundwater pumpage scenarios:

Scenario 1 : Future pumpage based on Scenario 1 of the water demand projections (see Table 8.5.1)

Scenario 2 : Future pumpage based on Scenario 2 of the water demand projections (see Table 8.5.1)

Scenario 3 : Future pumpage based on Scenario 3 of the water demand projections (see Table 8.5.1)

Scenario 4 : Future pumpage based on Scenario 4 of the water demand projections (see Table 8.5.1)

Scenario 5 : Discharge in 1990 continues up to 2010.

Table 8.5.1 summarizes the characteristics the first four scenarios.

TABLE 8.5.1 CHARACTERISTICS OF THE SCENARIOS

Scenario No.	MWSS Surface Water Supply Projects	Future Pumpage of Commercial & Industrial Private Wells	CDS Connection in Cavite MSA
1	On-schedule completion of ongoing projects	Increasing(1	Bacoor 100% covered, Kawit 50%, others 0%
2	Same as Scenario 1	Increases(2 up to year-2000, thereafter pumpage is constant	All municipalities covered
3	Same as Scenario 1	Increases(2 up to year-1995, thereafter pumpage is constant	All municipalities covered
4	Two-year delay in completion of ongoing projects	Same as Scenario 1	Same as Scenario 1

Note: (1 With respect to future demand increases but maintaining year-1990 percentage shares

(2 With respect to future demand increases and up to the year indicated

Yearly groundwater productions of Scenario 1 to Scenario 4 in the modeled area is shown in Figure 8.5.20. In each graph, groundwater production from 1981 until 1990 is the actual figure. The discharge distribution maps in 2010 of Scenarios 1 and 2 are shown in Figure 8.5.21; those of Scenarios 3 and 4 are shown in Figure 8.5.22.

The results of simulations are follows:

(a) Scenario 1

The simulated piezometric contours in 2010 (Figure 8.5.24 (a)) show a large piezometric depression appearing in northwestern Metro Manila. The piezometric heads at north Valenzuela shall be lower than -170 masl. Also, considerable lowering of piezometric heads shall be seen in the southwestern, southern and eastern parts of Metro Manila. In Cavite, the piezometric heads shall be as deep as -90 masl.

The piezometric changes from 1991 to 2010 are shown in Figure 8.5.26 (a). Piezometric heads in 2010 shall rise at the southern part of Quezon City and in Metro Manila, i.e., in Parañaque, Las Piñas and Bacoor. A maximum rise of 20m of piezometric head is pre-dicted at the coastal area of Las Piñas because of decrement in pumpage. However, piezometric heads will go down at the northern and southern parts of Metro Manila. Significant drawdowns such as 83m in north Valenzuela, 57m in Cavite and 37m in Pasig are predicted.

Figure 8.5.28 (a) shows that piezometric heads in Cavite and Caloocan City shall decline in the period 1991 to 2000, and then stabilize after that. A constant decline shall be seen in Pasig for the period 1991 to 2010. Piezometric heads in Las Piñas for the period 1991 to 2000 shall rise, but will go down gradually after 2005.

(b) Scenario 2

A large piezometric depression shall be seen in northwestern part of Metro Manila (Figure 8.5.24 (b)). The lowest piezometric head will be -149 masl at north Valenzuela. An area of low piezometric heads where the heads range from -60 to -80 masl lies from Cavite to Marikina through Muntinlupa and Parañaque.

From year-1991 onward, the piezometric heads shall go down 59m north of Valenzuela and 33m in Cavite (see Figure 8.5.26 (b)). Piezometric heads will decline in most of Metro Manila for the period 1991 to 2000, then stabilize or slightly recover after

2001 as shown in Figure 8.5.28 (b).

(c) Scenario 3

This scenario is the most ideal case in which all ongoing projects will be completed on schedule and be able to supply surface water to the area. But the simulated piezometric contours still show a large depression as deep as -134 masl in northern part of Metro Manila (Figure 8.5.25 (a)).

Piezometric heads in 2010 shall be higher than those in 1990 for north Valenzuela and Cavite, respectively, 50m and 29m (Figure 8.5.27 (a)). Recovery of piezometric heads shall occur in almost all areas of Metro Manila for the period 2001 to 2005 due to decreasing of pumpage (Figure 8.5.28 (c)).

(d) Scenario 4

This is the scenario where the maximum groundwater discharge could be found. The discharge shall increase for the periods 1991 to 2000 and 2005 to 2010. As a result, the simulated piezometric heads (Figure 8.5.25 (b)) will be lower than those in Scenario 1.

The drawdowns of piezometric heads are estimated at 90m in north Valenzuela and 56m in Cavite (Figure 8.5.27 (b)). Piezometric heads in most of Metro Manila shall show significant declines until the year-2000, afterwhich the decline will become gradual or stable (Figure 8.5.28 (d)).

(e) Scenario 5

This case assumes that the discharge of 316.572MCM in 1990 continues up to 2010. As shown in Figure 8.5.23, piezometric heads in 2010 relative to piezometric heads in 1990 shall recover at a maximum of 10.7m at the central part of Metro Manila. Decline of piezometric heads shall be seen at the northern, eastern (along Marikina River), and southern to southwestern parts of Metro Manila. The expected maximum drawdowns are 21.7m (at the northern part of Quezon City) and 16.9m (in Rosario, at the southern part of

Metro Manila).

The results of simulation show that the maximum drawdown of 50m will occur even in Scenario 3 where the discharge is the smallest among the future groundwater use plans. This may cause severe saline water intrusion and damage even inland areas.

8.5.4 Permissible Groundwater Pumpage

The simulation study shows the large drawdown of piezometric heads in Metro Manila to be caused by heavy pumpage. The changes of piezometric levels are mainly influenced by the changes of pumpage. Although some parts of Metro Manila have already been under overdeveloped conditions, and as wells become more numerous, development of the basin reaches and exceeds its natural recharge capability. If this overdevelopment continues thereafter without a management plan, depletion of groundwater resources could occur.

In the simulation model, the piezometric heads are computed as a result of water balance in the aquifer system. In other words, the groundwater level indicates a balance between the quantity of water supplied to the basin and the amount extracted from the basin.

The lowering of piezometric heads causes seawater intrusion, land subsidence, worsening groundwater quality, decrease well yield, and so on. Therefore, a permissible water level should be established to prevent these risks and to optimize utilization of the water in the basin. The permissible water level is determined not only from geologic and hydrologic considerations but also from the economic, legal, political, and financial standpoints.

To prevent further saline water intrusion in Metro Manila, the groundwater exploitation should be controlled. Several future discharge plans have been made to simulate the relations between reductions of groundwater pumpage and piezometric changes.

(1) Pumpage control settings

The following settings/assumptions were made in planning future groundwater pumpage:

Regulated area

A regulated area for groundwater pumpage was established along the coastal area of Metro Manila (Figure 8.5.29) after considering the present piezometric heads, positions of saline water intrusion, future plans for surface water supply, etc. The area covers fifteen (15) municipalities, viz., Caloocan City (south), Valenzuela, Malabon, Navotas, Manila, Makati (western part), Pasay city, Parañaque, Las Piñas (northern part), Bacoor (northern part), Imus (northern part), Cavite, Kawit, Noveleta and Rosario.

Time schedule

The regulation of pumpage is assumed to begin in 1996, with the target regulated pumpage being reached by year-2000. The 5-year period from 1991 to 1995 is considered for investigation and preparation; pumpage in this period follows Scenario 1. After year-2000, the target regulated pumpage is maintained up to year-2010. Pumpage outside the regulated areas follows Scenario 1, i.e., from 1991 up to 2010.

Regulated pumpage

A target regulated pumpage is set based on the year-1990 pumpage. The reduction of pumpage will be done for both MWSS and private wells using one reduction rate. Seven (7) pumpage regulation plans were made for the simulations:

Plan (a): Year-1995 pumpage of Scenario 1 is maintained up to 2010.
Plan (b): Target regulated pumpage by 2000 is the 1990 pumpage.
Plan (c): Target regulated pumpage by 2000 is 90% of the 1990 pumpage.
Plan (d): Target regulated pumpage by 2000 is 80% of the 1990 pumpage.
Plan (e): Target regulated pumpage by 2000 is 70% of the 1990 pumpage.
Plan (f): Target regulated pumpage by 2000 is 60% of the 1990 pumpage.
Plan (g): Target regulated pumpage by 2000 is 50% of the 1990 pumpage.

The discharge distribution of the above plans in 2010, including Scenario 1, are shown in Figure 8.5.30 and Figure 8.5.31. The yearly groundwater production of the future plans are shown in Figure 8.5.32 and Figure 8.5.33.

(2) Results of simulations

Table 8.5.2 summarizes the results of simulation. The simulated piezometric heads in 2010 are given in Figure 8.5.34 and Figure 8.5.35. Figure 8.5.36 and Figure 8.5.37 show simulated piezometric changes from 1991 to 2010. Simulated piezometric changes over time at the observation points are shown in Figure 8.5.38 and Figure 8.5.39.

Plan (a) is the most lenient, in which the discharge in the regulated area increases by 14.4 MCM/year from 1991 to 1995. With this plan, maximum drawdowns of 40.2m and 28.5m are expected by 2010 in the northern and southern parts of Metro Manila, respectively.

Plan (b) has the 1995 pumpage reduced to the 1990 pumpage level by year 2000. Maximum drawdowns of 9.7m in the north and 18.7m in the south are predicted, mainly due to the increase in pumpage between 1991 and 1995.

Plan (c) to Plan (g) reduce the 1995 pumpage to target regulated pumpages which are less than the 1990 pumpage level. The recovery of the piezometric heads depends upon the level of the target regulated pumpage in year 2000. Maximum recoveries of 55.3m in the north and 30.7m in the south are expected in Plan (g). In Plan (g), the lowest piezometric head shall be -50 masl in Valenzuela.

Regional piezometric head recoveries may differ from place to place. While recoveries may be large in the northern part of Metro Manila, they may be small in the southern part. In Cavite, the piezometric head recovers only by 12.4m under Plan (g). In most cases, such phenomenon could be explained by the dynamic groundwater flow. That is, the groundwater in the regulated area flows towards the piezometric head depressions in Muntinlupa and Parañaque where pumpage is greater and not regulated.

There is a need for piezometric heads to recover from the present heads to prevent further saline water intrusion in the future. For this purpose, the future discharge in the regulated area should be reduced to at least 80% of the 1990 pumpage. But, due to the existence of piezometric depression mentioned above, the saline water may intrude further landward in southern Metro Manila even though the piezometric heads in the coastal area have recovered.

The velocity of saline water intrusion the in Las Piñas-Muntinlupa area can be roughly estimated using the simulated piezometric heads in 2010 of Plan (g). If the simulated piezometric heads are assumed to be constant, a maximum hydraulic gradient in the area would be 0.032. Using a transmissivity value of $33.6m^2/d$ (or a permeability of 1.12m/d) obtained from the pumping tests at the test wells in Las Piñas, the velocity can be computed by Darcy's Law:

$$v = Q/A = (kAi)/A = ki = 1.12 \times 0.032 = 13.08m/year$$

where v is the velocity, Q is the flowing rate, A is the area, and i is the hydraulic gradient. Actually, the flow is limited to the pore space only so that the average interstitial velocity va is:

$$va = Q/pA$$

where p is porosity. The effective porosity in the area is estimated as 0.05 so that the actual flow velocity is computed as 262.8m/year. The distance between the present front of saline water and the center of depression in Muntinlupa is 4,050m, therefore the saline water will reach the depression after 15.4 years.

The results of these simulations indicate the necessity of discharge regulation not only in the coastal area but also in the inland area.

8.6 SALINE WATER INTRUSION MODEL

The Las Piñas area is one of those Metro Manila areas most affected by saline water intrusion. The saline water intrusion may have been caused by the decline of the groundwater head which resulted from the increase in groundwater pumpage. The source of saline water in Las Piñas might be seawater, but the mechanism has yet to be clarified.

Generally, in coastal areas like Las Piñas, saltwater occurs underground, not at sea level but at a depth below it which is about 40 times the height of the fresh water above sea level. This phenomenon, which is generally referred to as the Ghyben-Herzberg relation, is attributed to a hydrostatic equilibrium existing between two fluids of different densities. But in many areas with extensive groundwater development, the Las Piñas area included, a hydrodynamic equilibrium may exist due to the dynamic groundwater flow caused by groundwater extraction, so the Ghyben-Herzberg relation cannot be applied directly.

Most researchers have approached the seawater intrusion problem by describing the landward movement of a discrete interface between seawater and freshwater. This approach assumes that seawater infiltrates solely from an offshore outcrop of the aquifer. If, however, a coastal aquifer is overlain by a leaky confining layer, this assumption is often inappropriate because seawater can potentially migrate from above. A discrete interface approach does not consider such leakage.

Therefore, in applying this approach to the Las Piñas area poses some difficulties : (1) the aquifer system is divided into a shallow aquifer and deeper aquifers by leaky confining layers; (2) both the confined aquifers and the confining layers tilt toward the sea; and (3) the groundwater flow is very much disturbed by groundwater pumping so that the pattern of saltwater intrusion is different from that of the Ghyben-Herzberg relation.

According to the measurement of electric conductivity (EC) logging and water quality analysis in Las the Piñas area, saline water occurs in shallow aquifers up to a depth of 100m below mean sea level. In contrast, EC values and chloride concentration in deeper aquifers decrease with depth. This may occur because seawater and saline surface water are forced to infiltrate into the underground with the lowering of piezometric heads by groundwater extraction.

The two-dimensional solute transport and dispersion models was employed to verify this hypothesis and to understand the mechanism of saline water intrusion. This model may also aid in predicting the quantity and location of saltwater resulting from future groundwater utilization or regulation.

The solute transport model was originally developed for plane two-dimensional problem, but it has been modified for vertical two-dimensional multiple aquifers system to allow for more detailed analysis of results. The two-dimensional flow equation in the vertical plane may be written as

$$\left(Kxx\frac{\partial^2 h}{\partial x^2}\right)_l + \left(Kyy\frac{\partial^2 h}{\partial y^2}\right)_l = \left(Ss\frac{\partial h}{\partial t}\right)_l + W(x,y,t)$$

where,

Kxx : the permeability in x-direction, L/T;
Kyy : the permeability in y-direction, L/T;
h : the hydraulic head, L;
Ss : the specific storage, 1/L;
W(x,y,t): the volume flux per unit area, L/T; and
l : the identification number of the layer.

The continuity between the two layers is expressed as

$$\left(Kyy\frac{\partial h}{\partial y}\right)_l = \left(Kyy\frac{\partial h}{\partial y}\right)_{l+1}.$$

A vertical two-dimensional model was made along the geological section line shown in Figure 8.6.1. The section line is almost perpendicular to the coastal line. The line which is taken as the x-axis for the model is divided into 40 nodes. Each nodal spacing is 100m and the width of 100m for each side of the line is taken into account for model domain.

Figure 8.6.2 shows the grid of the vertical two-dimensional model. Vertically, the elevations from +30m to -330m are modeled. Each cell is 15m-thick so that the volume of each cell is 15m x 100m x 200m = .sr0 300,000m^3.

The computer program of the solute-transport model allows a grid to have up to 40 rows and 40 columns for groundwater flow calculations. Because the numerical procedure requires that the outer rows and columns represent no-flow boundaries, the aquifer itself is limited to a maximum of 38 rows and 38 columns. Further, the grid size for transport calculation is limited to 20 rows and 20 columns which can be assigned to any area of the flow grid.

Therefore, the grid size for the flow calculation in Las Piñas was fixed 24 rows and 40 columns, and transport subgrid size at 20 rows and 20 columns (see Figure 8.6.2).

Hydrogeologic unit of each cell, viz., Alluvial clay, aquifer (sand) and aquiclude (clay) have been specified (Figure 8.6.3) based on the hydrogeological section made in the study.

8.6.1 Model Parameters and Boundary Conditions

(1) Model Parameters

Input parameters used in the model were those collected/measured by the Study Team during Stage I to III. After data processing was completed, input data for the MOC model were prepared. The parameters were inputted to the model, then modified and identified through model calibration.

Model parameters used in the model are as follows:

(a) Transmissivity

Transmissivity values of the aquifers came from the results of the pumping tests conducted in the test wells by the Study Team. Transmissivity of aquiclude was estimated from the core observation.

Table 8.6.1 summarizes the aquifer parameters of the hydrogeologic units. The apparent transmissivity (Taxx) which was inputted in the model was computed as Kxx x 200m because the width of each cell is 200m. The ratio of longitudinal transmissivity (Tyy) to transverse transmissivity (Txx) is assumed as 0.1 because the aquifer systems may be anisotropic due to the sedimental structure.

TABLE 8.6.1 HYDROGEOLOGICAL UNITS AND AQUIFER PARAMETER

Hydrogeologic unit (label)	Actual transmissivity Txx(m^2/d)	Permeability Kxx(m/d)	Apparent transmissivity Taxx (ft^2/s)
Alluvium (A)	(4.4)	1.46×10^{-1}	3.6×10^{-3}
Aquifer-1 (B)	220.0	7.30	181.9×10^{-3}
Aquiclude-1(C)	(4.4)	1.46×10^{-1}	3.6×10^{-3}
Aquifer-2 (D)	61.2	2.04	50.8×10^{-3}
Aquiclude-2(E)	(2.4)	8.00×10^{-2}	2.0×10^{-3}
Aquifer-3 (F)	33.6	1.12	27.9×10^{-3}
Aquiclude-3(G)	(2.4)	8.00×10^{-2}	2.0×10^{-3}
Aquifer-4 (H)	(30.0)	1.00	24.9×10^{-3}

( ): estimated values

Figure 8.6.4 shows the transmissivity map inputted in the model.

(b) Storage coefficient

Storage coefficient was uniformly set to zero for the steady-state simulation.

(c) Aquifer thickness

Apparent thickness of aquifer for the model was uniformly set to 200m (656.2ft) in the modeled domain because the width of each cell is modeled as 200m. The actual aquifer thickness is the total thickness of the aquifer cells.

(d) Leakance

In this model constant-head boundaries were simulated by adjusting the leakance. A sufficiently high value (such as 1.0/s) was assigned at constant-head boundaries. In the rest of the area leakance was modeled as 0. The actual leakance in the aquifer system was expressed as (permeability of aquiclude)/(thickness of aquiclude).

(e) Initial heads

The initial heads were set at 0m except the uppermost cells representing the ground surface, the sea and marine pond. The water levels in the uppermost cells were treated as constant. Phreatic water levels were estimated from the topography.

(f) Direct recharge

The groundwater recharge was estimated from the water balance study. Because the actual area of each cell is 200m x 100m = 20,000m^2 the input recharge values were computed as

Input recharge at each cell(m^3)
= 20,000m^2 x estimated recharge(m^3/m^2)

The obtained recharge values were given to the uppermost cells representing ground surface.

(g) Discharge

The groundwater discharge was estimated from the results of the groundwater use survey. The location of pumping wells within the model domain were projected on the vertical grid. If the well structure was known, the depth of the well and the screen positions were also projected; otherwise, they are assumed. The discharge values were distributed into the cells where the screens are located (Figure 8.6.5). It is assumed that if a cell expresses an aquiclude, groundwater is not extracted from the cell.

(h) Initial chloride concentration

The initial chloride concentration of the domain was set at 0mg/l except the cells representing the sea and marine ponds. The chloride concentration of seawater and marine ponds water is assumed 21,500mg/l.

(i) Transport parameters

Several parameters were assigned for the transport simulation. Table 8.6.2 summarizes inputted transport parameters.

TABLE 8.6.2 TRANSPORT PARAMETERS

Maximum number of particles	6400
Initial number of particles per node	9
Reaction specifier	NO REACTION
Effective porosity	0.05
Longitudinal dispersivity	7.00ft
Ratio of transverse to longitudinal dispersivity	1.0
Source concentration	21500mg/l

(2) Boundary Conditions

As shown in Figure 8.6.2, outer flows and columns of the flow grid were treated as no-flow boundaries. It was assumed that the phreatic water levels in the uppermost cells are constant so that the constant-head boundary condition was assigned to these cells. Cells which are located in the sea, rivers and marine ponds were also treated as constant-head boundaries.

8.6.2 Steady-State Simulation

Steady-state simulation was carried out for identification of the model. Duration of the simulation is 10 years, with values of input discharge and recharge being obtained from year-1990 data. The calculated piezometric heads show good agreement with the observed values without modification of hydrogeological parameters (Figure 8.6.6).

After computing the groundwater flow, the solute transport model was calibrated. The boundary conditions of initial chloride concentration, effective porosity, longitudinal and transverse dispersivity were modified during model calibration. Figure 8.6.7 shows chloride concentration after a 10- year simulation using finalized parameters and boundary conditions.

During model verification, several sets of parameters were prepared and inputted into the model in order to compare the saline water movement. The location of the source, and dispersivity were changed for this purpose.

(1) Saline Water Movement versus Time

The movement of saline water was studied under steady-state conditions. Figure 8.6.8 shows the steady-state piezometric contours in the flow grid and solute transport grid. Changes of chloride concentration were monitored at four (4) observation points, with these points coinciding with screen positions of the test wells as shown in Table 8.6.3.

TABLE 8.6.3 OBSERVATION POINTS IN THE MODEL

Observation Point	Name of Test Well (depth)
Obs-1	LPS2-3 (100m)
Obs-2	LPS2-2 (200m)
Obs-3	LPS2-1 (300m)
Obs-4	LPS3-1 (300m)

Figure 8.6.9 to Figure 8.6.11 show changes of concentration over time. The saline water moves downward and reaches the bottom of Aquiclude-1 by 2.2 years since simulation started. After passing Aquiclude-1, the saline water intrudes in Aquifer-2 along the flow direction towards the low piezometric heads. By 7.1 years since simulation started, the forefront of saline water reaches the center of piezometric depression in Aquifer-3. After 10 years, the 2000mg/l-contour reaches the center of piezometric depression.

Figure 8.6.12 shows changes of chloride concentration at the observation points. The chloride concentration increases from the first year since simulation started at Obs-1, and then rises steeply from the second to the fourth year. By the sixth year the concentration shows a salinity that is almost as high as seawater.

At Obs-2, the chloride concentration rises in the fourth year since simulation started. It then increases gradually and reaches 13,000mg/l after 10 years of simulation. At Obs-3 the concentration after 10 years is only 33mg/l. Saline water appears after 6 years of simulation.

The saline water appears at Obs-4 after 5 years of simulation. The concentration after then increases constantly and reaches 6,000 mg/l by 10 years.

(2) Source of Saline Water and Dispersivity

In order to identify the source of saline water, it was modeled that the sources of saline water be located at Manila Bay (x=3,y=2) and a marine pond (3,8). In this study it is assumed that the chloride concentrations of sea water and marine pond water are the same.

Figure 8.6.13 shows simulated chloride concentrations after 4.4 years and after 10 years. The longitudinal and transverse dispersivity is 7.0ft. The saline water from Manila Bay mainly goes downward in Aquifer-1 and intrudes slowly towards inland in Aquifer-2. The forefront moves 200m in the lateral direction. In contrast, the saline water from the marine pond goes downward in Aquifer-1, and then moves as far as 1400m in Aquifer-2 and Aquifer-3, towards the center of piezometric depression. All these observations indicate the significant contribution of marine ponds and salty rivers to the saline water intrusion.

The simulated chloride concentration using 33.0ft of longitudinal and transverse dispersivity is shown in Figure 8.6.14. The locations of saline water sources are the same as those in Figure 8.6.13. The results show that the saline water from both the sea and the marine pond disperses wider than the previous case. The saline water moves more downwards so that the contour of 2,000mg/l does not reach the center of piezometric depression. The saline water from the sea moves only 300m in the lateral direction even in this case. However, the simulated distribution of saline water is different from the actual distribution so that the dispersivity should be smaller than 33ft.

(3) Mechanism of Saline Water Intrusion

Above results show that the groundwater flow patterns greatly affect the movement of saline water. The marine ponds also substantially contribute to the saline water occurrence. To illustrate: If the source of saline water is only the sea, the distribution of saline water is very limited near the shoreline; in case the source of the saline water is assumed to be both the sea and marine ponds, the result shows good agreement with the actual saline water distribution and concentration.

8.6.3 Future Movement of Saline Water

The groundwater flow pattern in the future will be different from the present pattern because the locations and amount of discharge may be changed. Subsequently, the pattern of saline water occurrence may also be different.

The future movement of saline water will be controlled by the future pumpage in the area. It is easily predicted that if the existing depression of piezometric heads moves more inland, or a new bigger depression is formed deeper inland, the saline water also moves deeper inland. Also, if deeper wells are constructed to extract from deeper aquifers, the saline water may intrude more deeper portions.

According to the future water demand projections, the groundwater discharge in Las Piñas, Muntinlupa and Parañaque will decrease in the future, but the discharge in Cavite area will increase. Under Scenario 1, the results of the groundwater flow simulation in Metro Manila show that large piezometric depressions will occur in Cavite, in the southern part of Las Piñas, and in Muntinlupa and Parañaque in the year 2010. This will cause further saline water intrusion in the area.

As already discussed in Subsection 8.5.4, the piezometric depressions will remain in Muntinlupa and Parañaque even with the regulation of discharge in the coastal area. In this case saline water from Manila

Bay will move towards the depressions, because the piezometric heads in the coastal area where saline water is already present are higher than those in the inland area.

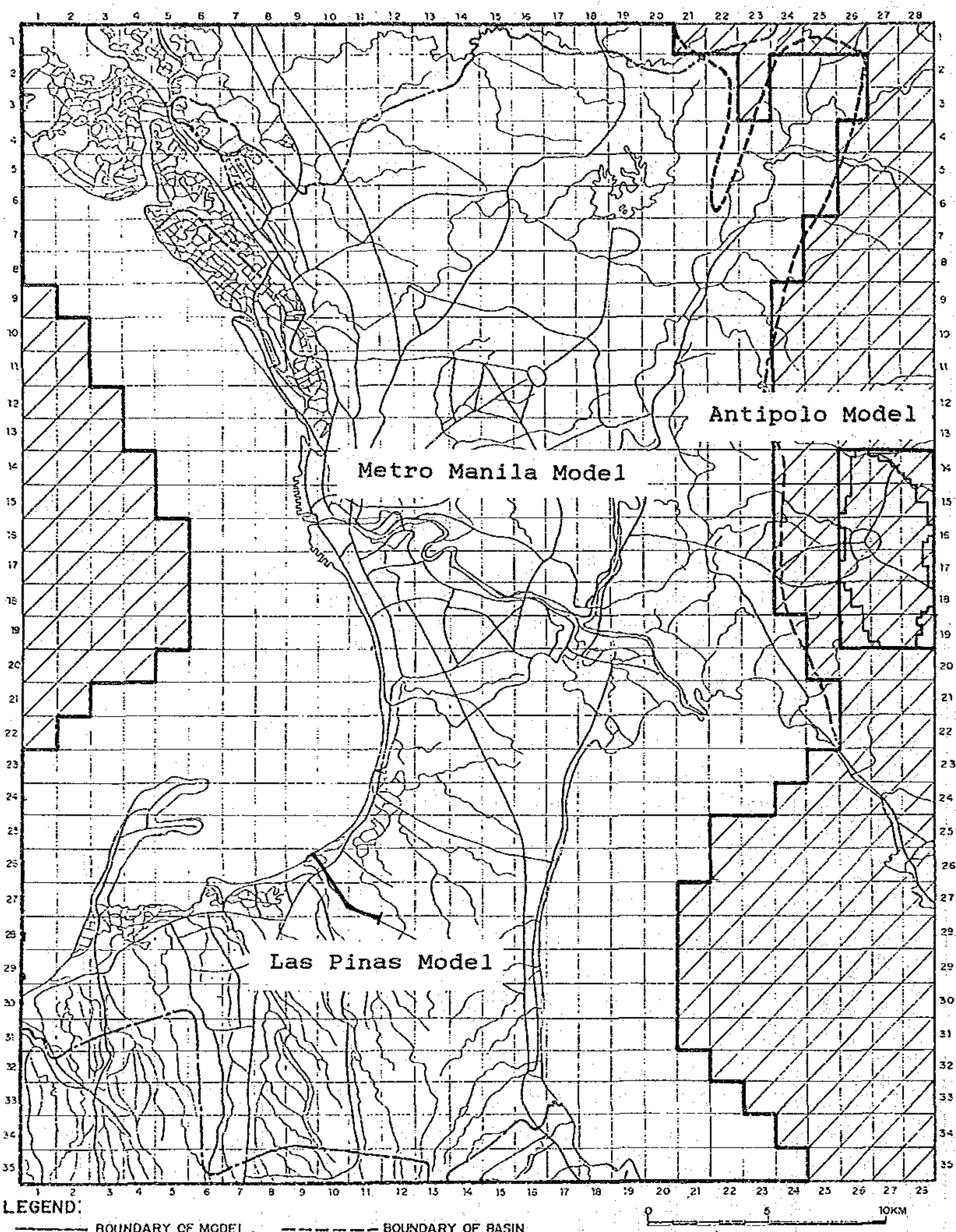
The model can simulate the future movement of saline water and its concentration, as well as future piezometric heads, after future plans of well locations and pumpage have been prepared.

TABLE 8.5.2 RESULTS OF REGULATED DISCHARGE SIMULATION

Regulation Plan	Pumpage in 2000 (upper:Metro Manila) (lower:Modeled area) (MCM)	Reduction of pumpage in regulated area (Compare to 1990) (MCM)	Lowest head in regulated area (in 2010)		Maximum head change in regulated area('10-'90)		Simulated head in 2010(upper)(masl) Head change since 1990(lower)(masl)			
			(north) (masl)	(south) (masl)	(north) (m)	(south) (m)	VLZ (masl)	CLC (masl)	MNL (masl)	CVC (masl)
(Scenario 1)	409.301 364.859	-39.653	-173.1 (VLZ)	-88.5 (CVC)	-83.1 (VLZ)	-57.4 (CVC)	-173.1 -83.1	-126.7 -51.1	-80.8 -26.7	-88.5 -57.4
a) The 1995's pumpage of Scenario 1 continues up to 2010.	394.039 349.597	-14.384	-130.2 (VLZ)	-74.2 (LPS)	-40.2 (VLZ)	-25.8 (ROS)	-130.2 -40.2	-102.1 -26.5	-63.7 -9.6	-47.5 -16.4
b) Regulated to the 1990's pumpage by 2000.	379.655 335.213	0.000	-102.7 (CLC)	-80.6 (LPS)	-9.7 (VLZ)	-18.7 (ROS)	-95.9 -5.9	-72.6 3.0	-45.2 8.9	-32.7 -1.6
c) Regulated to 90% of the 1990's pumpage by 2000.	369.857 325.415	9.798	-92.6 (CLC)	-76.4 (LPS)	14.7 (CLC)	12.8 (MNL)	-87.1 2.9	-65.6 10.0	-41.3 12.8	-29.9 1.2
d) Regulated to 80% of the 1990's pumpage by 2000.	360.060 315.618	19.595	-82.5 (CLC)	-72.2 (LPS)	24.8 (CLC)	16.7 (MNL)	-78.2 11.8	-58.3 17.3	-37.4 16.7	-27.1 4.0
e) Regulated to 70% of the 1990's pumpage by 2000.	350.260 305.818	29.393	-72.3 (CLC)	-68.0 (LPS)	35.0 (CLC)	20.5 (MNL)	-69.3 20.7	-51.1 24.5	-33.6 20.5	-24.3 6.8
f) Regulated to 60% of the 1990's pumpage by 2000.	340.462 296.020	39.190	-62.2 (CLC)	-63.8 (LPS)	45.1 (CLC)	24.4 (MNL)	-60.4 29.6	-43.9 31.7	-29.7 24.4	-21.5 9.6
g) Regulated to 50% of the 1990's pumpage by 2000.	330.653 286.211	48.988	-52.0 (CLC)	-59.6 (LPS)	55.3 (CLC)	30.7 (BCR)	-51.6 38.4	-36.7 38.9	-25.8 28.3	-18.7 12.4

BCR: Bacoor, CLC: Caloocan, CVC: Cavite, LPS: Las Piñas, MNL: Manila, ROS: Rosario, VLZ: Valenzuela

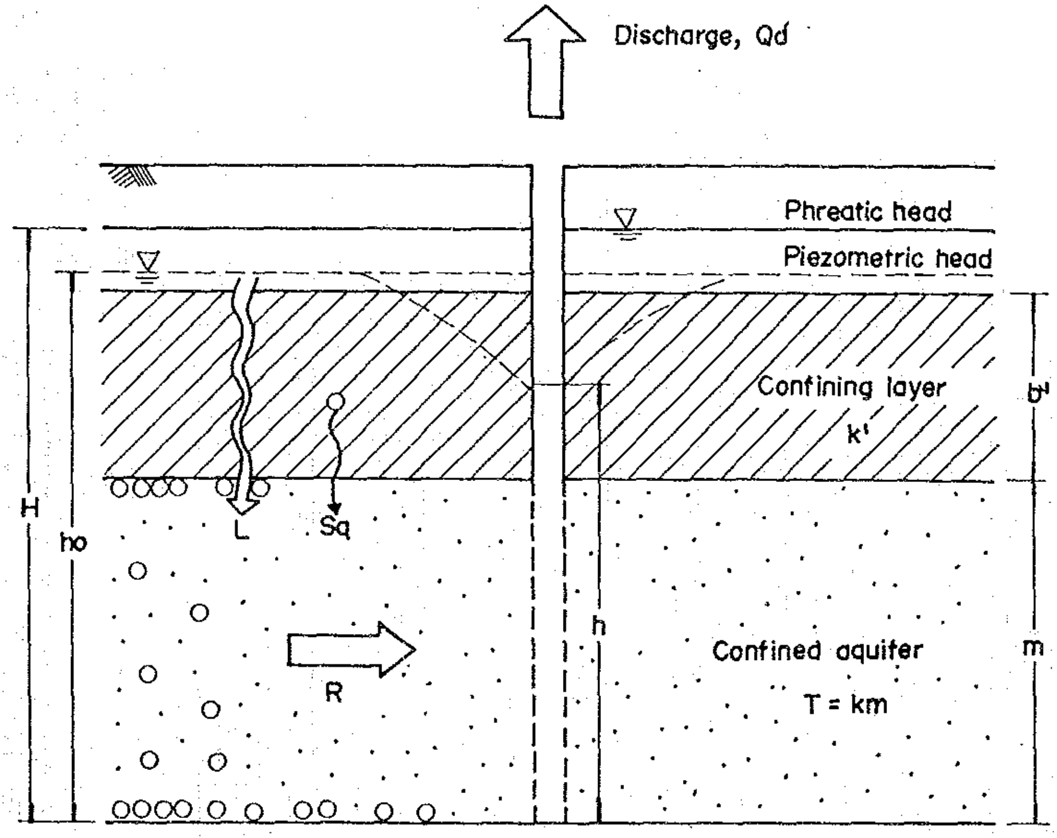
* The total discharge in entire Metro Manila is 339.611MCM in 1990, the dicharge in the modeled area is 316.572MCM in 1990.



LEGEND:
——— BOUNDARY OF MODEL, - - - - - - BOUNDARY OF BASIN

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA
JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.1
LOCATION OF GROUNDWATER MODELING

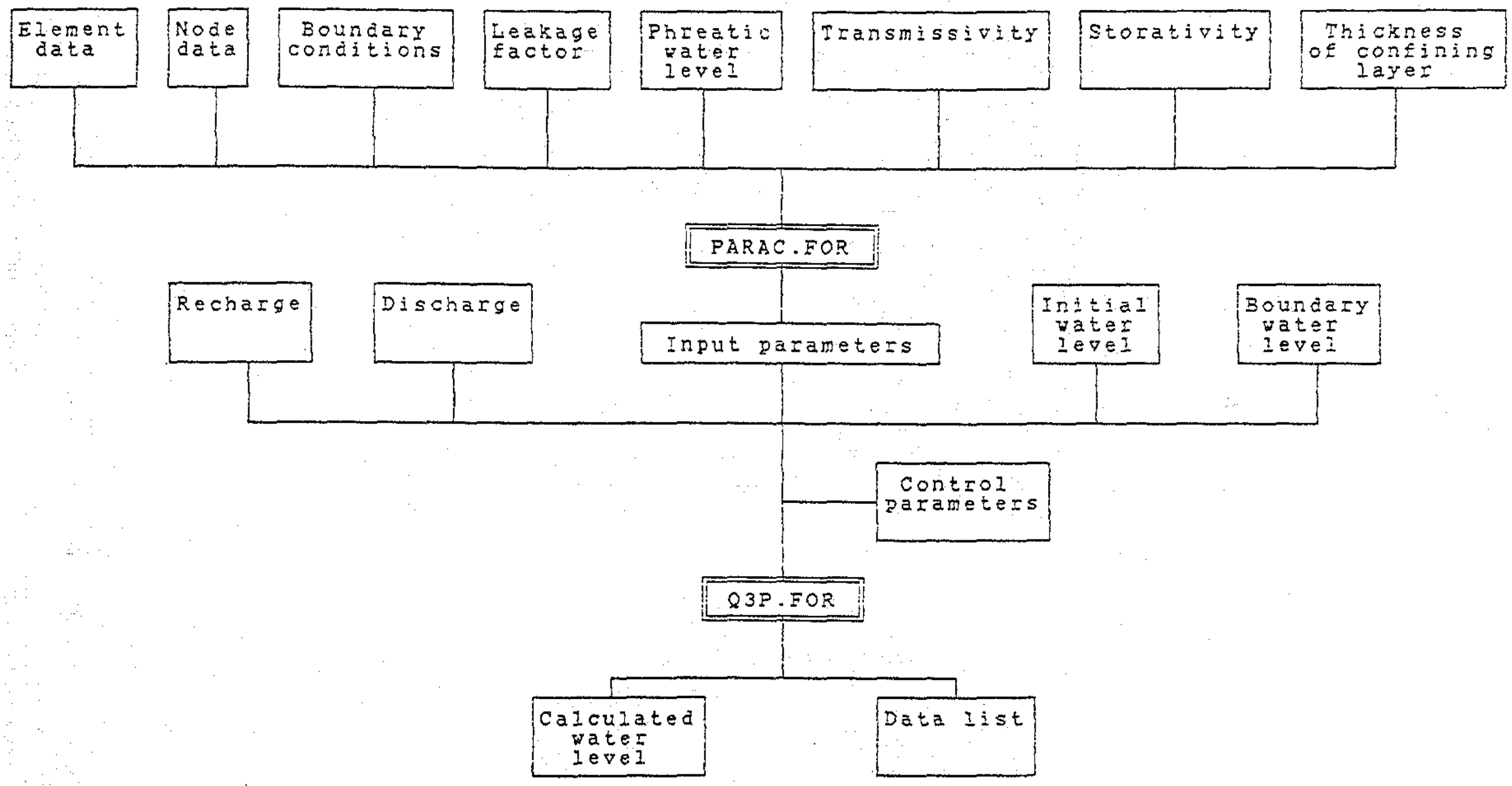


STUDY FOR THE GROUNDWATER DEVELOPMENT
IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.2.1

SCHEMATIC CROSS-SECTION OF THE
QUASI THREE-DIMENSIONAL MODEL

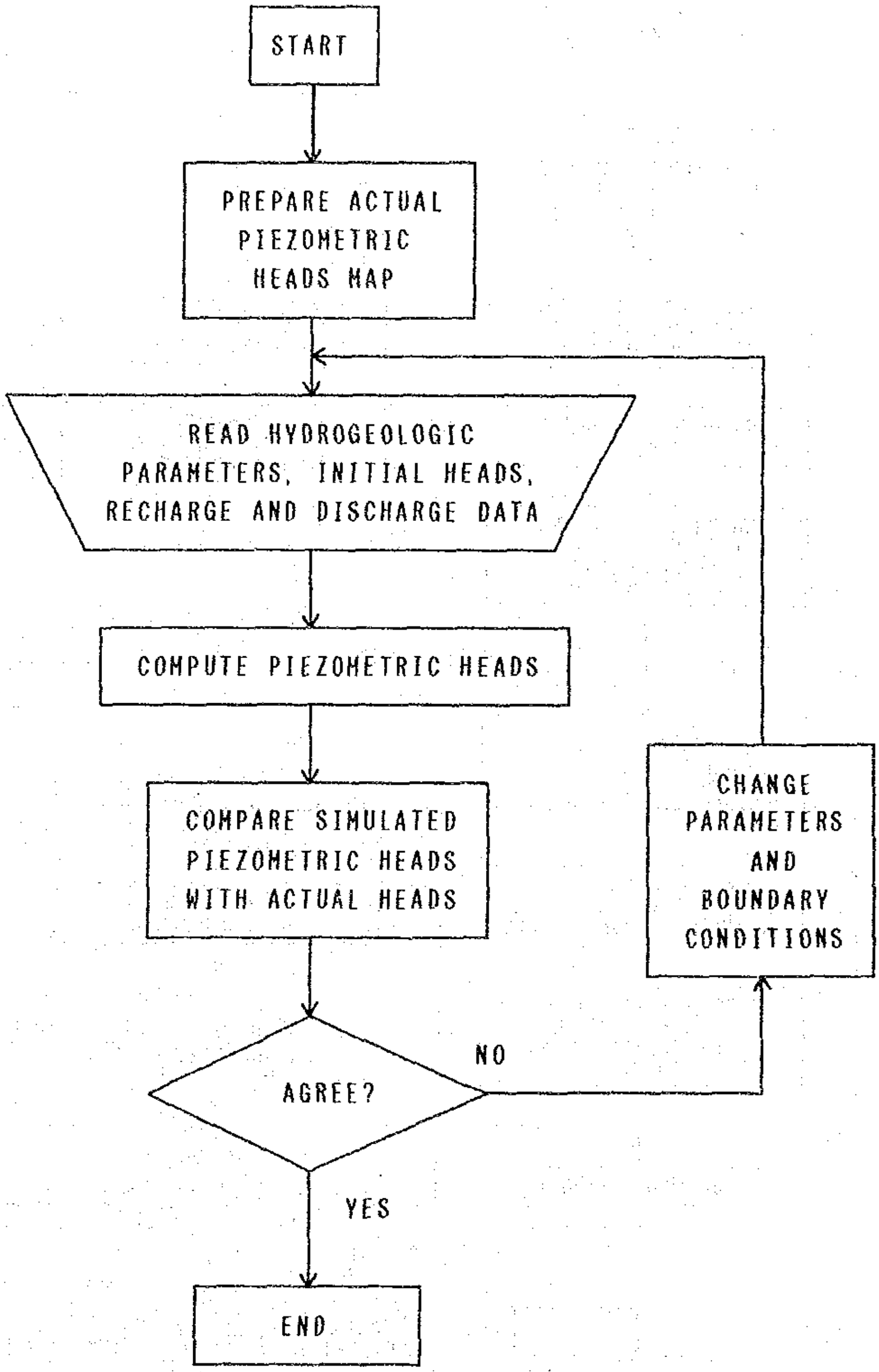


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

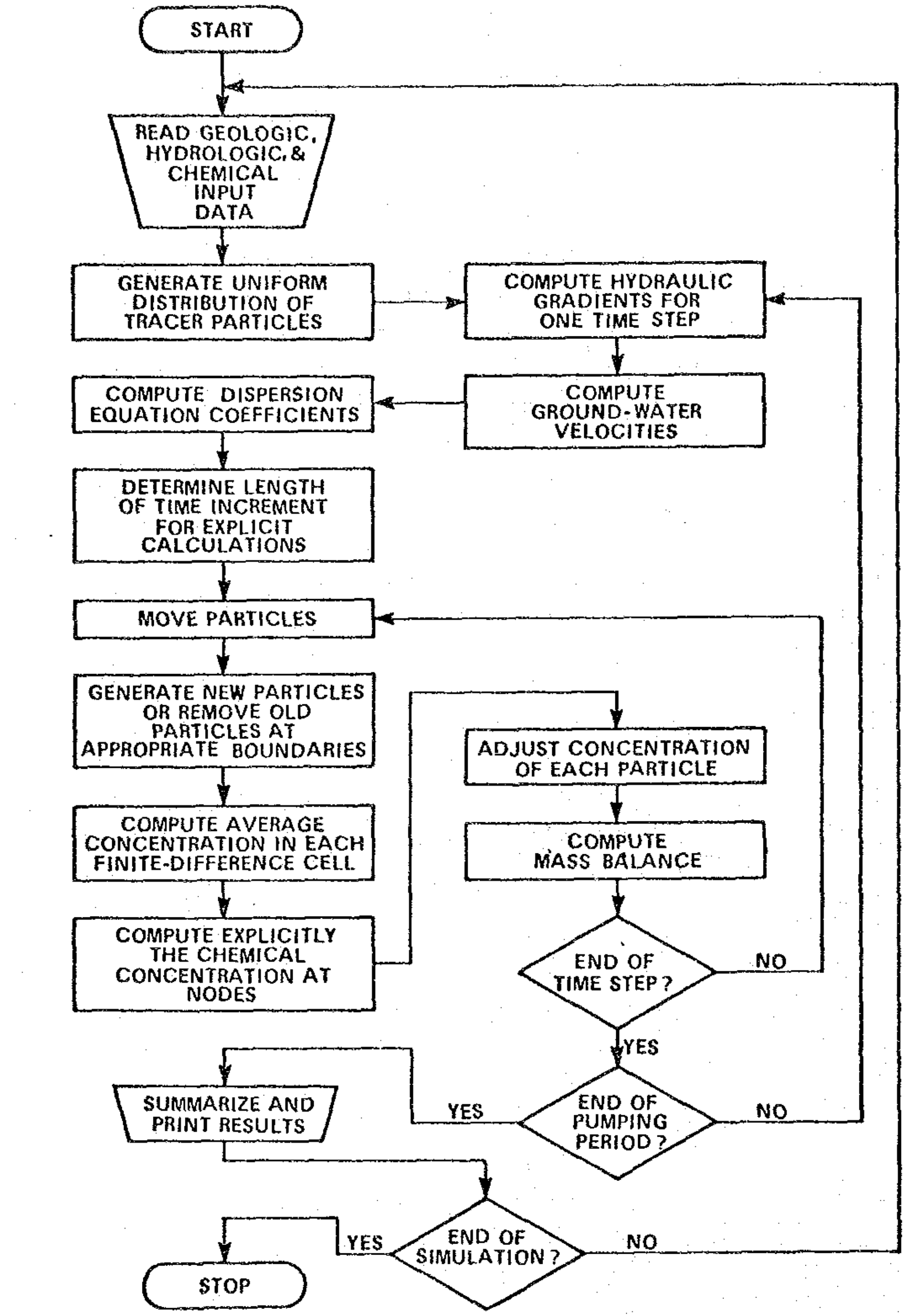
JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.2.2

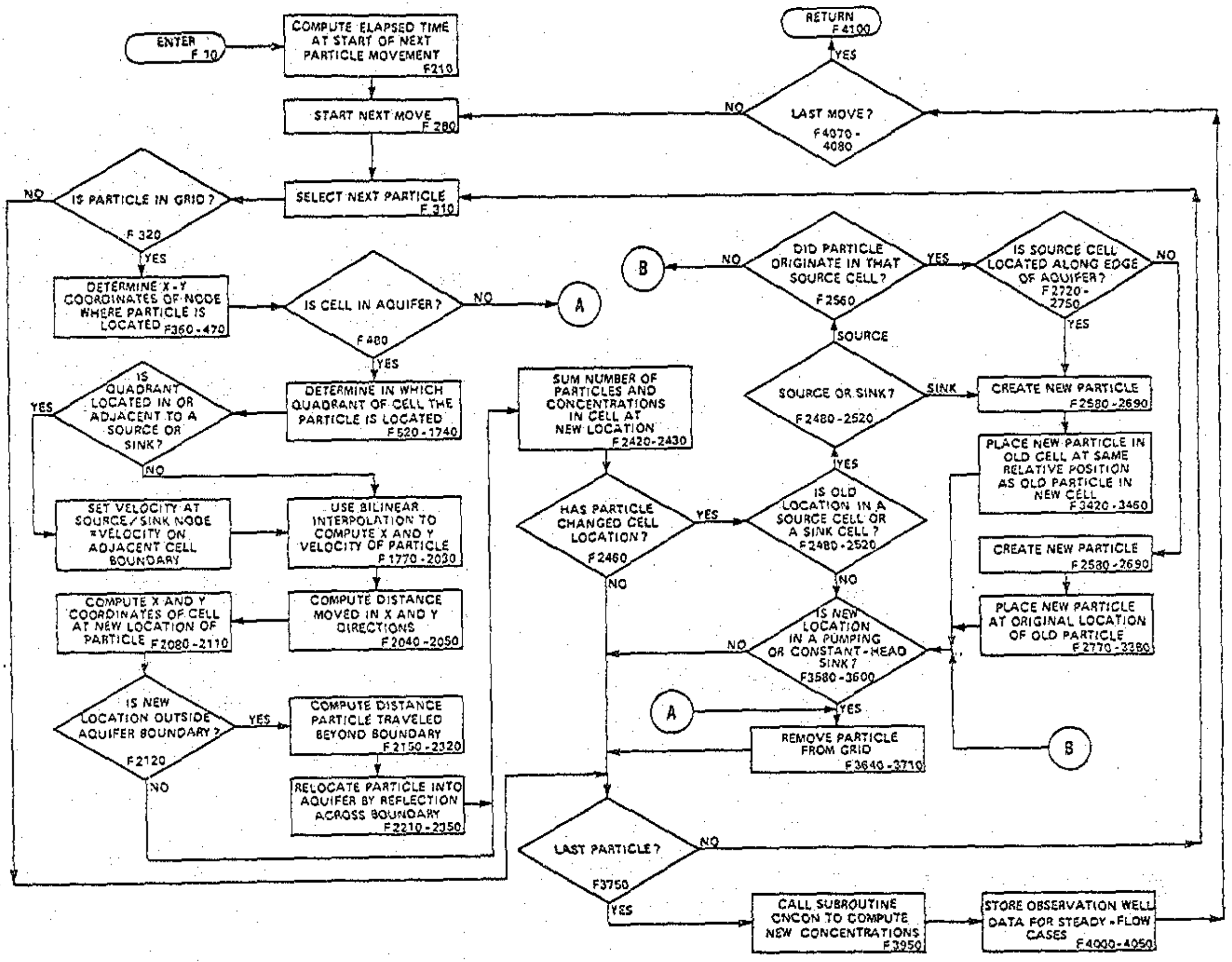
SIMPLIFIED FLOW CHART OF THE QUASI THREE-DIMENSIONAL FEM FLOW MODEL (Q3P)



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.2.3
JAPAN INTERNATIONAL COOPERATION AGENCY	SIMPLIFIED FLOW CHART OF THE COMPUTATIONAL PROCEDURE



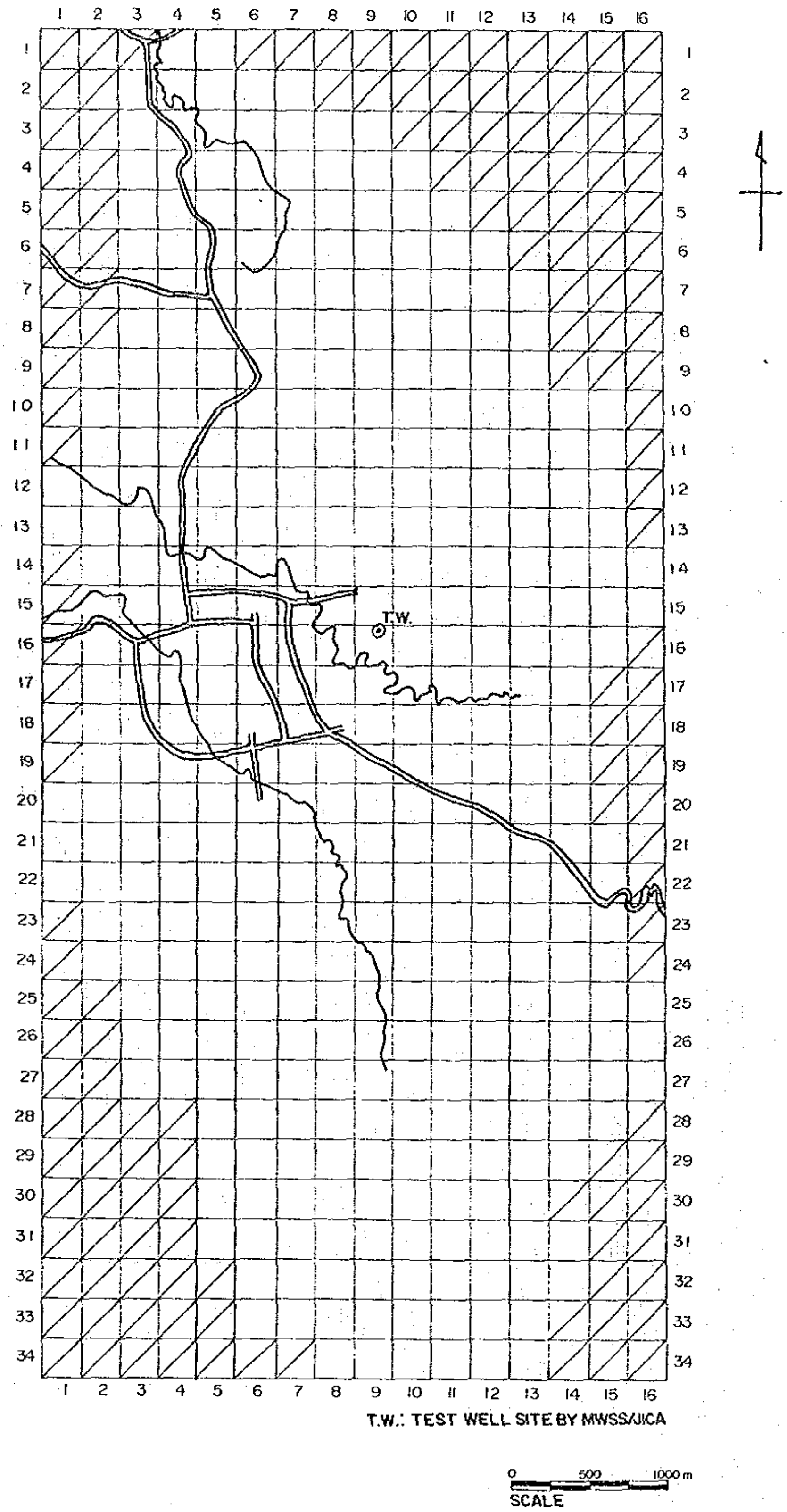
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.3.1
JAPAN INTERNATIONAL COOPERATION AGENCY	SIMPLIFIED FLOW CHART ILLUSTRATING THE MAJOR STEPS IN THE CALCULATION PROCEDURE



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.3.2
GENERALIZED FLOW CHART ILLUSTRATING THE PARTICLE TRACKING PROCEDURE IN THE SOLUTE TRANSPORT CALCULATION

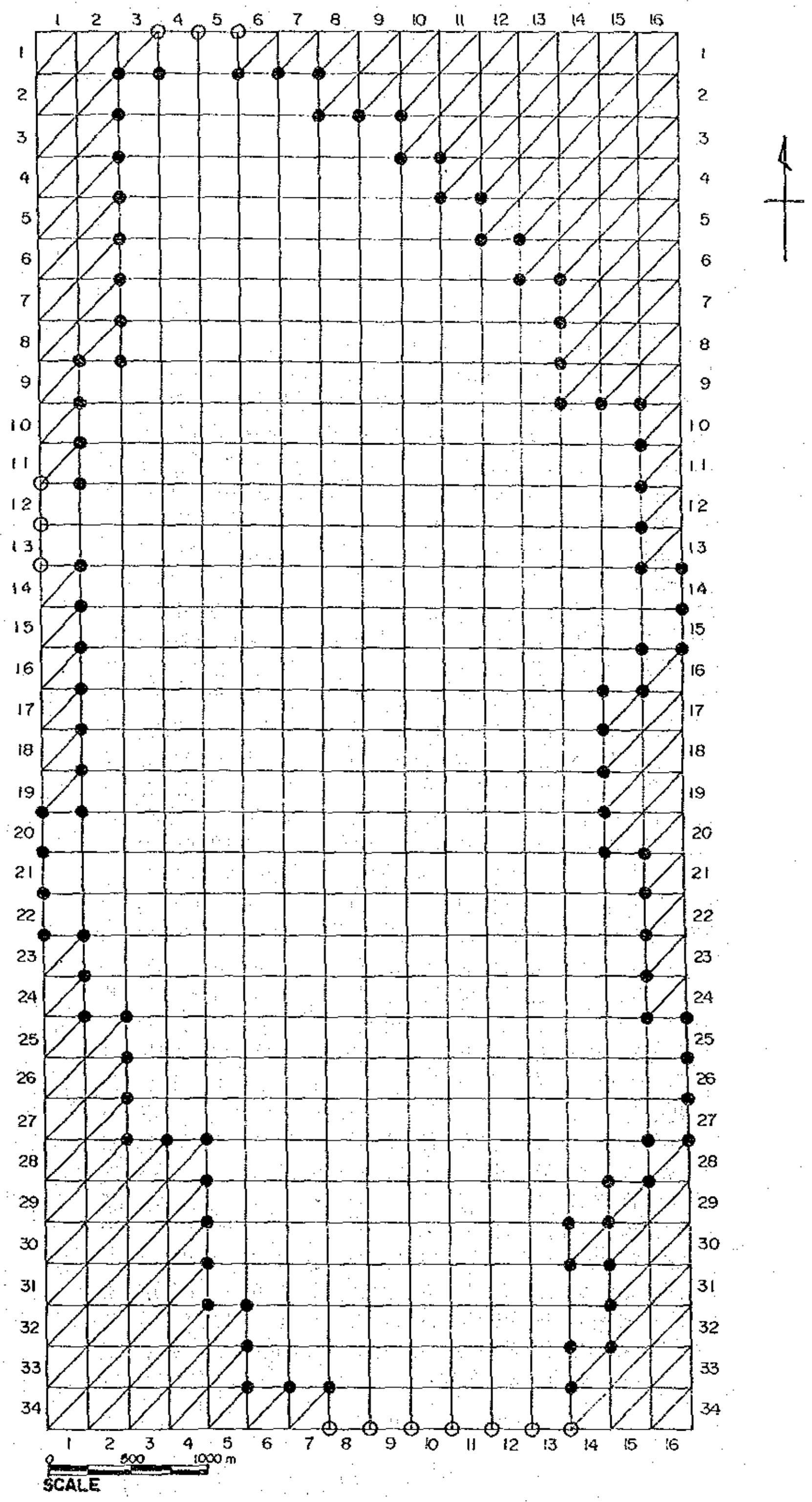


T.W.: TEST WELL SITE BY MWSS/JICA

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.4.1
FINITE-ELEMENT GRID USED TO MODEL THE ANTIPOLO BASIN



LEGEND:

● NO-FLOW BOUNDARY

○ CONSTANT-HEAD BOUNDARY

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.4.2
JAPAN INTERNATIONAL COOPERATION AGENCY	BOUNDARY CONDITIONS FOR THE ANTIPOLO GROUNDWATER BASIN MODEL

```
   1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16
 19999999999992000200099999999999999999999999999999999999999999999   1
 29999999 500 500 500 500 500999999999999999999999999999999999999   2
 39999999  75 250 250 250  75 500 5009999999999999999999999999999   3
 49999999  10  10 250 250 250  75  75 50099999999999999999999999   4
 59999999  75  10  75  75 250 250  75  75 5009999999999999999999   5
 69999999  75  10  10  75  75 250  10  10  10 500999999999999999   6
 79999999  75  75  10  10  10 250  10  75  10  10 50099999999999   7
 89999999  75  75  75  75  75  10  10  75  75  10 50099999999999   8
 99999  75  75 250 250 250 250  75  75  75  75  10 50099999999999   9
109999  75  75 250  75  75  75  75  75  75 150 150  10 500 5009999  10
119999  75  75 250  75  75  75  75 150 150  75 150 150  10 5009999  11
121000 250 250 250 250  75  75 150 150  75  75 150  75  10 5009999  12
131000 250 250 250 250 250 250 250 150 150  75  75 150  10 5009999  13
149999 250 150 250 250 250 250 250 150 150  75  75  75  75  10 500  14
159999 250 250 150 150 150 150 150 150 150  75  75  75  75  10 500  15
169999 250 250 250 150 150 150 150 150  75  75  75  75  10 5009999  16
179999 250 150 250 150 150 150 150 150 150 150  75  75 50099999999  17
189999 250 150 250 150 150 150 150 150 150 150  75  75 50099999999  18
199999 250 150 150 250 150 150 150 150 150  75  75  75 50099999999  19
202000 250 250  75  75 250 250 150 150  75  75  75  75 50099999999  20
212000 250 250  75  75  75 150 150 150  75  75  75  75  10 5009999  21
222000  75 250  25  25  75 150 150 150  75  75  75  75  10 5009999  22
239999 500  10  25  25  25  75 150 150 150  75  75  75  10 5009999  23
249999 500  10  25  25  25  25  75 150 150  75  75  75  10 5009999  24
2599999999 500  10  25  25  25  75  75  75  75  75  75  75  10 500  25
2699999999 500  10  25  25  25  75  75  75  75  75  75  75  10 500  26
2799999999 500 500  10  25  75  75  75  75  75  75  75  75  10 500  27
289999999999999999 500  10  75  75  75  75  75  75  75  75  759999  28
299999999999999999 500  10  75  75  75  75  75  75  75  7599999999  29
309999999999999999 500  10  75  75  75  75  75  75  759999999999  30
319999999999999999 500  10  75  75  75  75  75  75  75  7599999999  31
3299999999999999999999 500  10  75  75  75  75  75  75  7599999999  32
3399999999999999999999 500 500  10  75  75  75  75  759999999999  33
349999999999999999999999999999200020002000200020002000999999999999  34
   1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16
```

(UNIT : m^2/d)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.4.3
JAPAN INTERNATIONAL COOPERATION AGENCY	FINAL DISTRIBUTION OF TRANSMISSIVITY

```
     1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16
 1999999999999  13999999999999999999999999999999999999999999999999999   1
 299999999  13  10  13  13  13999999999999999999999999999999999999999   2
 399999999  13  13  10  13  13  13  139999999999999999999999999999   3
 499999999  13  13  13  10  13  13  13  13999999999999999999999999   4
 599999999  13  13  13  13  13  13  13  13  1399999999999999999999   5
 699999999  13  13  13  13  13  13  13  13  13  139999999999999999   6
 799999999  13  13  13  13  13  13  13  13  13  13  13999999999999   7
 899999999  13  13  13  13  13  13  13  13  13  13  13999999999999   8
 99999  13  13  13  13  13  13  13  13  13  13  13  13999999999999   9
109999  13  13  13  13  13  13  13  13  13  13  13  13  13  139999  10
119999  13  13  13  13  13  13  13  13  13  13  13  13  13  139999  11
12  13  10  10  10  13  13  13  13  13  13  13  13  13  13  139999  12
13  13  13  13  10  13  13  13  13  13  13  13  13  13  13  139999  13
149999  13  13  13  10  10  10  10  13  13  13  13  13  13  13  13  14
159999  13  13  13  13  13  13  13  13  13  13  13  13  13  13  13  15
169999  13  13  13  13  13  13  13  13  13  13  13  13  13  139999  16
179999  13  13  13  13  13  13  13  13  13  13  13  13  1399999999  17
189999  13  13  13  13  13  13  13  13  13  13  13  13  1399999999  18
199999  13  13  13  13  13  13  13  13  13  13  13  13  1399999999  19
20  13  13  13  13  13  13  13  13  13  13  13  13  13  1399999999  20
21  13  13  13  13  13  13  13  13  13  13  13  13  13  13  139999  21
22  13  13  13  13  13  13  13  13  13  13  13  13  13  13  139999  22
239999  13  13  13  13  13  13  13  13  13  13  13  13  13  139999  23
249999  13  13  13  13  13  13  13  13  13  13  13  13  13  139999  24
2599999999  13  13  13  13  13  13  13  13  13  13  13  13  13  13  25
2699999999  13  13  13  13  13  13  13  13  13  13  13  13  13  13  26
2799999999  13  13  13  13  13  13  13  13  13  13  13  13  13  13  27
289999999999999999  13  13  13  13  13  13  13  13  13  13  139999  28
299999999999999999  13  13  13  13  13  13  13  13  13  1399999999  29
309999999999999999  13  13  13  13  13  13  13  13  13999999999999  30
319999999999999999  13  13  13  13  13  13  13  13  13  1399999999  31
3299999999999999999999  13  13  13  13  13  13  13  13  1399999999  32
3399999999999999999999  13  13  13  13  13  13  13  13999999999999  33
349999999999999999999999999999  13  13  13  13  13  13999999999999  34
     1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16
```

(S= 1x10^(x/10), UNIT : dimensionless)

STUDY FOR THE GROUNDWATER DEVELOPMENT
IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.4.4

FINAL DISTRIBUTION OF
STORAGE COEFFICIENT

```
      1     2     3     4     5     6     7     8     9    10    11    12    13    14    15    16    17
 19999.99999.99999.9  90.0  87.0  85.09999.99999.99999.99999.99999.99999.99999.99999.99999.99999.99999.9   1
 29999.99999.9  92.4  89.9  89.5  91.1 104.4 106.99999.99999.99999.99999.99999.99999.99999.99999.99999.9   2
 39999.99999.9  92.3  93.4  95.1  99.5 104.3 114.4 125.0 126.99999.99999.99999.99999.99999.99999.99999.9   3
 49999.99999.9  99.3  98.1 102.9 107.8 113.4 121.2 124.5 133.4 138.79999.99999.99999.99999.99999.99999.9   4
 59999.99999.9 139.1 136.1 112.3 113.3 120.2 125.4 131.1 138.3 144.3 149.89999.99999.99999.99999.99999.9   5
 69999.99999.9 144.3 143.8 124.1 124.0 127.0 130.7 133.5 141.7 149.4 155.7 161.59999.99999.99999.99999.9   6
 79999.99999.9 149.7 150.5 150.7 134.4 132.8 137.7 138.9 166.7 169.5 161.9 166.2 172.19999.99999.99999.9   7
 89999.99999.9 152.9 153.2 154.6 156.6 156.4 145.1 143.1 171.8 174.2 177.0 174.1 173.59999.99999.99999.9   8
 99999.9 151.0 152.6 154.3 155.7 157.8 159.6 161.6 168.2 173.9 177.3 178.9 178.3 178.09999.99999.99999.9   9
109999.9 148.8 150.2 153.4 154.9 157.9 161.0 164.4 170.6 175.4 180.0 182.1 180.7 183.4 187.7 188.49999.9  10
119999.9 141.2 143.7 151.4 153.0 158.5 163.9 169.0 174.3 178.0 181.0 183.4 185.4 187.0 188.2 189.19999.9  11
12 103.0 116.1 136.1 147.7 153.4 158.5 165.7 171.7 175.6 178.4 181.8 185.8 187.0 188.2 190.8 190.79999.9  12
13 108.0 121.2 135.7 146.9 154.6 160.1 166.8 171.9 175.3 179.1 182.9 186.8 189.2 190.8 192.6 192.59999.9  13
14 140.0 126.1 140.2 149.8 156.5 162.2 167.3 171.9 175.4 179.9 183.1 187.9 190.9 192.5 193.5 194.6 195.8  14
159999.9 146.6 148.6 154.4 158.9 163.7 168.1 172.3 176.2 180.6 183.9 188.9 192.2 194.5 195.7 196.2 196.0  15
169999.9 155.2 156.1 158.7 162.5 166.0 168.8 172.7 177.5 181.1 185.0 189.7 193.3 195.4 197.2 196.9 196.4  16
179999.9 161.4 161.3 162.8 165.0 168.1 170.4 174.0 178.6 182.3 186.3 189.6 193.8 197.2 197.5 197.39999.9  17
189999.9 166.6 166.7 167.2 167.4 169.5 172.5 175.8 179.8 183.2 186.2 189.0 194.0 197.6 197.89999.99999.9  18
199999.9 171.3 171.3 170.2 170.5 172.5 175.1 177.5 180.9 183.9 185.1 187.7 193.8 198.2 198.59999.99999.9  19
20 177.0 176.6 174.8 174.0 173.6 176.4 179.0 180.5 182.9 185.0 185.4 187.1 192.8 199.2 199.39999.99999.9  20
21 177.1 177.1 177.0 177.1 178.9 180.1 181.2 183.4 186.1 187.5 189.7 191.1 194.5 199.4 201.8 203.89999.9  21
22 177.4 177.4 178.2 178.8 181.6 184.4 186.1 187.3 189.2 190.8 193.4 196.0 198.5 200.3 204.4 204.29999.9  22
23 177.5 177.7 178.6 180.2 187.0 188.5 189.2 190.5 191.9 193.6 196.0 198.7 200.9 202.5 205.4 205.49999.9  23
249999.9 178.2 178.2 186.5 188.7 192.2 192.7 192.8 193.4 194.9 196.9 200.2 202.4 203.9 206.4 206.39999.9  24
259999.9 178.1 177.6 177.6 189.8 192.8 194.5 194.6 194.4 195.5 197.8 200.7 203.0 204.7 206.6 207.2 207.6  25
269999.99999.9 176.1 176.3 187.1 189.7 192.8 193.7 194.3 195.7 197.8 200.1 202.4 204.4 205.7 207.7 207.6  26
279999.99999.9 174.8 173.8 173.5 165.3 187.0 189.8 191.7 193.6 195.8 198.2 200.6 202.7 204.3 207.7 207.6  27
289999.99999.9 174.1 173.5 168.7 165.6 183.7 185.2 187.3 189.5 191.9 194.5 197.2 200.0 202.3 207.0 207.6  28
299999.99999.99999.99999.9 162.1 162.6 177.4 178.9 181.0 183.5 186.2 189.1 192.3 196.0 199.8 203.59999.9  29
309999.99999.99999.99999.9 156.9 157.0 169.0 170.4 172.7 175.6 178.8 182.1 185.2 190.1 196.19999.99999.9  30
319999.99999.99999.99999.9 150.4 151.3 157.9 159.0 162.5 165.7 169.6 173.5 177.0 176.6 173.59999.99999.9  31
329999.99999.99999.99999.9 148.5 140.4 135.8 149.2 149.2 153.6 158.4 163.9 168.5 171.3 172.29999.99999.9  32
339999.99999.99999.99999.99999.9 130.6 127.2 124.8 136.5 137.3 144.9 153.5 160.8 166.2 170.99999.99999.9  33
349999.99999.99999.99999.99999.9 127.6 125.1 107.6 106.1 116.3 128.4 143.0 155.3 159.99999.99999.99999.9  34
359999.99999.99999.99999.99999.99999.99999.9  95.0 105.0 110.0 130.0 142.0 157.0 170.09999.99999.99999.9  35
      1     2     3     4     5     6     7     8     9    10    11    12    13    14    15    16    17
```

(UNIT : masl)

STUDY FOR THE GROUNDWATER DEVELOPMENT
IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.4.5

COMPUTED INITIAL HEADS IN 1981

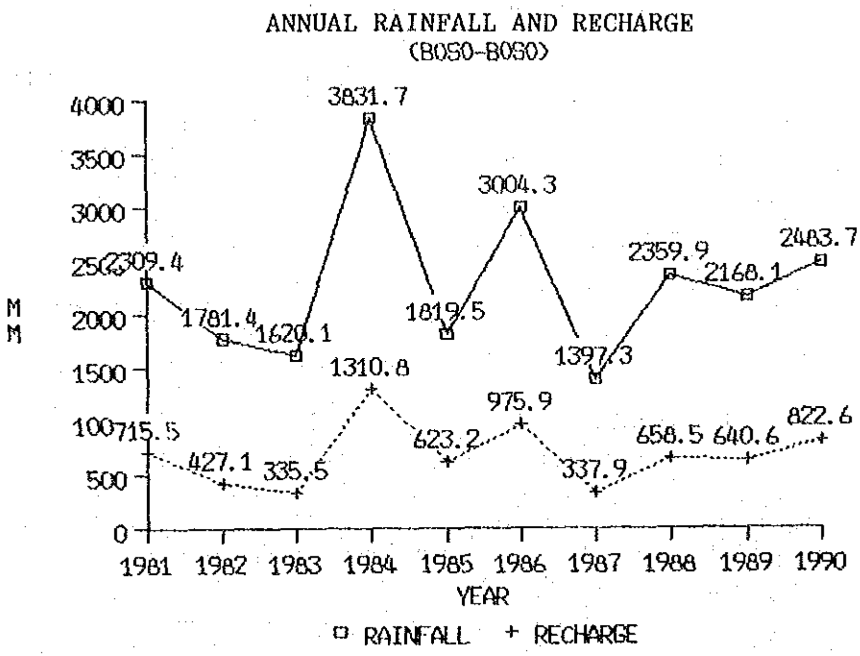


FIGURE 8.4.6 ANNUAL RAINFALL AND ESTIMATED RECHARGE AT BOSO-BOSO STATION .

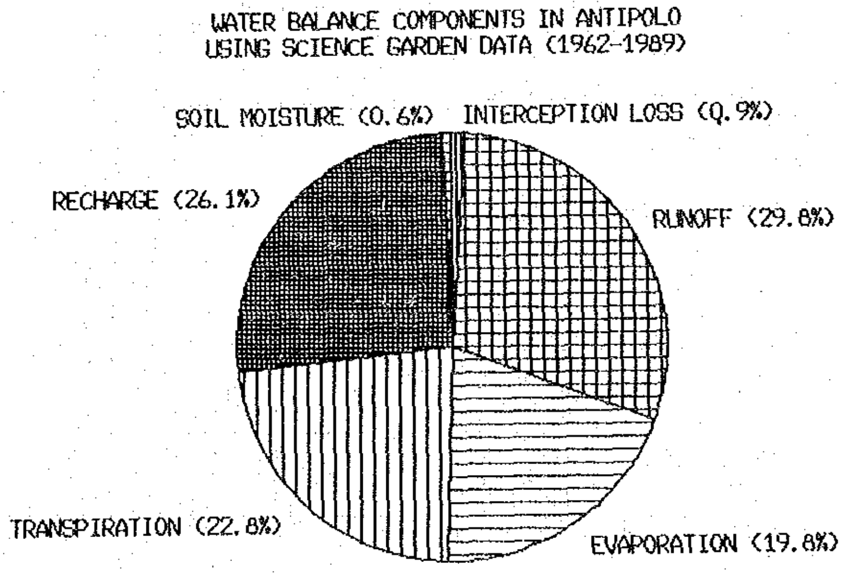
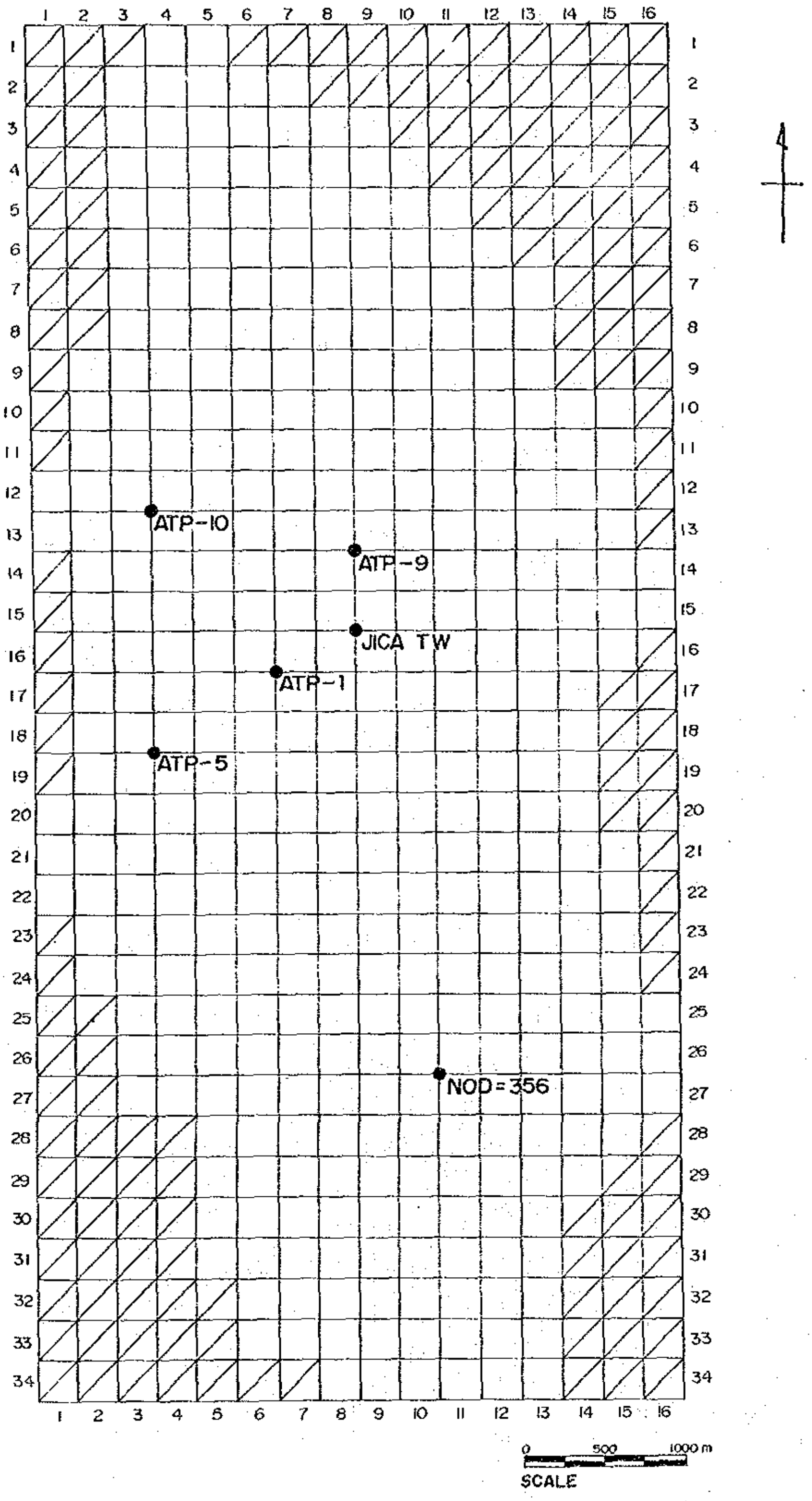


FIGURE 8.4.7 WATER BALANCE COMPONENTS IN THE ANTIPOLO BASIN USING SCIENCE GARDEN DATA

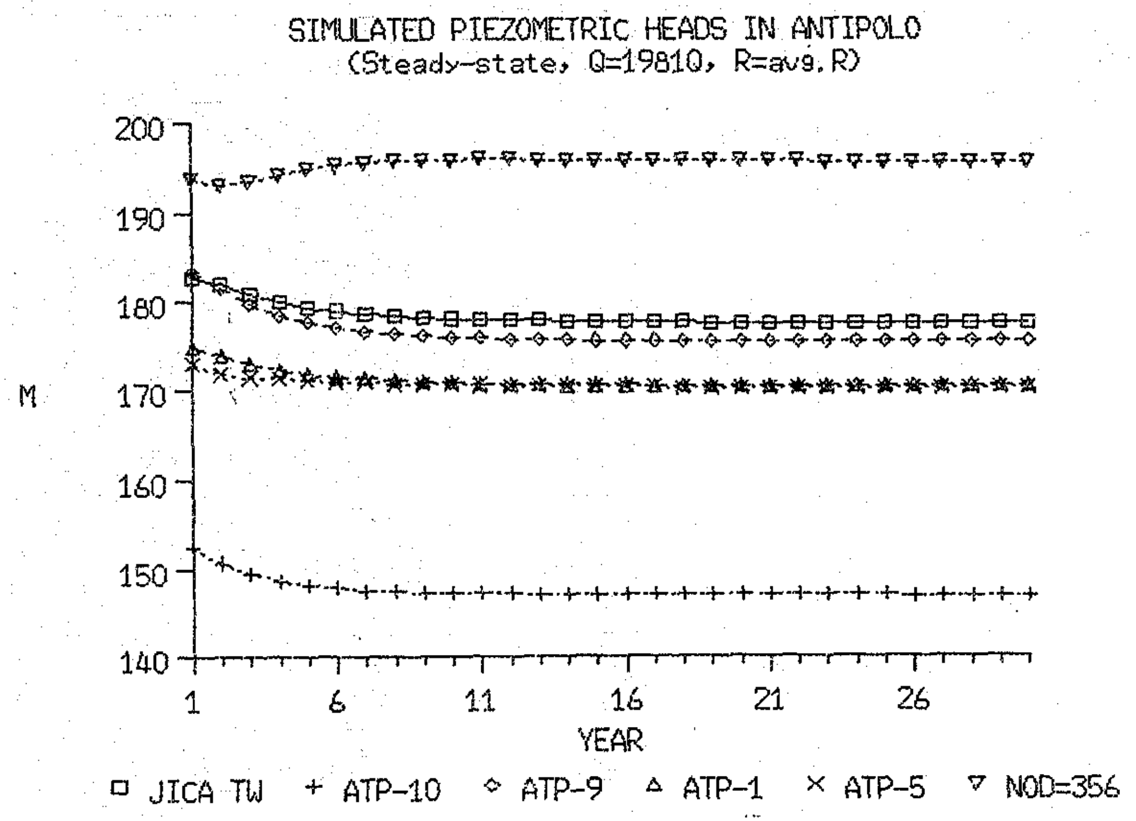


STUDY FOR THE GROUNDWATER DEVELOPMENT
IN METRO MANILA

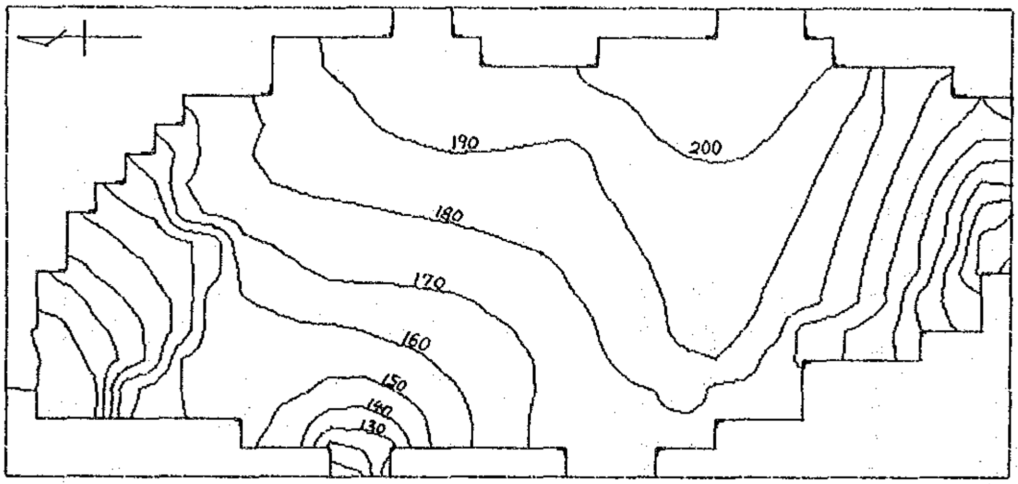
JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.4.8

LOCATION OF OBSERVATION POINTS

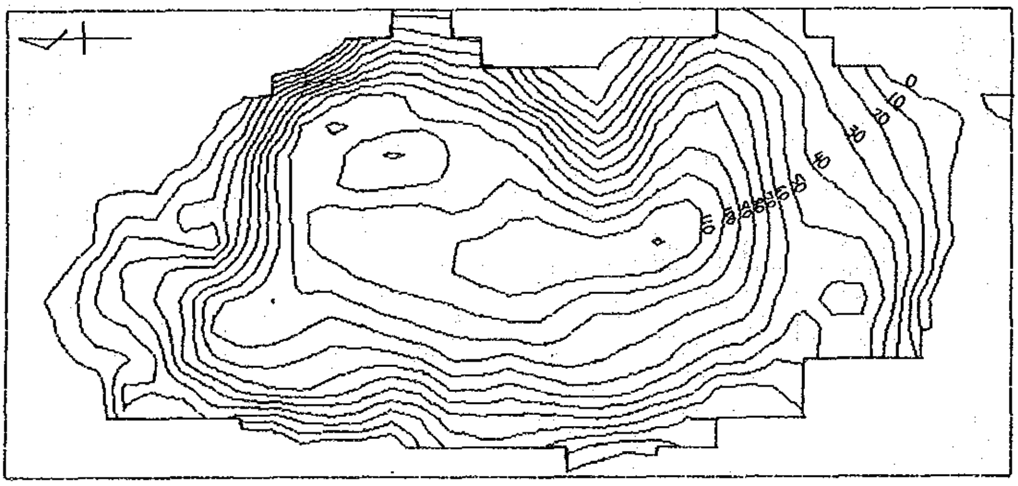


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.4.9)
JAPAN INTERNATIONAL COOPERATION AGENCY	30-STEP STEADY-STATE CALCULATION TO MAKE INITIAL HEADS OF 1981



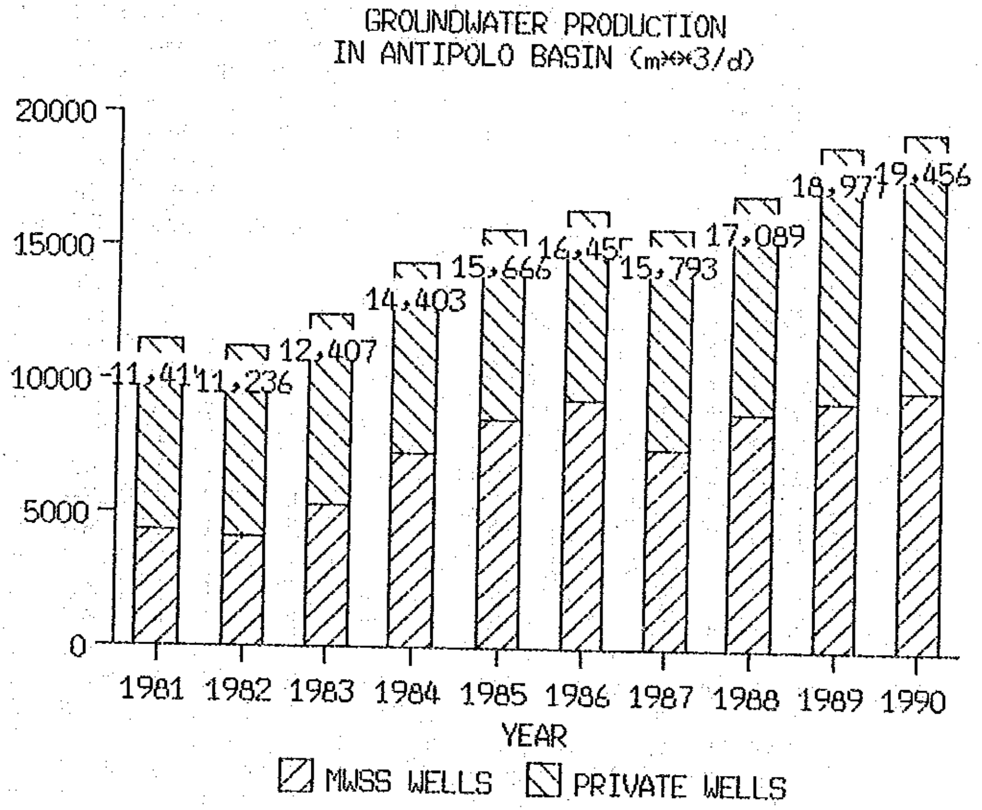
(UNIT : masl)

FIGURE 8.4.10 INITIAL PIEZOMETRIC HEADS OF 1981 FOR NONSTEADY-STATE SIMULATION



(UNIT : m)

FIGURE 8.4.11 PIEZOMETRIC HEIGHTS FROM THE BOTTOM OF THE AQUIFER IN 1981



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.4.12
JAPAN INTERNATIONAL COOPERATION AGENCY	GROUNDWATER PRODUCTION IN THE ANTIPOLO BASIN (1981-1990)

```
***ATP Q MAP (m^3/d)***
       ***YEAR:  1981***

      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
 19999.9999.9999.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.    1
 29999.9999.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.    2
 39999.9999.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.    3
 49999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.    4
 59999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.    5
 69999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.    6
 79999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.    7
 89999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.    8
 99999.   0.   0.   0.   0.   0.   0.   0. 454.   0.   0.   0.   0.9999.9999.9999.    9
109999.   0.   0.   0. 500.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.   10
119999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.   11
12   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.   12
13   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.   13
149999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   14
159999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   15
169999.   0. 601.   0.   0.   0.1377.   0.   0.   0.   0.   0.   0.   0.   0.9999.   16
179999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.   17
189999.   0.   6.   0.1636.   0.1021.   0.   0.   0.   0.   0.   0.   0.9999.9999.   18
199999.   0.   0. 735.   0.   0.   0. 756.   0.   0.1444.   0.   0.   0.9999.9999.   19
20   0.   0.   0.   0.   0.   0. 302.   0.   0. 252.   0.1363.   0.   0.9999.9999.   20
21   0.   0.   0.   0.   0.   0. 302.   0.   0.  99.   0.   0.   0.   0.   0.9999.   21
22   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.   22
239999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.   23
249999.   0.   0.   0.   0.   0.   0.   0. 533.   0.   0.   0.   0.   0.   0.9999.   24
259999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   25
269999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   26
279999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   27
289999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.  38.   0.   0.   0.9999.   28
299999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.   29
309999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   30
319999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.   31
329999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.   32
339999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   33
349999.9999.9999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.9999.9999.9999.   34
      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16

              TOTAL Q IN MODELED AREA = 11419.m^3/d
```

STUDY FOR THE GROUNDWATER DEVELOPMENT
IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.4.13(1)
DISCHARGE MAP IN 1981

```
***ATP Q MAP (m^3/d)***
      ***YEAR:  1982***

      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
 19999.9999.9999.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.   1
 29999.9999.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.   2
 39999.9999.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.   3
 49999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.   4
 59999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.   5
 69999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.   6
 79999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   7
 89999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   8
 99999.   0.   0.   0.   0.   0.   0.   0. 454.   0.   0.   0.   0.9999.9999.9999.   9
109999.   0.   0.   0. 500.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  10
119999.   0.   0.   0.   0.   0.  27.   0.   0.   0.   0.   0.   0.   0.   0.9999.  11
12   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  12
13   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  13
149999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  14
159999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  15
169999.   0. 449.   0.   0.   0.1284.   0.   0.   0.   0.   0.   0.   0.   0.9999.  16
179999.   0.   0.   0. 466.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  17
189999.   0.   6.   0.1636.   0. 737.   0.   0.   0.   0.   0.   0.   0.9999.9999.  18
199999.   0.   0. 709.   0.   0.   0. 634.   0.   0.1444.   0.   0.   0.9999.9999.  19
20   0.   0.   0.   0.   0.   0. 302.   0.   0. 252.   0.1363.   0.   0.9999.9999.  20
21   0.   0.   0.   0.   0.   0. 302.   0.   0.  99.   0.   0.   0.   0.   0.9999.  21
22   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  22
239999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  23
249999.   0.   0.   0.   0.   0.   0.   0. 533.   0.   0.   0.   0.   0.   0.9999.  24
259999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  25
269999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  26
279999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  27
289999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.  38.   0.   0.   0.9999.  28
299999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  29
309999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.  30
319999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  31
329999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  32
339999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.  33
349999.9999.9999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.9999.9999.9999.  34
      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16

                 TOTAL Q IN MODELED AREA = 11235.m^3/d
```

STUDY FOR THE GROUNDWATER DEVELOPMENT
IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.4.13(2)
DISCHARGE MAP IN 1982

```
***ATP Q MAP (m^3/d)***
        ***YEAR: 1983***

      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
 19999.9999.9999.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.    1
 29999.9999.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.    2
 39999.9999.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.    3
 49999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.    4
 59999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.    5
 69999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.    6
 79999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.    7
 89999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.    8
 99999.   0.   0.   0.   0.   0.   0.   0. 454.   0.   0.   0.   0.9999.9999.9999.    9
109999.   0.   0.   0. 500.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.   10
119999.   0.   0.   0.   0.   0.  27.   0.   0.   0.   0.   0.   0.   0.   0.9999.   11
12   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.   12
13   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.   13
149999.   0.   0.   0.   0.   0.   0. 604.   0.   0.   0.   0.   0.   0.   0.   0.   14
159999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   15
169999.   0. 421.   0.   0.   0.1024.   0.   0.   0.   0.   0.   0.   0.   0.9999.   16
179999.   0.   0.   0.1513.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.   17
189999.   0.   0.   0.1636.   0. 529.   0.   0.   0.   0.   0.   0.   0.9999.9999.   18
199999.   0.   0. 679.   0.   0.   0. 580.   0.   0.1444.   0.   0.   0.9999.9999.   19
20   0.   0.   0.   0.   0.   0. 302.   0.   0. 252.   0.1363.   0.   0.9999.9999.   20
21   0.   0.   0.   0.   0.   0. 302.   0.   0.  99.   0.   0.   0.   0.   0.9999.   21
22   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.   22
239999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.   23
249999.   0.   0.   0.   0.   0.   0.   0. 535.   0.   0.   0.   0.   0.   0.9999.   24
259999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   25
269999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   26
279999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   27
289999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.  38.   0.   0.   0.9999.   28
299999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.   29
309999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   30
319999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.   31
329999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.   32
339999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   33
349999.9999.9999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.9999.9999.9999.   34
      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16

                  TOTAL Q IN MODELED AREA = 12406.m^3/d
```

STUDY FOR THE GROUNDWATER DEVELOPMENT
IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.4.13(3)
DISCHARGE MAP IN 1983

```
***ATP Q MAP (m^3/d)***
      ***YEAR:  1984***

      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
 19999.9999.9999.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.   1
 29999.9999.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.   2
 39999.9999.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.   3
 49999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.   4
 59999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.   5
 69999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.   6
 79999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   7
 89999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   8
 99999.   0.   0.   0.   0.   0.   0.   0. 454.   0.   0.   0.   0.9999.9999.9999.   9
109999.   0.   0.   0. 500.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  10
119999.   0.   0.   0.   0.   0.  27.   0.   0.   0.   0.   0.   0.   0.   0.9999.  11
12   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  12
13   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  13
149999.   0.   0.   0.   0.   0.   0.1405.1252.   0.   0.   0.   0.   0.   0.   0.  14
159999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  15
169999.   0. 398.   0.   0.   0. 832.   0.   0.   0.   0.   0.   0.   0.   0.9999.  16
179999.   0.   0.   0.1663.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  17
189999.   0.   6.   0.1536.   0. 646.   0.   0.   0.   0.   0.   0.   0.9999.9999.  18
199999.   0.   0. 666.   0.   0.   0. 584.   0.   0.1444.   0.   0.   0.9999.9999.  19
20   0.   0.   0.   0.   0.   0. 302.   0.   0. 252.   0.1363.   0.   0.9999.9999.  20
21   0.   0.   0.   0.   0.   0. 302.   0.   0.  99.   0.   0.   0.   0.   0.9999.  21
22   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  22
239999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  23
249999.   0.   0.   0.   0.   0.   0.   0. 533.   0.   0.   0.   0.   0.   0.9999.  24
259999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  25
269999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  26
279999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  27
289999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.  38.   0.   0.   0.9999.  28
299999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  29
309999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.  30
319999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  31
329999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  32
339999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.  33
349999.9999.9999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.9999.9999.9999.  34
      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16

                TOTAL Q IN MODELED AREA = 14402.m^3/d
```

STUDY FOR THE GROUNDWATER DEVELOPMENT
IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.4.13(4)

DISCHARGE MAP IN 1984

```
***ATP Q MAP (m^3/d)***
      ***YEAR:  1985***

     1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
 19999.9999.9999.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.   1
 29999.9999.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.   2
 39999.9999.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.   3
 49999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.   4
 59999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.   5
 69999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.   6
 79999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   7
 89999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   8
 99999.   0.   0.   0.   0.   0.   0.   0. 454.   0.   0.   0.   0.9999.9999.9999.   9
109999.   0.   0.   0. 500.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  10
119999.   0.   0.   0.   0.   0.  27.   0.   0.   0.   0.   0.   0.   0.   0.9999.  11
12   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  12
13   0.   0.   0. 756.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  13
149999.   0.   0.   0.   0.   0.1132.1435.   0.   0.   0.   0.   0.   0.   0.   0.  14
159999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  15
169999.   0. 439.   0.   0.   0.1465.   0.   0.   0.   0.   0.   0.   0.   0.9999.  16
179999.   0.   0.   0.1652.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  17
189999.   0.   6.   0.1636.   0. 678.   0.   0.   0.   0.   0.   0.   0.9999.9999.  18
199999.   0.   0. 618.   0.   0.   0. 527.   0.   0.1444.   0.   0.   0.9999.9999.  19
20   0.   0.   0.   0.   0.   0. 302.   0.   0. 252.   0.1363.   0.   0.9999.9999.  20
21   0.   0.   0.   0.   0.   0. 302.   0.   0.  99.   0.   0.   0.   0.   0.9999.  21
22   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  22
239999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  23
249999.   0.   0.   0.   0.   0.   0.   0. 533.   0.   0.   0.   0.   0.   0.9999.  24
259999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  25
269999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  26
279999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  27
289999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.  45.   0.   0.   0.9999.  28
299999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  29
309999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.  30
319999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  31
329999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  32
339999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.  33
349999.9999.9999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.9999.9999.9999.  34
     1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16

                    TOTAL Q IN MODELED AREA = 15665.m^3/d
```

STUDY FOR THE GROUNDWATER DEVELOPMENT
IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.4.13(5)
DISCHARGE MAP IN 1985

```
***ATP Q MAP (m^3/d)***
         ***YEAR:  1986***

      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
 19999.9999.9999.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.    1
 29999.9999.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.    2
 39999.9999.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.    3
 49999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.    4
 59999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.    5
 69999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.    6
 79999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.    7
 89999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.    8
 99999.   0.   0.   0.   0.   0.   0.   0. 454.   0.   0.   0.   0.9999.9999.9999.    9
109999.   0.   0.   0. 500.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.   10
119999.   0.   0.   0.   0.   0.  27.   0.   0.   0.   0.   0.   0.   0.   0.9999.   11
12   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.   12
13   0.   0.   0.1493.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.   13
149999.   0.   0.   0.   0.   0.   0.1203.1434.   0.   0.   0.   0.   0.   0.   0.   14
159999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   15
169999.   0. 625.   0.   0.   0.1407.   0.   0.   0.   0.   0.   0.   0.   0.9999.   16
179999.   0.   0.   0.1651.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.   17
189999.   0.   6.   0.1636.   0. 686.   0.   0.   0.   0.   0.   0.   0.9999.9999.   18
199999.   0.   0. 589.   0.   0.   0. 403.   0.   0.1444.   0.   0.   0.9999.9999.   19
20   0.   0.   0.   0.   0.   0. 302.   0.   0. 252.   0.1363.   0.   0.9999.9999.   20
21   0.   0.   0.   0.   0.   0. 302.   0.   0.  99.   0.   0.   0.   0.   0.9999.   21
22   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.   22
239999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.   23
249999.   0.   0.   0.   0.   0.   0.   0. 533.   0.   0.   0.   0.   0.   0.9999.   24
259999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   25
269999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   26
279999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   27
289999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.  45.   0.   0.   0.9999.   28
299999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.   29
309999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   30
319999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.   31
329999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.   32
339999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   33
349999.9999.9999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.9999.9999.9999.   34
      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16

                     TOTAL Q IN MODELED AREA = 16454.m^3/d
```

STUDY FOR THE GROUNDWATER DEVELOPMENT
IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.4.13(6)

DISCHARGE MAP IN 1986

```
***ATP O MAP (m^3/d)***
     ***YEAR:  1987***

      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
 19999.9999.9999.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.   1
 29999.9999.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.   2
 39999.9999.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.   3
 49999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.   4
 59999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.   5
 69999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.   6
 79999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   7
 89999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   8
 99999.   0.   0.   0.   0.   0.   0.   0. 454.   0.   0.   0.   0.9999.9999.9999.   9
109999.   0.   0.   0. 500.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  10
119999.   0.   0.   0.   0.   0.  27.   0.   0.   0.   0.   0.   0.   0.   0.9999.  11
12   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  12
13   0.   0.   0.1152.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  13
149999.   0.   0.   0.   0.   0.   0.1053.1181.   0.   0.   0.   0.   0.   0.   0.  14
159999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  15
169999.   0. 639.   0.   0.   0.1259.   0.   0.   0.   0.   0.   0.   0.   0.9999.  16
179999.   0.   0.   0.1335.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  17
189999.   0.   6.   0.1636.   0. 225.   0.   0.   0.   0.   0.   0.   0.9999.9999.  18
199999.   0.   0. 587.   0.   0.   0. 261.   0.   0.1444.   0.   0.   0.9999.9999.  19
20   0.   0.   0.   0.   0.   0. 302.   0.   0. 252.   0.1363.   0.   0.9999.9999.  20
21   0.   0.   0.   0.   0.   0. 302.   0.   0.  99.   0.   0.   0.   0.   0.9999.  21
22   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  22
239999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  23
249999.   0.   0.   0.   0.   0.   0.   0. 533.   0.   0.   0.   0.   0.   0.9999.  24
259999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  25
269999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  26
279999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  27
289999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.  45.   0.   0.   0.9999.  28
299999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  29
309999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.  30
319999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.1134.   0.   0.9999.9999.  31
329999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  32
339999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.  33
349999.9999.9999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.9999.9999.9999.  34
      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16

                    TOTAL O IN MODELED AREA = 15790.m^3/d
```

STUDY FOR THE GROUNDWATER DEVELOPMENT
IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.4.13(7)
DISCHARGE MAP IN 1987

```
***ATP Q MAP (m^3/d)***
        ***YEAR:  1988***

      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
 19999.9999.9999.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.   1
 29999.9999.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.   2
 39999.9999.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.   3
 49999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.   4
 59999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.   5
 69999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.   6
 79999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   7
 89999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   8
 99999.   0.   0.   0.   0.   0.   0.   0. 454.   0.   0.   0.   0.9999.9999.9999.   9
109999.   0.   0.   0. 500.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  10
119999.   0.   0.   0.   0.   0.  27.   0.   0.   0.   0.   0.   0.   0.   0.9999.  11
12   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  12
13   0.   0.   0.1260.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  13
149999.   0.   0.   0.   0.   0.   0.1230.1358.   0.   0.   0.   0.   0.   0.   0.  14
159999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  15
169999.   0. 774.   0.   0.   0.1147.   0.   0.   0.   0.   0.   0.   0.   0.9999.  16
179999.   0.   0.   0.1518.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  17
189999.   0.   6.   0.1636.   0. 878.   0.   0.   0.   0.   0.   0.   0.9999.9999.  18
199999.   0.   0. 555.   0.   0.   0. 269.   0.   0.1444.   0.   0.   0.9999.9999.  19
20   0.   0.   0.   0.   0.   0. 302.   0.   0. 252.   0.1363.   0.   0.9999.9999.  20
21   0.   0.   0.   0.   0.   0. 302.   0.   0.  99.   0.   0.   0.   0.   0.9999.  21
22   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  22
239999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  23
249999.   0.   0.   0.   0.   0.   0.   0. 533.   0.   0.   0.   0.   0.   0.9999.  24
259999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  25
269999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  26
279999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  27
289999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.  45.   0.   0.   0.9999.  28
299999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  29
309999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.  30
319999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.1134.   0.   0.9999.9999.  31
329999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  32
339999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.  33
349999.9999.9999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.9999.9999.9999.  34
      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16

                 TOTAL Q IN MODELED AREA = 17087.m^3/d
```

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.4.13(8) DISCHARGE MAP IN 1988
JAPAN INTERNATIONAL COOPERATION AGENCY	

```
***ATP O MAP (m^3/d)***
       ***YEAR:  1989***

      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
 19999.9999.9999.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.   1
 29999.9999.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.   2
 39999.9999.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.   3
 49999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.   4
 59999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.   5
 69999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.   6
 79999.9999.   0.   0.   0. 681.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   7
 89999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   8
 99999.   0.   0.   0.   0.   0.   0.   0. 454.   0.   0.   0.   0.9999.9999.9999.   9
109999.   0.   0.   0. 500.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  10
119999.   0.   0.   0.   0.   0.  27.   0.   0.   0.   0.   0.   0.   0.   0.9999.  11
12   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  12
13   0.   0.   0.1490.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  13
149999.  27.   0.   0.   0.   0.   0.1539.1524.   0.   0.   0.   0.   0.   0.   0.  14
159999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  15
169999.   0. 920.   0.   0.   0. 997.   0.   0.   0.   0.   0.   0.   0.   0.9999.  16
179999.   0.   0.   0.1387.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  17
189999.   0.   6.   0.1636.   0. 867.   0.   0.   0.   0.   0.   0.   0.9999.9999.  18
199999.   0.   0. 447.   0.   0.   0. 309.   0.   0.1444.   0.   0.   0.9999.9999.  19
20   0.   0.   0.   0.   0.  36. 302.   0.   0. 252.   0.1363.   0.   0.9999.9999.  20
21   0.   0.   0.   0.   0.   0. 302.   0.   0.  99.   0.   0.   0.   0.   0.9999.  21
22   0.   0.   0.   0.   0.  54[illegible] [illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.9999.  22
239999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  23
249999.   0.   0.   0.   0.   0.   0.   0. 533.   0.   0.   0.   0.   0.   0.9999.  24
259999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  25
269999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  26
279999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  27
289999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   5.  45.   0.   0.   0.9999.  28
299999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  29
309999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.  30
319999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.1134.   0.   0.9999.9999.  31
329999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  32
339999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.  33
349999.9999.9999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.9999.9999.9999.  34
      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16

                  TOTAL O IN MODELED AREA = 18974.m^3/d
```

STUDY FOR THE GROUNDWATER DEVELOPMENT
IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.4.13(9)
DISCHARGE MAP IN 1989

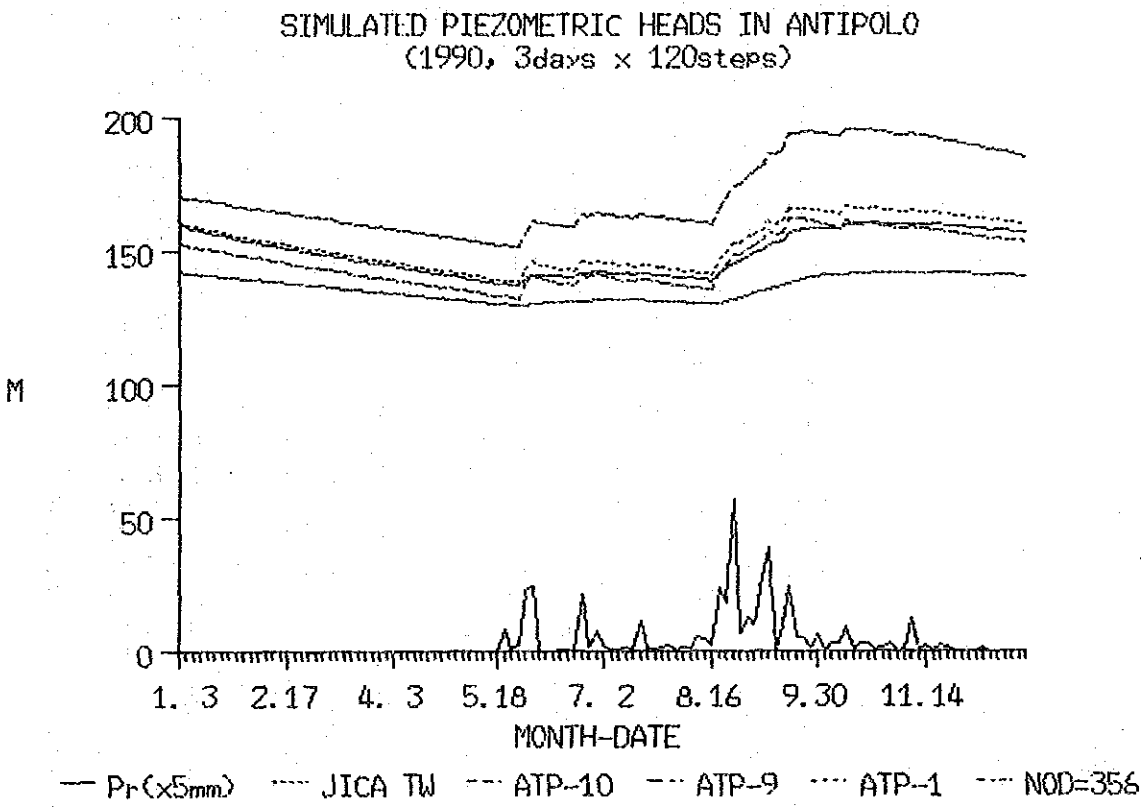
```
***ATP Q MAP (m^3/d)***
      ***YEAR:  1990***

      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
 19999.9999.9999.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.   1
 29999.9999.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.   2
 39999.9999.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.   3
 49999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9990.9999.9999.9999.9999.9999.   4
 59999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.   5
 69999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.   6
 79999.9999.   0.   0.   0. 681.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   7
 89999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   8
 99999.   0.   0.   0.   0.   0.   0.   0. 454.   0.   0.   0.   0.9999.9999.9999.   9
109999.   0.   0.   0. 500.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  10
119999.   0.   0.   0.   0.   0.  27.   0.   0.   0.   0.   0.   0.   0.   0.9999.  11
12   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  12
13   0.   0.   0.1571.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  13
149999.  27.   0.   0.   0.   0.   0.1700.1558.   0.   0.   0.   0.   0.   0.   0.  14
159999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  15
169999.   0. 918.   0.   0.   0.1076.   0.   0.   0.   0.   0.   0.   0.   0.9999.  16
179999.   0.   0.   0.1370.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  17
189999.   0.   6.   0.1636.   0. 881.   0.   0.   0.   0.   0.   0.   0.9999.9999.  18
199999.   0.   0. 509.   0.   0.   0. 377.   0.   0.1444.   0.   0.   0.9999.9999.  19
20   0.   0.   0.   0.   0.  36. 302.   0.   0. 252.   0.1363.   0.   0.9999.9999.  20
21   0.   0.   0.   0.   0.   0. 302.   0.   0.  99.   0.   0.   0.   0.   0.9999.  21
22   0.   0.   0.   0.   0. 648.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  22
239999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  23
249999.   0.   0.   0.   0.   0.   0.   0. 533.   0.   0.   0.   0.   0.   0.9999.  24
259999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  25
269999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  26
279999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  27
289999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   5.  45.   0.   0.   0.9999.  28
299999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  29
309999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.  30
319999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.1134.   0.   0.9999.9999.  31
329999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  32
339999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.  33
349999.9999.9999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.9999.9999.9999.  34
      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16

                         TOTAL Q IN MODELED AREA = 19454.m^3/d
```

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.4.13(10)

DISCHARGE MAP IN 1990



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.4.14 SIMULATED PIEZOMETRIC HEADS BY 120-STEP CALCULATION USING IDENTIFIED STORAGE COEFFICIENT
JAPAN INTERNATIONAL COOPERATION AGENCY	

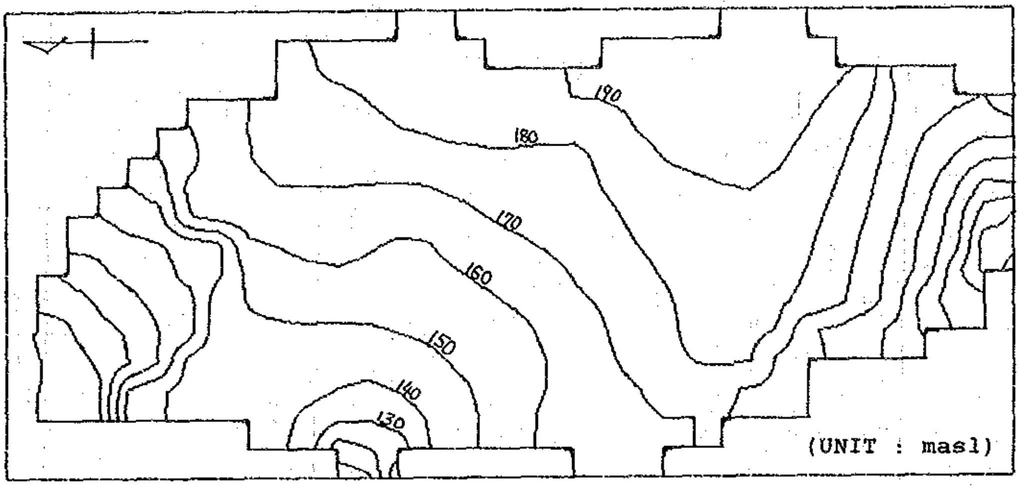


FIGURE 8.4.15 SIMULATED PIEZOMETRIC HEADS IN 1990

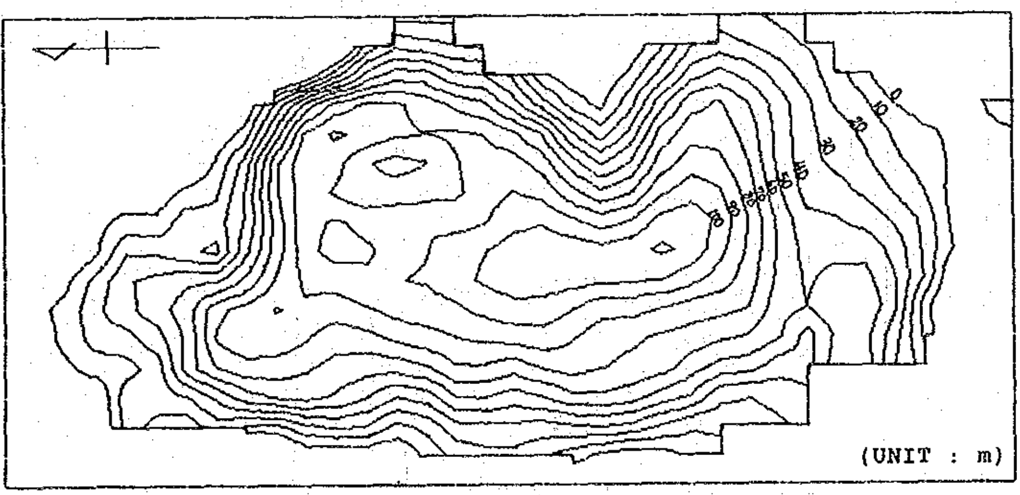
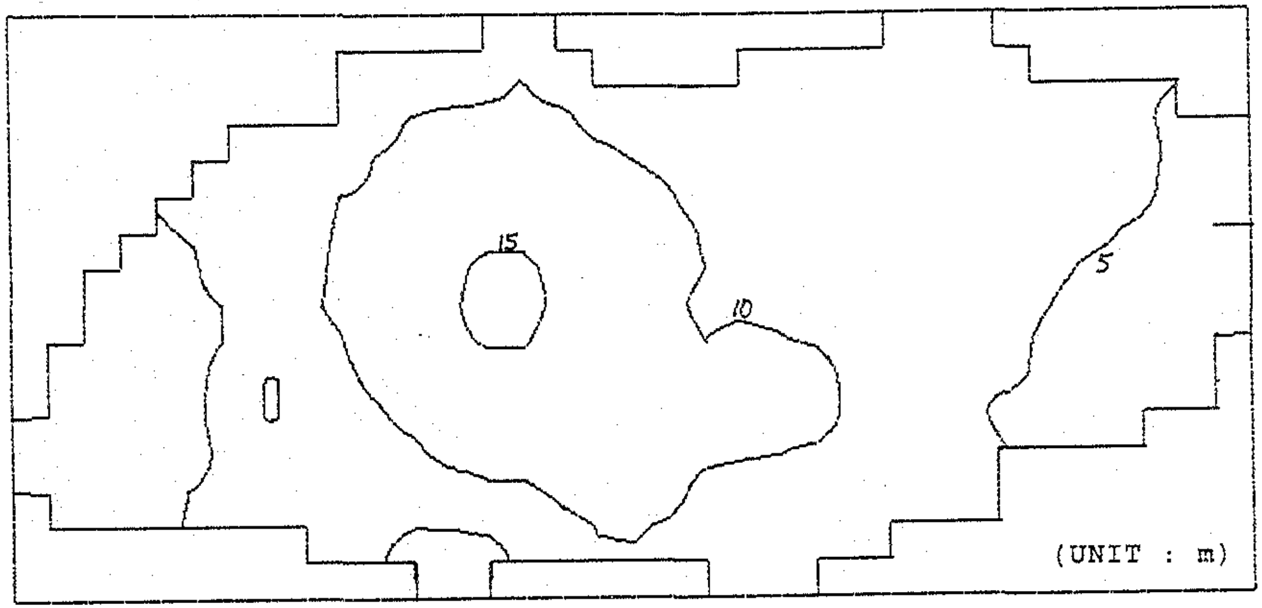


FIGURE 8.4.16 SIMULATED PIEZOMETRIC HEIGHTS FROM THE BOTTOM OF THE AQUIFER IN 1990



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.4.17

SIMULATED DRAWDOWN FROM 1981 TO 1990

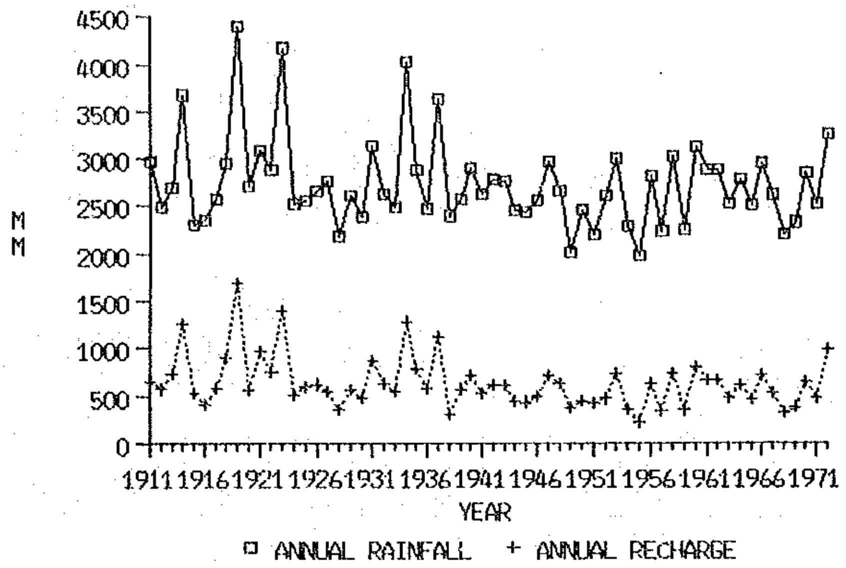


FIGURE 8.4.18 ANNUAL RAINFALL AND ESTIMATED RECHARGE IN ANTIPOLO USING SUMULONG STATION'S DATA (1911-1972)

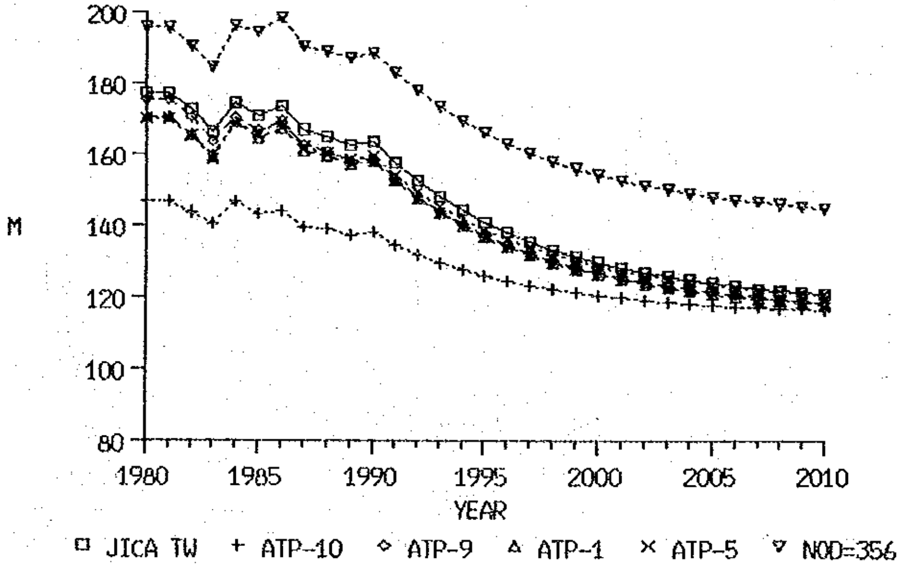


FIGURE 8.4.19 SIMULATED PIEZOMETRIC HEADS (Discharge from 1991 to 2010 = Discharge of 1990)

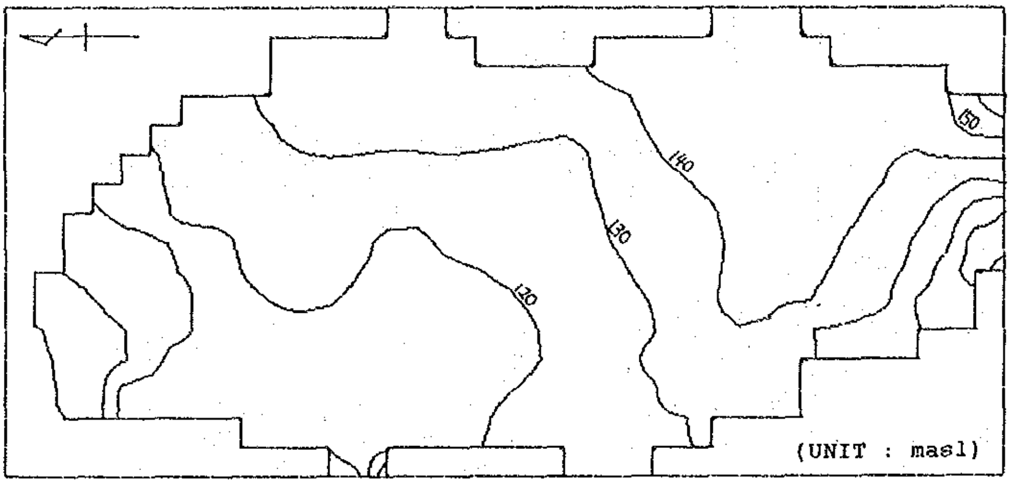


FIGURE 8.4.20 SIMULATED PIEZOMETRIC HEADS IN 2010
(Discharge from 1991 to 2010 = Discharge of 1990)

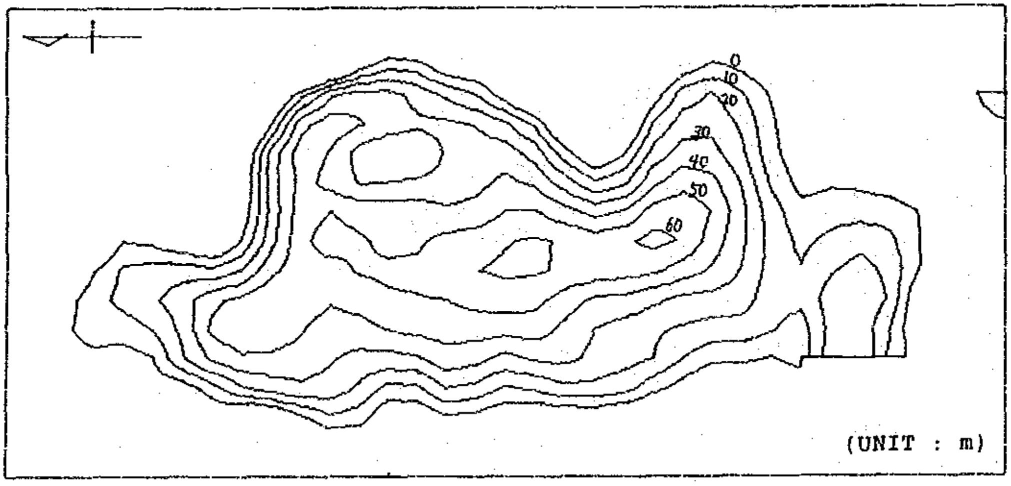


FIGURE 8.4.21 SIMULATED PIEZOMETRIC HEIGHTS FROM THE BOTTOM OF THE AQUIFER IN 2010
(Discharge from 1991 to 2010 = Discharge of 1990)

```
***ATP Q MAP (m^3/d)***
      ***YEAR:  1991***

      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16
 19999.9999.9999.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.9999.   1
 29999.9999.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.9999.9999.   2
 39999.9999.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.9999.   3
 49999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.9999.   4
 59999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.9999.   5
 69999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.9999.   6
 79999.9999.   0.   0.   0. 581.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   7
 89999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.   8
 99999.   0.   0.   0.   0.   0.   0.   0. 454.   0.   0.   0.   0.9999.9999.9999.   9
109999.   0.   0.   0. 500.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  10
119999.   0.   0.   0.   0.   0.  27.   0.   0.   0.   0.   0.   0.   0.   0.9999.  11
12   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  12
13   0.   0.   0.1778.   0.   0.   0.   0. 830.   0.   0.   0.   0.   0.   0.9999.  13
149999.  27.   0.   0.   0.   0. 830.1907.1765.   0.   0.   0.   0.   0.   0.   0.  14
159999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  15
169999.   0.1125.   0.   0.   0.1490.   0.   0.   0.   0.   0.   0.   0.   0.9999.  16
179999.   0.   0.   0.1577.   0. 830.   0.   0.   0.   0.   0.   0.   0.9999.9999.  17
189999.   0.   6.   0.1636.   0.1088. 830.   0.   0.   0.   0.   0.   0.9999.9999.  18
199999.   0.   0. 716.   0.   0.   0. 584.   0.   0.1444.   0.   0.   0.9999.9999.  19
20   0.   0.   0.   0.   0.  36. 132. 830.   0. 252.   0.1363.   0.   0.9999.9999.  20
21   0.   0.   0.   0.   0.   0. 302. 830.   0.  99.   0.   0.   0.   0.   0.9999.  21
22   0.   0.   0.   0.   0. 648.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  22
239999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.  23
249999.   0.   0.   0.   0.   0.   0.   0. 533.   0.   0.   0.   0.   0.   0.9999.  24
259999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  25
269999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  26
279999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  27
289999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   5.  45.   0.   0.   0.9999.  28
299999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  29
309999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.  30
319999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.1134.   0.   0.9999.9999.  31
329999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.  32
339999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.   0.   0.9999.9999.9999.  33
349999.9999.9999.9999.9999.9999.9999.   0.   0.   0.   0.   0.   0.9999.9999.9999.  34
      1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16

            TOTAL Q IN MODELED AREA = 27334.m^3/d
```

□ : Location of New MWSS Wells

FIGURE 8.4.22 OPTIMAL DISCHARGE PLAN IN THE ANTIPOLO BASIN

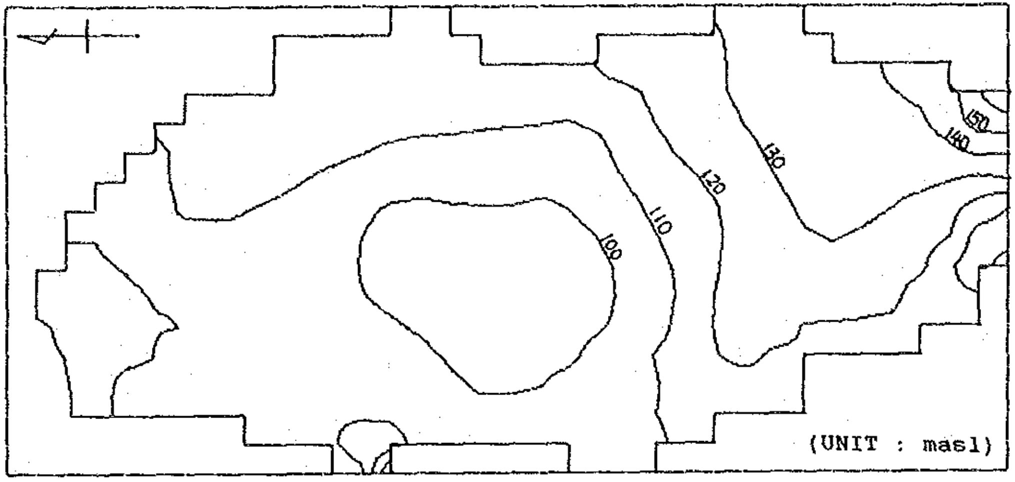


FIGURE 8.4.23 SIMULATED PIEZOMETRIC HEADS IN 2010
(Discharge from 1991 to 2010 = Optimal Plan)

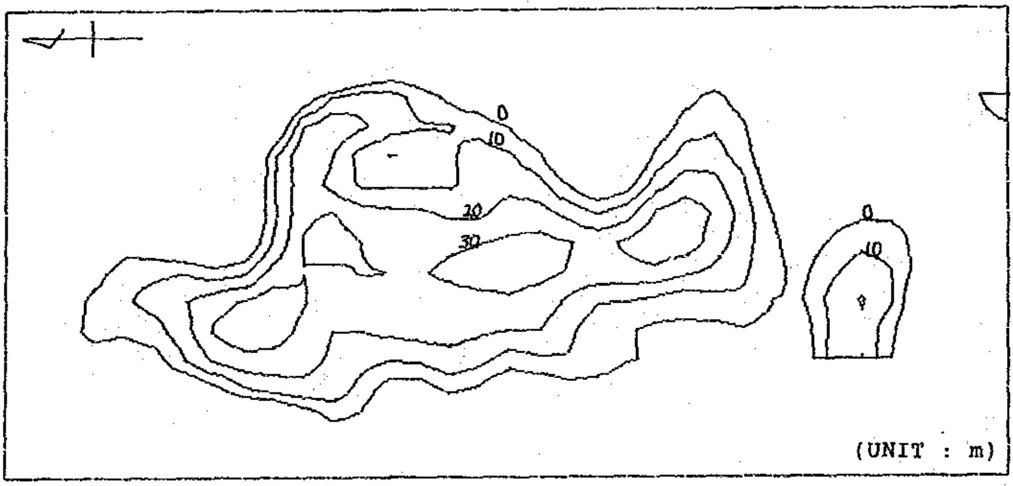


FIGURE 8.4.24 SIMULATED PIEZOMETRIC HEIGHTS FROM THE BOTTOM OF THE AQUIFER IN 2010
(Discharge from 1991 to 2010 = Optimal Plan)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	JAPAN INTERNATIONAL COOPERATION AGENCY

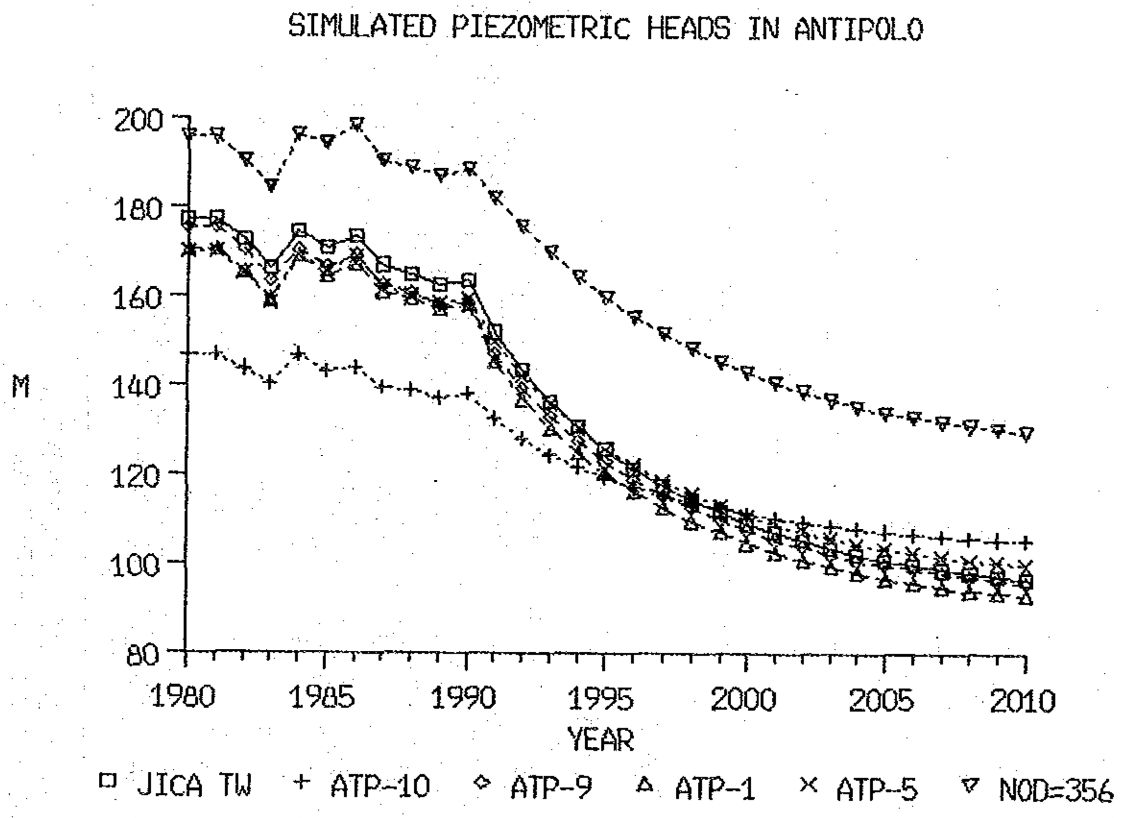
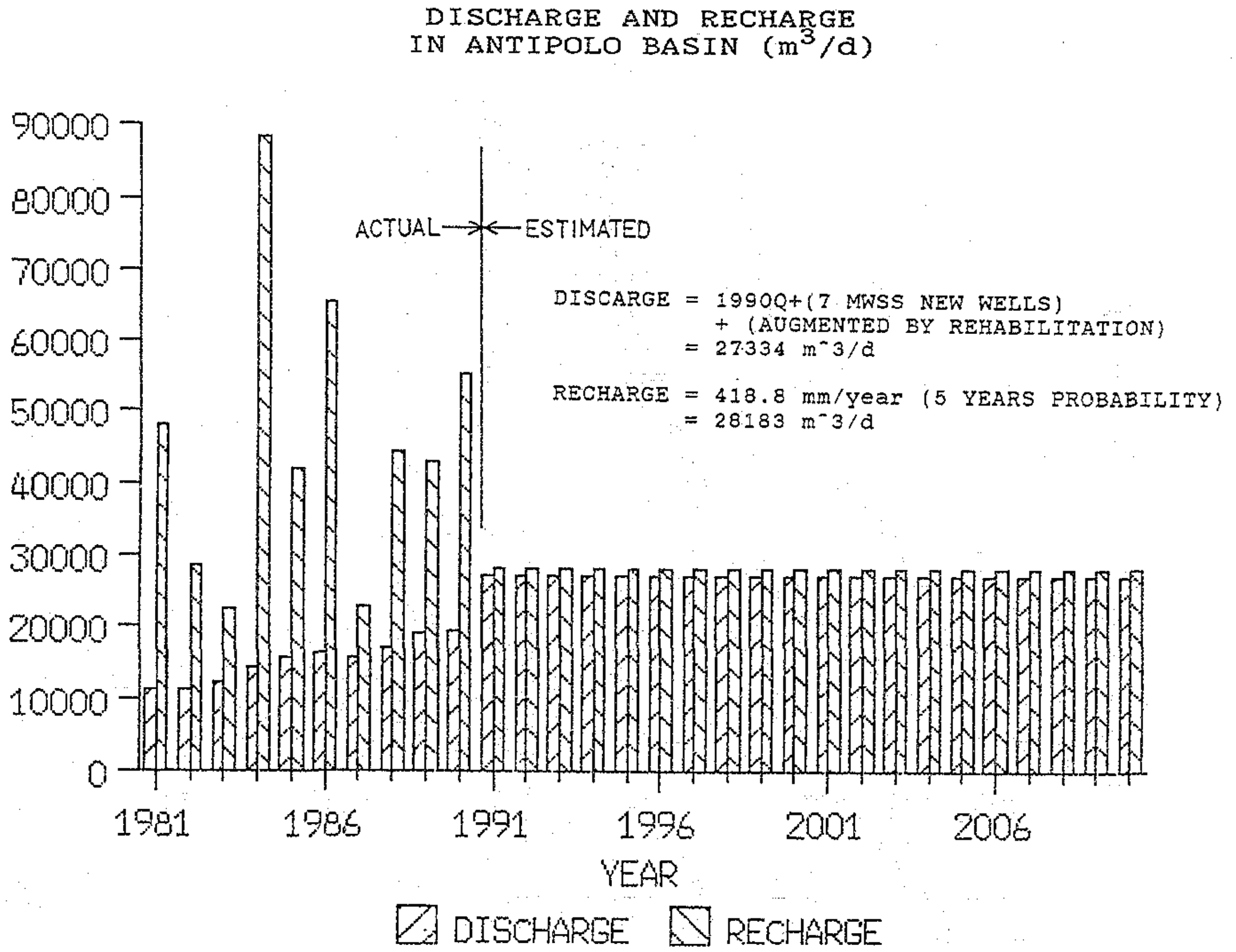


FIGURE 8.4.25

SIMULATED PIEZOMETRIC HEADS

(Discharge from 1991 to 2010 = Optimal Plan)



DISCARGE = 1990Q+(7 MWSS NEW WELLS)
+ (AUGMENTED BY REHABILITATION)
= 27334 m^3/d

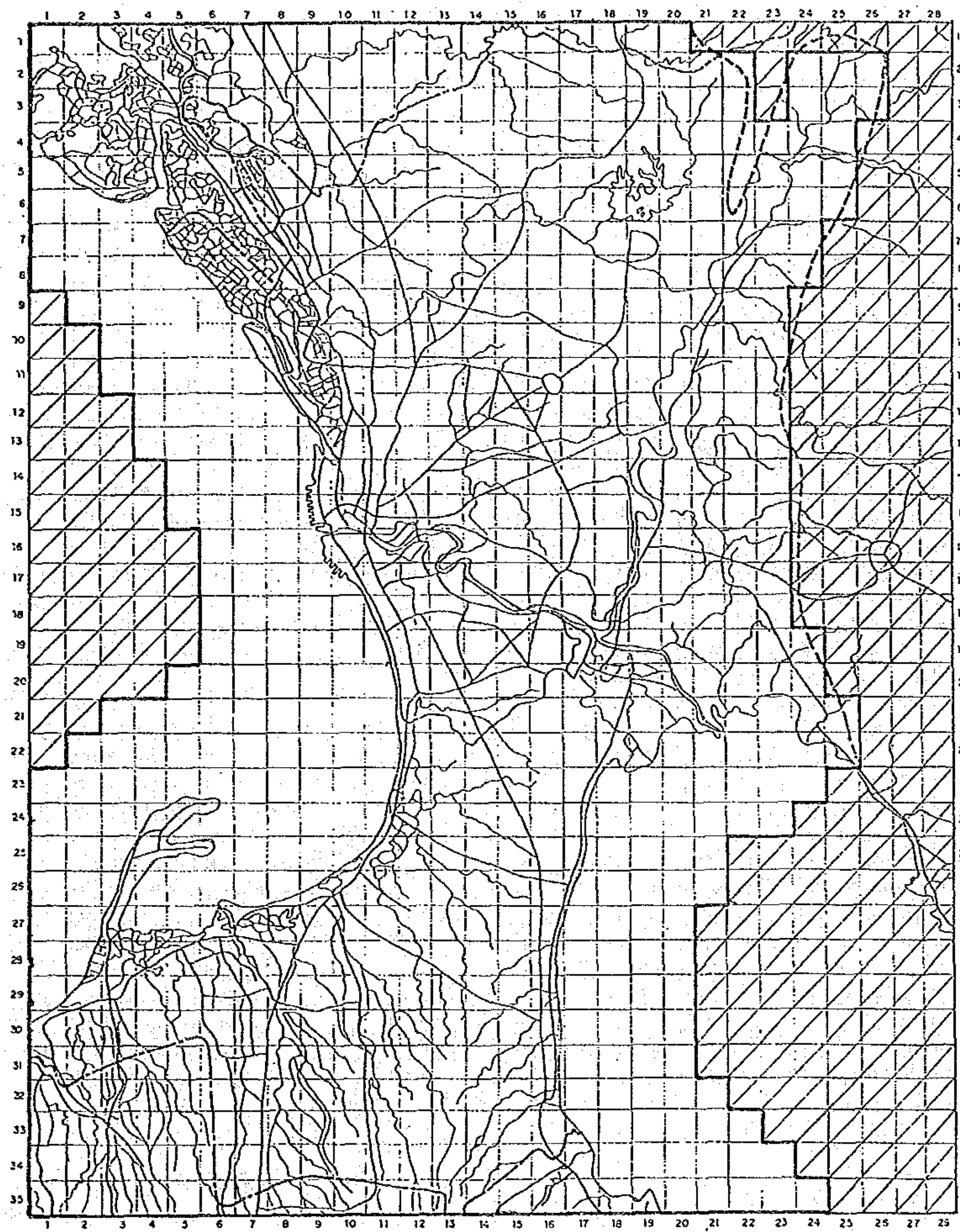
RECHARGE = 418.8 mm/year (5 YEARS PROBABILITY)
= 28183 m^3/d

STUDY FOR THE GROUNDWATER
DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.4.26

OPTIMAL DISCHARGE AND RECHARGE
PLAN IN THE ANTIPOLO BASIN



LEGEND:

——— BOUNDARY OF MODEL , – – – – – – BOUNDARY OF BASIN

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.1 FINITE-ELEMENT GRID USED TO MODEL THE METRO MANILA BASIN

```
     1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28
 1  10  10  10  10  10  10  10  10  10  10  10  10  10  50  50  50  50  50  50  5099999999999999999999999999999999   1
 2  10  55  55  55  55  55  50  45  40  35  30  25  25  50  50  50  50  50  50  50  50  509999 150 150 15099999999   2
 3  10  55  55  55  55  55  55  50  45  40  35  30  25  50  50  50  50  50  50  50  50  509999 150 150 15099999999   3
 4  10  55  55  55  55  55  55  52  45  40  35  35  35  50  50  50  50  50  50  50  50  50 150 150 150999999999999   4
 5  10  55  55  55  55  60  60  55  45  40  35  35  40  50  50  75  70  65  50  50  50  75 160 155 150999999999999   5
 6  10  50  55  55  55  60  65  60  50  40  30  30  35  40  60  95  95  90  50  50  50  65  80 125 140999999999999   6
 7  20  50  45  40  40  45  50  70  84  30  28  30  35  40  50 145 190 120  60  50  65  90  63 1209999999999999999   7
 8  20  20  50  30  30  30  27  25  56  32  29  35  40  45  53  95 160 110  75  55  70 315 120 1109999999999999999   8
 99999  20  20  50  30  30  32  21  25  90  30  40  50  60  75 105 120 110  85  70 306 305 11099999999999999999999   9
1099999999  20  50  30  30  30  25  20  20  15  70  90  85 105 110 115  90  80 110 110  70  5099999999999999999999  10
1199999999  20  20  50  30  25  20  20  20  18  65 210  90 100 105  90  80  90 170  50  35  2099999999999999999999  11
12999999999999  20  50  30  25  20  17  20  20  50 270  12  50  75  80  90 100 150  70  30  2099999999999999999999  12
13999999999999  20  20  50  30  25  20  25  20  11 250  40  45  55  65  75 170 200 100  80  2099999999999999999999  13
149999999999999999  20  50  30  30  30  25  25  22  40  30  40  60  90 170 210 180 140  75  2599999999999999999999  14
159999999999999999  20  20  50  30  30  30  25  25  35  35  40  60  95  95 140 130 120  90  3099999999999999999999  15
1699999999999999999999  20  50  30  25  20  15  20  30  35  40  60  80  20  60  80 130 150  6099999999999999999999  16
1799999999999999999999  20  50  25  20  14   8  15  20  30  40  95  40  15  10  60  70 220 20099999999999999999999  17
1899999999999999999999  20  50  30  30  20   5  30  55  50  25  40  30  20  15  60  80 164 23299999999999999999999  18
1999999999999999999999  20  50  35  40  40  60 110 120  75  30  10  20  15  12  55  70 100 120  409999999999999999  19
209999999999999999  20  20  50  35  40  50 120 190 100  70  45  53  70  80  75  75  75  70  80  509999999999999999  20
2199999999  20  20  20  50  35  40  45  80 140 180  85  60  40  45 100 155  90  85  80  70  60  50  20999999999999  21
229999  20  20  50  50  35  40  40  60 110 140 160 150  55  35  40 120  90  85  75  70  60  55  50  20999999999999  22
23 100  20  20  45  40  40  40  45  80 120 130  75 195  60  30  21 130  65  70  75  70  65 300 3009999999999999999  23
24 100 100  60 110  25  40  40  60  90 140 120  80  75  40  25  15  85  80  80 250 300 300 30099999999999999999999  24
25 100 100  80 120  25  35  42  70 110 180 110  85  90  55  30  25  30  85  90 250 3009999999999999999999999999999  25
26 100  60  75  70  55  35  40  60 121 180  90  80 110 170  60  30  70  85 250 300 3009999999999999999999999999999  26
27 100 130 130 125  90  16  59  70 210 200  90  85  95 120  70  23 150 210 250 30099999999999999999999999999999999  27
28 100 180 195 220 175 100  90  80 110  95  90  85  85  90  95 130 210 220 250 30099999999999999999999999999999999  28
29 100 185 240 210 170 125 100  90  90  90  80  80  80  85  90 150 220 220 250 30099999999999999999999999999999999  29
30 170 170 236 200 140 100  95  90  80 100 100 100  80  90 120 250 220 220 250 30099999999999999999999999999999999  30
31 120 120 110  95  90  85  80  75 100 100 100 100  80  90 120 270 220 220 250 30099999999999999999999999999999999  31
32  90  90  90  90  85  80  75 100 100 100 100 100  75  85  95 210 220 220 250 300 3009999999999999999999999999999  32
33  85  85  85  80  80  75 100 100 100 100 100 100 100  80  90 140 220 220 220 250 300 300999999999999999999999999  33
34  75  75 100 100 100 100 100 100 100 100 100 100 100 100  80  90 160 220 220 220 250 300 30099999999999999999999  34
35 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 200 220 220 250 300 300 3009999999999999999  35
     1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28
```

(UNIT : m^2/d)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.2

DISTRIBUTION OF TRANSMISSIVITY

```
      1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28
  1  25  40  40  40  30  30  30  25  25  25  25  25  20  20   0 -40 -40 -40 -40 -4099999999999999999999999999999999   1
  2  25  30  30  30  30  30  30  30  30  30  30  25  20  20  10 -20 -40 -40 -40 -40 -40 -409999  10  10   099999999   2
  3  25  30  30  30  30  30  30  30  30  30  30  30  25  25  10 -20 -20 -20 -40 -40 -40 -409999  10  25   099999999   3
  4  25  30  30  30  30  30  30  30  30  30  30  30  30  20  10 -20 -20 -20 -20 -40 -40 -40 -40  25  25999999999999   4
  5  30  30  30  30  30  30  30  30  30  30  30  30  30  25  25 -20 -20 -20 -20 -20 -40 -40 -20  25 -30999999999999   5
  6  30  30  30  30  30  30  30  30  30  25  25  25  25  25  25 -20 -20 -20 -20 -20 -20 -20 -20  25 -30999999999999   6
  7  30  30  30  30  30  30  25  25  25  25  25  25  25  25  25  25 -20 -20  -5  -5 -10 -20 -20 -309999999999999999   7
  8  30  30  30  30  30  30  25  25  25  25  25  25  25  25  25  25  25 -20  -5  -5 -10  25  25 -309999999999999999   8
 99999  30  30  30  30  30  30  25  25  25  25  25  25  25  25  25  25 -20  -5  -5  -5  25 -3099999999999999999999   9
 1099999999  30  30  30  30  30  25  25  25  25  25  25  25  25  30  30  25  25  20  20  25 -3099999999999999999999  10
 1199999999  20  30  30  30  30  25  25  25  25  25  25  25  25  30  30  25  25  25  25  25 -3099999999999999999999  11
 12999999999999  20  30  25  25  25  25  25  25  25  25  25  25  30  30  25  25  25  25  25 -3099999999999999999999  12
 13999999999999  20  20  25  25  25  25  25  25  25  25  25  25  30  25  25  25  25  25  25 -3099999999999999999999  13
 149999999999999999   0  25  25  25  25  25  25  25  25  25  25  25  25  25  25  25  25  25 -3099999999999999999999  14
 159999999999999999   0   0  25  25  25  25  25  30  30  25  25  25  25  25  25  25  25  25 -3099999999999999999999  15
 1699999999999999999999   0  25  25  25  25  30  30  30  25  25  25  25  25  25  25  25  25 -3099999999999999999999  16
 1799999999999999999999   0  25  30  30  30  30  30  30  25  25  25  25  25  25  25  25  20  1099999999999999999999  17
 1899999999999999999999   0  25  30  30  30  30  30  25  25  25  25  25  25  25  25  20  20  1099999999999999999999  18
 1999999999999999999999   0  25  30  30  30  30  25  25  25  25  25  25  25  25  25  20  20  10   09999999999999999  19
 209999999999999999   0   0  25  30  30  30  25  25  25  25  25  25  25  25  25  25  20  20  20   29999999999999999  20
 2199999999   0   0   0  25  25  30  30  25  25  25  25  25  25  25  25  25  25  25  20  20  20  20  10999999999999  21
 229999   0   0  25  25  25  25  30  25  25  25  25  25  25  25  25  25  25  25  25  25  25  25  25  25999999999999  22
 23   0   0  25  25  25  25  30  30  25  25  25  25  25  25  25  25  25  25  25  25  25  25   0   09999999999999999  23
 24   0  25  25  25  25  25  30  30  25  25  25  25  25  25  25  25  25  25  25  25   0   0   099999999999999999999  24
 25   0  25  25  25  25  25  30  30  25  25  25  25  25  25  25  25  25  25  25  25   09999999999999999999999999999  25
 26   0  25  25  25  25  25  25  25  25  25  25  25  25  30  25  25  25  25  25   0   09999999999999999999999999999  26
 27  25  25  25  25  25  25  25  25  25  25  25  25  30  30  25  25  25  25  25   099999999999999999999999999999999  27
 28  25  25  25  25  25  25  25  25  25  30  30  25  25  25  25  25  25  25  25   099999999999999999999999999999999  28
 29  25  25  25  25  25  25  25  25  25  30  30  25  25  25  25  25  25  25  25   099999999999999999999999999999999  29
 30  25  25  25  25  25  13  13  13  25  25  25  25  25  30  25  25  25  25  25   099999999999999999999999999999999  30
 31   0  25  25  25  25  13  13  13  25  25  25  25  25  25  25  25  25  25  25   099999999999999999999999999999999  31
 32   0  25  25  25  25  13  13  13  25  25  20  20  20  20  20  20  25  25  25   0   09999999999999999999999999999  32
 33   0  25  25  25  25  15  13  13  13  13  10  10  10  10  10  20  20  25  25  25   0   0999999999999999999999999  33
 34   0  10  10  10  10  10   5   5   5   5  10  10  10  10  10  20  20  25  25  25  25   0   099999999999999999999  34
 35   1   1   1   1   1   1   1   1   1   1  10  10  10  10  10  10  20  20  25  25  25  25  25  2599999999999999999  35
      1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28
```

(S= 1x10^(x/10), UNIT : dimensionless)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.3
JAPAN INTERNATIONAL COOPERATION AGENCY	FINAL DISTRIBUTION OF STORAGE COEFFICIENT

```
    1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
 1 26 27 28 29 30 31 32 33 33 33 33 31 33 27 19 17 15 14 13 1399999999999999999999999999999999   1
 2 25 27 27 26 29 30 31 31 32 32 33 31 32 30 24 18 15 15 13 13 13 139999 10  9  799999999   2
 3 25 25 25 24 26 30 31 31 31 31 32 31 30 31 28 19 16 15 14 14 13 139999 12 10  999999999   3
 4 25 24 24 23 23 27 30 31 30 31 31 30 28 32 31 24 16 16 15 15 14 15 12 13 13999999999999   4
 5 24 23 23 22 22 22 28 30 28 30 31 31 27 30 32 27 17 16 15 15 15 25 16 15 15999999999999   5
 6 22 22 22 22 22 22 24 28 25 21 30 33 25 24 30 30 19 16 16 16 16 26 18 16 16999999999999   6
 7 21 21 21 21 21 21 22 22 27 13 27 33 28 21 23 27 18 16 16 17 18 24 19 199999999999999999   7
 8 22 23 22 22 21 21 22 19 21 31 19 30 26 20 17 18 17 17 18 21 25 22 22 219999999999999999   8
 99999 24 23 23 22 20 21 17 16 25 21 22 23 17 16 16 17 24 23 25 24 21 2599999999999999999999   9
1099999999 25 24 24 21 19 16 16 15 22 17 16 16 15 16 17 25 27 25 23 22 2799999999999999999999  10
1199999999 [illegible] [illegible] [illegible] 25 24 22 22 18 16 28 17 15 14 15 16 22 31 24 23 24 2999999999999999999999  11
1299999999999999 30 30 30 30 33 41 26 17 19 18 13 13 13 16 22 31 22 17 24 3099999999999999999999  12
1399999999999999 31 31 31 31 34 34 30 23 18 16 11 10 12 15 24 25 16 16 26 3499999999999999999999  13
14999999999999999999 33 33 33 33 33 31 24 17 11 10 10 12 16 34 23 15 21 30 3899999999999999999999  14
15999999999999999999 33 33 33 33 33 31 25 18 13 11 11 15 21 36 25 16 27 38 4399999999999999999999  15
1699999999999999999999 33 33 33 32 31 27 21 16 16 15 18 25 28 24 18 31 39 5199999999999999999999  16
1799999999999999999999 33 33 33 33 33 28 25 25 21 19 16 31 37 27 23 19 18 3699999999999999999999  17
1899999999999999999999 33 33 33 33 33 28 26 33 25 21 15 21 28 28 32 22 16 2199999999999999999999  18
1999999999999999999999 33 33 33 33 32 31 36 46 28 22 15 15 27 27 48 27 21 16 279999999999999999  19
20999999999999999999 33 33 33 33 33 33 31 30 27 28 22 16 15 27 27 30 28 24 19 259999999999999999  20
2199999999 29 30 33 33 33 33 33 33 31 27 13 18 24 18 15 25 26 26 27 24 22 25 27999999999999  21
229999 28 29 30 31 33 33 33 33 32 30 25 15 12 19 19 21 24 25 26 27 25 23 25 28999999999999  22
23 27 28 28 28 31 32 33 32 31 31 31 28 18 15 23 18 12 25 26 27 27 25 24 249999999999999999  23
24 27 27 28 28 30 33 33 32 31 31 25  7 16 25 22 16 15 27 27 27 27 25 2499999999999999999999  24
25 27 28 28 27 28 30 31 31 30 27 10 15 28 24 22 21 25 30 28 28 279999999999999999999999999999  25
26 27 28 30 33 28 24 22 24 22 13 10 30 30 19 23 15 39 33 30 29 289999999999999999999999999999  26
27 27 28 43 40 27 10 22 11 10 19 18 31 27 19 23 33 43 42 39 3099999999999999999999999999999999  27
28 27 53 43 39 23 10 13 10 11 13 28 30 26 19 22 39 42 42 36 3099999999999999999999999999999999  28
29 24 42 27 22 19 15 19 15 16 23 30 29 27 21 30 48 45 43 34 3099999999999999999999999999999999  29
30 18 12 16 21 21 20 23 22 25 30 31 29 25 22 31 49 46 45 34 3099999999999999999999999999999999  30
31 10 15 19 22 23 25 25 27 30 30 31 28 25 22 28 37 39 42 33 3099999999999999999999999999999999  31
32 18 19 22 24 25 26 28 31 30 31 31 29 27 23 25 28 30 33 31 30 309999999999999999999999999999  32
33 19 22 24 25 27 28 30 31 31 31 32 30 28 33 29 26 34 34 33 33 31 30999999999999999999999999  33
34 22 24 25 26 28 30 31 32 31 32 33 31 29 39 39 34 36 37 36 34 32 31 3099999999999999999999  34
35 24 25 27 28 30 31 31 32 32 33 33 31 31 40 40 37 39 39 39 37 34 33 31 309999999999999999  35
    1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
```

(UNIT : m)

STUDY FOR THE GROUNDWATER DEVELOPMENT
IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.4
AQUITARD THICKNESS (b')

```
    1234567890123456789012345678
    0         1         2
 1  FFFFFFCAAAAA3111111222222222  1
 2  FFFFFFFFAAAA3221111111111222  2
 3  8FFFFFFFFAAA3221111111111222  3
 4  8FFFFFFFFFFF4221111111111222  4
 5  8FFFFFFFFF774221111111111222  5
 6  888FFFFFFF4263111111111111222 6
 7  88866FFFFF447864111111111222  7
 8  888666F767887666111111111222  8
 9  FF86666557B8655AA11111111222  9
10  FF8666F33666454AB21111222222 10
11  FFF88F333766534AB22222222222 11
12  FFFFFF367875567BB54554222222 12
13  FFFFFF3557766676433552222222 13
14  FFFFFF52224AA862223633222222 14
15  FFFFFFAA885F9882256533322222 15
16  FFFFFFFFFFFF88843C5311222222 16
17  FFFFFFFFFFFFFA45421223222222 17
18  FFFFFFFFFFFF5325532335A52222 18
19  FFFFFFFFFFFF22474223AAAA2222 19
20  FFFFFFFFFF5322774234AAAA7222 20
21  FFFFFFFFF5324446534AAAAAA444 21
22  FFFFFFFF54444456555AAAAAA444 22
23  FFAAFFFF44444666765588884444 23
24  FF3147FF44444642213444444444 24
25  FFA857FF44423522112344444444 25
26  FF677754456224311123444444444 26
27  FFFFFF7577356642223444444444 27
28  FFFFFF746A722342224444444444 28
29  FF6333126CC11331113444444444 29
30  5551111121111740113444444444 30
31  5553111111222211124444444444 31
32  4444111111332111234444444444 32
33  4444444444566633334444444444 33
34  444444444445AAAAAA6644444444 34
35  444444444444AAAAAAAA44444444 35
    1234567890123456789012345678
    0         1         2
```

0	1	2	3	4	5	6	7	LABEL
1.0E-1	5.0E-3	2.0E-3	1.0E-3	7.0E-4	5.0E-4	2.0E-4	1.0E-4	K'(m/d)
8	9	A	B	C	D	E	F	LABEL
7.0E-5	5.0E-5	2.0E-5	1.0E-5	7.0E-6	5.0E-6	2.0E-6	1.0E-9	K'(m/d)

STUDY FOR THE GROUNDWATER DEVELOPMENT
IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.5
LABELS OF IDENTIFIED
AQUITARD PERMEABILITY (k')

```
   1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28
 1   1   1   1   1   1   1   1   1   1   1   1   1  31 186  -1  -1  -1  -1  -1  -1999999999999999999999999999999999   1
 2   1   1   1   1   1   1   1   1   1   1   1   1  32  67  -1  -1  -1  -1  -1  -1  -1  -19999  -1  -1  -199999999   2
 3   3   1   1   1   1   1   1   1   1   1   1   1  34  65  72  -1  -1  -1  -1  -1  -1  -19999  -1  -1  -199999999   3
 4   3   1   1   1   1   1   1   1   1   1   1   1  25  63  65  -1  -1  -1  -1  -1  -1  -1  -1 385 385999999999999   4
 5   3   1   1   1   1   1   1   1   1   1   4   4  26  67  63  -1  -1  -1  -1  -1  -1  -1  -1 334 334999999999999   5
 6   4   4   4   1   1   1   1   1   1   1  24  61   8  42 167  -1  -1  -1  -1  -1  -1 193 278 313 313999999999999   6
 7   4   4   4  10  10   1   1   1   1   1  26  22   4   4   9  26  -1  -1  -1 295 278 209 264  -19999999999999999   7
 8   4   4   4  10  10  10   1   6  10   4   4   3   4  10  12  12 295  -1  -1 239 200 228 228  -19999999999999999   8
 99999   1   4   9  10  10  10  30  32   4   1   4   9  30  32   2   2  -1  -1 200 209 239  -1999999999999999999999   9
 1099999999   3   9   9  10   1  56  63  14  10  12  44  32  47   2   1  81 186 200 218 228  -1999999999999999999999  10
 1199999999   1   3   3   1  42  46  46   6  13   8  30  67  50   2   1  91  65  84  37  84  -1999999999999999999999  11
 12999999999999   1   1   1  34   7   3   3   6  27  28  16   8   1   1  23  23  23  30  30  -1999999999999999999999  12
 13999999999999   1   1   1  33  15  15   4   5  12  13  19  10  17  47  42  41  32  32  77  -1999999999999999999999  13
 1499999999999999999   1   1  16  61  61  65  30   2   2   8  20 167 126  59  44  14  48  34  5399999999999999999999  14
 1599999999999999999   1   1   1   1   3   3  21   1   4   7   7 134  96  14   8  32  38  27  -1999999999999999999999  15
 1699999999999999999999   1   1   1   1   1   1   1   5   5   5  39  41   1  21  56 162 129  4099999999999999999999  16
 1799999999999999999999   1   1   1   1   1   1   1   1   1  37  32  23  55 186  87 106  56  5699999999999999999999  17
 1899999999999999999999   1   1   1   1   1   1   1  16  41  96  34  24  36  72  32  46  32  1999999999999999999999  18
 1999999999999999999999   1   1   1   1   1   1   1  44  72  32   7  47  75  75  21   1   1   2  -1999999999999999999  19
 2099999999999999999   1   1   1   1   1   1  17  34  75  72   5   7  47  75  38  24   1   1   2  1999999999999999999  20
 2199999999   1   1   1   1   1   1   1  16  33  75  54  39  30  12  34  41  27   1   1   1   1   1  1999999999999  21
 229999   1   1   1   1   1   1   1  16  22  24  26  47  59  27  11  24  21  21   1   1   1   1   1  1999999999999  22
 23   1   1   1   1   1   1   1   1  23  23  23  25  39  14   9  12   9   8  20  19   3   3   3  3999999999999999999  23
 24   1   1  36 179  24   4   1   1  23  23  28 100  44   8  32 126 134 186  38  26  26  28  30999999999999999999999  24
 25   1   1   1   3  18   4   1   1  24  26  70 134  36  21  91  96 200 167  72  36  2699999999999999999999999999999  25
 26   1   1   7   4   4   5  23  30  32  39  20  67  67  37  44 334 129 152  67  35  2599999999999999999999999999999  26
 27   1   1   1   1   1   1   5  46  10  10  56  17   8  11  31  61  47  48  26  249999999999999999999999999999999999  27
 28   1   1   1   1   1   1   8  70  19   2   4  67  77  53  32  52  48  48  20  249999999999999999999999999999999999  28
 29   1   1   8  46  53  67 264 134  13   1   1 173 186  48  34 105 112 117  30  249999999999999999999999999999999999  29
 30  28  42  32 239 239 250 218 228  81 167 162 173 200   5 232041 109 112  30  249999999999999999999999999999999999  30
 31  51  34  27  46 218 200 200 186 167 167  65  72  77  91 179 136 129  48  22  249999999999999999999999999999999999  31
 32  39  37  32  30 200 193 179 162 167 162  -1  -1  -1  -1 200 179  67  31  23  24  24999999999999999999999999999999  32
 33  37  32  30  28  26  -1  -1  -1  -1  -1  -1  -1  -1  -1  35  39  30  30  22  22  23  2499999999999999999999999999  33
 34  32  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1   1   1   1   1   6   6  22  23  24999999999999999999999  34
 35  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1   1   1   1   1   1   1  21  22  23  24999999999999999999  35
   1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28
```

(UNIT : x10^-6 (/d))

-1 : Direct Recharge Grid

FIGURE 8.5.6 COMPUTED LEAKANCE

```
      1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28
 1   0   0   0   0   0   1   1   2   2   2  10  12  26  20  32  42  44  52  64  8899999999999999999999999999999999   1
 2   0   1   1   0   0   1   1   2   4   6  10  16  24  24  32  37  44  56  64  86  48  389999  20  18  1899999999   2
 3   0   1   1   0   0   2   2   1   2   4   8   8  20  40  49  49  56  60  72  82  26  269999  18  17  1899999999   3
 4   0   0   0   1   2   2   2   1   1   3   4   8  18  35  52  51  69  80  68  69  78  60  16  14  16999999999999   4
 5   0   1   2   0   2   2   2   1   2   1   4  16  20  36  35  36  52  68  68  68  66  11  10  17  18999999999999   5
 6   0   0   2   2   2   2   2   1   1   1   5  16  20  22  26  29  40  50  65  58  28  10  11  18  20999999999999   6
 7   0   0   0   0   1   1   1   2   2   1   6  11  17  18  28  30  40  49  60  34  14  10  12  209999999999999999   7
 8   0   0   0   0   0   0   1   1   1   2   9   9  10  12  19  37  43  48  58  36   8  10  15  249999999999999999   8
 99999   0   0   0   0   0   0   0   1   1   2   4   8  11  26  34  37  51  62   8   7  10  1799999999999999999999   9
1099999999   0   0   0   0   0   0   1   1   2   3  14  13  20  31  37  44  42   5  10  13  2299999999999999999999  10
1199999999   0   0   0   0   0   0   1   2  10  15   5   7  24  33  39  52  14   4   7  16  2799999999999999999999  11
12999999999999   0   0   0   0   0   0   0   2  10   8  12  16  32  42  42  10   4  11  12  3499999999999999999999  12
13999999999999   0   0   0   0   0   0   0   2   2   5   4   8  20  38  42   6   2   8   9  2499999999999999999999  13
149999999999999999   0   0   0   0   0   2   2   2   6   2   8  27  44  16   4   8   7   7  2099999999999999999999  14
159999999999999999   0   0   0   0   0   1   2   2   2   2   8  16  28  10   6   6   6   7  1199999999999999999999  15
1699999999999999999999   0   0   0   0   2   1   1   3   3   2  12  32  11   7   5   6   6  1299999999999999999999  16
1799999999999999999999   0   0   0   0   1   2   1   2   1   3   8  32   7   4   2   4   6   699999999999999999999  17
1899999999999999999999   0   0   0   0   0   1   1   3   3   2   4   4   4   2   2   2   2   499999999999999999999  18
1999999999999999999999   0   0   0   0   0   2   1   2   4  10  13   4   3   2   2   2   4   4  109999999999999999  19
209999999999999999   0   0   0   0   0   0   0   2   2   4  14  16   2   1   1   2   1   0   0   09999999999999999  20
2199999999   0   0   0   0   0   0   0   0   0   2   3   4   9   6   1   1   0   0   0   0   0   0   0999999999999  21
229999   0   0   0   0   0   0   0   0   0   0   2   3  10  10   9   1   0   0   0   0   0   0   0   0999999999999  22
23   0   0   0   0   0   0   0   0   0   0   0   2   3   5  12  11   1   0   0   0   0   0   0   09999999999999999  23
24   0   0   0   0   0   0   0   0   0   0   0   1   2   6  12  20   2   0   0   0   0   0   099999999999999999999  24
25   0   0   0   0   0   0   0   0   0   0   2   2   2   9  16  20   1   0   0   0   09999999999999999999999999999  25
26   0   0   0   0   0   0   0   0   0   1   2   2   6  10  16  12   2   0   0   0   09999999999999999999999999999  26
27   0   0   0   0   0   0   0   1   1   3   4   6   8  14  20   8   2   0   0   099999999999999999999999999999999  27
28   0   0   2   2   1   1   1   1   4   6  10  14  14  16  12   2   0   0   0   099999999999999999999999999999999  28
29   0   0   2   2   3   3   4   5   7  10  10  18  22  23  11   2   0   0   0   099999999999999999999999999999999  29
30   2   2   3   5   5   8   8   9   9  14  14  15  30  24  10   2   0   0   0   099999999999999999999999999999999  30
31   5   5   5   7  10  10  12  12  16  19  24  20  32  28  16   2   0   0   0   099999999999999999999999999999999  31
32   8  10  10  11  13  14  18  18  22  30  30  36  30  27  17   2   0   0   0   0   09999999999999999999999999999  32
33  12  14  15  17  17  22  27  28  32  32  36  36  41  28  15   4   0   0   0   0   0   0999999999999999999999999  33
34  14  16  20  24  24  30  32  35  44  52  50  48  49  32  19   6   0   0   0   0   0   0   099999999999999999999  34
35  20  27  28  30  35  41  42  40  40  64  68  68  59  34  19   7   1   0   0   0   0   0   0   09999999999999999  35
      1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28
```

(UNIT : m)

STUDY FOR THE GROUNDWATER DEVELOPMENT
IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.7 PHREATIC WATER LEVEL

```
       1     2     3     4     5     6     7     8     9    10    11    12    13    14    15    16    17    18    19    20    21    22    23    24    25    26    27
 1 -55.0 -55.1 -54.3 -52.3 -48.9 -44.0 -37.5 -29.6 -20.4 -10.3   0.3  10.9  20.2  27.2  31.0  34.1  45.5  56.6  63.9  65.7  60.19999.99999.99999.99999.99999.9    1
 2 -50.1 -51.0 -51.2 -50.3 -48.2 -44.4 -39.1 -32.3 -23.9 -13.9  -2.6  10.0  22.9  34.7  43.4  49.2  57.0  63.7  66.5  64.2  56.5  46.3  35.9  27.2  20.9  16.5  13.2    2
 3 -44.7 -46.6 -48.0 -48.5 -47.6 -45.3 -41.3 -35.7 -28.4 -19.2  -7.9   6.0  22.4  39.5  53.0  59.4  65.5  69.2  68.4  62.7  52.7  40.9  29.9  21.6  16.5  13.6  11.9    3
 4 -38.8 -42.0 -44.8 -46.7 -47.5 -46.8 -44.5 -40.5 -35.0 -27.3 -17.5  -4.1  14.5  37.3  56.5  60.6  67.4  70.9  68.7  60.4  48.1  34.7  23.1  15.7  12.7  12.0  12.3    4
 5 -32.3 -37.0 -41.4 -45.3 -48.0 -49.2 -48.7 -46.8 -43.7 -38.5 -32.5 -22.9  -5.5  21.9  48.9  45.6  59.2  67.4  66.4  57.0  42.9  28.1  16.1  10.4  10.4  12.49999.9    5
 6 -25.1 -31.4 -37.7 -43.8 -49.1 -52.7 -54.2 -54.5 -54.3 -51.2 -51.5 -50.2 -40.2 -15.1   9.3  10.0  35.7  58.4  62.0  52.5  37.2  21.9  10.8   7.9  11.2  15.99999.9    6
 7 -17.2 -25.0 -33.3 -42.1 -50.6 -57.4 -61.2 -63.2 -65.9 -62.9 -71.0 -79.4 -79.2 -55.2 -24.6 -10.0  22.8  52.9  57.7  47.1  31.1  16.6   7.3   7.7  13.8  22.59999.9    7
 8  -8.7 -17.5 -27.5 -39.1 -51.4 -63.1 -71.9 -75.5 -72.6 -74.8 -89.3-102.4-105.5 -87.2 -44.4 -33.7  -5.1  31.0  48.2  40.3  25.0  13.0   7.8  12.7  22.39999.99999.9    8
 9   0.0  -9.0 -19.8 -33.2 -48.6 -65.0 -80.9 -91.3 -91.6 -93.9-110.0-119.9-124.1-117.1 -50.2 -38.0 -24.6  15.6  43.3  36.7  19.9  11.1  13.5  22.5  35.19999.99999.9    9
109999.9  -0.1 -10.1 -23.7 -38.9 -54.3 -68.1 -72.4 -58.1 -93.5-125.5-123.8-116.6-105.7 -63.9 -30.8 -15.3   9.5  28.2  20.8   6.2   5.2  18.5  32.89999.99999.99999.9   10
119999.99999.9  -1.1 -12.8 -23.9 -32.0 -34.1 -26.4 -18.1 -82.1-121.2-120.7-113.6 -77.5 -62.3 -32.7 -14.2  -1.5   3.1  -4.6 -11.6  -0.8  18.8  40.19999.99999.99999.9   11
129999.99999.9   0.7  -5.6 -11.0 -12.9  -9.1  -1.2  -4.6 -66.6-108.3-112.6-102.4 -70.0 -51.3 -26.9 -11.2 -10.8 -19.2 -31.7 -40.8 -26.9   5.4  41.49999.99999.99999.9   12
139999.99999.99999.9  -0.4  -3.2  -2.5   1.6   7.0   4.1 -43.9 -87.5 -92.2 -82.5 -66.7 -46.6 -18.7  -0.9 -11.9 -30.7 -47.2 -64.3 -49.5  -4.7  45.09999.99999.99999.9   13
149999.99999.99999.9   0.4  -0.7   0.3   2.0   2.5   5.1 -15.7 -45.9 -65.9 -72.3 -73.2 -52.8 -13.4  17.1   0.2 -23.8 -35.2 -48.7 -39.1   0.4  54.09999.99999.99999.9   14
159999.99999.99999.99999.9   0.1   0.8   1.8   3.0   6.5   2.2 -20.5 -56.1 -80.7 -94.3 -71.1 -21.5  14.7  10.5 -15.4 -21.8 -30.2 -25.4   3.5  54.79999.99999.99999.9   15
169999.99999.99999.99999.9   0.5   0.1  -2.1  -5.9 -10.7 -20.4 -43.8 -69.8 -86.7 -93.0 -70.1 -31.0 -15.0 -15.6 -51.9 -74.8 -46.9 -29.9  -9.4  37.09999.99999.99999.9   16
179999.99999.99999.99999.99999.9  -0.2  -8.0 -20.5 -38.5 -64.3 -93.2 -90.6 -83.8 -74.4 -55.5 -31.9 -58.1 -72.6 -64.5 -43.2 -28.5 -30.9 -30.7   8.09999.99999.99999.9   17
189999.99999.99999.99999.99999.9  -0.3 -12.2 -29.7 -52.5 -79.7-100.8 -86.0 -67.8 -53.0 -47.3 -27.4 -82.8-113.1 -78.8 -32.2 -22.7 -33.3 -40.6  -6.09999.99999.99999.9   18
199999.99999.99999.99999.99999.9  -0.8 -13.5 -30.2 -48.8 -65.7 -72.2 -58.8 -45.1 -35.0 -58.0 -50.6 -37.1 -39.8 -39.0 -16.7 -13.8 -25.5 -29.2   3.9  52.39999.99999.9   19
209999.99999.99999.99999.9   0.2  -4.3 -14.6 -26.5 -37.6 -44.3 -42.2 -31.7 -35.7 -44.9 -46.4 -32.9 -21.0 -19.7 -20.5  -9.1  -8.8 -19.1 -24.5 -17.2  28.39999.99999.9   20
219999.99999.9   0.4  -0.3  -3.5  -8.7 -15.8 -22.8 -27.5 -28.1 -24.0 -20.1 -31.8 -42.7 -39.4 -33.6 -18.5 -16.8 -17.5 -11.3 -10.7 -16.8 -20.7 -14.1  16.2  54.09999.9   21
229999.9   0.1  -2.3  -4.0  -7.7 -13.3 -18.6 -21.9 -22.0 -19.0 -14.6 -13.6 -22.5 -43.2 -44.8 -26.4 -12.0 -11.9 -12.6 -10.0 -10.2 -13.7 -15.4  -9.0  11.1  39.09999.9   22
23  -0.1  -3.2  -5.6  -8.0 -12.3 -19.7 -24.2 -24.9 -21.6 -15.8 -10.8 -10.6 -13.6 -35.9 -45.1 -42.3 -27.9 -14.5  -9.0  -6.6  -7.1  -9.2  -9.7  -4.7   9.1  29.29999.9   23
24  -5.4  -7.9 -10.1 -12.5 -17.3 -28.9 -33.1 -31.5 -25.3 -17.0 -11.0 -15.7 -24.1 -43.6 -56.0 -57.7 -39.0 -13.0  -4.2  -1.8  -2.6  -4.4  -4.5  -1.4   8.09999.99999.9   24
25 -11.3 -13.5 -15.7 -18.4 -24.5 -41.0 -44.7 -39.4 -31.5 -21.4 -10.5 -10.6 -22.6 -35.4 -49.7 -65.3 -45.2  -3.0   1.8   3.1   1.3  -0.7  -0.5   0.39999.99999.99999.9   25
26 -16.4 -18.2 -20.2 -22.4 -27.1 -37.4 -42.0 -40.1 -37.0 -33.4 -30.7 -20.7 -26.5 -36.1 -41.8 -71.3 -76.1  -8.5   5.1   5.9   3.0   0.29999.99999.99999.99999.99999.9   26
27 -19.3 -20.3 -21.4 -20.9 -20.2 -23.3 -28.3 -31.4 -34.8 -37.0 -37.9 -17.8 -14.0 -28.9 -42.0 -53.0 -50.8 -14.4   1.3   4.2   2.2   0.19999.99999.99999.99999.99999.9   27
28 -19.2 -18.3 -16.8 -13.3  -8.6  -5.3 -11.9 -16.4 -21.6 -27.5 -28.3  -8.6  -4.2 -19.6 -34.9 -43.0 -25.0  -9.4  -0.3   1.9   0.39999.99999.99999.99999.99999.99999.9   28
29 -17.1 -14.7 -11.5  -7.0  -2.0   0.7  -2.4  -3.7  -6.5 -12.2 -11.4  -0.9  -1.0 -11.4 -19.4 -19.8 -15.9  -7.0  -1.2   0.6   0.09999.99999.99999.99999.99999.99999.9   29
30 -14.3 -11.0  -7.3  -3.1   0.7   2.0  -0.8  -3.9  -3.0  -3.9  -2.3   2.5   1.7  -4.2  -5.5  -3.0  -4.7  -2.9  -0.7   0.2   0.09999.99999.99999.99999.99999.99999.9   30
31 -11.2  -7.6  -3.8  -8.0   3.0   4.0   2.8   1.4   2.1   2.7   4.0   7.1   7.2   4.5   2.6   1.0  -1.1  -0.9  -0.1   0.2   0.09999.99999.99999.99999.99999.99999.9   31
32  -7.9  -4.1  -0.3   3.2   6.0   7.6   8.0   8.2   9.4  10.7  12.3  14.2  14.3  12.4   8.9   4.1   1.3   1.0   1.1   1.0   0.5  -8.09999.99999.99999.99999.99999.9   32
33  -4.2  -0.3   3.5   7.2  10.3  12.6  14.4  16.1  18.1  20.1  22.0  23.2  22.6  20.1  15.8  10.6   6.8   4.9   3.7   2.6   1.6   0.7   0.09999.99999.99999.99999.9   33
34  -0.1   4.0   8.0  12.0  15.6  18.8  21.8  24.7  27.7  30.5  32.7  33.6  32.3  28.8  23.8  18.2  13.4   9.9   7.3   5.2   3.4   1.9   0.7   0.09999.99999.99999.9   34
35   4.5   8.8  13.2  17.5  21.7  25.8  29.8  33.9  37.8  41.5  44.3  45.2  43.0  36.5  32.6  26.2  20.4  15.5  11.6   8.4   5.7   3.5   1.7   0.6   0.09999.99999.9   35
36   9.5  14.0  18.7  23.4  28.3  33.2  38.2  43.2  48.2  52.8  56.4  57.7  54.5  48.7  41.7  34.4  27.4  21.3  16.2  11.9   8.2   5.3   2.9   1.2   0.09999.99999.9   36
       1     2     3     4     5     6     7     8     9    10    11    12    13    14    15    16    17    18    19    20    21    22    23    24    25    26    27
```

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.8

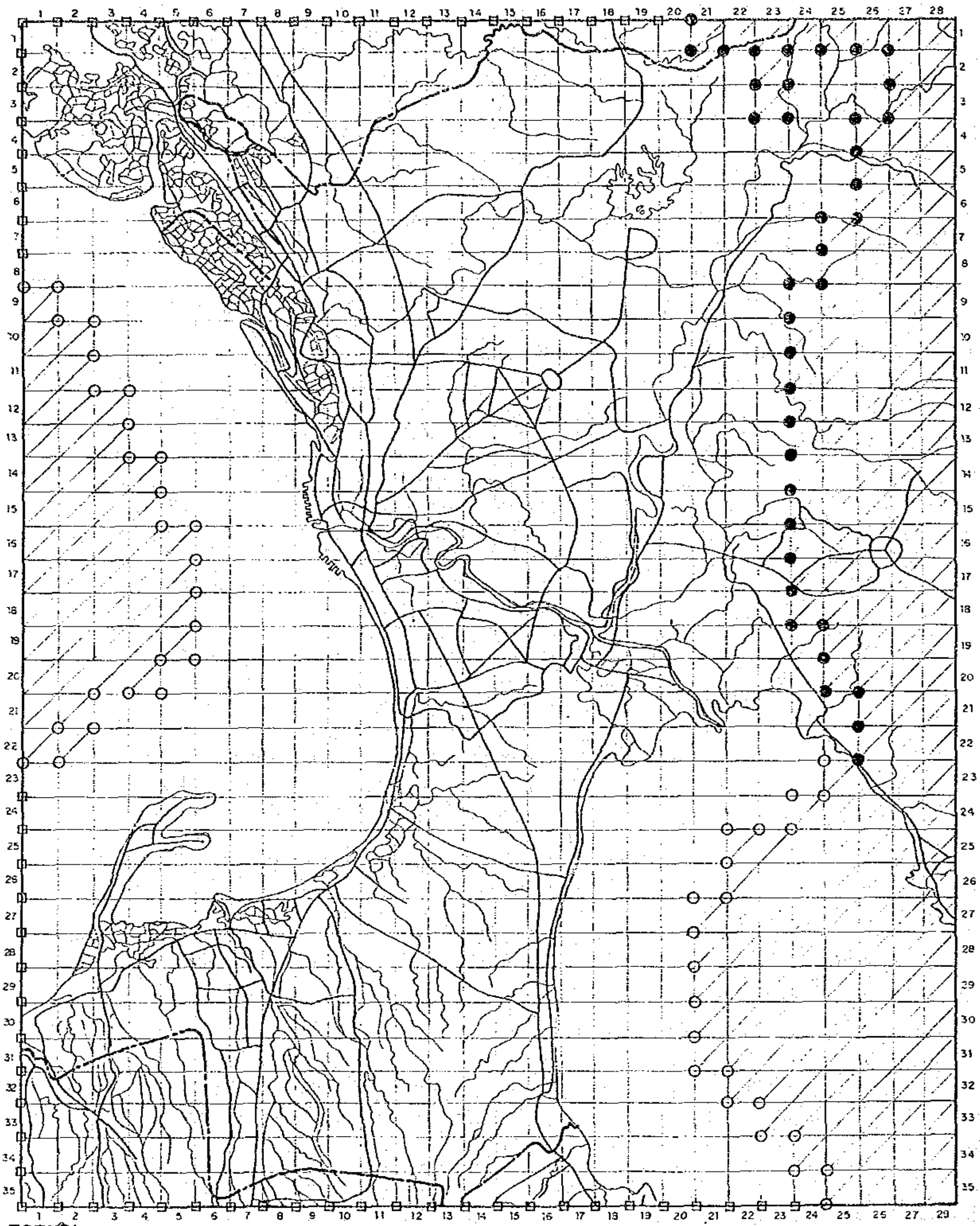
INITIAL PIEZOMETRIC HEADS IN 1981

(UNIT : masl)

```
    1234567890123456789012345678
    0         1         2
 1  0000000000000011111199999999  1
 2  0000000000000011111111911199  2
 3  0000000000000001111111911199  3
 4  0000000000000001111111100999  4
 5  0000000000000001111111100999  5
 6  0000000000000001111110000999  6
 7  0000000000000000111000019999  7
 8  0000000000000000011000019999  8
 9  9000000000000000011000199999  9
10  9900000000000000000000199999 10
11  9900000000000000000000199999 11
12  9990000000000000000000199999 12
13  9990000000000000000000199999 13
14  9999000000000000000000099999 14
15  9999000000000000000000199999 15
16  9999900000000000000000099999 16
17  9999900000000000000000099999 17
18  9999900000000000000000099999 18
19  9999900000000000000000019999 19
20  9999000000000000000000009999 20
21  9900000000000000000000000999 21
22  9000000000000000000000000999 22
23  0000000000000000000000009999 23
24  0000000000000000000000099999 24
25  0000000000000000000009999999 25
26  0000000000000000000009999999 26
27  0000000000000000000099999999 27
28  0000000000000000000099999999 28
29  0000000000000000000099999999 29
30  000000000000000C000099999999 30
31  0000000000000000000099999999 31
32  0000000000111100000099999999 32
33  0000011111111100000000999999 33
34  0111111111111100000000099999 34
35  1111111111111100000000009999 35
    1234567890123456789012345678
    0         1         2
```

1 : Direct Recharge Grid
0 : Leakage Recharge Grid
9 : Out of Model

FIGURE 8.5.9 DIRECT RECHARGE AREA



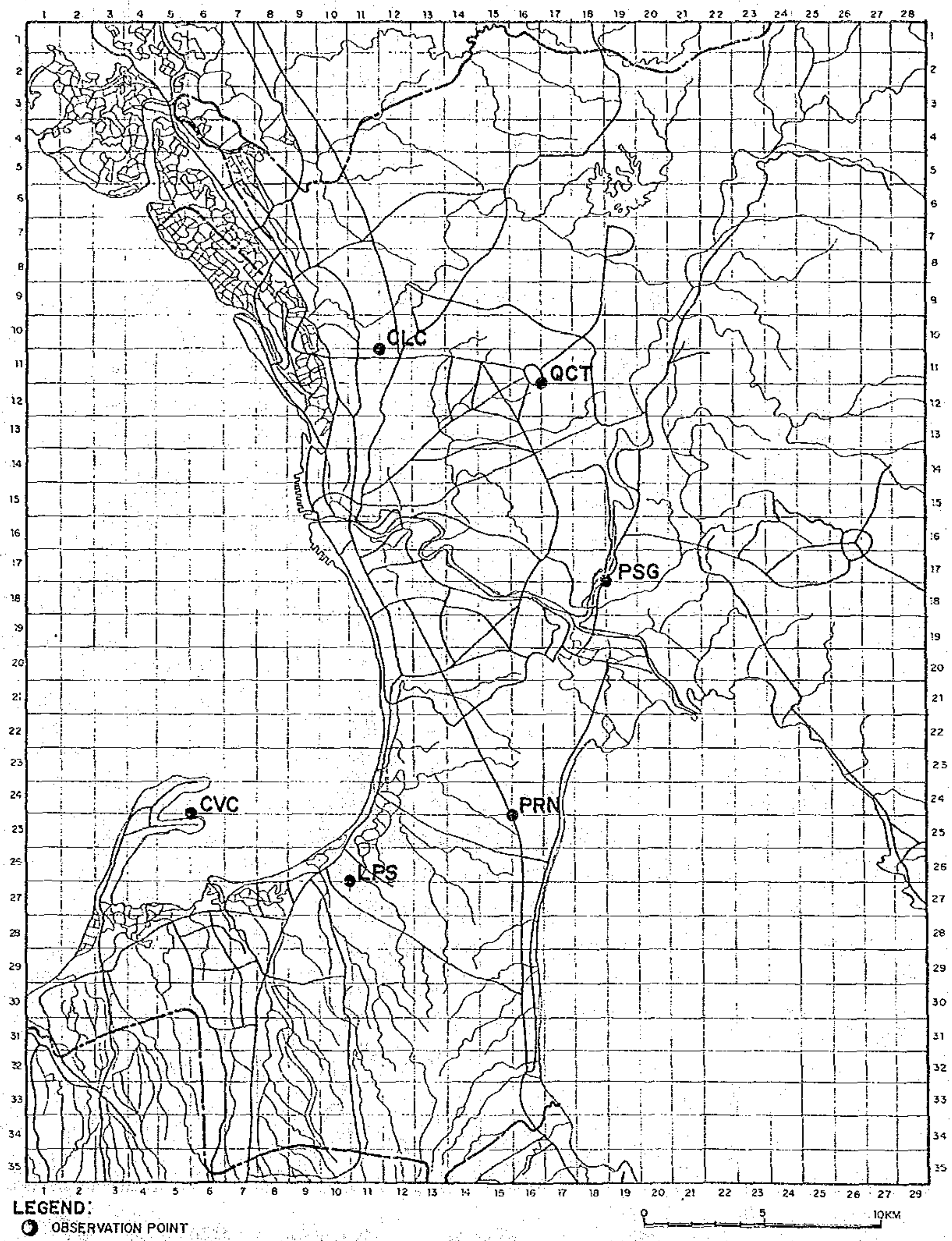
LEGEND:

● NO-FLOW BOUNDARY, ○ CONSTANT-HEAD BOUNDARY, □ CONSTANT-FLOW BOUNDARY

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

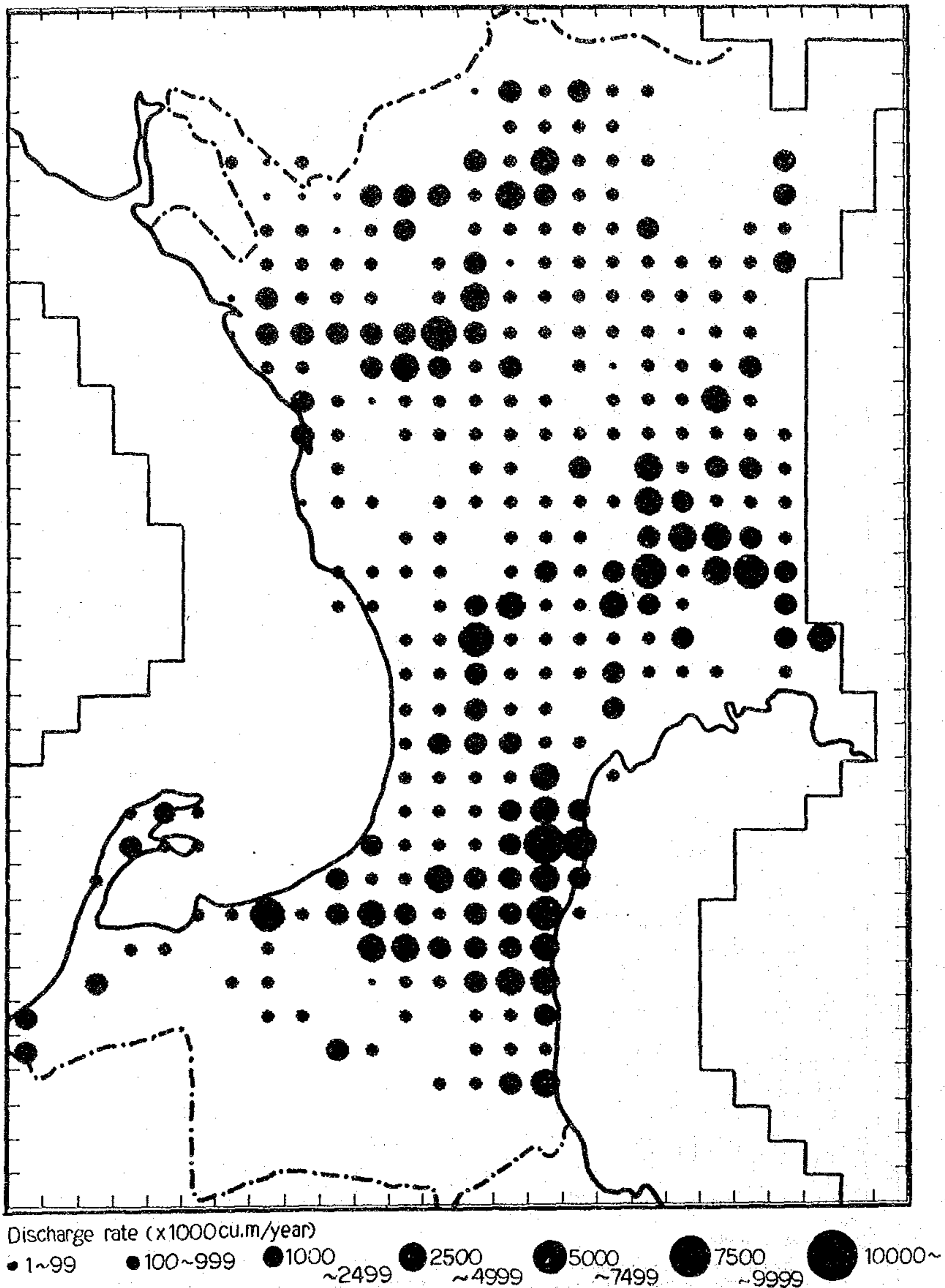
FIGURE 8.5.10
BOUNDARY CONDITIONS FOR THE METRO MANILA GROUNDWATER BASIN



STUDY FOR THE GROUNDWATER
DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.11 OBSERVATION POINTS



STUDY FOR THE GROUNDWATER DEVELOPMENT
IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.12

DISCHARGE DISTRIBUTION IN 1981

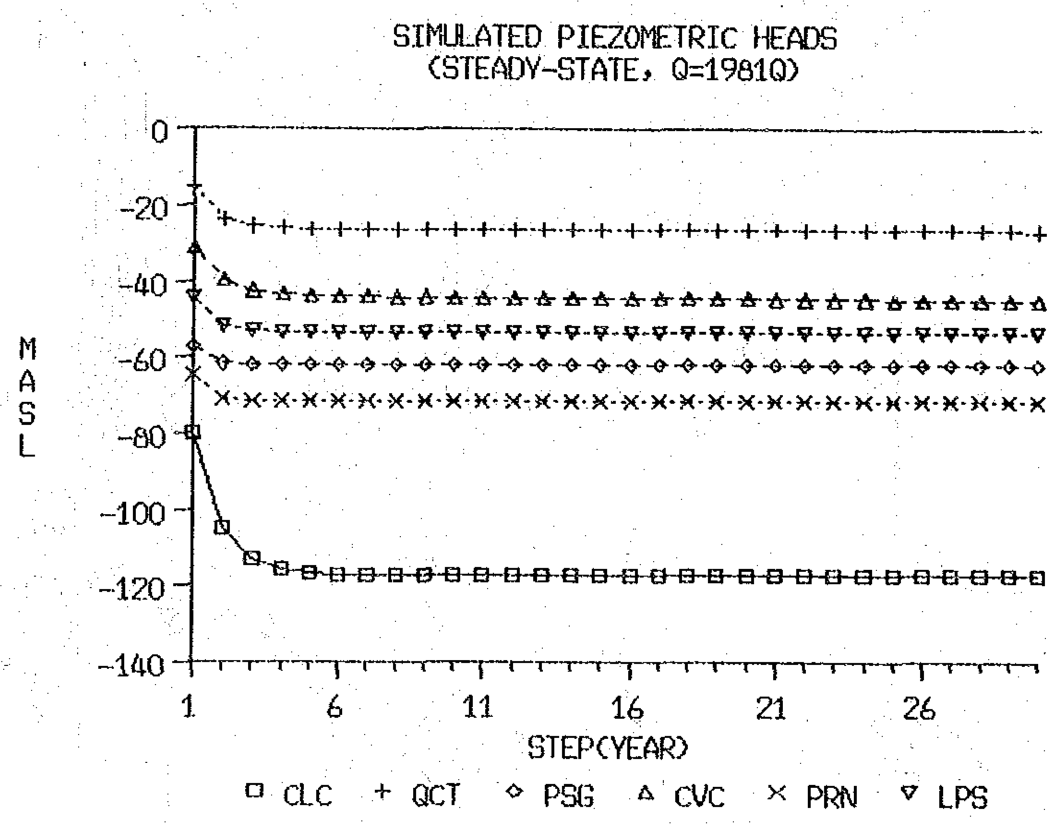
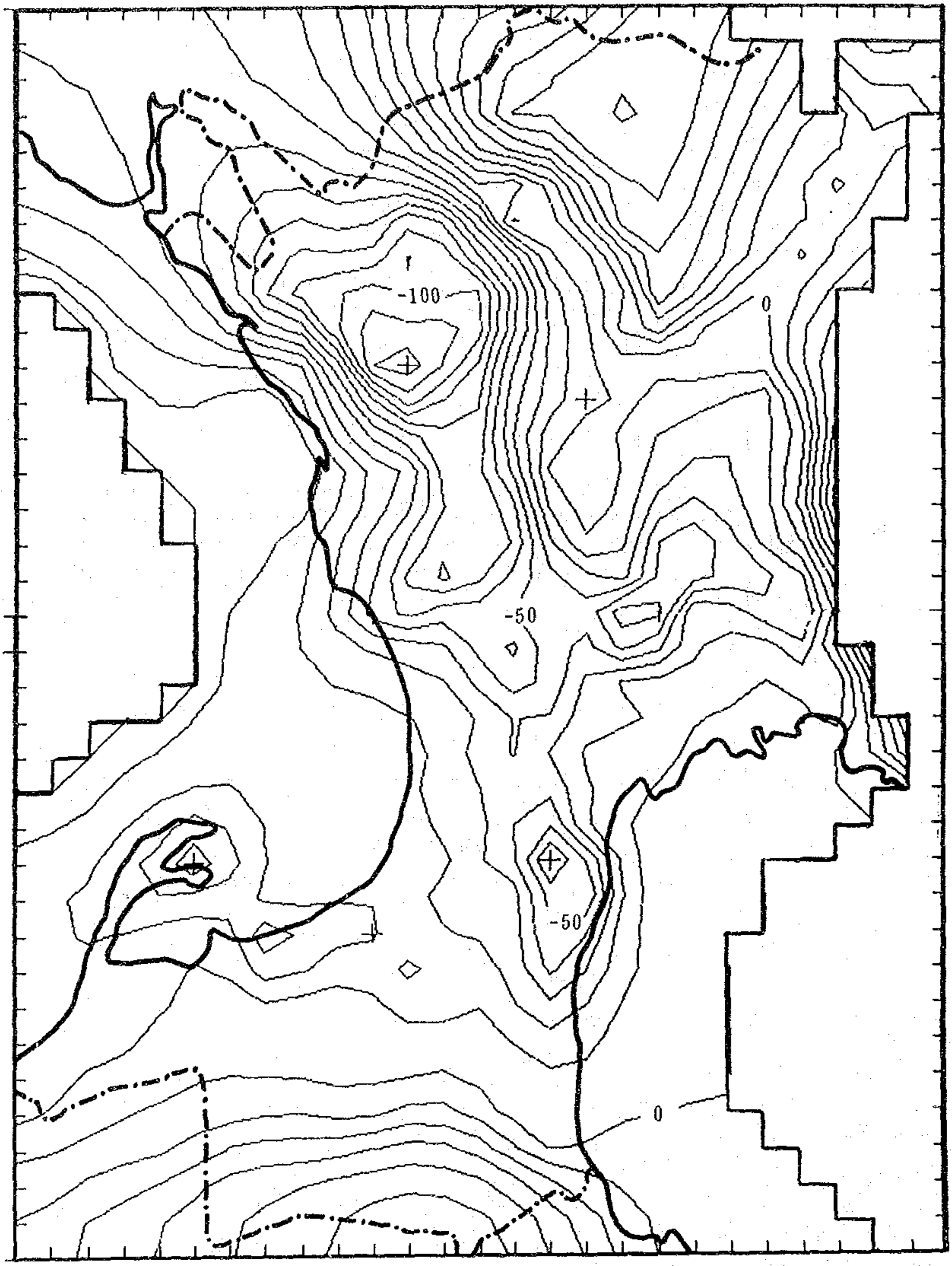


FIGURE 8.5.13

SIMULATED PIEZOMETRIC HEADS BY 30-STEP STEADY-STATE CALCULATION



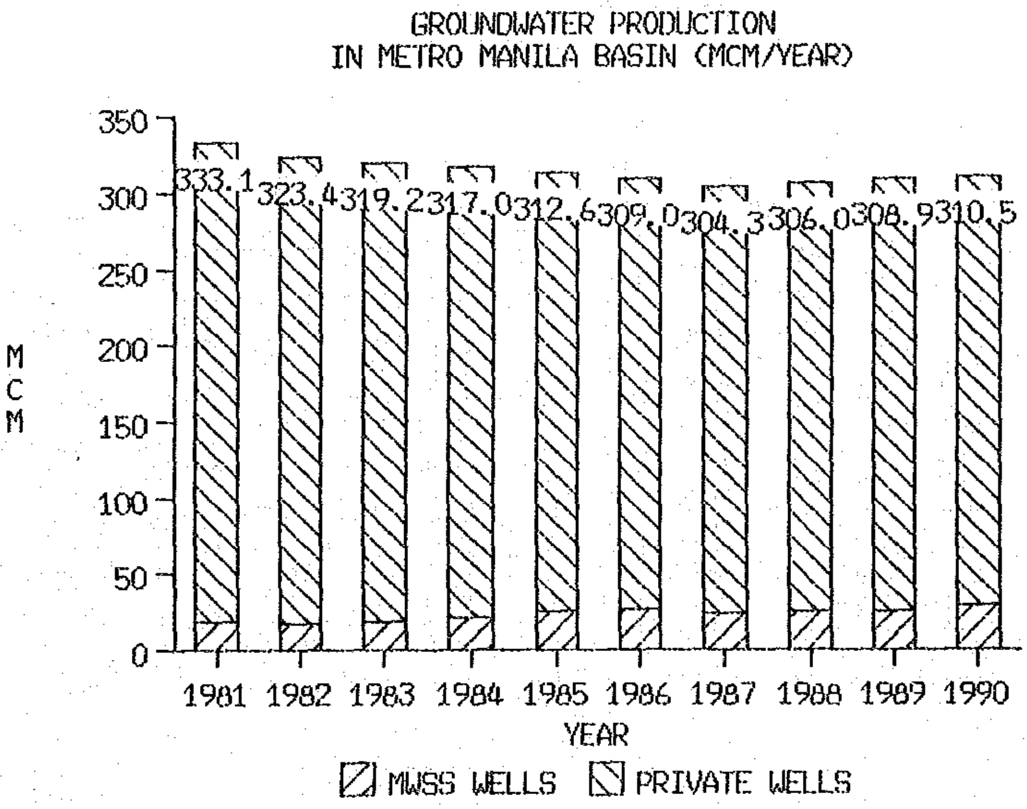
(Contour Interval: 10m, Unit: masl)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.14

SIMULATED PIEZOMETRIC HEADS IN 1981



	Total	MWSS	Private
1981	333.1	18.2	315.0
1982	323.4	17.6	305.8
1983	319.2	18.1	301.1
1984	317.0	21.9	295.2
1985	312.6	25.1	287.5
1986	309.0	26.0	283.0
1987	304.3	24.3	280.0
1988	306.0	25.3	280.7
1989	308.9	24.7	284.2
1990	310.5	29.0	281.5

(MCM)

FIGURE 8.5.15
GROUNDWATER PRODUCTION IN THE METRO MANILA BASIN