shaded portions indicate the latter exception.

Since 1981, the further decline in piezometric head has been caused by increased heavy pumping in the Study Area. Also, the rapid decline of the piezometric head had occurred due to overdraft. Between 1981 and 1990, the range of annual decline has been from 5 to 7m in the Bacoor-Las Piñas area.

Over the Study Area, the dewatering of aquifers appears to average roughly to 40m, with local minima reaching 120m below sea level. Dewatered volumes of aquifer extend beneath the bed of Manila Bay.

As shown in Figure 3.4.3, the highest recovery of groundwater level is 90mm in Pasig, followed by 80mm on the boundaries of Manila, Quezon City, San Juan, Mandaluyong, and Makati; it is 80m in western Quezon City near Caloocan City, 70mm in Navotas and 40 in Marikina. As mentioned earlier, this recovery of water level was brought about by the completion in 1987 Of MWSP II which almost doubled the supply in the MSA.

<u>Antipolo Groundwater Basin</u>

As discussed in Section 3.2, the Antipolo Plateau forms an independent groundwater basin.

As shown in Figure 3.4.4, groundwater flows northward and southward--from topographically higher grounds to springs along the marginal zone of the plateau where groundwater is discharged from the basin. It moves westward to the depressions in the central part of the basin from the eastern boundary. These depressions are caused by groundwater pumpage over this area.

3.4.3 Seasonal Fluctuations

<u>Metro Manila Groundwater Basin</u>

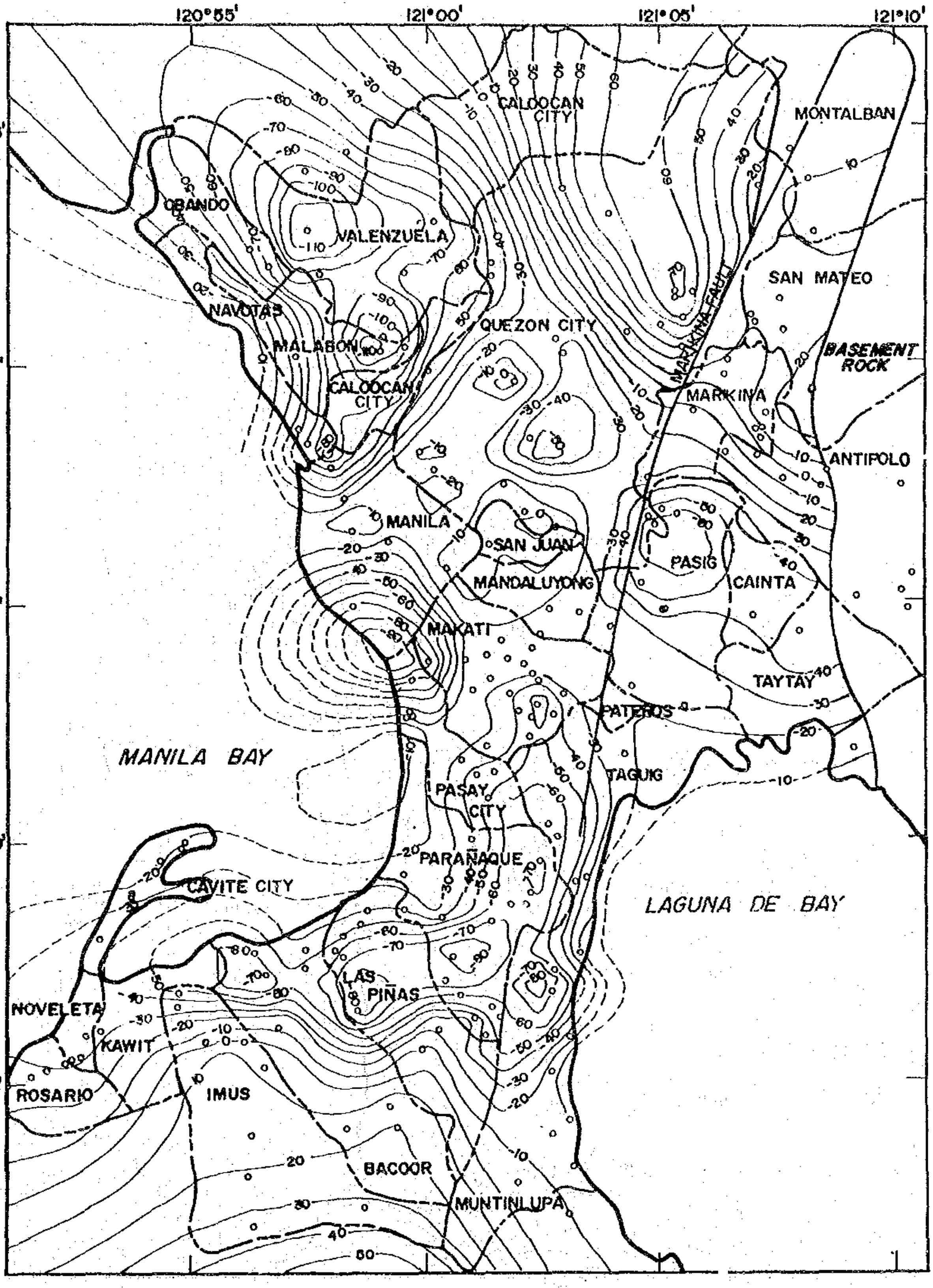
Figures 3.4.5 and 3.4.6 show the seasonal fluctuations in piezometric conditions between May 1990 and November 1990, and between August and May 1991, respectively. As depicted in Figure 3.4.5, the groundwater

level declines from the end of the wet season to the end of the dry season. Shaded portions closed by the -2m contour line in this figure reveal areas with more than two-meter lowering of groundwater level. Groundwater level during the dry season could decline up to six meters.

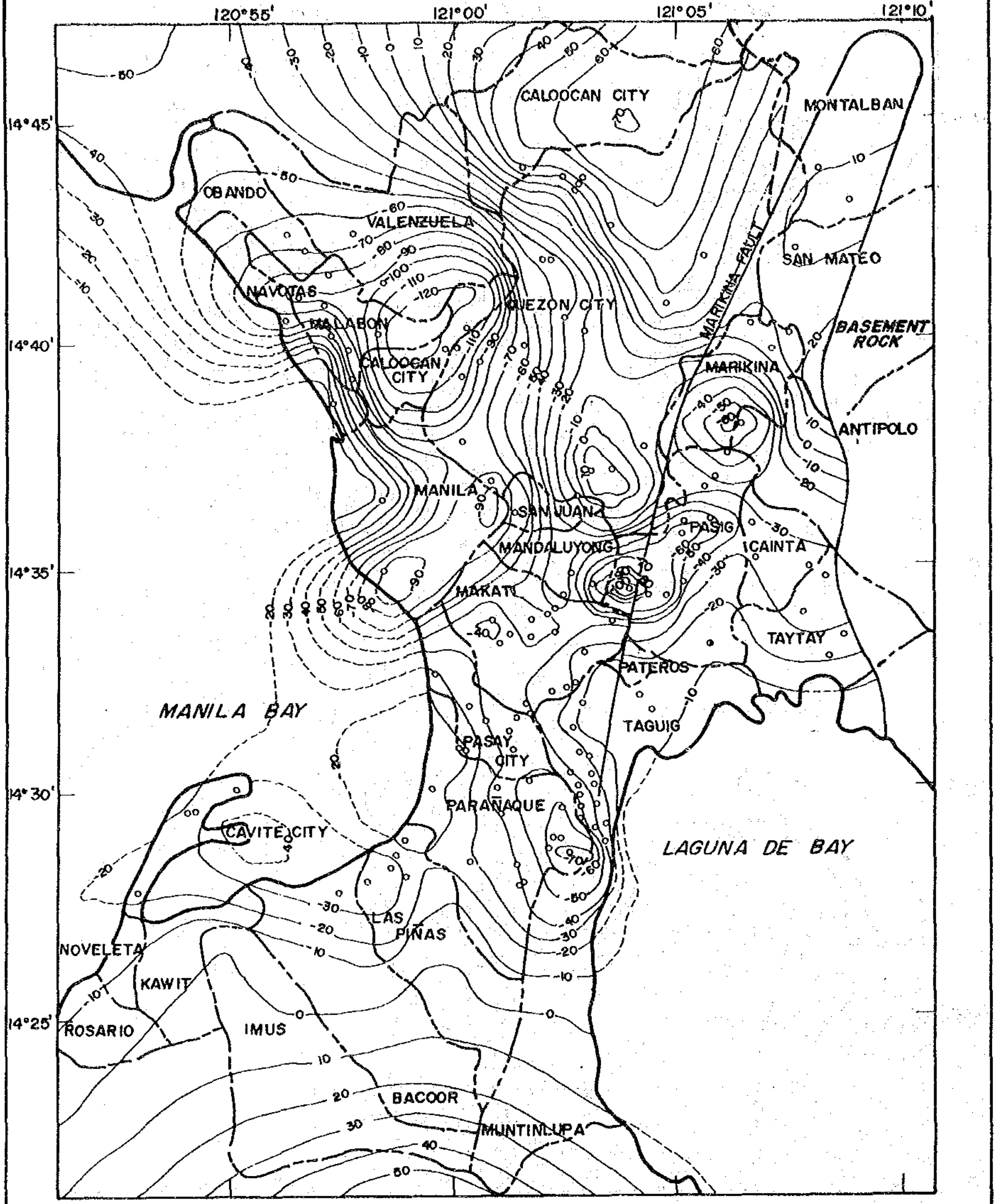
As shown in Figure 3.4.6 (unshaded portions), the fluctuation between May and August 1991 indicates that the groundwater level rose by 1 to 6m in the north and east sectors of the Study Area, and by 2 to 4mm in the south sector. These observations mean that in the north and south recharge areas the rise in the water level is due to recharge from rainfall. In other areas, the rise in water level is perhaps due to decrease in pumpage. The shaded portions indicate areas where water levels have continuously declined since November 1990.

Antipolo Area

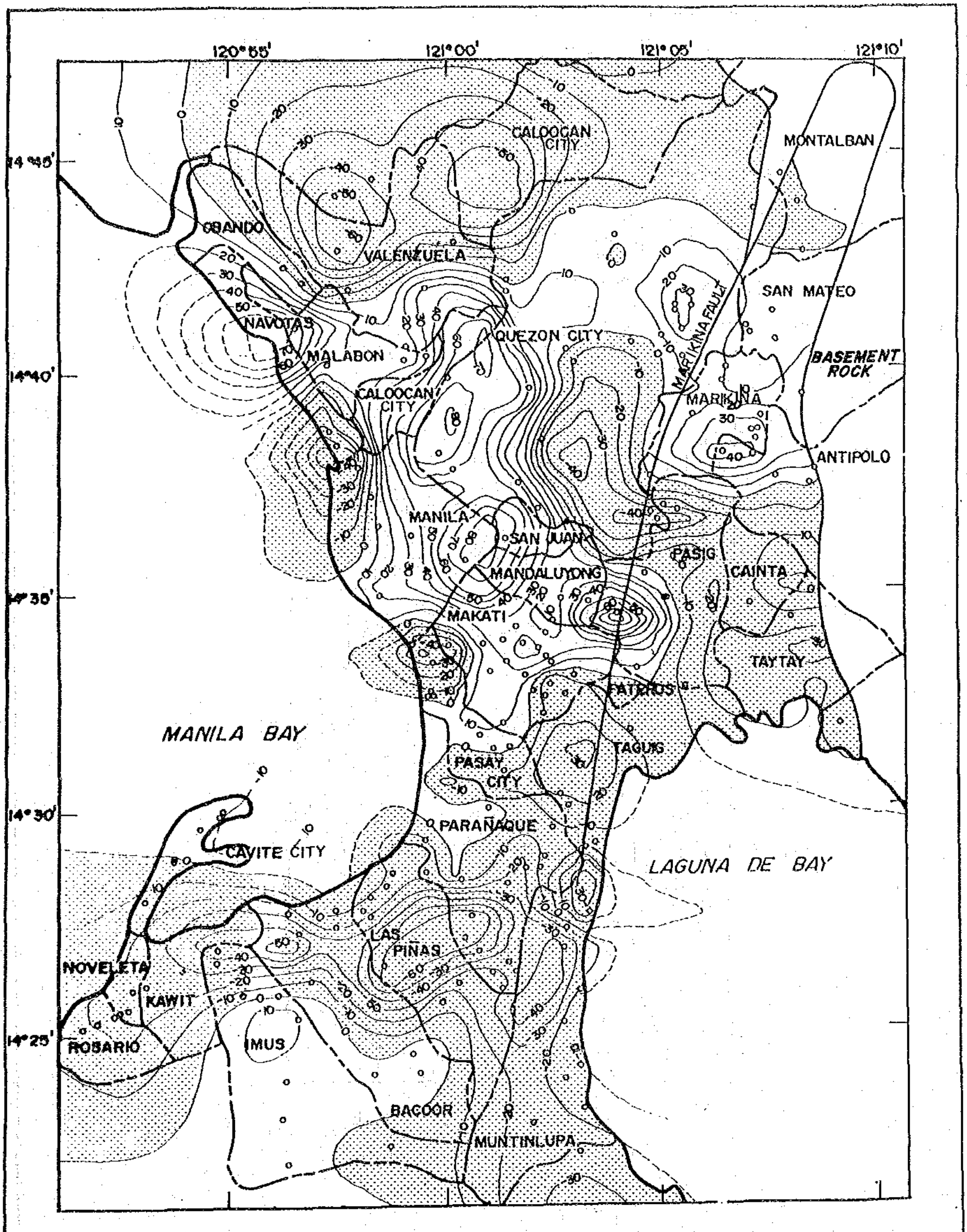
As shown in Figure 3.4.7, the groundwater level in the central part of the basin declined by as much as seven meters in the dry season period between November 1990 and May 1991. Figure 3.4.8 reveals that the piezometric heads rose by 2m from the end of the dry season to the middle of the rainy season due to direct recharge from rainfall.



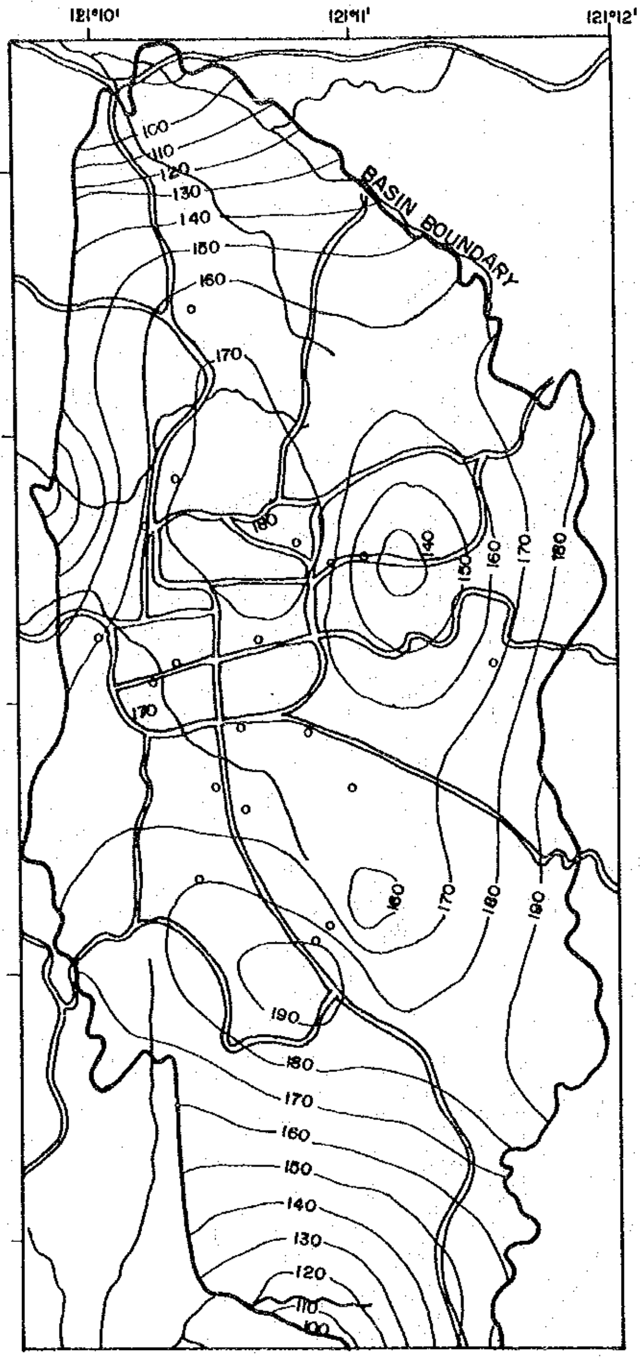
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.4.1 PIEZOMETRIC CONTOUR MAP OF THE STUDY AREA, 1990
JAPAN INTERNATIONAL COOPERATION AGENCY	



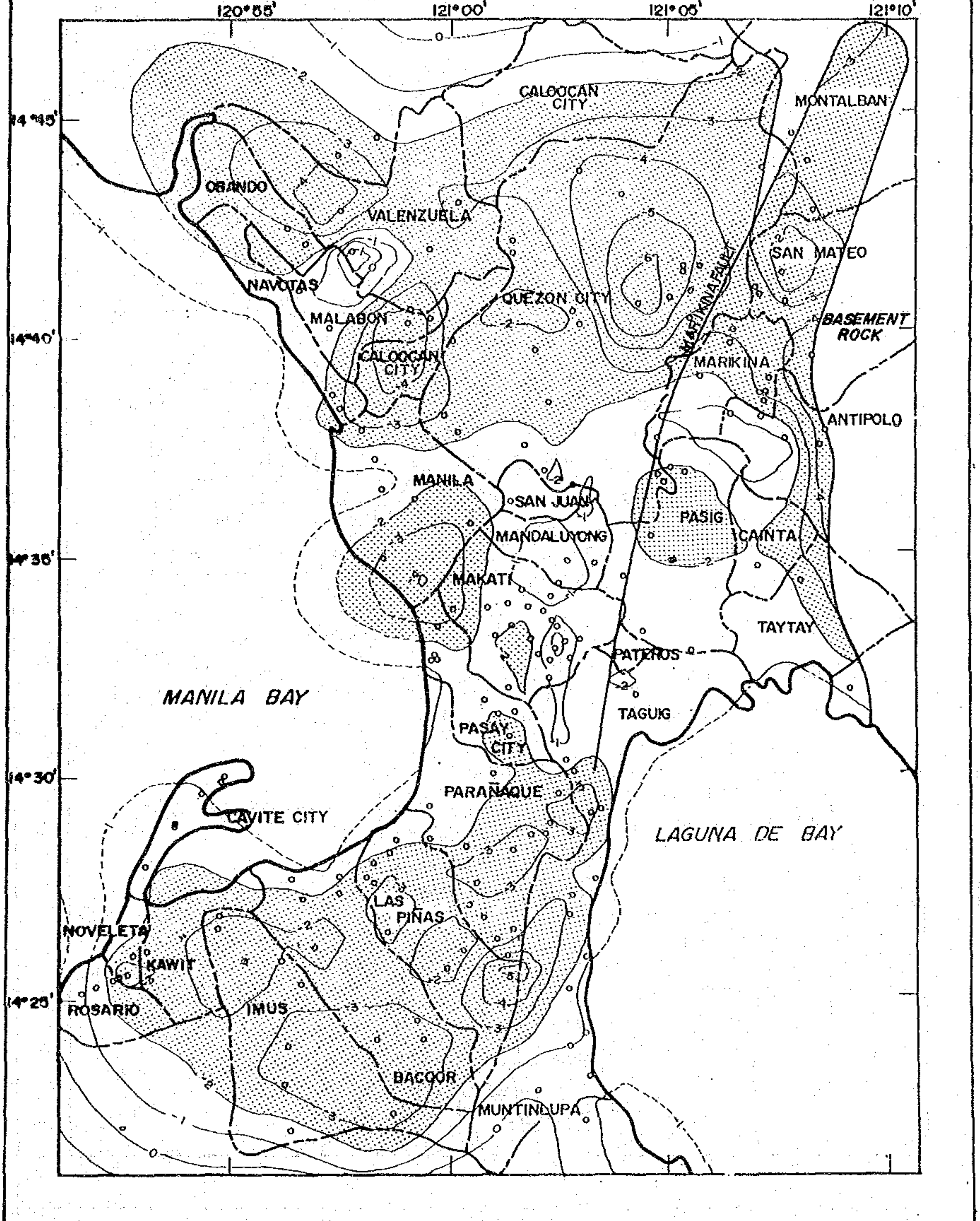
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.4.2
JAPAN INTERNATIONAL COOPERATION AGENCY	PIEZOMETRIC CONTOUR MAP OF THE STUDY AREA, 1981



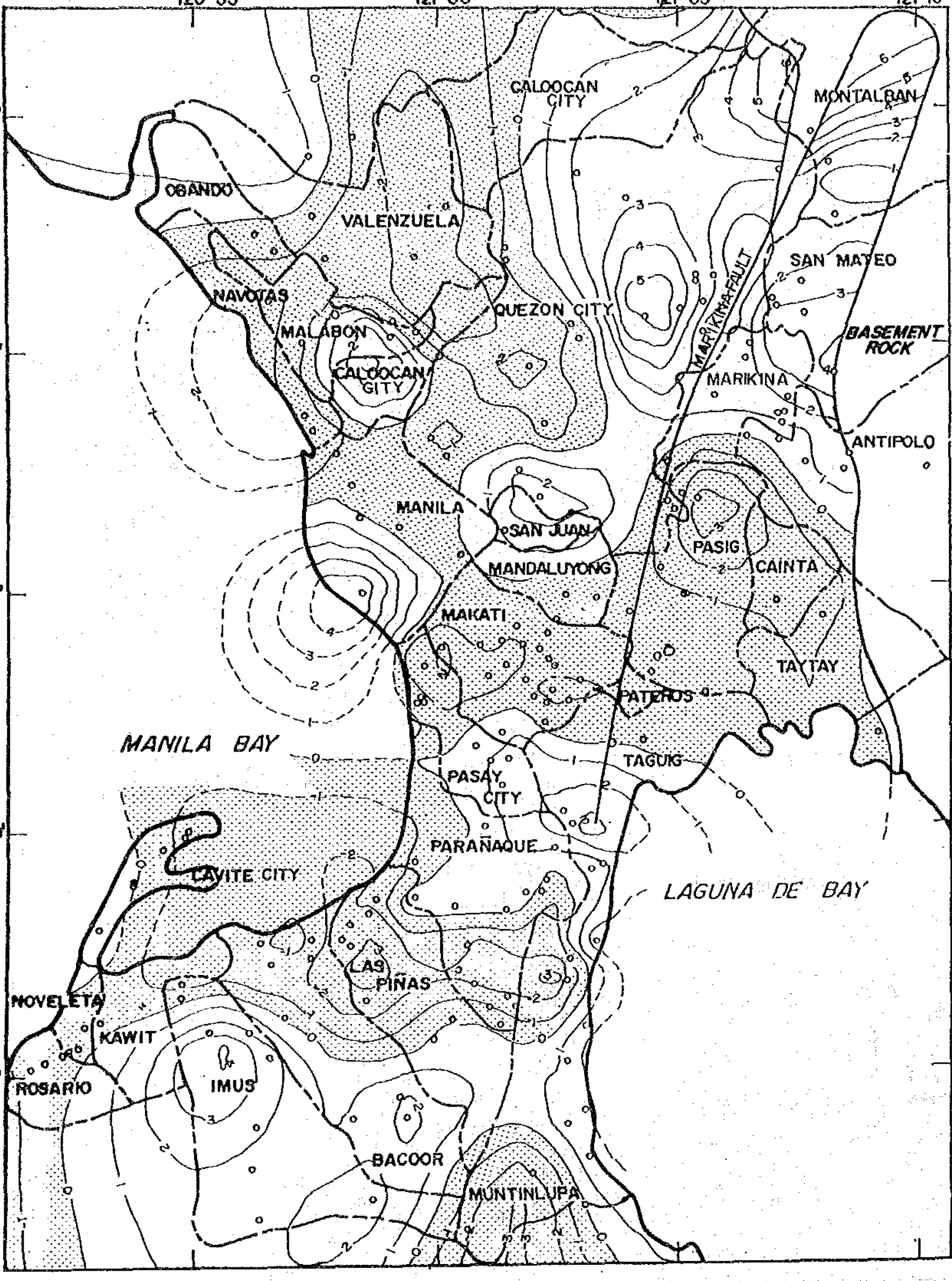
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.4.3 CHANGE IN PIEZOMETRIC CONTOURS IN THE STUDY AREA FROM 1981 TO 1990
JAPAN INTERNATIONAL COOPERATION AGENCY	



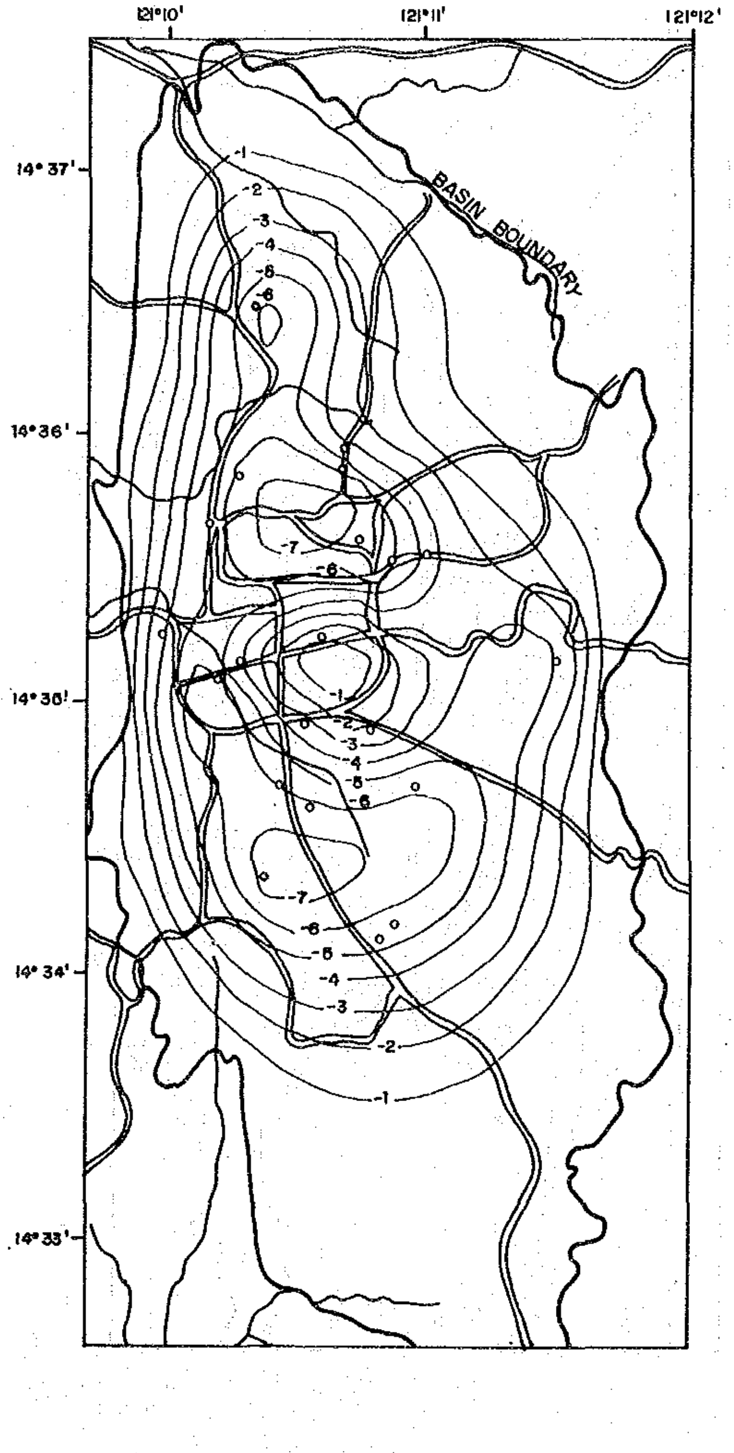
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.4.4 PIEZOMETRIC CONTOUR MAP OF THE ANTIPOLO AREA, 1990
JAPAN INTERNATIONAL COOPERATION AGENCY	



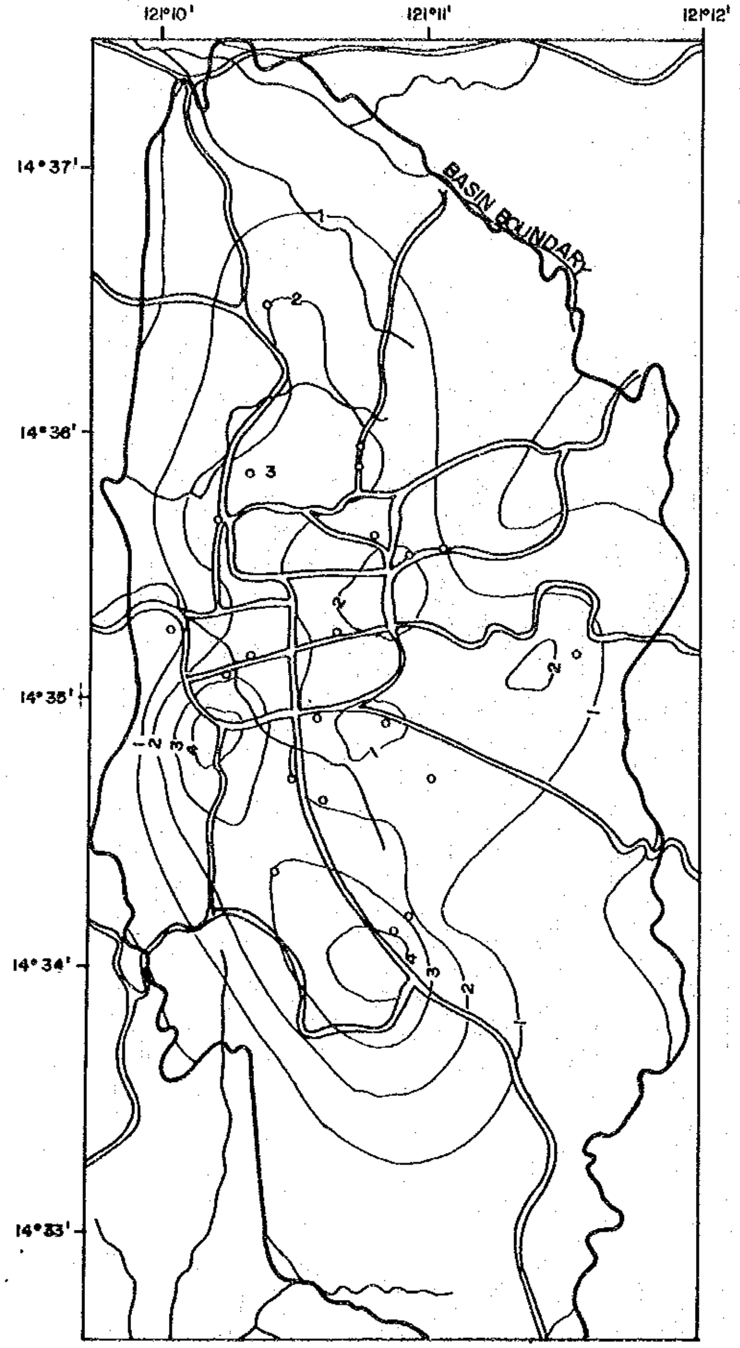
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.4.5
JAPAN INTERNATIONAL COOPERATION AGENCY	CHANGE IN PIEZOMETRIC CONTOURS FROM NOV. 1990 TO MAY 1991, STUDY AREA



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.4.6 CHANGE IN PIEZOMETRIC CONTOURS FROM MAY 1991 TO AUG. 1991, STUDY AREA
JAPAN INTERNATIONAL COOPERATION AGENCY	



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.4.7 CHANGE IN PIEZOMETRIC CONTOURS FROM NOV. 1990 TO MAY 1991, ANTIPOLO AREA
JAPAN INTERNATIONAL COOPERATION AGENCY	



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.4.8 CHANGE IN PIEZOMETRIC CONTOURS FROM MAY 1991 TO AUG. 1991, ANTIPOLO AREA
JAPAN INTERNATIONAL COOPERATION AGENCY	

3.5 RECHARGE ANALYSIS

3.5.1 Water Balance Equation

The water balance equation used in defining recharge is

$$P = R + E + I$$

where, P = mean annual rainfall in mm;
R = runoff in mm;
E = evaporation in mm; and
I = effective infiltration in mm.

Here the direct recharge (effective infiltration) actually includes the infiltration of the precipitation, that from the flow and underflow of the precipitation, that from the flow and underflow of the streams, and that from the percolation of the rice fields.

3.5.2 Estimation of Recharge Components

(1) Rainfall

The isohyetal map of mean annual rainfall for the Study Area is shown in Figure 3.5.1. This map was calculated and plotted using contouring programs which provided nodal values for the isohyets. Areal rainfall was determined using these nodal values.

In the case of Antipolo, the rainfall record (years 1911 to 1990) which was used came from the Sumulong Station, which is located at the center of the groundwater basin. Unreliable portions of the record (1973-90) were reconstructed and missing data from 1911 to 1972 wee estimated using regression analysis, with rainfall data (1865-1990) at Port Area as the independent variable.

(2) Runoff

Previous studies (Bulacan Bulk Water Supply Project, 1984; Philippine Groundwater Salinity Intrusion Control Study, 1987) have used a runoff coefficient of 0.45 for the Guadalupe formation. Considering the present land use condition in Metro Manila, however, a runoff coefficient of 0.60 was instead assumed in this Study. This assumption made use of the results of a previous JICA study (The Study on Flood Control and Drainage Project in Metro Manila, 1990).

(3) Evapotranspiration

For the Study Area and Antipolo, the pan evaporation data from the Science Garden were considered. The actual evapotranspiration was estimated as shown in Table 3.5.1.

3.5.3 Estimated Annual Recharge

Tables 3.5.1 presents the direct recharge estimations for the Study Area. The rainfall over the Study Area is 2,329.7mm; runoff depth is 1,397.9mm; and actual evapotranspiration is 816.6mm. Hence, the direct recharge is estimated at 115.3mm or 4.9% of annual rainfall.

The direct recharge estimates over the northern and southern parts of the Study Area are 153.6mm (or 6.1% of the 2498.8mm-annual rainfall) and 114.7mm (or 5% of the 2308.2mm-annual rainfall), respectively. Over the central area, it is 96.7mm or 4.3% of the 2264.2mm-annual rainfall.

Over the Antipolo groundwater basin, rainfall is 2720.8mm; runoff is 1142,7mm; and actual evapotranspiration is 958.8mm. The recharge depth is estimated at 6193mm or 23% of annual rainfall. Refer to Table 3.5.2.

TABLE 3.5.1 WATER BALANCE CALCULATIONS FOR THE STUDY AREA

(unit, all in mm)

a) Study Area

month	P	PET	AET (E)
jan	18.4	84.9	18.4
feb	7.5	103.6	7.5
mar	15.8	144.7	15.8
apr	30.8	142.0	30.8
may	165.8	140.8	140.8
jun	332.6	99.8	99.8
jul	439.6	90.4	90.4
aug	503.6	95.2	95.2
sep	355.8	88.1	88.1
oct	260.8	76.2	76.2
nov	141.1	74.3	74.3
dec	57.9	79.3	79.3
total	2329.7	1219.3	816.6

I = P - E - R, R = 0.6*P
I = 115.3 (or 4.9% of P)

b) Central Part of the Study Area

month	P	PET	AET (E)
jan	16.7	84.9	16.7
feb	6.4	103.6	6.4
mar	14.3	144.7	14.3
apr	27.3	142.0	27.3
may	160.1	140.8	140.8
jun	329.1	99.8	99.8
jul	422.8	90.4	90.4
aug	491.3	95.2	95.2
sep	346.6	88.1	88.1
oct	260.4	76.2	76.2
nov	136.4	74.3	74.3
dec	52.8	79.3	79.3
total	2264.2	1219.3	808.8

I = P - E - R, R = 0.6*P
I = 96.7 (or 4.3% of P)

c) Northern Part of the Study Area

month	P	PET	AET (E)
jan	26.0	84.9	26.0
feb	11.4	103.6	11.4
mar	20.4	144.7	20.4
apr	44.0	142.0	44.0
may	180.7	140.8	140.8
jun	345.8	99.8	99.8
jul	485.8	90.4	90.4
aug	540.5	95.2	95.2
sep	375.5	88.1	88.1
oct	254.5	76.2	76.2
nov	147.1	74.3	74.3
dec	67.1	79.3	79.3
total	2498.8	1219.3	845.9

I = P - E - R, R = 0.6*P
I = 153.6 (or 6.1% of P)

d) Southern Part of the Study Area

month	P	PET	AET (E)
jan	13.7	84.9	13.7
feb	6.1	103.6	6.1
mar	14.8	144.7	14.8
apr	29.9	142.0	29.9
may	174.1	140.8	140.8
jun	351.4	99.8	99.8
jul	410.1	90.4	90.4
aug	512.5	95.2	95.2
sep	336.9	88.1	88.1
oct	260.9	76.2	76.2
nov	141.7	74.3	74.3
dec	56.1	79.3	79.3
total	2308.2	1219.3	808.6

I = P - E - R, R = 0.6*P
I = 114.7 (or 5.0% of P)

PET, potential evapotranspiration
AET, actual evapotranspiration

TABLE 3.5.2

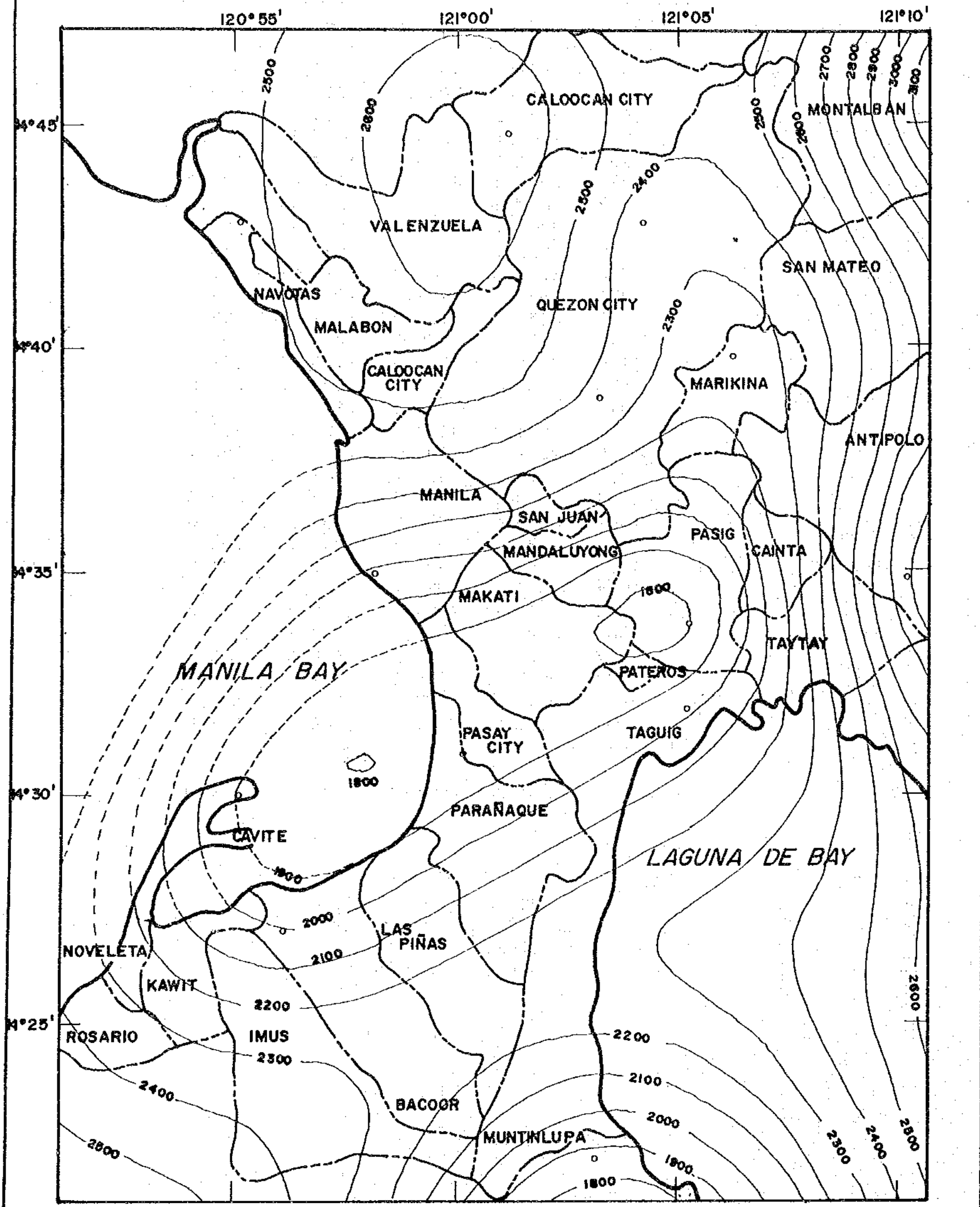
WATER BALANCE CALCULATION FOR ANTIPOLO

YEAR	P	AET (E)	R	I
1911	2968.5	1074.3	1246.8	647.5
1912	2490.2	872.3	1045.9	572.0
1913	2699.9	839.2	1134.0	726.7
1914	3676.3	873.0	1544.0	1259.3
1915	2305.8	812.4	968.4	525.0
1916	2359.4	960.9	990.9	407.6
1917	2576.6	908.0	1082.2	586.4
1918	2945.8	802.8	1237.2	905.8
1919	4402.6	870.9	1849.1	1682.6
1920	2706.2	1004.4	1136.6	565.2
1921	3085.7	824.3	1296.0	965.4
1922	2883.4	916.1	1211.0	756.3
1923	4171.1	1026.7	1751.9	1392.5
1924	2532.3	955.5	1063.6	513.2
1925	2560.0	894.4	1075.2	590.4
1926	2668.8	925.3	1120.9	622.6
1927	2757.5	1050.0	1158.2	549.4
1928	2179.5	907.5	915.4	356.6
1929	2612.0	946.8	1097.0	568.2
1930	2383.1	900.2	1000.9	482.0
1931	3132.8	939.6	1315.8	877.4
1932	2634.9	892.5	1106.7	635.7
1933	2495.6	898.7	1048.2	548.7
1934	4032.0	1051.4	1693.4	1287.2
1935	2879.4	887.0	1209.3	783.1
1936	2475.2	858.3	1039.6	577.3
1937	3639.8	988.3	1528.7	1122.8
1938	2396.8	1087.1	1006.7	303.0
1939	2574.6	922.2	1081.3	571.1
1940	2893.9	968.0	1215.4	710.5
1941	2633.9	992.1	1106.2	535.6
1942	2782.1	998.6	1168.5	615.0
1943	2769.9	998.1	1163.4	608.5
1944	2450.3	980.6	1029.1	440.6
1945	2436.3	979.0	1023.3	434.0
1946	2557.3	988.7	1074.1	494.6
1947	2962.6	1006.6	1244.3	711.7
1948	2664.7	909.4	1119.2	636.1
1949	2020.2	796.9	848.5	374.8
1950	2456.1	981.2	1031.6	443.3
1951	2197.7	848.6	923.0	426.0
1952	2613.1	1045.7	1097.5	469.8
1953	3006.4	1008.6	1262.7	735.1
1954	2281.8	962.0	958.4	361.5
1955	1978.3	924.1	830.9	223.3
1956	2813.5	1000.0	1181.7	631.8
1957	2235.3	956.8	938.8	339.7
1958	3013.1	1008.9	1265.5	738.8
1959	2257.3	959.3	948.1	350.0
1960	3126.6	1013.9	1313.2	799.5

YEAR	P	AET (E)	R	I
1961	2882.7	1003.1	1210.7	668.9
1962	2886.1	1003.2	1212.2	670.7
1963	2522.4	987.1	1059.4	475.9
1964	2780.1	998.5	1167.6	613.9
1965	2504.7	986.3	1052.0	466.4
1966	2956.3	1006.3	1241.6	708.3
1967	2618.3	991.4	1099.7	527.3
1968	2203.4	953.3	925.4	324.7
1969	2328.9	967.2	978.1	383.6
1970	2856.1	1001.9	1199.6	654.6
1971	2525.7	987.3	1060.8	477.7
1972	3255.1	891.9	1367.1	996.1
1973	2264.5	960.1	951.1	353.4
1974	3395.9	1025.8	1426.3	943.8
1975	2350.0	969.5	987.0	393.5
1976	3159.3	1015.3	1326.9	817.0
1977	3214.9	1017.8	1350.3	846.8
1978	2631.1	991.9	1105.1	534.1
1979	2249.2	958.4	944.7	346.2
1980	2553.7	988.5	1072.5	492.6
1981	2223.4	955.5	933.8	334.0
1982	2221.0	955.2	932.8	332.9
1983	1856.4	905.2	779.7	171.5
1984	2540.1	987.9	1066.8	485.4
1985	2910.1	1004.3	1222.2	683.5
1986	3831.5	1045.1	1609.2	1177.1
1987	1965.8	922.2	825.6	218.0
1988	2955.9	1006.3	1241.5	708.1
1989	2577.4	989.6	1082.5	505.3
1990	3069.3	1011.4	1289.1	768.9
MEAN	2720.8	958.8	1142.7	619.3

Note:

P - Annual precipitation, mm
AET - Annual actual evapotranspiration, mm
R - Annual runoff, mm
I - Annual recharge, mm



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 3.5.1
MEAN ANNUAL RAINFALL (MM)
STUDY AREA

3.6 AQUIFER PARAMETERS

Transmissivity, storativity and leakance are the basic aquifer parameters in the evaluation of groundwater flow, change of storage and leakage. Specific capacity is a measure of the productivity of a well.

Since accurate and reliable data are necessary in the evaluation of groundwater resources, data collection on and pumping tests of existing wells were conducted.

3.6.1 Existing Data

Pumping test and aquifer data obtained during GWD-MWSP II (1983) from 150 wells in Metro Manila were reviewed. Collected data include well depth, static water level, drawdown, test pumping rate, specific capacity and transmissivity.

Results of 123 pumping tests conducted after 1983 were also collected and sifted for data on well depth, static water level, drawdown, test pumping rate and specific capacity. In this collection, a few transmissivity data were included. The Study Team likewise made a list of specific capacities involving 163 MWSS wells.

3.6.2 Pumping Tests of MWSS Wells

The step-drawdown test, the constant rate test and the recovery test were conducted for fifteen (15) wells selected from the active MWSS deep wells. These pumping tests were done to evaluate well efficiency, specific capacity, transmissivity and storativity. Some of the selected wells have pumping test data that were obtained during construction. The tests used are applicable to confined aquifers in unsteady-state conditions.

The location map of the 15 selected MWSS wells is shown in Figure 3.6.1. These wells are detailed in Table 3.6.1.

The 15 selected MWSS deep wells operate twenty four (24) hours a day. This continuity of operation considered, the duration of pumping and recovery tests was shortened. The pumping test program was then set as follows:

(1) Step-drawdown test: five (5) steps at two (2) hours per step
(2) Constant rate test: eight (8) hours pumping at constant discharge
(3) Recovery test : four (4) hours recovery

For five (5) wells, the tests that were conducted are the step-drawdown test, the constant rate test and the recovery test. For the other ten (10) wells, however, the step-drawdown test was omitted because of the need to immediately supply water.

Preparatory works were undertaken prior to the conduct of the pumping tests. These works include the installation of sounding tubes for the measurement of water levels after completion of the pumping test.

3.6.3 Pumping Tests of Test Wells

Step-drawdown pumping tests, continuous pumping tests and recovery tests were performed in the seven (7) test wells drilled by the Study Team. Transmissivity and storativity were calculated from the results of continuous and recovery tests using different methods--Theis method, Cooper-Jacob method and Recovery method. Specific capacity was also computed from the results of continuous pumping tests.

The pumping tests in Las Piñas revealed that the transmissivity of the shallow aquifer is higher than that of the deep aquifer; transmissivities of the 100-m wells vary from 116 m^2/day to 219 m^2/d; transmissivities of the 200-m and 300-m wells vary from 13 m^2/d to 54 m^2/d. Storativities range widely, from 1x10-10 to 2x10-1, and do not show clear correlation with depths.

The test wells in Antipolo tapped the deeper aquifer belonging to member IV of the Guadalupe formation (Gmd). The results of the pumping tests show small transmissivity (8.8 m^2/d) and poor productivity of the aquifer.

3.6.4 Transmissivity and Specific Capacity

Figure 3.6.2 shows the distribution of transmissivity values of 196 wells in Metro Manila. The logarithmic average and standard deviation were computed for statistical analyses. The average transmissivity in the Metro Manila area is 77.5 m^2/d, with a 90% reliable range of 21.9 m^2/d to 274.3 m^2/d. Figure 3.6.3 shows the transmissivity map of the Metro Manila area. This map was drawn based on statistical analyses.

As mentioned earlier, the amount of transmissivity data is less than the amount of specific capacity data. Specific capacity values were thus used for the estimation of transmissivity. The empirical relation between transmissivity and specific capacity was given by Logan (1964) in the following equation:

$$T = 1.22Sc$$

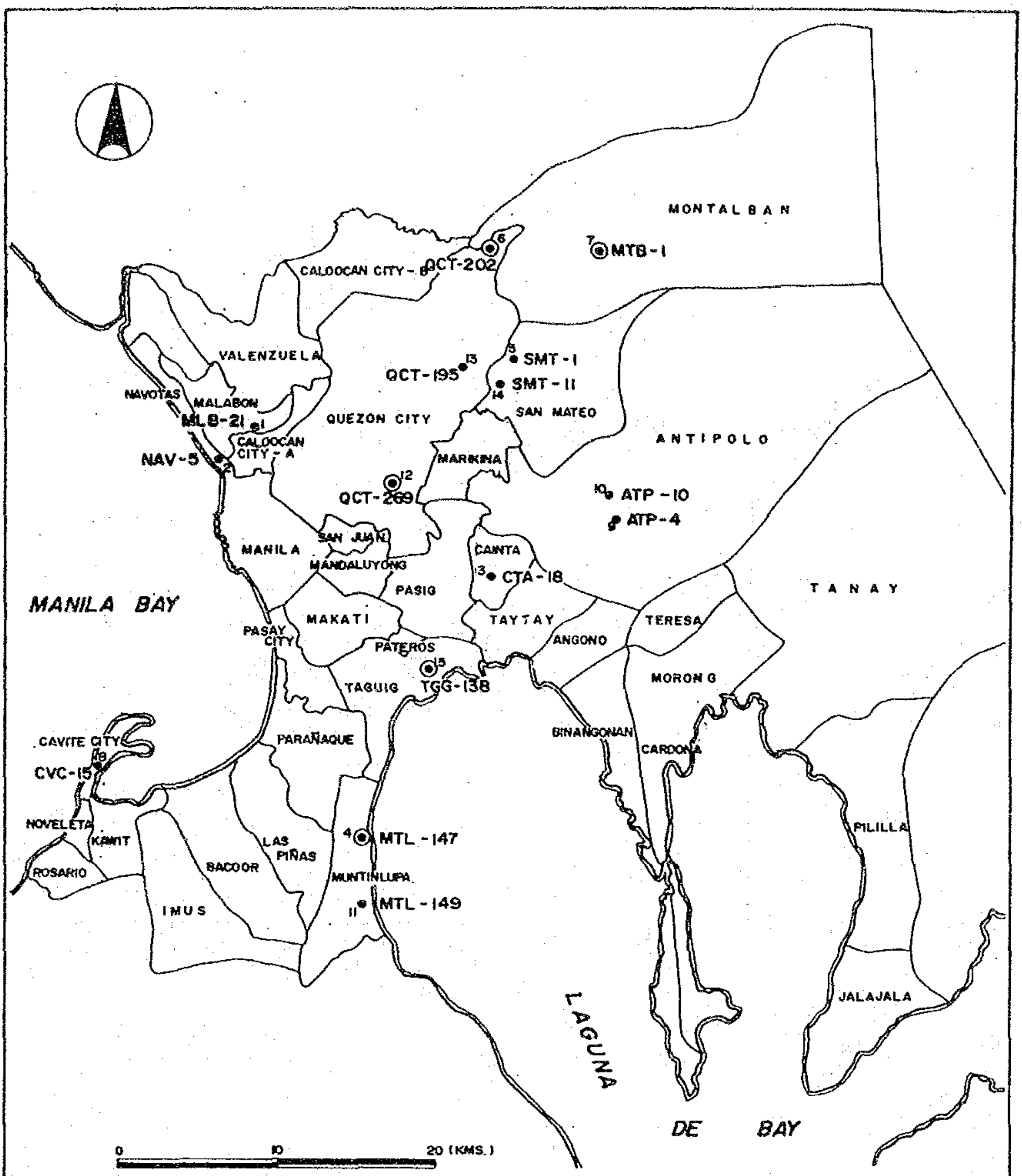
where, T= transmissivity (m^2/d) and Sc= specific capacity (m^2/d). Figure 3.6.4 shows the correlation between the collected/measured transmissivity and specific capacity. It also illustrates the applicability of Logan's equation to the Metro Manila area. The advantages of using specific capacity instead of transmissivity lie not only in increasing the number of data available for analysis but also in making the more reliable data reflect actual aquifer characteristics. Also, even with the most careful conduct of the pumping test, a wide range of transmissivity values is often obtained from such test.

Figure 3.6.5 shows the distribution of transmissivity values of 278 wells, which were estimated from Logan's equation. The logarithmic average is 58.3 m^2/d, with a 90% reliable range of 17.3 m^2/d to 197.1 m^2/d. Figure 3.6.6 shows the estimated transmissivity map of Metro Manila. The input transmissivity data for the Metro Manila groundwater flow model was prepared from the transmissivity map.

TABLE 3.6.1 BRIEF DESCRIPTION OF 15 MWSS WELLS FOR PUMPING TEST

No.	Owner	No.	Locations	Operating Non-Operating	Casing Size (dia.)	Well Depth (m)	Pumping Rate (l/min)	Screen (m)	Remark
1	MWSS	MLB-21	Catmon, Malabon	Operating	(8″)	268	-	164-262	(C+R) test
2	MWSS	NAV-5	NHA-1 Dagat-dagatan	Operating	8″-6″	243.8	(206)	140-237	(C+R) test
3	MWSS	CTA-18	Sto. Domingo, Cainta	Operating	12″ -10″	200	(240)	60-178	(C+R) test
4	MWSS	MTL-147	Sucat Elem. Sch., Muntinlupa	Operating	10-8″	287	(521)	119-283	(S+C+R) test
5	MWSS	SMT-1	Public Market, San Mateo	Operating	10″	137.19	(937.5)	NA	(C+R) test
6	MWSS	QCT-202	Lagro No. 1, Q.C.	Operating	8″	243.84	(1323)	NA	(S+C+R) test
7	MWSS	MTB-1	San Jose, Montalban	Operating	12″-10″	202.16	(545)	NA	(S+C+R) test
8	MWSS	CVC-I5	Ejercito, Cavite City	Operating	8″-6″	257	(450)	136-298	(C+R) test
9	MWSS	ATP-4	Nursery, Antipolo	Operating	8″-6″	100	(666)	NA	(C+R) test
10	MWSS	ATP-10	Saguinsin, Antipolo	Operating	10″-8″	125	(1304)	51-71 82-88 112-115	(C+R) test
11	MWSS	MTL-149	Tunasan, Muntinlupa	Operating	10″-8″	305	(461)	Multi.	(C+R) test
12	MWSS	QCT-269	Escopa, Proj. 4, Q.C.	Operating	10″-8″	244	(500)	146-244	(S+C+R) test
13	MWSS	QCT-195	IBP No. 2, Q.C.	Operating	10″	274	(375)	115-197	(C+R) test
14	MWSS	SMT-II	Banaba-Ampid, San Mateo	Operating	10-8″	174	(642)	73-140	(C+R) test
15	MWSS	TGG-138	Signal Vill. No. 1, Taguig	Operating	10″-8″	171	-	60-170	(S+C+R) test

C: Continuous Pumping Test, R: Recovery Test,
S: Step Drawdown Test

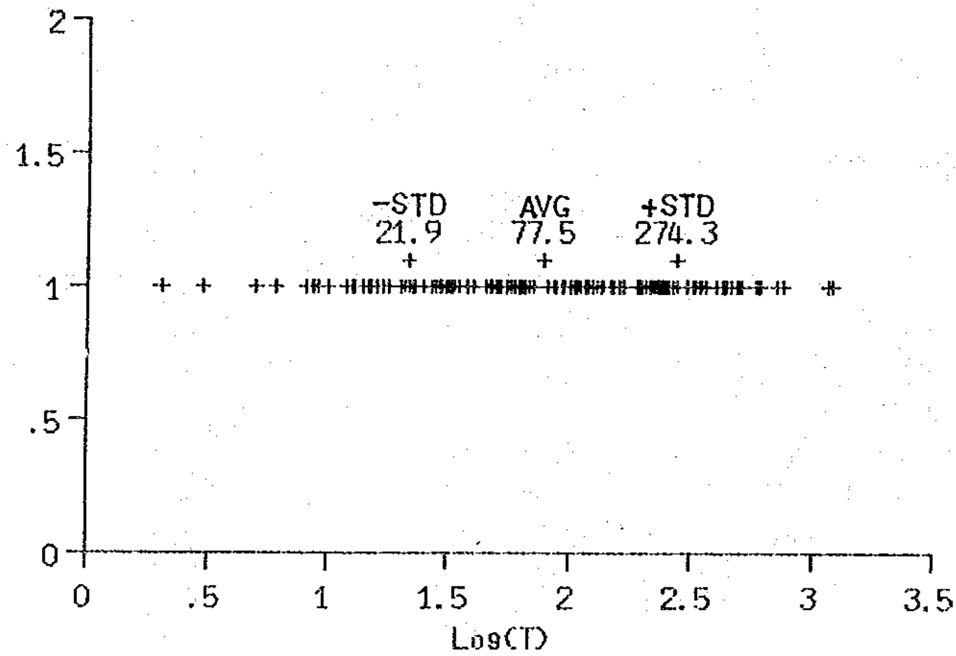


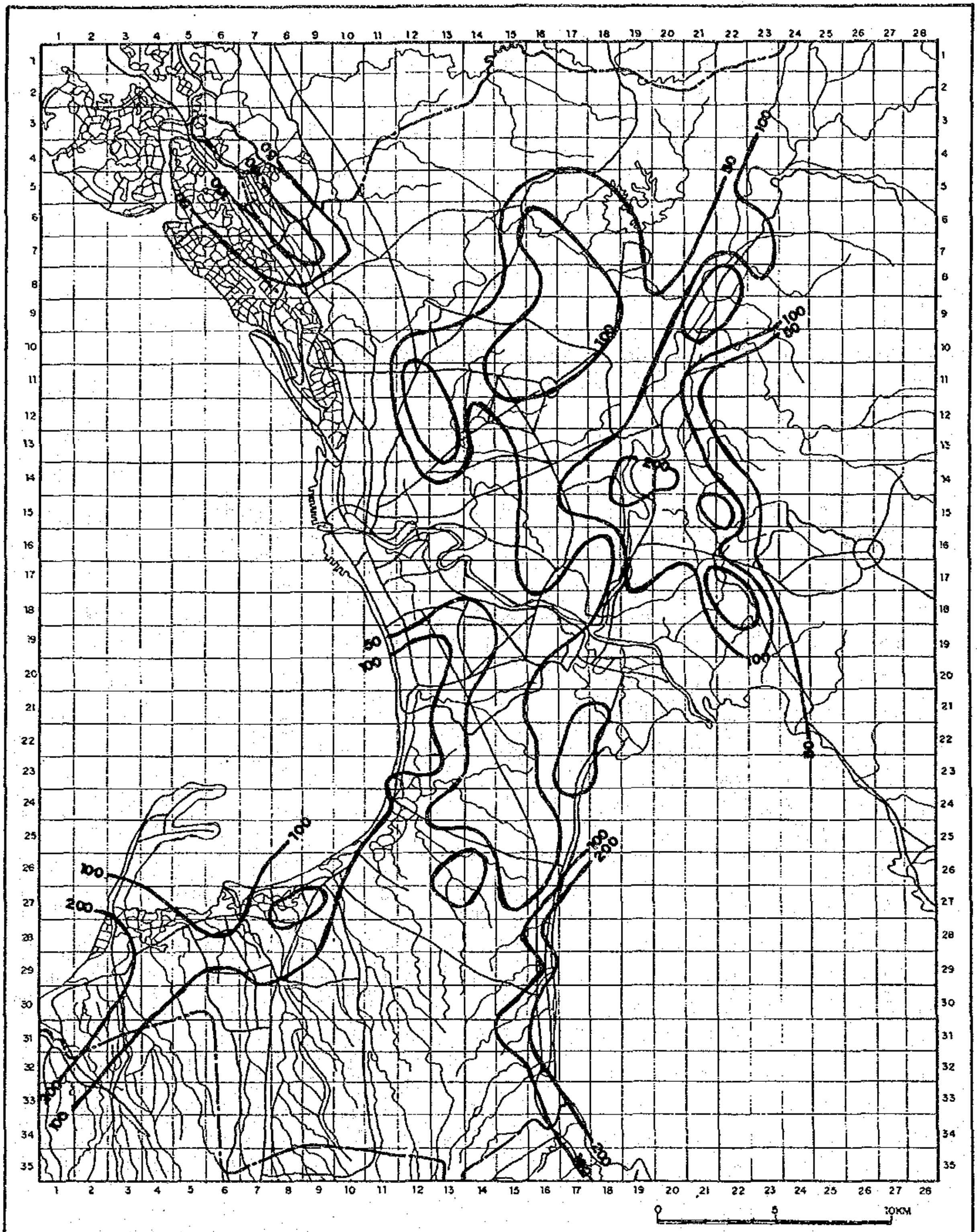
LEGEND :

- • PUMPING TEST SITES (CONTINUOUS DISCHARGE TEST & RECOVERY TEST)
- ◉ PUMPING TEST SITES (STEP-DRAWDOWN, CONTINUOUS DISCHARGE TEST & RECOVERY TEST)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.6.1 FIFTEEN WELLS PUMPING TEST SITES
JAPAN INTERNATIONAL COOPERATION AGENCY	

FIGURE 3.6.2 DISTRIBUTION OF TRANSMISSIVITY (m^2/d)
(number of samples = 196)





STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 3.6.3

TRANSMISSIVITY MAP OF METRO MANILA

FIGURE 3.6.4 CORRELATION BETWEEN TRANSMISSIVITY AND SPECIFIC CAPACITY (m^2/d)

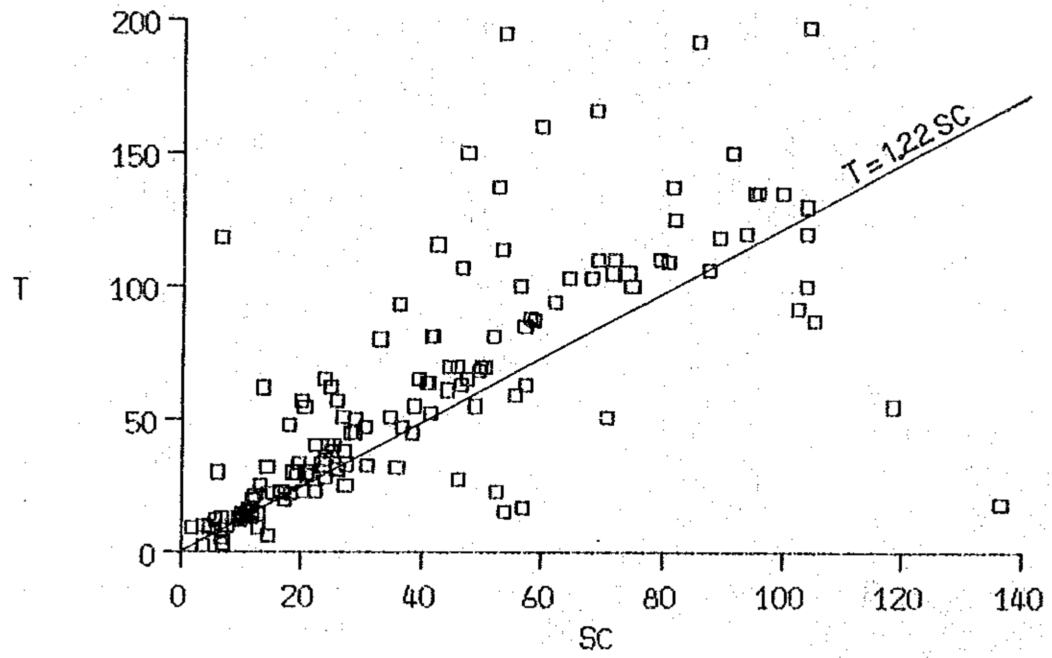
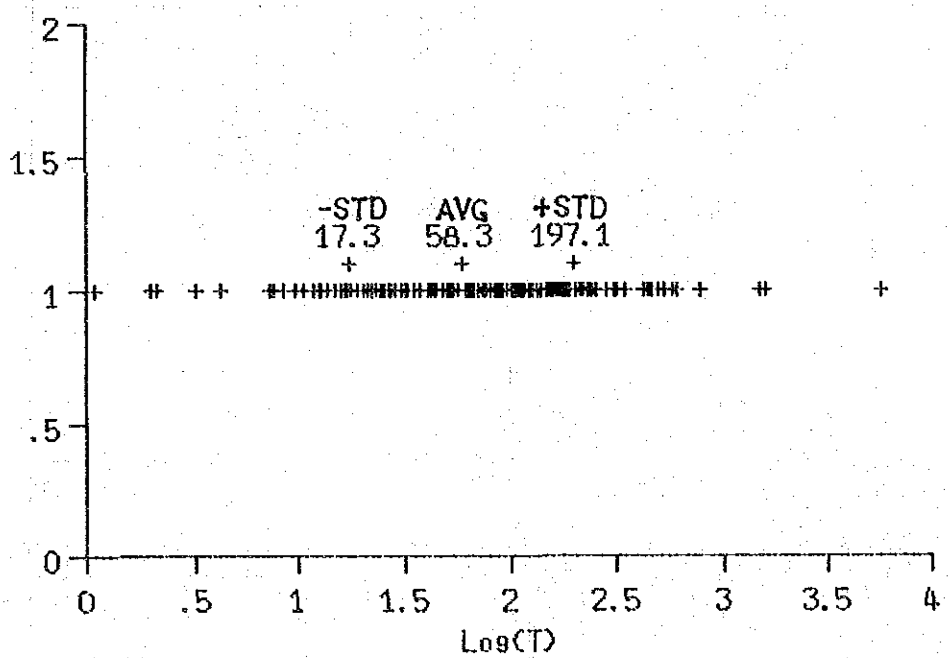
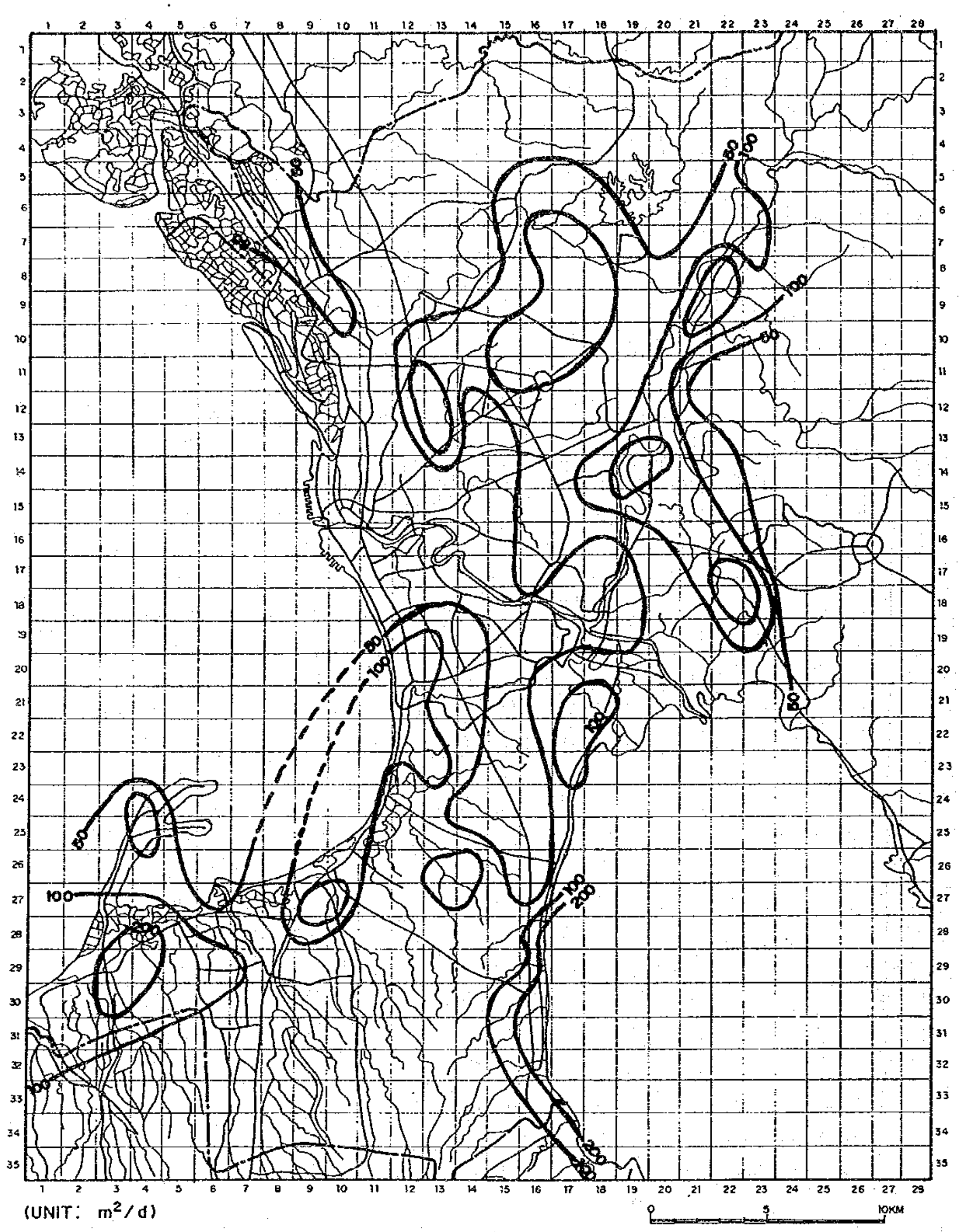


FIGURE 3.6.5 DISTRIBUTION OF TRANSMISSIVITY (m^2/d)
(T=1.22×S, Number of samples = 278)





STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 3.6.6
ESTIMATED TRANSMISSIVITY MAP FROM SPECIFIC CAPACITY

3.7 GROUNDWATER QUALITY

3.7.1 Groundwater Sampling

Groundwater sampling and water quality analysis were performed in order to characterize the bodies of groundwater in the Metro Manila groundwater basin in terms of their chemical composition, and to clarify the distribution of chloride ion in the area affected by saline water intrusion.

A total of 90 water samples were collected and analyzed. Operational MWSS deep wells were given first priority as sampling points. Where no operating MWSS deep well exists in a locality, sampling points were selected from existing private deep wells. In choosing deep wells as sampling points, the priority is given to those with data on lithologic log, well design, etc.

Water samples were also collected from rivers, from the sea, and from the JICA test wells drilled in Las Piñas and Antipolo. For tritium (^3H) analysis, water samples were collected from wells of different depths.

The list of sampling points is shown in Table 3.7.1, and their location is presented in Figure 3.7.1. Results of analyses are summarized in Table 3.7.2.

3.7.2 Hydrochemical Facies

3.7.2.1 Trilinear Diagram Representation

In terms of topography and geology, location of groundwater sampling points can be clustered into four sections, namely, the coastal plain of Manila Bay, the Guadalupe Hill, the Marikina Valley and the Antipolo Plateau (Figure 3.7.1). The results of chemical analysis were separately plotted on the trilinear diagram of each section (Figure 3.7.2).

(1) The Coastal Plain

Most of the samples are plotted on domains III and IV of the diagram. The water in domain III is of the carbonate alkali type, while that in domain IV is of the noncarbonate alkali type. A few samples are plotted on domain II (carbonate hardness type). These samples are located close to the Guadalupe Hill.

Samples plotted on domain IV are salinized and contain more than 200 mg/l of chloride. In JICA's two 100-m test wells in Las Piñas, the chloride concentration is extremely high and reaches more than 17,000 mg/l. In addition, their calcium-magnesium content is higher than that of seawater.

Samples plotted on domain III are not salinized. Their chemical composition is thought to change from II to III along the flow paths, and such composition may be altered to the noncarbonate alkali (domain IV) due to saline water intrusion.

Most samples belong to the sodium-potassium type in terms of cation, except for salinized water which shifts to the calcium type. In terms of anion, the samples have a wide range of distribution. They are classified into bicarbonate, chloride and nondominant types in accordance with the degree of salinization.

(2) Guadalupe Hill

Samples of the Guadalupe Hill are plotted on domains II and III. They are of the sodium-potassium type in terms of anion and of the bicarbonate type in terms of cation. Alteration in the chemistry of groundwater commonly occurs when it moves along flowlines from the recharge area to the discharge area. From this point of view, samples plotted on domain III may have evolved geochemically from domain II. Chloride and sulfate concentrations of these samples are low and amount to less than 50 mg/l, suggesting that groundwater of the Guadalupe aquifer in the hill is not contaminated yet by saline water.

(3) Marikina Valley

Samples are plotted on all the domains from I to IV. Two samples plotted on domain I are remarkable. These samples came from deep wells in Cainta. Another two samples plotted on domain IV are also remarkable. These samples came from deep wells in Taguig and Taytay, which are located downstream of the Marikina River. Chloride concentration of these latter samples show more than 140 mg/l. The sample from Taguig in particular reached 457 mg/l.

According to MGB which drilled a test well (PS-4) downstream of the Marikina River, the Guadalupe aquifer contains connate water in deeper formations. The Electrowatt Study also mentioned the existence of connate water in this valley.

Since water samples taken at the shallow Guadalupe aquifer belong to domains II or III, samples plotted on domains I and IV are possibly contaminated by connate saline water.

(4) Antipolo Plateau

All samples are plotted on domain II. Surface water samples taken from Wawa Dam also belong to domain II. It therefore follows that the chemical component of the groundwater in the plateau is similar to that of surface water.

Groundwater belongs to the bicarbonate type in terms of anion. In terms of cation, it belongs to either calcium type or to no dominant type.

These characteristics of groundwater suggest that it has not been long since rainwater infiltrated through the soil into the aquifer system.

3.7.2.2 Hydrochemical Profile

Hydrochemical facies are represented on the west-east cross section of Metro Manila as shown in Figure 3.7.3.

Hydrochemical facies in the coastal plain are of the noncarbonate alkali type ($NaSO_4$-$NaCl$) of domain IV. Groundwater is obviously being salinized. Water quality in the Guadalupe Hill and Antipolo Plateau belongs to the carbonate hardness type ($Ca(HCO_3)_2$) of domain II. The carbonate alkali type ($NaHCO_3$) of domain III is distributed in a limited area in the coastal plain and Marikina Valley.

The groundwater quality of the Guadalupe aquifer is considered as originally belonging to domain II, but which has been altered along the flow paths. In the coastal area, it has shifted to the noncarbonate alkali type due to saline water intrusion. In Marikina Valley, connate water migrates upward into the shallow aquifer due to upconing.

3.7.2.3 Pattern Diagram

A distribution of pattern diagrams is shown in Figure 3.7.4. The larger the area of the polygonal shape, the greater the concentration of the various ions. The diagrams distributed north of the Guadalupe Hill and the Antipolo Plateau are small and have disc-like or fish-like shapes.

On the other hand, in the coastal plain and the south of the Guadalupe Hill, the diagrams are large because of the high concentration of dissolved ions. Particularly, as groundwater is highly salinized and contains high concentrations of sodium, potassium and chloride, the pattern diagrams show their upper part to be larger and both of their sides longer.

3.7.3 Chemical Evolution and Hydrologic Cycle of Groundwater

3.7.3.1 Chemical Evolution

As groundwater moves along its flow paths in the saturated zone, what normally occurs is an increase of total dissolved solids and of most major ions. In addition, alteration of the chemical composition of groundwater occurs systematically due to:

1) Dissolution from the formation
2) Change in environment from oxidization to reduction
3) Ion exchange between the ions contained in water and those in clay minerals

From these considerations follow the conclusion that shallow groundwater in recharge areas is lower in dissolved solids than water which is located deeper in the same system. The latter type of groundwater has the same characteristic as the water in shallow zones of discharge areas.

The alteration process is generally termed as the chemical evolution of groundwater. Sugisaki and Shibata (1961) explained this process on a key diagram like the one shown in Figure 3.7.5. Groundwater evolves geochemically along the line indicated by the arrow.

Carbonate minerals are first dissolved when rain infiltrates through the unsaturated zone into the aquifer system. Groundwater quality is denoted (1) in domain II of the diagram. As groundwater moves, it chemically evolves and changes to (2) and (3) in domain II due to solution from rock minerals and organic decomposition. Ion exchange between Ca^{++} and Mg^{++} in water and Na^{+} in clay minerals occurs in the process. Chemical composition thereby changes to (4), and then (5) in domain III.

Applying the chemical evolution process to the Study Area, the groundwater in the Guadalupe aquifer system on the northern Guadalupe Hill and Antipolo Plateau is in process (1) and (2). It is in process (3) to (5) in the southern Guadalupe Hill, the Marikina Valley and the coastal plain.

The chemical characteristics of groundwater are related to the minerals of the soils and rocks in contact with it; that is, to the facies of the formation and their geological age.

The Guadalupe formation is covered by the younger Diliman formation in the northern Guadalupe Hill. The Guadalupe formation is also thought to be younger in Antipolo than in Guadalupe Hill. So considered, it can be concluded that it has not been so long since rain reached the aquifer system in these areas.

The evolution of the quality of groundwater in the southern Guadalupe Hill, the coastal plain and Marikina Valley is so long in time due to long travel or stagnancy along its flow paths.

3.7.3.2 Tritium Dating and Hydrologic Cycle

In order to estimate the groundwater cycle, four (4) groundwater samples from JICA test well sites and one (1) seawater sample from Manila Bay were taken to Japan for tritium analysis.

Tritium is a radioactive isotope of hydrogen with a half life of 12.4 years. The presence of tritium in water of the hydrologic cycle arises from both natural and manmade sources. Tritium is produced naturally in the earth's atmosphere by the interaction of cosmic ray-produced neutrons and nitrogen. Until 1952 the average natural tritium content of precipitation worldwide is in the range of about 5 to 20 TU. With the beginning of large scale atmospheric testing of thermonuclear bombs in 1952, the tritium contents of precipitation rose sharply.

From 1962 to 1963, tritium content of the atmosphere reached a maximum of about 80,000 TU in some localities, over a thousand times greater than that for the period prior to nuclear bomb testing. With the restriction of atmospheric testing, tritium contents have been declining, but still in larger concentrations than those naturally produced.

The longest continuous record of ^3H concentration in precipitations came from Ottawa, Canada, where sampling had begun in 1952. ^3H versus time record for this location is shown in Figure 3.7.6. The trends displayed are representative of the ^3H trends recorded elsewhere in the northern hemisphere.

Tritium is widely used for groundwater dating in this context: Very low tritium concentrations, around the level of detectability, indicate that the water is principally from the pre-nuclear period. If a sample of groundwater contains tritium at concentration levels of hundreds or thousands of TU, it is evident that the water, or at least a large fraction of it, originally entered the groundwater zone sometime after 1953. If the water has less than 5-10 TU, it must have originated prior to 1953 (Freeze and Cherry, 1979).

Results of analysis are shown below:

Locality	TU
Las Piñas No.2 300m well	4.63
Las Piñas No.2 200m well	3.25
Las Piñas No.2 100m well	2.58
Antipolo 200m well	1.60
Sea Water (Matabungkay Beach)	4.16

Tritium concentrations indicate that the water may have originated prior to 1953 or may have mixed with post-1953 water. Tritium concentrations in shallow aquifers are lower than those in deep aquifers. This may be explained as follows:

> Significant amounts of the post-1953 water with high tritium con tent are still present in deep aquifers although tritium has de cayed. On the other hand, the shallow aquifer has been replenished with more recent low tritium water. However, the result that tritium content of the seawater is almost the same as that of the groundwater in the deep aquifers could not be explained at present. Further studies using various kinds of environmental isotopes are necessary to clarify the flow mechanism in the Guadalupe aquifers.

3.7.4 Groundwater Salinization

Analysis of groundwater samples collected in the coastal area shows a chemical composition different from a simple proportional mixing of seawater and groundwater (Figure 3.7.2). The samples are located in the lower area of domain IV or the Na+K dominant area of domains III and IV. The highly salinized water samples are located in the Cl+SO4 area of domain IV.

Chloride concentrations of JICA's 100-m test wells in Las Piñas show 17,144 mg/l at LPS-1 and 21,100 mg/l at LPS-2. In addition, concentrations of Na and Ca are higher than those of seawater (Table 3.7.2).

Shifts in the chemical composition of seawater entering an aquifer may occur under three processes (Revelle, 1941):

(1) Base exchange between water and minerals of the aquifer;
(2) Sulfate reduction and substitution of carbonic or other weak acid radicals; and
(3) Solution and precipitation.

Only the last process can change the total salt concentration; however, the first two processes which require maintenance of ionic balance can alter the percentage by weight of the different salt components and thereby the total dissolved solids in mg/l (Todd,1980).

Clay minerals in the formation generally adsorbs Na. Chemical equilibrium is achieved when these minerals come in contact with water containing Ca as shown below.

$$2NaX+Ca^{2+} \qquad CaX_2+2Na^{+}$$

Reaction occurs from right to left in the above equation if the concen tration of Na is abnormally high.

The Ca/Mg, Ca/Cl and Mg/Cl ratios of samples which denote more than 100 mg/l of chloride concentration are presented in Table 3.7.5. Ca/Mg ratio of all samples are higher than that of seawater. This ratio ranges from 1 to 10, even in the samples which show lower than 200 mg/l of chloride concentration. The Ca/Mg ratio of seawater is only 0.0379.

Ca/Cl ratios of all samples are higher than the Ca/Cl ratio (0.0211) of seawater, suggesting the chemical composition of groundwater to have been changed by seawater intrusion. On the other hand, Mg/Cl ratios of almost all samples are lower than that (0.0684) of seawater, which is still valid (Tables 3.7.3 and 3.7.4).

Revelle (1941) proposed the Cl/HCO_3 ratio as a criterion for evaluating intrusion. Chloride is the dominant anion of ocean water and is not affected by the earlier said processes. It normally occurs in groundwater in only small amounts. On the other hand, bicarbonate is usually the most abundant anion in groundwater and occurs in only minor amounts in seawater.

Groundwater samples in the Study Area show the Cl/HCO_3 ratio to be increasing linearly (Figure 3.7.7), clearly indicating the intrusion of seawater into the aquifer system.

TABLE 3.7.1 LOCATIONS AND NAMES OF WELLS FOR GROUNDWATER SAMPLING

ID NO.	NAME	WELL NO.	LOCATION
1	LPS-1 Well # 2		Quirino Avenue, Las Piñas, M.M.
2	LPS-1 Well # 3		Quirino Avenue, Las Piñas, M.M.
3	LPS-2 Well # 3		Beside Public Market Zapote, Las Piñas
4	URIC Sub. Div.		Alabang Zapote Rd., Las Piñas
5	Manuela Sub. Div.	LPS-117	Alabang Zapote Rd., Las Piñas
6	LPS-2 Well # 2		Beside Public Market, Zapote, Las Piñas
7	Samonte Park # 1	CVC-1	Samonte Park Compound, Cavite City
8	Ejercito P/S	CVC-15	Ejercito St., Cavite City
9	Noveleta Elem. Sch.	NOV-7	Noveleta Elem. Sch., Noveleta, Cavite
10	Noveleta Well # 2	NOV-2	San Antonio, Noveleta, Cavite
11	Noveleta Well # 5	NOV-5	Abandoned Rail Road, Noveleta, Cavite
12	Noveleta Well # 8	NOV-8	Abandoned Rail Road, Noveleta, Cavite
13	Nursery Well # 4	ATP-4	Nursery, Antipolo, Rizal
14	Saguinsin Well # 10	ATP-0	Along Circumferential Rd., Antipolo, Rizal
15	Cogeo Pump # 2	ATP-30	Cogeo Village, Antipolo, Rizal
16	San Juan Pump # 3	CTA-19	San Juan Cainta, Rizal
17	Bangiad Pump Station	TYY-0	Bangiad, Taytay, Rizal
18	Sto. domingo	CTA-18	Sto. Domingo, Cainta, Rizal
19	LPS-1 Well # 1		Quirino Avenue, Las Piñas, M.M.
20	Manila Japanese School		Levitown, Parañaque, M.M.
21	Aguinaldo	KWT-4	Aguinaldo Elem. Sch., Kawit, Cavite
22	IBP # 2	QCT-196	Batasang Pambansa, Q.C.
23	Fairview Pump # 3	QCT-208	Pearl St., Fairview, Q.C.
24	Lagro # 1	QCT-202	Lagro, Quezon City
25	Wawa Dam		Wawa, Montalban, Rizal
26	San Jose Pumping Station	MTB-1	San Jose, Montalban, Rizal
27	Public Market	SMT-1	San Mateo Public Market, San Mateo, Rizal
28	LPS-2 Well # 1		Beside Public Market, Zapote, Las Piñas
29	Combalay		Combalay, Kawit, Cavite
30	Plaza Garcia	IMS-21	Plaza Garcia, Imus, Cavite
31	Green Meadow # 3	QCT-34	Green Meadow, Q.C.
32	Kapitolyo	PSG-97	Bgy. Capitolyo, Pasig, M.M.
33	Escopa	QCT-269	Escopa, Proj. 4, Q.C.
34	Catmon Deepwell	MLB-21	Catmon, Malabon, M.M.
35	Pasolo Elem. School	VLZ-214	Pasolo Elem. Sch., Valenzuela, M.M.

TABLE 3.7.1 (CONTINUATION)

ID NO.	NAME	WELL NO.	LOCATION
36	T. de Leon	VLZ-125	Fortune Vill., Valenzuela, M.M.
37	Banaba-Amoid	SMT-0	Amoid, San Mateo, Rizal
38	EEMI		Ever Electrical Mfg. Inc., Malanday, Marikina
39	HPPC		Hanson Paper Phil. Corp., Manggahan, Pasig
40	LPS-3 Well # 1		R. Castillo, Las Piñas, M.M.
41	Talaba	BCK-5	Bo. Talaba, Bacoor, Cavite
42	Naga Well # 2	LPS-39	Naga, Las Piñas, M.M.
43	ATP JICA Test Well		Antipolo, Rizal
44	Sucat Elem. School	MTL-147	Sucat Elem. Sch., Sucat, Muntinlupa
45	MWSS Alabang	MTL-150	Alabang Junction, Muntinlupa, M.M.
46	Muntinlupa Bliss		Muntinlupa Bliss, Muntinlupa, M.M.
47	Merville Subdivision	MLB-101	Tanza Merville Subd., Navotas, M.M.
48	Dagat-Dagatan # 1		Dagat-Dagatan, Navotas, M.M.
49	Forbes Park # 11	MKT-11	Forbes Park, Cambridge Circle, Makati
50	Ecology Village	MKT-145	Ecology Village, Makati
51	Signal Village II # 5	TGG-135	Signal Vill. II, Taguig, M.M.
52	Silver Swan Mfg. Co.		Panghulo Rd., Malabon
53	Vanson Paper Ind.		150 R. Delfin St., Marulas, Valenzuela
54	Quezon Institute		E. Rodriguez Ave., Q.C.
55	World Paper Mills		2 Baler St., Q.C.
56	Farola ice Cold (ICSC)		Muella Industria Manila
57	Procter & Gamble Phil. Inc.		Velasquez St., Tondo, Manila
58	Sta. Teresita College		P. Tuazon Q.C.
59	INNOTECH		Commonwealth Ave., UP Diliman, Q.C.
60	Sumulong Taytay		MWSS
61	Cardinal Santos Medical Center		Wilson St., Q.C.
62	IBP # 3		MWSS
63	Latex City		Alabang Zapote Rd.
64	Goodyear Steel Pipe		128 Quirino Hi-Way Q.C.
65	Rubber World		328 Quirino Hi-Way Q.C.
66	IBP (July 13/91)		Quezon City
67	Manila Hotel		Roxas Blvd., Manila
68	BF Homes # 22 L.P.		Madrid St., Las Piñas
69	BF Homes # 1		Lalaiene Beth St., Pamplona
70	BF Homes # 9		Salamita St., Las Piñas, M.M.

TABLE 3.7.1 (CONTINUATION).

ID NO.	NAME	WELL NO.	LOCATION
71	BF # 4 CRM		Menche St., Almanza, Las Piñas
72	BF Homes # 7		Back of Chapel, Las Piñas
73	IBP Q.C.		
74	La Perla		Quirino Ave., Parañaque, M.M.
75	Hyatt Regency Hotel		Roxas Blvd., Manila
76	J.C. Aqua Marine		Parañaque, M.M.
77	Olivares Hospital		Sucat Rd. Parañaque, M.M.
78	Malayan Textile Mill		Sta. Ana Drive
79	Ireneville Subd.		South Super Hi-way Sunvalley Parañaque
80	Cogeo # 6 (Step Drawdown)		Cogeo, Antipolo
81	Cogeo ATP # 1		Cogeo, Antipolo
82	Cogeo # 6 (Constant Pump.)		Cogeo, Antipolo
83	La Huerla		MWSS Parañaque, M.M.
84	Maricaban Pump # 1		Pasay City
85	Liberty Flour Mills		Mandaluyong, M.M.
86	International Oil (Baguio Oil)		San Juan, M.M.
87	National Steel Corp.		Calauan Sur Pasig, M.M.
88	Makati Medical Center		Makati M.M.
89	Oscar Rodriguez		Degaro St., Caloocan City
90	Ramitex		Gen. Luis St., Caloocan City

TABLE 3.7.2 MAJOR ION ANALYSIS OF GROUNDWATER SAMPLES IN MSA

NAME	MWSS WELL NO.	DATE OF SAMPLING	T	EC	NA+		K+		Ca++		Mg++		Cations		CO 3 --		HCO 3 --		CL-		SO 4 --		Anions	
			C	MS/cm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
1. LPS-1 WELL #2		Jan. 29, 91	32	760	128	5.57	17	0.44	14	0.70	9	0.74	-	7.44	0	0.00	251	4.11	56	1.58	23	0.48	-	6.17
2. LPS-1 WELL #3		Jan. 21, 91	30	39100	9700	421.74	232	5.95	1160	58.00	2290	188.48	-	674.17	0	0.00	292	4.79	17144	483.61	4250	88.50	-	576.90
3. LPS-2 WELL #3		Jan. 15, 91	29	37100	8125	353.26	339	8.69	1450	72.50	1409	115.97	-	550.42	0	0.00	365	5.98	21100	595.20	2500	52.10	-	653.28
4. URCI, LAS PINAS		Feb. 15, 91	31	880	68	2.96	18	0.46	61	3.05	21	1.73	-	8.20	0	0.00	377	6.18	25	0.71	11	0.23	-	7.11
5. MANUELA SUBD.		Feb. 15, 91	31	1190	100	4.35	15	0.38	75	3.75	18	1.48	-	9.96	0	0.00	411	6.74	62	1.75	31	0.65	-	9.13
6. LPS-2 WELL #2		Jan. 18, 91	32	14050	1595	69.35	164	4.21	951	47.55	268	22.06	-	143.16	0	0.00	239	3.92	4923	138.87	250	5.20	-	147.99
7. SAMONTE PARK WELL NO.1		Feb. 20, 91	25	1803	297	12.91	27	0.69	40	2.00	7	0.58	-	16.18	0	0.00	241	3.95	383	10.80	68	1.42	-	16.17
8. EJERCITO WELL		Feb. 20, 91	25	617	127	5.52	11	0.28	5	0.25	1	0.08	-	6.14	31	1.03	196	3.21	39	1.10	26	0.54	-	5.89
9. NOVELETA ELEM. SCHL.		Feb. 20, 91	25	536	110	4.78	14	0.36	7	0.35	3	0.25	-	5.74	0	0.00	246	4.03	28	0.79	23	0.48	-	5.30
10. NOVELETA, CAVITE NO. 2		Feb. 21, 91	34	680	114	4.96	13	0.33	6	0.32	4	0.33	-	5.92	36	1.20	128	2.10	37	1.04	28	0.58	-	4.93
11. NOVELETA CAVITE NO. 5		Feb. 21, 91	33	690	108	4.70	16	0.41	12	0.60	3	0.25	-	5.95	18	0.60	205	3.36	39	1.10	28	0.58	-	5.64
12. NOVELETA CAVITE NO. 8		Feb. 21, 91	35	710	118	5.13	13	0.33	4	0.20	3	0.25	-	5.91	18	0.60	178	2.92	40	1.13	29	0.60	-	5.25
13. NURSERY WELL NO. 4		Feb. 22, 91	27	361	15	0.65	5	0.13	47	2.35	10	0.82	-	3.95	0	0.00	142	2.33	32	0.90	9	0.19	-	3.42
14. SQUINSIN WELL NO. 10		Feb. 22, 91	27	566	20	0.87	1	0.03	67	3.35	26	2.14	-	6.39	0	0.00	292	4.79	25	0.71	26	0.54	-	6.03
15. COGEO ANTIPOLO		Feb. 20, 91	30	320	12	0.52	4	0.10	32	1.60	9	0.74	-	2.97	0	0.00	146	2.39	5	0.14	1	0.02	-	2.56
16. SAN JUAN PUMP STN		Feb. 25, 91	29	1143	74	3.22	8	0.21	118	5.90	25	2.06	-	11.38	0	0.00	200	3.28	167	4.71	157	3.27	-	11.26
17. BANGIAD PUMP STN.		Feb. 25, 91	30	420	79	3.43	4	0.10	8	0.40	4	0.33	-	4.27	23	0.77	137	2.25	17	0.48	26	0.54	-	4.03
18. STO. DOMINGO		Feb. 25, 91	30	1481	119	5.17	14	0.36	96	4.80	52	4.28	-	14.61	0	0.00	205	3.36	248	7.00	214	4.46	-	14.82
19. LPS-1 WELL #1		Feb. 27, 91	35	1240	182	7.91	0.3	0.01	12	0.60	1	0.08	-	8.60	23	0.77	58	0.95	221	6.23	77	1.60	-	9.56
20. MNL JAP SCHL.		Feb. 27, 91	32	820	139	6.04	17	0.44	12	0.60	4	0.33	-	7.41	27	0.90	321	5.26	32	0.90	12	0.25	-	7.31
21. AGUINALDO E/S WELL		Feb. 27, 91	34	710	115	5.00	14	0.36	7	0.35	5	0.41	-	6.12	31	1.03	160	2.62	40	1.13	33	0.69	-	5.47
22. QUEZON IBP #2		Feb. 28, 91	29	500	104	4.52	0.6	0.02	6	0.30	4	0.33	-	5.17	32	1.07	162	2.66	30	0.85	2	0.04	-	4.61
23. FAIRVIEW PUMP NO. 3		Feb. 28, 91	28	640	123	5.35	0.4	0.01	7	0.35	4	0.33	-	6.04	59	1.97	140	2.30	40	1.13	1	0.02	-	5.41
24. LAGRO #1		Feb. 28, 91	30	580	117	5.09	0.5	0.01	10	0.50	1	0.08	-	5.68	26	0.87	243	3.98	7	0.20	2	0.04	-	5.09
25. WAWA DAM		Mar. 5, 91	27	340	18	0.78	4	0.10	34	1.70	5	0.41	-	3.00	0	0.00	122	2.00	9	0.25	17	0.35	-	2.61
26. SAN JOSE		Mar. 5, 91	29	350	21	0.91	4	0.10	32	1.60	4	0.33	-	2.94	0	0.00	165	2.70	10	0.28	8	0.17	-	3.15
27. SAN MATEO PUBLIC MKT.		Mar. 5, 91	28	460	36	1.57	3.5	0.09	40	2.00	6	0.49	-	4.15	0	0.00	210	3.44	16	0.45	8	0.17	-	4.06
28. LPS-2 WELL #1		Mar. 6, 91	35	1190	166	7.22	9	0.23	5	0.25	1	0.08	-	7.78	8	0.27	85	1.39	162	4.57	80	1.67	-	7.90
29. COMBALAY, KAWIT		Mar. 6, 91	33	690	116	5.04	13	0.33	2	0.10	1	0.08	-	5.56	8	0.27	198	3.25	37	1.04	29	0.60	-	5.16

TABLE 3.7.2 (CONTINUATION)

NAME	MWSS WELL NO.	DATE OF SAMPLING	T	EC	NA+		K+		Ca++		Mg++		Cations		CO 3 --		HCO 3 --		CL-		SO 4 --		Anions	
			C	MS/cm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
30. PLAZA GARCIA IMUS		Mar. 6, 91	34	690	115	5.00	13	0.33	5	0.25	0.7	0.06	-	5.64	23	0.77	182	2.98	35	0.99	19	0.40	-	5.13
31. GREENMEADOW #3		Mar. 7, 91	30	660	83	3.61	9.5	0.24	18	0.90	4	0.33	-	5.08	0	0.00	146	2.39	90	2.54	4	0.08	-	5.02
32. KAPITOLYO PASIG		Mar. 7, 91	30	560	44	1.91	22	0.56	30	1.50	8	0.66	-	4.64	0	0.00	220	3.61	45	1.27	6	0.13	-	5.00
33. ESCOPA PROJ. 4		Mar. 7, 91	31	450	48	2.09	9	0.23	18	0.90	6	0.49	-	3.71	0	0.00	196	3.21	12	0.34	2	0.04	-	3.59
34. CATMON DEEPWELL		Mar. 11, 91	33	460	92	4.00	3	0.08	2	0.10	0.7	0.06	-	4.23	23	0.77	127	2.08	25	0.71	13	0.27	-	3.82
35. POSOLO ELEM SCHL.		Mar. 11, 91	32	420	87	3.78	5	0.13	2	0.10	0.7	0.06	-	4.07	26	0.87	129	2.11	14	0.39	2	0.04	-	3.42
36. T. DE LEON WELL		Mar. 11, 91	32	450	89	3.87	5	0.13	4	0.20	1	0.08	-	4.28	18	0.60	168	2.75	14	0.39	1	0.02	-	3.77
37. BANABA AMPID		Mar. 12, 91	28	440	48	2.09	7	0.18	40	2.00	5	0.41	-	4.68	0	0.00	155	2.54	30	0.85	21	0.44	-	3.82
38. EVER ELCT. MNFG. INC.		Mar. 12, 91	28	604	76	3.30	12	0.31	24	1.20	4	0.33	-	5.14	0	0.00	192	3.15	77	2.17	16	0.33	-	5.65
39. HANSSON PAPER PHIL.		Mar. 12, 91	31	390	25	1.09	6	0.15	38	1.90	8	0.66	-	3.80	0	0.00	168	2.75	19	0.54	9	0.19	-	3.48
40. LPS-3 WELL #1		Mar. 13, 91	34	780	121	5.26	10	0.26	4	0.20	1	0.08	-	5.80	18	0.60	137	2.25	76	2.14	40	0.83	-	5.82
41. BO. TALABA		Mar. 13, 91	32	1030	137	5.96	33	0.85	18	0.90	2	0.16	-	7.87	0	0.00	223	3.66	123	3.47	20	0.42	-	7.54
42. NAGA WELL #2		Mar. 13, 91	31	2000	183	7.96	35	0.90	73	3.65	21	1.73	-	14.23	0	0.00	246	4.03	274	7.73	46	0.96	-	12.72
43. ATP JICA TEST WELL		Mar. 14, 91	28	490	48	2.09	6	0.15	47	2.35	9	0.74	-	5.33	0	0.00	242	3.97	12	0.34	2	0.04	-	4.35
44. SUCAT E/S		Mar. 18, 91	31	1390	180	7.83	15	0.38	52	2.60	14	1.15	-	11.96	0	0.00	342	5.61	144	4.06	65	1.35	-	11.02
45. ALABANG JUNCTION		Mar. 18, 91	30	750	103	4.48	9	0.23	24	1.20	6	0.49	-	6.40	0	0.00	301	4.93	15	0.42	30	0.63	-	5.98
46. MUNTINLUPA BLISS		Mar. 18, 91	29	740	58	2.52	8	0.21	47	2.35	17	1.40	-	6.48	0	0.00	288	4.72	28	0.79	34	0.71	-	6.22
47. MERVILLE SUBDV.		Mar. 20, 91	33	530	88	3.83	1.6	0.04	4	0.20	1	0.02	-	4.15	0	0.00	118	1.93	47	1.33	32	0.67	-	3.93
48. DAGAT-DAGATAN #1		Mar. 20, 91	30	600	106	4.61	4	0.10	5	0.25	5	0.41	-	5.37	0	0.00	73	1.20	72	2.03	25	0.52	-	3.75
49. TALISAY ST. FORBES PARK		Mar. 19, 91	31	610	40	1.74	16	0.41	25	1.25	33	2.72	-	6.12	0	0.00	241	3.95	17	0.48	16	0.33	-	4.76
50. ECOLOGY VILLAGE		Mar. 19, 91	30	610	50	2.17	17	0.44	24	1.20	27	2.22	-	6.03	0	0.00	273	4.48	16	0.45	10	0.21	-	5.14
51. SIGNAL VILLAGE		Mar. 19, 91	29	700	45	1.96	13	0.33	42	2.10	31	2.55	-	6.94	0	0.00	281	4.61	12	0.34	42	0.88	-	5.82
52. SILVER SWAN MA.		Jul. 2, 91	25	861	160	6.96	10	0.26	14	0.70	4	0.33	-	8.24	0	0.00	155	2.54	173	4.88	16	0.33	-	7.75
53. VANSON PAPER IND.		Jul. 2, 91	25	344	60	2.61	6	0.15	8	0.40	1	0.08	-	3.24	8	0.27	143	2.34	20	0.56	5	0.10	-	3.28
54. QUEZON INSTITUTE		Jul. 3, 91	27	343	68	2.96	3	0.08	4	0.20	3	0.25	-	3.48	13	0.43	88	1.44	26	0.73	28	0.58	-	3.19
55. WORLD PAPER MILLS		Jul. 3, 91	27	355	50	2.17	10	0.26	14	0.70	6	0.49	-	3.62	23	0.77	113	1.85	20	0.56	3	0.06	-	3.25
56. FAROLA ICE COLD		Jul. 5, 91	25	1174	180	7.83	14	0.36	29	1.45	3	0.25	-	9.88	13	0.43	46	0.75	221	6.23	97	2.02	-	9.44
57. PROCTER & GAMBLE		Jul. 5, 91	25	736	130	5.65	8	0.21	11	0.55	3	0.25	-	6.65	23	0.77	63	1.03	138	3.89	20	0.42	-	6.11
58. STA. TERESITA COLLEGE		Jul. 8, 91	24	536	38	1.65	16	0.41	34	1.70	22	1.81	-	5.57	0	0.00	228	3.74	39	1.10	19	0.40	-	5.23
59. INNOTECH		Jul. 8, 91	24	404	16	0.70	10	0.26	40	2.00	16	1.32	-	4.27	0	0.00	200	3.28	31	0.87	3	0.06	-	4.22

TABLE 3.7.2 (CONTINUATION)

NAME	MWSS WELL NO.	DATE OF SAMPLING	T	EC	NA+		K+		Ca++		Mg++		Cations		CO 3 --		HCO 3 --		CL-		SO 4 --		Anions	
			C	MS/cm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
60. SUMULONG TAYTAY		Jul. 8, 91	24	972	155	6.74	1	0.03	39	1.95	5	0.41	-	9.13	0	0.00	96	1.57	140	3.95	149	3.10	-	8.63
61. CARDINAL SANTOS		Jul. 10, 91	24	397	48	2.09	1	0.03	20	1.00	10	0.82	-	3.94	0	0.00	205	3.36	20	0.56	7	0.15	-	4.07
62. IBP NO. 3		Jul. 10, 91	24	202	12	0.52	3	0.08	20	1.00	8	0.66	-	2.26	0	0.00	100	1.64	20	0.56	6	0.13	-	2.33
63. LATEX CITY		Jul. 12, 91	25	16930	1150	50.00	45	1.15	1640	82.00	283	23.29	-	156.45	0	0.00	305	5.00	5672	160.00	456	9.50	-	174.50
64. GOODYEAR STEEL		Jul. 15, 91	25	362	48	2.09	5	0.13	18	0.90	6	0.49	-	3.61	0	0.00	142	2.33	18	0.51	20	0.42	-	3.25
65. RUBBER WORLD		Jul. 15, 91	25	485	54	2.35	6	0.15	26	1.30	14	1.15	-	4.95	13	0.43	201	3.30	24	0.68	11	0.23	-	4.63
66. IBP (JULY 13,91)		Jul. 17, 91	25	182	12	0.52	3	0.08	16	0.80	8	0.66	-	2.06	0	0.00	87	1.43	18	0.51	0	0.00	-	1.93
67. MANILA HOTEL		Jul. 17, 91	25	560	115	5.00	4	0.10	5	0.25	2	0.16	-	5.52	0	0.00	73	1.20	63	1.78	128	2.67	-	5.64
68. BF HOMES # 22		Jul. 19, 91	25	630	93	4.04	17	0.44	9	0.45	8	0.66	-	5.59	0	0.00	255	4.18	55	1.55	23	0.48	-	6.21
69. BF HOMES # 1		Jul. 19, 91	25	576	89	3.87	17	0.44	16	0.80	10	0.82	-	5.93	0	0.00	228	3.74	40	1.13	25	0.52	-	5.39
70. BF HOMES # 9		Jul. 23, 91	25	605	100	4.35	17	0.44	20	1.00	8	0.66	-	6.44	0	0.00	220	3.61	42	1.18	5	0.10	-	4.90
71. BF HOMES # 4		Jul. 23, 91	25	600	100	4.35	15	0.38	10	0.50	2	0.16	-	5.40	0	0.00	215	3.52	53	1.50	6	0.13	-	5.14
72. BF HOMES # 7		Jul. 24, 91	25	575	99	4.30	14	0.36	11	0.55	1	0.08	-	5.30	0	0.00	155	2.54	63	1.78	43	0.90	-	5.21
73. IBP Q.C.		Jul. 18, 91	25	237	19	0.83	2	0.05	26	1.30	4	0.33	-	2.51	0	0.00	132	2.16	15	0.42	3	0.06	-	2.65
74. LA PERLA		Jul. 26, 91	25	2060	315	13.70	30	0.77	32	1.60	17	1.40	-	17.46	0	0.00	237	3.89	418	11.79	58	1.21	-	16.88
75. HYATT REGENCY		Jul. 26, 91	25	1733	200	8.70	40	1.03	53	2.65	20	1.65	-	14.02	0	0.00	268	4.39	201	5.67	91	1.90	-	11.96
76. J.C. AQUA MARINE		Jul. 29, 91	23	1819	260	11.30	20	0.51	15	0.75	11	0.91	-	13.47	40	1.33	92	1.51	343	9.68	48	1.00	-	13.52
77. OLIVAREZ HOSPITAL		Jul. 29, 91	23	1568	210	9.13	21	0.54	47	2.35	37	3.05	-	15.06	31	1.03	365	5.98	135	3.81	184	3.83	-	14.66
78. MALAYAN TEXTILE		Jul. 31, 91	25	635	47	2.04	20	0.51	40	2.00	20	1.65	-	6.20	0	0.00	304	4.98	11	0.31	1	0.02	-	5.31
79. IRENEVILL SUBD.		Jul. 31, 91	25	605	85	3.70	20	0.51	21	1.05	10	0.82	-	6.08	0	0.00	281	4.61	18	0.51	3	0.06	-	5.18
80. COGEO # 6(STEP)		Aug. 6, 91	25	433	10	0.43	3	0.08	41	2.05	25	2.06	-	4.62	0	0.00	155	2.54	33	0.93	4	0.08	-	3.56
81. COGEO #1		Aug. 6, 91	25	478	11	0.48	3	0.08	48	2.40	27	2.22	-	5.16	0	0.00	244	4.00	22	0.62	2	0.04	-	4.66
82. COGEO#6(CPT)		Aug. 6, 91	25	448	7	0.30	1	0.03	51	2.55	24	1.98	-	4.86	0	0.00	238	3.90	20	0.56	3	0.06	-	4.53
83. LA HUERTA		Aug. 7, 91	25	848	50	2.17	13	0.33	73	3.65	27	2.22	-	8.38	0	0.00	366	6.00	42	1.18	1	0.02	-	7.21
84. MARICABAN PUMP		Aug. 7, 91	26	960	154	6.70	30	0.77	12	0.60	7	0.58	-	8.64	0	0.00	317	5.20	112	3.16	1	0.01	-	8.37
85. LIBERTY FLOUR MILLS		Aug. 9, 91	26	592	70	3.04	25	0.64	8	0.40	8	0.66	-	4.74	0	0.00	181	2.97	66	1.86	1	0.01	-	4.84
86. INTERNATIONAL OIL		Aug. 9, 91	26	951	90	3.91	13	0.33	47	2.35	33	2.72	-	9.31	0	0.00	268	4.39	147	4.15	1	0.01	-	8.55
87. NATIONAL STEEL		Aug. 12, 91	26	1915	300	13.04	40	1.03	36	1.80	22	1.81	-	17.68	0	0.00	107	1.75	457	12.89	120	2.50	-	17.15
88. MAKATI MED. CENTER		Aug. 12, 91	26	880	100	4.35	30	0.77	28	1.40	11	0.91	-	7.42	0	0.00	244	4.00	88	2.48	45	0.94	-	7.42
89. OSCAR RODRIGUEZ		Aug. 14, 91	26	406	12	0.52	6	0.15	41	2.05	19	1.58	-	4.29	0	0.00	221	3.62	18	0.51	3	0.06	-	4.19

TABLE 3.7.2 (CONTINUATION)

NAME	MWSS WELL NO.	DATE OF SAMPLING	T	EC	NA+		K+		Ca++		Mg++		Cations		CO 3 --		HCO 3 --		CL-		SO 4 --		Anions	
			C	MS/cm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
90. RAMITEX		Aug. 14, 91	26	370	40	1.74	5	0.13	24	1.20	7	0.58	-	3.64	0	0.00	184	3.02	18	0.51	6	0.13	-	3.65

TABLE 3.7.3 CHEMICAL COMPOSITION OF SEAWATER

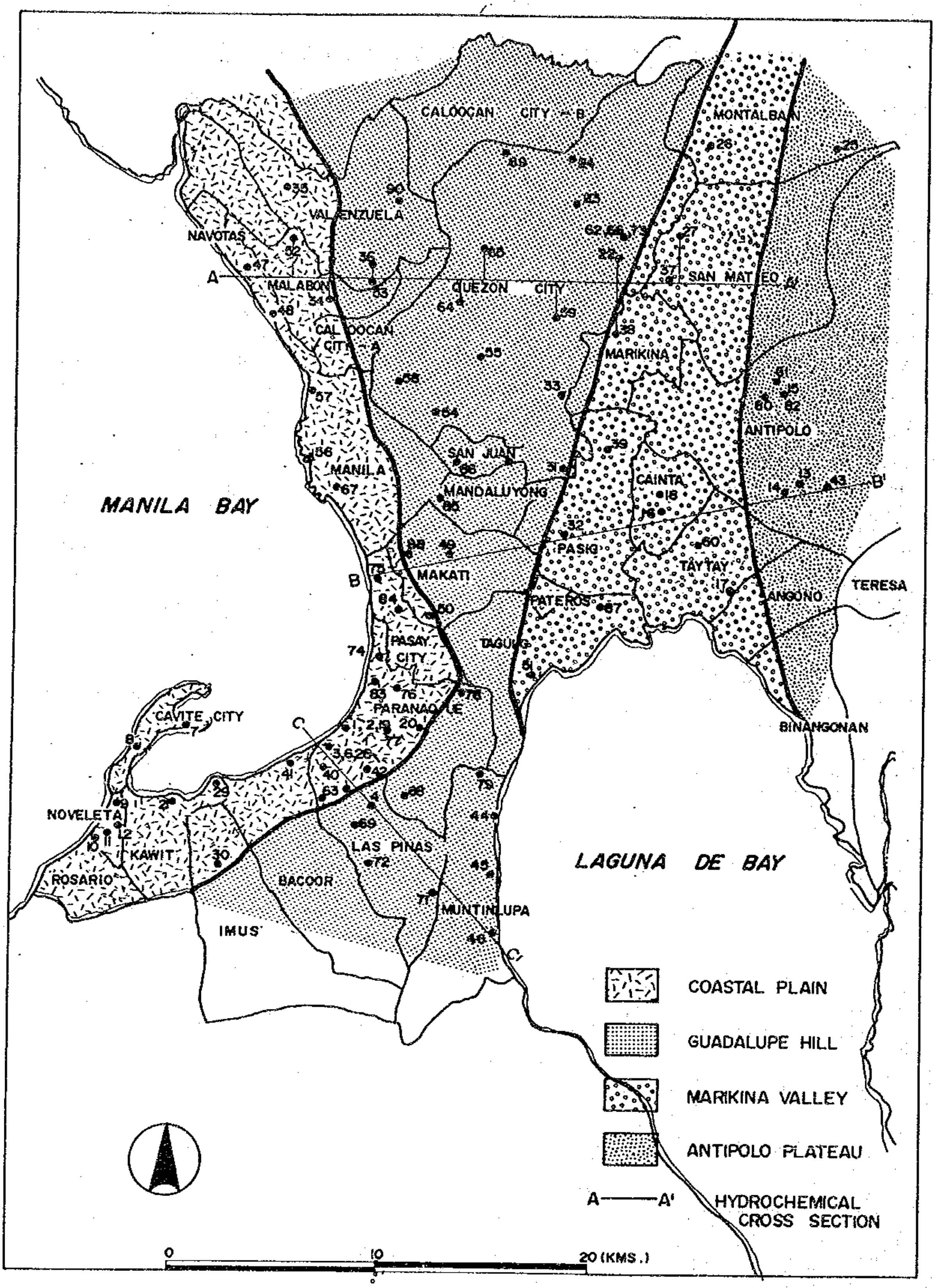
Ion	g/kg	%	Ion	g/kg	%
Cl-	18.980	55.04	Mg2+	1.272	3.69
Bi-	0.065	0.19	Ca2+	0.400	1.16
SO_4^{2-}	2.469	7.68	Sr2+	0.007	0.02
HCO-3	0.140	0.41	K+	0.380	1.10
F-	0.001	0.00	Na+	10.556	30.61
H3BO3	0.026	0.07	Total	34.476	99.97

TABLE 3.7.4 DEFINITE WEIGHT AND EQUIVALENT WEIGHT RATIO OF MAJOR CONSTITUENTS VERSUS CHLORIDE OF SEAWATER

	Weight Ratio	Equivalent Weight Ratio
Na:Cl	0.5526	0.85
K:Cl	0.0200	0.18
Mg:Cl	0.0684	0.20
Ca:Cl	0.0211	0.038
Sr:Cl	0.00042	0.036
SO4:Cl	0.1396	0.10
HCO3:Cl	0.00738	0.0043
H3BO3:Cl	0.00137(atomic ratio)	0.00083
Si:Cl	0.0002 (atomic ratio)	0.0002

TABLE 3.7.5 WEIGHT RATIO AMONG Ca, Mg, AND Cl

No.	Locations	Ca/Mg	Ca/Cl	Mg/Cl	Cl
2	LPS-1 No.3	0.507	0.068	0.134	17,144
3	LPS-2 No.3	1.029	0.069	0.067	21,100
6	LPS-2 No.2	3.549	0.193	0.054	4,923
7	Samonte Park	5.714	0.104	0.018	383
16	San Juan Pump	4.72	0.707	0.150	167
18	Sto. Domingo	1.846	0.387	0.210	268
19	LPS-1 No.1	12.0	0.054	0.005	221
28	LPS-2 No.2	5.0	0.031	0.006	162
41	Bo. Talba	9.0	0.146	0.016	123
42	Naga Well No. 2	3.476	0.266	0.077	274
44	Sucat E/S	3.714	0.361	0.097	144
52	Silver Swan	3.5	0.081	0.023	173
56	Farola Ice Cold	9.667	0.131	0.013	221
57	Procter & Gamble	3.667	0.080	0.022	138
63	Latex City	5.795	0.289	0.050	5,672
74	La Perla	1.882	0.077	0.041	418
75	Hyatt Regency	2.65	0.264	0.010	201
76	J.C. Aqua	1.364	0.044	0.032	343
77	Olivares Hospital	1.27	0.348	0.274	135
87	National Steel	1.636	0.079	0.048	457
	Sea Water	0.0379	0.0211	0.0684	



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.7.1 LOCATION OF WATER SAMPLING POINTS
JAPAN INTERNATIONAL COOPERATION AGENCY	

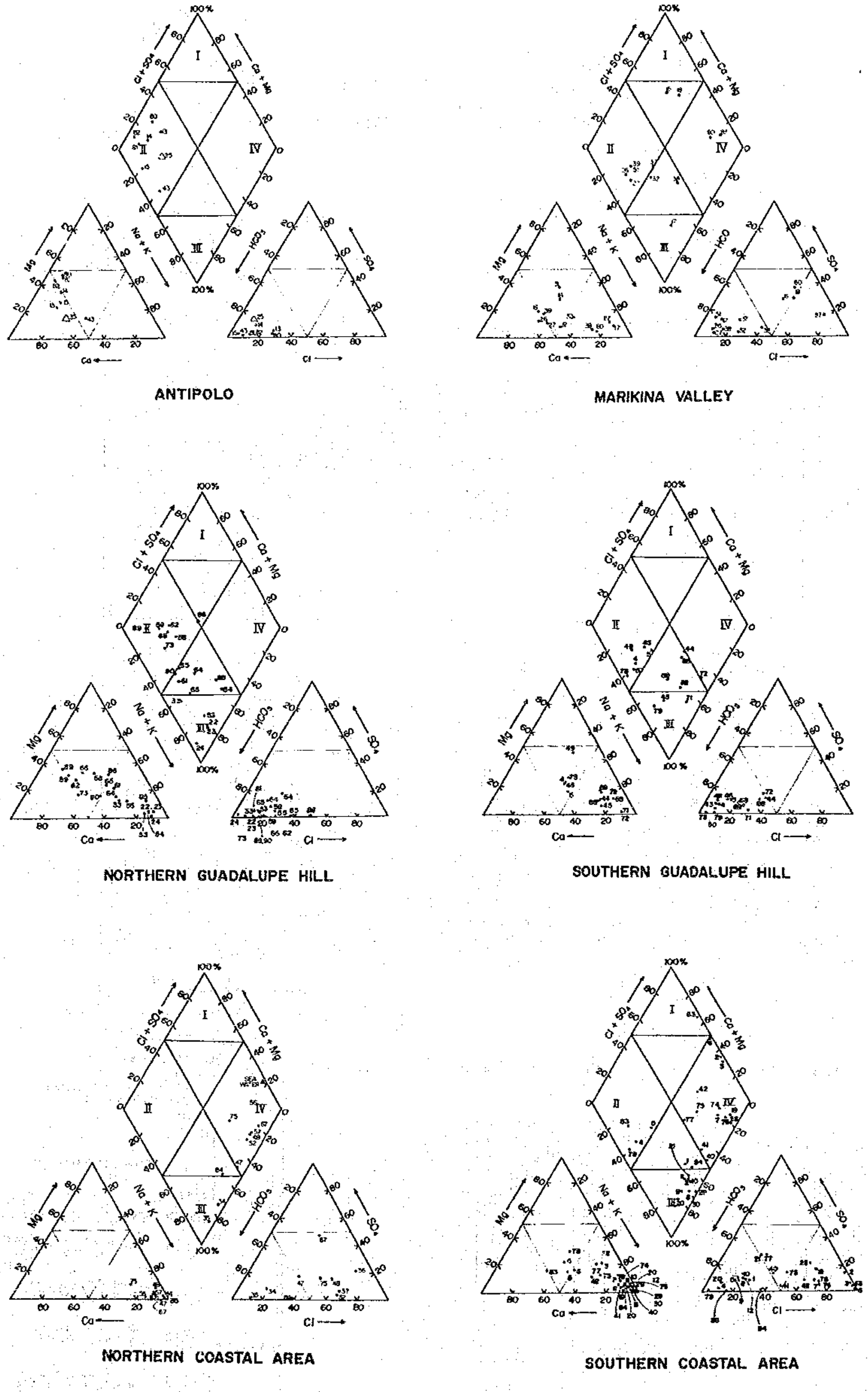
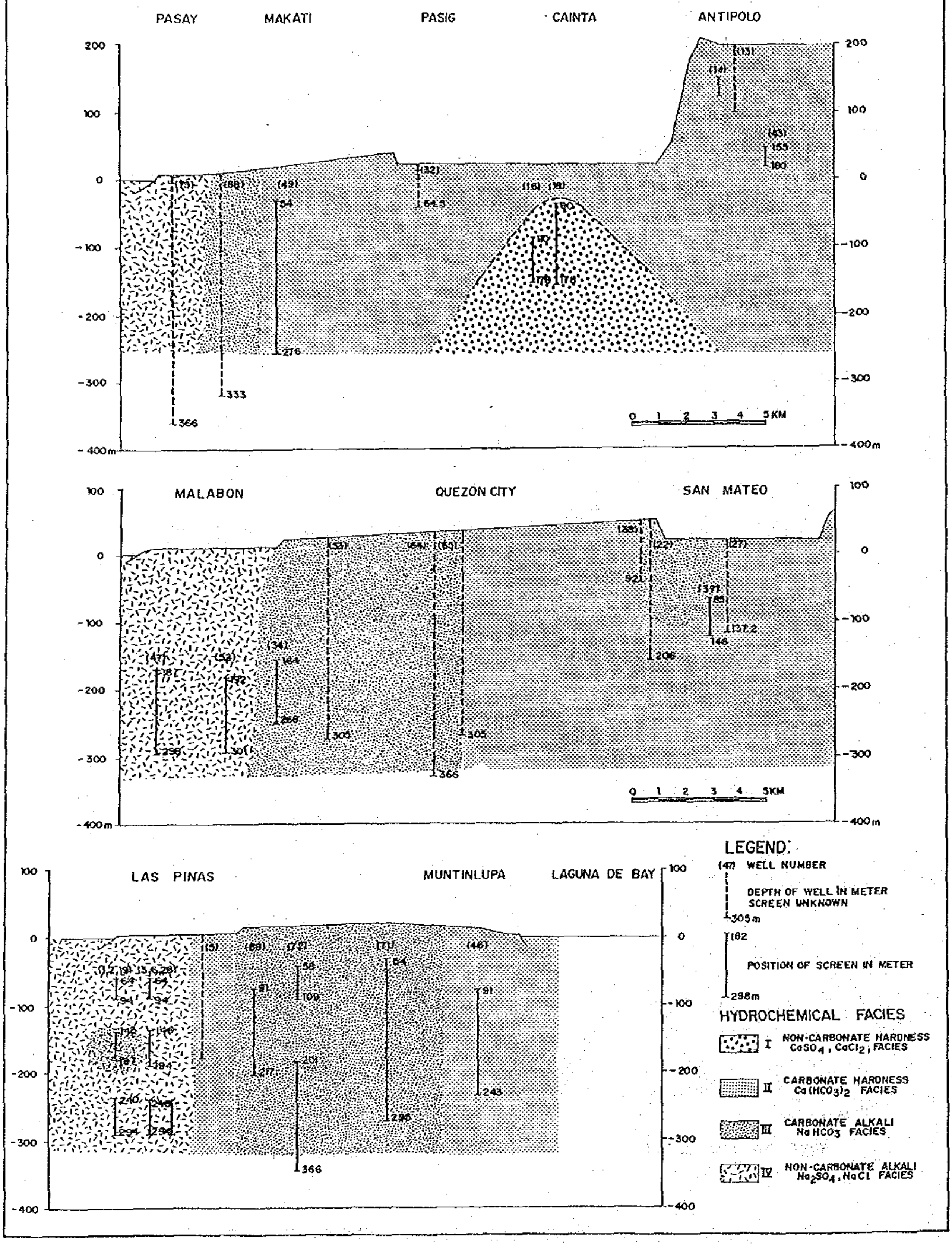
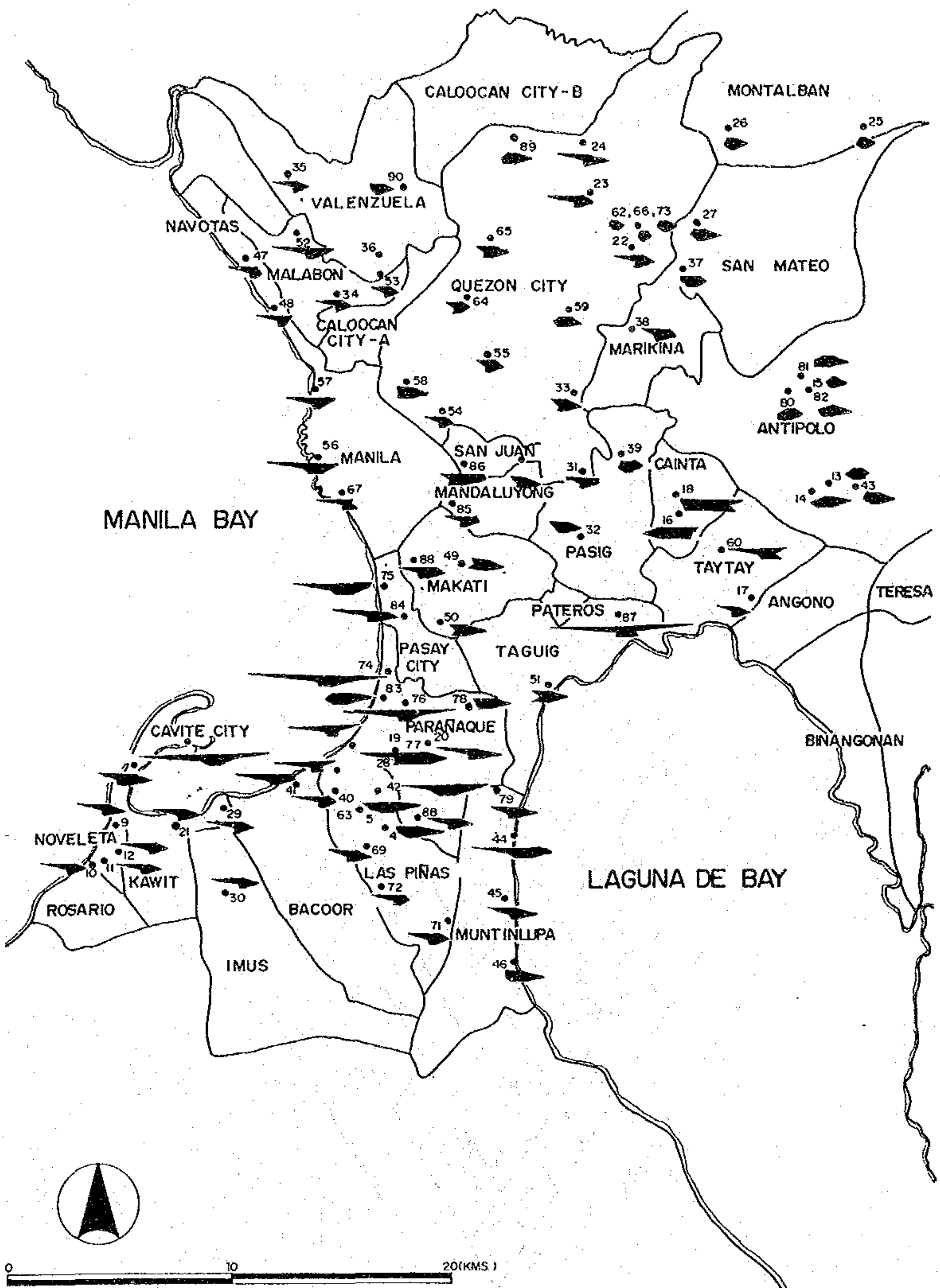


FIGURE 3.7.2 TRILINEAR DIAGRAM REPRESENTATION OF GROUNDWATER SAMPLES IN METRO MANILA

FIGURE 3.7.3 HYDROCHEMICAL CROSS SECTION OF THE METRO MANILA GROUNDWATER BASIN





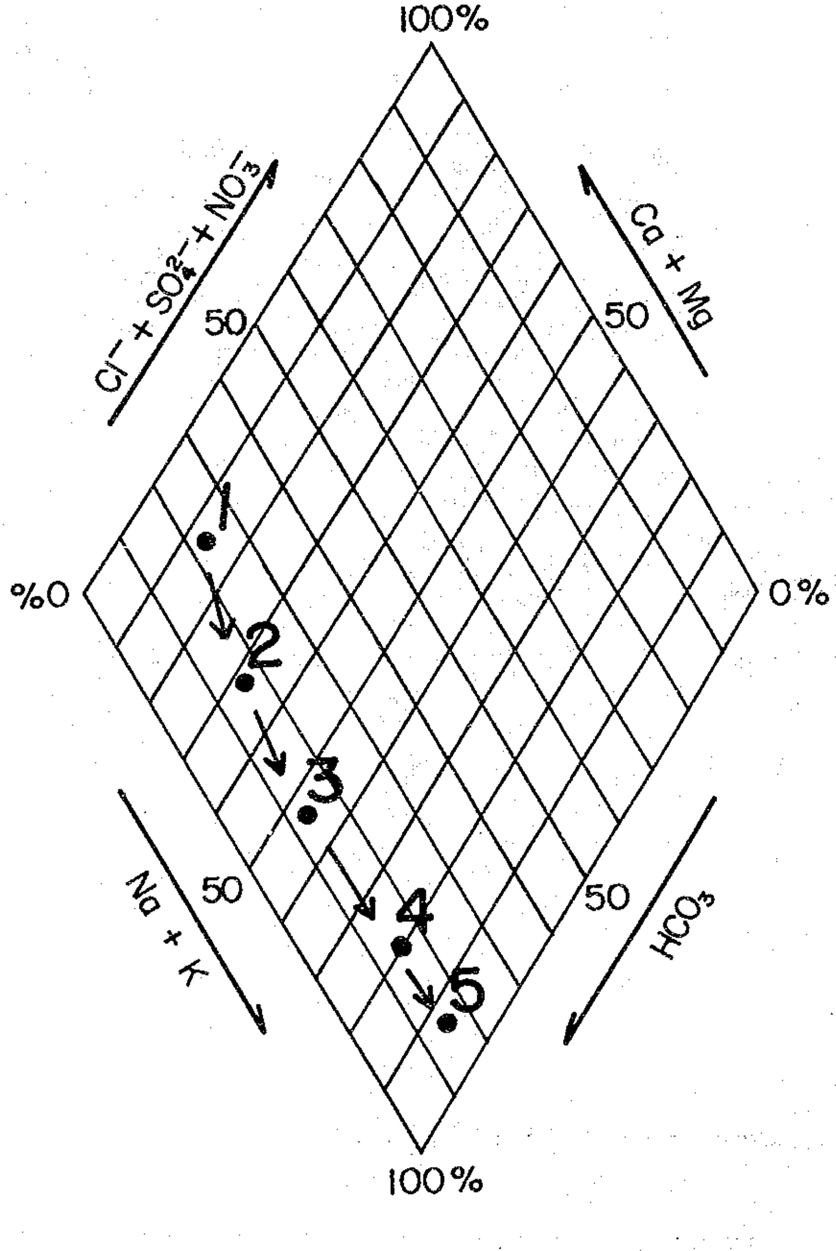
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 3.7.4

PATTERN DIAGRAM

FIGURE 3.7.5 CHEMICAL EVOLUTION OF GROUNDWATER
(AFTER SUGISAKI :1961)



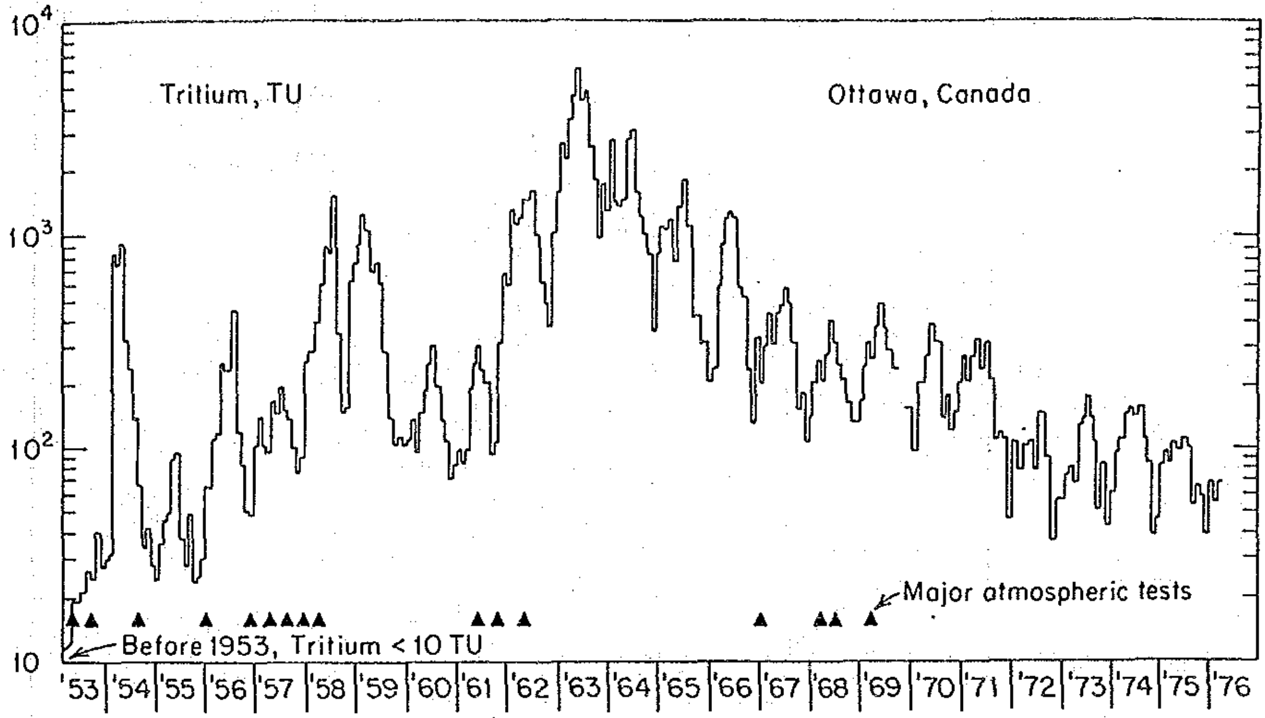
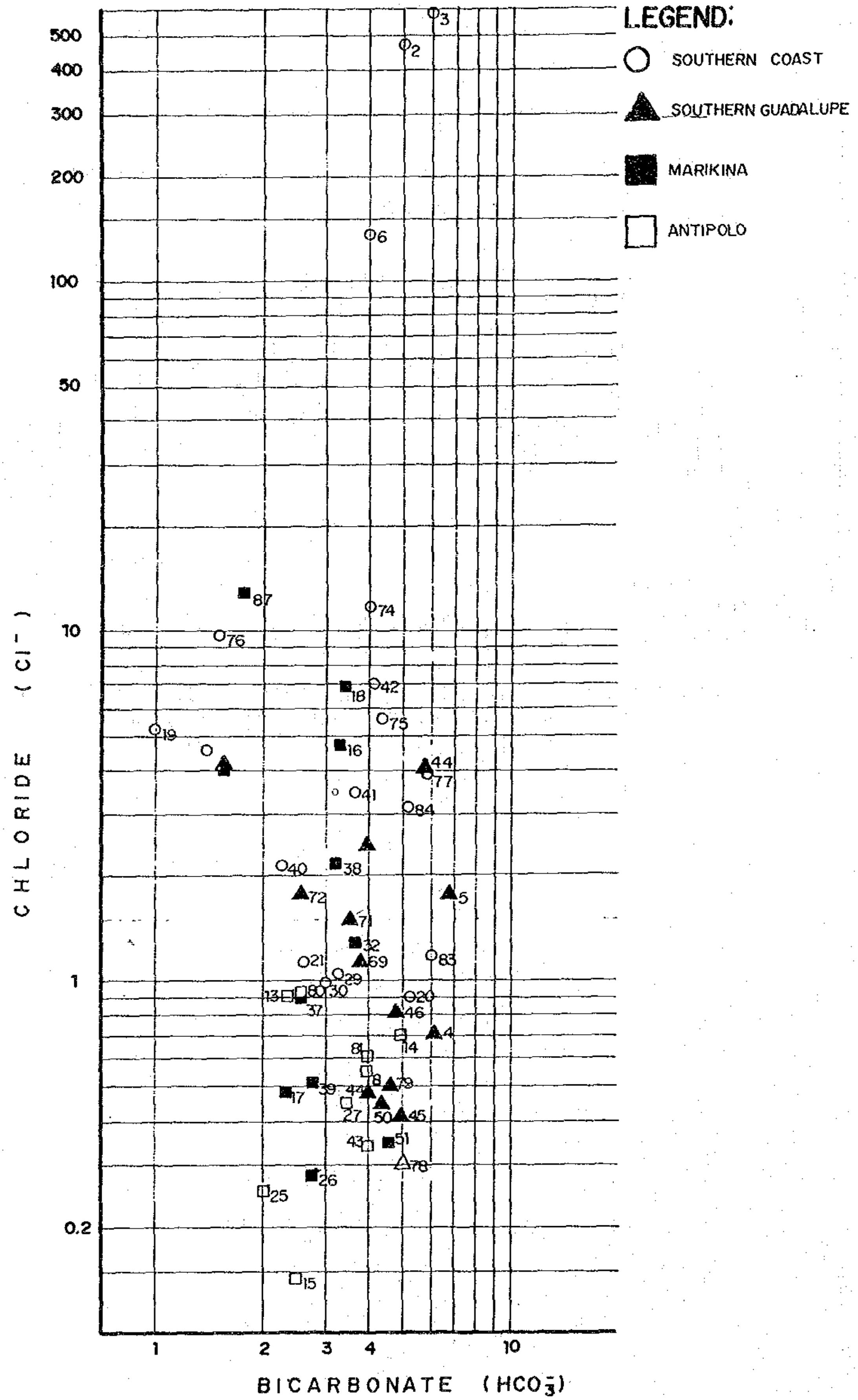


FIGURE 3.7.6 VARIATIONS OF TRITIUM IN PRECIPITATION (MEAN MONTHLY CONCENTRATIONS, TU) AT OTTAWA, CANADA (AFTER FREEZE AND CHERRY: 1979)

FIGURE 3.7.7

RELATIONSHIP BETWEEN Cl^- AND HCO_3^-



3.8 SALINE WATER INTRUSION

3.8.1 Saline Water Intrusion in Metro Manila

Saline water intrusion in the coastal areas of Metro Manila has already been observed in the late 1960s. In 1968, Hernando Quiason reported that (at that time) the groundwater level had dropped to 40 meters below sea level in the Malabon-Navotas-Caloocan area and that, from near-surface to about 100m, saline groundwater was found in the near-shore groundwater zones from Las Piñas to Malabon and in the vicinity of areas away from shore with salty surface water.

In the early 1980s, Electrowatt studied the hydrogeology of Metro Manila as part of the MWSP-II project. This study found out in 1981 that the groundwater level in the Guadalupe aquifer system in Metro Manila had continuously declined since 1955. The rate of decline had reached 5 to 12 m/year, with deep cones of depression appearing in areas with heavy withdrawals of groundwater. This lowering of water level resulted in the saline water intrusion of the Guadalupe aquifer system and has largely affected the quality of groundwater. Figure 3.8.1 shows the distribution of conductivity values of groundwater in Metro Manila. High conductivity zones were observed in the coastal areas along Manila Bay.

Distribution of electric conductivity (EC) values measured in year 1991 is illustrated in Figure 3.8.2. Relation between chloride content and EC is presented in Figure 3.8.3. Pattern of distribution in year 1991 is basically the same as that in year 1981. As samples were taken from operational deep wells with an average depth of about 300m, the number of zones with high conductivity (more than 1,000 microsiemens (μS)/cm) is limited in the area. These zones cannot be seen particularly in Manila, Malabon and Navotas, where measured EC values range from 400 to 800 μS/cm. Groundwater tapped by 300-m deep wells is still unaffected by saline water intrusion even if they are located near the shore.

3.8.2 Saline Water Intrusion Mechanism

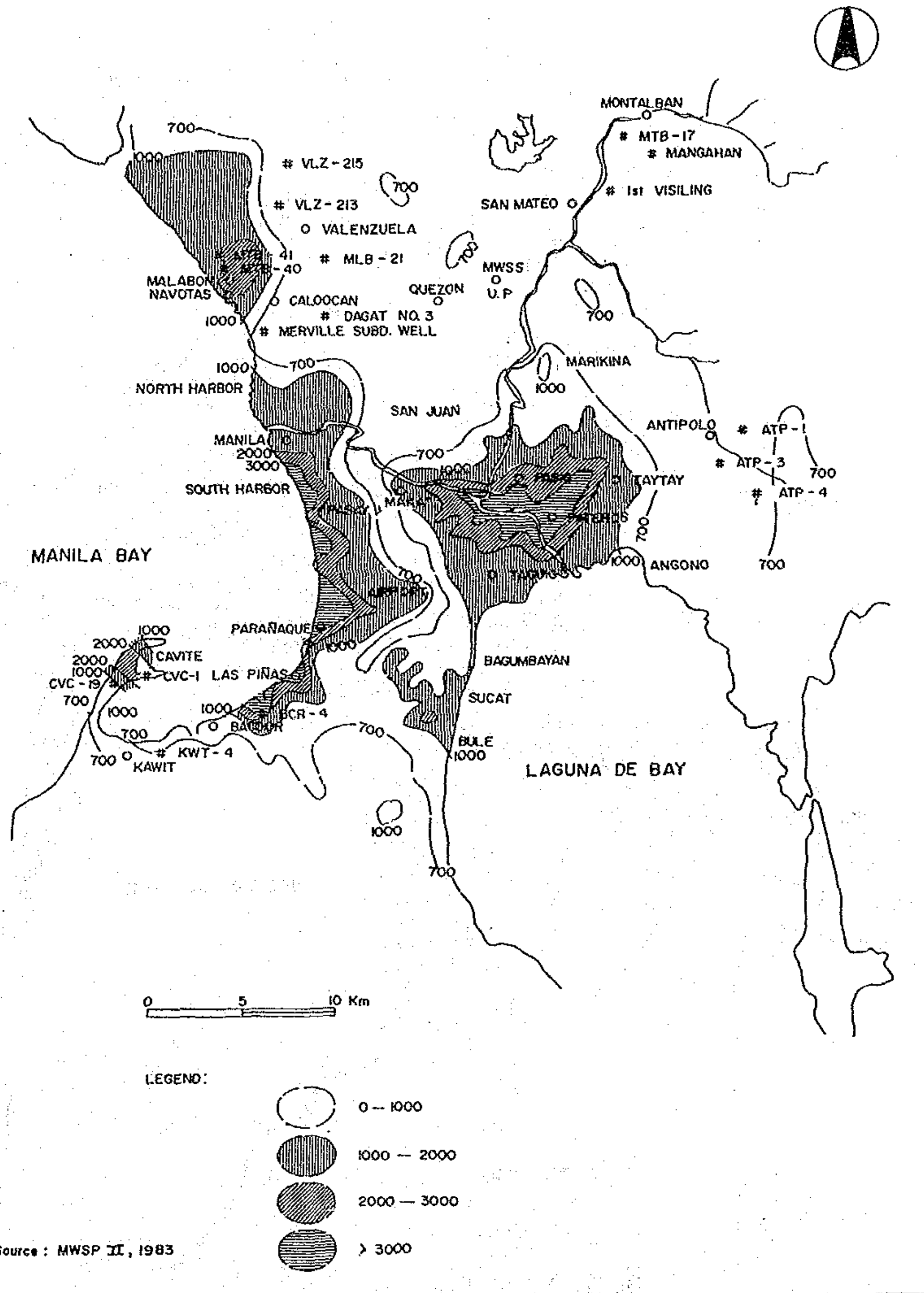
In 1988, MWSS discovered a chloride concentration of 2,884 mg/l at Latex well located 2.0 km from the coast in Pamplona, Las Piñas. In addition, high chloride concentrations of more than 600 mg/l were observed in an area of about $6 km^2$ in Las Piñas. Results of recent measurements show virtually the same salinity distribution as shown in Figure 3.2.20.

Electric conductivity and chloride concentration of groundwater in the Las Piñas test wells differ from aquifer to aquifer (Figure 3.8.4). In the 100-m wells at sites No.1 and No.2, high chloride concentrations of 17,144 mg/l and 21,100 mg/l were found. In the 200-m well at Las Piñas No.2, chloride concentration is 4,923 mg/l. However, groundwater is not salinized in the deep aquifer as observed in the 200-m and 300-m wells at Las Piñas No.1, and in the 300-m wells in No.2 and No.3. Chloride concentration in these wells is less than 200 mg/l.

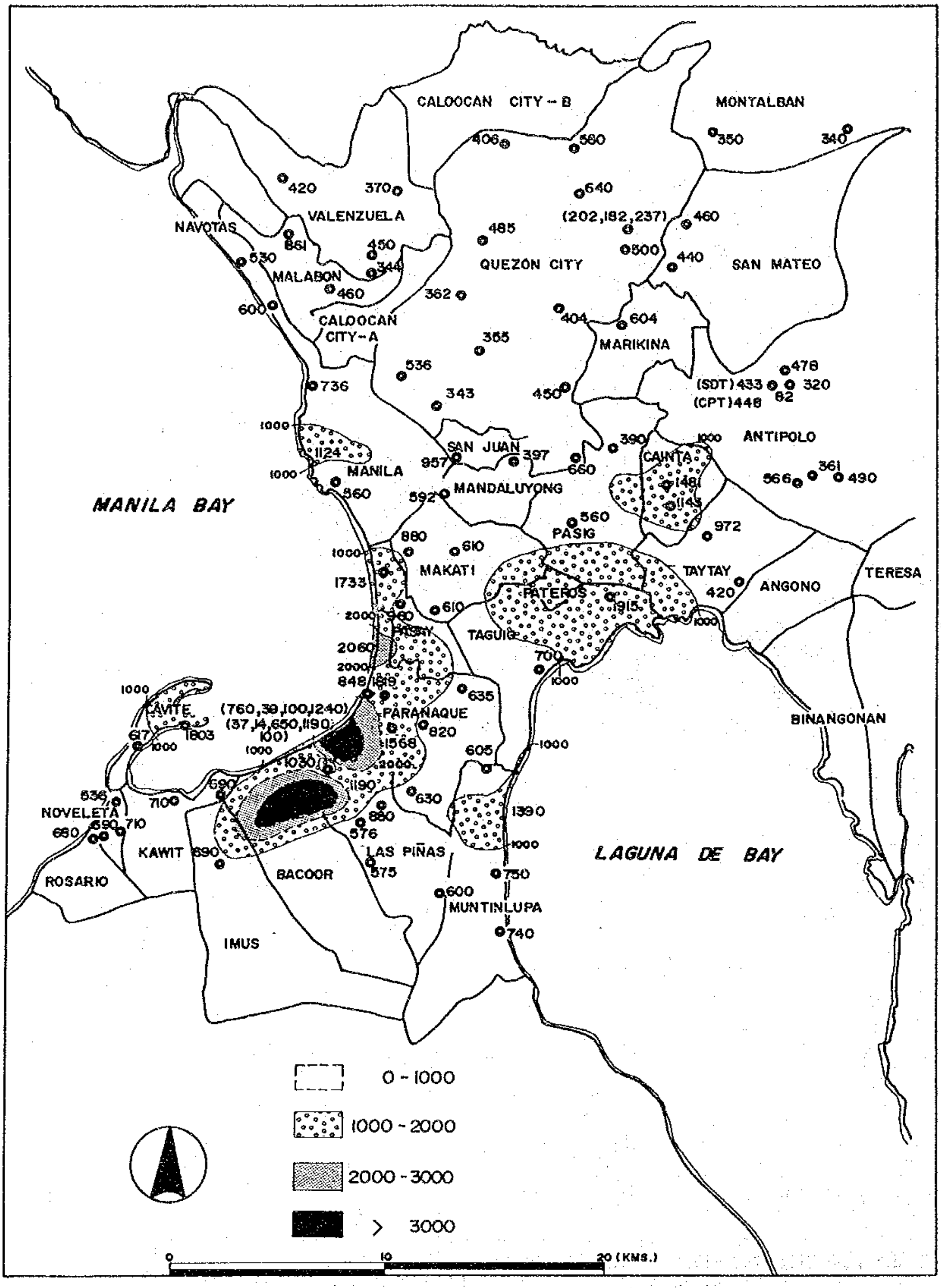
Considering the different concentration in each aquifer, it is apparent that saline water migrates downward from the first aquifer to the second aquifer by leakage. The first aquifer may be salinized mainly by seawater encroachment from Manila Bay. Another cause of contamination may be the existence of the marine pond spreading 1.5 to 2.0 km inland from the coast and the tidal inundation of the Zapote river. EC and chloride distributions in other coastal areas, such as those in Manila, Malabon and Navotas give the same observations.

In Marikina Valley, saline water was found in the deeper Guadalupe aquifers, i.e., at the MGB PS-4 well that was drilled in the 1960s. The recorded well depth is 457.2m. Since groundwater was highly salinized, the well was sealed below 243.8m. Water afterwards was taken from shallower aquifers between 100m and 200m. Chloride concentration of the water then became 574 mg/l, which is about 1/10 of that from deep aquifers (Figure 3.8.5). This finding indicates the possible existence of fossil water in the Guadalupe aquifers.

As discussed earlier, some of the water samples from the Marikina Valley were plotted on domain I of the trilinear diagram, unlike most of the samples from Guadalupe Hill and the coastal area. In this case, upconing or upward leakage may be happening in shallow aquifers (100-200m).



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.8.1 ELECTRIC CONDUCTIVITY OF GROUNDWATER IN METRO MANILA
JAPAN INTERNATIONAL COOPERATION AGENCY	



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 3.8.2

DISTRIBUTION OF ELECTRIC CONDUCTIVITY

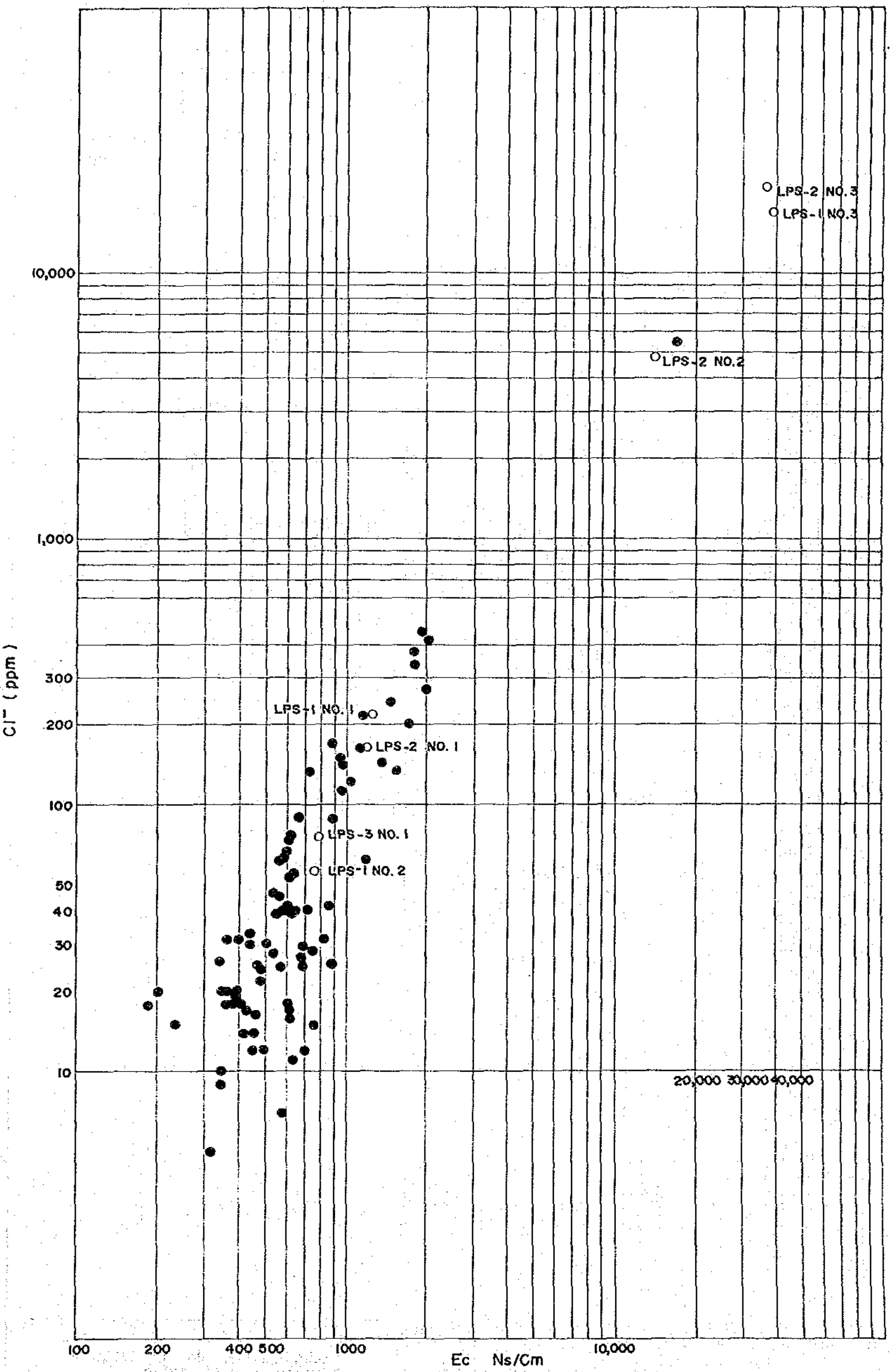
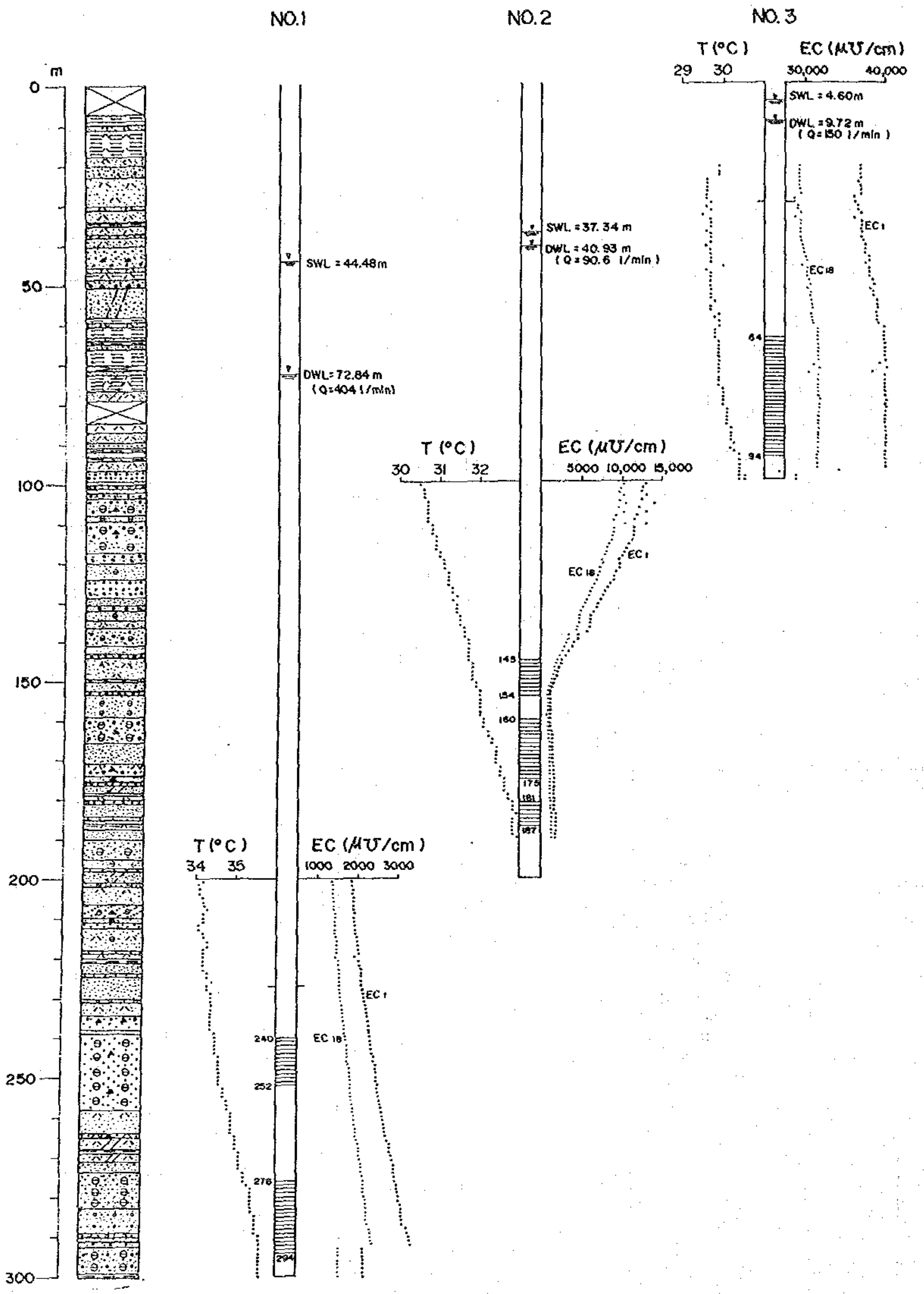
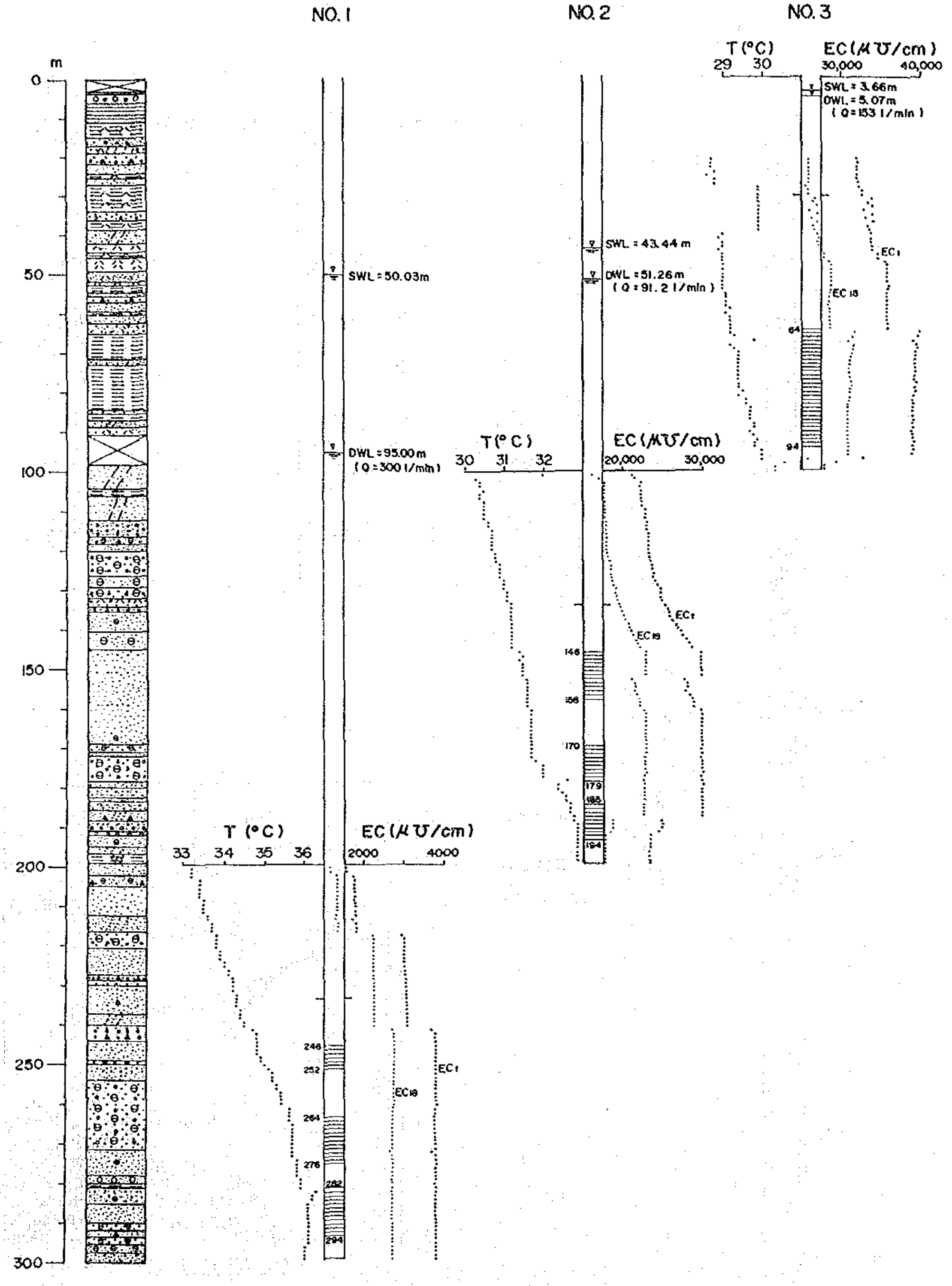


FIGURE 3.8.3 RELATION BETWEEN CHLORIDE CONTENT AND ELECTRIC CONDUCTIVITY



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.8.4(1) TEMPERATURE AND EC LOGS AT SITE NO. 1, LAS PIÑAS
JAPAN INTERNATIONAL COOPERATION AGENCY	

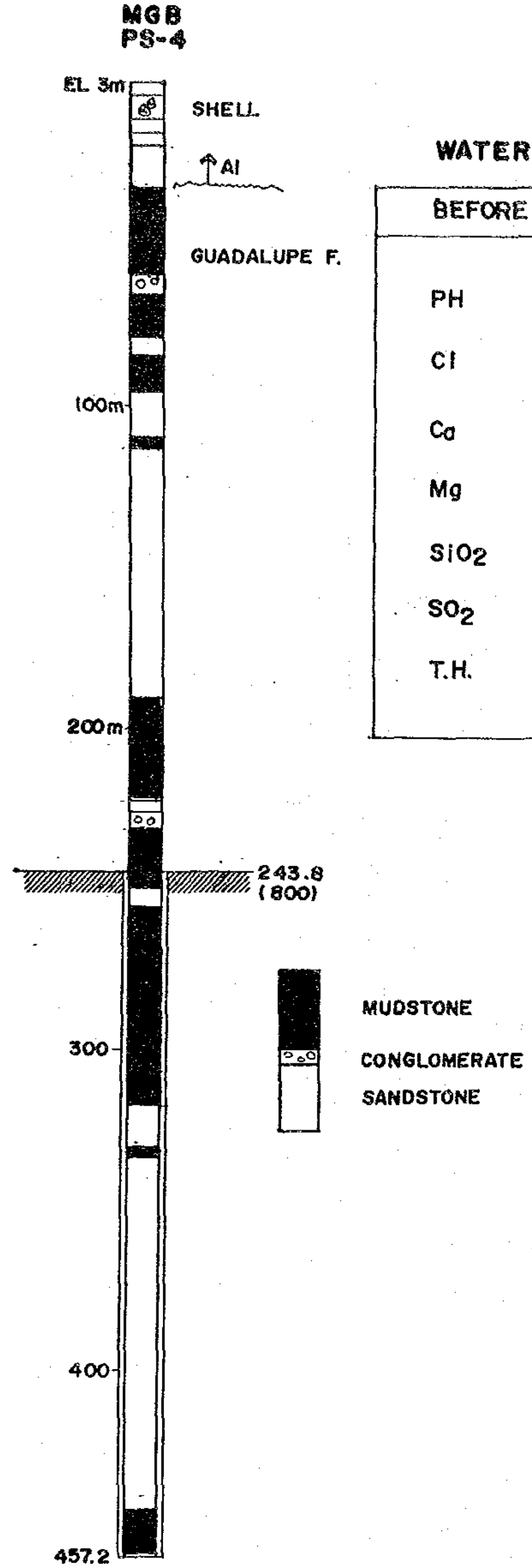


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

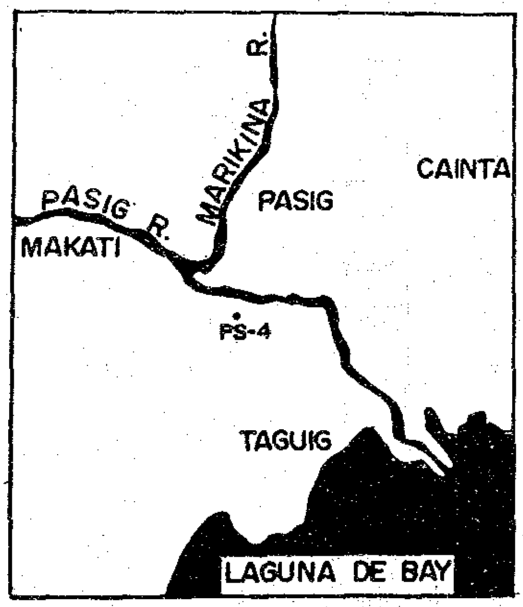
FIGURE 3.8.4(2)

TEMPERATURE AND EC LOGS AT SITE NO. 2, LAS PIÑAS



WATER QUALITY

	BEFORE SEALING	AFTER SEALING AT 243.8m
PH	7.0	7.5
Cl	5060 mg/l	574 mg/l
Ca	2120 mg/l	113 mg/l
Mg	320 mg/l	59 mg/l
SiO_2	40 mg/l	—
SO_2	269 mg/l	—
T.H.	2445 mg/l	172 mg/l



LOCATION OF PS-4

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.8.5
JAPAN INTERNATIONAL COOPERATION AGENCY	LITHOLOGY AND WATER QUALITY OF MGB PS-4 WELL

3.9 POSSIBILITY OF LAND SUBSIDENCE

The rapid and heavy decline of groundwater level in the coastal area throughout the 1960s and 1970s brought forth the belief that land subsidence may have occurred in some areas in Metro Manila.

Land subsidence in general is principally caused by the withdrawal of groundwater, particularly in the alluvial plain. As the coastal areas of Manila Bay and Laguna de Bay and the areas along Marikina River are covered by soft, clayey deposits of Alluvium age, the lowering of the groundwater head of underlying aquifers could cause the consolidation of these clayey deposits. Metro Manila in this sense has the requisite condition for land subsidence.

3.9.1 Field Observation

Indications of land subsidence are generally found at well sites, on roads, dikes, buildings, bridges, etc. Such indications can also be observed on typical foundations such as piles of buildings and bridges. In the latter case, the displacement between ground surface and building can be easily identified. Inclination and cracks on walls of buildings due to unequal at-place subsidence rates can often be observed.

A field observation in the downstream area of the Pasig River and the coastal areas of Manila and Navotas was conducted. Several tall buildings and bridges located along the Pasig River (from Nagtahan Bridge near Malacañang Palace to Del Pan Bridge) were investigated. No clear physical evidence of land subsidence was found by the Study Team. However, this does not mean that land subsidence is not happening in Metro Manila area. What the outcome of the investigation provided was at least a negative evidence of land subsidence. The area's frequent flooding in the rainy season is due to its topographically low elevation and not due to land subsidence.

3.9.2 Soil Properties of Alluvial Clay

According to a previous soil and foundation study carried out by DPWH (1977), the ranges of consolidation characteristics of alluvial clay in the coastal areas of Pasay and Manila are shown in Table 3.9.1. The data indicate that the alluvial clay is in normally consolidated condition. The range of consolidation parameters is basically the same as that of alluvial clays found in the world's coastal plains.

The clay layer can be easily consolidated by overburden or by the decline of pore water pressure. The final settlement is determined by the stress and the thickness of the consolidated layer.

As mentioned earlier, the alluvial clay is generally thin and limited to the coastal areas of Metro Manila. Also, groundwater is mainly pumped from deep Guadalupe aquifers. For these reasons, the probability of land subsidence taking place is nil, even though the area has the soil properties required for land subsidence.

3.9.3 Rise of Mean Sea Level

The mean sea level (MSL) in Manila has markedly risen since the mid-Sixties (Figure 3.9.2). Though not as marked the same rise and fluctuation of the MSL can be observed in Legaspi, Cebu and Davao.

Note that from 1965 to 1989 the MSL in Manila appears to have risen by 0.478m. Assuming the MSL does not change, it can be inferred that land subsidence is occurring in the vicinity of the tidal staff gage.

3.9.4 Elevations of Benchmarks

Though elevation of the reference benchmark differs, NAMRIA's benchmarks were simply compared in order to know the vertical tendency of the displacement of land.

Differences in elevation of benchmarks between years 1966 and 1987 appear to indicate land subsidence. However, several benchmarks are located on a hill composed of consolidated Guadalupe formation (Figure 3.9.3 and Table 3.9.3).

Assuming that one of the benchmarks on the hill is the reference benchmark of the levelings in 1987 and those before 1966, the differences in elevation of other benchmarks become almost negligible errors.

Obtaining clear evidence of land subsidence therefore requires the establishment of immovable points (control points) in the regional leveling in Metro Manila. The control points should be placed in a nearby mountainous area composed of hard rocks to properly evaluate the difference in elevation between two different levelings.

TABLE 3.9.1 RANGES OF CONSOLIDATION CHARACTERISTICS

Area	Py (kg/cm^2)	Cv (cm2/min)		mv.P	Cc
		Primary consolidation	24-hr consolidation		
BB-1	h-0.5	0.18 to 0.42	0.1 to 0.2	1.27×10^{-1}	0.58
BB-3	h+0.2	less than 0.43	0.1 to 0.45	8.15×10^{-2}	0.38
BRA-1	h+0.2				0.37
BRA-2	h+0.48				0.28 to 0.58
BRA-3	h+0.06 to 0.27				
BL-1	h-0.73 to -0.35	0.13 to 0.33	3.8×10^{-2} to 1.8×10^{-1}	9×10^{-2} to 2.3×10^{-1}	0.41 to 1.86
BL-2	h-0.07 to +0.25	1.3×10^{-2} to 4.4×10^{-2}	1.1×10 to 2.4×10^{-1}	1.4×10	1.21 to 1.71
BL-4	h-0.68 to +0.33	1.9×10^{-1} to 1.7	4.2×10^{-3} to 6.4×10^{-1}	8.5×10^{-2} to 2.2×10^{-1}	0.66 to 2.36

DATA SOURCE: DPWH, 1977

TABLE 3.9.2 ANNUAL MEAN SEA LEVELS AND VARIATIONS

Page 1 DATA SOURCE: NAMRIA

Year	MANILA OTS (1901) Mean m.	MANILA Divergence m.	LEGASPI OTS (1947) Mean m.	LEGASPI Divergence m.	CEBU OTS (1935) Mean m.	CEBU Divergence m.	DAVAO OTS (1947) Mean m.	DAVAO Divergence m.	JOLO OTS (1947) Mean m.	JOLO Divergence m.	SAN FERNANDO OTS (1947) Mean m.	SAN FERNANDO Divergence m.
1947	(2) [2.236]		(4) [1.595]		(5) [1.806]				(10) [1.999]			
1948	2.188	2.188	[1.543]	-0.052	1.728	-0.078	(2) [1.833]		1.968	-0.031	1.383	
1949	2.181	-0.007	1.542	-0.001	1.720	-0.008	1.832	-0.001	(6) [1.948]	-0.020	1.352	0.031
1950	2.25	0.069	1.545	0.003	1.804	0.082	1.938	0.106	(1) [2.079]	0.131		
1951	2.205	-0.045	1.558	0.013	1.733	-0.071	(5) [1.820]	-0.118	2.022	-0.057		
1952	2.21	0.005	(1) [1.607]	0.049	1.749	0.016	(1) [1.912]	(4) 0.092	(4) [2.034]	0.012		
1953	2.252	0.042	(1) [1.630]	0.023	1.748	-0.001	(1) [1.900]	-0.012	(7) [1.994]	-0.040		
1954	2.238	-0.014	(1) [1.626]	-0.004	1.773	0.025	1.894	-0.006	2.052	0.058		
1955	2.218	-0.02	1.633	0.007	1.781	0.008	1.928	0.034	(2) [2.056]	0.004		
1956	2.234	0.016	1.620	-0.013	1.776	-0.005	(2) [1.888]	-0.040	2.042	-0.014		
1957	2.173	-0.061	1.583	-0.037	(5) [1.697]	-0.079	(1) [1.842]	-0.046	1.988	-0.044		
1958	2.154	-0.019	1.592	0.009	(10) [1.670]	-0.027	1.817	-0.025	(2) [1.982]	-0.016		
1959	2.18	0.026	1.590	-0.002	1.714	0.044	1.838	0.021	-			
1960	2.245	0.065	1.605	0.015	1.742	0.028	1.912	0.074	2.016			
1961	2.215	-0.03	1.579	-0.026	1.711	-0.031	1.866	-0.046	(1) [1.971]	-0.045		
1962	2.234	0.019	1.613	0.034	1.755	0.044	1.932	0.066	2.024	0.053		
1963	2.195	-0.039	1.571	-0.042	1.693	-0.062	(1) [1.873]	-0.059	1.962	-0.062		
1964	2.219	0.024	1.594	0.023	1.718	0.025	1.903	0.030	1.975	0.013		
1965	2.238	0.019	1.612	0.018	(1) [1.722]	0.004	(2) [1.897]	-0.006	1.970	-0.005		
1966	2.262	0.024	1.618	0.006	1.725	0.003	1.912	0.015	1.972	0.002		
1967	2.288	0.026	1.572	-0.046	(2) [1.724]	-0.001	1.904	-0.008	1.946	-0.026		
1968	2.283	-0.005	1.548	-0.024	(1) [1.697]	-0.027	1.932	0.028	1.952	0.006		

[ ] Number of months due to instrument breakdown.

The integer above the bracket means the number of months.

TABLE 3.9.2 (CONTINUATION)

Page 2

DATA SOURCE: NAMRIA

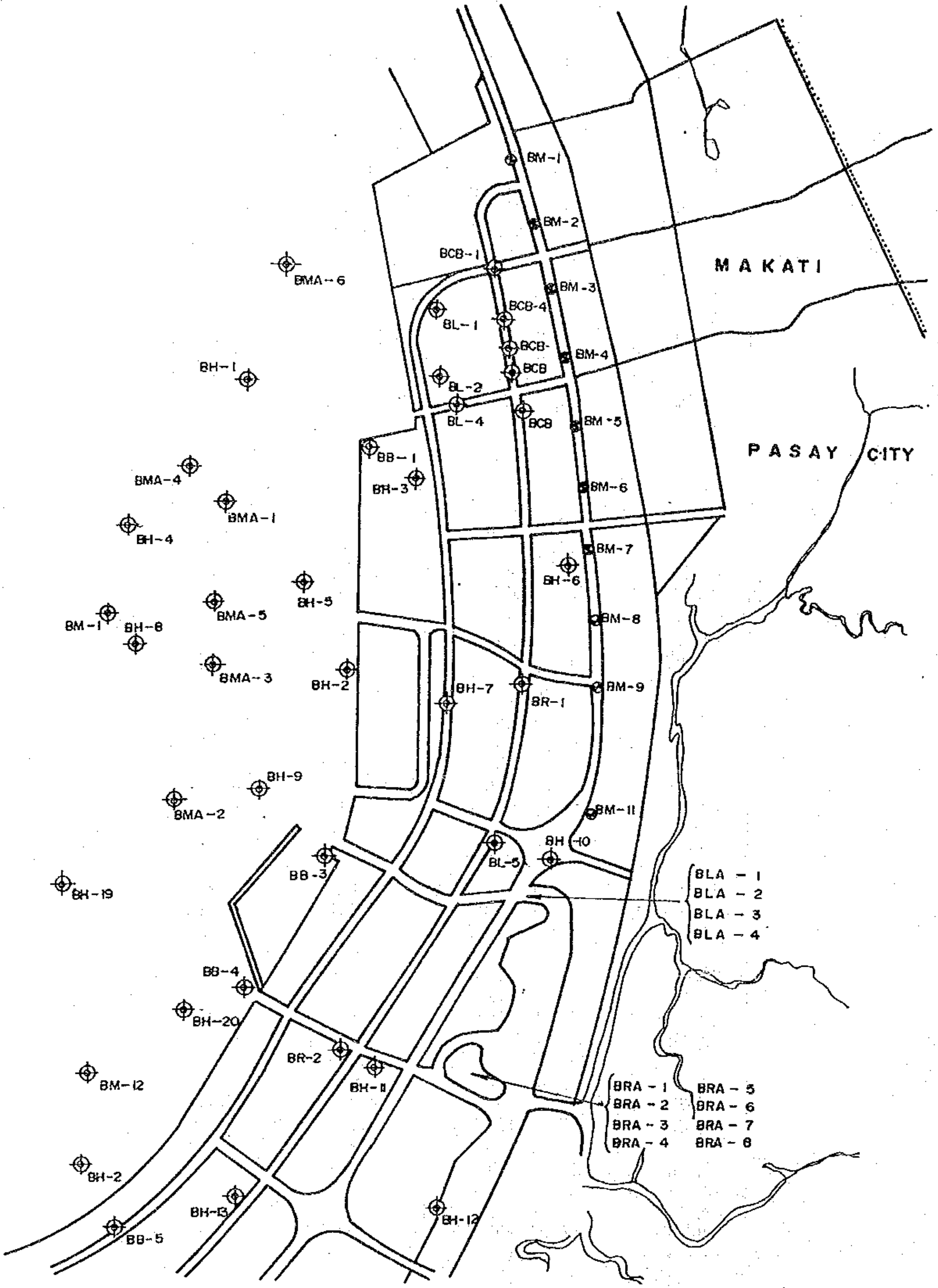
Year	MANILA OTS (1901) Mean m.	Divergence m.	LEGASPI OTS (1947) Mean m.	Divergence m.	CEBU OTS (1935) Mean m.	Divergence m.	DAVAO OTS (1947) Mean m.	Divergence m.	JOLO OTS (1947) Mean m.	Divergence m.	SAN FERNANDO OTS (1947) Mean m.	Divergence m.
1969	2.328	0.045	1.533	-0.015	1.657	-0.040	1.888	-0.044	1.938	-0.014		
1970	2.400	0.072	1.593	0.060	4 (1.678)	0.021	1 (1.952)	0.064	2.008	0.070		
1971	2.431	0.031	1 (1.612)	0.019	3 (1.773)	0.095	2.022	0.070	2.019	0.011		
1972	2.441	0.010	1.588	-0.024	1.712	-0.061	6 (1.925)	-0.097	1.932	-0.087		
1973	2.423	-0.018	1.579	-0.009	1.781	0.069	1.998	0.073	1.991	0.059		
1974	2.488	0.065	1.652	0.073	1.871	0.090	1.994	-0.004	2 (2.031)	0.040		
1975	2.514	0.026	1.738	0.086	1 (1.788)	-0.083	2.056	0.062	1 (2.048)	0.017		
1976	1 (2.541)	0.027	1.698	-0.040	1.752	-0.036	1.979	-0.077	1.972	-0.076		
1977	1 (2.538)	-0.003	1.697	-0.001	1.745	-0.007	2.008	0.029	2.008	0.036		
1978	2.561	0.023	1.680	-0.017	7 (1.692)	-0.053	2.051	0.043	2 (2.004)	-0.004		
1979	2 (2.583)	0.022	1.668	-0.012	-		2.021	-0.030	-			
1980	2.536	-0.047	1.653	-0.015	6 (1.663)		1.956	-0.065	1.973			
1981	2.575	0.039	1.675	0.022	1.726	0.063	1.992	0.036	1 (1.991)	0.018		
1982	2.575	0.000	1.692	0.017	1.711	-0.015	1 (1.959)	-0.033	1.929	-0.062		
1983	1 (2.578)	0.003	1.745	0.053	1.668	-0.043	2.017	0.058	1.932	0.003		
1984	2.658	0.080	1.738	-0.008	1.769	0.101	2.130	0.113	1 (2.035)	0.103	1.484	
1985	2.632	-0.024	1.715	-0.022	6 (1.693)	-0.076	2.078	-0.052	4 (1.985)	-0.050	2 (1.461)	-0.023
1986	2.606	-0.026	1.682	-0.033	1 (1.726)	0.033	2.061	-0.017	1.980	-0.005	2 (1.397)	-0.064
1987	2.568	-0.038	1.657	-0.025	4 (1.745)	0.019	2.012	-0.049	3 (1.947)	-0.033	6 (1.433)	0.036
1988	2.647	0.079	1.762	0.105	1.787	0.042	2.113	0.101	2.022	0.075	1 (1.430)	0.057
1989	2.716	0.069	1.818	0.056			2.115	0.002			1.489	-0.001

( ) Number of months due to instrument breakdown.

The integer above the bracket means the number of months.

TABLE 3.9.3 ELEVATIONS OF SELECTED BENCHMARKS IN METRO MANILA

Bench Mark	Elevations (m) Above MSL 1987	Elevations (m) Above MSL before 1966	Difference (m)	Remarks
BM-25	3.220	3.254	-0.034	
GM-8A	2.812	2.834	-0.022	
GM-7A	3.371	3.348	0.023	
GM-6A	2.820	2.759	0.061	
GM-9M	3.235	3.317	-0.082	
GM-8Ma	3.014	---	---	
GM-7M	3.117	3.190	-0.073	
GM-6M	2.691	2.811	-0.120	
GM-5Ma	3.226	---	---	
GM-U2	2.645	---	---	
GM-U1A	3.098	---	---	
GM-V1A	2.817	---	---	
F-10	2.721	---	---	
BMX	2.813	---	---	
BM25	3.220	3.254	-0.034	
GM-3A	2.139	2.223	-0.084	
GM-9C	2.643	2.772	-0.129	
P2a	2.833	---	---	
CIMA18a	1.955	2.006	-0.051	
E-36a	2.089	---	---	
GM-4Ja	4.410	---	---	
GM-N3a	7.340	---	---	
GM-N4	9.140	9.347	-0.207	
OS-3	19.906	20.066	-0.160	
OS-2	25.159	25.310	-0.151	
OS-1a	36.162	---	---	
GM-R4	34.307	34.441	-0.134	
GM-S9	40.941	41.101	-0.160	
GM-S8	14.029	14.124	-0.095	
GM-S7a	8.135	---	---	
OC-1a	4.743	---	---	
OC-2	4.861	5.114	-0.253	
OC-3	5.421	5.547	-0.126	
OC-4a	6.697	---	---	
BMX	2.8132	---	---	
BM 81	1.831	---	---	
GM 9AB	3.446	---	---	
GM-1A	3.716	3.859	-0.143	
GM-1B	3.546	3.677	-0.131	
FA-1a	3.187	---	---	
GM-2B	2.738	2.866	-0.128	
GM-3Ba	3.429	3.567	-0.138	
GM-4Ba	2.919	---	---	
GM-1Eb	3.154	---	---	
GM-2Ea	2.325	---	---	
GM-1Fa	6.159	---	---	
GM-1Fb	6.133	---	---	
GM-2Fa	2.420	---	---	
GM-2Fb	1.732	---	---	
GM-3Fa	3.311	---	---	
GM-4F	2.100	2.660	-0.560	
D-1a	3.287	---	---	
GM-5Fa	1.994	---	---	



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.9.1
JAPAN INTERNATIONAL COOPERATION AGENCY	LOCATION OF FOUNDATION DRILLING (DPWH, 1977)

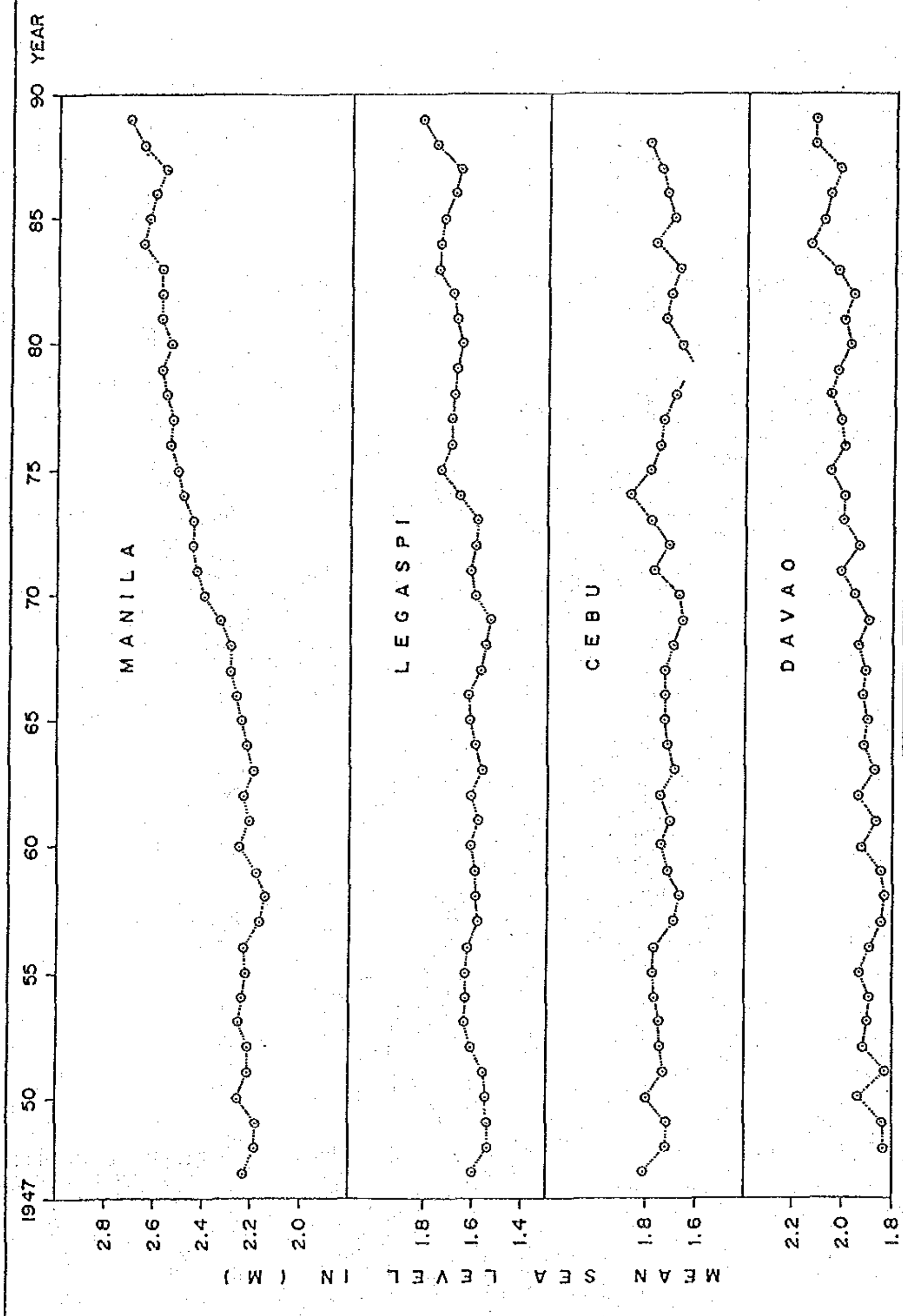
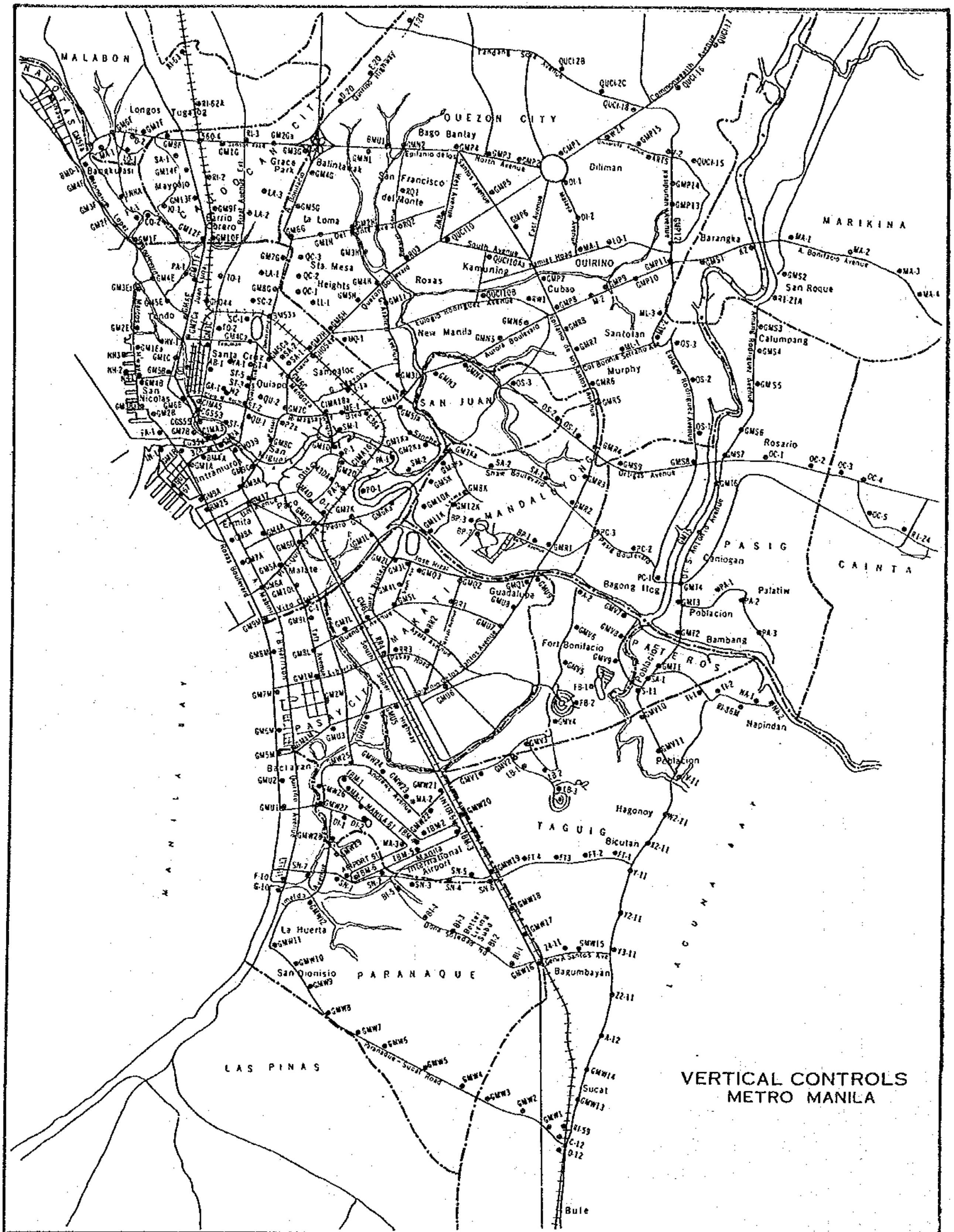


FIGURE 3.9.2 ANNUAL MEAN SEA LEVEL VARIATIONS

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.9.3
JAPAN INTERNATIONAL COOPERATION AGENCY	VERTICAL CONTROLS METRO MANILA

CHAPTER 4

GROUNDWATER DATABASE

CHAPTER 4 GROUNDWATER DATABASE

CONTENTS

CHAPTER 4 GROUNDWATER DATABASE

4.1 GROUNDWATER DATABASE SYSTEM

The groundwater database system aims to support the groundwater development and conservation program of the Metropolitan Waterworks and Sewerage System (MWSS). The system is designed to facilitate the retrieval of necessary information from the database as well as the inputting of data directly (from the source document) into the computer.

The system is composed of five databases containing the following information:

- o well inventory data
- o meteorological data
- o hydrological data
- o hydrogeological data
- o related literature records

4.2 HARDWARE REQUIREMENT

The system runs on IBM PC/AT or any compatible microcomputer system whose configuration is characterized by the following:

1. A memory size of at least one megabyte (MB)
2. With at least one 3.5" floppy disk drive
3. With hard disk of at least 40 megabytes (MB) storage capacity
4. With DOS 3.0 or higher
5. A printer similar to Epson FX-1000

JICA provided the following hardware components:

a) Computer

TOSHIBA Personal Computer model J3100SGX with 100 MB hard disk drive and 1 MB floppy disk drives; ROM: 96k; RAM: 2 MB; CPU: 386 TM (20MHZ); Operating systems: MS-DOS (Version 3.1)

b) Display: Plazma

c) Printer: TOSHIBA PW5269A

d) Mouse: J33MS001

4.3 SOFTWARE REQUIREMENT

The system is designed to be user-friendly and has a program named WELL which was developed specifically to hide the complexity of its database's internal structures and procedures. WELL was based on DBASE III Plus.

4.4 DATABASE FILE STRUCTURES

4.4.1 Well Inventory Database

Well inventory database includes MWSS-supervised wells and turned-over deep wells, private wells applying for water rights from NWRB, wells inventoried during the Electrowatt project, wells from MGB, wells visited during the groundwater use survey and groundwater leveling, test wells drilled during this JICA study, wells inventoried in NWRB's Philippine Groundwater Summary, and wells from drilling companies.

Data gathered from these are stored in four related data files:

1. Filename: WELLDATA.DBF (Contains Well Casing Data)
2. Filename: WCASING.DBF (Contains Well Casing Schedule)
3. Filename: WSCREEN.DBF (Contains Well Screen Section)
4. Filename: WSTRATUM.DBF (Contains Well Log Record)

4.4.2 Meteorological Database

The meteorological database contains data on meteorological stations including the daily, monthly, and annual records of rainfall, temperature (mean, minimum and maximum), evaporation, humidity, wind velocity and sunshine hours measured from these stations. There are 25 data files comprising this database,contents of which are:

1. Filename: MSTATION.DBF (Data on Meteorological Stations)
2. Filename: RAIN_D.DBF (Daily Rainfall Data)
3. Filename: TMAV_D.DBF (Daily Mean Temperature)
4. Filename: TMIN_D.DBF (Daily Minimum Temperature)
5. Filename: TMAX_D.DBF (Daily Maximum Temperature)
6. Filename: EVAP_D.DBF (Daily Evaporation)
7. Filename: HUMID_D.DBF (Daily Humidity)
8. Filename: SUN_D.DBF (Daily Sunshine Duration)
9. Filename: WIND_D.DBF (Daily Wind Velocity)
10. Filename: RAIN_M.DBF (Monthly Rainfall Data)
11. Filename: TMAV_M.DBF (Monthly Mean Temperature)
12. Filename: TMIN_M.DBF (Monthly Minimum Temperature)
13. Filename: TMAX_M.DBF (Monthly Maximum Temperature)
14. Filename: EVAP_M.DBF (Monthly Evaporation)
15. Filename: HUMID_M.DBF (Monthly Humidity)
16. Filename: SUN_M.DBF (Monthly Sunshine Duration)
17. Filename: WIND_M.DBF (Monthly Wind Velocity)
18. Filename: RAIN_Y.DBF (Yearly Rainfall Data)
19. Filename: TMAV_Y.DBF (Yearly Mean Temperature)
20. Filename: TMIN_Y.DBF (Yearly Minimum Temperature)
21. Filename: TMAX_Y.DBF (Yearly Maximum Temperature)
22. Filename: EVAP_Y.DBF (Yearly Evaporation)
23. Filename: HUMID_Y.DBF (Yearly Humidity)
24. Filename: SUN_Y.DBF (Yearly Sunshine Duration)
25. Filename: WIND_Y.DBF (Yearly Wind Velocity)

4.4.3 Hydrological Database

The hydrological database provides information about the hydrological gaging stations as well as the daily, monthly, and annual continuous observations on the river discharge and gage height measured from the said station. It also contains the simultaneous observations on spring discharge and streamflow in the Antipolo Area. The database comprises nine data files with the following data items:

1. Filename: HSTATION.DBF (Information on Hydrological Station)
2. Filename: RDIS_D.DBF (Daily River Discharge)

3. Filename: GAGE_D.DBF (Daily Gage Height)
4. Filename: RDIS_M.DBF (Monthly River Discharge)
5. Filename: GAGE_M.DBF (Monthly Gage Height)
6. Filename: RDIS_Y.DBF (Yearly River Discharge)
7. Filename: GAGE_Y.DBF (Yearly Gage Height)
8. Filename: SPRING.DBF (Spring Discharge)
9. Filename: STREAM.DBF (Streamflow)

4.4.4 Hydrogeological Database

The hydrogeological database contains data of those wells tested and measured during actual test drillings, rehabilitation studies, pumping test and groundwater quality investigations of wells. The database is composed of six related data files containing the following data items.

1. Filename: HGEO.DBF (Pumping Test Data)
2. Filename: WGWS.DBF (Groundwater Level Simultaneous Observation)
3. Filename: WGWC_D.DBF (Daily Groundwater Level Continuous Observation)
4. Filename: WGWC_M.DBF (Monthly Groundwater Level Continuous Observation)
5. Filename: WGWC_Y.DBF (Annual Groundwater Level Continuous Observation)
6. Filename: WCHEM.DBF (Chemical Quantity of Water)

4.4.5 Literature Database

The literature database provides literature records relevant to the groundwater development study. Data items are the following:

1. Filename: LITR.DBF (Contains Literature Records)