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METROPOLITAN WATERWORKS AND SEWERAGE SYSTEM

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

VOLUME 3
SUPPORTING REPORT

1

JUNE 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

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STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

SUPPORTING REPORT

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ABBREVIATIONS

LIST OF ABBREVIATIONS

ADB	Asian Development Bank
AWSOP	Angat Water Supply Optimization Project
BMG	Bureau of Mines and Geosciences
BSWM	Bureau of Soils and Water Management
CDS	Central Distribution System
CMD	Cubic Meter Per Day
DTI	Department of Trade and Industry
DPWH	Department of Public Works and Highways
EMB	Environmental Management Bureau
ERS	Electric Resistivity Survey
FAWSP	Fringe Areas Water Supply Project
GMA	Greater Manila Area
GNP	Gross National Product
GRDP	Gross Regional Domestic Product
GWD-MWSP II	Groundwater Development - Manila Water Supply Project II
HLURB	Housing and Land Use Regulatory Board
IA	Implementing Arrangement
IDRCC	International Development Research Center of Canada
JICA	Japan International Cooperation Agency
LPS	Liter Per Second
MCM	Million Cubic Meters
MGB	Mines and Geosciences Bureau
MLD	Million Liters Per Day
MCD	Million Cubic Meters Per Day
MMA	Metropolitan Manila Authority
MMGWDP	Metro Manila Groundwater Development Project
MMWDP	Metro Manila Water Distribution Project
MSA	MWSS Service Area
MSL	Mean Sea Level
MWSP II	Manila Water Supply Project II
MWSP III	Manila Water Supply Project III

MWSRP I	Manila Water Supply Rehabilitation Project I
MWSRP II	Manila Water Supply Rehabilitation Project II
MWSS	Metropolitan Waterworks and Sewerage System
NAMRIA	National Mapping and Resource Information Authority
NCR	National Capital Region
NDA	No Data Available
NEDA	National Economic and Development Authority
NEPC	National Environmental Protection Council
NHA	National Housing Authority
NHRC	National Hydraulic Research Center
NIA	National Irrigation Administration
NPC	National Power Corporation
NSO	National Statistics Office
NSCB	National Statistical Coordination Board
NWRB	National Water Resources Board
OPPDC	Office of the Provincial Planning and Development Coordinator
OPPDC-RP	Office of the Provincial Planning and Development Coordinator - Rizal Province
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration
PGSCS	Philippine Groundwater Salinity Control Study
PIA	Philippine Information Agency
PNR	Philippine National Railways
RDFP	Regional Development Framework Plan
RPWSIP	Rizal Province Water Supply Improvement Project
WRMM-MM	Water Resources Management Model for Metro Manila

CHAPTER 1

PREVIOUS STUDIES ON GROUNDWATER IN METRO MANILA

CHAPTER 1 A REVIEW OF STUDIES ON GROUNDWATER IN METRO MANILA

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CHAPTER 1 A REVIEW OF PREVIOUS STUDIES ON GROUNDWATER IN METRO MANILA

1.1 STUDIES IN THE LATE SIXTIES AND SEVENTIES

Studies on groundwater resources in Metro Manila date back to the 1960s with most of them having been undertaken by researchers of the Bureau of Mines and Geosciences (BMG). But these studies were only preliminary and were general unpublished, with the more useful ones for assessing the groundwater condition in the late 1960s having been written by Hernando Quiazon of the BMG. Such Quiazon studies are contained in two reports: in 1966, "Geology and Groundwater Resources of Quezon City"; in 1968, "Geology and Groundwater Resources of Manila and Suburbs."

In the 1968 report, Quiazon discussed the water bearing properties of rocks, the hydrometeoric condition, water balance and hydrology. It is worth noting that at that time the groundwater level had already dropped to 40 meters below sea level in the Malabon, Navotas and Caloocan areas. From near-surface to about 300 feet, saline groundwater was found in the near-shore groundwater zone from Las Piñas to Malabon and in the vicinity of areas away from shore with salty surface water.

Quiazon concluded in the same report that no less than twenty (20) additional square kilometers of aquifers from depths of 300 to 500 feet were lost to salty water during the 1959-1966 period, and that the experience at the Manila Bay basins could guide the use of other groundwater basins.

Moreover, he stressed the necessity of regulating the disposition of the groundwater that underlies private lands and those in the public domain, as groundwater is in the same category as underground mineral resources. His concluding remark on not exceeding the safe yield of basin, unless the public interest requires it, deserves thoughtful attention.

Throughout the 1970s very little studies were done on Metro Manila's groundwater resources. As far as Quiazon's work is concerned, he made at least two unpublished reports regarding Manila and its environs in 1971 and 1975.

In the 1971 report and based on the construction records of wells and other data, he discussed the water levels, hydrogeologic properties of formations, groundwater movement, recharge and discharge, and the water quality in Manila and suburbs. Quiazon observed that in an area of about 300 square kilometers of the pumped zone between Guiguinto (in Bulacan province), Manila, Quezon City and Marikina Valley, the decline of the groundwater level had reached 2 to 50 feet per year, and he warned that many pumpwell sites may become inoperative within a span of 10 years.

1.2 STUDIES FROM 1980-1983 (THE ELECTROWATT STUDY)

In 1980 and in the light of the government's "crash program" of groundwater development to augment the MWSS supply, the Groundwater Development - Manila Water Supply Project II (GWD-MWSPII) was launched with the aim of transforming it into a long range program of water management. This long range program was envisioned to provide for a most effective exploitation and use of the groundwater resources of the Metro Manila area.

The above project was jointly implemented by MWSS and Electrowatt. It constitutes the first study that tried to comprehensively delineate existing and future conditions of the capital region's groundwater resources.

A corollary feature of GWD-MWSP II was the preparation of a program of groundwater development which shall keep pace with the demand in outlying areas and also relieve shortages of water supply within the nominal service area of the central distribution system (CDS) of the MWSS.

The scope of GWD-MWSP II or the Electrowatt Study focused on four aspects:

- Groundwater development including completion of the ongoing program, and siting and specifications for 50 project wells.
- Hydrogeologic investigations to describe groundwater conditions in Metro Manila and to determine the effects of present developments

on the occurrence and quality of groundwater and the future prospect for groundwater development.

- o Master Plan studies to lay out the future program of investigation, regulation and development
- o Training and Institutional Development to create an organization within MWSS that will carry out the future program of investigaion and development.

1.2.1 Hydrogeologic Investigations

(1) Well Inventory and Groundwater Use

The Electrowatt Study had carried out an inventory of existing wells which in end-August 1982 had 2292 records of wells collected and inventoried with location maps. Water levels of 58 idle wells were measured and 381 operating wells were sampled for laboratory analysis of major chemical and physical properties based on inventoried well data. These data were used as the basis for the 1981 water level contour map and the water quality characteristics map.

Aquifer parameters such as transmissibility and specific capacity were processed and represented on a map according to pumping test data and discharge-drawdown data (Table 1.2.1).

Since there were no wells equipped with meters, groundwater pumpage in the Metro Manila area was estimated by using the discharge capacity of wells, their energy consumption or other indirect data.

According to the estimation, total withdrawals for industrial, commercial and public supply wells were 261 MCMY (689 MLD) as shown in Table 1.2.2 and Figure 1.2.1. In addition, total withdrawal for domestic supply from about 20,000 privates shallow wells in the Metro Manila Area was estimated as 14 MCMY(38 MLD).

(2) Groundwater Condition

Surface geological studies were carried out by using aerial photographs,

satellite imagery and field observations throughout the Metro Manila Area. A detailed surface geologic survey was made for Cogeo and the vicinity of Antipolo.

Surface resistivity surveys were done in the Marikina Valley to try to locate shallow salt-water bodies, and around the municipalities of Antipolo and Cogeo, to try to locate structural breaks in the rocks.

In addition, electric logs of about 100 wells were collected. The results of these studies were represented on a geological map of 1/50,000 scale.

Based on such work mentioned, groundwater condition in the Metro Manila Area was described in the Electrowatt report, from which some of the important findings are:

Groundwater Geology

The rocks and sediments of the Metro Manila Area are divided into the Manila Bay Aquifer System, the Antipolo Plateau Aquifer System and the Volcanic rocks of the Cogeo Area. The alluvial and diluvial sediments in Marikina Valley graben are included in the Manila Bay Aquifer System.

The Manila Bay Aquifer System consists of rocks and unconsolidated sediments of the Quaternary alluvium and underlying Guadalupe Formation. A part of the Guadalupe formation consists of sediments of volcanic rock reworked and deposited. These sands and conglomerate comprise the most productive water bearing rocks in the Metro Manila Area.

The Antipolo Plateau Aquifer System consists of rocks which are classified as part of the Guadalupe formation, but which are isolated from the Guadalupe rocks of the Manila Bay Aquifer System by fissure basalt along the bounding Cogeo fault of the east side of Marikina Valley. The water bearing zone is made up of coarse-grained facies of the Guadalupe formation.

The Volcanic rocks of the Cogeo Area include basaltic and andesitic lava flows and related eruptive rocks. The water bearing zone of these rocks contains cracks and fractures.

In the north and east of Montalban and the Antipolo Plateau, folded clastic rocks and limestone of Tertiary age occur, but these sedimentary rocks have not supported any groundwater development other than a few wells in the Teresa area.

Water Bearing Properties of the Aquifer

The distributions of transmissibility and specific capacity of the Manila Bay Aquifer System are shown in Figures 1.2.2 and 1.2.3.

The transmissibility commonly ranges from about 100 to 250 m^2/d. A high range of transmissibility can be found in the Muntinlupa-San Pedro area located east of the Marikina Fault, where the value ranges from 450 to 1192 m^2/d.

Southwest of the Metro Manila area from Imus to Rosario, the transmissibility values range from 400 to 700 m^2/d. In most of the Antipolo town, the transmissibility exceeds 200 m^2/d. This is true as well in the vicinity of Taytay, in a large area in Cavite Province, and much of the Marikina Valley.

Effects of Development

Large-scale development of groundwater from the Manila Bay Aquifer System greatly altered the flow regime in the underground. This was elucidated by the historical piezometric surface maps reproduced from the records obtained in the years 1955, 1967 and 1981. (Figure 1.2.4,5,6)

The groundwater flow pattern in 1955 suggests that recharges from southern Tagaytay reached Taguig, Makati, Parañaque, Pasay, and Manila Bay and Laguna de Bay. By 1967, the recharge was still able to reach these areas. However, the 1981 map indicates that the groundwater flow from the south is largely diverted to the areas of heavy groundwater pumpage in Sucat-Bicutan, Las Piñas, Cavite City and Bacoor and is no longer reaching Makati.

The water level however, has continuously declined since 1955. In 1981 the rate of decline had reached 5 to 12 m/year with a deep cone of

depression appearing in the heavy pumping area. This lowering of water level resulted to saline water intrusion of the Manila Bay Aquifer System and has largely affected the quality of groundwater. Figure 1.2.7 shows the distribution of conductivity that were observed in the coastal area along the Manila Bay.

In regard to saline water, Electrowatt's study subdivided the Metro Manila into 4 areas based on the occurrence and source of saline water (Figure 1.2.8):

A: Sea water intrusion

This zone is affected by seawater intrusion due to the increase in groundwater pumpage and the downward drainage of seawater through faulty well.

B: Connate water zone

The presence of connate water at depths was positively verified in the southern Marikina Valley, the vicinity of the Manila International Airport (MIA), and the industrial area of Sucat and Bagumbayan.

C: Saline water from compound source

In San Dionisio, Parañaque and MIA, seawater intruded the shallow part of the aquifer and connate water occurs at depth.

D: Freshwater to possibly 400m depth

1.2.2 Master Plan Studies

Master plan studies were carried out in two contexts. One is in the projection of the future condition of the groundwater in the Metro Manila Area to guide future MWSS development programs; the other is in the identification of priority projects and of potentially serious problems and the determination of potentials for groundwater development in unexplored reaches of aquifer system.

A finite-element groundwater model was formulated to simulate ground-

water flow in the Manila Bay Aquifer System. Calibration of the model was done and parameters such as transmissibility and storativity were identified. Aerial recharge rate was taken at 100mm/year.

Results of simulation indicate that if pumpage were continued to the year 2000 at the 1982 rate, the mean water level would approach 90m below MSL, more than double the 1982 depth. The model's projection also indicated that even if pumpage were completely stopped in 1990, water level recovery would be at a rate of only 2m/year, and after 10 years, at a rate of about 1m/year. This means that the aquifer parallel to Manila Bay would be vulnerable to sea water intrusion for several decades.

Based on the conclusion, recommendations concerning construction, pumpage modification, legal and administrative investigations were made.

1.3 RECENT STUDIES

1.3.1 Philippine Groundwater Salinity Intrusion Control Study (PGSICS)

This study was undertaken in 1985 by the National Environmental Protection Council (NEPC) and was aimed at a definition of the affected area by saline water intrusion, the formulation of a proposal for a comprehensive measurement and monitoring system, and recommendations for the development and management of groundwater considering economic, legal and institutional aspects.

The study focused on Metro Manila and the provinces of Cebu, Bulacan, Pampanga, Capiz and Sorsogon.

Most of the data used in this study were secondary and collected from various agencies. However, in Metro Manila, groundwater samples were taken and water levels were measured at selected wells in pilot areas. Chemical analysis were made and plotted on the trilinear diagram. The Electric conductivity map and piezometric surface map in 1985 were presented and compared to those of 1981. These maps are useful in the assessment of groundwater condition in Metro Manila in the mid-1980s (Figure 1.3.1 and 1.3.2), but they are only approximate as the surveyed

wells were limited in number. They may at least indicate, however, that the groundwater level and salinity condition in 1985 are virtually the same as in 1981.

Based on PGSICS water quality data in Metro Manila, cation-anion composition are represented on hexa-diagram in the present Study (Table 1.3, Figure 1.11). It is evident that the water affected by saline water intrusion is shaped so differently in the diagram when compared to non-affected water.

Moreover, the relation between bicarbonate and chloride is very clear as shown in Figure 1.3.4. The position of contaminated groundwater in the graph gradually moved to the upper portion in accordance with the degree of salinity.

In the PGSICS, the economic impact of salinity in groundwater use was discussed and evaluated based on case studies. In addition, regulatory and institutional measures were discussed and recommended. These will provide the basis in the establishment of groundwater monitoring system in Metro Manila and shall require further discussions.

1.3.2 Fringe Areas Water Supply Project (FAWSP)

This is an ongoing project of MWSS and feasibility studies have been developed to identify potential groundwater resources, and also, to design a feasible scheme of supply for the fringe areas of Metro Manila. The project aims to supply water to areas not served by surface water even after the completion of AWSOP or MWSP II.

In September 1990, the draft feasibility study report No. 1 covering Antipolo, Montalban, San Mateo, Imus and Muntinlupa has been finished.

The No. 1 report incorporates study results on existing water supply systems, population and water demand projections, and water resource evaluation. Based on the study, locations and design of wells have been proposed, with the contract for construction of several wells having already been awarded and executed.

With regard to hydrogeological study, meteorological and hydrological

data were collected, but primary data were not obtained yet, except for those on water quality of existing wells and measurements of water levels and spring flows, also in limited areas and numbers.

In the project, one (1) well in Antipolo has been completed and another in Cogeo has been under construction since October 1990.

1.3.3 Rizal Province Water Supply Improvement Project (RPWSIP)

This is a feasibility study for improving the water supply in the nine (9) municipalities of Rizal Province: Angono, Baras, Binangonan, Cardona, Jala-Jala, Morong, Pililla, Tanay and Teresa. It was carried out by MWSS and SOGREAH Consulting Engineers and financed by the Government of France.

A feasibility study report of the RPWSIP was submitted in December 1989. The study scope includes water demand, water resources, alternative schemes, financial analysis and institutional aspects.

According to the study, the only source of water supply in the nine towns is groundwater. One of the important conclusions reached in the report is that the groundwater would be able to supply the whole population of the nine (9) towns up to the year 1999.

Regarding groundwater investigations, existing geological and hydrogeological data were collected and analyzed, but little primary data were obtained. Flow measurements of springs in Teresa and rivers in Morong and Tanay were done for nine (9) months (February to September, 1989). In addition, electric resistivity survey (ERS) was carried out in order to explore the alluvial aquifers along the coast of Laguna de Bay between Angono and Jala-Jala. Another ERS was carried out in a specific location in the study area in order to decide the sites of investigation boreholes.

Based on hydrological and hydrogeological data, recharge to the aquifers is roughly estimated to be from 1,340 to 2,640 LPS (116-228 MLD) for the whole study area. These aquifers were considered as a potential groundwater sources.

As of October 1990, five (5) exploratory boreholes have been drilled in the project. But the pumping tests have yet to be started. These wells would be converted to MWSS production wells if their productivity would be favorable for supply.

1.3.4 Other Ongoing Studies

The National Hydraulic Research Center (NHRC), in association with the International Development Research Center (IDRC) of Canada, is conducting a research project entitled "Water Resources Management Model for Metro Manila" (WRMM-MM). Cooperating agencies of the project are MWSS, NEDA, NWRC, MGB and EMB.

The main objective of the project is to develop a Water Resources Management Model for Metro Manila and its environs, and it will take into account both surface water and groundwater resources in the region. The project will devote attention to the following aspects:

a) aquifer characteristics and basin yield

b) total hydrologic cycle which accounts for the conjunctive use of surface water and groundwater

c) actual recharge, distribution points and their recharge potential within the Laguna Lake Basin

d) policy recommendation on water resources development and management

The project which started in May 1990 shall last for 3 years. The first and second progress reports were published in August 1990 and November 1990, respectively.

Another groundwater-related study that was begun in 1988 is being conducted by EMB. Groundwater samples from Metro Manila and other provinces where saline water had intruded had been taken. Several radioactive isotopes, such as deuterium, tritium, oxygen 18 and carbon 14 have been measured. But the report is yet to be published.

TABLE 1.2.1 PUMPING TEST RESULTS AND AQUIFER CHARACTERISTICS OF SELECTED WELLS IN METRO MANILA

MWSS No.	O W N E R	Depth (m)	S.W.L. (m)	Drawdown (m)	Test Pumping Rate (/s)	Specific Capacity (/s/m)	Transmissibility (m /d)	Aquifer Tapped
ATP-54	Sumulong 67	183	23	11	18.0	1.60	210	GP
ATP-73	San Isidro Elem. School	177	-	20	28.4	1.41	208	GP
ATP-101	Ang Tahanan	213	28	23	28.0	1.20	444	GP
ATP-102	Cogeo	117	13	74	10.0	0.13	-	GP
BCR-3	Banalo	305	21	26	15.8	0.61	137	Qal.Qt.
BCR-4	Bo. Niog	274	39	15	30.0	2.00	220	Qal.Qt.
BCR-11	Magdiwang Realty Corp.	152	17	1	6.0	6.00	700	Qal.Qt.
BCR-13	NIA, Bo. Bayanan	161	9	19	13.5	0.70	245	Qal.Qt.
CLC-36	Bagong Barrio #1	305	167	10	6.9	0.73	160	GS
CLC-37	Bagong Barrio #2	274	120	22	4.4	0.20	20	GS
CLC-B-53	Sacred Heart Novitiate	213	16	71	22.1	0.31	51	GS
CTA-19	San Juan	213	31	6	13.0	2.20	255	Qal.Qt.
CTA-20	Sumulong Highway	195	69	16	15.8	0.99	192	Qal.Qt.
CTA-66	Marick Subdivision	177	52	34	25.4	0.75	103	Qal.Qt.
CTA-67	Irma Street	177	42	40	26.5	0.65	63	Qal.Qt.
CVC-11	Crescini Street	317	25	7	12.6	1.80	360	
CVC-12	Public Market	247	7	18	25.3	1.41	350	
CVC-17	Antonio Street	266	14	17	11.4	0.68	88	
GTR-2	NIA, Brgy. Santiago	61	3	6	19.0	3.40	430	Qal.Qt.
GTR-3	NIA, Brgy. San Juan	98	7	6	16.7	2.80	350	Qal.Qt.
IMS-3	Topacio	244	15	15	18.0	1.20	100	Qal.Qt.
IMS-6	NIA, Alapan II	192	13	17	46.6	2.70	220	Qal.Qt.
IMS-7	NIA, Anabu II	200	8	14	33.6	2.50	420	Qal.Qt.
IMS-8	NIA, Tinabunan	190	8	11	10.4	0.90	600	Qal.Qt.
IMS-21	P. Garcia Plaza	305	27	35	33.0	0.97	137	Qal.Qt.
LPS-37	Naga Rd. #1	306	43	36	10.0	0.30	28	Qal.Qt.
LPS-48	General Motors Inc. #1	306	43	36	10.0	0.30	28	Qal.Qt.
LPS-64	Las Pinas Elem. School	228	37	10	21.0	2.10	243	Qal.Qt.
MKT-11	Cambridge Circle F. Park	306	17	31	32.0	1.00	118	GS
MKT-12	Kayamanan "D"	310	14	19	32.0	1.70	212	GS
MKT-18	Ayala #21	263	15	19	30.0	1.60	18	GS
MKT-23	Ayala #26	214	11	15	36.0	2.40	275	GS
MKT-25	Ayala #28	206	10	25	30.0	1.20	120	GS
MKT-31	Ayala #31	201	9	33	11.0	0.30	50	GS
MKT-33	Ayala #36	310	35	44	6.0	0.10	20	GS
MKT-46	Bank of America Bldg.	305	18	42	7.0	0.20	32	GS
MKT-48	China Banking Corporation	274	25	53	9.0	0.20	22	GS
MKT-67	Peninsula Hotel	305	45	29	7.0	0.20	30	GS
MKT-122	Banaba Circle	204	20	17	9.0	0.50	70	GS
MKT-128	Poblacion Elem. Sch.	274	78	50	12.9	0.26	23	GS
MKT-136	Eastern Telecom	305	50	30	33.0	1.10	135	GS
MKT-145	Ecology Village	303	58	34	7.9	0.23	57	GS
MLB-20	Brgy. Catmon	263	82	35	5.0	0.10	21	Qal.Qt.
MLB-32	Bo. Daapalit	233	31	52	8.0	0.20	25	Qal.Qt.
MLB-57	MWSS Niugan	305	20	61	13.0	0.20	22	Qal.Qt.
MLB-110	Santolan	305	99	13	7.9	0.62	23	Qal.Qt.

MWSS No.	O W N E R	Depth (m)	S.W.L. (m)	Drawdown (m)	Test Pumping Rate (/s)	Specific Capacity (/s/m)	Transmissibility (c /d)	Aquifer Tapped
MLB-113	Dampalit	305	65	38	9.0	0.20	23	Qal.Qt.
MDL-10	National Mental Hospital	201	31	20	11.0	0.50	65	Qal.Qt.
MNL-101	F.E.U.	305	8	75	4.0	0.10	9	Qal.Qt.
MNL-148	Balut, Tondo	305	87	22	7.0	0.32	33	Qal.Qt.
MRK-3	Industrial Valley	178	39	12	13.0	1.10	120	Qal.Qt.
MTB-15	Mangqahan	213	11	22	31.8	1.47	240	
MTL-1	Bliss Project	305	11	105	12.0	0.10	12	Qal.GS
MTL-7	CDCP Sucat Interchange	152	15	7	4.0	0.60	68	Qal.GS
MTL-8	Ford Philippines	305	43	90	7.0	0.10	13	Qal.GS
MTL-17	Pepsi Cola	305	15	33	37.8	1.15	590	Qal.GS
MTL-22	Tahanan Village #3	305	24	51	15.0	0.30	40	Qal.GS
MTL-23	Tahanan Village #1	215	24	33	17.0	0.50	70	Qal.GS
MTL-27	Ayala Corp. Well B	305	13	110	33.0	0.30	31	Qal.GS
MTL-34	Ayala Corp. Well #10	305	37	30	35.0	1.20	455	Qal.GS
MTL-44	Pacific Multi Homes Inc.	305	50	24	20.0	0.80	110	Qal.GS
MTL-59	International Textile	363	37	85	11.0	0.10	13	Qal.GS
MTL-69	PECCO	249	7	29	24.0	0.80	105	Qal.GS
MTL-91	Ayala #12	305	52	67	19.0	0.30	40	Qal.GS
MTL-147	MWSS Sucat Elem. School	302	18	30	29.5	0.98	750	Qal.GS
MTL-148	MWSS Poblacion	305	15	36	22.3	0.62	195	Qal.GS
MTL-149	MWSS Tunasan	305	9	17	3.6	4.72	400	Qal.GS
MTL-150	MWSS Alabang	250	13	9	20.3	2.09	350	Qal.GS
MTL-151	MWSS Putatan	305	6	12	39.4	3.24	222	Qal.GS
MTL-152	Transpacific Prop.,Tunasan	305	13	4	23.7	6.41	1,150	Qal.GS
MTL-159	Cupang Elem. School	287	10	12	23.4	1.95	1,192	Qal.GS
NAV-3	NHA #4	244	20	33	11.0	0.30	45	Qal.GS
NAV-4	NHA #5	277	76	24	7.0	0.30	38	Qal.GS
NAV-8	NHA #3	305	8	45	10.0	0.20	30	Qal.GS
NAV-17	Merville, Tanza	305	92	26	7.0	0.30	30	Qal.GS
NOV-5	PNR 7	299	13	17	28.1	1.67	302	Qal.GS
NOV-6	PNR 8	299	14	18	41.0	2.24	217	Qal.GS
NOV-7	Noveleta Elem. School	304	13	8	34.2	4.16	592	Qal.GS
PRN-8	Gelmart Inc.	244	52	43	22.0	0.50	61	Qal.GS
PRN-14	Standard Elect. Mfg.	230	72	37	5.0	0.10	13	Qal.GS
PRN-20	Naga Road #2	244	32	9	15.0	1.60	197	Qal.GS
PRN-66	Packaging Product #2	274	42	36	10.0	0.30	35	Qal.GS
PRN-74	Bo. San Dionisio	181	26	47	21.0	0.40	55	Qal.GS
PRN-78	MIA #2	256	29	44	20.0	0.50	65	Qal.GS
PRN-77	MIA #1	256	28	19	21.0	1.10	135	Qal.GS
PRN-135	Johnson & Johnson	244	42	14	12.0	0.90	105	Qal.GS
PRN-153	Sucat Rd. 3, S. Dionisio	177	20	56	11.6	0.20	48	Qal.GS
PRN-154	MIA #3	250	47	31	20.5	0.66	85	Qal.GS
PRN-155	MIA #4	244	45	61	23.1	0.38	80	Qal.GS
PRN-156	Bo. San Dionisio #4	143	26	47	26.5	0.56	55	Qal.GS
PRN-157	South Bay, San Dionisio	305	84	53	6.6	0.12	14	Qal.GS
PSC-20	PAL Inflight Center	244	40	23	19.9	0.86	100	Qal.GS
PSC-44	Manila Sanitarium	305	81	27	4.0	0.10	9	Qal.GS
PSC-49	Maricaban	244	44	25	15.0	0.60	81	Qal.GS
PSC-55	Nayong Kabataan #1	152	11	11	3.0	0.30	33	Qal.GS
PSC-69	School of Deaf	610	61	98	12.7	0.13	16	Qal.GS

MWSS No.	O W N E R	Depth (m)	S.W.L. (m)	Drawdown (m)	Test Pumping Rate (/s)	Specific Capacity (/s/m)	Transmissibility (m /d)	Aquifer Tapped
PSG-12	Meralco	366	37	26	11.0	0.40	47	Qal.GS
PSG-186	Dreamhouse, dela Paz	226	72	14	12.0	0.85	207	Qal.GS
PSG-187	Urban Bliss	243	34	39	18.8	0.48	81	Qal.GS
PSG-188	Marbay & Co.	305	62	16	8.6	0.54	107	Qal.GS
QCT-65	ABS-CBN #2	122	40	17	3.0	0.20	22	Qal.GP
QCT-86	Capital Hills Golf Club #1	171	37	10	12.0	1.20	130	Qal.GP
QCT-121	Veterans Hospital #1	290	25	43	14.0	0.30	45	GS.GP
QCT-122	Veterans Hospital #2	271	31	13	15.0	1.20	135	GS.GP
QCT-195	Constitution Hill #1	274	16	67	15.0	0.20	30	GS.GP
QCT-250	Poblacion Novaliches	244	26	15	14.0	0.90	109	GS.GP
QCT-251	Bo. Bagbag	200	35	26	14.0	0.50	63	GS.GP
QCT-257	Project 8, Congressional	274	101	12	11.0	0.90	110	GS.GP
QCT-269	Bo. Escopa Project 4	274	85	20	13.0	0.70	100	GS.GP
QCT-276	D. Tuazon Pumping Station	244	11	59	8.0	0.10	15	GS.GP
QCT-277	D. Tuazon Elem. School	244	11	104	8.0	0.10	8	GS.GP
QCT-330	Constitutional Hill #4	305	56	27	12.0	0.40	45	GS.GP
ROS-10	Sapa	286	10	16	21.6	1.39	402	
ROS-11	PNR - 1	305	13	21	34.9	1.66	352	
ROS-12	PNR - 2	305	13	24	34.9	1.43	340	
ROS-13	PNR - 3	305	15	22	21.2	0.95	490	
ROS-14	PNR - 4	302	13	27	29.1	1.07	265	
ROS-15	PNR - 5	302	8	24	38.0	1.60	-	
ROS-16	Nawa	302	8	24	42.5	1.77	230	
ROS-17	Town Plaza	299	10	18	44.7	2.37	266	
ROS-18	PNR - 6	299	13	20	31.7	1.56	235	
SJN-6	Bo. Once, San Juan	220	5	49	12.0	0.20	29	GS.GP
SMT-2	Bo. Ampid	152	6	12	35.0	2.90	365	Qal.Qt.
SMT-3	Bo. Malanday	183	12	24	14.0	0.60	70	Qal.Qt.
SMT-4	Bo. Naly	209	12	54	14.0	0.30	40	Qal.Qt.
SMT-10	Dulong Bayan	123	13	20	18.9	0.94	125	Qal.Qt.
SMT-11	Ampid	174	11	8	32.8	4.31	1,150	Qal.Qt.
SPD-5	Cosmos Bottling Co.	305	Flowing	8	55.3	7.00	600	Qal.Qt.
TGG-16	Triumph Builders	213	34	68	6.0	0.10	10	Qal.Qt.
TGG-18	Tuktukan	183	20	25	17.0	0.70	87	Qal.Qt.
TGG-19	Maharlika Village	183	29	33	19.0	0.60	70	Qal.Qt.
TGG-24	Bicutan Military	183	21	5	13.0	2.60	320	Qal.Qt.
TGG-32	Mrs. Betina de Leon	152	28	20	8.0	0.40	51	Qal.Qt.
TGG-48	Century Canning	244	50	51	11.0	0.20	30	Qal.Qt.
TGG-97	Upper Bicutan	213	58	29	13.9	0.48	52	Qal.Qt.
TGG-138	Signal Village 1	177	33	30	23.9	0.80	166	Qal.Qt.
TGG-139	Signal Village 2	171	65	38	20.8	0.57	150	Qal.GS.
TNZ-2	NIA, Calibuyo	100	5	9	9.5	1.10	150	Qal.GS.
TNZ-3	NIA, Punta	200	9	5	15.7	3.30	495	Qal.Qt.
TYY-10	Bo. San Isidro	179	26	7	40.0	5.70	700	Qal.SS.
TYY-11	Sta. Ana	153	27	6	16.0	2.70	330	Qal.GS.
VLZ-18	Bo. Marulas	305	128	16	5.0	0.30	38	Qal.GS.
VLZ-37	Tamaraw Hills	305	95	53	6.0	0.10	13	Qal.GS.
VLZ-106	Isla Valenzuela	274	38	61	9.0	0.10	14	Qal.GS.

MWSS No.	O W N E R	Depth (m)	S.W.L. (m)	Drawdown (m)	Test Pumping Rate (/s)	Specific Capacity (/s/m)	Transmissibility (m /d)	Aquifer Tapped
VLI-125	MWSS T. de Leon, Malinta	308	106	25	7.9	0.27	23	Qal.Bb.
VLI-212	MWSS - Malinta	309	106	29	8.0	0.30	65	Qal.Bb.
VLI-213	Arkong Bato	305	104	13	8.0	0.60	114	Qal.Bb.
VLI-214	Pasolo Elem. School	305	107	10	8.0	0.80	110	Qal.Bb.
VLI-215	Malanday, Kadiwa Center	304	106	16	7.6	0.47	64	Qal.Bb.
VLI-216	Bagong Lipunan Health Center, Coloong	302	62.5	10.3	6.8	0.65	17	Qal.Bb.

Source: BKD-MWSPII

TABLE 1.2.2 GROUNDWATER PUMPAGE IN THE GREATER MANILA AREA, BY USER TYPE: 1981-1982

(million cubic meters)

Municipality	No. of wells	Industrial	Public Supply	Commercial	Agricultural	Total
1. Antipolo	71	1.32	4.87	0.25	-	6.44
2. Bacoor	35	-	2.04	-	0.66	2.70
3. Cainta	65	7.47	1.51	0.23	-	9.21
4. Caloocan City A & B	76	2.75	1.405	1.963	-	6.118
5. Cavite City	28	-	7.20	-	-	7.20
6. General Trias	24	-	0.02	-	1.44	1.46
7. Imus	20	0.32	1.05	0.12	0.08	1.57
8. Kawit	11	-	0.99	-	0.58	1.57
9. Las Piñas	118	4.59	8.55	0.35	-	13.49
10. Makati	133	1.69	10.48	6.94	-	19.11
11. Malabon	120	4.72	1.39	0.28	-	6.39
12. Mandaluyong	69	2.76	0.34	1.02	-	4.12
13. Manila	120	1.35	1.16	1.457	-	3.967
14. Marikina	54	6.10	1.21	0.59	-	7.90
15. Meycauayan	26	4.90	1.79	-	-	6.69
16. Montalban	14	1.29	0.45	0.05	-	1.79
17. Muntinlupa	143	7.48	6.99	1.35	-	15.82
18. Navotas	22	1.05	0.94	0.304	-	2.294
19. Noveleta	6	-	0.10	-	-	0.10
20. Paranaque	142	0.68	7.62	2.87	-	11.17
21. Pasay City	57	0.11	3.74	1.78	-	5.63
22. Pasig	161	14.37	2.53	2.17	-	21.07
23. Pateros	6	0.20	0.38	-	-	0.58
24. Quezon City	383	23.25	17.394	11.32	-	51.964
25. Rosario	18	0.97	0.09	0.68	-	1.74
26. San Juan	9	1.40	0.41	0.05	-	1.86
27. San Mateo	9	0.40	2.12	-	-	2.52
28. San Pedro	31	9.08	1.22	0.37	-	10.67
29. Taguig	137	7.20	3.95	2.97	-	14.12
30. Tanza	17	0.90	-	-	0.46	1.36
31. Taytay	45	2.32	2.78	1.18	-	6.28
32. Valenzuela	122	8.71	4.063	0.97	-	13.74
T O T A L	2,292	119.38	98.78	39.26	3.22	260.64

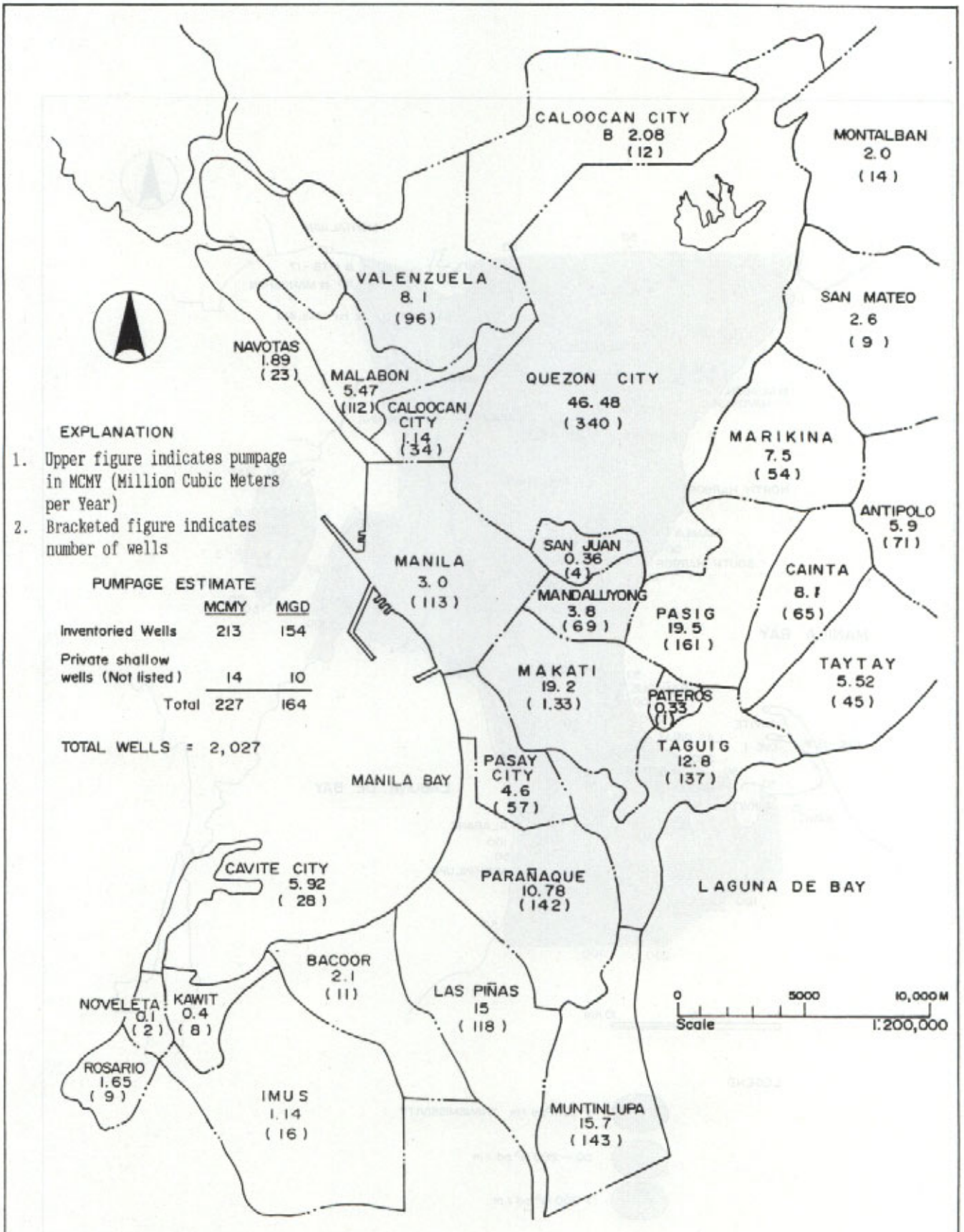
Source: GWD-MWSPII

TABLE 1.3.1 MAJOR ION ANALYSIS OF SELECTED SAMPLES IN METRO MANILA, 1985

WELL NO.	WELL DESCRIPTION					DATE OF SAMPLING	Na		K		Ca		Mg		Cations	Cl		HCO3		SO4		Anions	
	LOCATION/OWNER	YEAR	DEPTH	SCREEN	AQUIFER		ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
CTA 12	Hooven Camalo Id.	1971	48.80	-	A	09-05-85	157.5	5.98	10.0	0.26	185.6	9.28	15.5	1.29	-	16.81	344.4	9.70	208.6	3.42	68.0	1.42	-	14.54
MDL 3	Insular Sugar Ref.	1949	132.23	-	G	09-04-85	1200.0	52.17	52.5	1.35	150.4	7.52	149.7	12.48	-	73.52	2026.0	57.07	612.4	10.04	61.0	1.27	-	68.38
MIT 92	Fort Bonifacio #9	1977	136.90	-	G	09-03-85	140.0	6.09	10.0	0.46	38.4	1.92	13.6	1.13	-	9.60	108.0	3.04	361.6	5.93	30.0	0.63	-	9.60
MSL 146	MM Center	-	-	-	-	09-04-85	1425.0	61.96	115.0	2.95	1056.0	52.80	1283.0	106.92	-	224.63	5968.4	196.57	236.7	3.88	91.0	1.90	-	202.35
PSC 1	PAF, Nichols A.B. #1	-	240.80	-	G	09-02-85	142.5	6.20	20.0	0.51	18.0	0.80	9.7	0.81	-	8.32	27.0	0.76	431.1	7.07	6.5	0.14	-	7.97
PSC 7	PAF, Nichols A.B. #7	-	206.60	-	G	09-02-85	130.0	5.65	3.5	0.09	6.4	0.32	7.8	0.65	-	6.71	54.0	1.52	334.3	5.48	4.5	0.09	-	7.09
PSC 11	PAF, Nichols A.B. #11	-	225.50	-	G	09-02-85	187.5	8.15	9.2	0.24	9.6	0.48	5.8	0.48	-	9.35	63.0	1.77	417.2	6.84	10.0	0.21	-	8.82
PSC 13	PAF, Nichols A.B. #13	-	249.90	-	G	08-30-85	208.0	9.04	8.5	0.22	6.4	0.32	5.8	0.48	-	10.06	80.1	5.07	336.7	5.52	6.0	0.13	-	10.72
PSC 14	PAF, Nichols A.B. #14	1977	249.90	-	G	09-02-85	192.5	8.37	20.5	0.53	44.9	2.24	7.8	0.65	-	11.79	130.6	3.68	458.7	7.52	12.5	0.26	-	11.46
PSC 44	Manila Sanitarium	1979	305.00	272-362	A	09-06-85	400.0	17.39	7.5	0.19	76.8	3.84	7.8	0.65	-	22.07	535.7	15.09	273.3	4.48	81.0	1.69	-	21.26
PSC 46	Derhan Park	-	200.00	144-193	A	09-06-85	105.0	4.57	2.5	0.06	86.4	4.32	27.2	2.27	-	11.22	58.5	1.65	361.2	5.92	216.0	4.50	-	12.07
PSC 50	US Seafront Cpd.	1978	457.30	-	A	09-06-85	297.5	12.93	25.0	0.64	22.4	1.12	11.7	0.98	-	15.67	279.1	7.86	258.6	4.24	234.0	4.87	-	16.97
PSG 52	Metro Lab.	1979	182.90	90-182	G	09-05-85	3600.0	156.52	100.0	2.56	25.6	1.28	112.7	9.39	-	159.75	4254.5	119.85	403.8	6.62	174.0	3.63	-	130.10
PSG 57	Philippine Cement	1969	182.90	91-182	G	09-05-85	107.5	4.67	15.0	0.38	16.0	0.80	5.8	0.48	-	6.33	114.8	3.23	152.5	2.50	22.0	0.46	-	6.19
PTR 1	MWSS Fort Bonifacio	1976	99.10	-	G	09-03-85	450.0	19.57	50.0	1.28	179.2	8.96	60.3	5.03	-	34.84	855.0	24.08	511.2	8.38	14.0	0.29	-	32.79
PTR 6	Camera Steel	-	-	-	-	09-05-85	275.0	11.96	10.0	0.26	131.2	6.56	56.4	4.70	-	23.48	576.3	16.23	194.7	3.19	128.0	2.67	-	22.09
TGG 14	Elizalde Steel	-	243.90	-	G	09-05-85	682.5	29.67	57.5	1.47	67.2	3.36	21.4	1.78	-	36.28	1238.1	34.81	167.1	2.74	76.0	1.58	-	39.13
TGG 20	MWSS Ususan	1978	180.00	-	G	09-05-85	387.5	16.85	60.0	1.54	54.4	2.72	21.4	1.78	-	22.89	567.3	15.98	222.0	3.64	11.0	0.23	-	19.85
TGG 102	Eusebio Elem. School	-	-	-	-	09-05-85	412.5	17.93	37.5	0.96	19.2	0.96	9.7	0.81	-	20.66	405.2	11.41	403.0	6.62	89.5	1.84	-	19.87
TGG 115	Century Canning	-	-	-	-	09-06-85	195.0	8.48	21.0	0.54	32.0	1.60	3.9	0.33	-	10.95	117.0	3.30	389.2	6.38	3.0	0.06	-	9.74
TYY 11	MWSS Sta. Ana	1980	153.00	-	G	09-05-85	70.0	3.04	10.0	0.26	76.8	3.84	21.9	1.83	-	8.97	90.0	2.54	345.5	5.68	32.0	0.67	-	8.89

AQUIFER: A; Alluvium, G; Guadalupe

source: 1985 Major Ion Analysis by PASIG (1985)
Details of Well Inventory by GWD-MWSP II
Compiled by JICA



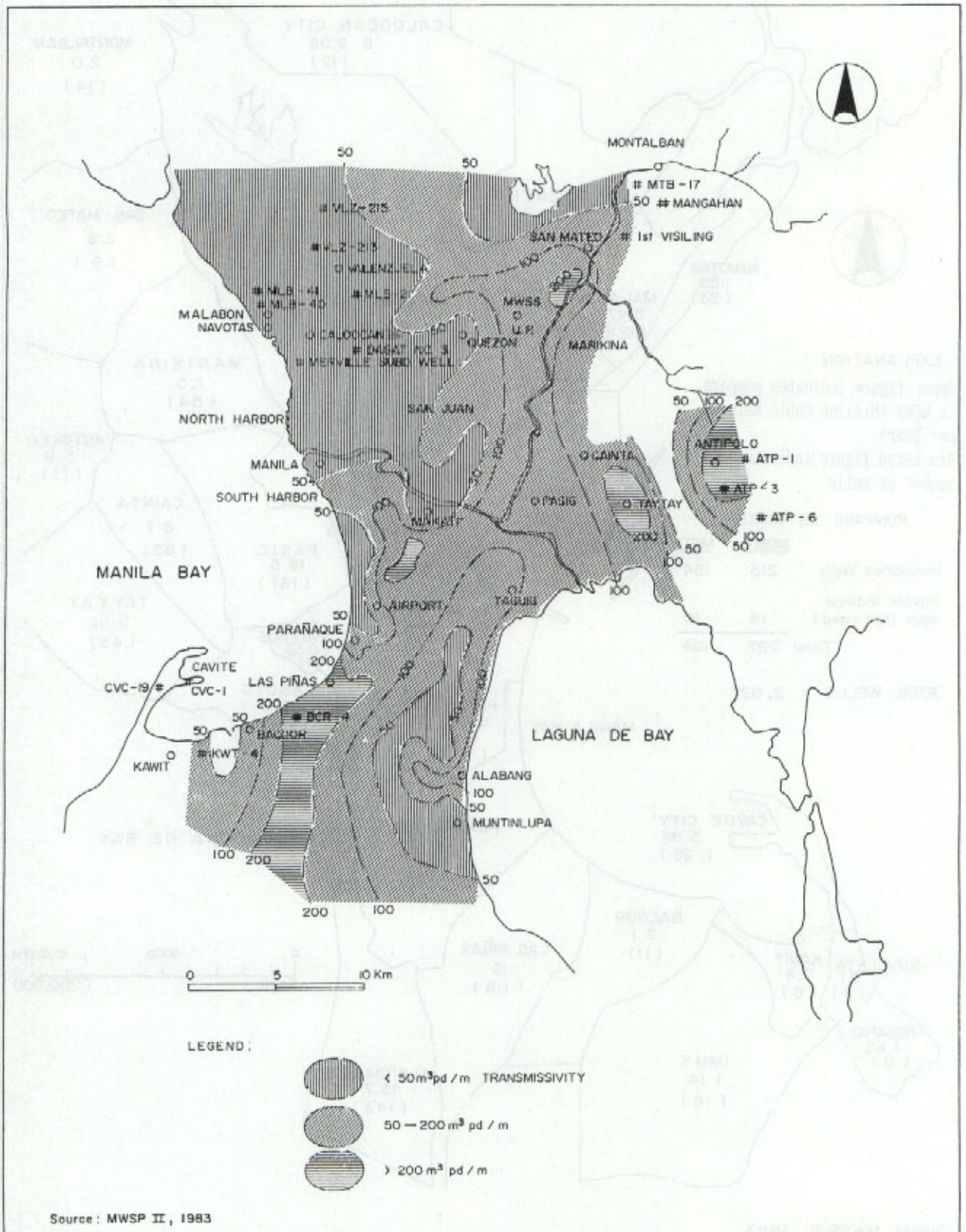
Source: MWSP II, 1983

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

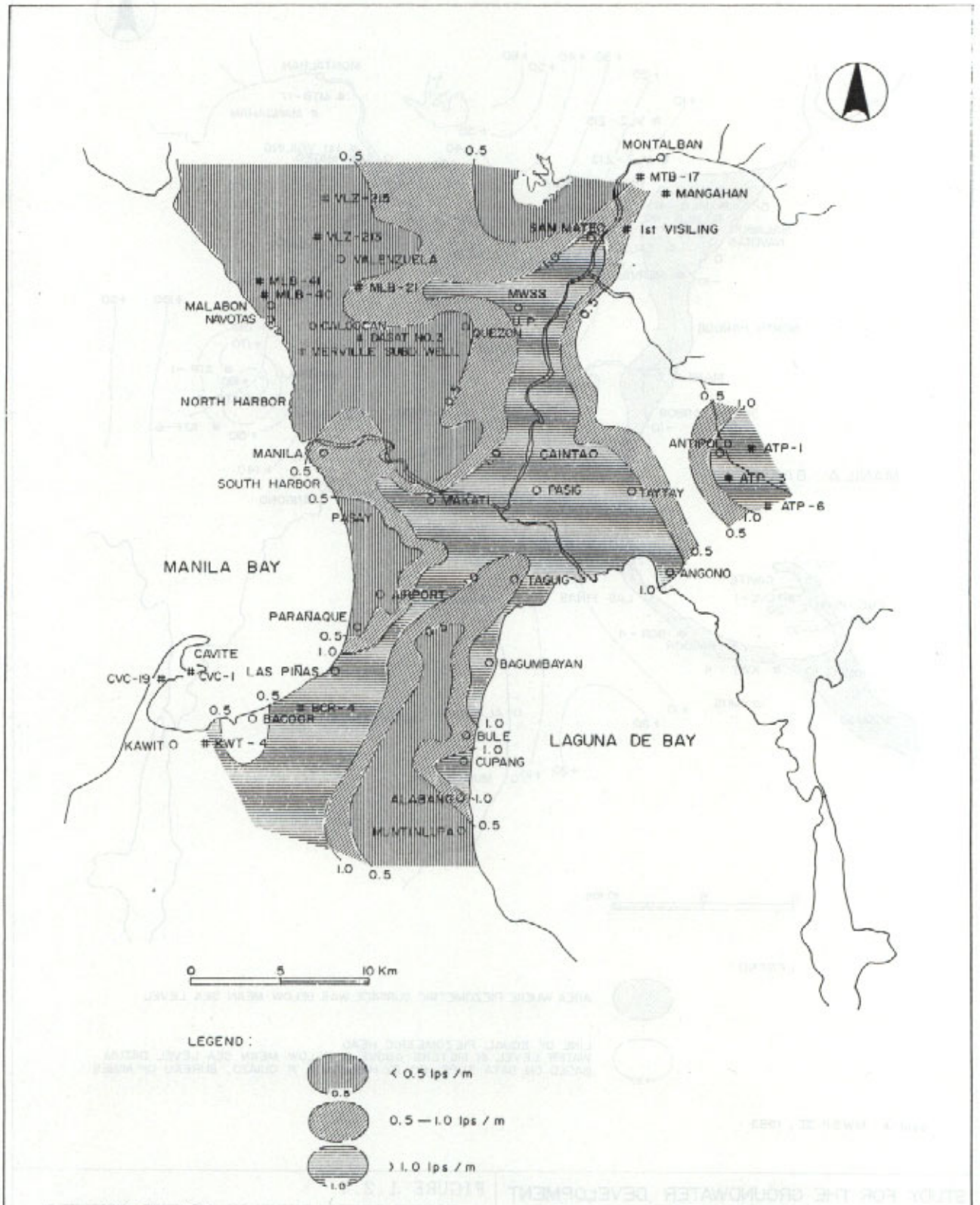
FIGURE 1.2.1

GROUNDWATER PUMPAGE IN THE GMA, 1981



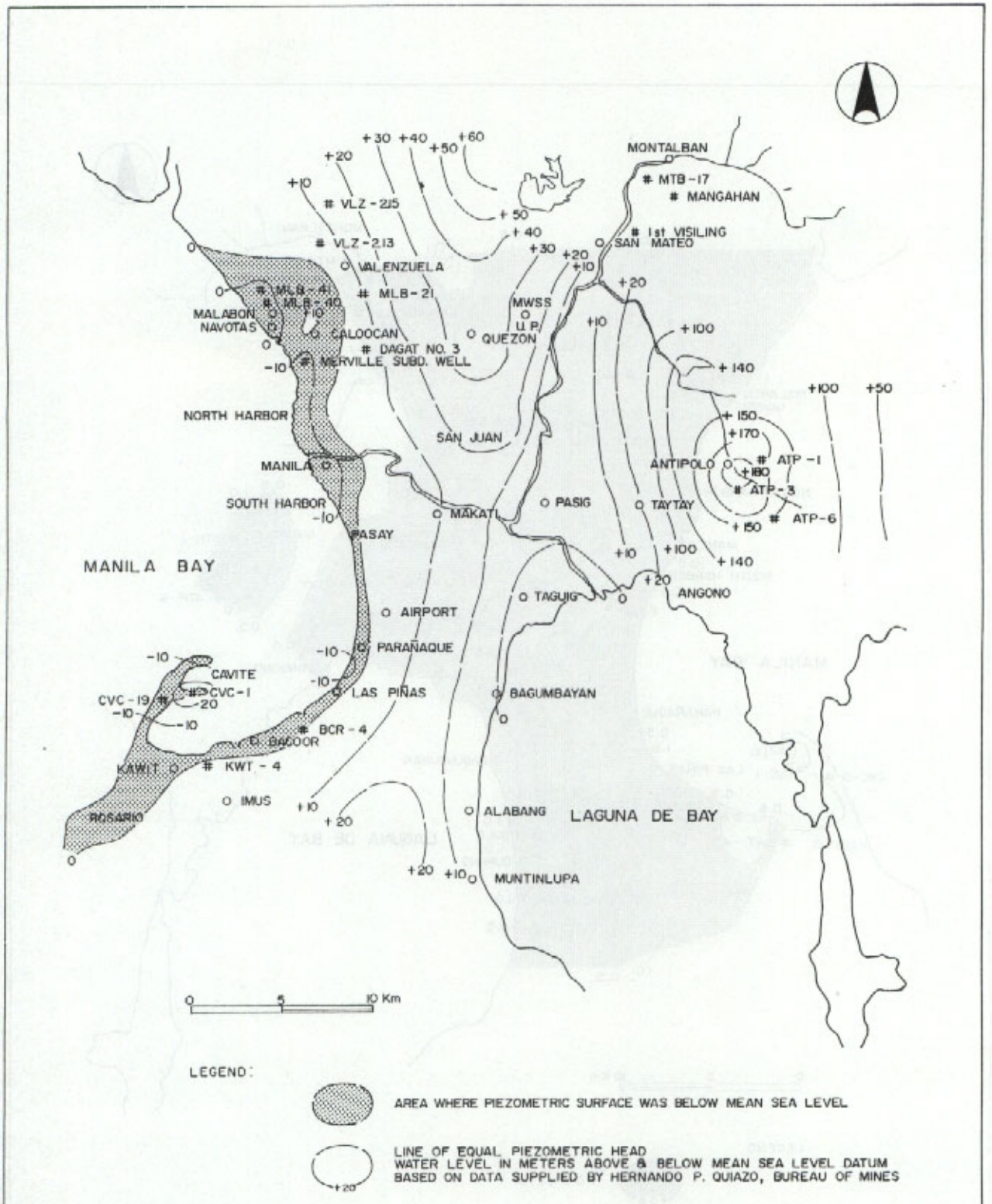
Source : MWSP II, 1983

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 1.2.2 TRANSMISSIVITY OF THE AQUIFER SYSTEM IN METRO MANILA
JAPAN INTERNATIONAL COOPERATION AGENCY	

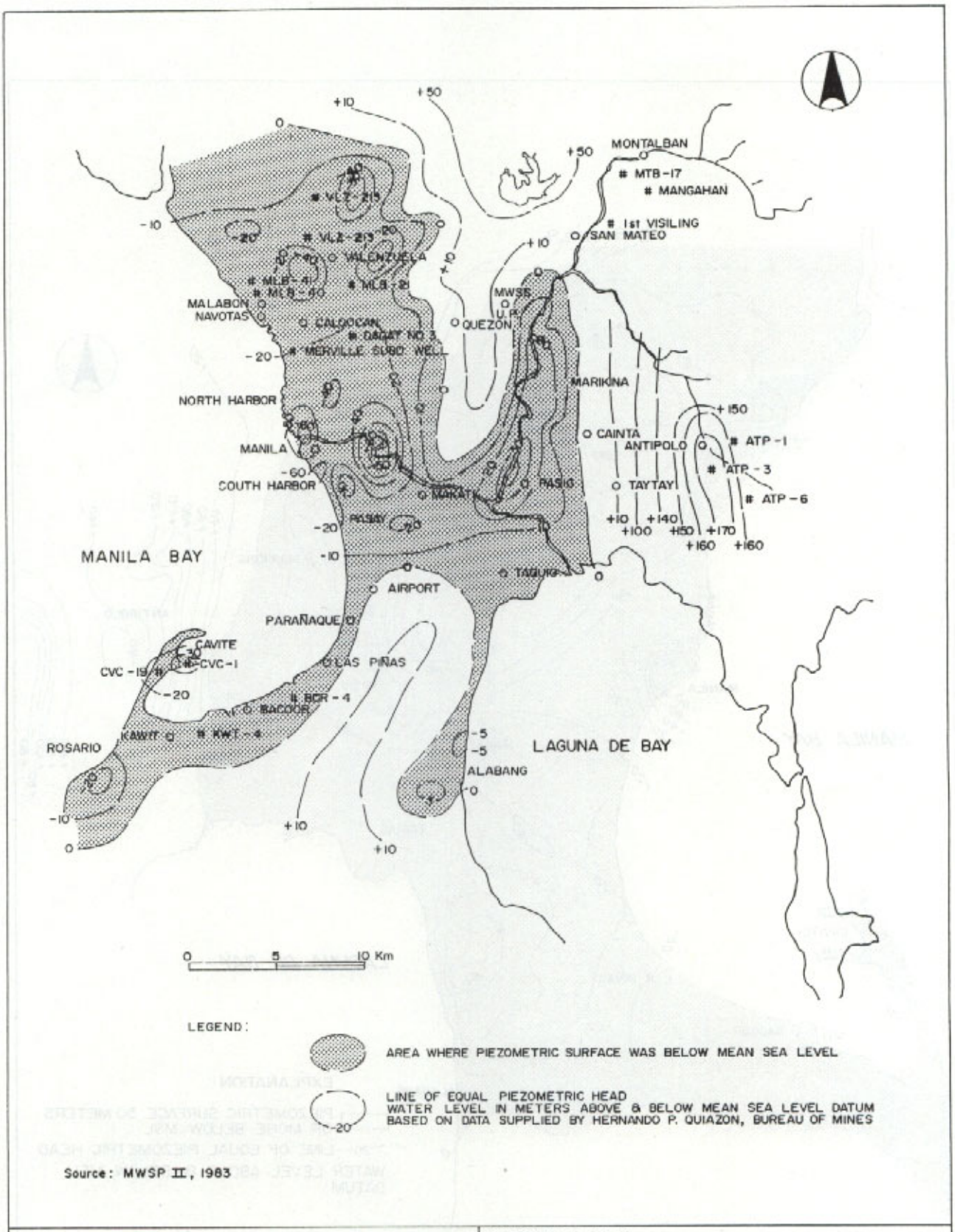


Source : MWSP II, 1983

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA JAPAN INTERNATIONAL COOPERATION AGENCY	FIGURE 1.2.3 SPECIFIC CAPACITY OF GROUNDWATER IN METRO MANILA

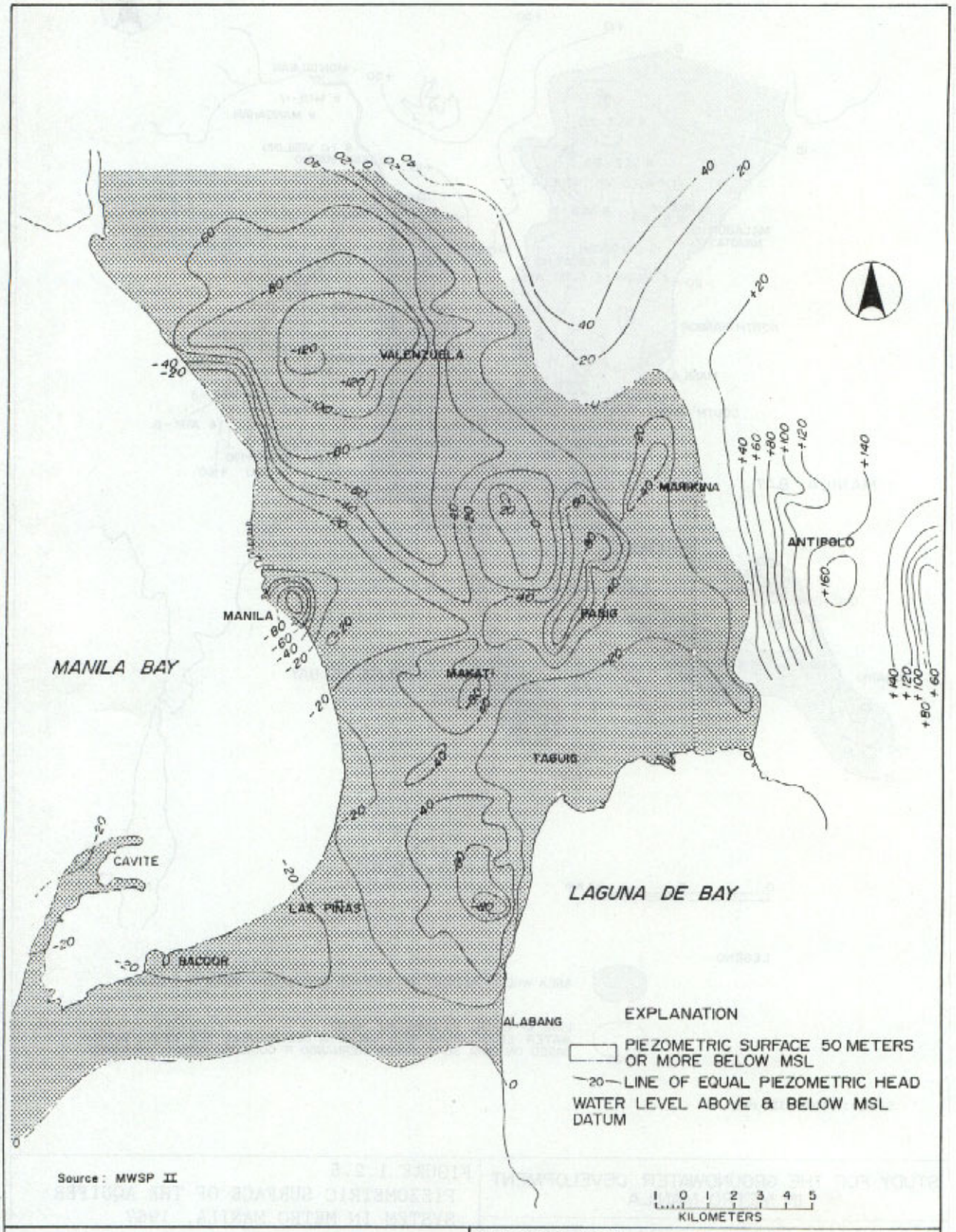


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 1.2.4 PIEZOMETRIC SURFACE OF THE AQUIFER SYSTEM IN METRO MANILA, 1955
JAPAN INTERNATIONAL COOPERATION AGENCY	

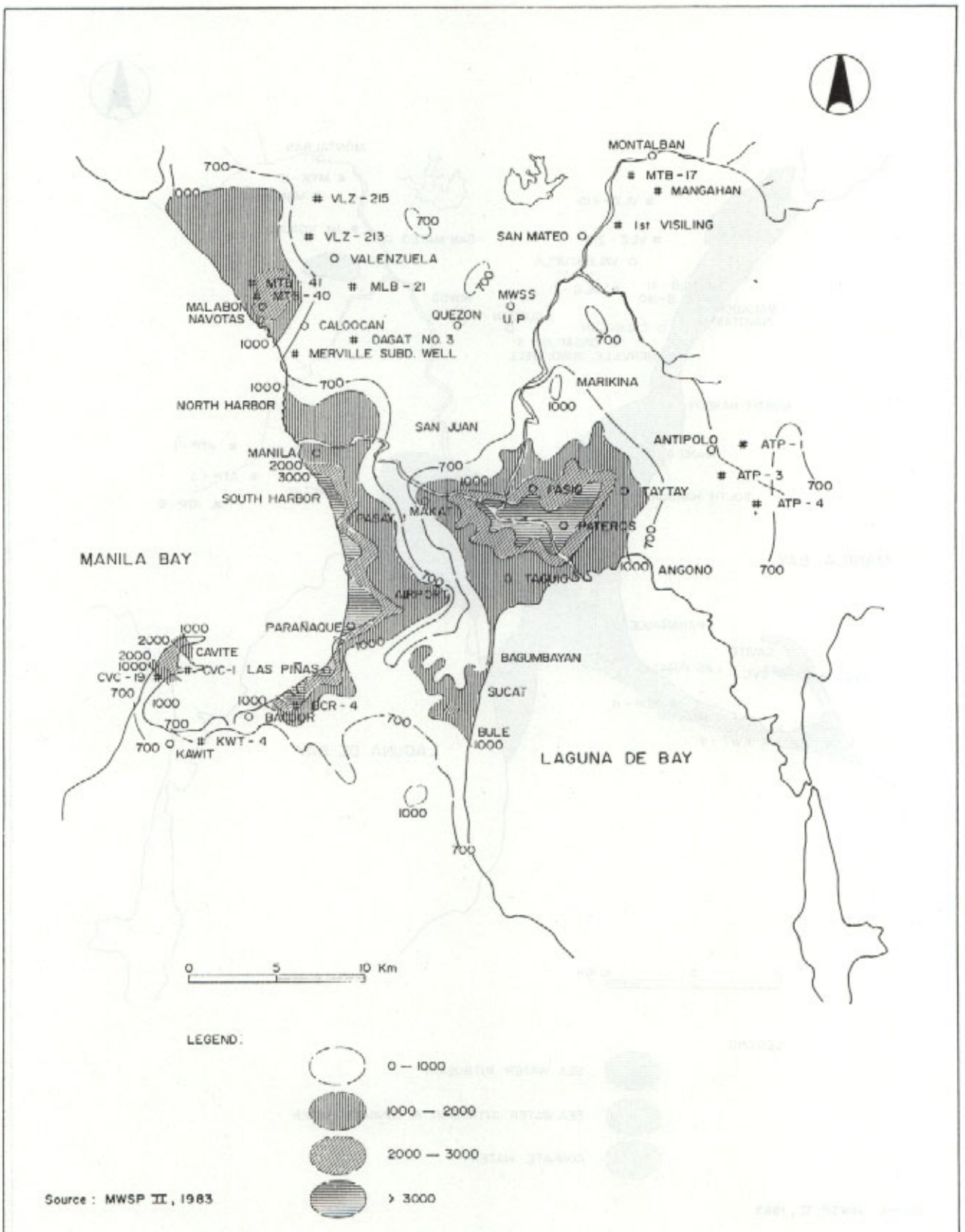


Source: MWSP II, 1983

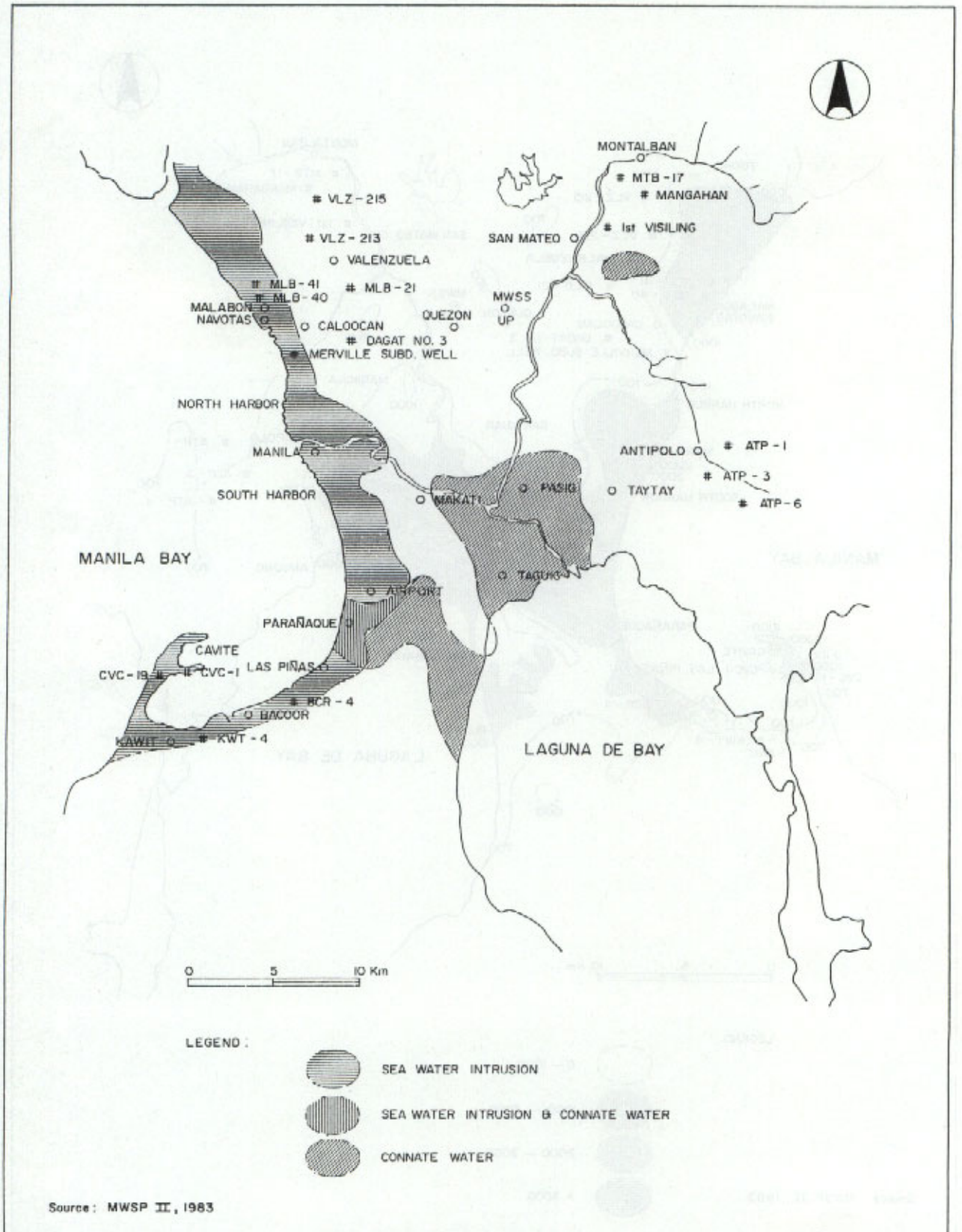
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 1.2.5 PIEZOMETRIC SURFACE OF THE AQUIFER SYSTEM IN METRO MANILA, 1967
JAPAN INTERNATIONAL COOPERATION AGENCY	



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 1.2.6 PIEZOMETRIC SURFACE OF THE AQUIFER SYSTEM IN METRO MANILA, 1981
JAPAN INTERNATIONAL COOPERATION AGENCY	

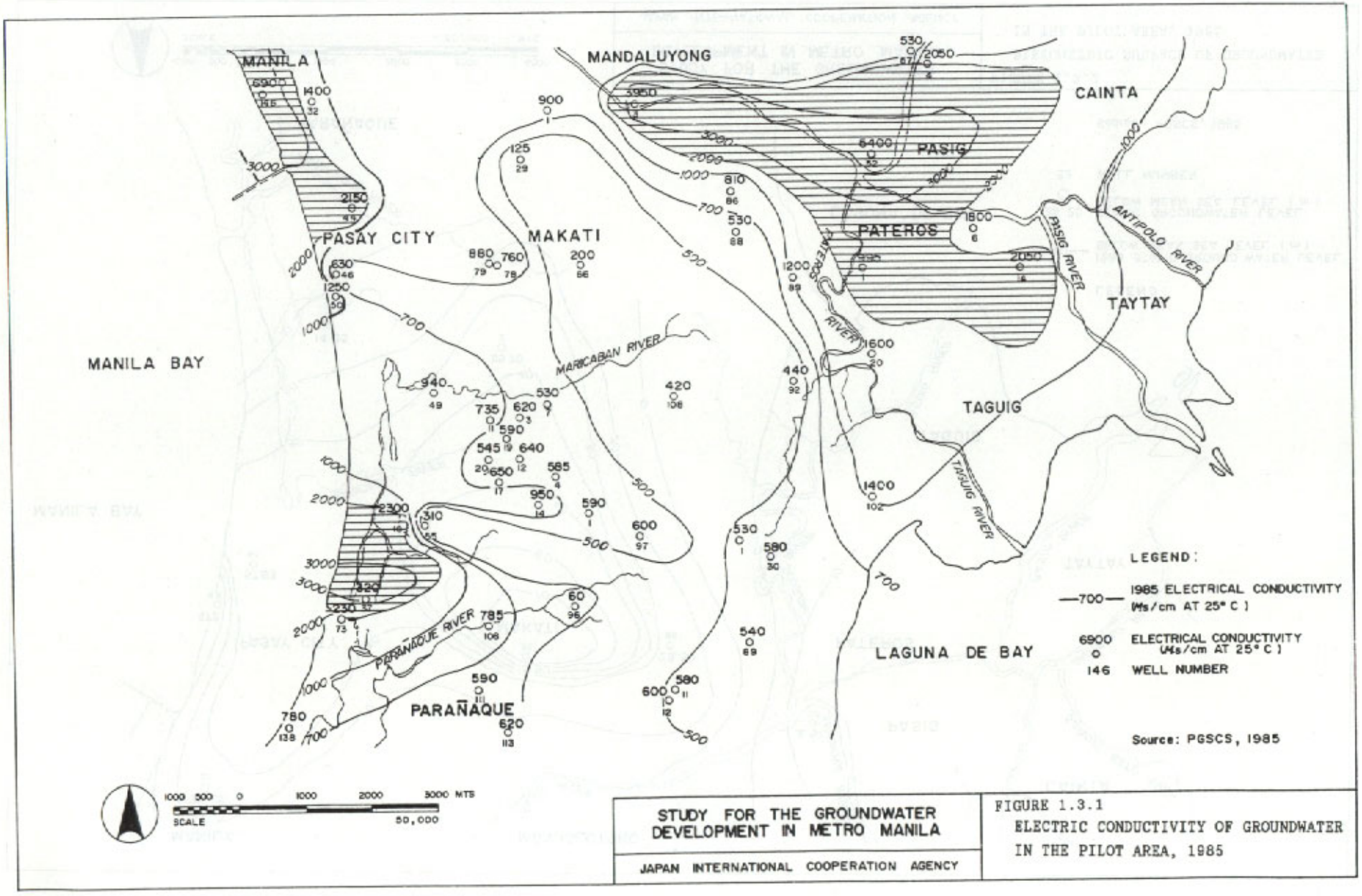


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 1.2.7 ELECTRIC CONDUCTIVITY OF GROUNDWATER IN METRO MANILA
JAPAN INTERNATIONAL COOPERATION AGENCY	



Source : MWSP II, 1983

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 1.2.8 AREA OF SALINE WATER CONTAMINATION
JAPAN INTERNATIONAL COOPERATION AGENCY	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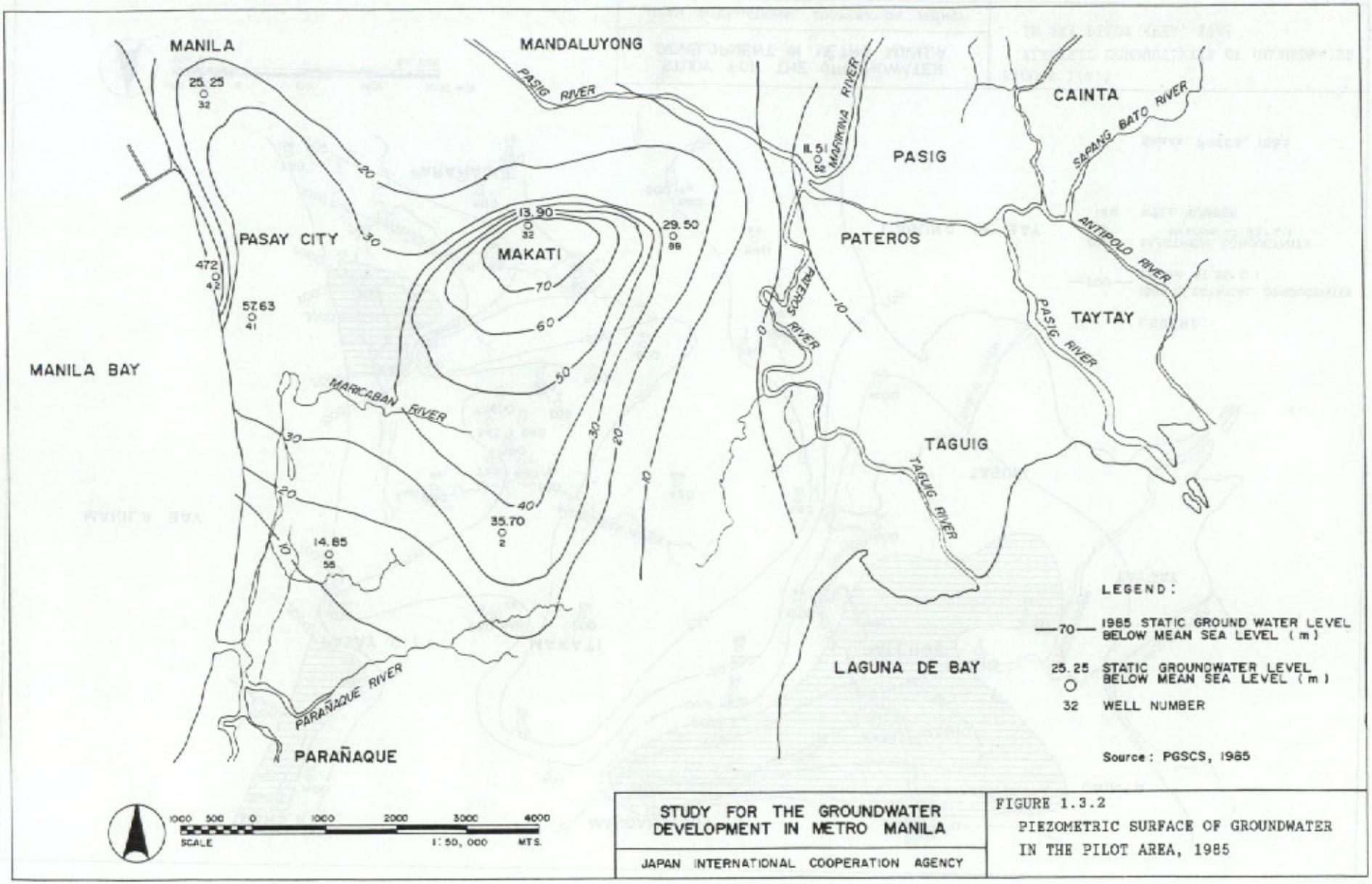
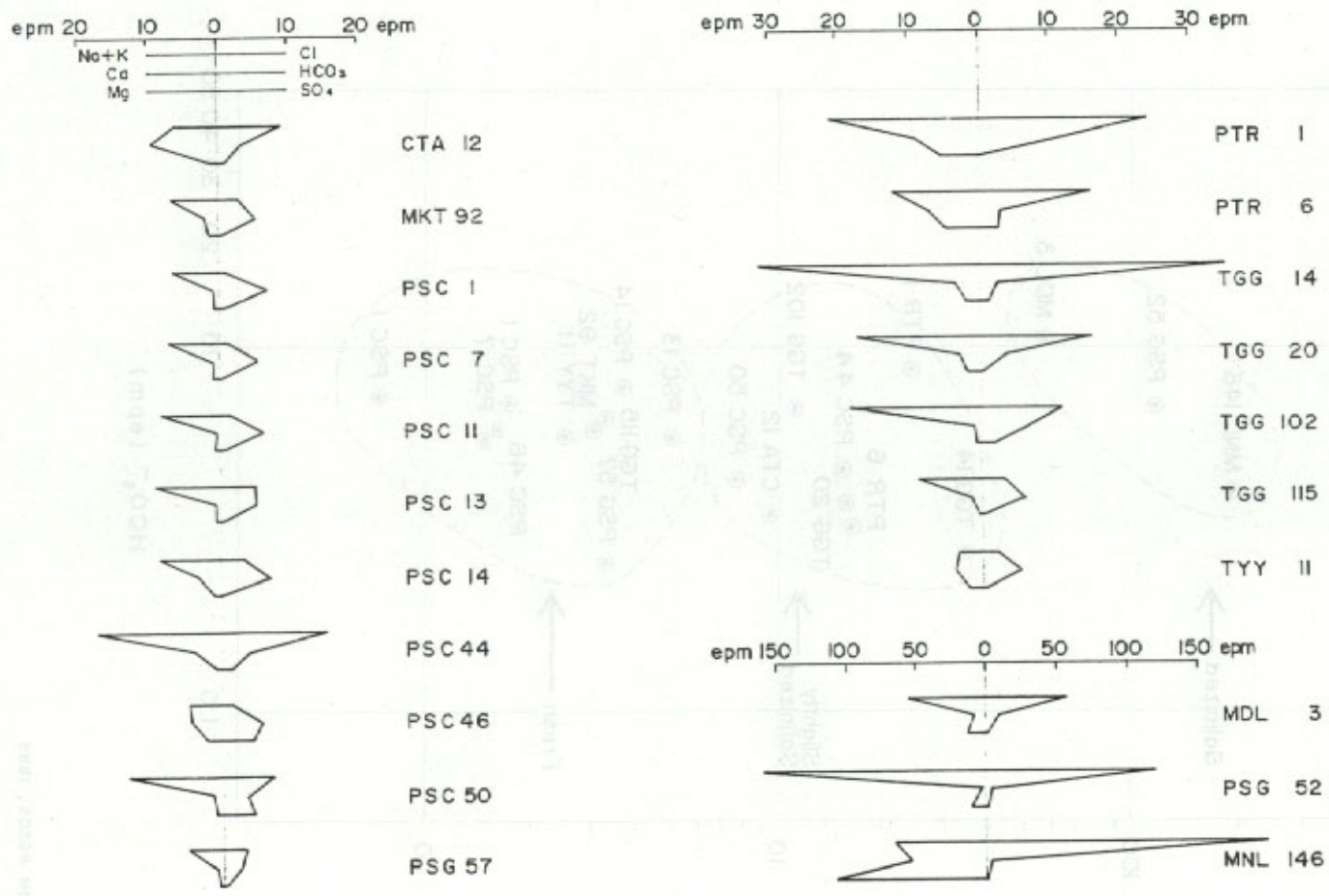
MANDALUYONG
CAINTA
PASIG
PATEROS
PASAY CITY
MAKATI
TAYTAY
TAGUIG
PARAÑAQUE
MANILA BAY
LAGUNA DE BAY
MARICABAN RIVER
PASIG RIVER
ANTIPOLO RIVER
TAGUIG RIVER
PARAÑAQUE RIVER
LEGEND:
—700— 1985 ELECTRICAL CONDUCTIVITY (Ms/cm AT 25° C)
6900 ELECTRICAL CONDUCTIVITY (Ms/cm AT 25° C)
146 WELL NUMBER
Source: PGSCS, 1985
1000 500 0 1000 2000 3000 MTS
SCALE 50,000
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA
JAPAN INTERNATIONAL COOPERATION AGENCY
FIGURE 1.3.1
ELECTRIC CONDUCTIVITY OF GROUNDWATER IN THE PILOT AREA, 1985



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

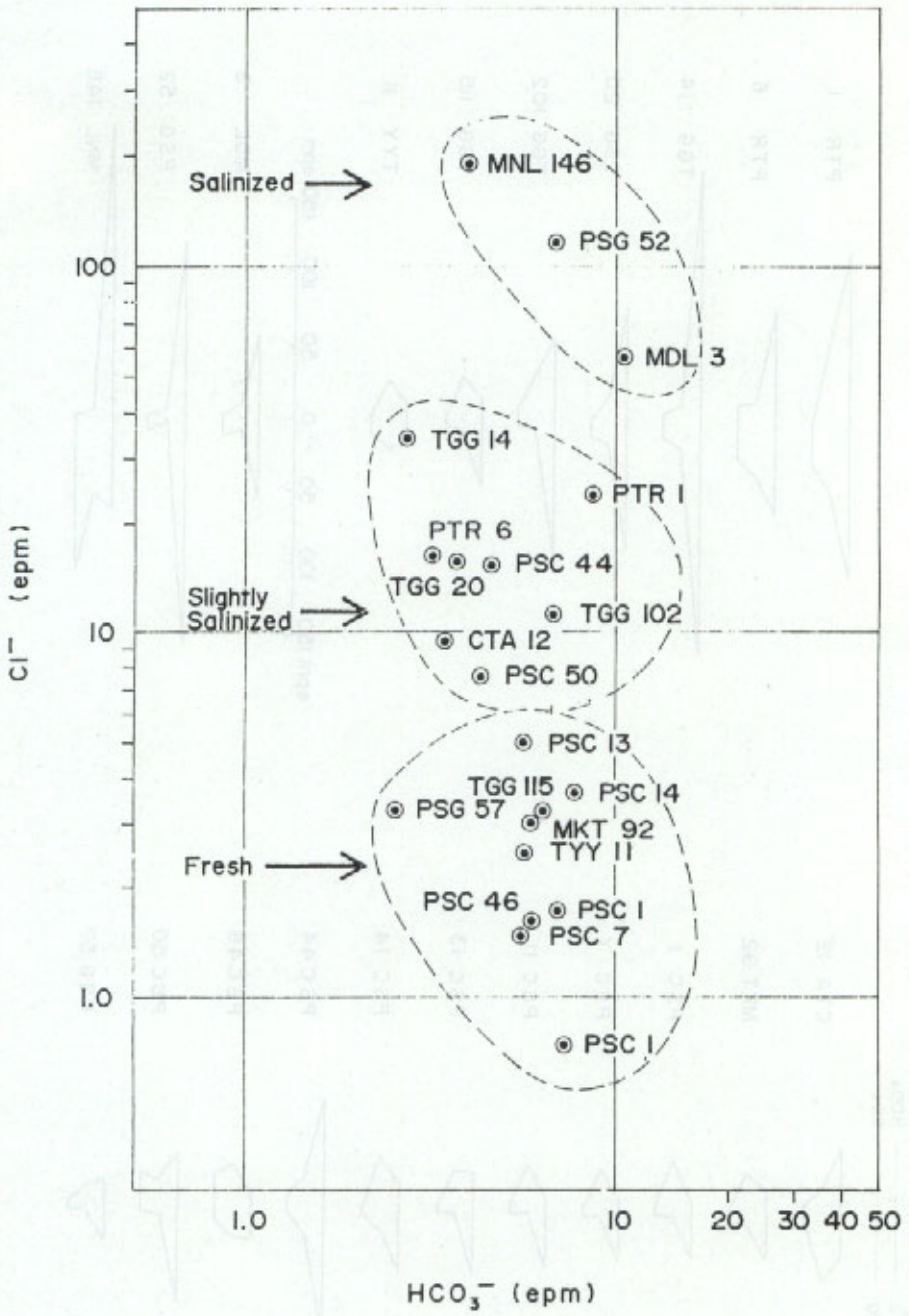
JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 1.3.2
PIEZOMETRIC SURFACE OF GROUNDWATER IN THE PILOT AREA, 1985



PRIMARY DATA FROM PGSCS, 1985

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 1.3.3 HEXA-DIAGRAM REPRESENTATION OF WATER QUALITY
JAPAN INTERNATIONAL COOPERATION AGENCY	



PRIMARY DATA FROM PGSCS, 1985

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 1.3.4 RELATION BETWEEN BICARBONATE AND CHLORIDE
JAPAN INTERNATIONAL COOPERATION AGENCY	

CHAPTER 2

ELECTRIC RESISTIVITY SURVEY

CHAPTER 2 ELECTRIC RESISTIVITY SURVEY

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CHAPTER 2. ELECTRIC RESISTIVITY SURVEY

2.1 METHOD OF SURVEY

An electric resistivity survey was conducted in the Antipolo area, located east of Manila, to determine its geological structure and to obtain and investigate hydrogeological information.

The survey area is a distinct and independent plateau having steep slopes and an elevation range of 160 m to 260 m. It has a land size of approximately 9.2 km. x 4 km. and is developing as a new settlement site for the spill-over population of the swelling capital. This inparticularly, facilities for the delivery of adequate and efficient water supply, with groundwater as an immediate alternative.

The survey was conducted from October 3 to October 23, 1990 using the McOhm resistivity survey meter and Wenner's measuring method. The results were examined for match or harmony with the data of geological survey and the columnar sections of existing wells to precisely interpret the geological structures.

The survey was conducted in thirty (30) points widely distributed in the area and along the roads, excluding the downtown at the center of the Antipolo area because of its urbanization and the heavy traffic. The survey points are shown in Fig. 2.1.1 Measuring depth was 260 m in most points but was less than 190 m in three points as there were no straight roads and the topography was uneven.

The data of the survey were plotted on the log-log papers to present σ - a curves. The analysis was by direct visual interpretation method using a Sundberg standard curve. The results of the analysis were presented on the topographical sections connecting each measuring point. Such results were also presented in vertical directions for each measuring depth. For these maps, similar and same tendencies of measuring values were justified to be equivalent formations and were connected. The results of the analysis are shown in Figure 2.1.1(1) - Figure 2.2.1(3). Prior to the resistivity survey, the peculiar resistivities of typical formations distributed in the Antipolo area were measured as reference

for the interpretation and analysis of the survey results in seven sites.

This time, there were no available data on existing columnar sections of wells near the measuring points. Thus, the data could not be compared with the sections. Interpretation of the survey results may involve some unreliability, and the results of test boring in the area which shall also be used in conjunction with the survey result may likewise modify the interpretation and analysis.

2.2 INTERPRETATION

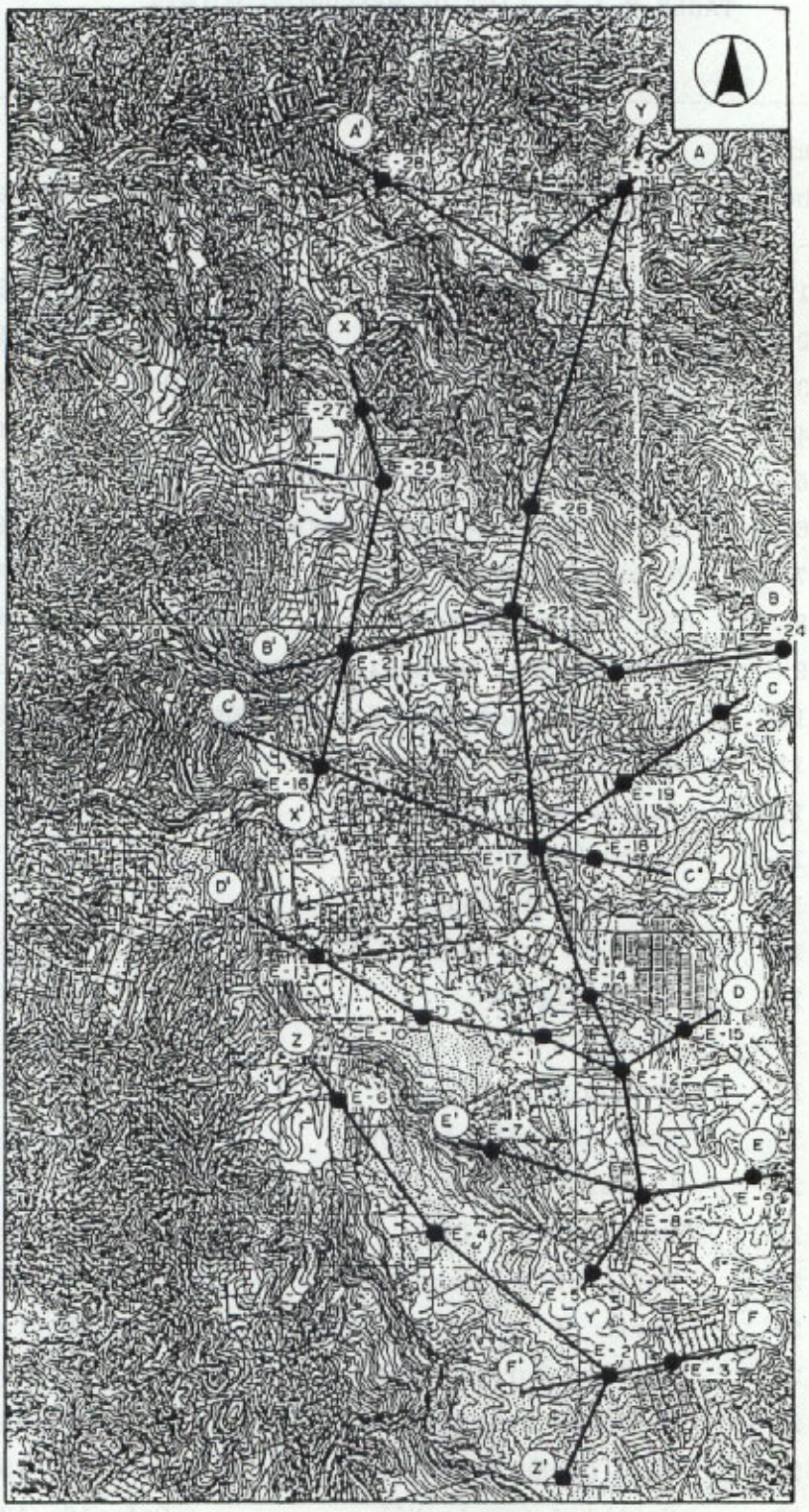
The survey data show that the geological structures fall under six formations.

The columnar sections are shown in Figures 2.2.1(1)-2.2.1(3).

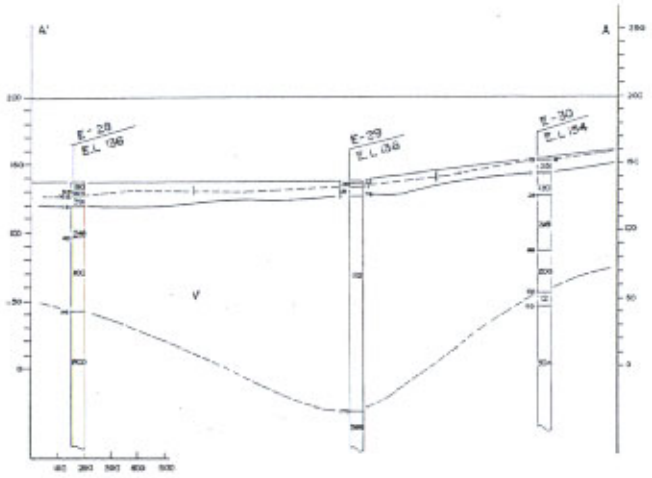
The resistivity range and corresponding formation such as formation name, geologic age and lithology are also shown the said Figures.

TABLE 2.1.1 LIST OF MEASURING POINTS

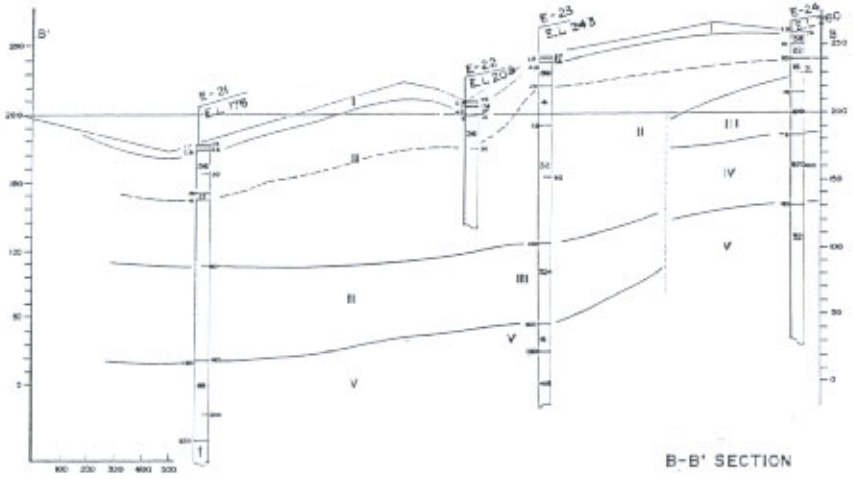
Measuring Number	Measuring Points	Measuring Date
E - 1	South of Angono	Oct. 19, 1990
E - 2	East of Angono	Oct. 23, 1990
E - 3	Yupangco Subd.	Oct. 4, 1990
E - 4	Northwest of Angono	Oct. 13, 1990
E - 5	South of Sra. Dela Paz Subd.	Oct. 4, 1990
E - 6	South of Ponde Rosa Height	Oct. 18, 1990
E - 7	Nayong Silangan Subd.	Oct. 4, 1990
E - 8	Sra. Dela Paz Subd.	Oct. 19, 1990
E - 9	East of Sra. Delapaz Subd.	Oct. 17, 1990
E - 10	East of Ponde Rosa Heights Subd.	Oct. 4, 1990
E - 11	West of San Antonio Vil.	Oct. 18, 1990
E - 12	San Antonio Vil.	Oct. 17, 1990
E - 13	Grand Heights Subd.	Oct. 22, 1990
E - 14	San Antonio Vil.	Oct. 8, 1990
E - 15	East of San Antonio Vil.	Oct. 8, 1990
E - 16	Villa Ligaya	Oct. 18, 1990
E - 17	Antipolo Town	Oct. 13, 1990
E - 18	Antipolo Town	Oct. 18, 1990
E - 19	East of Antipolo Town	Oct. 9, 1990
E - 20	La Salle Heights	Oct. 9, 1990
E - 21	Bankers Vil. III	Oct. 15, 1990
E - 22	North of Bermuda Subd.	Oct. 15, 1990
E - 23	North of La Salle Heights	Oct. 15, 1990
E - 24	East of Europa Subd.	Oct. 23, 1990
E - 25	North of Angela Vil.	Oct. 16, 1990
E - 26	East of Europa Subd.	Oct. 19, 1990
E - 27	North of Angela Vil.	Oct. 16, 1990
E - 28	West of Padella Subd.	Oct. 23, 1990
E - 29	South of Town Country Hill	Oct. 16, 1990
E - 30	Town Country Hill	Oct. 22, 1990



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 2.1.1 MEASURING POINT & CROSS-SECTION LINE
JAPAN INTERNATIONAL COOPERATION AGENCY	MEASURING POINTS (E-1 ~ E-30) CROSS-SECTION LINES (A-A' ~ Z-Z')



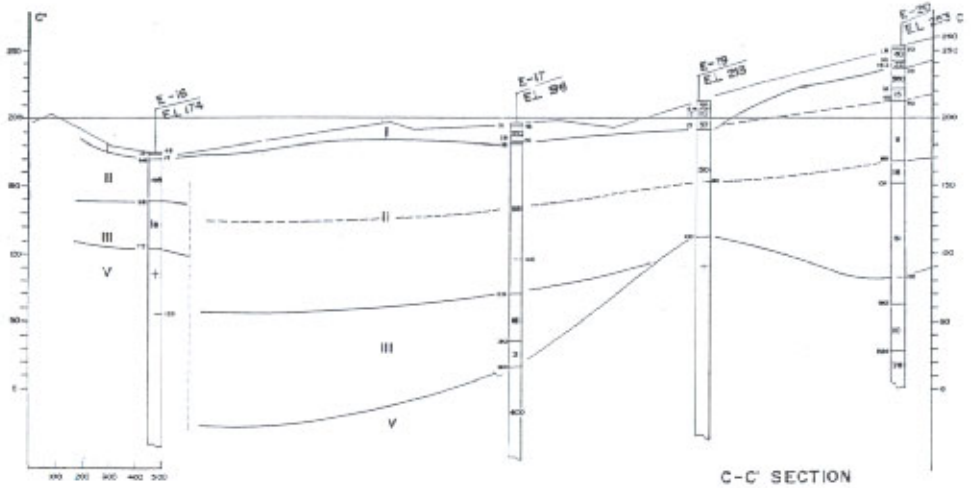
A-A' SECTION



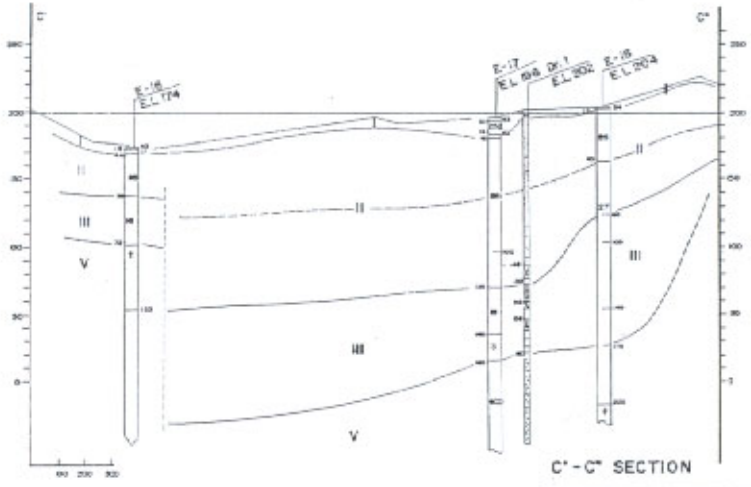
B-B' SECTION

LEGEND

Electric Classification	Resistivity (Ω-m)	Corresponding Formation		
		Formation	Geologic Age	Lithology
I	10 100	Surface layer	Quaternary Holocene	Soil humus weathered rock
II	20 70	Guadalupe Formation	Pleistocene	Tuff breccia Welded tuff Lapilli tuff Tuffaceous sandstone
III	20 300		Pliocene	Mudstone Sandstone Conglomerate
IV	870	Angat Formation	Neogene Miocene	Limestone
V	50 500	Antipolo Andesite Kilauban F.	Paleogene ~ CRETACEOUS	Diorite Propylite Altered Spilitic Basalt
VI		Antipolo Basalt Porphyry	Pleistocene ~ Pliocene	Basalt Porphyry dyke and sheet

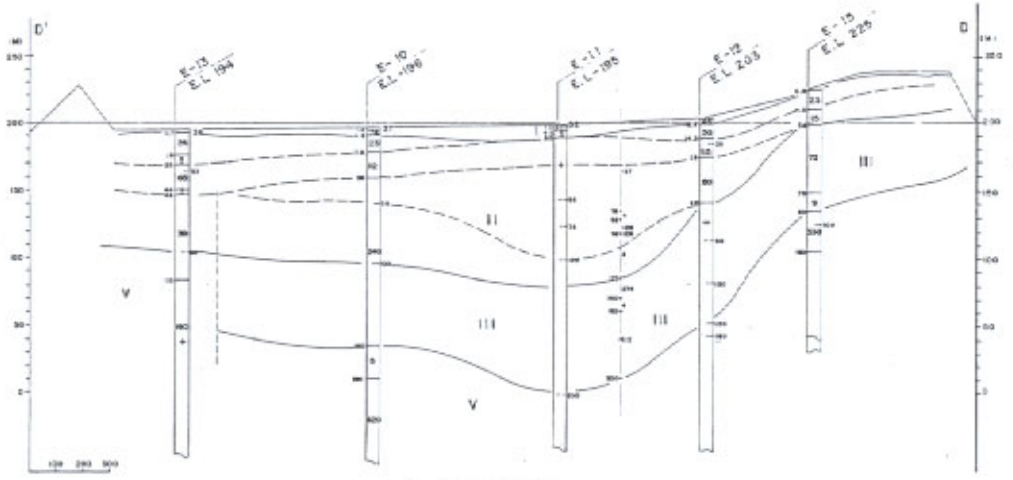


C-C' SECTION

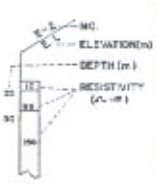


C'-C" SECTION

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	Figure ELECTRIC RESISTIVITY SURVEY Profile III
JAPAN INTERNATIONAL COOPERATION AGENCY	

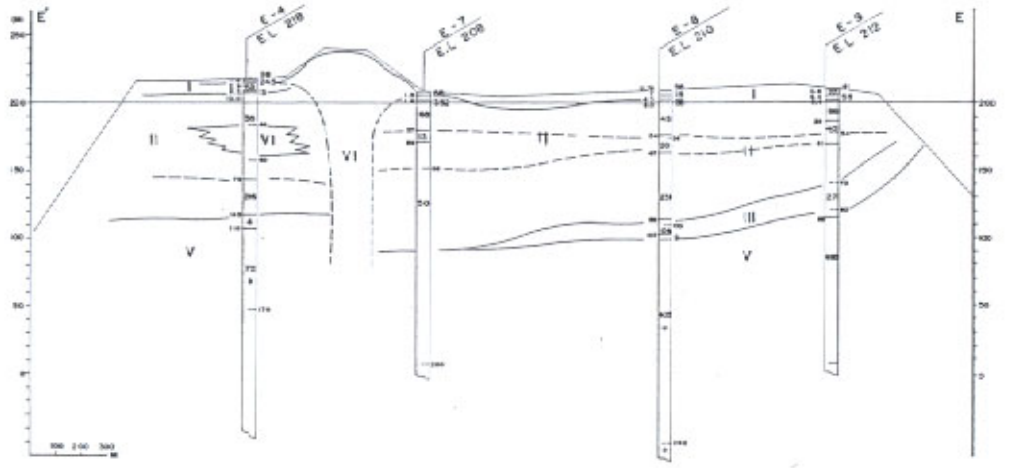


D-D' SECTION

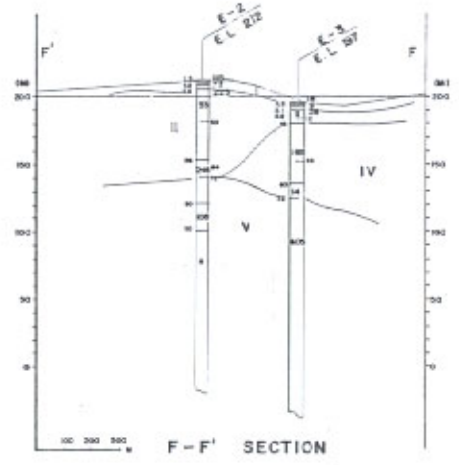


LEGEND

Strata Classification	Resistivity (Ω-m)	Corresponding Formation		
		Formation	Geologic Age	Lithology
I	0~100	Surface layer	Quaternary Holocene	Soil Various Weatheredrock
II	25~230	Guadalupe Formation	Pleistocene ~ Pliocene	Tuffbreccia Welded tuff Lapilli tuff Tuffaceous Sandstone
III	50~100			Mudstone Sandstone Conglomerate
IV	85	Jagor Formation	Neogene Miocene	Limestone
V	70~400+	Antipolo Diorite	Palaeogene ~ CRETACEOUS	Diorite Propyrite altered Spilitic Basalt
VI	350+	Antipolo Basalt Porphyry	Pleisto-cene ~ Pliocene	Basalt Porphyry dyke and sheet



E-E' SECTION



F-F' SECTION

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	Figure ELECTRIC RESISTIVITY SURVEY PLATE 21
JAPAN INTERNATIONAL COOPERATION AGENCY	

CHAPTER 3

DRILLING AND PUMPING TEST

CHAPTER 3 DRILLING AND PUMPING TEST

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CHAPTER 3 DRILLING AND PUMPING TEST

3.1 GENERAL

The work done during Stage I of the Study showed that there was insufficient data for evaluating the hydrogeologic condition in the Antipolo Area and the Las Piñas-Parañaque Area. This was particularly true in the Las Piñas-Parañaque Area where saltwater intrusion had widely occurred. It was therefore planned that deep test wells be drilled in each area for evaluating the geology, aquifer parameters and water quality, with adjacent core borings (in Las Piñas only) for observation and sampling purposes.

Data obtained from the above activities will be used for evaluating the groundwater conditions in the two areas. This in turn will assist in the planning of groundwater development and management in Metro Manila.

3.2 TEST WELLS AND LOCATIONS

Two (2) test wells of 250m and 200m depth were drilled in Barangay San Jose, Antipolo to evaluate geological and hydrogeological conditions of aquifers throughout their total depth and to confirm the depth of Pre-Quaternary basement. The 250-m well was used as a pumping well, the 200-m well for observation. Screen sections of the two (2) wells were set at the same aquifers. Test well locations are shown in Figure 3.2.1.

As shown in Figure 3.2.2, seven (7) test wells were drilled at three (3) locations in the coastal area of Las Piñas. Prior to the drilling of test wells, two (2) core borings were carried out in Las Piñas (No. 1 and No. 2) to evaluate the geological conditions and to take core samples for observation and laboratory analysis. Depth of each hole was 300m.

For evaluating the hydrogeological condition and water quality of aquifers, test wells of different depths were drilled in each location.

- Las Piñas No.1: Three wells of 300m, 200m and 100m depths
- Las Piñas No.2: Three wells of 300m, 200m and 100m depths
- Las Piñas No.3: One well of 300m depth

3.3 GEOLOGICAL DESCRIPTION

Test wells in Antipolo and Las Piñas were drilled using the rotary method. During the drilling operation, samples of cuttings were collected at one (1) meter intervals and penetration rates were recorded for geological interpretation. After completion of each drilling, spontaneous potential logging and resistivity logging were conducted within an uncased hole. After interpretation of all these data in terms of formation characteristics, the depth and length of the screen sections were fixed and test holes were cased and developed.

In Las Piñas, two series of core samples up to the depth of 300m were continuously taken, for geological observation and description by means of the wire-line drilling method. Lithologic data as well as geophysical logging data were interpreted for determination of screen section in test wells.

3.3.1 Antipolo

The lithologic log of a 250m well in San Jose, Antipolo is described as follows (Figure 3.3.1):

The upper part of the formation which is continuous up to a depth of 25m consists of reddish brown clay with gravels. This formation is underlain by boulder formation with a thickness of 8m. Thick, dark-brownish sand formation can be observed at depths of 32m to 118m where resistivity values are relatively higher. Sand grains are fine to coarse in size and are supposed to be derived from volcanic rocks. This sand formation could be a good aquifer.

Finer formations consist of clay and fine sand with clay. They occur consistently at a thickness of 50m beneath the shallow aquifer. The resistivity values are also lower than those of the overlying formation. The clay is sometimes consolidated and could be an aquiclude. Such

finer formations are underlain by medium sand formations which occur at depths of 170m to 188m. One clayey formation is intercalated in the sand formations. The sand formations also contain clay, but the grain sizes are larger and the resistivity values slightly higher than clayey formations. The formations therefore could be confined aquifers.

The drilling activities verified the presence of basement rock, encountered 189m below ground level. The basement rock consists of greenish meta-basalt with its surface portion at depths of 189m to 200m being a weathered and fractured zone so that the penetration rates and resistivity values are small, for all the spontaneous potentials indicate negative values. The fresh portion of the basement rock below 200m is so hard that the penetration rates range from 0.3cm/min to 2cm/min and the resistivity values exceed 150ohm-m.

In order to evaluate the productivity of deeper aquifers that are overlain by confined layers, screens were set at depths of 152m to 173m and 185m to 194m. Aquifers above 118m were not considered since most of the existing wells set screens in shallow aquifer, and the productivity can be evaluated from existing pumping test data.

3.3.2 Las Piñas No.1

The lithology at Las Piñas No.1 up to a depth of 300m is described as follows (Figure 3.3.2):

The site is located near the coastal line, but the alluvium is less than 7m in thickness. The rest of the formations belong to the Guadalupe formation. Generally, the cores of the Guadalupe formation are well-consolidated and tuffaceous.

The upper portion of the formation up to a depth of 76m consists of tuffaceous silt, fine sand and medium to coarse sand. Significant thickness of clayey sediments that form the confining layer (CL) has been identified at depths of 58m to 76m. This clayey layer can be traced to Las Piñas No.2. The formation overlain by this clayey layer consists mainly of alternated tuffaceous, fine to coarse, sand layers. Four characteristic pumice-bearing layers which can be treated as key beds, namely PM1, PM2, PM3 and PM4, occur at depths of 105m to 117m,

159m to 165m, 240m to 257m and 274m to 283m, respectively. These pumice- bearing layers contain coarse materials such as coarse sand, granules and pebbles so that the resistivity curves indicate high anomalies.

After the observation of core samples and the interpretation of geophysical loggings, the casing program of each well was fixed. In Well No.1 (300m depth), screens were set at depths of 240m to 252m and 276m to 294m in order to investigate deeper aquifers. In Well No.2 (200m depth), screens were set at depths of 145m to 154m, 160m to 175m and 181m to 187m. In Well No.3 (100m depth), screens were set at depths of 64m to 94m to evaluate the characteristics of shallow aquifer.

3.3.3 Las Piñas No.2

Geology of LAS PIÑAS NO. 2 can be classified into Alluvium and Guadalupe Formation. The Alluvium (11.1m thickness) consists of soft clay and loose gravel layers and is underlain by well-consolidated Guadalupe Formation (Figure 3.3.3).

The upper portion of the Guadalupe formation up to a depth of 89m consists of tuffaceous silt, fine sand and medium to coarse sand. Significant thickness of clayey sediments (CL), which was found in LAS PIÑAS NO. 1, can be traced at depths of 65m to 89m. Alternated tuffaceous, fine to coarse, sand layers which are geologically well-correlated with LAS PIÑAS NO. 1 by four characteristic pumice-bearing layers are overlain by CL. The occurrence of PM1, PM2, PM3, and PM4 are at depths of 120m to 132m, 169m to 179m, 254m to 271m and 291m to 297m, respectively. The characteristics of pumice-bearing layers as well as the facies and thickness of the rest of the formations are very similar to those of LAS PIÑAS NO. 1 (Figure 3.3.4).

After the observation of core samples and the interpretation of geophysical loggings, the casing program of each well was fixed. In Well No. 1 (300m depth), screens were set at depths of 246m to 252m, 264m to 276m and 282m to 294m in order to investigate the deeper aquifers. In Well No. 2 (200m depth), screens were set at depths of 146m to 158m, 170m to 179m and 185m to 194m. In Well No. 3, screens were set at depths of 64m to 94m to evaluate the characteristics of shallow aquifer.

3.4 RESULTS OF PUMPING TEST

The step-drawdown, constant rate and recovery tests were conducted in the three 300-m wells in Las Piñas and the 250-m well in Antipolo. In other wells, the constant rate and recovery tests were conducted. Prior to the pumping tests, electric conductivity (EC) and temperature were measured at different depths in each test well. EC and temperature were also measured at every time-step during pumping tests. Water samples were taken during the constant rate test.

Time-drawdown measurements and semi-log plot of the step-drawdown tests are included in Chapter 2 of this study's Data Report. Well loss parameters were calculated using Jacob's formula.

3.4.1 Antipolo

The well development performed prior to the pumping test revealed that the static water level (SWL) of the 250-m well was deeper than 60m and the discharge rate during airlifting showed a poor water output of 5 to 10 1/min.

On the other hand, the SWL of the 200-m well was about 35m, and this well was anticipated to be more productive than the 250-m well, despite its having the same screen positions and being only eight (8) meters away from the other well. The difference may be caused by the non-homogeneity of aquifers in terms of materials contained in the formation.

Observation of drill cuttings shows the lower part of the formation in the 250-m well to contain more silty materials than the 200-m well, though the resistivity curves of these two wells look the same.

It was therefore decided that the 200-m well be used as the pumping well instead of the 250-m well. The 250-m well was used for observation purposes.

A constant rate pumping test was performed on 12 March 1991. It was begun at 10:30am and was planned to run for forty eight (48) hours at 51.6 l/min, but it was aborted at 11:30pm due to power failure (brown out). The test was restarted at 10:30am on 13 March and it lasted for

twenty four (24) hours. Discharge was 51.6 l/min. During the test, the water level of the 250m well was stable and unaffected by the adjacent pumping. After the pumping test was completed, a recovery test was carried out and water level was measured for eight (8) hours.

The electric conductivity (EC), pH and temperature were frequently checked during the test. EC ranged from 480 to 490 μs/cm, pH was 7.6, and temperature was 27°C.

Drawdown and recovery measurements are included in Chapter 2 of the Data Report. Time-drawdown on semi-log and log-log graph papers are also included in the Data Report.

Analysis results show that, transmissivity was 8.8m2/day and specific capacity was 1.67m3/day/m. These figures indicate that the lower Guadalupe aquifers are less permeable and poorly productive.

3.4.2 Las Piñas No.1

Continuous pumping and recovery tests were carried out in three test wells, viz., Well No.1 (300m), Well No.2 (200m) and Well No.3 (100m) in Las Piñas No.1. In Well No.1, the step-drawdown test was conducted ahead of the continuous pumping test.

In Well No.1, a 30-HP submersible pump was installed at a depth of 120m below ground level. The diameters of casing and riser pipes were 8 in. and 2.5 in., respectively. The static water level before pumping was 44.48m.

Five steps of discharge rate were intended to be employed before conducting the pumping tests. Because of the unexpected small discharge due to the small diameter of the riser pipe, only four steps of discharge rate, viz., 198 l/min, 402 l/min, 606 l/min and 648 l/min were performed. The duration of each step was two hours. The time-drawdown graph of the step-drawdown test is shown in Chapter 2 of the Data Report. The results of step-drawdown test are given in Table 3.4.1.

From the results, well loss parameters were calculated using Jacob's equation. The values of B and C obtained from Q-s/Q graph were

0.2949d/m2 and 2.60x10-6d2/m5, respectively. Well efficiency was calculated at 98.6% when the discharge rate was 606 l/min (872.6m3/day).

In order to determine the transmissivity T and storage coefficient S of the aquifer, the continuous pumping test and recovery test were carried out in each well. In Well No.1, the discharge rate determined from the step-drawdown test was 402 l/min. Duration of pumping was 48 hours. In Well No.2 and Well No.3, the duration of continuous pumping was 12 hours. The discharge rate of Well No.2 and Well No.3 was small because the diameter of the casing pipe was only 4 in., and only a smaller submersible pump could be installed. The residual drawdown in each well was measured for at least eight hours after the pumping has stopped. Time-drawdown graphs were plotted on logarithmic and semi-logarithmic papers. Time ratio (t/t')-residual drawdown graphs were plotted on semi-logarithmic paper. Both types of graphs are shown in the Data Report.

The results of continuous pumping and recovery tests, as well as EC and temperature measurements, are summarized in Table 3.4.2 and Figure 3.4.1.

It is noted that the static water level of Well No.3 (100m) is only 4.60m, whereas the static water levels of Well No. 2 (200m) and Well No.1 (300m) are 37.34m and 44.48m, respectively. This could indicate the separation of the shallow aquifer of Well No.3 from deeper aquifers.

During the continuous pumping in Well No.1, water levels in Well No.2 and Well No.3 remained stable and were unaffected by the pumping. EC values during the pumping tests and the difference in T values also support this idea. Based on the geological investigation mentioned before, significant thicknesses of clayey formations that could form a confining layer have been identified at depths of 58m to 76m. It can be said that the clayey layer separates the shallow aquifer from the deeper aquifers, and with it acting as a significant aquiclude.

3.4.3 Las Piñas No.2

Continuous pumping and recovery tests were carried out in three test wells in Las Piñas No.2, viz., Well No.1 (300m), Well No.2 (200m) and Well No.3 (100m). In Well No.1, the step-drawdown test was conducted

prior to the continuous pumping test.

In Well No.1, a 30-HP submersible pump was installed at a depth of 120m below ground level. The diameters of casing and riser pipes were 8 in. and 2.5 in., respectively. The static water level before pumping was 50.03m.

Five steps of discharge rate, viz., 101.4 l/min, 198.6 l/min, 300.0 l/min, 402.0 l/min and 445.8 l/min were employed for the step-drawdown test. The duration of each step was two hours. The time-drawdown graph is shown in Chapter 2 of the Data Report. Results of the step drawdown test are given in Table 3.4.3.

From the results, well loss parameters were calculated using Jacob's equation. The values of B and C obtained from Q-s/Q graph were 0.07612d/m^2 and 2.40x10-^{5}d^2/m^5, respectively. Well efficiency was calculated at 84.6% when the discharge rate was 402.0 l/min (578.9m^3/day).

In order to determine the transmissivity T and storage coefficient S of the aquifer, continuous pumping and recovery tests were carried out in each well. In Well No.1, the discharge rate determined from the step-drawdown test was 300 l/min. Duration of pumping was 48 hours. In Well No.2 and Well No.3, the duration of continuous pumping was 12 hours. The discharge rate of Well No.2 and Well No.3 was small because the diameter of the casing pipe was only 4 in., and only a smaller submersible pump could be installed. The residual drawdown in each well was measured for at least 8 hours. Time-drawdown graphs were plotted on logarithmic and semi-logarithmic papers. Time ratio (t/t')-residual drawdown graphs were plotted on semi-logarithmic paper. Both types of graphs are shown in the Data Report.

The results of continuous pumping tests and recovery tests, as well as EC and temperature measurements, are summarized in Table 3.4.4 and Figure 3.4.2.

The static water table of Well No. 3 (100m) is shallow whereas the static water levels of Well No. 2 (200m) and Well No. 1 (300m) are deep. This is similar to Las Piñas No.1. The EC values of Well No.2 are

higher than those of Las Piñas No. 1. It is noted as an interesting phenomenon that the EC_{18} value before pumping in Well No.2 was 22783 µs/cm, which after pumping became 9483 µs/cm. The transmissivity of Well No.3 is higher than those of Well No.2 and Well No.1.

3.4.4 Las Piñas No.3

The step-drawdown test, continuous pumping and recovery tests were carried out in Well No.1 (300m), Las Piñas No.3.

A 30-HP submersible pump was installed at a depth of 120m below ground level. The diameters of casing and riser pipes were 8 in. and 2.5 in., respectively. The static water level before pumping was 64.90m.

Four steps of discharge rate, viz., 102 l/min, 198 l/min, 300 l/min, 402 l/min were employed for the step-drawdown test. The duration of each step was two hours. The time-drawdown graph is shown in the Data Report. The results of the step-drawdown test are given in Table 3.4.5.

From the results, well loss parameters were calculated using Jacob's equation. The values of B and C obtained from Q-s/Q graph are $0.04807 d/m^2$ and $1.57 \times 10^{-5} d^2/m^5$, respectively. Well efficiency is calculated as 87.6% when discharge rate is 300 l/min ($432 m^3$/day).

In order to determine the transmissivity T and storage coefficient S of the aquifer, continuous pumping and recovery tests were carried out. The discharge rates determined from the step-drawdown test was 300 l/min. Duration of pumping was 48 hours. Time-drawdown graphs were plotted on logarithmic and semi-logarithmic papers. The time ratio (t/t')-residual drawdown graph was plotted on logarithmic paper. Both types of graphs are shown in Chapter 2 of the Data Report.

The results of continuous pumping tests and recovery tests, as well as EC and temperature measurements, are summarized in Table 3.4.6.

The static water level of this well is the lowest among the test wells in Las Piñas. The values for maximum and minimum EC_{18} before and after pumping are also the lowest. Transmissivity values range from $28.7 m^2$/day to $38.8 m^2$/day. Storage coefficient ranges from 9.73×10^{-5} to

6.18×10^{-6}.

3.5 ANALYSIS OF CORE SAMPLES

In order to clarify the stratigraphy and geological environment of Alluvium and Guadalupe formation, various geological methods of analysis were employed.

Laboratory analysis of core samples taken at Las Piñas sites include:

1)	Carbon 14 dating	2 samples
2)	Fission track dating	5 samples
3)	Micro-fossils (Foraminifera and Diatom)	6 samples
4)	Heavy minerals	20 samples
5)	Chloride content	10 samples

Samples were sent to Japan for laboratory analysis.

3.5.1 Fission Track Dating

The age of zircon grains contained in PM1 to PM5 layers were analyzed by the fission track method. Absolute age of all samples ranged from 80.0 to 139.5 million years as shown in Table 3.5.1. While the result shows very old age, the Guadalupe formation is believed to be younger, i.e., Plio-Pleistocene.

Very few zircon grains were found in the core samples. Also, heavy minerals were affected by diagenesis and weathering due to their deposition in the lake environment near volcanoes. Therefore, these sediments may not be original and may have been disturbed by water flow during their transport and deposition in view of the grain shape, lamina, wooden fragment and roundness of conglomerate.

Accordingly, the result of dating could indicate similarity in the absolute age of the Kinabuan formation (basalt) and that of another formation. These formations underlie the volcanoes in Bataan, Corregidor, Taal and Laguna.

3.5.2 Diatom Analysis

Most of the diatoms found in the core samples (obtained at depths of 7.7 to 10.5m) were marine or marine to brackish. In contrast, only limnetic diatoms were identified in the core samples taken at depths of 24.8 to 298m (Table 3.5.2).

This finding suggests that the uppermost sediments were laid down in the shallow sea of Holocene age while lower sediments, i.e., below 10.5 to 300m, were deposited in the lake environment of Pleistocene age.

The environment of deposition of the Guadalupe formation up to a depth of about 2,000m is yet to be clarified. However, the presence of saline water in the deeper part of the formation, i.e., at depths below 300m, which was discovered during the 1960s by GMB through a drilling it carried out downstream of the Marikina River, could indicate that the deeper formation was deposited in a marine environment.

3.5.3 Analysis of Heavy Minerals

A heavy mineral assemblage analysis was carried out to obtain basic data for the stratigraphic correlation. The content of heavy minerals was less than 10% of total grains in each sample. Augite, hyperthene and magnetite were the dominant heavy minerals. Hornblende can be found in samples taken at shallow depths reaching up to 165m. The amount of Hyperthene at depths below 265m was very small.

The difference in heavy mineral assemblage may be caused by change of volcanic activities and/or environment during the deposition. Therefore, the Guadalupe formation within a depth of 300m at this location can be divided into at least three units by heavy mineral assemblage.

Many volcanic glasses, rock fragments and weathered rock particles are found in the samples instead of small contents of heavy minerals. From the content and type of volcanic glasses that are indicative of neighboring volcanic activities, it is possible to classify the formation. The content of volcanic glass exceeds 50% of total grains in the samples taken at depths of 99m to 105m, 134m to 144m, 184m to 197m, 231m to 142m, and 281m. The assemblage of volcanic glass below the 281m depth

can be characterized by the dominance of black volcanic glass and brown volcanic glass, whereas in the upper samples, white volcanic glass and brown volcanic glass are dominant.

The heavy mineral analysis as well as the volcanic glass analysis may be done even with the use of well cuttings. The assemblage of both heavy minerals and volcanic glass could be a good marker and should help future geologic correlation in the Metro Manila.

Results of analysis of heavy mineral are shown in Table 3.5.3.

3.5.4 Analysis of Chloride Content

Chloride content of sandy core samples were analyzed to evaluate the degree of contamination caused by saltwater intrusion.

The findings show that the samples taken from shallow aquifers at depths of 10m, 27m and 52.5m yield much higher chloride content than those from deep aquifers. This could indicate that encroachment of saltwater is mainly on the shallow aquifer from Manila Bay and the surface (Table 3.5.4).

3.5.5 Carbon Dating

Carbon dating was carried out for Site No.2, Las Piñas sing two alluvial humic clay samples. Sample No.1 and Sample No.2 were taken from depths of 7.7m and 10.5m, respectively. The measured radiocarbon age before the year 1950 of Sample No.1 is 7040, plus or minus 150 years. That of sample No. 2 is 7360, plus or minus 110 years.

This age shows that the alluvial clay was deposited during the global transgression after Wurm glacial stage (Japanese name "Jomon transgression").

TABLE 3.3.1 RESULTS OF STEP-DRAWDOWN TEST AT WELL NO.1, LAS PIÑAS NO.1

Step	Discharge rate, Q		Drawdown, s	s/Q
	(ℓ/min)	(m^3/day)	(m)	(d/m^2)
1	198	285.1	8.62	0.03023
2	402	578.9	18.20	0.03144
3	606	872.6	26.10	0.02991
4	648	933.1	29.37	0.03148

TABLE 3.3.2 RESULTS OF PUMPING TESTS AND EC & TEMPERATURE LOGS IN LAS PIÑAS NO.1

	Well No.1 (300m)	Well No.2 (200m)	Well No.3 (100m)
Static W.L. (m)	44.48	37.34	4.60
Dynamic W.L. (m)	72.84	40.99	9.72
Discharge(ℓ/min)	404.0	90.6	150.0
Max. & Min. ECt at Logging(μs/cm)	3330 1850	13200 1110	40200 28900
Max.& Min.Temp. at Logging(deg.C)	35.6 34.1	32.9 30.5	30.4 29.5
Max.& Min.EC_{18} at Logging(μS/cm)	2401 1364	10300 1110	31804 22706
EC_{18} before & after pumping (μS/cm)	1060 917	598 546	31542 29876
T by Theis (m^2/day)	52.2	35.8	593.0
T by Cooper-Jacob(m^2/day)	62.1	29.4	111.4
T by recovery (m^2/day)	48.7	30.3	119.8
S by Theis	$4.08x10^{-5}$	$4.63x10^{-2}$	$1.08x10^{-3}$
S by Cooper-Jacob	$1.80x10^{-3}$	$2.05x10^{-1}$	$1.40x10^{-10}$

TABLE 3.3.3 RESULTS OF STEP-DRAWDOWN TEST AT WELL NO.1, LAS PIÑAS NO.2

Step	Discharge rate, Q (ℓ/min)	(m^3/day)	Drawdown, s (m)	s/Q (d/m^2)
1	101.4	146.0	13.88	0.09506
2	198.6	286.0	23.73	0.08298
3	300.0	432.0	39.95	0.09248
4	402.0	578.9	52.10	0.09000
5	445.8	642.0	55.33	0.08619

TABLE 3.3.4 RESULTS OF PUMPING TEST AND EC & TEMPERATURE LOGS IN LAS PIÑAS NO.2

	Well No.1 (300m)	Well No.2 (200m)	Well No.3 (100m)
Static W.L. (m)	50.03	43.44	3.66
Dynamic W.L. (m)	95.00	51.26	5.07
Discharge(ℓ/min)	300.0	91.2	153.0
Max. & Min. ECt at Logging(μs/cm)	3830 1510	30100 21300	39800 28000
Max.& Min.Temp. at Logging(deg.C)	36.3 33.2	33.0 30.3	31.0 28.6
Max.& Min.EC_{lg} at Logging(μS/cm)	2783 1132	23012 16284	31932 21773
EC_{lg} before & after pumping (μS/cm)	1592 765	22784 9483	30757 29654
T by Theis (m^2/day)	9.1	34.0	149.5
T by Cooper-Jacob(m^2/day)	10.7	227.1	176.8
T by recovery (m^2/day)	18.4	11.4	260.2
S by Theis	2.64×10^{-2}	1.43×10^{-7}	7.24×10^{-2}
S by Cooper-Jacob	1.51×10^{-2}	$<1.00\times10^{-10}$	1.38×10^{-2}

TABLE 3.3.5 RESULTS OF STEP-DRAWDOWN TEST AT WELL NO.1, LAS PIÑAS NO.3

Step	Discharge rate, Q (ℓ/min)	(m^3/day)	Drawdown, s (m)	s/Q (d/m^2)
1	102	146.9	7.40	0.05038
2	198	285.1	15.06	0.05282
3	300	432.0	23.70	0.05486
4	402	578.9	29.55	0.05105

TABLE 3.3.6 RESULTS OF PUMPING TESTS AND EC & TEMPERATURE LOGS IN LAS PIÑAS NO.3

	Well No.1 (300m)
Static W.L. (m)	64.90
Dynamic W.L. (m)	86.83
Discharge(ℓ/min)	300.0
Max. & Min. ECt at Logging(μs/cm)	1900 760
Max.& Min.Temp. at Logging(deg.C)	35.2 30.2
Max.& Min.EC_{18} at Logging(μs/cm)	1380 596
EC_{18} before & after pumping (μs/cm)	552 526
T by Theis (m^2/day)	28.7
T by Cooper-Jacob(m^2/day)	33.2
T by recovery (m^2/day)	38.8
S by Theis	9.73×10^{-5}
S by Cooper-Jacob	6.18×10^{-5}

TABLE 3.4.1

FISSION TRACK AGES OF ZIRCON

SAMPLE NO.	SPONTANEOUS TRACK NUMBER	SPONTANEOUS TRACK DENSITY X10 cm	INDUCED TRACK NUMBER	INDUCED TRACK DENSITY X10 cm	THERMAL NEUTRON DOSE X10 cm	F	NUMBER OF GRAINS	AGE AND STD. ERROR (Ma)	RELATIVE STD. ERROR (%)	METHOD	ID
PM1	263	8.646 ± 0.533	53	1.742 ± 0.239	3.94 ± 0.14	1.62	4	116.4 ± 18	15.5	ESED	9104003
PM2	68	5.365 ± 0.651	20	1.578 ± 0.353	3.94 ± 0.14	0.01	2	80.0 ± 20.6	25.7	ESED	9104004
PM3	125	8.218 ± 0.735	21	1.381 ± 0.301	3.94 ± 0.14	0.32	4	139.5 ± 33.3	23.8	ESED	9104005
PM4	76	9.993 ± 1.146	19	2.495 ± 0.573	3.94 ± 0.14	1.82	2	94.1 ± 24.4	25.9	ESED	9104006
PM5	75	7.718 ± 0.891	14	1.441 ± 0.385	3.94 ± 0.14	0.05	4	125.7 ± 36.9	29.3	ESED	9104007

*1 Thermal neutron dose $\delta = \delta k \times u \times k$ (Ma): Mega-annum

δk : thermal neutron dose of standard glass [NBS SRM-913] irradiated at NBS nuclear reactor
$= 4.75 \pm 0.05 \ (\times 10^{4} cm^{2})$

u : track density of muscovite attached to standard glass irradiated with sample
$= 7.370 \times 10^{4} cm^{-2} = 2201 \text{ tracks}/3.0 \times 10^{-2} \times cm^{2}$

k : track density of muscovite attached to standard glass which irradiated at NBS nuclear reactor
$= 8.885 \times 10^{4} cm^{-2} = 1770 \text{ tracks}/2.0 \times 10^{-2} cm^{2}$

*2 F-value, Hayashi and Sugiyama, 1987

*3 $\text{Age} = 6.45 \times 10^{9} \ln (1 + 9.32 \times 10^{-18} \times \sigma \times s / i)$

^{235}U

s = spontaneous track density of ^{235}U

i = induced track density of ^{235}U

*4 ESED, External-Surface External-Detector method, Daishi et al., 1986

TABLE 3.4.2 DIATOM ANALYSIS OF CORE SAMPLES IN LAS PIÑAS
(JICA NO.1 TESTWELL)

NAME OF FOSSILS	M.O.L.	7.7m	-10.5	-24.8	-63-3	-116m	-150.	-238.	-295m
Achnanthes brevipes var intermedia	M	3	8						
Achnanthes covergens	F-B			12					
Achnanthes delicatula	B	1							
Achnanthes sp.	M		1						
Amphora holsatica	M	1	5						
Amphora spp.	F-B			2					
Amphora strigosa	B		2						
Bacillaria paradoxa	F-B		2						
Cyclotella sp.	F					3			
Cyclotella striata? sp.	M	84	1						
Cymbella sp.	F			1					
Diploneis interupta	B	3	6						
Diploneis ovalis?	F			1					
Diploneis smithii	M	1	55						
Diploneis sp.	F							1	
Diploneis suborbicularis	M-B	9	14						
Epthemia sp.	F					2			
Fragilaria sp.	F					1			
Comphonema spp.	F			3					
Grammatophora macilenta	M	7							
Gyrosigma scalproides	F		1						
Gyrosigma spp.	F		2	3					
Hyalodiscus scoticus	B-M	1							
Melosira roeseana	F							2	
Melosira sp.	F			1					

TABLE 3.4.2 (CONTINUATION)

NAME OF FOSSILS	M.O.L.	7.7m	-10.5	-24.8	-63-3	-116m	-150.	-238.	-295m
Navicula contenta	F					1		15	
Navicula gregaria	M			5					
Navicula mutica	F		1			1			
Navicula pupula	F			3					
Navicula spp.	F		2	6				1	
Navicula thienemanni	F			1					
Nitzschia cocconeiformis	M	20	27						
Nitzchia fonticola	F			1					
Nitzschia glanurata	M	11	17						
Nitzshia hohnkii	B		1						
Nitzshia hungarica	F-B		1						
Nitzshia littoralis	B		2						
Nitzschia obtusa	F			21					
Nitzschia palea	F					1			
Nitzschia parvula	F-B			1					
Nitzschia punctata	M	2	2						
Nitzschia sigma	M	2	20						
Nitzschia sp.1	F					1			
Nitzschia sp.2	F					5			
Nitzschia sp.3	F-B			1					
Nitzschia spp.	?	1	4	13					
Nitzschia supralitorea	F			42					
Paralia sulcata	M	20							
Pinnularia hemiptera	F		1						
Pinnularia spp.	F	4		19				2	
Rhaphoneis surirella	M	1							

TABLE 3.4.2 (CONTINUATION)

NAME OF FOSSILS	M.O.L.	7.7m	-10.5	-24.8	-63-3	-116m	-150.	-238.	-295m
Rhopalodia gibberula	F-B	2		71					
Synedra rumpens	F					5			
Synedra sp.	F					32			
Talasiosira sp.	?	6							
Thalassionema nitzschioides	M	14							
Thalassiosira bramaptrae	F-B		1						
gen. et sp. indet	?	1	6	3				5	
TOTAL		202	182	210	0	52	0	26	0

M.O.L. : Mode of Life
F : Fresh, B: Brackish, M: Marine

TABLE 3.4.3(1) GRAIN COMPOSITION

SAMPLE NO.	DEPTH (m)	VOLCANIC GLASS				WEATHER PARTICLES	ROCK FRAGMENTS	LIGHT MINERAL	HEAVY MINERAL
		WHITE	BROWN	BLACK	TOTAL				
1	10.0	49.8	0.0	0.0	49.8	24.9	19.9	5.0	0.5
3	24.0	0.0	0.0	0.0	0.0	68.0	26.6	4.9	0.5
6	41.0	0.0	0.0	0.0	0.0	70.0	11.0	17.0	2.0
10	79.3	0.0	0.0	0.0	0.0	56.9	4.0	7.1	2.0
11	95.9	39.0	31.0	4.0	74.0	0.0	9.0	14.0	3.0
12	105.1	43.9	36.1	7.8	87.8	0.0	7.8	3.9	0.5
13	114.1								
14	123.8	0.0	0.0	0.0	0.0	89.6	5.0	5.0	0.5
15	134.0	26.0	32.0	9.0	67.0	0.0	20.0	8.0	5.0
16	143.9	7.1	49.5	4.0	60.6	0.0	35.4	3.0	1.0
17	156.0	0.0	0.0	0.0	0.0	88.6	5.0	6.0	0.5
18	165.0	0.0	0.0	0.0	0.0	89.6	5.0	5.0	0.5
19	177.5								
20	184.0	90.5	0.0	0.0	90.5	3.0	5.0	1.0	0.5
21	197.0	64.0	14.0	5.0	83.0	0.0	8.0	8.0	1.0
22	207.1	8.1	30.3	6.0	44.4	0.0	30.3	15.2	10.1
23	216.5	25.0	16.0	5.0	46.0	0.0	40.0	12.0	2.0
24	231.7	71.8	17.4	3.1	92.3	0.0	6.2	1.0	0.5
25	241.5	47.3	19.7	14.8	81.8	0.0	13.8	3.9	0.5
26	249.5								
27	264.5	0.0	0.0	0.0	0.0	98.5	0.5	0.5	0.5
28	277.1	36.0	0.0	3.0	39.0	28.0	20.0	16.0	2.0
29	280.7	29.9	24.9	39.8	94.6	0.0	0.5	4.0	1.0
30	283.8								
31	290.5	0.0	0.5	0.5	1.0	97.1	0.5	1.0	0.5
32	297.6	0.0	0.0	0.0	0.0	73.4	15.2	8.9	2.5

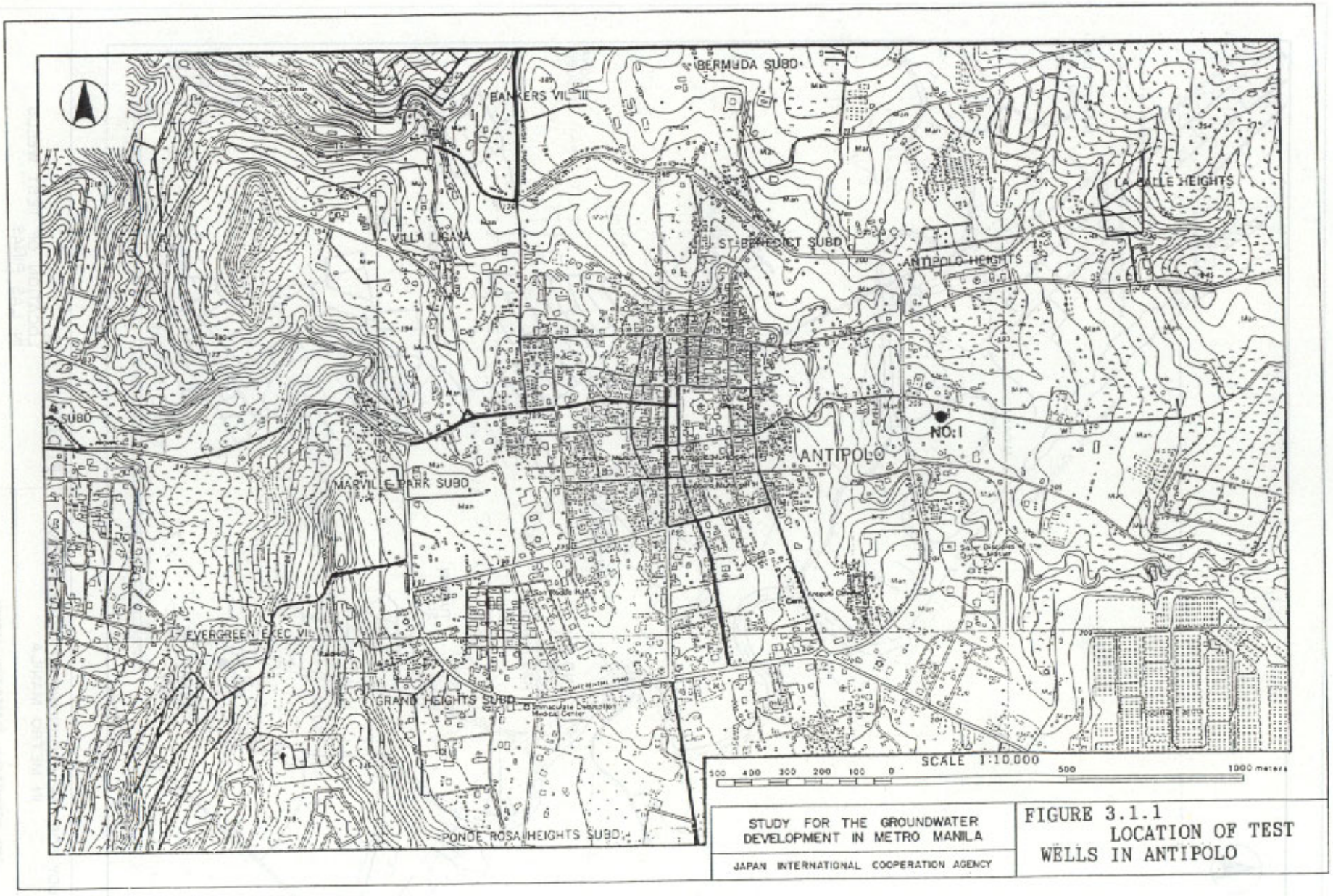
TABLE 3.4.3(2) HEAVY MINERAL COMPOSITION (%)

SAMPLE NO.	DEPTH (m)	Au	Hy	Ho	Zi	Mg	Py
1	10.0	70.0	20.0	5.0	0.0	5.0	0.0
3	24.0	96.0	1.0	1.0	0.0	2.0	0.0
6	41.0	71.0	18.0	5.0	0.0	6.0	0.0
10	79.3	0.0	0.0	0.5	0.0	99.5	0.0
11	98.9	31.0	37.0	0.0	0.0	32.0	0.0
12	105.1	50.0	20.0	0.0	0.0	30.0	0.0
13	114.1						
14	123.8	24.0	10.0	10.0	0.0	56.0	0.0
15	134.0	38.0	28.0	0.0	0.0	34.0	0.0
16	143.9	50.5	12.1	0.0	0.0	36.4	1.0
17	156.0	14.0	0.0	0.0	0.0	86.0	0.0
18	165.0	58.5	12.7	8.8	0.0	0.5	19.5
19	177.5						
20	184.0	50.0	20.0	0.0	0.0	30.0	0.0
21	197.0	51.0	34.0	0.0	0.0	15.0	0.0
22	207.1	58.0	5.0	0.0	1.0	36.0	0.0
23	216.5	56.0	32.0	0.0	0.0	7.0	5.0
24	231.7	49.0	13.0	0.0	0.0	23.0	15.0
25	241.5	19.0	53.0	0.0	0.0	28.0	0.0
26	249.5						
27	264.5	35.0	30.0	0.0	0.0	35.0	0.0
28	277.1	59.4	0.5	0.0	0.5	39.6	0.0
29	280.7	64.4	0.5	0.0	0.5	34.7	0.0
30	283.8						
31	290.5	80.0	0.0	0.0	0.0	20.0	0.0
32	297.6	58.0	1.0	0.0	0.0	41.0	0.0

Au: Augite Hy: Hypersthene Ho: Hornblende
Zi: Zircon Mg: Magnetite Py: Pyrite

TABLE 3.4.4 CHLORIDE CONTENT OF CORE SAMPLES IN LAS PIÑAS NO.1

SAMPLE NO.	QUANTITY (g)	CHLORIDE (g)	CHLORIDE QTY. (g) PER SAMPLE (kg)
1	0.5023	2.48×10^{-2}	49.0
4	0.4984	3.9×10^{-3}	7.8
7	0.5132	6.74×10^{-3}	13.0
11	0.5181	5.9×10^{-4}	1.1
15	0.5514	2.4×10^{-4}	0.4
19	0.5412	1.2×10^{-4}	0.2
21	0.5107	1.4×10^{-4}	0.3
24	0.5186	2.1×10^{-4}	0.4
26	0.5017	3.9×10^{-4}	0.8
29	0.5361	3.2×10^{-4}	0.6
32	0.5213	5.7×10^{-4}	1.1



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

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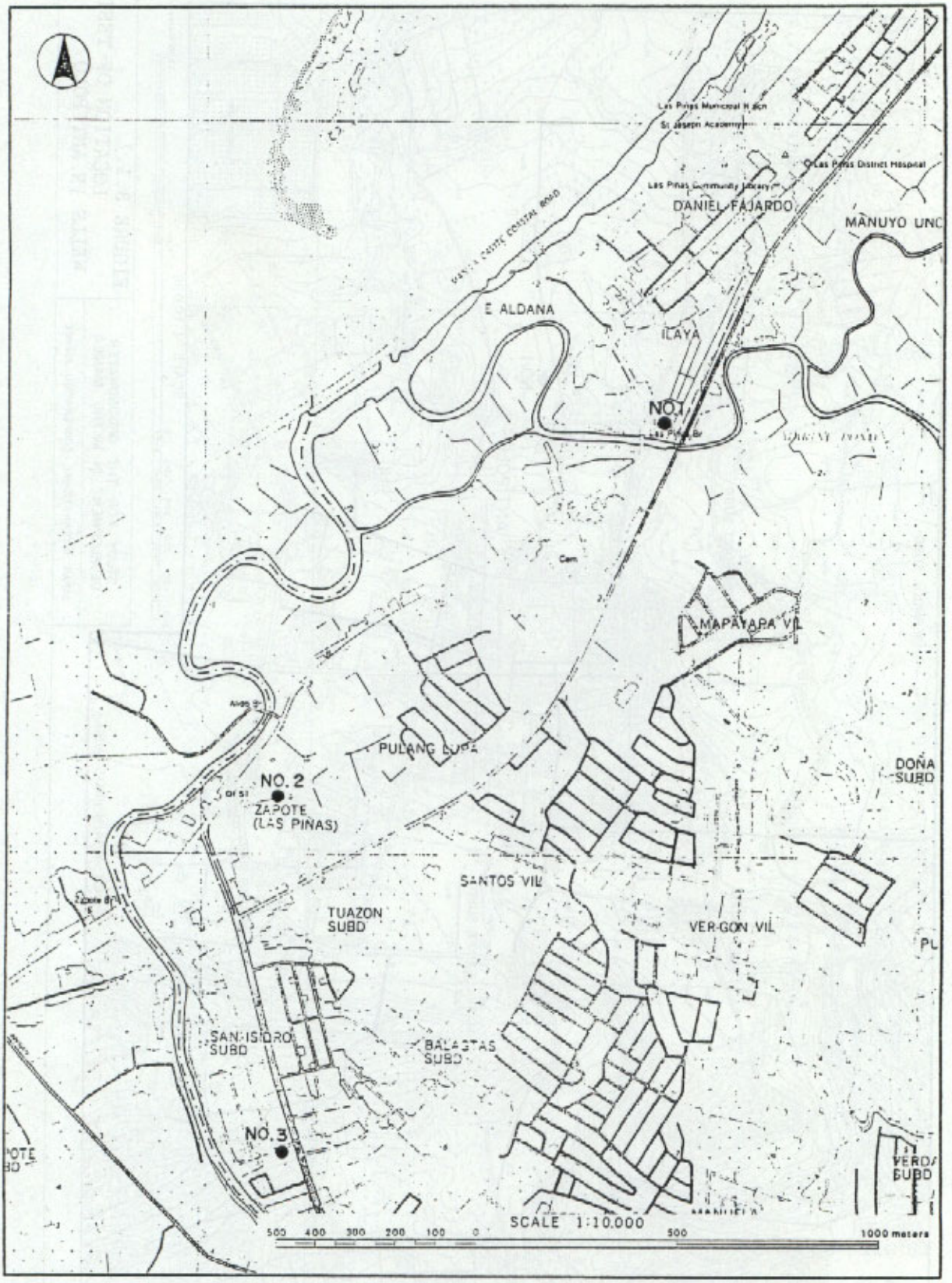
FIGURE 3.1.1
LOCATION OF TEST WELLS IN ANTIPOLO



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

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FIGURE 3.1.2
LOCATION OF TEST WELLS IN LAS PIÑAS

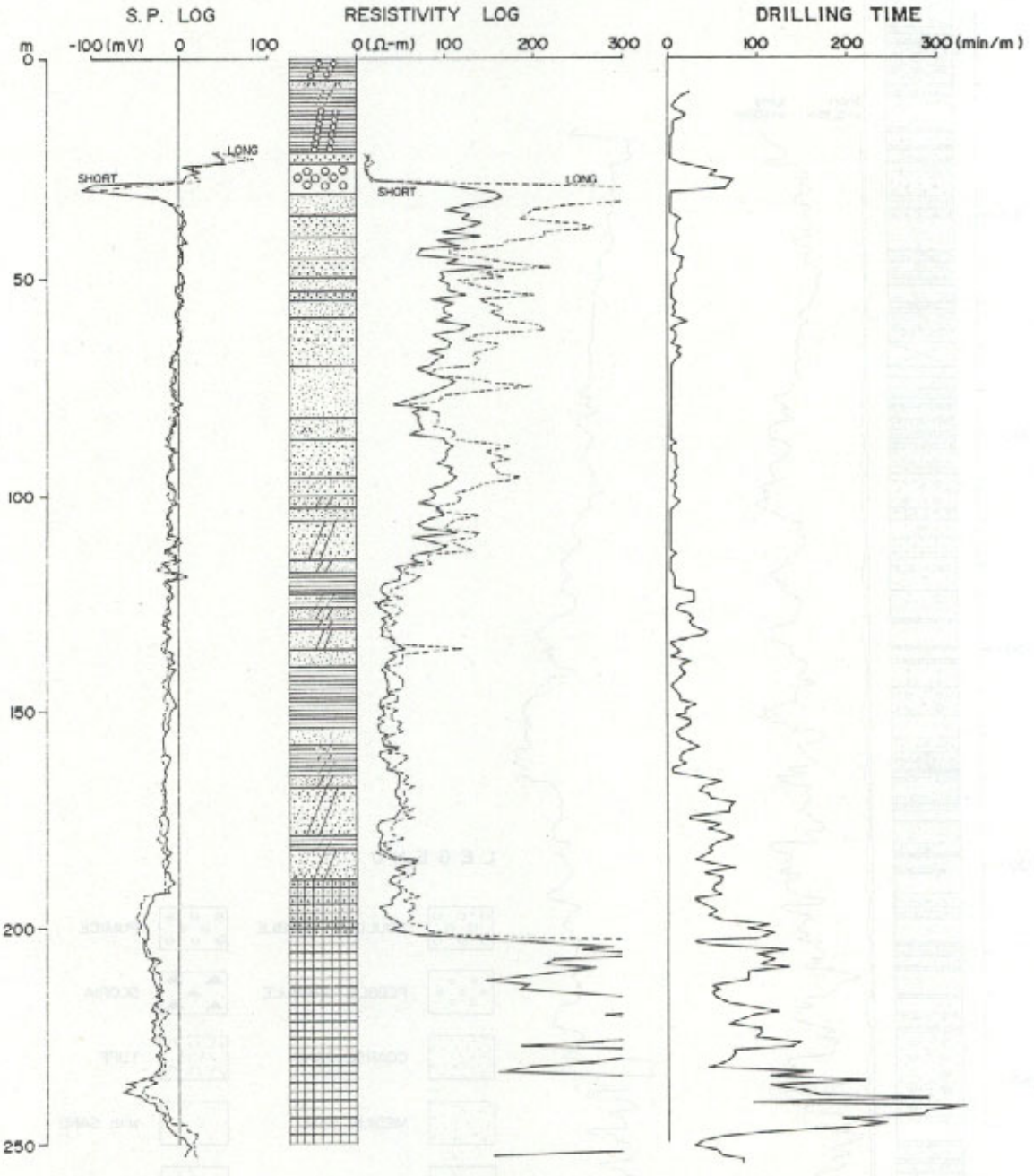

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FIGURE 3.2.1
WELL LOGS OF WELL No. 1 (250m), ANTIPOLO

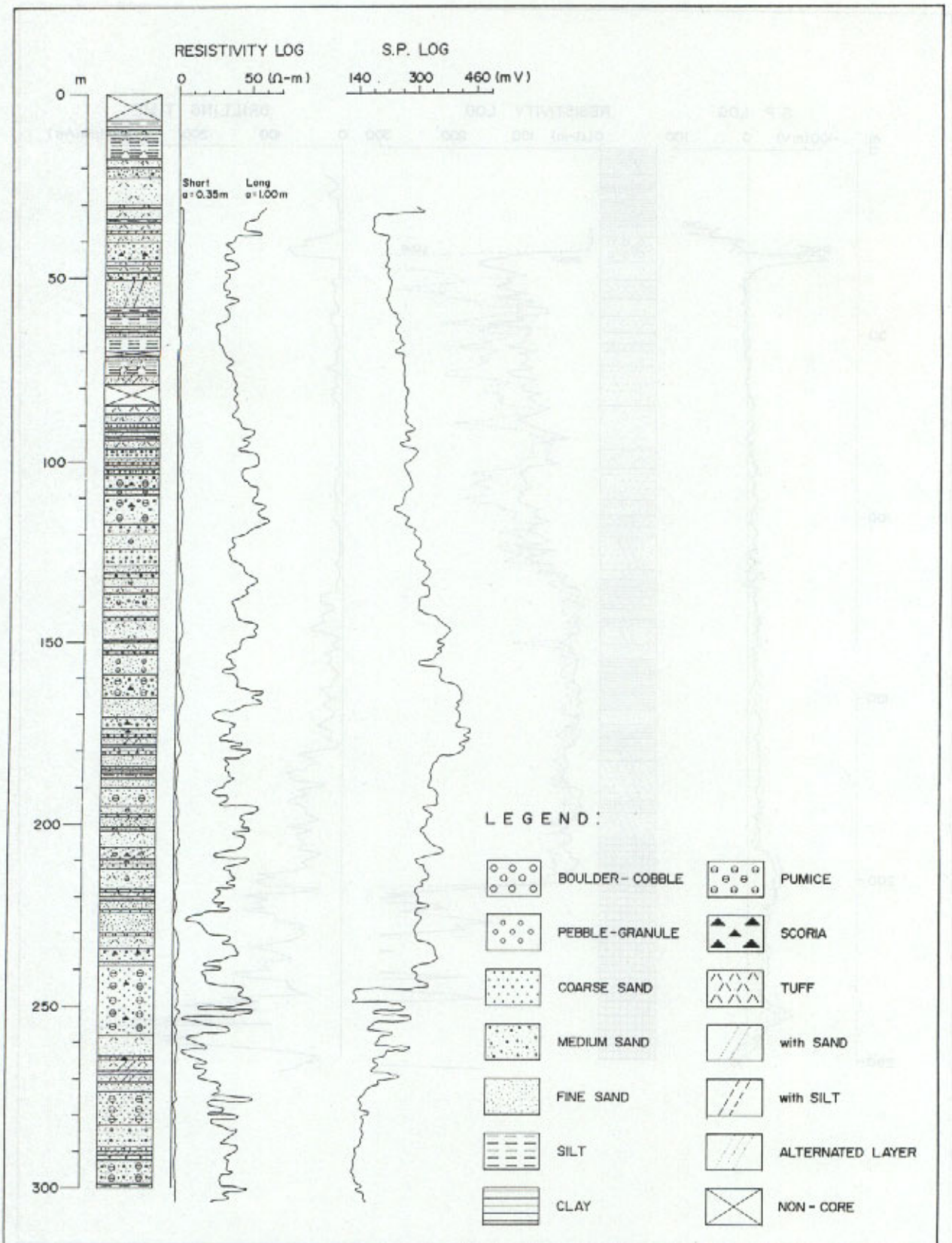

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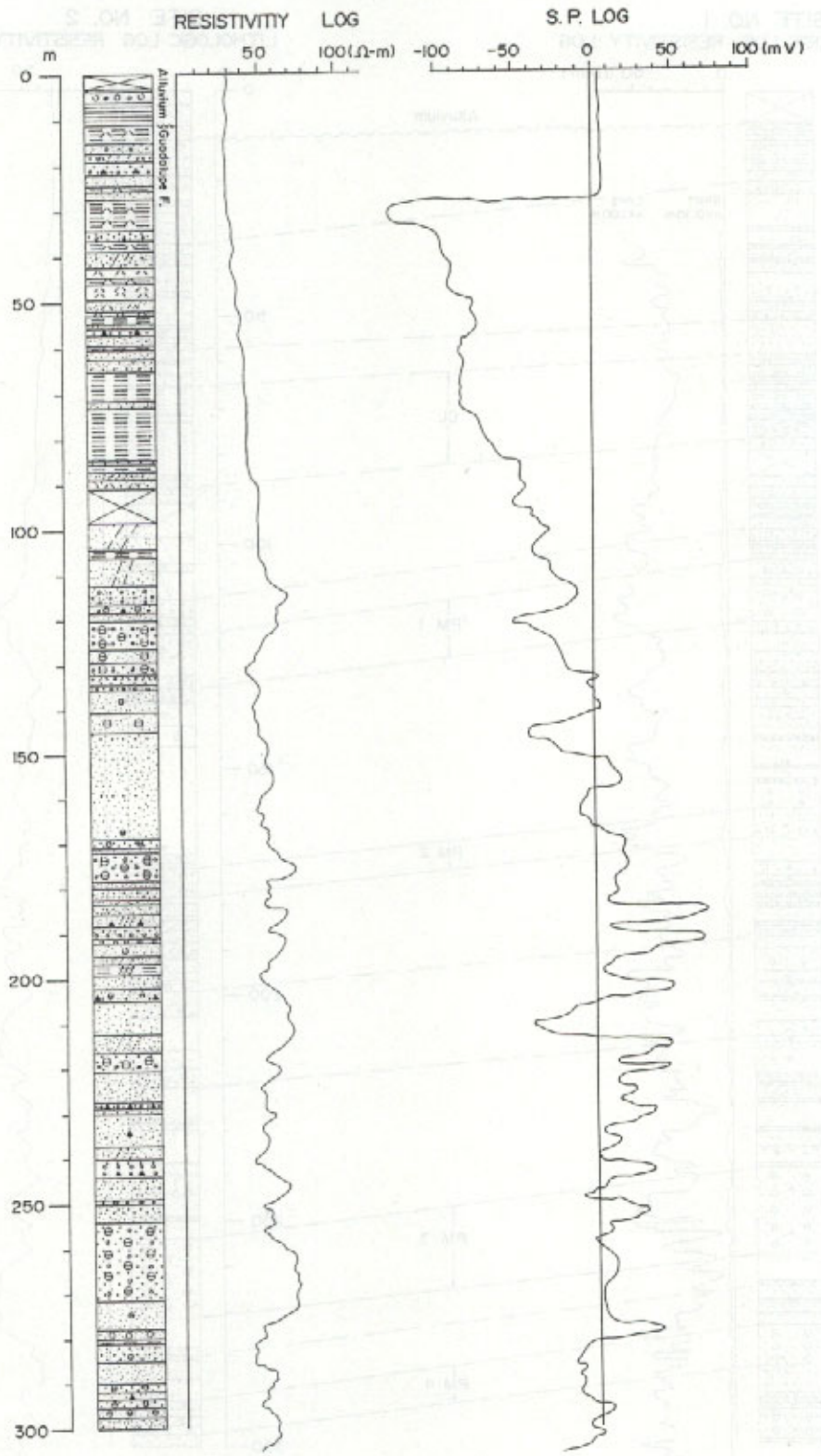
FIGURE 3.2.2
COLUMNAR SECTION OF CORE DRILLING AT SITE NO. I, LAS PIÑAS



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

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FIGURE 3.2.3
COLUMNAR SECTION OF CORE DRILLING AT SITE NO. 2, LAS PIÑAS

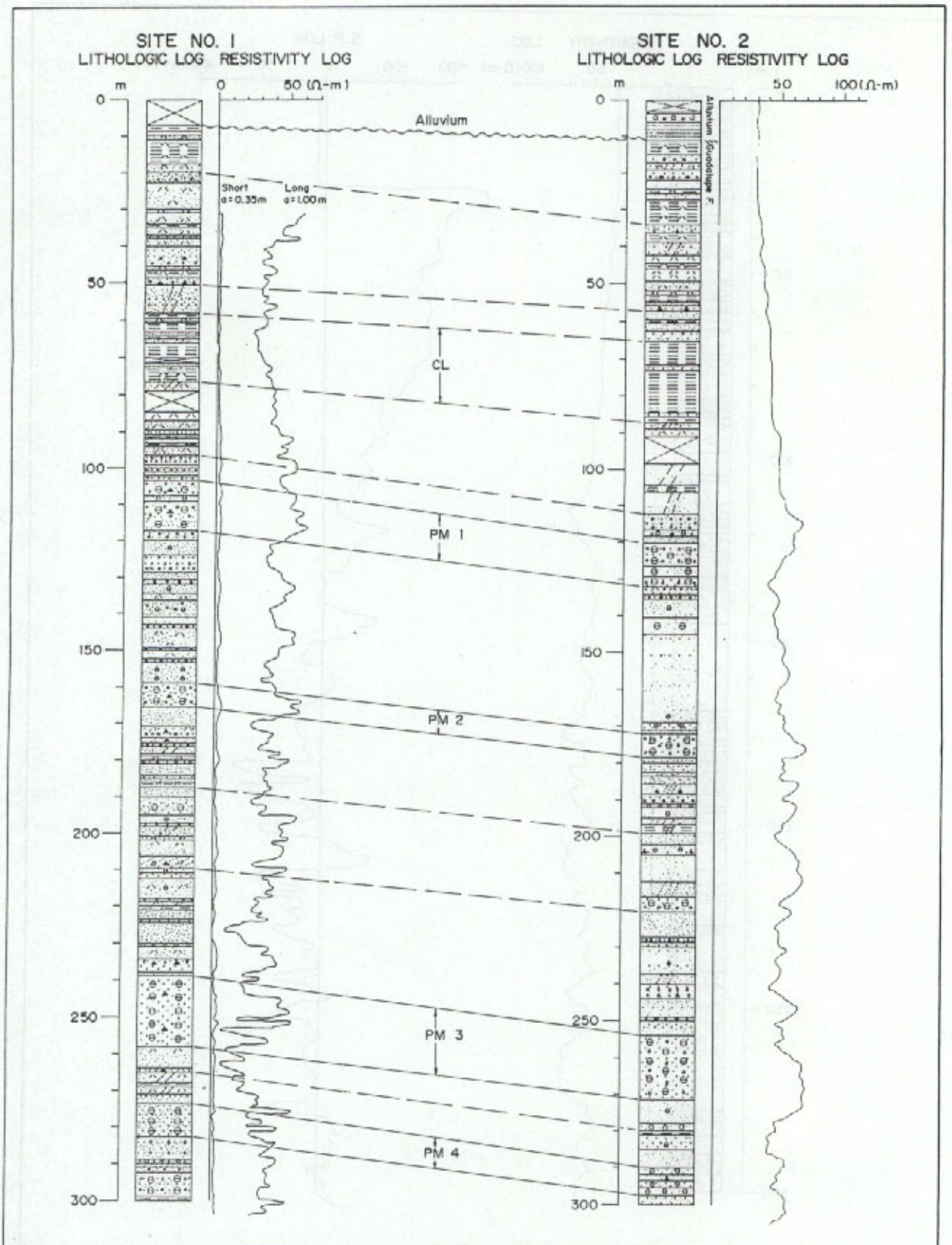

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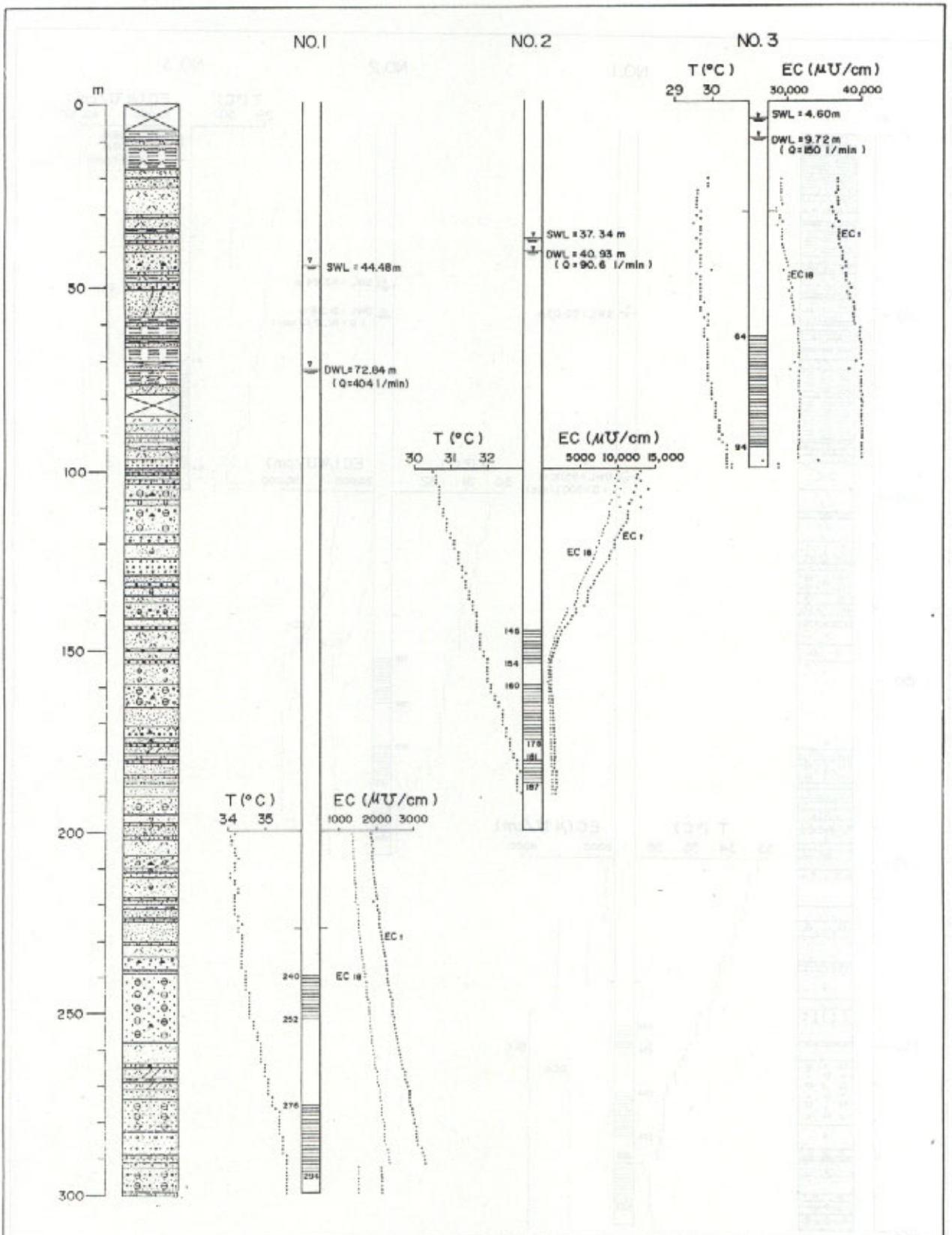
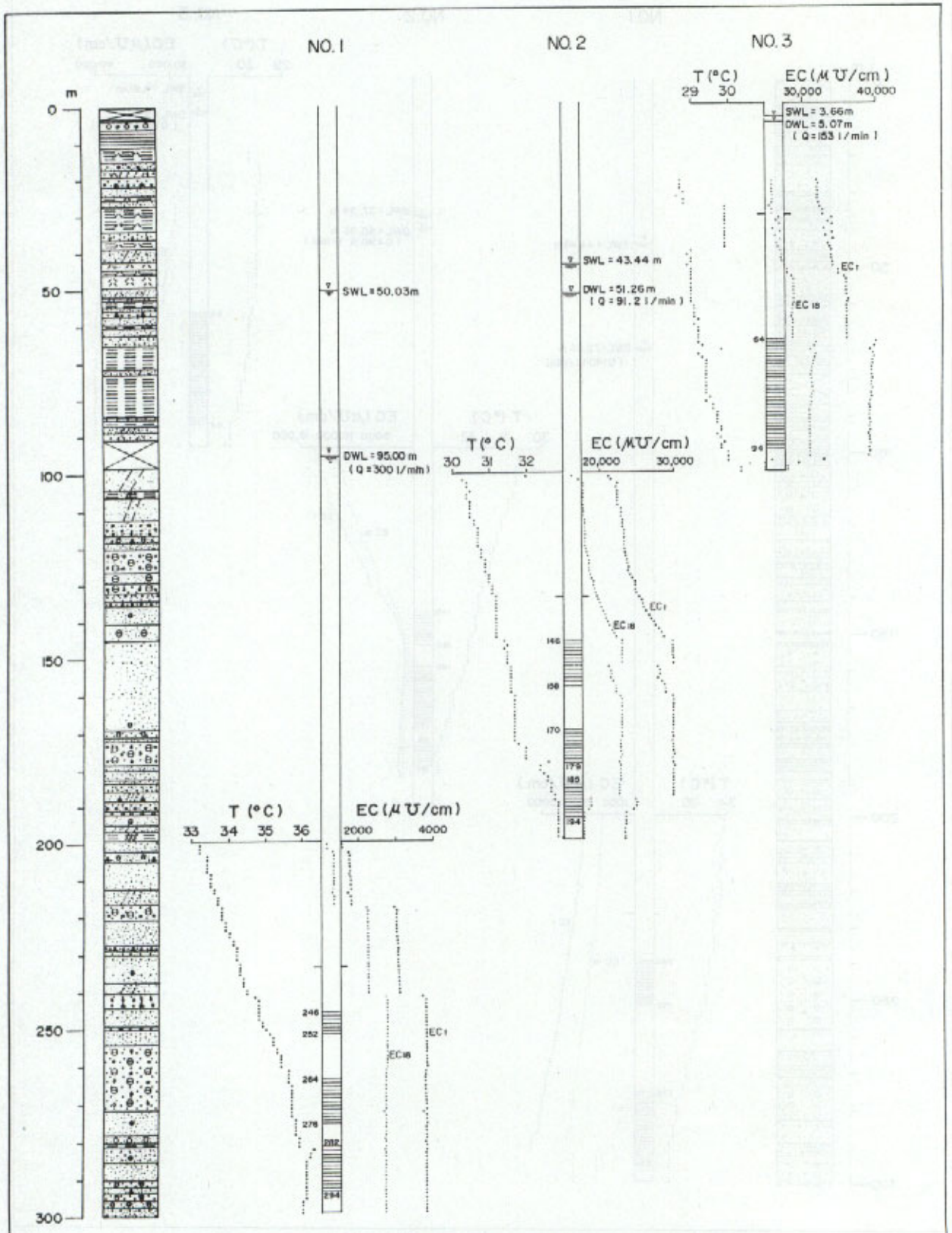
FIGURE 3.2.4
GEOLOGIC CORRELATION BETWEEN SITES NO.1 & NO.2, LAS PIÑAS



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 3.3.1
TEMPERATURE AND EC LOGS AT SITE NO. 1, LAS PIÑAS



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA JAPAN INTERNATIONAL COOPERATION AGENCY	FIGURE 3.3.2 TEMPERATURE AND EC LOGS AT SITE NO. 2, LAS PIÑAS

CHAPTER 4

AQUIFER PARAMETERS

CHAPTER 4 AQUIFER PARAMETERS

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CHAPTER 4 AQUIFER PARAMETERS

4.1 EXISTING DATA

Transmissivity, storativity and leakance are the basic aquifer parameters in the evaluation of groundwater flow, change of storage and leakage.

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 one hundred twenty three (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 one hundred and sixty three (163) MWSS wells.

4.2 PUMPING TESTS OF MWSS WELLS

The step-drawdown test, the constant rate test and 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. 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 4.2.1. These wells are detailed in Table 4.2.1. Some of these selected wells have pumping test data which were obtained during their construction.

The fifteen(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 step-drawdown, the constant rate and recovery tests. 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.

4.3 PUMPING TEST 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; transmissivity values of the 100-m wells vary from 116 m^2/day to 219 m^2/d; transmissivity values of the 200-m and 300-m wells vary from 13 m^2/d to 54 m^2/d. Storativity values 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.

4.4 TRANSMISSIVITY AND SPECIFIC CAPACITY

The transmissivity values collected from results of previous pumping

tests plus those obtained from pumping tests conducted by the Study Team are summarized in Table 4.4.1. Figure 4.4.1 shows the distribution of transmissivity values of one hundred and ninety six (196) wells in Metro Manila. The logarithmic average and logarithmic standard deviation were computed for statistical analyses. The average value of the 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 4.4.2 shows the transmissivity map of the Metro Manila area. This was drawn based on the statistical analyses.

As mentioned earlier, the amount of transmissivity data is less than the amount of the specific capacity data. Specific capacity 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 4.4.3 shows the correlation between the collected/measured transmissivity and specific capacity as detailed in Table 4.4.1. 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 the increased amount of data produced, but also in making the more reliable data reflect actual aquifer characteristics, considering that transmissivity values obtained from a pumping test often take a wide range, even with a most careful conduct of the test.

Table 4.4.2 presents the transmissivity values estimated from specific capacities of MWSS wells. Transmissivity values culled from existing data by the Study Team are also summarized in Table 4.4.3. Figure 4.4.4 shows the distribution of the estimated transmissivity values of two hundred and seventy eight (278) wells. The logarithmic average is 58.3m^2/d, with a 90% reliable range of 17.3 m^2/d to 197.1 m^2/d. Figure 4.4.5 shows the estimated transmissivity map of the Metro Manila area. The input transmissivity data for the Metro Manila groundwater flow model is prepared from the transmissivity map.

TABLE 4.2.1 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)	60-170	(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-15	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	(C+R) test
11	MWSS	MTL-149	Tunasan, Muntinlupa	Operating	10"-8"	305	(461)	112-115 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-11	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

TABLE 4.4.1 ACTUAL TRANSMISSIVITY AND SPECIFIC CAPACITY

MWSS No.	X	Y	T (actual) (m^2/d)	LATI			LONGI			SC (lps/m)	SC (m^2/d)
				D	M	S	D	M	S		
ATP-101	27	16	444	14	35	31	121	10	55	1.2	105.2
ATP-102	26	13		14	37	35	121	9	51	.13	11.7
BCR-11			700							6	518.4
BCR-13			245							.7	61.4
BCR-3	7	27	137	14	27	17	120	55	43	.61	52.5
BCR-4	9	27	220	14	27	22	120	57	17	2	172.8
CLC-36	12	10	160	14	40	15	120	59	42	.73	59.6
CLC-37	12	10	20	14	39	56	120	59	48	.2	17.3
CLC-B-53			51							.31	26.9
CTA-19	23	18	255	14	34	20	121	7	43	2.2	187.2
CTA-20	21	13	192	14	38	9	121	6	19	.99	85.3
CTA-66	21	13	103	14	38	7	121	6	19	.75	64.5
CTA-67	21	17	63	14	34	58	121	6	28	.65	57.2
CVC-11	4	25	360	14	29	6	120	53	39	1.8	155.5
CVC-12	4	25	350	14	28	57	120	53	49	1.41	121.4
CVC-17	3	26	88	14	27	57	120	52	57	.68	57.9
GTR-2			430							3.4	273.6
GTR-3			350							2.8	240.5
IMS-21	7	29	137	14	25	52	120	56	2	.97	81.5
IMS-3	7	29	100	14	25	48	120	56	4	1.2	103.7
IMS-6			220							2.7	236.8
IMS-7			420							2.5	207.4
IMS-8			600							.9	81.7
LPS-37	11	26	28	14	27	54	120	59	9	.3	24
LPS-48			28							.3	24
LPS-64	11	25	243	14	28	52	120	58	33	2.1	181.4
MDL-10	16	17	65	14	35	1	121	2	27	.5	47.5
MKT-11			118							1	89.2
MKT-12			212							1.7	145.5
MKT-122	16	20	70	14	32	36	121	2	41	.5	45.7
MKT-128	15	18	23	14	33	55	121	1	54	.26	22.3
MKT-136			135							1.1	95
MKT-145			57							.23	20.1
MKT-18			18							1.6	136.4
MKT-23			275							2.4	207.4
MKT-25	14	18	120	14	33	46	121	1	8	1.2	103.7
MKT-31			50							.3	28.8
MKT-33			20							.1	11.8
MKT-46			32							.2	14.4
MKT-48			22							.2	14.7
MKT-67			30							.2	20.9
MLB-110			23							.62	52.5
MLB-113			23							.2	20.5
MLB-20			21							.1	12.3
MLB-32	8	9	25	14	41	6	120	56	23	.2	13.3
MLB-57	9	10	22	14	40	13	120	57	11	.2	18.4
MNL-101			9							.1	4.6
MNL-148	10	13	33	14	37	57	120	57	54	.32	27.5
MRK-3	19	13	120	14	37	39	121	4	40	1.1	93.6
MTB-15	24	5	240	14	43	32	121	8	33	1.47	124.9
MTL-1	16	32	12	14	23	51	121	2	36	.1	9.9
MTL-147	17	26	750	14	27	52	121	3	11	.98	85
MTL-148	16	32	195	14	23	30	121	2	37	.62	53.5
MTL-149	17	33	400	14	23	10	121	3	10	4.72	18.2
MTL-150	16	30	350	14	25	7	121	2	37	2.09	194.9
MTL-151	16	31	222	14	24	24	121	2	56	3.24	283.7
MTL-152			1,150							6.41	511.9
MTL-159			1,192							1.95	168.5
MTL-17			580							1.15	99

TABLE 4.4.1 (CONTINUATION)

MTL-22			40							.3	25.4
MTL-23			70							.5	44.5
MTL-27			31							.3	25.9
MTL-34			455							1.2	100.8
MTL-44			110							.8	72
MTL-59			13							.1	11.2
MTL-69			105							.8	71.5
MTL-7			68							.6	49.4
MTL-8			13							.1	6.7
MTL-91			40							.3	24.5
NAV-17	7	9	30	14	40	54	120	56	2	.3	21.6
NAV-3			45							.3	28.8
NAV-4			38							.3	25.2
NAV-8			30							.2	19.2
NOV-5			302							1.67	142.8
NOV-6	2	30	217							2.24	196.8
NOV-7	3	29	592	14	25	59	120	52	41	4.16	369.4
PRN-135			105							.9	74.1
PRN-14			13							.1	11.7
PRN-153	12	24	48	14	29	18	120	59	25	.2	17.9
PRN-154			85							.66	57.1
PRN-155			80							.38	32.7
PRN-156			55							.56	48.7
PRN-157			14							.12	10.8
PRN-20	14	26	197	14	28	6	121	0	45	1.6	144
PRN-66			35							.3	24
PRN-74			55							.4	38.6
PRN-77	13	23	135							1.1	95.5
PRN-78	13	23	65							.5	39.3
PRN-8			61							.5	44.2
PSC-20			100							.86	74.8
PSC-44			9							.1	12.8
PSC-49	13	21	81	14	31	50	121	0	24	.6	51.8
PSC-55			33							.3	23.6
PSC-69			16							.13	11.2
PSG-12	18	16	47							.4	36.6
PSG-186	20	14	207	14	37	0	121	5	38	.85	74.1
PSG-187			81							.48	41.6
PSG-188			107							.54	46.4
QCT-121			45							.3	28.1
QCT-122			135							1.2	99.7
QCT-195	20	8	30							.2	19.3
QCT-250	16	6	109	14	43	20	121	2	16	.9	80.6
QCT-251	15	8	63	14	41	56	121	1	56	.5	46.5
QCT-257	15	10	110	14	40	25	121	1	37	.9	79.2
QCT-269	18	13	100	14	37	36	121	4	19	.7	56.2
QCT-276	12	13	15	14	38	11	120	59	46	.1	11.7
QCT-277	12	13	8	14	37	45	120	59	46	.1	6.6
QCT-330	20	8	45	14	41	54	121	5	41	.4	38.4
QCT-65			22							.2	15.2
QCT-86			130							1.2	103.7
ROS-10	0	30	402	14	24	52	120	50	47	1.39	116.6
ROS-11	1	30	352	14	24	54	120	51	32	1.66	143.6
ROS-12	1	30	340	14	24	57	120	51	42	1.43	125.6
ROS-13	2	30	490	14	25	2	120	51	50	.95	83.3
ROS-14	2	30	265	14	25	7	120	51	58	1.07	93.1
ROS-15	2	30		14	25	10	120	52	8	1.6	136.8
ROS-16	0	29	230	14	25	59	120	50	56	1.77	153
ROS-17	1	31	266							2.37	214.6
ROS-18			235							1.56	136.9
SJN-6			29							.2	21.2
SMT-10			125							.94	81.6
SMT-11			1,150							4.31	354.2
SMT-2	21	9	365	14	40	32	121	6	35	2.9	252
SMT-3	23	7	70	14	42	24	121	7	34	.6	50.4

TABLE 4.4.1 (CONTINUATION)

SMT-4	23	7	40	14	42	21	121	7	38	.3	22.4
SPD-5			600							7	597.2
TGG-138	17	23	166	14	30	44	121	3	19	.8	68.8
TGG-139	17	23	150	14	30	7	121	3	8	.57	47.3
TGG-16			10							.1	7.6
TGG-18	18	21	87	14	31	51	121	4	19	.7	58.8
TGG-19	18	23	70	14	30	40	121	3	52	.6	49.7
TGG-24			320							2.6	224.6
TGG-32			51							.4	34.6
TGG-48			30							.2	18.6
TGG-97	16	23	52	14	30	13	121	2	51	.48	41.4
TNZ-2			150							1.1	91.2
TNZ-3			495							3.3	271.3
TYY-10	23	17	700	14	34	31	121	7	57	5.7	493.7
TYY-11	23	18	330	14	34	3	121	7	32	2.7	230.4
VLZ-106	8	7	14							.1	12.7
VLZ-125	11	8	25	14	41	18	120	59	8	.27	27.3
VLZ-18	11	9	38	14	40	38	120	59	1	.3	27
VLZ-212	10	8	65	14	41	25	120	57	47	.3	23.8
VLZ-213	8	7	114	14	42	38	120	56	53	.6	53.2
VLZ-214	9	7	110	14	42	31	120	57	44	.8	69.1
VLZ-215	9	6	64	14	43	5	120	57	27	.47	41
VLZ-216			17							.65	57
VLZ-37	11	9	13	14	40	50	120	58	59	.1	9.8
AGN-T351	25	21	6							.2	14.5
ATP-10			324							.8	73.3
CTA-T201	22	16	94							.7	62.1
MKT-T01	14	19	57							.3	25.8
MTL-T01	16	28	504							3	262.3
MTL-T02	15	32	27							5.3	46.2
NAV-T02	9	12	62							.3	24.8
NAV-T01	9	12	93							.4	36.1
PRN-T01	16	28	149							1.7	147.7
PRN-T02	16	27	5							.1	7.2
PRN-T03	10	26	5							.1	6.7
PRN-T101	12	26	55							1.4	118.6
PRN-T206	14	27	92							1.2	102.5
PRN-T212	16	27	3							.1	7.2
PRN-T304	13	24	30							.1	6
PRN-T305	15	26	10							.04	3.9
PSG-T01	19	18	81							.5	41.2
PSG-T351	22	15	396							2.1	183.3
PSC-T01	15	23	22							.2	17.4
QCT-T304	15	11	118							.1	6.4
QCT-T353	16	8	87							1.2	105.2
QCT-T357	17	7	47							.4	30.6
ROS-10			229								
TGG-T351	18	22	15							.6	53.9
TGG-T352	16	25	2							.04	3.8
VLZ-T02	8	6	274							.7	60.6
VLZ-T209			59							.6	55.5
MLB-21	9	10	14.7	14	40	3	120	57	38		10.2
NAV-5	9	12	8.5	14	38	54	120	57	15		6.83
CTA-18	22	16	61.8	14	35	18	121	6	58		13.7
MTL-147	17	26	63.7	14	27	52	121	3	11		40.7
SMT-1	22	8	400	14	41	54	121	7	10		151
QCT-202	18	5	51	14	44	11	121	3	56		70.7
MTB-1	23	5	106	14	43	53	121	8	5		87.4
CVC-15	3	26	12	14	28	26	120	53	13		5.82
ATP-4	26	16	278	14	35	16	121	10	4		42.4
ATP-10	26	16	251	14	35	39	121	10	15		53.6
MTL-149	17	33	223	14	23	10	121	3	10		56.3
QCT-269	18	13	320	14	37	36	121	4	19		144
QCT-195	20	8	32.7	14	41	54	121	5	32		30.7
SMT-II	21	9	197	14	40	32	121	6	35		104

TABLE 4.4.1 (CONTINUATION)

TGG-138	17	23	103	14	30	44	121	3	19		68.2
LPS1-1	11	25	54.3								20.5
LPS1-2	11	25	31.8								35.7
LPS1-3	11	25	115.6								42.2
LPS2-1	10	26	12.7								9.6
LPS2-2	10	26	22.7								16.8
LPS2-3	10	26	218.5								156.3
LPS3	10	27	33.6								19.7
ATP-2			8.8								1.6

TABLE 4.4.2 ESTIMATED TRANSMISSIVITY VALUES OF MWSS WELLS

MWSS No.	X	Y	Transmissivity 1.22*SC	LATI D	LATI M	LATI S	LONGI D	LONGI M	LONGI S	SC (lps/m)	SC (m^2/d)
ATP-0	26	16	73.8	14	35	39	121	10	15	.7	60.5
ATP-1	26	16	52.7	14	35	25	121	10	29	.5	43.2
ATP-2	27	17	98.0	14	35	14	121	10	39	.93	80.4
ATP-3	27	17	71.7	14	34	58	121	10	35	.68	58.8
ATP-4	26	16	41.1	14	35	16	121	10	4	.39	33.7
ATP-5	26	17	44.3	14	34	54	121	10	12	.42	36.3
ATP-6	27	17	131.8	14	34	55	121	10	50	1.25	108.0
ATP-29	27	13	9.5	14	37	39	121	10	53	.09	7.8
ATP-31	26	13	459.6	14	37	44	121	9	58	4.36	376.7
ATP-54	26	17	168.7	14	35	10	121	10	21	1.6	138.2
ATP-73	27	16	148.6	14	35	35	121	10	48	1.41	121.8
ATP-101	27	16	126.5	14	35	31	121	10	55	1.2	103.7
ATP-102	26	13	13.7	14	37	35	121	9	51	.13	11.2
BCR-1	8	27	66.4	14	27	20	120	56	23	.63	54.4
BCR-2	8	27	72.7	14	27	42	120	56	17	.69	59.6
BCR-3	7	27	62.2	14	27	17	120	55	43	.59	51.0
BCR-4	9	27	210.8	14	27	22	120	57	17	2	172.8
BCR-5	9	26	121.2	14	27	50	120	57	22	1.15	99.4
CTA-0	22	17	200.3	14	34	48	121	7	4	1.9	164.2
CTA-17	22	17	52.7	14	34	46	121	6	57	.5	43.2
CTA-18	22	16	52.7	14	35	18	121	6	58	.5	43.2
CTA-19	23	18	231.9	14	34	20	121	7	43	2.2	190.1
CTA-20	21	13	101.2	14	38	9	121	6	19	.96	82.9
CTA-66	22	13	79.1	14	38	7	121	6	52	.75	64.8
CTA-67	21	17	68.5	14	34	58	121	6	28	.65	56.2
CTA-75	22	18	164.4	14	34	21	121	7	18	1.56	134.8
CLC-37	12	10	21.1	14	39	56	120	59	48	.2	17.3
CLC-36	12	10	64.3	14	40	15	120	59	42	.61	52.7
CLC-39	12	11	44.3	14	39	2	120	59	18	.42	36.3
CVC-1	5	25	23.2	14	29	2	120	54	27	.22	19.0
CVC-2	5	25	25.3	14	29	3	120	54	17	.24	20.7
CVC-3	4	25	61.1	14	29	0	120	53	57	.58	50.1
CVC-4	4	25	15.8	14	29	7	120	53	59	.15	13.0
CVC-5	5	24	23.2	14	29	25	120	54	7	.22	19.0
CVC-6	4	24	72.7	14	29	28	120	53	58	.69	59.6
CVC-7	4	24	148.6	14	29	31	120	53	50	1.41	121.8
CVC-8	4	24	24.2	14	29	25	120	53	38	.23	19.9
CVC-9	4	24	110.7	14	29	17	120	53	46	1.05	90.7
CVC-10	4	25	21.1	14	29	10	120	53	52	.2	17.3
CVC-11	4	25	28.5	14	29	6	120	53	39	.27	23.3
CVC-12	4	25	27.4	14	28	57	120	53	49	.26	22.5
CVC-13	4	25	147.6	14	28	57	120	53	41	1.4	121.0
CVC-14	4	25	179.2	14	28	42	120	53	25	1.7	146.9
CVC-15	3	26	73.8	14	28	26	120	53	13	.7	60.5
CVC-16	3	26	89.6	14	28	4	120	52	57	.85	73.4
CVC-17	3	26	71.7	14	27	57	120	52	57	.68	58.8
CVC-18	4	25	44.3	14	28	59	120	53	21	.42	36.3
CVC-19	4	25	122.3	14	28	43	120	53	40	1.16	100.2
IMS-1	8	29	61.1	14	25	38	120	56	17	.58	50.1
IMS-2	7	29	8.4	14	26	2	120	56	12	.08	6.9
IMS-3	7	29	126.5	14	25	48	120	56	4	1.2	103.7
IMS-21	7	29	102.2	14	25	52	120	56	2	.97	83.8
KWT-1	7	27	54.8	14	27	8	120	55	39	.52	44.9
KWT-2	6	27	15.8	14	27	27	120	55	17	.15	13.0
KWT-4	5	28	175.0	14	26	37	120	54	9	1.66	143.4
LPS-37	11	26	79.1	14	28	19	120	58	36	.75	64.8
LPS-39	11	26	108.6	14	28	22	120	58	38	1.03	89.0
LPS-63	11	25	27.4	14	29	10	120	58	53	.26	22.5
LPS-64	11	25	221.4	14	28	52	120	58	33	2.1	181.4
LPS-62	11	25	28.5	14	28	58	120	58	56	.27	23.3
MKT-1	15	18	32.7	14	34	11	121	1	30	.31	26.8

TABLE 4.4.2 (CONTINUATION)

MKT-5	14	18	19.0	14	33	52	121	1	14	.18	15.6
MKT-8	14	19	279.3	14	33	25	121	1	17	2.65	229.0
MKT-9	15	19	11.6	14	33	45	121	2	0	.11	9.5
MKT-16	14	18	71.7	14	33	51	121	0	45	.68	58.8
MKT-17	15	19	216.1	14	33	38	121	2	10	2.05	177.1
MKT-19	15	18	22.1	14	33	50	121	1	39	.21	18.1
MKT-22	16	19	4.2	14	33	44	121	2	20	.04	3.5
MKT-25	14	18	126.5	14	33	46	121	1	8	1.2	103.7
MKT-26	14	19	114.9	14	33	14	121	0	53	1.09	94.2
MKT-28	15	19	209.8	14	33	38	121	1	52	1.99	171.9
MKT-30	14	19	34.8	14	33	12	121	1	2	.33	28.5
MKT-32	15	19	17.9	14	33	9	121	1	42	.17	14.7
MKT-128	15	18	27.4	14	34	12	121	1	42	.26	22.5
MKT-122	16	20	52.7	14	32	36	121	2	41	.5	43.2
MLB-0	9	8	26.4	14	41	18	120	57	9	.25	21.6
MLB-0	9	8	55.9	14	41	16	120	57	31	.53	45.8
MLB-21	9	10	16.9	14	40	3	120	57	38	.16	13.8
MLB-32	8	9	21.1	14	41	6	120	56	23	.2	17.3
MLB-57	9	10	23.2	14	40	13	120	57	11	.22	19.0
MDL-10	16	17	111.7	14	34	56	121	2	17	1.06	91.6
MDL-63	15	18	12.6	14	34	25	121	1	53	.12	10.4
MRK-1	21	11	3.2	14	39	36	121	6	10	.03	2.6
MRK-3	19	13	115.9	14	37	39	121	4	40	1.1	95.0
MRK-4	20	11	168.7	14	39	5	121	5	37	1.6	138.2
MTB-1	23	5	161.3	14	44	7	121	8	5	1.53	132.2
MTB-15	24	5	154.9	14	43	32	121	8	33	1.47	127.0
MTL-1	16	32	11.6	14	23	51	121	2	36	.11	9.5
MTL-147	17	27	103.3	14	27	42	121	3	11	.98	84.7
MTL-148	16	32	65.4	14	23	30	121	2	37	.62	53.6
MTL-149	17	33	497.5	14	23	10	121	3	10	4.72	407.8
MTL-150	16	30	220.3	14	25	7	121	2	37	2.09	180.6
MTL-151	16	31	341.5	14	24	8	121	2	56	3.24	279.9
NAV-5	9	12	16.9	14	38	54	120	57	15	.16	13.8
NAV-17	7	9	31.6	14	40	54	120	56	2	.3	25.9
NOV-5	2	30	176.0	14	25	17	120	52	26	1.67	144.3
NOV-6	3	30	236.1	14	25	21	120	52	35	2.24	193.5
NOV-7	3	29	438.5	14	25	59	120	52	41	4.16	359.4
PRN-19	13	26	54.8	14	28	24	121	0	14	.52	44.9
PRN-20	14	26	168.7	14	28	6	121	0	45	1.6	138.2
PRN-37	12	23	75.9	14	30	16	120	59	41	.72	62.2
PRN-73	12	23	4.2	14	30	1	120	59	24	.04	3.5
PRN-78	13	23	527.0	14	30	32	121	0	28	5	432.0
PRN-153	12	24	21.1	14	29	18	120	59	25	.2	17.3
PRN-74	12	24	421.6	14	29	43	120	59	17	4	345.6
PSC-0	13	21	87.5	14	31	59	121	0	19	.83	71.7
PSC-0	13	21	30.6	14	31	41	121	0	35	.29	25.1
PSC-49	13	21	64.3	14	31	50	121	0	24	.61	52.7
PSC-62	14	22	52.7	14	31	4	121	1	6	.5	43.2
PSC-63	14	22	40.1	14	31	3	121	1	3	.38	32.8
PSC-69	12	19	13.7	14	33	3	120	59	57	.13	11.2
PSC-77	13	22	160.2	14	30	54	121	0	11	1.52	131.3
PSG-20	19	19	11.6	14	33	36	121	4	40	.11	9.5
PSG-42	19	14	209.8	14	36	54	121	4	56	1.99	171.9
PSG-186	20	14	93.8	14	37	0	121	5	38	.89	76.9
QCT-195	20	8	24.2	14	41	54	121	5	32	.23	19.9
QCT-197	20	8	50.6	14	41	35	121	5	37	.48	41.5
QCT-199	18	7	65.4	14	42	11	121	4	11	.62	53.6
QCT-201	18	7	120.2	14	42	39	121	4	17	1.14	98.5
QCT-202	18	5	34.8	14	44	11	121	3	56	.33	28.5
QCT-203	18	6	84.3	14	43	29	121	3	57	.8	69.1
QCT-204	18	6	94.9	14	43	10	121	3	48	.9	77.8
QCT-205	18	5	94.9	14	43	53	121	3	51	.9	77.8

TABLE 4.4.2 (CONTINUATION)

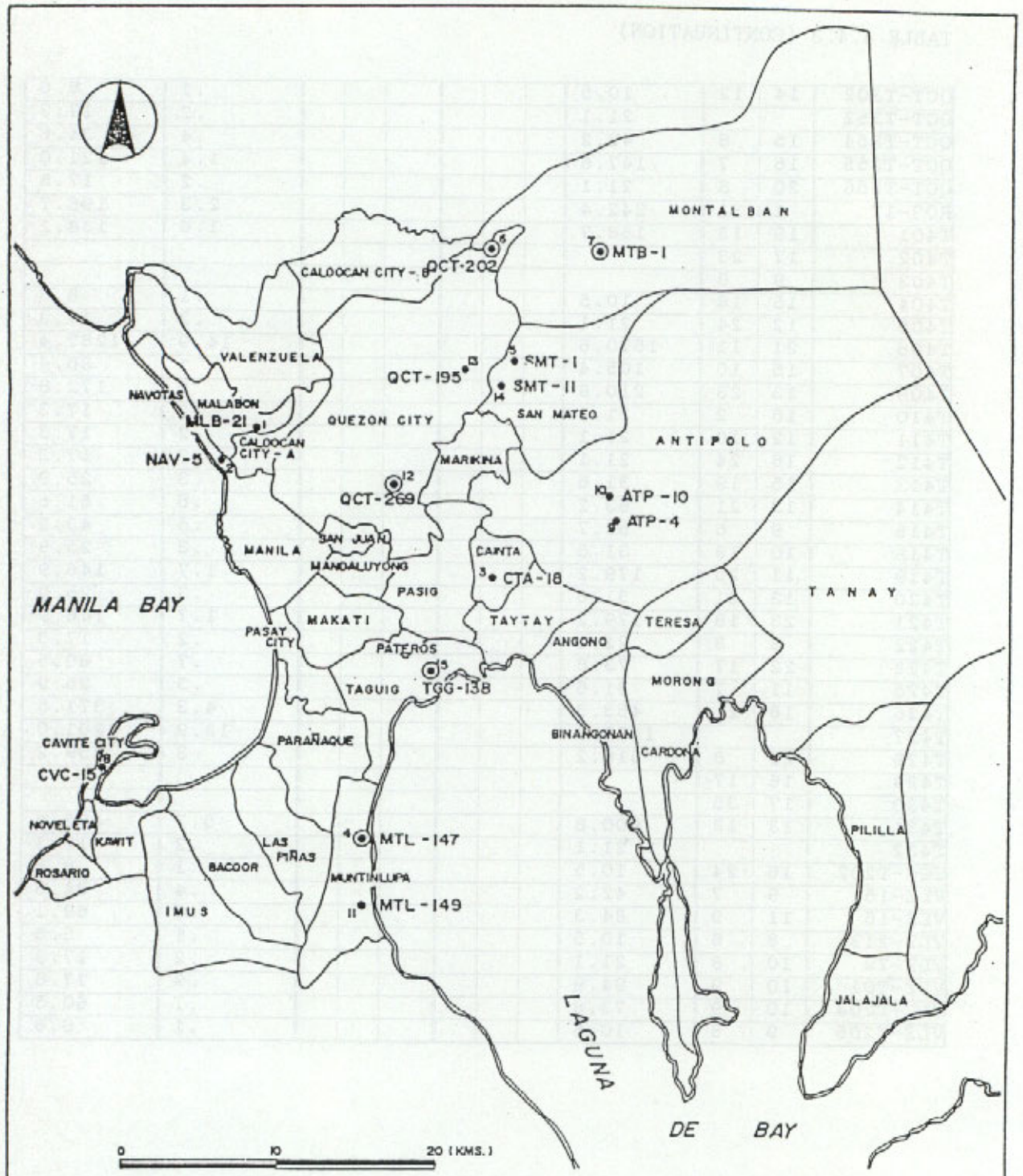
QCT-209	17	7	186.6	14	42	40	121	3	41	1.77	152.9
QCT-250	16	6	94.9	14	43	20	121	2	16	.9	77.8
QCT-251	15	8	52.7	14	41	56	121	1	56	.5	43.2
QCT-257	15	10	94.9	14	40	25	121	1	37	.9	77.8
QCT-269	18	13	73.8	14	37	36	121	4	19	.7	60.5
QCT-276	12	13	10.5	14	38	11	120	59	46	.1	8.6
QCT-277	12	13	10.5	14	37	45	120	59	46	.1	8.6
QCT-330	20	8	47.4	14	41	54	121	5	41	.45	38.9
ROS-10	0	30	42.2	14	24	52	120	50	47	.4	34.6
ROS-11	1	30	175.0	14	24	54	120	51	32	1.66	143.4
ROS-12	1	30	150.7	14	24	57	120	51	42	1.43	123.6
ROS-13	2	30	100.1	14	25	2	120	51	50	.95	82.1
ROS-14	2	30	112.8	14	25	7	120	51	58	1.07	92.4
ROS-15	2	30	168.7	14	25	10	120	52	8	1.6	138.2
ROS-16	0	29	249.8	14	25	59	120	50	56	2.37	204.8
SMT-0	22	8	315.2	14	41	41	121	6	48	2.99	258.3
SMT-2	21	9	305.7	14	40	32	121	6	35	2.9	250.6
SMT-3	23	7	63.2	14	42	24	121	7	34	.6	51.8
SMT-4	23	6	31.6	14	42	47	121	7	47	.3	25.9
TGG-18	18	21	73.8	14	31	51	121	4	19	.7	60.5
TGG-19	18	23	63.2	14	30	40	121	3	52	.6	51.8
TGG-20	18	21	154.9	14	32	10	121	3	58	1.47	127.0
TGG-97	16	23	21.1	14	30	13	121	2	51	.2	17.3
TGG-138	17	23	84.3	14	30	44	121	3	19	.8	69.1
TGG-139	17	23	60.1	14	30	25	121	3	8	.57	49.2
TYY-0	23	18	171.8	14	33	51	121	7	41	1.63	140.8
TYY-8	23	18	69.6	14	34	9	121	7	45	.66	57.0
TYY-9	23	18	69.6	14	34	17	121	7	49	.66	57.0
TYY-10	23	17	600.8	14	34	31	121	7	57	5.7	492.5
TYY-11	23	18	284.6	14	34	3	121	7	32	2.7	233.3
TYY-47	23	18	47.4	14	34	29	121	7	48	.45	38.9
VLZ-0	8	7	14.8	14	42	20	120	56	52	.14	12.1
VLZ-8	11	9	32.7	14	40	50	120	58	59	.31	26.8
VLZ-18	11	9	31.6	14	40	38	120	59	1	.3	25.9
VLZ-37	11	9	10.5	14	40	34	120	58	59	.1	8.6
VLZ-125	11	8	28.5	14	41	18	120	59	8	.27	23.3
VLZ-212	10	8	31.6	14	41	25	120	57	47	.3	25.9
VLZ-213	8	7	63.2	14	42	38	120	56	53	.6	51.8
VLZ-214	9	7	84.3	14	42	31	120	57	44	.8	69.1
VLZ-215	9	6	49.5	14	42	52	120	57	27	.47	40.6

TABLE 4.4.3 SPECIFIC CAPACITY DATA AND ESTIMATED TRANSMISSIVITY (COLLECTED BY THE STUDY TEAM)

WELL No.	X	Y	T (SC*1.22) (m^2/d)	LATI D	LATI M	LATI S	LONGI D	LONGI M	LONGI S	SC (lps/m)	SC (m^2/d)
ATP-8			137.0							1.3	112.3
ATP-T301	24	13	10.5							.1	8.6
ATP-T302			1.1							.01	.9
ATP-T351	23	14	3.2							.03	2.6
BCR-1	7	27	221.4							2.1	181.4
BCR-2	7	27	73.8							.7	60.5
BCR-5	8	27	84.3	14	27	24	120	56	32	.8	69.1
CTA-17	22	17	158.1							1.5	129.6
CTA-27	22	17	21.1							.2	17.3
IMS-2	7	29	105.4							1	86.4
KWT-3	4	28	179.2							1.7	146.9
LPS-37	11	26	94.9							.9	77.8
MDL-47	16	17	63.2							.6	51.8
MDL-55	17	16	73.8							.7	60.5
MDL-T201			2.1							.02	1.7
MKT-129			31.6							.3	25.9
MKT-68	14	19	94.9							.9	77.8
MKT-71	14	19	52.7							.5	43.2
MKT-73	15	18	42.2							.4	34.6
MKT-74	15	18	63.2							.6	51.8
MKT-75	15	18	31.6							.3	25.9
MKT-76	13	19	115.9							1.1	95.0
MKT-78	14	20	42.2							.4	34.6
MNL-T202	11	18	1.1							.01	.9
MNL-T203	11	17	7.4							.07	6.0
MNL-T204	10	17	10.5							.1	8.6
MTL-10	17	28	316.2							3	259.2
MTL-11	17	28	158.1							1.5	129.6
MTL-13	16	30	421.6							4	345.6
MTL-14	16	30	5765.8							54.7	4726.1
MTL-2	16	29	63.2							.6	51.8
MTL-3	16	27									
MTL-6	16	28	168.7							1.6	138.2
MTL-9			769.5							7.3	630.7
MTL-T202	16	30	21.1							.2	17.3
MTL-T203	15	30	115.9							1.1	95.0
MTL-T204	15	31	115.9							1.1	95.0
MTL-T208	13	30									
NOV-6	2	30	21.1							.2	17.3
PRN-153	12	24	115.9							1.1	95.0
PRN-T104	16	27	21.1							.2	17.3
PRN-T303	16	27	10.5							.1	8.6
PSC-13	14	21	52.7							.5	43.2
PSC-42	12	20	189.7							1.8	155.5
PSC-63	14	22	42.2							.4	34.6
PSG-10	17	16	105.4							1	86.4
PSG-11	18	16	42.2							.4	34.6
PSG-13	17	16	42.2							.4	34.6
PSG-14	19	17	126.5							1.2	103.7
PSG-16	19	18	4.2							.04	3.5
PSG-5	19	17	210.8							2	172.8
PSG-8	17	17	10.5							.1	8.6
PSG-T202	19	17	10.5							.1	8.6
QCT-20	15	14	42.2							.4	34.6
QCT-T01	13	12	579.7							5.5	475.2
QCT-T201	18	14	168.7							1.6	138.2

TABLE 4.4.3 (CONTINUATION)

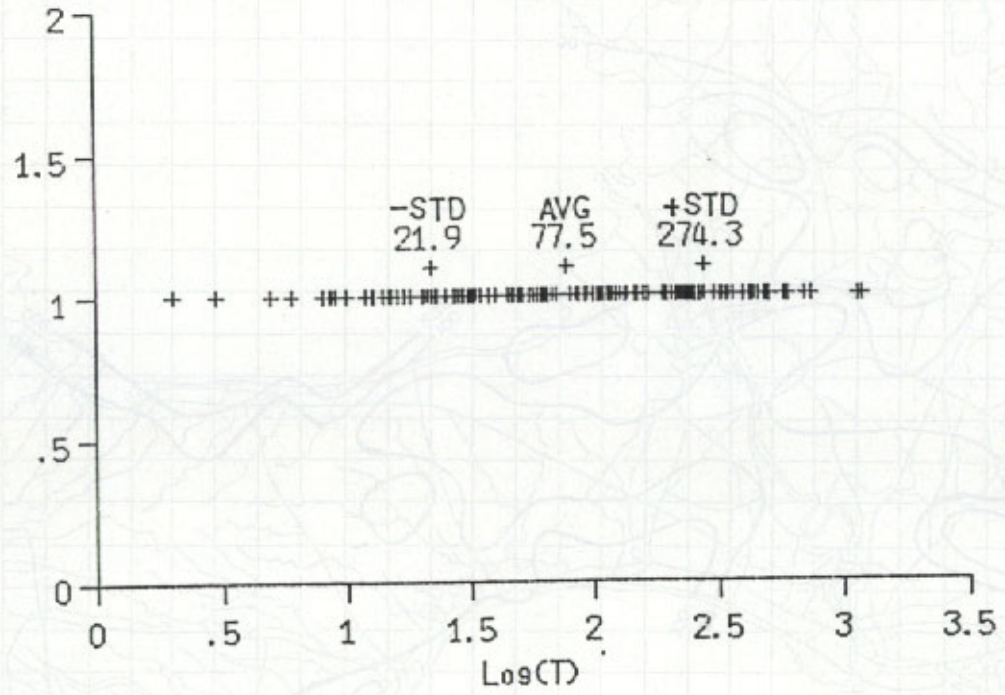
QCT-T302	14	12	10.5							.1	8.6
QCT-T352			21.1							.2	17.3
QCT-T354	15	8	42.2							.4	34.6
QCT-T355	16	7	147.6							1.4	121.0
QCT-T356	20	8	21.1							.2	17.3
ROS-17	1	31	242.4							2.3	198.7
T401	19	13	168.7							1.6	138.2
T402	17	23									
T403	9	8									
T404	15	18	10.5							.1	8.6
T405	12	24	21.1							.2	17.3
T406	21	11	1570.6							14.9	1287.4
T407	15	10	105.4							1	86.4
T408	13	23	210.8							2	172.8
T410	16	2	21.1							.2	17.3
T411	12	10	21.1							.2	17.3
T412	16	24	21.1							.2	17.3
T413	15	19	31.6							.3	25.9
T414	13	21	63.2							.6	51.8
T416	9	6	52.7							.5	43.2
T418	10	13	31.6							.3	25.9
T419	11	25	179.2							1.7	146.9
T420	13	21	31.6							.3	25.9
T421	23	18	179.2							1.7	146.9
T422	8	8	21.1							.2	17.3
T423	22	17	73.8							.7	60.5
T425	11	7	31.6							.3	25.9
T426	18	21	453.3							4.3	371.5
T427			1465.2							13.9	1201.0
T428	22	8	316.2							3	259.2
T429	16	17									
T430	17	35									
T431	13	13	600.8							5.7	492.5
T432			21.1							.2	17.3
TGG-T202	16	24	10.5							.1	8.6
VLZ-15	9	7	42.2							.4	34.6
VLZ-16	11	9	84.3							.8	69.1
VLZ-213	8	8	10.5							.1	8.6
VLZ-79	10	8	21.1							.2	17.3
VLZ-T01	10	9	94.9							.9	77.8
VLZ-T204	10	9	73.8							.7	60.5
VLZ-T206	9	6	10.5							.1	8.6



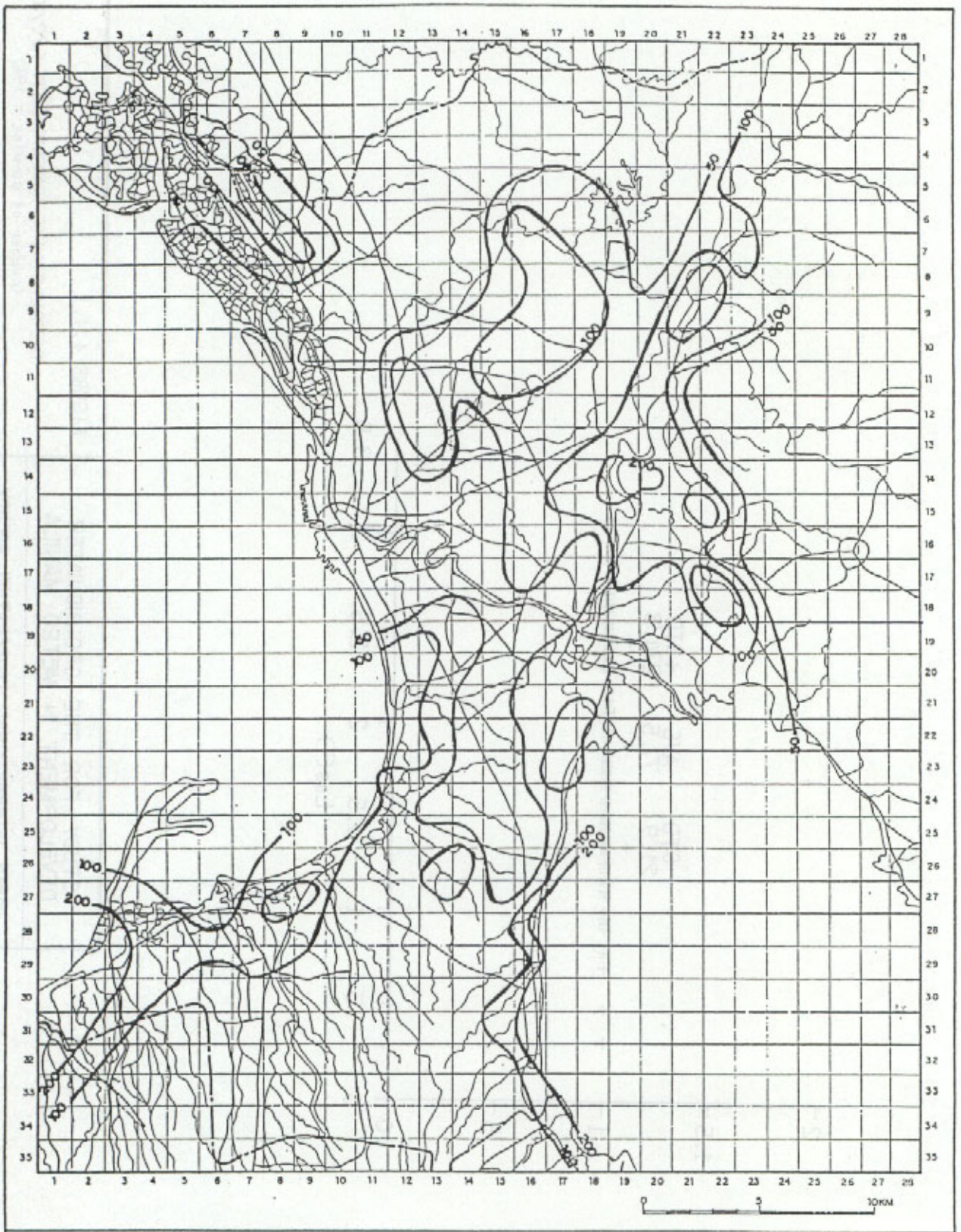
LEGEND :

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

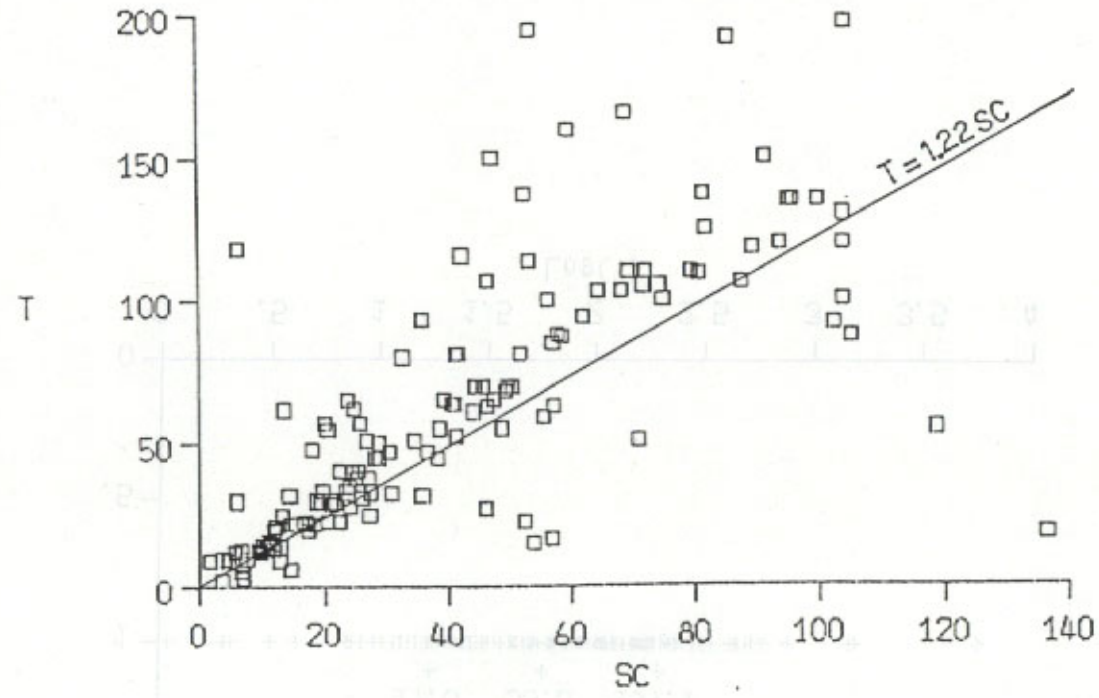
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 4.2.1 FIFTEEN WELLS PUMPING TEST SITES
JAPAN INTERNATIONAL COOPERATION AGENCY	



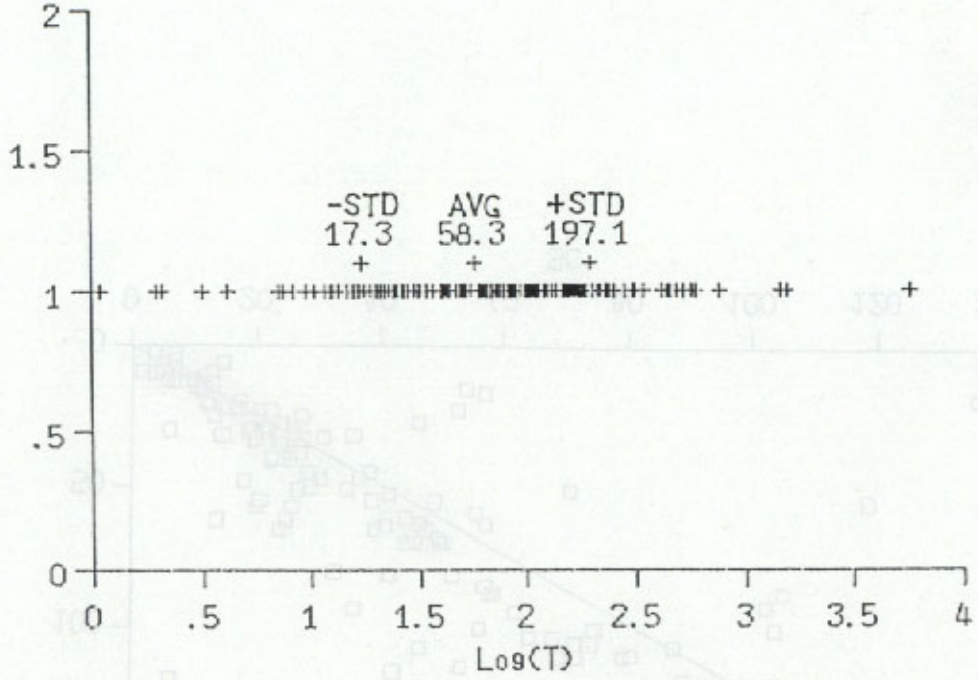
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 4.4.1 DISTRIBUTION OF TRANSMISSIVITY (m^2/d) (number of samples = 196)
JAPAN INTERNATIONAL COOPERATION AGENCY	



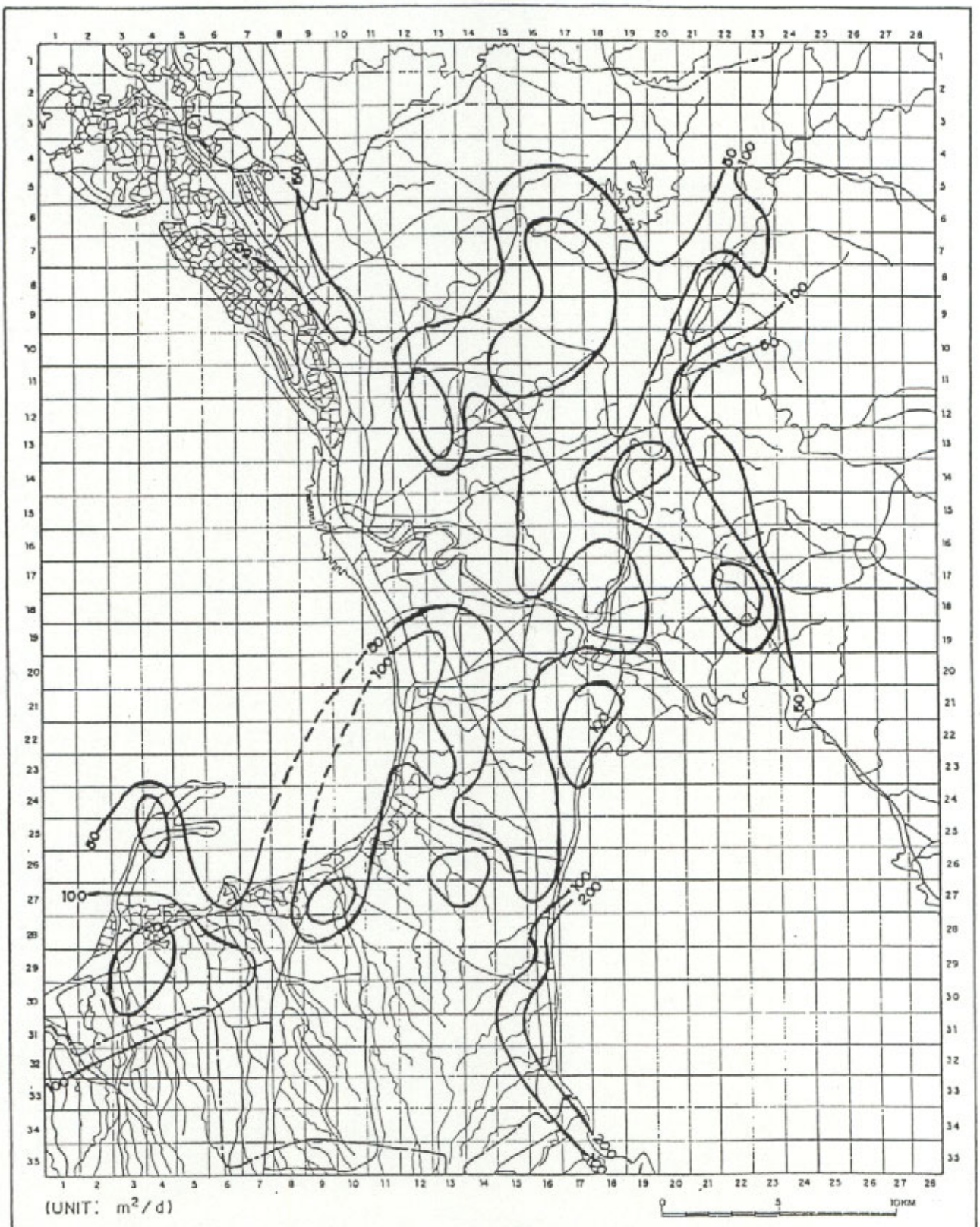
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA JAPAN INTERNATIONAL COOPERATION AGENCY	FIGURE 4.4.2 TRANSMISSIVITY MAP OF METRO MANILA



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 4.4.3 CORRELATION BETWEEN TRANSMISSIVITY AND SPECIFIC CAPACITY (m^2/d)
JAPAN INTERNATIONAL COOPERATION AGENCY	



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 4.4.4 DISTRIBUTION OF TRANSMISSIVITY (m^2/d) (T=1.22*S, Number of samples = 278)
JAPAN INTERNATIONAL COOPERATION AGENCY	



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 4.4.5
ESTIMATED TRANSMISSIVITY MAP FROM SPECIFIC CAPACITY

CHAPTER 5

HYDROLOGICAL OBSERVATIONS

CHAPTER 5 HYDROLOGICAL OBSERVATIONS

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CHAPTER 5 HYDROLOGICAL OBSERVATIONS

5.1 METEOROLOGICAL AND HYDROLOGICAL DATA

Basic hydrological and meteorological data needed for water balance analysis were collected from BRS and PAGASA. These data were then processed and entered into Lotus 123 files. After some counter-checking with the original PAGASA records, these data were transferred into the groundwater database system where they will be preserved and managed.

The meteorological data consist of records of rainfall, temperature, evaporation, relative humidity, wind speed and sunshine hours, while the hydrological data constitute records of discharge.

5.1.1 Meteorological Data

(1) Temperature and Humidity

PAGASA has four (4) synoptic stations recording atmospheric temperature and relative humidity observations. The stations are all situated within the Study Area, specifically in Port Area, Diliman, Pasay City, and Cavite City.

Present data indicate that, on the average, monthly temperature ranges from a minimum of 20°C to a maximum of 35°C. Mean monthly temperature varies from 25°C to 35°C. The coldest months are from December to February while the warmest are April and May.

The monthly average relative humidity ranges from a maximum of 86% to a minimum of 64%. The months of August and September recorded the highest relative humidity readings, while the months of March to May the lowest. Mean annual relative humidity was recorded at 74% for Port Area, 78% for Diliman, 76% for Pasay City and 76% for Cavite City. For the Study Area, annual relative humidity is approximately 76%. Monthly relative humidity plots are presented in Figure 5.1.1.

(2) Evaporation

There is only one (1) evaporation station within the Study Area and it is at the Science Garden in Diliman, Quezon City. The data collected from this station consist of records from 1976 to 1989.

Monthly pan evaporation shows a minimum of 62mm in July 1988 and a maximum of 24mm in May 1978. Estimated annual mean is set at 1,649mm (Refer to Figure 5.1.1)

(3) Rainfall

Monitoring of rainfall has been done in the Study Area as early as 1865 at Port Area, and since 1956 by the PAGASA. There are presently twenty four (24) rainfall stations within the Study Area, all manage by PAGASA. Table 5.1.1 lists the coordinates and periods of records of the stations. The approximate point locations of the stations are plotted in Figure 5.1.2.

The mean monthly rainfall values of the selected stations are plotted in Figure 5.1.3. Based on the given figure, it may be noted that much of the rainfall occurs from May to November, with August generally as the month of heaviest precipitation. Annual rainfall ranges from 1684mm (as observed in Cavite City) to 2356mm (as observed in Diliman). On the other hand, monthly mean varies from 2.1mm (as observed in Cavite City) to 505mm (as observed in Diliman).

5.1.2 Hydrological Data

Twelve (12) stream-gaging stations are within the Study Area and these were established by the former Bureau of Public Works (BPW). They are presently managed by the Bureau of Research and Standard (BRS). Streamflow observations started as early as the 1950s, and mainly at the Pasig River. The respective coordinates, drainage areas and periods of records of the different gaging stations are provided in Table 5.1.2; the approximate point locations are shown in Figure 5.1.4. The mean monthly values of the selected stations are plotted in Figure 5.1.5

5.2 SIMULTANEOUS HYDROLOGICAL OBSERVATIONS

Simultaneous hydrological observations were carried out in the Metro Manila groundwater basin area and the Antipolo Plateau. These observations were done at the end of the wet season (November 1990), at the end of the dry season (April 1991), and at the peak of the wet season (August 1991). Observation items include groundwater levels of wells in both areas, and spring and stream flows around the Antipolo Plateau.

5.2.1 Groundwater Leveling

(1) Simultaneous Observations

The purposes of groundwater leveling are:

- To prepare a groundwater contour map of the Study Area
- To investigate the changes between the 1981 and 1990 ground water levels in the study Area.
- To determine the seasonal changes of groundwater levels in the Study Area

The aforecited three simultaneous observations of groundwater levels were done by MWSS Staff under the supervision of the Study Team. Figure 5.2.1 shows the approximate locations of the 231 observation wells. Of the 231 wells, 117 were measured in November 1990, 190 in May 1991, and 152 in August 1991. Some of the wells previously visited were excluded from the observation because they were already operational, clogged, filled up, or simply unreliable.

Details of the survey data on groundwater leveling are given in the Data Report of this Study.

Comparison of the results of these three measurements indicates that some of the measurements were affected by either tidal fluctuations (those wells near the shore) or nearby pumping.

Of the 231 observation wells, only 204 were considered in the prepara-

tion of groundwater contour maps. The other wells were unreliable. Missing data were estimated using regression analysis. Table 5.2.1 presents three sets of augmented groundwater level data together with the observation wells' geographical location. Groundwater contours were calculated and plotted using computer programs. These programs provide nodal or grid values for the piezometric contours, which are important input data for groundwater modeling.

Figures 5.2.2, 5.2.3 and 5.2.4 show the observed piezometric contours in MSA in November 1990, May 1991 and August 1991, respectively. Figures 5.2.5, 5.2.6 and 5.2.7 show the piezometric contours in the Antipolo basin during the said periods.

(2) Continuous Observations

For the continuous monitoring of groundwater levels, 10 automatic water level recorders were installed: 5 in Las Piñas (Site No. 1: Wells 1 and 3, Site No. 2: Wells 1 and 3, and Site No 3: Well 1); 2 in Antipolo (JICA Test Well and new in MWSS Well in Buliran); 1 in Makati (abandoned MWSS Well in Magallanes Village); 1 in Quezon City (inactive MWSS Well in D. Tuazon Pumping Station); and 1 in Valenzuela (abandoned MWSS Well in Marulas Elementary School). Their locations are shown in Figure 5.2.8. Charts of said automatic water level recorders are collected monthly and processed by MWSS Staff.

Figures 5.2.9 (a) to (j) show the observed groundwater level hydrographs of these 10 wells.

5.2.2 Spring/Stream Flow Measurements

The discharge measurement aims for a quantitative estimate of the groundwater outflow from the Antipolo Plateau. This estimate shall be used in making a detailed water balance analysis of this area.

The Antipolo Plateau is located on the eastern portion of the Study Area. It sits on an area of about 22km^2 at an elevation of 200m above sea level. The Antipolo proper is drained by streams flowing westward to Marikina Valley or cascading through steep cliffs. Streams located east and north of the plateau originate from springs. Some of the

springs are being used for domestic water supply or irrigation. The streams measured on the northwestern boundary feed the Nangka River. These are: on the western side, the Sapang Baho River and Napindan Creek; southwestern border, the Bogad Creek, Bonguod Creek and Angono River; on the southern portion, the smaller creeks draining into Laguna de Bay; and on the eastern side, the Morong River.

Figure 5.2.10 shows the locations of abovesaid springs and streams. The selection of sites for measurement of discharge considered both the geology and hydrogeology of the area. The discharge measurements points are located just outside the hydrogeological boundaries previously determined during the geological investigation.

Three sets of simultaneous measurements were conducted for 15 small streams and 9 springs. These were done in November 1990 (end of wet season), May 1991 (end of dry season), and August 1991 (during the rainy season). Table 5.2.2 shows the results of measurements.

In November 1990, the spring discharge totaled 212.17 lps, while total stream flow was 1465.761 lps. The total spring flow was 0.85 lps at the end of the dry season (May 1991) and 304.29 lps during the rainy season (August 1991). The spring flows were quite limited-either very low or dry in the dry season. Total stream discharge was 238.36 lps in May 1991 and 3,216.08 lps in August 1991.

TABLE 5.1.1

DETAILS OF RAINFALL STATIONS

No.	LOCATION	COORDINATES LATITUDE	COORDINATES LONGITUDE	TYPE	RESPONSIBLE AGENCY	TIME OF MEASUREMENTS	PERIODS OF RECORD	PRESENT STATUS	DATA BEING OBSERVED
1	OBANDO, BULACAN	14° 43' N	120° 55' E	OR	PAGASA	8AM, 5PM	1969 - 1986	ABANDONED	R
2	CAMARIN, CALOOCAN, M.M.	14° 39' N	120° 58' E	OR	PAGASA	8AM, 5PM	1974 - PRESENT	ACTIVE	R
3	NOVALICHES, QUEZON CITY, M.M.	14° 43' N	121° 02' E	OR	PAGASA	8AM, 5PM	1956 - 1962	ABANDONED	R
4	NAVOTAS, METRO MANILA	14° 39' N	120° 57' E	OR	PAGASA	8AM, 5PM	1972-73; 1975-80	ABANDONED	R
5	ANTIPOLO, RIZAL	14° 35' N	121° 12' E	OR	PAGASA	8AM, 5PM	1972 - PRESENT	ACTIVE	R
6	PASIG, METRO MANILA	14° 34' N	121° 05' E	OR	PAGASA	8AM, 5PM	1976 - PRESENT	ACTIVE	R
7	BPI CUYAMBAY, TANAY, RIZAL	14° 32' N	121° 21' E	AGRO	PAGASA	8AM, 5PM	1970 - PRESENT	ACTIVE	T, SD, E, R
8	MARIKINA, METRO MLA	14° 37' N	121° 06' E	OR	PAGASA	8AM, 5PM	1976 - PRESENT	ACTIVE	R
9	MUNTINLUPA, METRO MANILA	14° 23' N	121° 03' E	OR	PAGASA	8AM, 5PM	1972 - PRESENT	ACTIVE	R
10	LAS PIÑAS, METRO MANILA	14° 29' N	120° 59' E	OR	PAGASA	8AM, 5PM	1976 - 1979	ABANDONED	R
11	QUEZON INSTITUTE, QUEZON CITY, M.M.	14° 37' N	121° 01' E	OR	PAGASA	8AM, 5PM	1972 - 1980	ABANDONED	R
12	BALARA FILTER, QUEZON CITY, M.M.	14° 39' N	121° 05' E	CR	PAGASA	8AM, 5PM	1956 - 1972	ABANDONED	R
13	PORT AREA, MANILA	14° 35' N	120° 58' E	SYNOP	PAGASA	8AM,2PM; 8PM,2AM	1957 - PRESENT	ACTIVE	T, H, WV, R
14	NIA PASAY CITY, METRO MANILA	14° 31' N	121° 00' E	SYNOP	PAGASA	8AM,2PM; 8PM,2AM	1951 - PRESENT	ACTIVE	T, H, WV, R
15	SCIENCE GARDEN, DILIMAN, Q.C.	14° 39' N	121° 03' E	SYNOP	PAGASA	8AM,2PM; 8PM,2AM	1961 - PRESENT	ACTIVE	T, H, WV, R
16	BOSO-BOSO ANTIPOLO, RIZAL	14° 38' N	121° 14' E	OR	PAGASA	8AM, 5PM	1972 - PRESENT	ACTIVE	R
17	ANGONO, RIZAL	14° 31' N	121° 09' E	OR	PAGASA	8AM, 5PM	-	ABANDONED	R
18	SITIO TABAK, MONTALBAN, RIZAL	14° 46' N	121° 11' E	OR	PAGASA	8AM, 5PM	1976 - PRESENT	ACTIVE	R
19	SANGLEY POINT, CAVITE CITY	14° 30' N	121° 55' E	SYNOP	PAGASA	8AM,2PM; 8PM,2AM	1974 - PRESENT	ACTIVE	T, H, WV, R
20	MABOLO ELEM. SCH. BACOOR, CAVITE	14° 27' N	120° 56' E	OR	PAGASA	8AM, 5PM	1975 - PRESENT	ACTIVE	R
21	BAGUMBAYAN, TAGUIG, M.M.	14° 28' N	121° 03' E	OR	PAGASA	8AM, 5PM	1975 - PRESENT	ACTIVE	R
22	TIPAS, TAGUIG, M.M.	14° 31' N	121° 05' E	OR	PAGASA	8AM, 5PM	1975 - PRESENT	ACTIVE	R
23	JUAN SUMULONG, ANTIPOLO, RIZAL			OR	PAGASA	8AM, 5PM	1971 - PRESENT	ACTIVE	R
24	BOS, CUYAMBAY, TANAY RIZAL	14° 35' N	121° 21' E	AGRO	PAGASA	8AM, 5PM	1969 - 1971	ABANDONED	T, SD, E, R

TYPE OF STATION:

OR - OFFICIAL RAINFALL STATION
CR - CLIMATOLOGICAL/COOPERATIVE RAINFALL STATION
AGROMET - AGROMETEOROLOGICAL STATION
SYNOP - SYNOPTIC STATION

NOTE:

R - RAINFALL
T - TEMPERATURE
E - EVAPORATION
H - HUMIDITY
SD - SUNSHINE DURATION
WV - WIND VELOCITY

TABLE 5.1.2

DETAILS OF STREAM GAGING STATIONS

STATION No.	RIVER/LOCATION	RIVER BASIN	COORDINATES LATITUDE	COORDINATES LONGITUDE	DRAINAGE AREA (SQ. KM.)	PERIODS OF RECORD
1	PASIG R - BEATA, PANDACAN, M. M.	PASIG - LAGUNA DE BAY	14° 35' 47"	121° 00' 37"	3923	1945 - 1970
2	PASIG R - SAN JOSE, MAKATI, M. M.	PASIG - LAGUNA DE BAY	14° 34' 13"	121° 02' 40"	3824	1946 - 1974
3	PASIG R - PINEDA, PASIG, M. M.	PASIG - LAGUNA DE BAY	14° 33' 50"	121° 03' 39"	3821	1946 - 1979
4	PASIG R - MCKINLEY, MAKATI, M. M.	PASIG - LAGUNA DE BAY	14° 33' 51"	121° 03' 42"	3807	1958 - 1975
5	MARIKINA R - ROSARIO, PASIG, M. M.	MARIKINA	14° 36' 12"	121° 05' 11"	532	1960 - 1977
6	MARIKINA R - MANGGAHAN, PASIG, M. M.	MARIKINA	14° 35' 12"	121° 05' 22"	527	1959 - 1970
7	MARIKINA R - STO NIÑO, MARIKINA, M. M.	MARIKINA	14° 38' 15"	121° 05' 30"	499	1958 - 1977
						1986 - PRESENT
8	NANGKA R - NANGKA, MARIKINA M. M.	MARIKINA	14° 41' 53"	121° 06' 30"	54	1960 - 1978
9	MARIKINA R - SAN RAFAEL, MONTALBAN, RIZAL	MARIKINA	14° 44' 00"	121° 10' 20"	282	1957 - 1979
10	PASIG R - NAPINDAN, TAGUIG, M. M.	PASIG - LAGUNA DE BAY	14° 32' 28"	121° 05' 44"	3159	1946 - 1978
						1984 - PRESENT
11	LAGUNA LAKE-TAYUMAN, BINANGONAN, RIZAL	PASIG - LAGUNA DE BAY	14° 31' 22"	121° 09' 16"	3158	1959 - PRESENT
12	LAGUNA LAKE - POBLACION, MUNTINLUPA, M. M.	PASIG - LAGUNA DE BAY	14° 21' 29"	121° 02' 46"	3158	1959 - PRESENT

TABLE 5.2.1 OBSERVED PIEZOMETRIC WATER LEVELS

WELL CODE	PIEZOMETRIC WATER LEVEL(m)			LATITUDE			LONGITUDE		
	NOV.'90	MAY '91	AUG.'91	D	M	S	D	M	S
1	76.3	71.3	75.3	14	35	24	121	12	13
3	167.6	163.4	163.6	14	34	47	121	11	23
4	114.5	108.1	112.0	14	37	39	121	10	53
5	114.0	107.6	108.9	14	37	28	121	10	1
6	-5.2	-6.1	-5.7	14	38	6	121	6	58
7	70.6	65.6	65.7	14	37	48	121	8	29
8	67.8	62.9	65.6	14	37	29	121	8	18
9	172.4	168.9	170.9	14	35	55	121	10	45
10	166.2	164.0	164.6	14	34	55	121	10	50
11	163.8	159.6	160.1	14	35	16	121	10	4
12	181.0	174.7	175.6	14	35	35	121	10	48
13	168.4	161.6	164.8	14	35	31	121	10	55
14	168.0	162.7	165.9	14	35	39	121	10	15
15	172.6	167.0	168.8	14	35	25	121	10	29
16	164.6	161.2	164.1	14	35	10	121	10	21
17	168.6	168.4	170.4	14	35	14	121	10	39
18	169.2	162.8	167.9	14	34	54	121	10	12
19	169.1	165.8	167.0	14	34	58	121	10	35
20	171.1	166.8	168.8	14	35	9	121	11	32
21	197.9	192.9	197.8	14	34	11	121	10	52
22	-87.0	-90.5	-93.1	14	27	15	120	56	28
23	-40.0	-42.0	-43.2	14	27	22	120	57	17
24	-51.2	-52.2	-53.0	14	27	42	120	56	17
25	17.8	14.6	17.0	14	24	26	120	59	7
26	18.2	14.9	15.7	14	24	0	120	58	14
27	23.5	20.1	22.5	14	23	58	120	59	17
28	-78.0	-81.2	-83.5	14	43	5	121	0	8
30	-16.4	-17.2	-17.3	14	38	9	121	6	18
32	-36.6	-38.5	-39.6	14	34	45	121	6	55
33	-2.2	-2.9	-1.7	14	37	40	121	7	35
34	-20.5	-20.9	-22.3	14	29	52	120	54	42
35	-20.3	-20.6	-22.1	14	29	59	120	54	47
36	-36.0	-37.8	-38.8	14	28	52	120	53	39
37	-11.1	-12.2	-11.2	14	28	57	120	53	36
38	-34.9	-36.7	-35.7	14	27	57	120	52	57
39	-16.0	-17.2	-17.7	14	29	39	120	54	13
40	3.9	1.5	3.9	14	25	46	120	56	3
41	34.3	32.9	34.7	14	21	58	120	56	17
42	0.3	-0.4	3.1	14	25	50	120	55	10
43	23.9	20.4	22.0	14	23	3	120	56	7
44	5.5	2.7	5.0	14	25	15	120	56	29
45	0.4	-0.3	-0.3	14	26	8	120	56	46
46	33.8	30.0	32.5	14	22	19	120	58	33
47	16.7	13.5	15.7	14	23	51	120	56	12
48	-34.1	-35.9	-36.5	14	26	31	120	54	37
49	-49.3	-51.6	-53.1	14	26	52	120	54	37
51	-28.3	-30.9	-31.2	14	26	1	120	52	38
52	-37.8	-38.6	-39.2	14	27	43	120	57	19

TABLE 5.2.1 (CONTINUATION)

WELL CODE	PIEZOMETRIC WATER LEVEL(m)			LATITUDE			LONGITUDE		
	NOV.'90	MAY '91	AUG.'91	D	M	S	D	M	S
54	-14.8	-16.0	-16.4	14	26	20	121	0	54
55	-7.6	-8.5	-9.1	14	25	40	120	59	48
56	-11.4	-12.5	-11.7	14	26	2	121	0	11
57	-64.2	-67.0	-68.9	14	27	46	120	57	59
58	-42.2	-44.3	-45.5	14	28	17	120	58	29
61	-92.6	-96.3	-99.0	14	26	27	120	58	24
62	-22.8	-23.8	-24.5	14	34	11	121	1	30
63	-21.7	-23.0	-24.1	14	33	52	121	1	14
64	-22.4	-23.8	-25.2	14	33	50	121	1	39
65	-18.6	-19.3	-19.5	14	33	45	121	2	0
67	-27.9	-29.2	-29.7	14	33	38	121	2	10
68	-25.6	-27.4	-28.8	14	33	25	121	1	17
69	-18.8	-21.2	-23.2	14	33	12	121	1	2
70	-18.0	-20.6	-21.9	14	33	46	121	1	8
71	-23.1	-24.5	-25.2	14	33	14	121	0	53
72	-14.0	-15.1	-15.2	14	33	51	121	0	45
74	-33.2	-35.0	-35.1	14	32	15	121	2	5
75	-54.9	-60.6	-59.7	14	32	48	121	1	53
76	-20.3	-21.2	-19.9	14	32	1	121	1	10
77	-24.0	-25.5	-26.2	14	34	4	121	2	9
78	-29.3	-31.0	-31.8	14	33	10	121	1	42
79	-65.0	-62.3	-64.0	14	32	54	121	2	13
80	-72.9	-69.9	-71.9	14	32	36	121	2	7
81	-24.4	-25.9	-26.6	14	33	25	121	2	18
82	-32.1	-33.8	-34.8	14	33	9	121	2	52
83	-34.3	-36.1	-37.2	14	32	44	121	2	36
85	-77.7	-80.6	-82.8	14	40	25	120	59	27
86	-13.9	-15.0	-17.5	14	41	8	120	56	28
87	-32.6	-34.3	-35.3	14	40	13	120	57	11
88	-23.3	-22.7	-23.3	14	34	23	121	2	25
89	-25.4	-26.9	-27.7	14	34	47	121	3	11
90	-21.2	-21.9	-22.9	14	34	51	121	2	32
93	-28.8	-31.0	-31.4	14	36	19	120	59	6
96	-76.9	-80.1	-75.1	14	34	59	120	58	22
97	-69.0	-71.9	-72.3	14	37	53	120	57	56
98	-1.4	-2.1	-2.3	14	37	13	120	58	12
99	4.5	1.7	1.6	14	35	42	121	0	21
100	-5.1	-5.9	-6.0	14	36	33	120	58	19
101	4.0	1.6	3.4	14	39	51	121	6	18
102	4.9	1.6	4.0	14	40	6	121	6	23
104	-21.1	-21.8	-22.4	14	37	39	121	4	39
105	-11.4	-13.2	-11.1	14	39	5	121	5	37
106	15.7	12.5	14.0	14	38	41	121	6	57
107	16.4	13.2	14.3	14	38	28	121	7	1
108	13.2	10.1	11.0	14	38	48	121	7	6
109	22.7	19.3	21.9	14	39	0	121	7	13
112	8.5	5.3	7.2	14	42	50	121	8	15
113	17.7	14.4	19.8	14	44	36	121	7	44

TABLE 5.2.1 (CONTINUATION)

WELL CODE	PIEZOMETRIC WATER LEVEL(m)			LATITUDE			LONGITUDE		
	NOV.'90	MAY '91	AUG.'91	D	M	S	D	M	S
115	13.7	10.6	10.7	14	43	57	121	8	6
116	-5.3	-5.2	-7.8	14	22	53	121	1	46
117	-22.9	-24.3	-25.0	14	27	19	121	2	39
118	-108.3	-112.5	-115.7	14	26	53	121	2	34
119	-11.8	-12.8	-11.1	14	23	50	121	2	35
120	-20.2	-21.5	-18.2	14	27	42	121	3	9
121	-10.0	-11.0	-8.7	14	25	52	121	2	55
122	-12.4	-13.5	-12.1	14	25	9	121	2	35
123	-8.7	-9.7	-7.9	14	23	9	121	3	0
124	-12.2	-13.3	-11.7	14	24	8	121	2	57
125	-80.5	-83.8	-86.6	14	38	26	120	57	22
126	-36.6	-38.4	-39.5	14	38	44	120	57	12
127	-28.6	-30.5	-30.8	14	25	59	120	52	41
128	-33.0	-38.8	-39.9	14	25	32	120	52	32
129	-33.6	-35.3	-34.1	14	25	25	120	52	20
130	-33.0	-34.7	-34.6	14	30	4	121	0	50
131	-18.1	-19.4	-20.5	14	26	31	121	1	16
132	-94.6	-98.4	-101.2	14	27	37	121	0	27
133	-76.8	-80.0	-79.7	14	28	58	121	2	5
134	-39.2	-41.2	-39.3	14	28	36	120	59	24
135	-59.5	-62.1	-61.2	14	29	36	121	2	18
136	-82.4	-85.7	-88.1	14	26	46	121	0	35
137	-23.0	-24.4	-23.7	14	28	24	121	0	14
138	-24.7	-26.2	-27.5	14	29	18	120	59	25
139	-65.7	-69.5	-68.6	14	28	21	121	1	15
140	-66.0	-73.1	-73.4	14	25	58	121	1	9
141	-65.9	-68.7	-70.6	14	26	19	121	1	24
142	-65.2	-68.0	-67.3	14	28	45	121	1	44
143	-66.9	-69.7	-71.7	14	27	5	121	0	19
144	-64.2	-67.0	-68.9	14	28	42	121	2	0
145	-17.6	-18.4	-18.5	14	32	48	120	59	32
146	-52.8	-55.2	-56.7	14	32	37	120	59	38
147	-96.8	-100.6	-103.4	14	33	28	120	59	37
148	-54.9	-57.4	-56.0	14	30	54	121	1	11
149	-41.7	-43.7	-42.1	14	31	27	121	0	57
150	-42.0	-44.1	-43.0	14	31	32	121	1	22
151	-41.9	-43.9	-43.7	14	31	43	121	0	39
152	-0.6	-1.3	-1.0	14	32	38	120	59	28
153	-21.9	-23.8	-23.9	14	32	51	121	5	22
154	-36.4	-38.3	-36.6	14	34	54	121	4	57
155	-20.2	-21.6	-21.8	14	33	18	121	4	15
156	-52.6	-55.0	-56.5	14	35	22	121	4	29
157	-20.0	-21.3	-21.9	14	34	31	121	3	49
158	-49.4	-51.7	-53.2	14	36	57	121	4	57
159	-59.0	-61.6	-66.2	14	36	52	121	5	16
160	-43.6	-45.7	-48.7	14	34	54	121	5	2
162	-41.8	-43.8	-45.0	14	42	13	121	1	19
163	30.6	27.0	26.8	14	40	24	121	5	23

TABLE 5.2.1 (CONTINUATION)

WELL CODE	PIEZOMETRIC WATER LEVEL(m)			LATITUDE			LONGITUDE		
	NOV.'90	MAY '91	AUG.'91	D	M	S	D	M	S
164	-0.5	-1.2	1.2	14	37	28	121	1	35
165	-60.4	-63.1	-65.0	14	38	29	121	2	6
166	50.2	45.9	48.5	14	43	45	121	2	50
167	7.5	4.6	7.0	14	36	54	121	2	3
168	59.1	54.5	57.2	14	43	10	121	3	48
170	-35.2	-37.1	-37.7	14	37	50	121	0	4
171	15.8	12.7	15.1	14	43	50	121	7	2
172	-71.4	-74.4	-76.5	14	36	40	121	4	46
173	-56.2	-58.7	-60.4	14	36	49	121	4	38
174	75.1	69.5	73.7	14	41	33	121	5	15
175	73.6	68.7	71.4	14	41	29	121	5	13
176	63.1	58.4	57.8	14	41	35	121	5	37
178	10.9	7.9	7.6	14	39	40	121	1	49
179	-1.0	-1.7	0.6	14	36	38	121	2	41
180	-47.0	-49.5	-49.6	14	41	55	121	1	21
181	-36.6	-38.4	-39.2	14	40	15	121	2	51
182	24.0	16.8	23.6	14	40	45	121	4	10
183	45.1	40.9	43.5	14	40	53	121	4	59
184	7.3	4.4	2.9	14	38	11	120	59	46
186	63.0	58.2	60.9	14	41	0	121	5	24
188	-40.8	-42.9	-44.1	14	39	54	121	0	2
189	-30.6	-32.6	-33.6	14	40	36	121	2	43
191	-36.7	-38.5	-39.6	14	25	20	120	52	10
192	-25.0	-25.8	-26.6	14	25	3	120	51	33
193	-26.3	-27.9	-28.6	14	25	10	120	51	48
194	-18.8	-20.4	-21.1	14	24	52	120	50	47
195	-14.1	-15.8	-18.6	14	24	59	120	50	56
196	-17.1	-18.3	-17.0	14	36	12	121	1	18
198	73.5	68.4	73.1	14	39	33	121	8	9
199	9.7	6.7	13.0	14	40	59	121	6	59
200	10.9	6.7	7.8	14	41	8	121	6	54
201	15.5	15.3	17.7	14	41	30	121	7	30
202	17.0	13.8	16.2	14	40	49	121	7	35
203	-18.6	-19.9	-18.9	14	29	15	121	3	16
204	-44.1	-49.3	-49.5	14	29	9	121	3	6
205	-21.1	-23.0	-23.4	14	31	51	121	4	8
206	-66.5	-67.0	-65.1	14	30	23	121	2	28
207	-65.8	-68.6	-64.3	14	30	11	121	2	41
208	89.6	83.9	83.8	14	35	5	121	9	5
209	-42.2	-44.2	-45.4	14	34	19	121	7	51
210	-104.9	-110.3	-105.1	14	40	22	120	58	55
211	-72.6	-69.1	-71.0	14	41	58	120	57	42
212	-122.7	-127.4	-130.9	14	40	38	120	59	1
213	-117.6	-122.1	-122.7	14	42	52	120	57	28
214	-57.4	-59.9	-61.6	14	41	58	120	59	27
215	-92.5	-96.2	-95.1	14	44	10	120	57	23
216	-53.7	-56.1	-55.2	14	42	32	120	56	13
217	-61.6	-64.3	-66.1	14	42	31	120	56	17

TABLE 5.2.1 (CONTINUATION)

WELL CODE	PIEZOMETRIC WATER LEVEL(m)			LATITUDE			LONGITUDE		
	NOV.'90	MAY '91	AUG.'91	D	M	S	D	M	S
218	-89.1	-92.7	-93.1	14	42	7	120	56	36
219	-60.5	-62.5	-64.2	14	44	35	120	58	15
220	89.8	84.2	85.1	14	18	14	120	54	26
221	90.2	84.8	87.6	14	18	15	120	55	20
222	75.3	70.2	70.0	14	19	14	120	57	8
223	56.8	52.2	52.5	14	19	55	120	56	15
224	-9.7	-10.7	-10.5	14	22	14	121	2	56
227	-9.4	-10.4	-10.6	14	31	59	121	9	2
228	50.6	46.3	49.4	14	33	38	121	13	1
229	-39.8	-41.7	-44.1	14	28	34	120	58	38
230	-45.0	-47.2	-50.1	14	28	5	120	58	7
231	-55.1	-57.6	-61.8	14	27	35	120	58	8

TABLE 5.2.2

RESULTS OF SPRINGFLOW MEASUREMENTS

STATION CODE	LOCATION	END OF WET SEASON		END OF DRY SEASON	
		DATE OF MEASUREMENT	DISCHARGE (LPS)	DATE OF MEASUREMENT	DISCHARGE (LPS)
H0028	DULONG BAYAN, TERESA, RIZAL	NOV. 29, 1990	1.51	MAY 17, 1991	0
H0029	DULONG BAYAN, TERESA, RIZAL	NOV. 29, 1990	9.22	MAY 17, 1991	0
H0030	GULOD, BINANGONAN, RIZAL (KAISAPAN)	NOV. 29, 1990	11.90	MAY 17, 1991	0
H0031	GULOD, BINANGONAN, RIZAL	NOV. 29, 1990	2.77	MAY 17, 1991	0
H0032	MAPUTING BATO, BINANGONAN, RIZAL (LIBERTY FARMS)	NOV. 29, 1990	140.00	MAY 17, 1991	0
H0033	MAPUTING BATO, BINANGONAN, RIZAL	NOV. 29, 1990	10.69	MAY 17, 1991	0.05
H0034	TAGBAK, ANTIPOLO, RIZAL	DEC. 01, 1990	18.30	MAY 16, 1991	0.80
H0035	TAGBAK, ANTIPOLO, RIZAL	DEC. 01, 1990	17.78	MAY 16, 1991	0

RESULTS OF STREAMFLOW MEASUREMENTS

STATION CODE	LOCATION	DRAINAGE AREA km2	END OF WET SEASON		END OF DRY SEASON	
			DATE OF MEASUREMENT	DISCHARGE (LPS)	DATE OF MEASUREMENT	DISCHARGE (LPS)
H0013	MARCOS HI-WAY (AFTER JUNCTION) (NANGKA RIVER) COGEO, ANTIPOLO, RIZAL	2.791	NOV. 24, 1990	268.60	MAY 18, 1991	51.03
H0014	MARCOS HI-WAY (BEFORE JUNCTION) (NANGKA RIVER) COGEO, ANTIPOLO, RIZAL	0.970	NOV. 24, 1990	29.27	MAY 16, 1991	0
H0015	COGEO, ANTIPOLO, RIZAL (NANGKA RIVER)	1.821	NOV. 24, 1990	58.08	MAY 16, 1991	5.94
H0016	TAKTAK ROAD, ANTIPOLO, RIZAL (SAPANG BAHO RIVER)	0.541	NOV. 24, 1990	33.29	MAY 16, 1991	0
H0017	TAKTAK ROAD, ANTIPOLO, RIZAL (SAPANG BAHO RIVER)	7.012	NOV. 24, 1990	290.00	MAY 16, 1991	78.30
H0018	BILIBIRAN, BINANGONAN, RIZAL (LAGUNA BAY)	2.626	NOV. 25, 1990	15.30	MAY 18, 1991	0
H0019	CONCRETE AGGREGATES, ANGONO, RIZAL (ANGONO RIVER)	4.093	NOV. 25, 1990	140.27	MAY 18, 1991	5.51
H0020	CONCRETE AGGREGATES, ANGONO, RIZAL (ANGONO RIVER)	3.386	NOV. 25, 1990	146.71	MAY 18, 1991	30.98
H0021	GRANDSPAN, BILIBIRAN, BINANGONAN, RIZAL (LAGUNA BAY)	8.030	NOV. 26, 1990	106.88	MAY 18, 1991	1.08
H0022	LORESVILLE SUBDIVISION, ANTIPOLO, RIZAL (NAPINDAN CREEK)	0.480	NOV. 27, 1990	37.38	MAY 16, 1991	0
H0023	PROVINCIAL ROAD, ANTIPOLO, RIZAL (SAPANG BAHO RIVER)	8.595	NOV. 27, 1990	188.79	MAY 16, 1991	50.97
H0024	MAYIBA, TERESA, RIZAL (MORONG RIVER)	0.937	DEC. 01, 1990	47.25	MAY 17, 1991	2.84
H0025	TERESA, RIZAL (MORONG RIVER)	0.464	DEC. 01, 1990	9.09	MAY 17, 1991	0
H0026	TAGBAK, ANTIPOLO, RIZAL (MORONG RIVER)	0.400	DEC. 01, 1990	41.61	MAY 16, 1991	11.71
H0027	TAGBAK, ANTIPOLO, RIZAL (MORONG RIVER)	1.896	DEC. 01, 1990	53.84	MAY 16, 1991	STAGNANT

TABLE 5.2.2 (CONTINUATION)

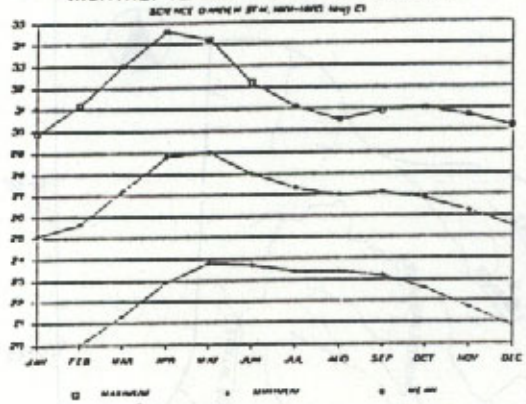
RESULTS OF SPRING FLOW MEASUREMENTS
(SEPTEMBER 1991)

DATABASE NUMBER	LOCATION	DATE OF MEASUREMENT	DISCHARGE (LPS)
H0028	DULONG BAYAN, TERESA, RIZAL	12-Sep-91	3.78
H0029	DULONG BAYAN, TERESA, RIZAL	12-Sep-91	20.54
H0030	GULOD, BINANGONAN, RIZAL (KAISAPON)	12-Sep-91	14.98
H0031	GULOD, BINANGONAN, RIZAL	12-Sep-91	4.57
H0032	MAPUTING BATO, BINANGONAN, RIZAL (LIBERTY FARMS)	12-Sep-91	175.00
H0033	MAPUTING BATO, BINANGONAN, RIZAL	12-Sep-91	17.72
H0034	TAGBAK, ANTIPOLO, RIZAL	11-Sep-91	41.05
H0035	TAGBAK, ANTIPOLO, RIZAL	11-Sep-91	26.67

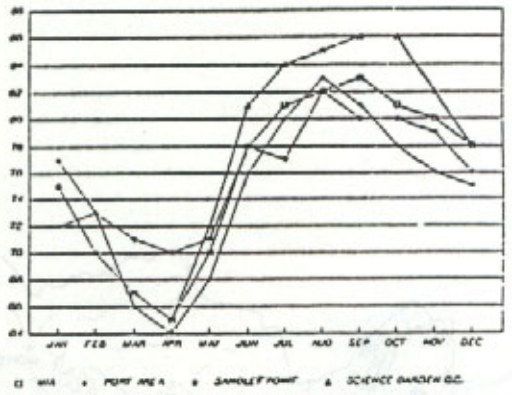
RESULTS OF STREAM FLOW MEASUREMENTS
(SEPTEMBER 1991)

DATABASE NUMBER	LOCATION	DRAINAGE AREA (km^2)	DATE OF MEASUREMENT	DISCHARGE (LPS)
H0013	MARCOS HI-WAY (AFTER JUNCTION) (NANGKA RIVER) COGEO, ANTIPOLO, RIZAL	2.791	10-Sep-91	410.50
H0014	MARCOS HI-WAY (BEFORE JUNCTION) (NANGKA RIVER) COGEO, ANTIPOLO, RIZAL	0.970	10-Sep-91	68.22
H0015	COGEO, ANTIPOLO, RIZAL (NANGKA RIVER)	1.821	10-Sep-91	84.76
H0016	TAKTAK ROAD, ANTIPOLO, RIZAL (SAPANG BAHO RIVER)	0.541	10-Sep-91	60.22
H0017	TAKTAK ROAD, ANTIPOLO, RIZAL (SAPANG BAHO RIVER)	7.012	10-Sep-91	524.60
H0018	BILIBIRAN, BINANGONAN, RIZAL (LAGUNA DE BAY)	2.626	13-Sep-91	69.71
H0019	CONCRETE AGGREGATES, ANGONO, RIZAL (ANGONO RIVER)	4.093	13-Sep-91	503.64
H0020	CONCRETE AGGREGATES, ANGONO, RIZAL (ANGONO RIVER)	3.386	13-Sep-91	492.80
H0021	GRANDSPAN, BILIBIRAN, BINANGONAN, RIZAL (LAGUNA DE BAY)	8.030	13-Sep-91	232.96
H0022	LORESVILLE SUBDIVISION, ANTIPOLO, RIZAL (NAPINDAN CREEK)	0.480	11-Sep-91	46.72
H0023	PROVINCIAL ROAD, ANTIPOLO, RIZAL (SAPANG BAHO RIVER)	8.595	11-Sep-91	420.65
H0024	MAY-IBA, TERESA, RIZAL (MORONG RIVER)	0.937	12-Sep-91	106.34
H0025	TERESA, RIZAL (MORONG RIVER)	0.464	12-Sep-91	43.40
H0026	TAGBAK, ANTIPOLO, RIZAL (MORONG RIVER)	0.400	11-Sep-91	66.07
H0027	TAGBAK, ANTIPOLO, RIZAL (MORONG RIVER)	1.896	12-Sep-91	85.49

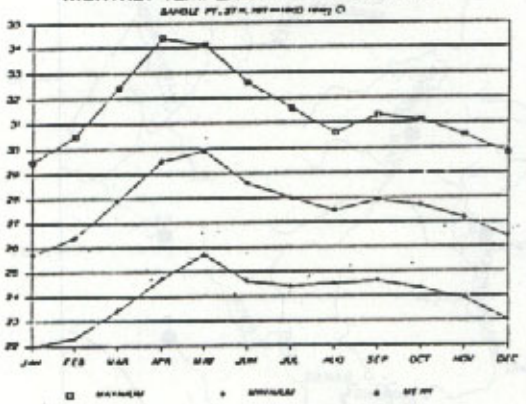
MONTHLY TEMPERATURE DISTRIBUTION



MONTHLY RELATIVE HUMIDITY DISTRIBUTION



MONTHLY TEMPERATURE DISTRIBUTION



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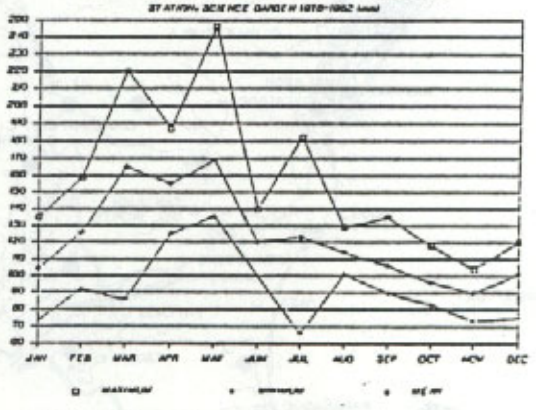

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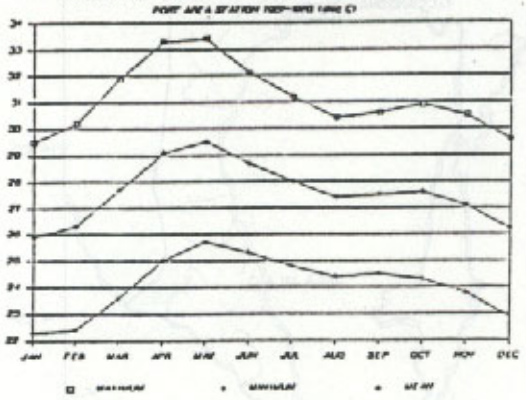

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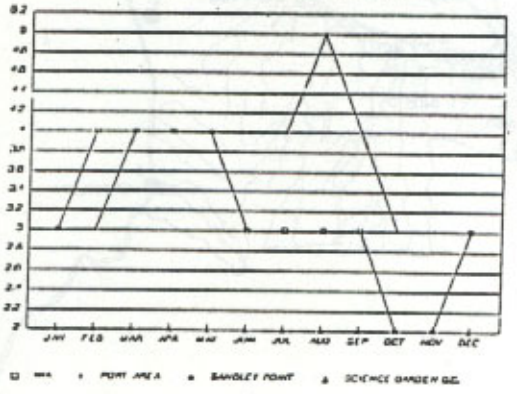

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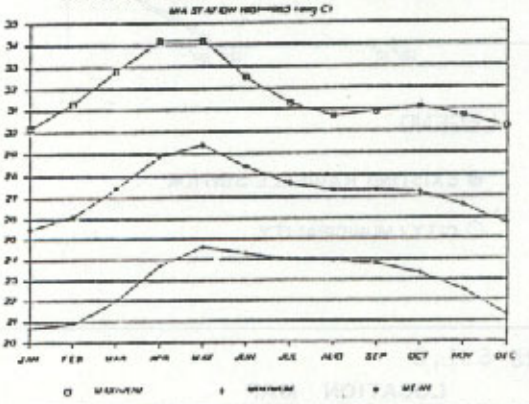
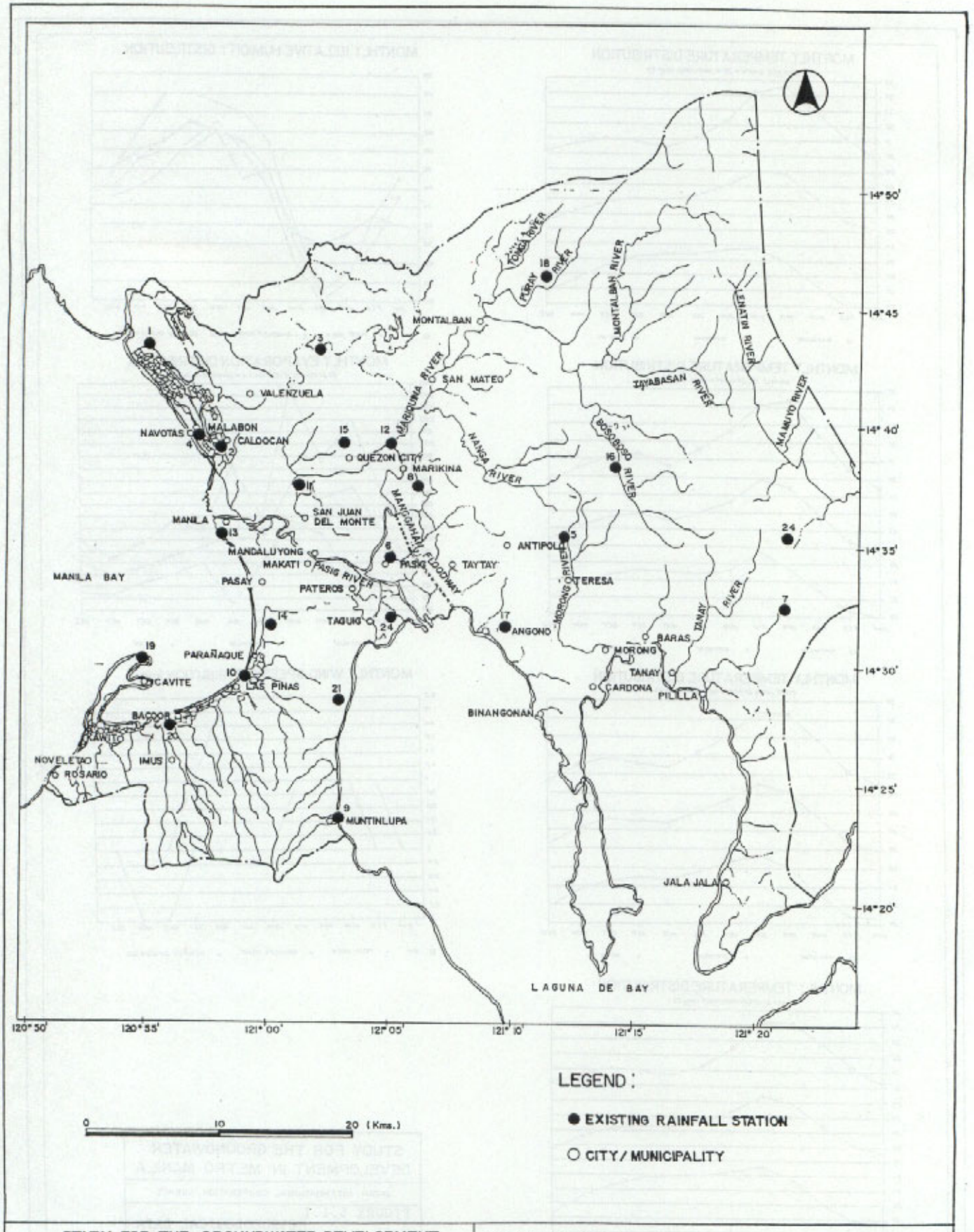


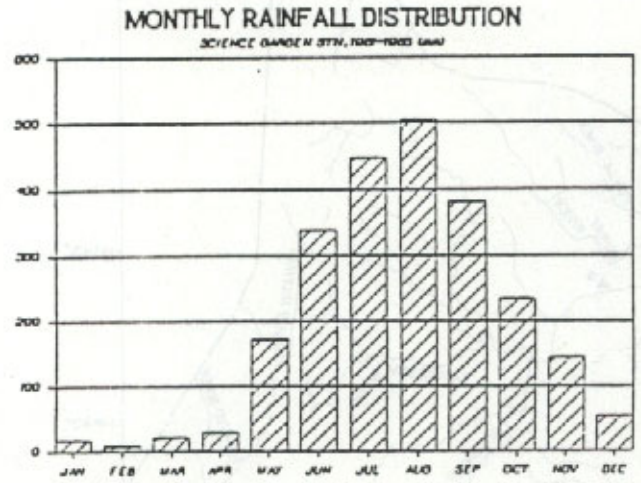
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

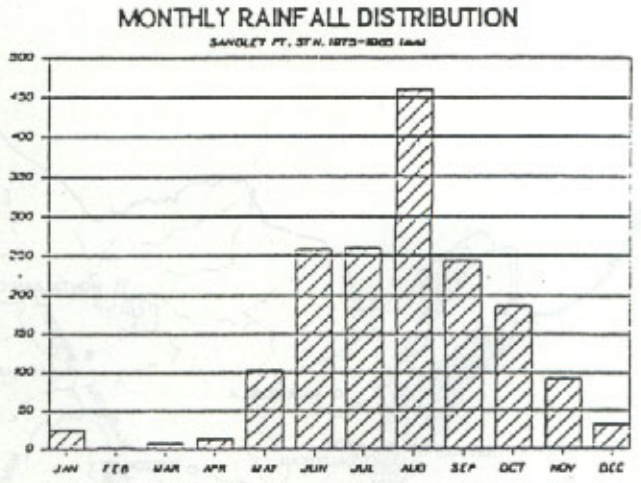
JAPAN INTERNATIONAL COOPERATION AGENCY

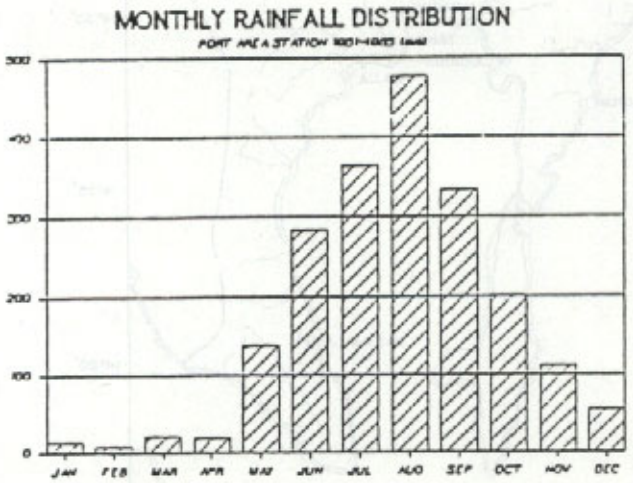
FIGURE 5.1.1 METEOROLOGICAL DATA

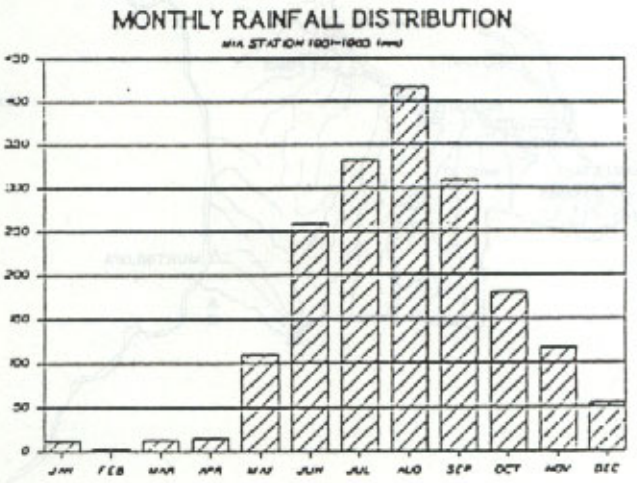


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA JAPAN INTERNATIONAL COOPERATION AGENCY	FIGURE 5.1.2 LOCATION MAP OF EXISTING RAINFALL STATIONS

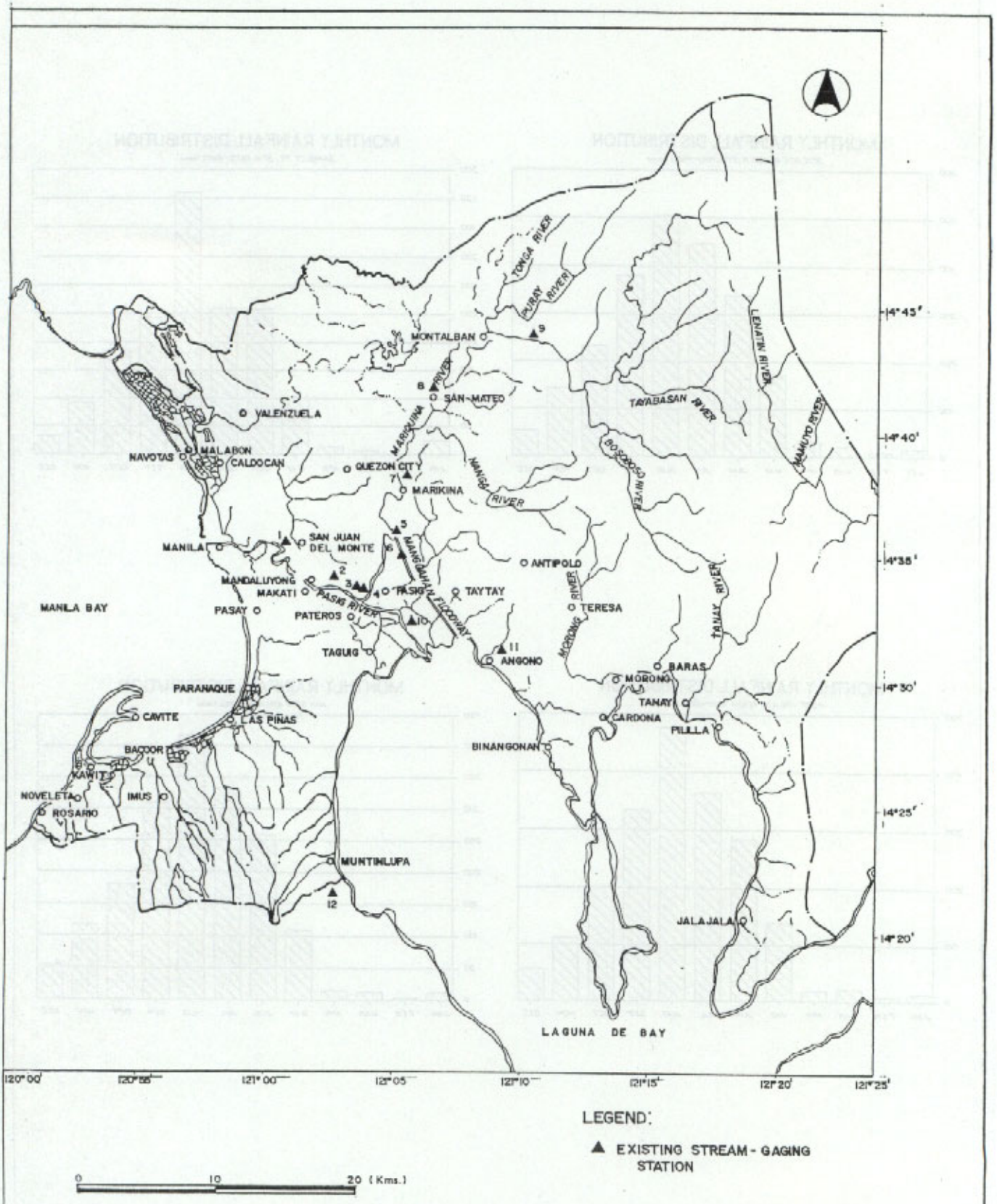




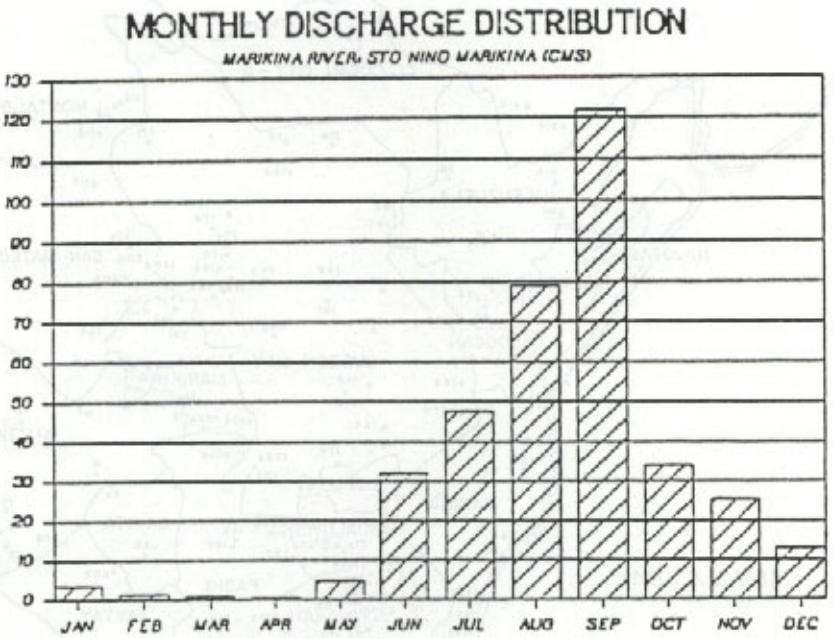


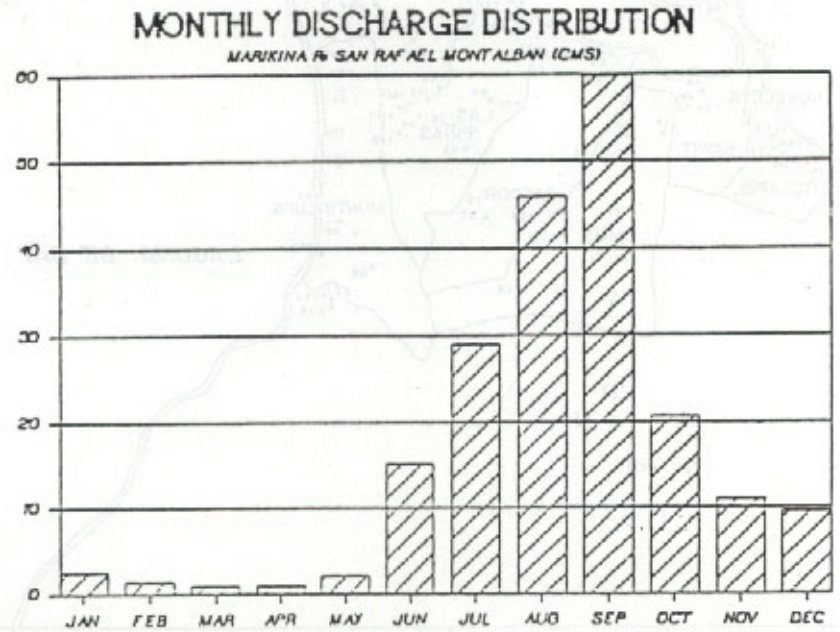


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA JAPAN INTERNATIONAL COOPERATION AGENCY	FIGURE 5.1.3 MONTHLY RAINFALL DISTRIBUTION

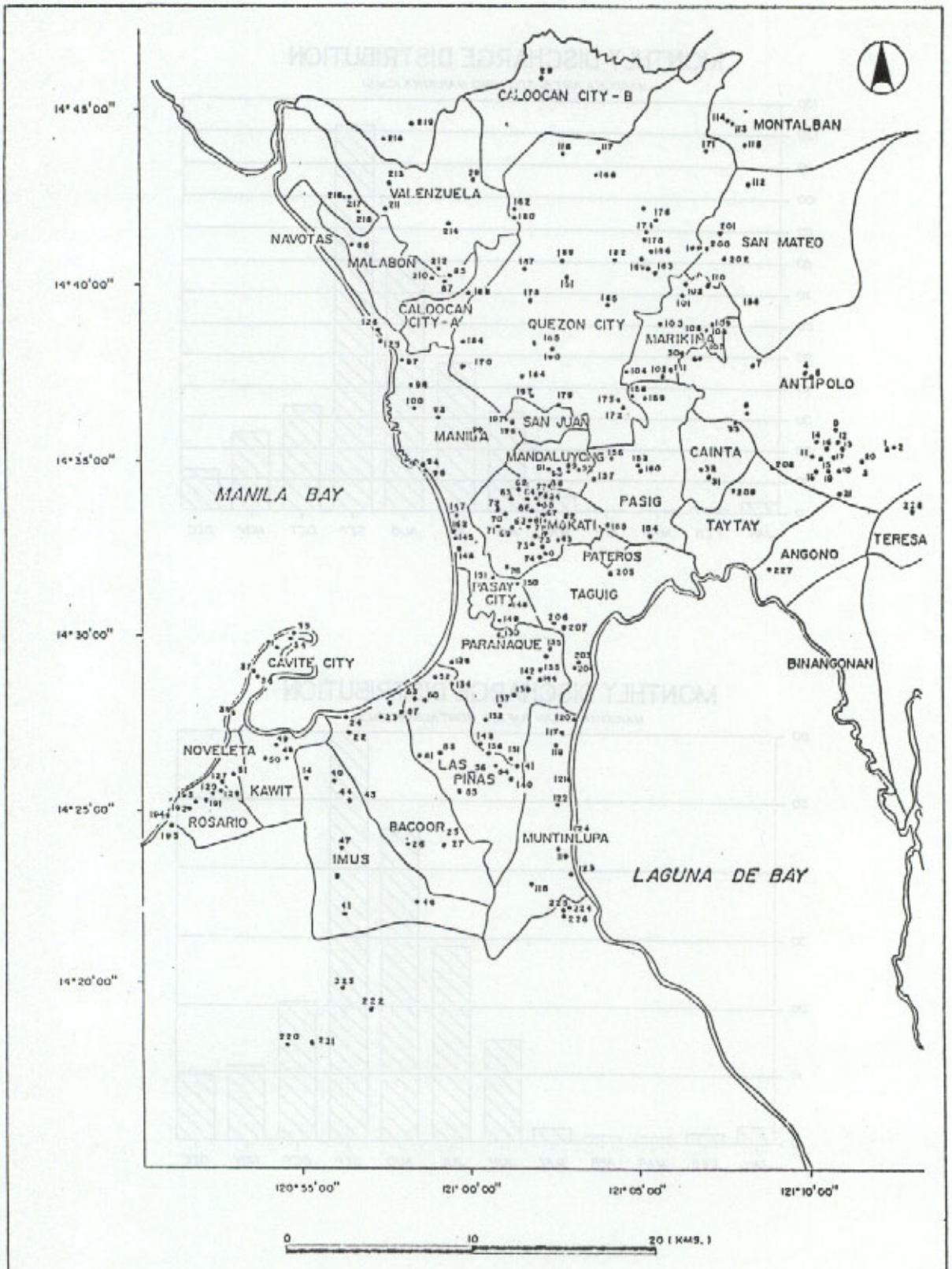


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 5.1.4 LOCATION MAP OF STREAM GAGING STATIONS
JAPAN INTERNATIONAL COOPERATION AGENCY	

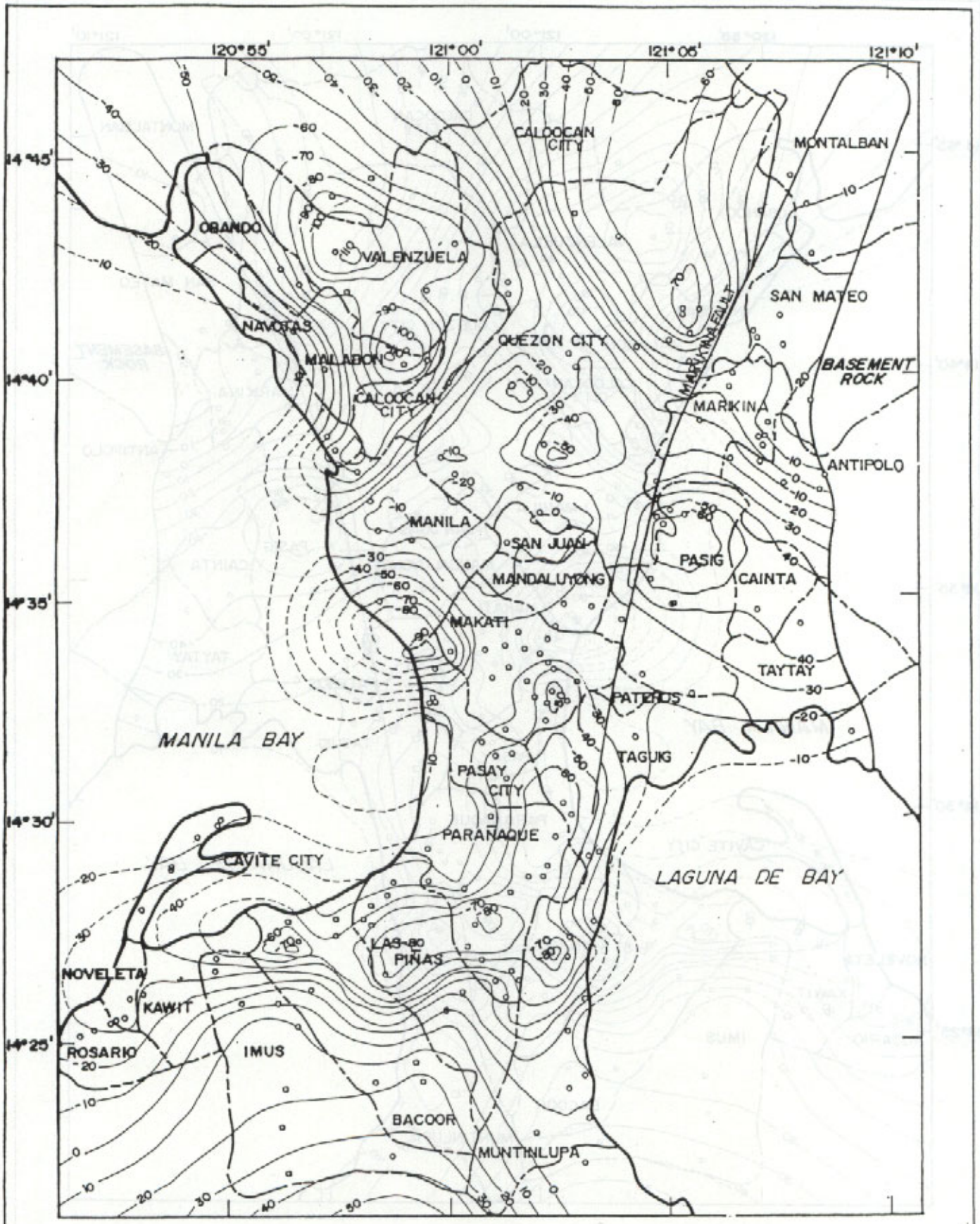




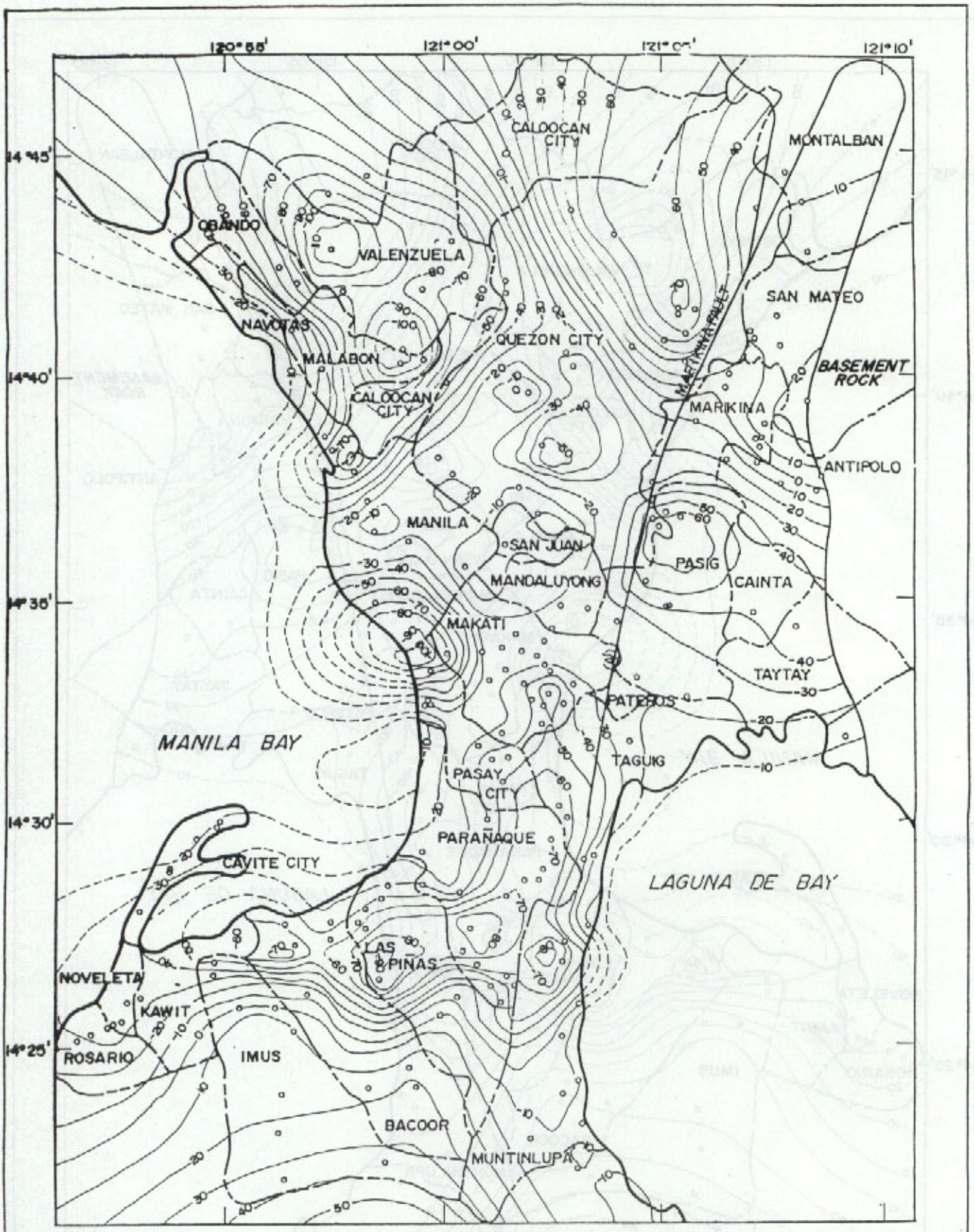
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 5.1.5 MONTHLY DISCHARGE DISTRIBUTION
JAPAN INTERNATIONAL COOPERATION AGENCY	



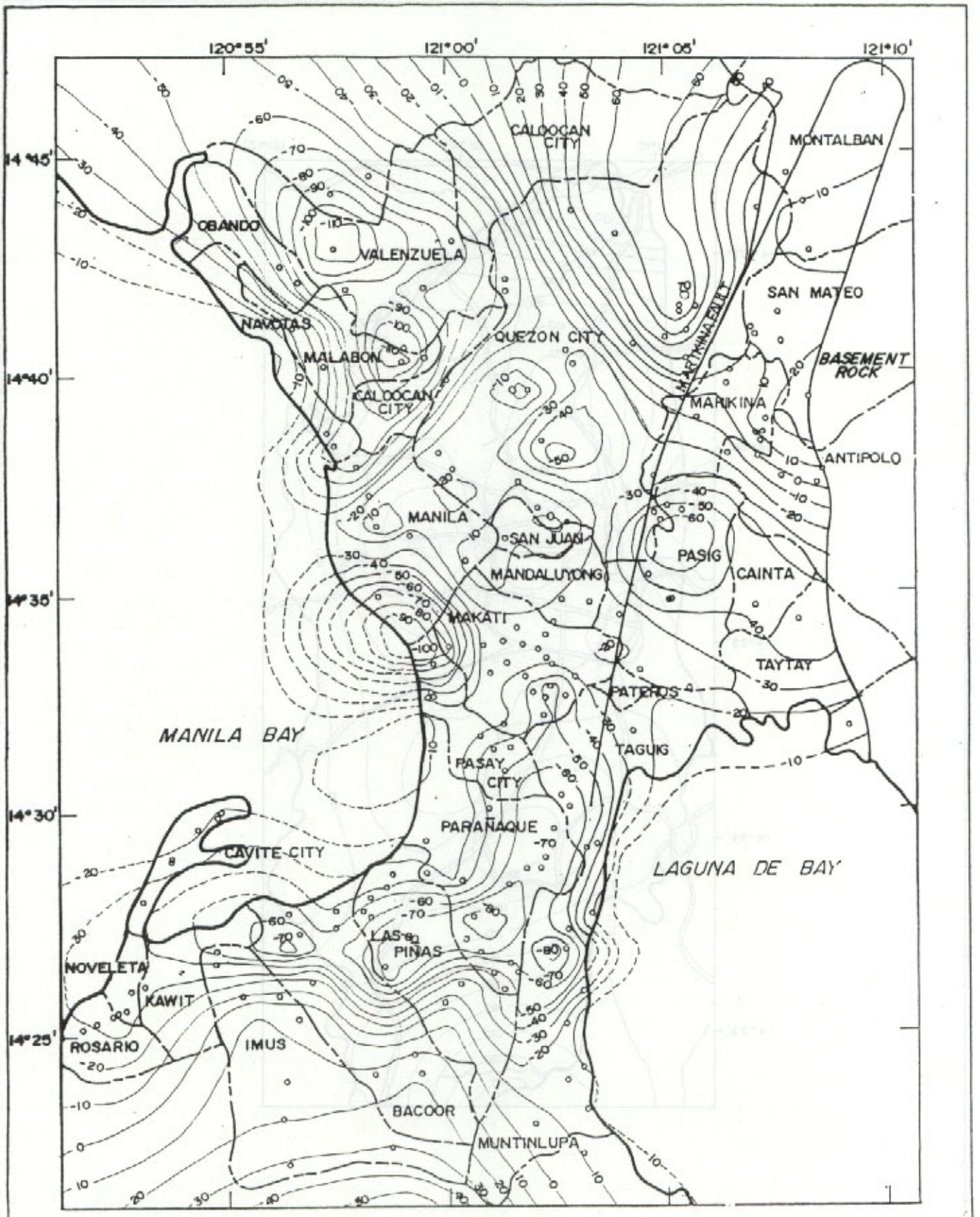
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA JAPAN INTERNATIONAL COOPERATION AGENCY	FIGURE 5.2.1 LOCATION MAP OF GROUNDWATER LEVEL OBSERVATION WELLS



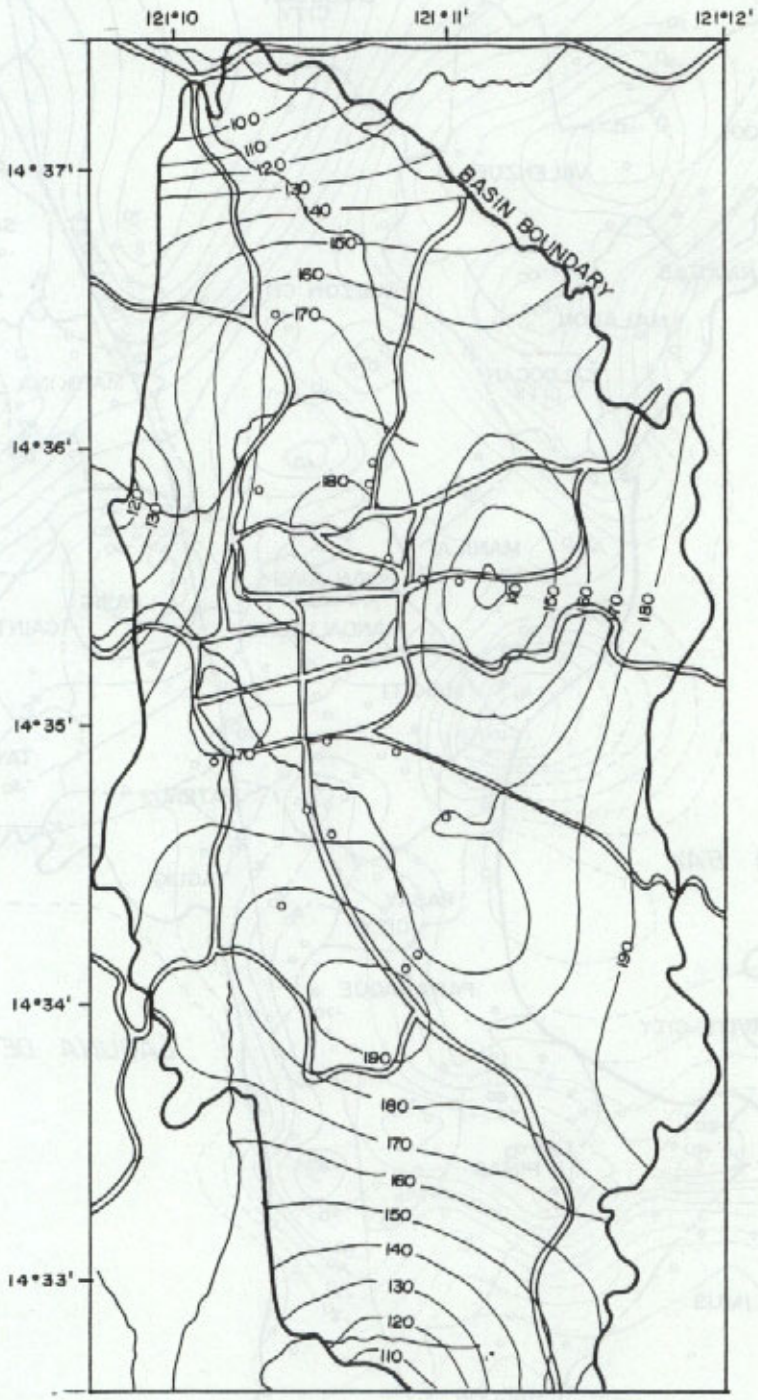
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 5.2.2
JAPAN INTERNATIONAL COOPERATION AGENCY	PIEZOMETRIC CONTOUR MAP OF THE STUDY AREA (END OF WET SEASON, NOV. 1990)



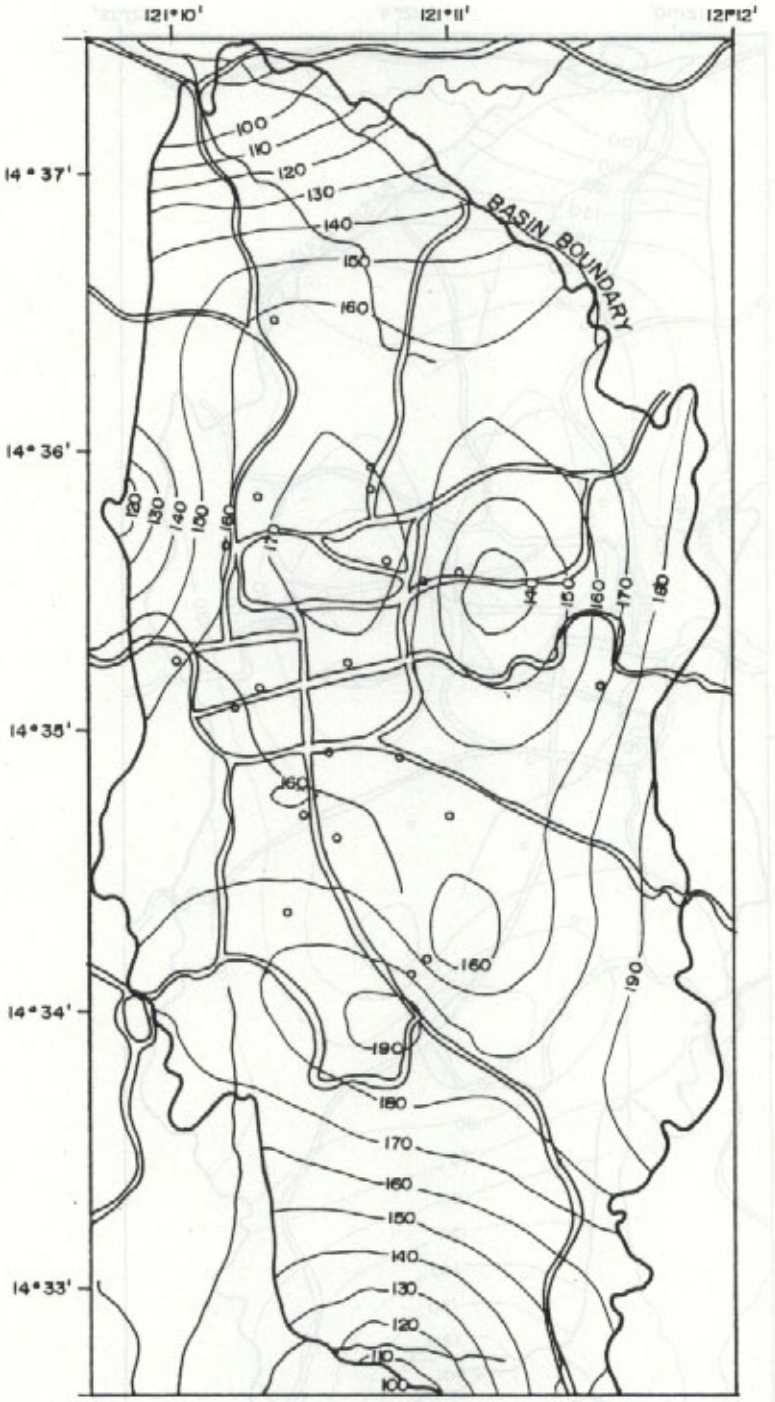
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 5.2.3 PIEZOMETRIC CONTOUR MAP OF THE STUDY AREA(WET SEASON, AUG. 1991)
JAPAN INTERNATIONAL COOPERATION AGENCY	



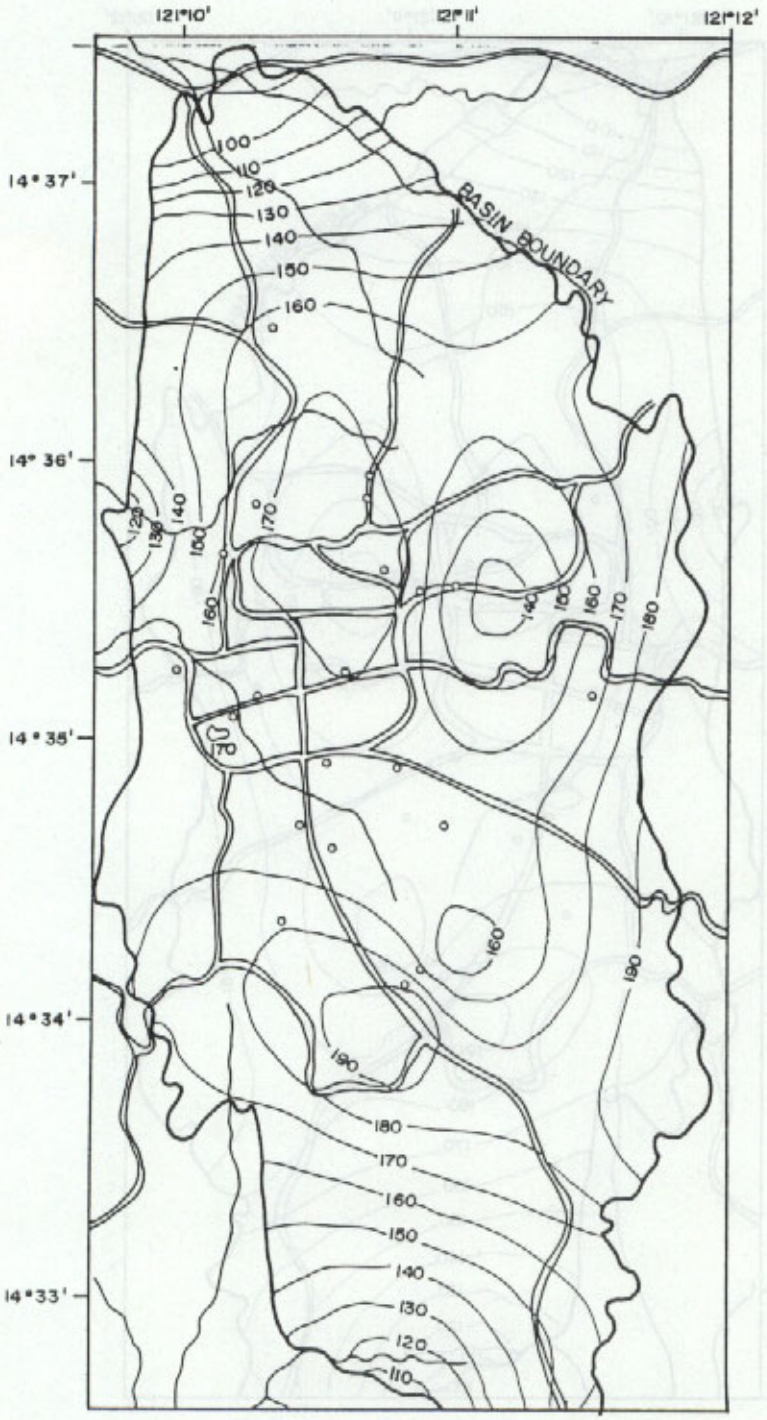
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 5.2.4 PIEZOMETRIC CONTOUR MAP OF THE STUDY AREA (END OF DRY SEASON, MAY 1991)
JAPAN INTERNATIONAL COOPERATION AGENCY	



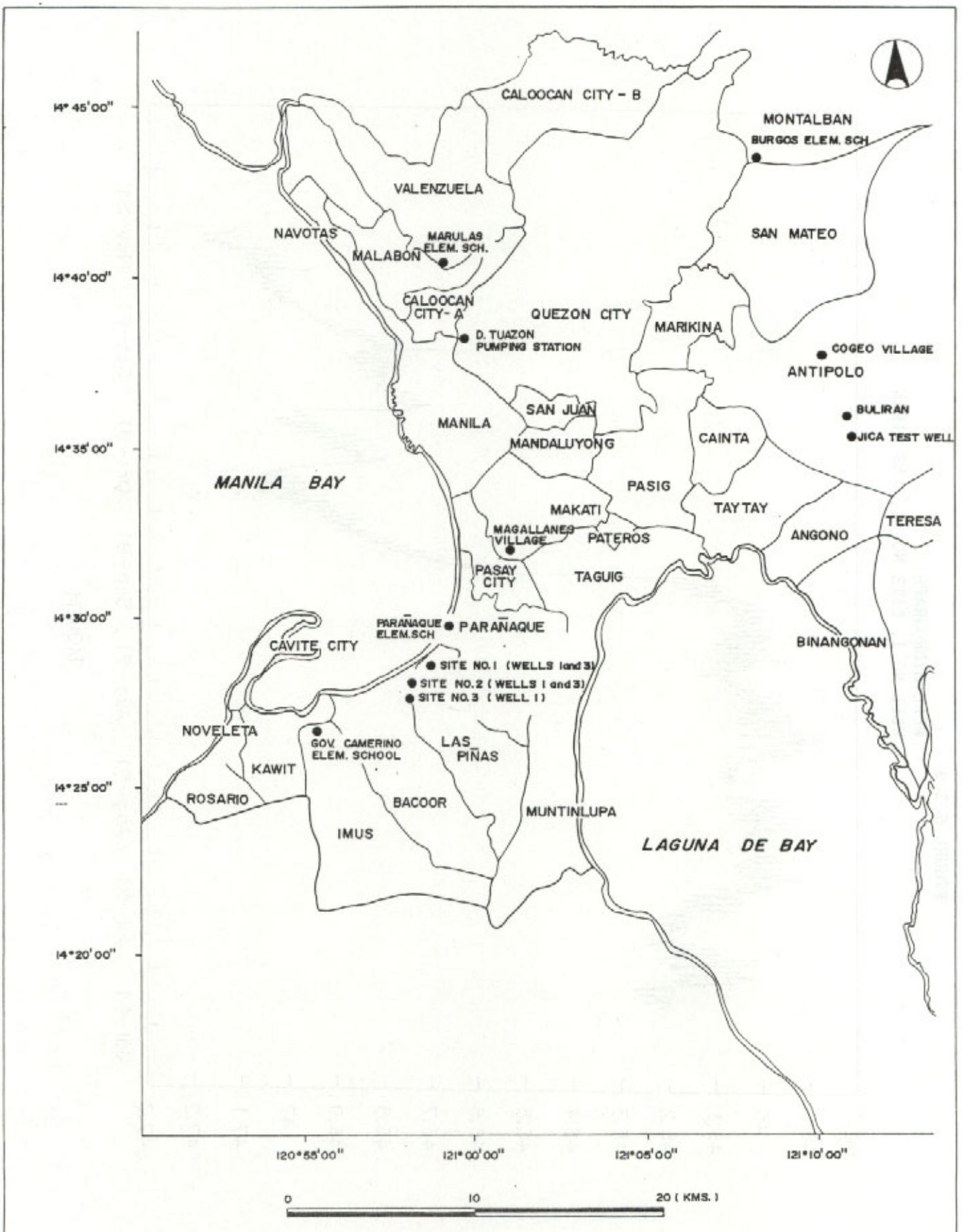
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA JAPAN INTERNATIONAL COOPERATION AGENCY	FIGURE 5.2.5 PIEZOMETRIC CONTOUR MAP OF THE ANTIPOLO AREA (END OF WET SEASON, NOV. 1990)



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 5.2.6 PIEZOMETRIC CONTOUR MAP OF THE ANTIPOLO AREA (END OF DRY SEASON, MAY 1991)
JAPAN INTERNATIONAL COOPERATION AGENCY	



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 5.2.7 PIEZOMETRIC CONTOUR MAP OF THE ANTIPOLO AREA (WET SEASON, AUG. 1991)
JAPAN INTERNATIONAL COOPERATION AGENCY	



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 5.2.8

LOCATION MAP OF INSTALLED WATER LEVEL RECORDERS

FIGURE 5.2.9

WELL HYDROGRAPH
WELL NO.1, SITE NO. 1, LAS PIÑAS

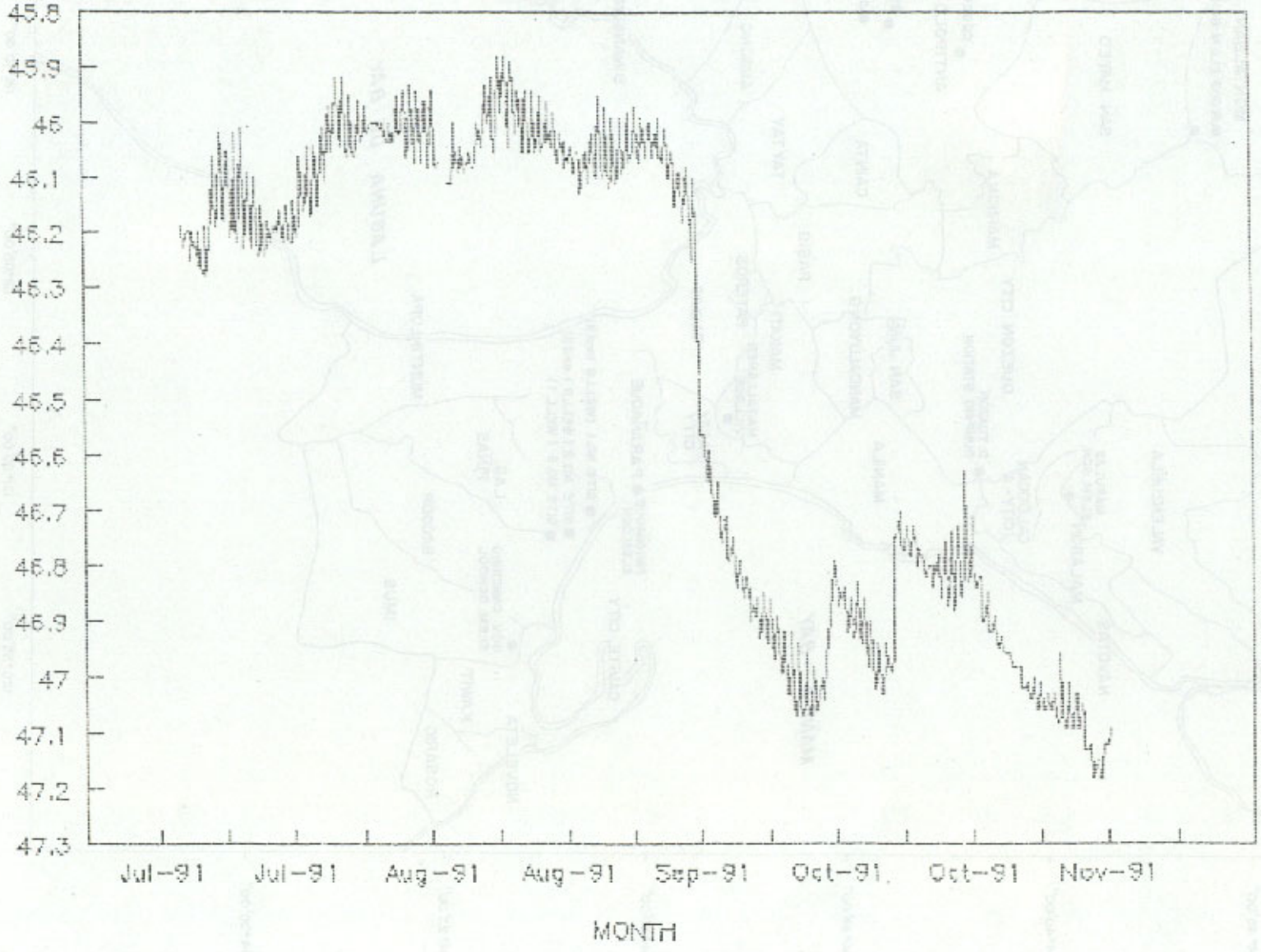


FIGURE 5.2.9 (CONTINUATION)
WELL HYDROGRAPH
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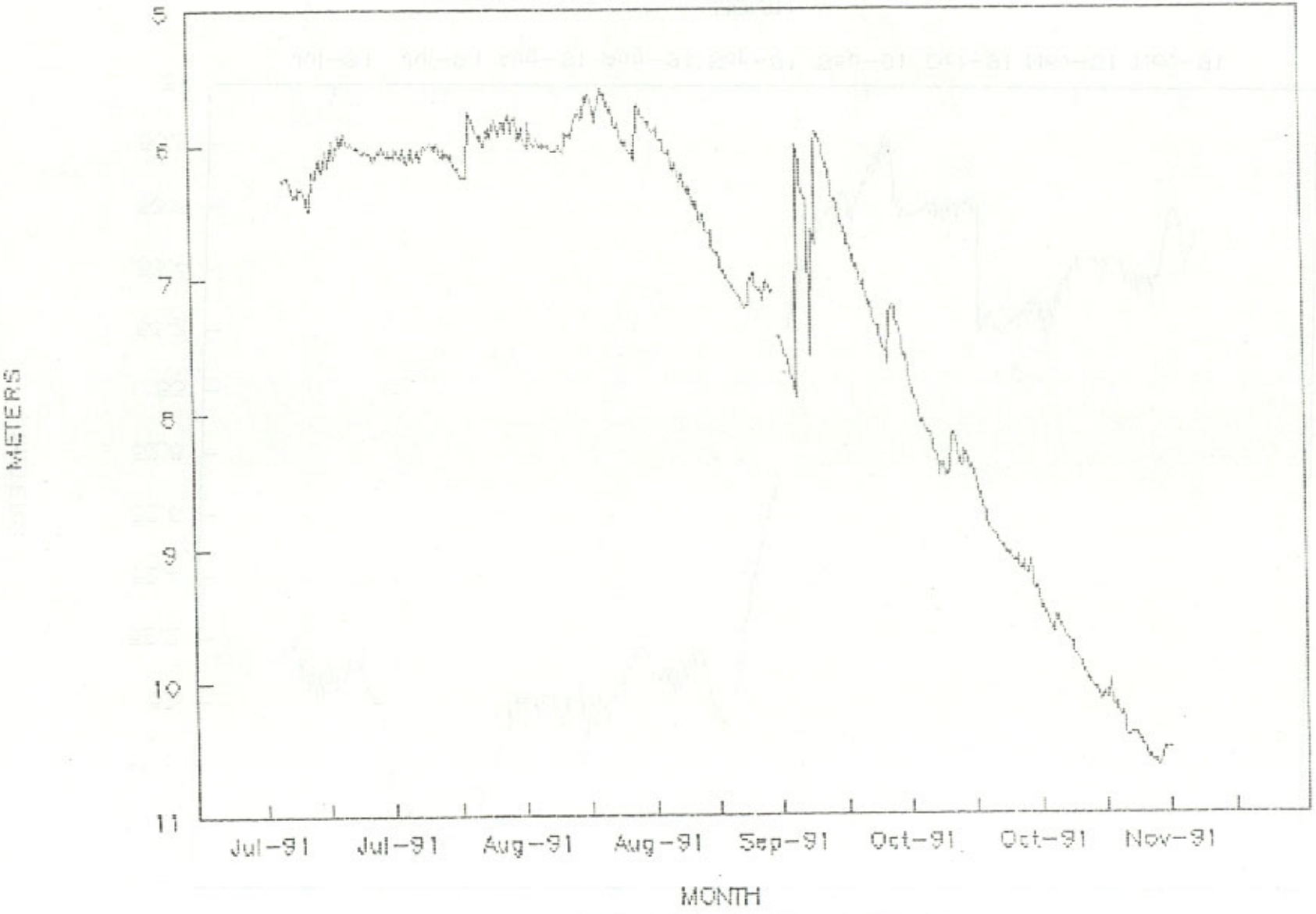

FIGURE 5.2.9 (CONTINUATION)
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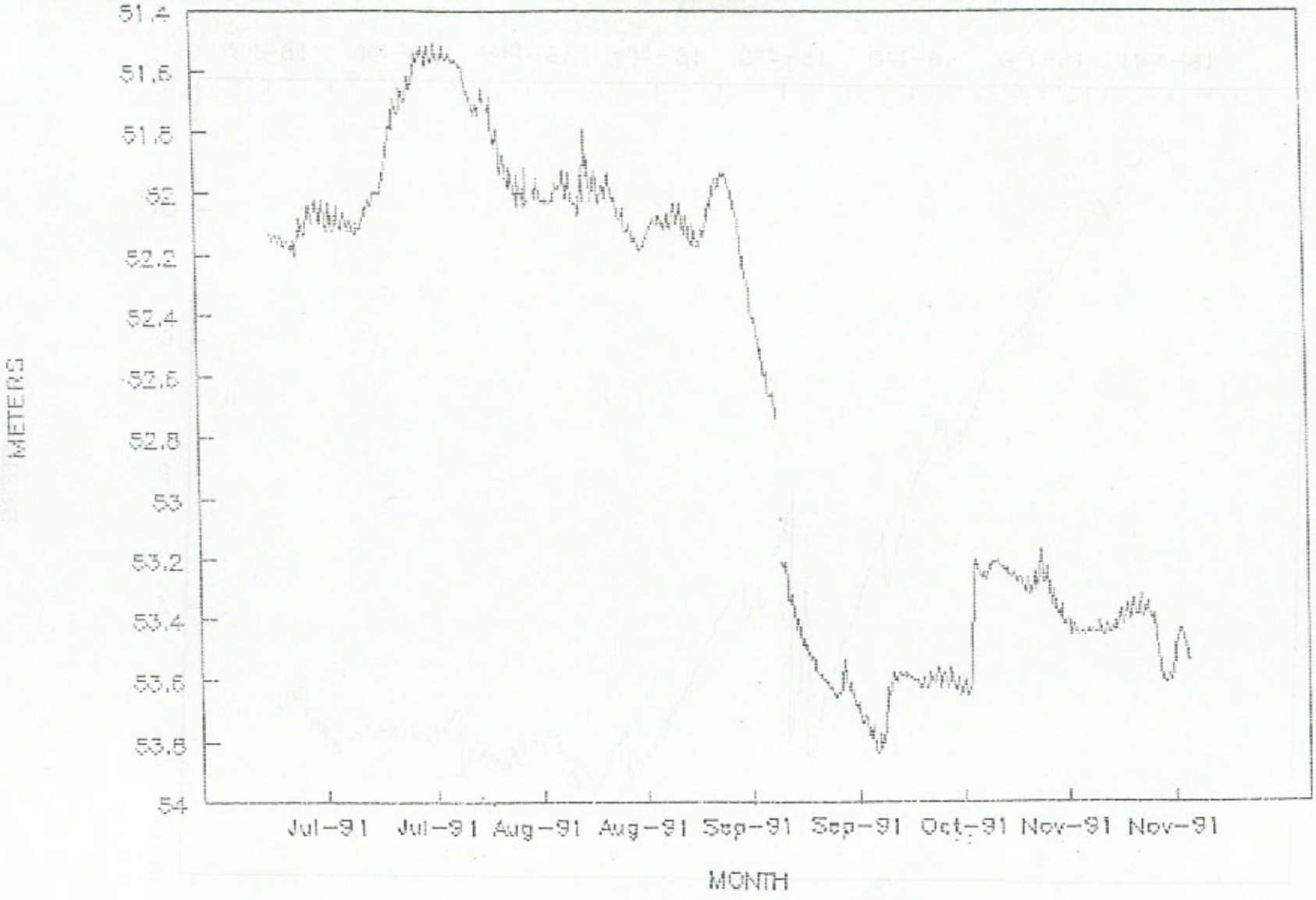

FIGURE 5.2.9 (CONTINUATION)
WELL HYDROGRAPH
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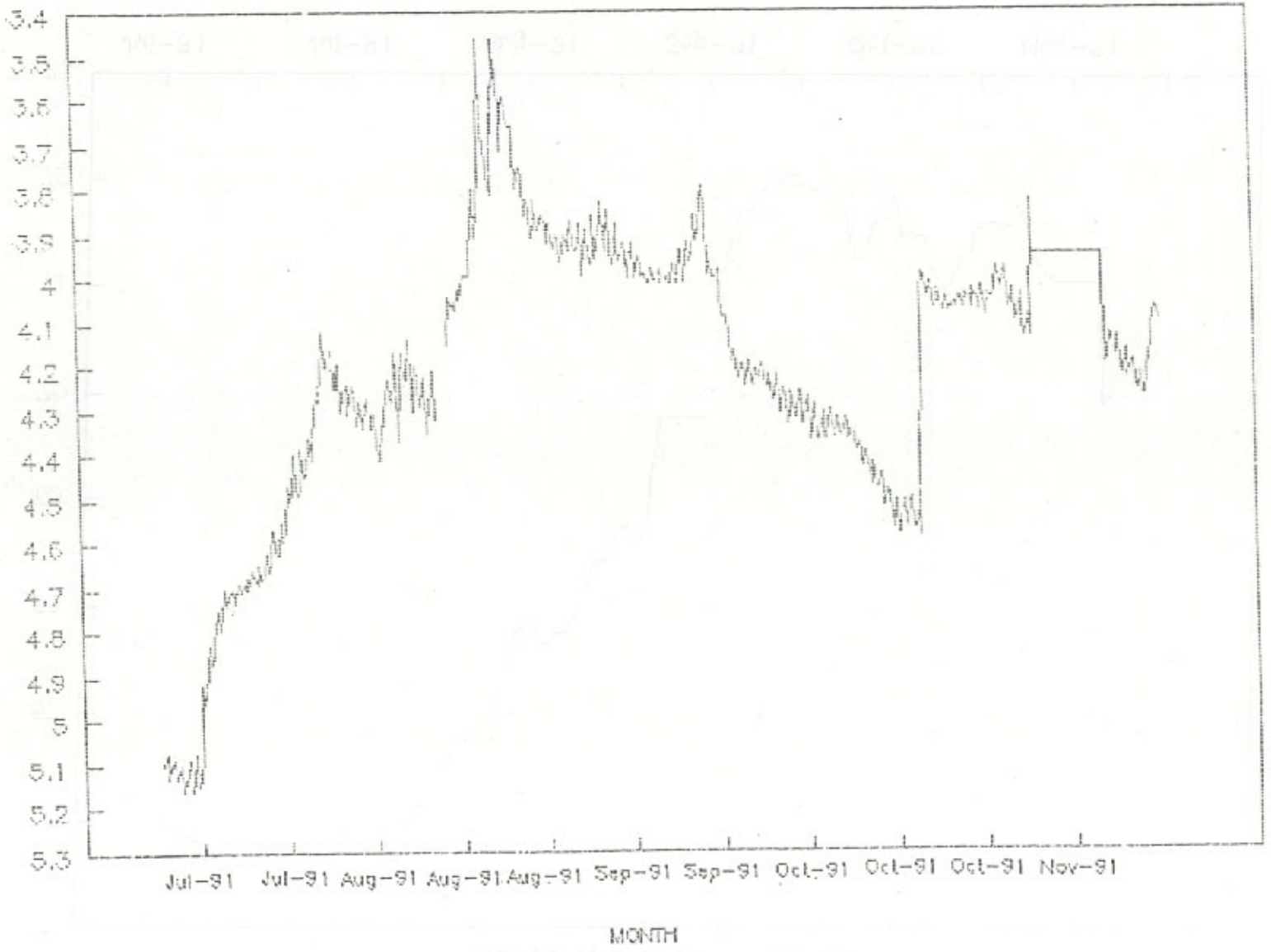

FIGURE 5.2.9 (CONTINUATION)
WELL HYDROGRAPH
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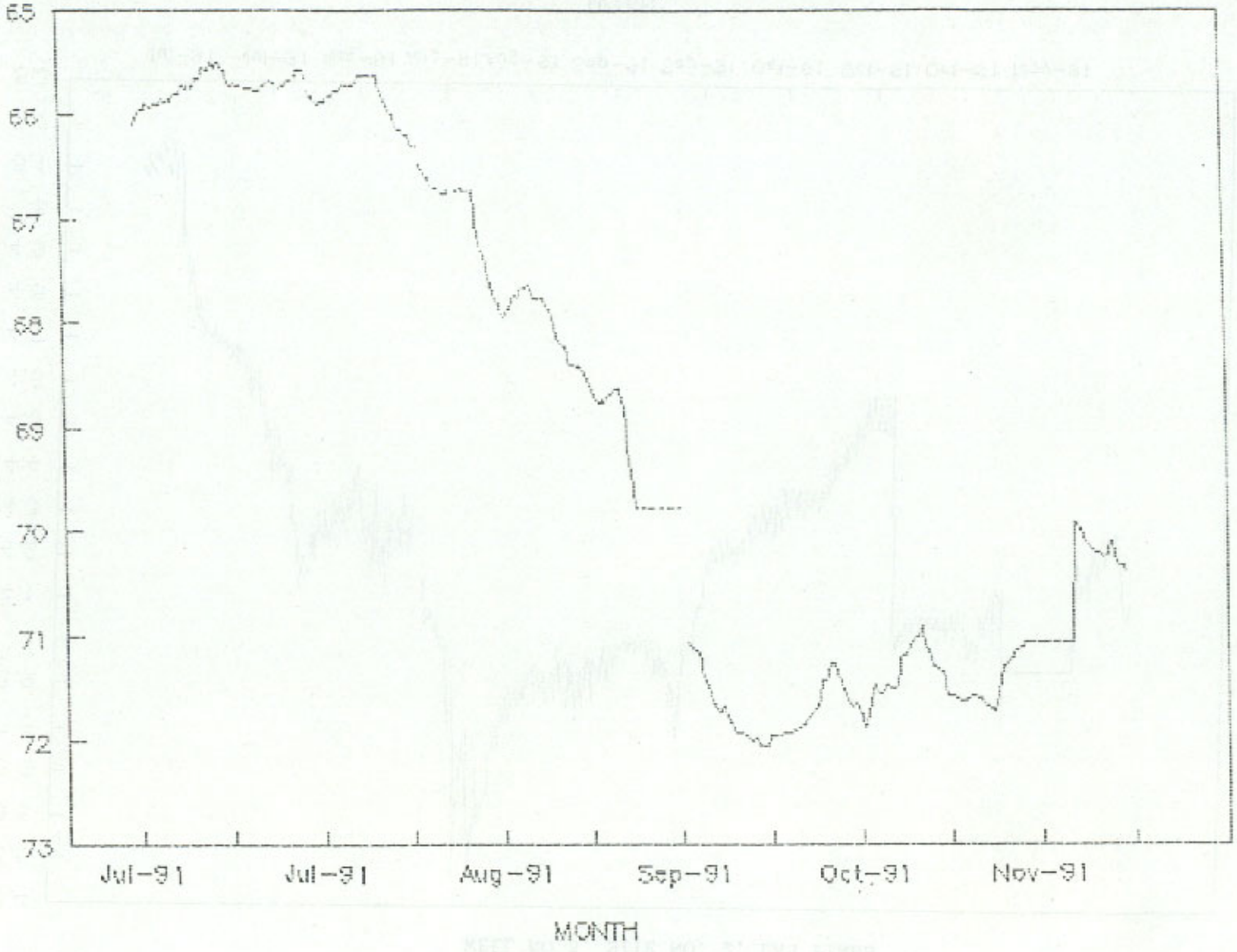


FIGURE 5.2.9 (CONTINUATION)
WELL HYDROGRAPH
MARULAS ELEM. SCHOOL, VALENZUELA

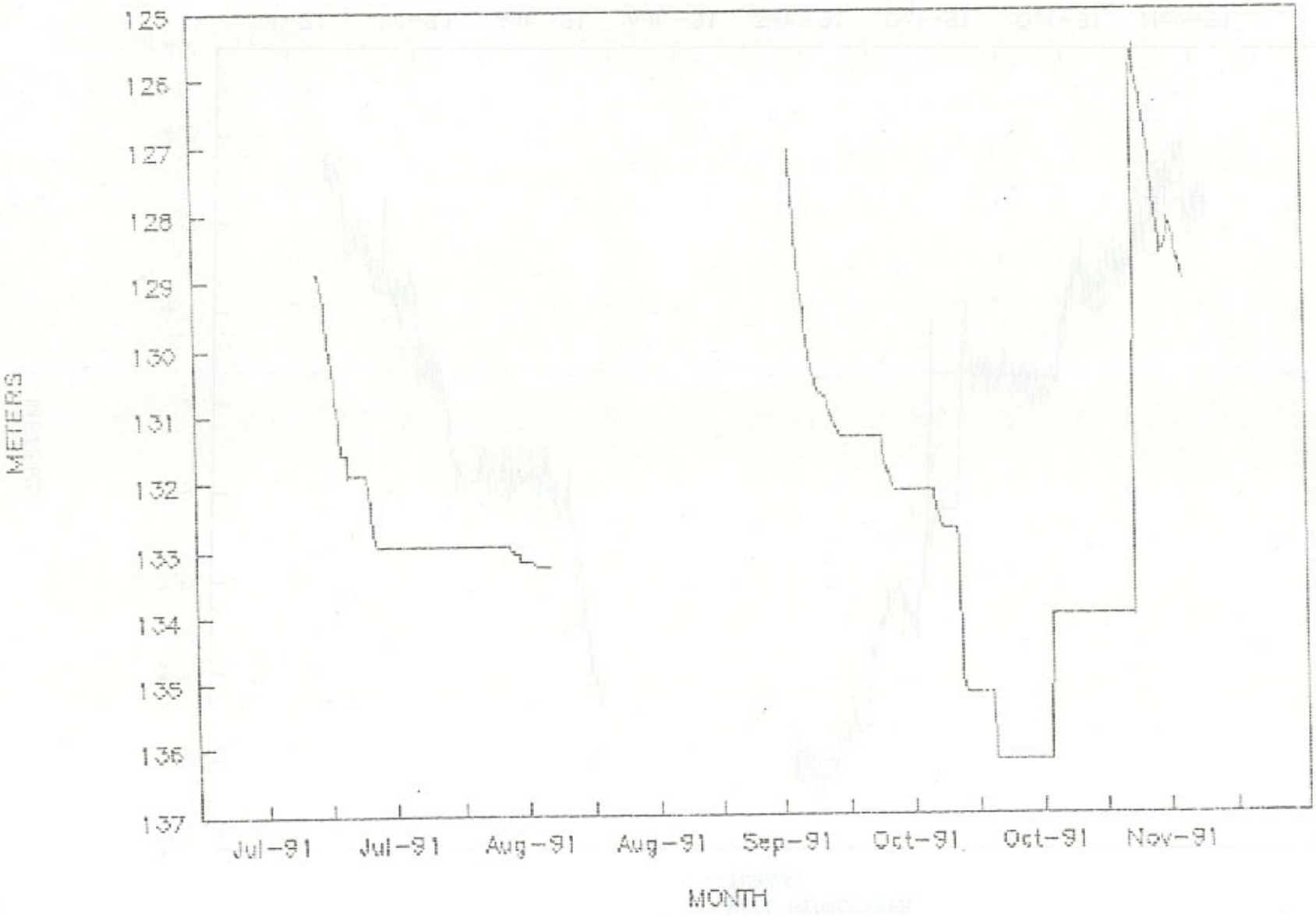


FIGURE 5.2.9 (CONTINUATION)
WELL HYDROGRAPH
TUAZON

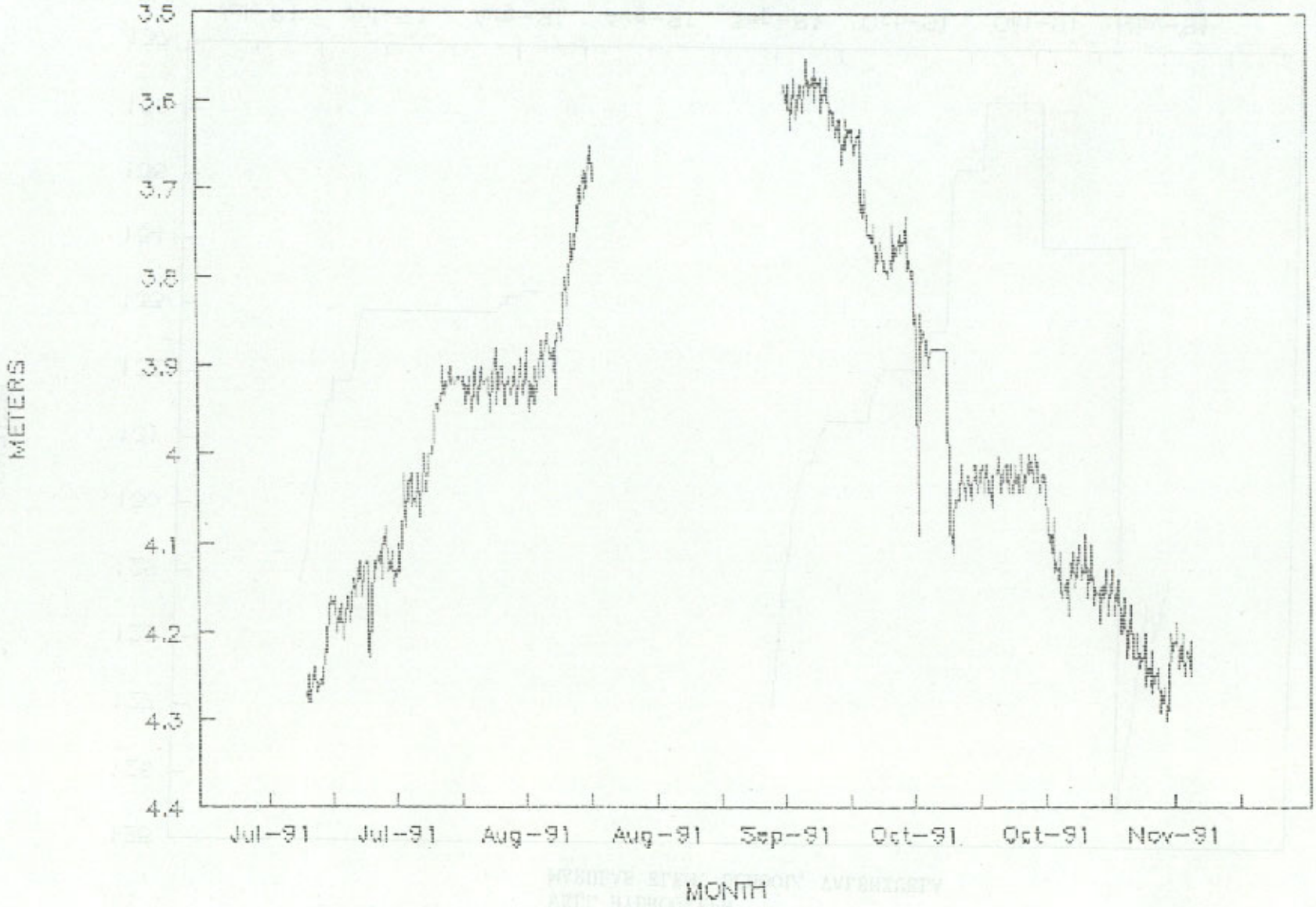


FIGURE 5.2.9 (CONTINUATION)
WELL HYDROGRAPH
MAGALLANES VILLAGE

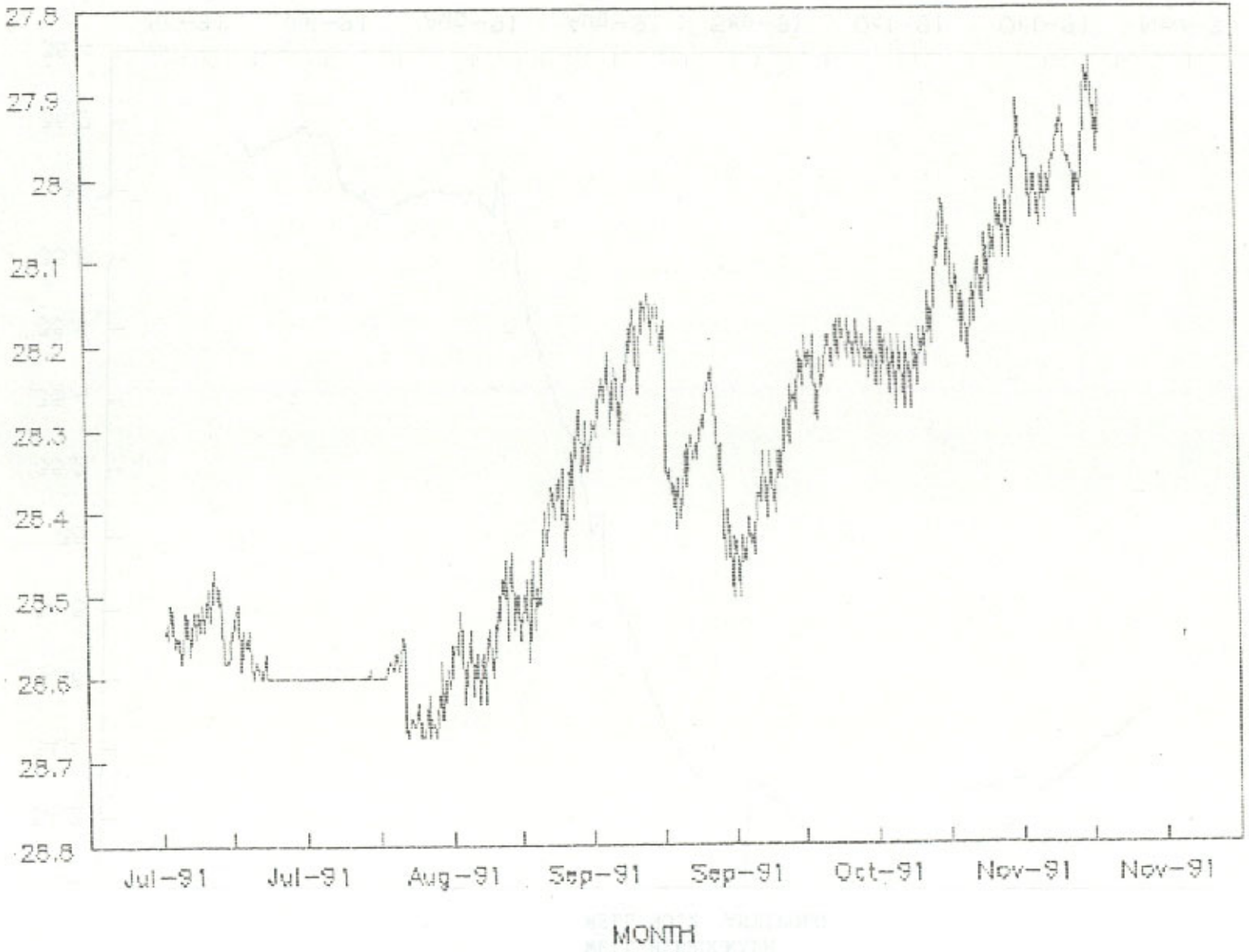


FIGURE 5.2.9 (CONTINUATION)
WELL HYDROGRAPH
WELL NO.2, ANTIPOLO

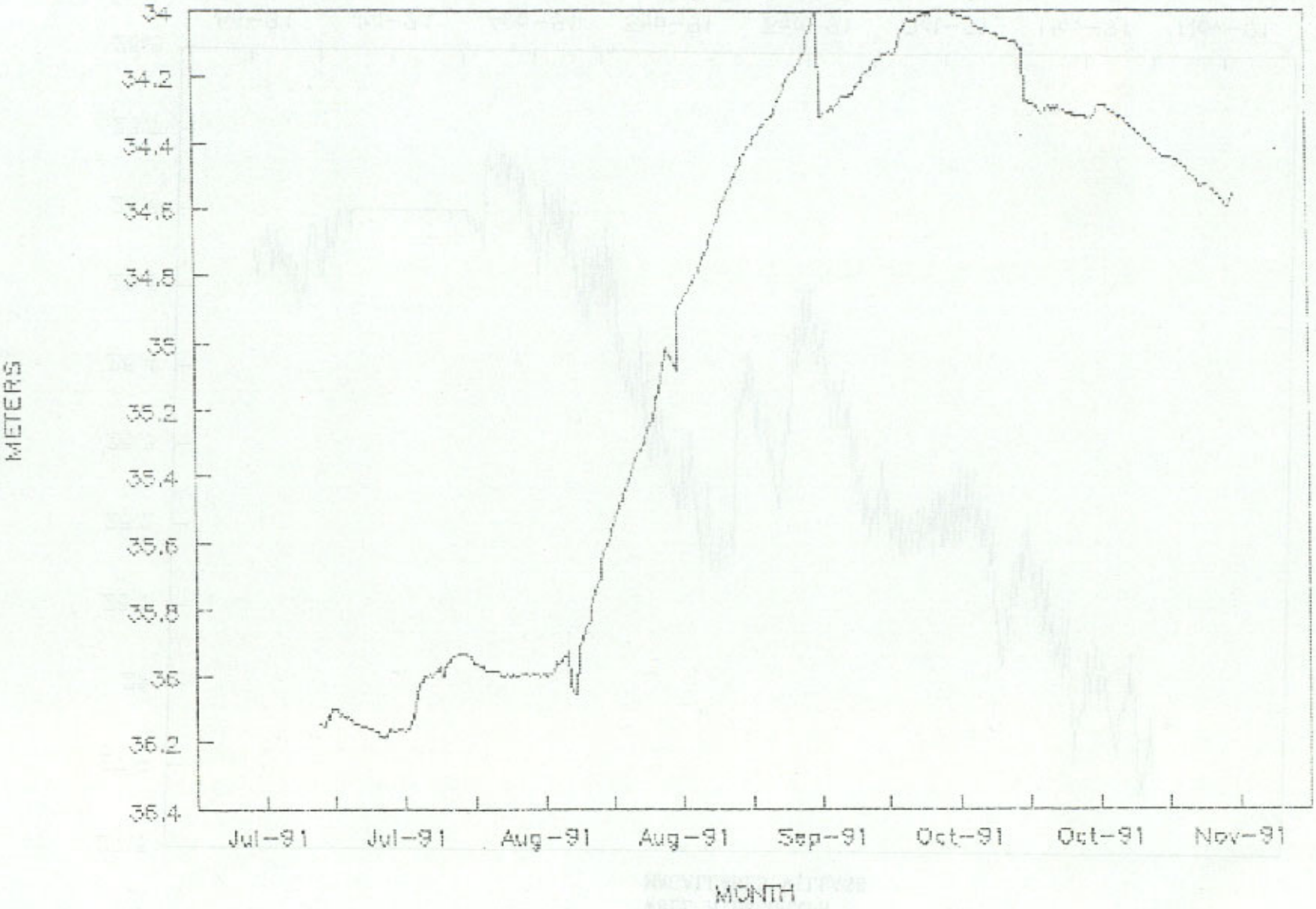
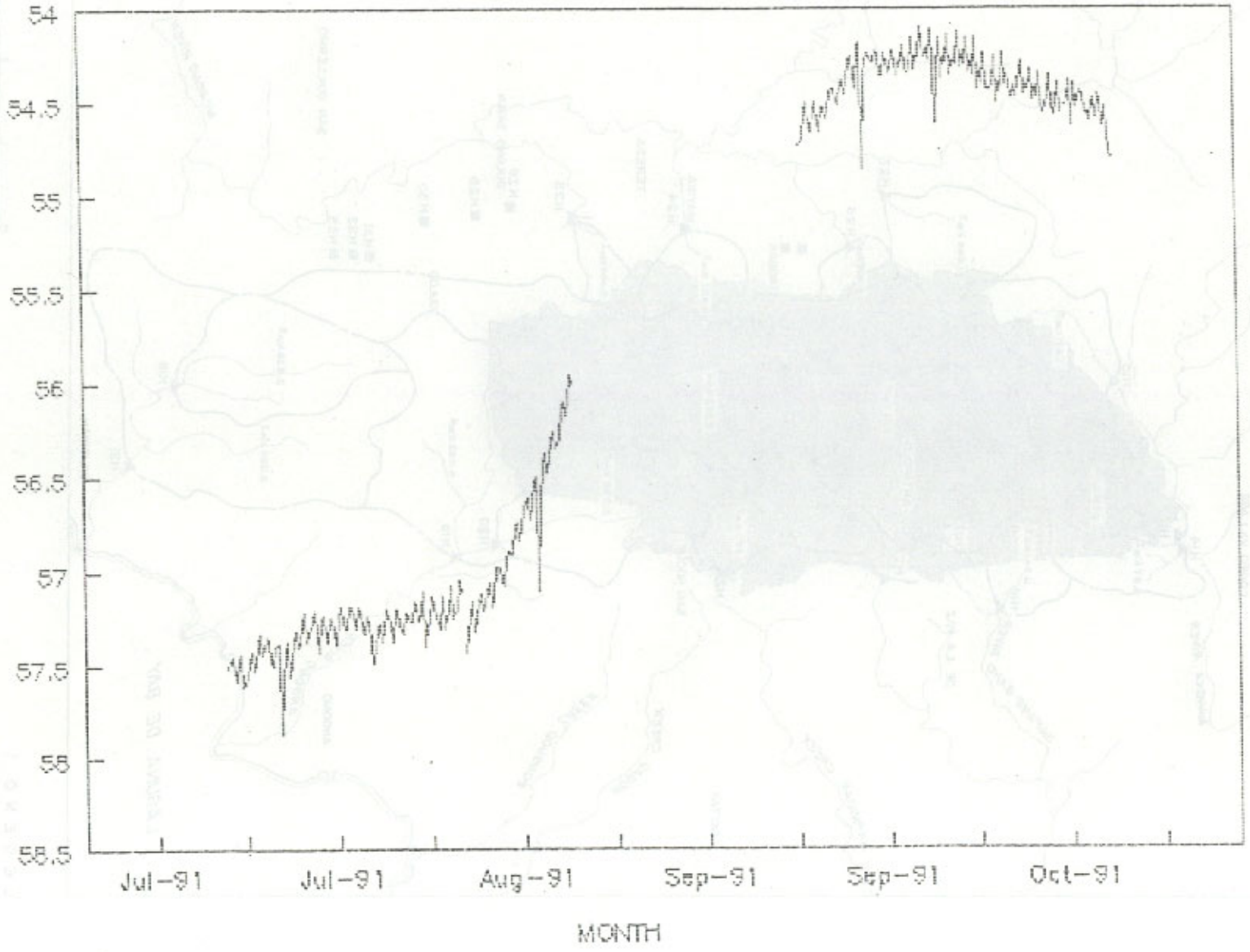
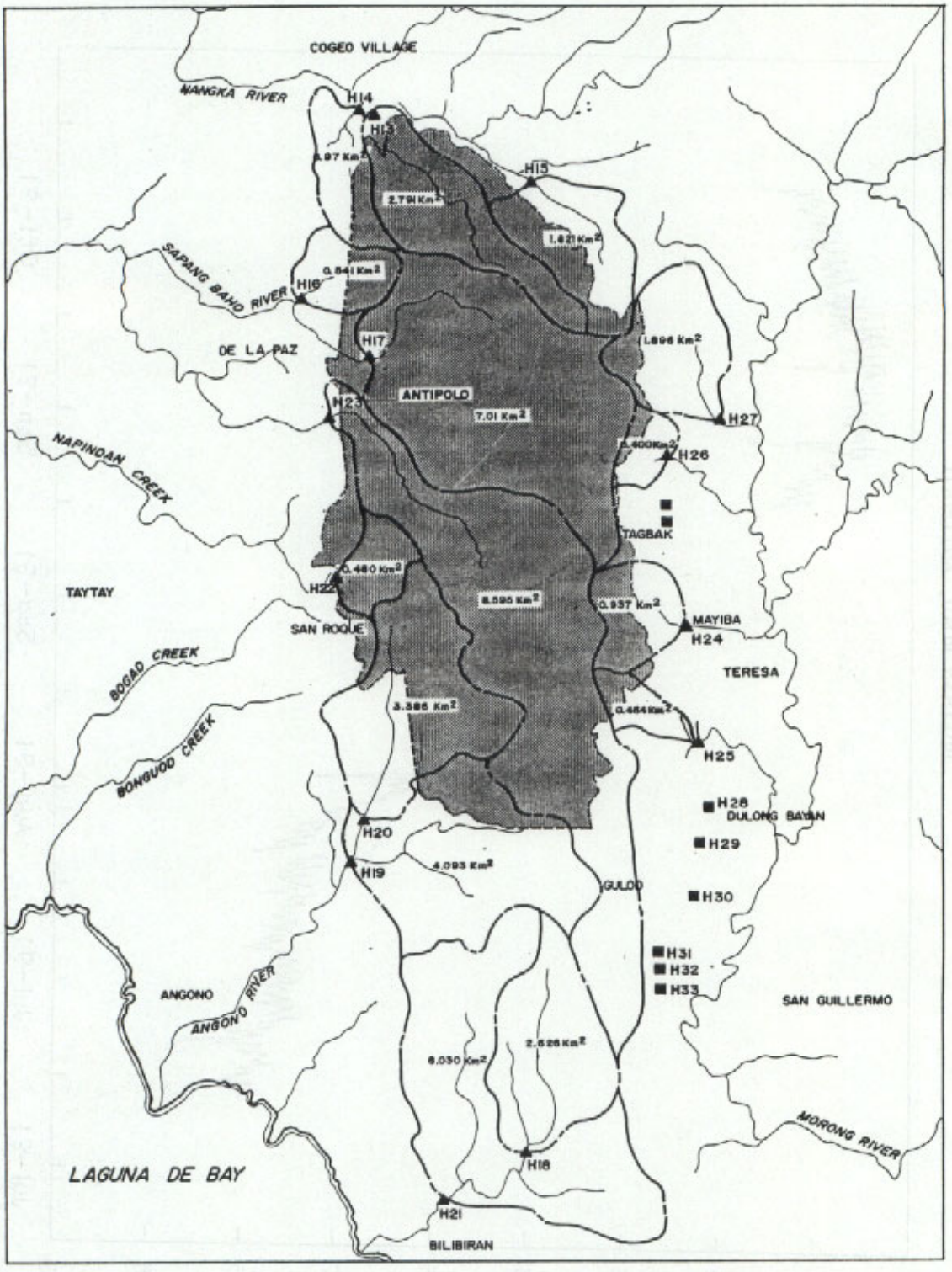


FIGURE 5.2.9 (CONTINUATION)
WELL HYDROGRAPH
BULIRAN ROAD, ANTIPOLO





LEGEND :

▲ STREAM FLOW OBSERVATION POINT

■ SPRING FLOW OBSERVATION POINT

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 5.2.10 LOCATION MAP OF SPRING & STREAM FLOW MEASUREMENTS
JAPAN INTERNATIONAL COOPERATION AGENCY	

CHAPTER 6

WELL INVENTORY AND GROUNDWATER USE SURVEY

CHAPTER 6 WELL INVENTORY AND GROUNDWATER USE SURVEY

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CHAPTER 6 WELL INVENTORY AND GROUNDWATER USE SURVEY

6.1 WELL INVENTORY

6.1.1 Introduction

Well inventory provides the basic data to carry out the different investigations and surveys of this Study, e.g., selection of wells for rehabilitation studies and pumping tests, monitoring of groundwater levels and quality, choice of sites for test and core drillings, and conduct of geological and electric resistivity surveys. It involves the collection of all available data on existing wells including:

- Location (well address, coordinates)
- Well Design and Construction (date of construction, driller, well depth, casing diameter (s), screen positions)
- Static Water Level
- Pumping Tests Results (pumping water level, discharge, specific Capacity, transmissivity)
- Electric Log
- Lithologic Log
- Water Quality

6.1.2 Previous Well Inventory

A comprehensive well inventory involving 2,292 deep wells was conducted during the early-1980s by MWSS and Electrowatt through the Ground Water Development - Manila Water Supply Project II (MWSS GWD-MWSP II). This was the first systematic inventory ever undertaken in Metro Manila. It yielded important data on static water levels in idle wells, quality of groundwater, specific capacities of wells, and aquifer tests and water pumpage. These data were used in the preparation of the 1981 ground-

water level contour map, the characterization of water quality, and the estimates of the water-bearing properties of the rocks.

The National Water Resources Board (NWRB), together with the government agencies, implemented in 1990 a project named "The Philippine Groundwater Summary" involving the countrywide inventory of existing wells. At present, the Local Water Utilities Administration (LWUA) is conducting a nationwide groundwater databanking through UNDP funding.

6.1.3 Collection of Well Inventory Data

All available data on MWSS-supervised wells and turned-over deep wells, private wells applying for water permit clearance from the NWRB, and wells inventoried during the GWD-MWSP II were collected, arranged and summarized by the MWSS Staff.

The Study Team also collected well data from the Mines and Geosciences Bureau (MGB) and the NWRB. The MGB provided some well log (lithology) data. The NWRB, tasked to compile all the well data in a databank, shared data from their well inventory.

To augment the well data collected from aforesaid government agencies, the Study Team collected from well drilling companies data for around 157 wells.

Table 6.1.1 presents the listing of the collected electric logs, lithologic logs, well designs, pumping test results and water quality analysis per municipality. The well inventory has retrieved 247 electric logs, 547 lithologic logs, 448 well designs, 393 pumping test results, and 116 water quality analysis. This Study was able to inventory around 3,434 private deep wells and 258 MWSS-supervised wells in the Study Area.

All well inventory data for each well were entered in the groundwater database system. Details of the well inventory are given in the Data Report of this study.

6.2 GROUNDWATER USE SURVEY

6.2.1 Objectives and Area Coverage

To estimate the year-1990 total groundwater abstraction in the MSA, a questionnaire survey was conducted by MWSS Staff under the supervision of the Study Team. This survey sought not only to obtain as estimate of the year-1990 pumpage for groundwater modeling and water demand projections; it also tried to determine the present pattern of groundwater withdrawal in the Study Area.

The survey covered 28 municipalities and involved approximately 3,434 inventoried private deep wells.

6.2.2 Survey Methods

Data Gathering

Wells were identified either as MWSS or private wells.

MWSS Wells

Data on the pumpage of MWSS wells were obtained from the 1990 production records of 131 operational wells. (As of March 1991, MWSS has 258 wells, of which 75 are inactive and 52 are abandoned.)

Private Wells

Since the existing data on private wells did not provide information on the actual pumpage, a random sample of 600 wells was selected from approximately 2,566 inventoried private wells.

Private wells were sub-classified as follows:

(1) By area, based on depth of 1981 piezometric surface in Metro Manila

a) +40 m to 0 (includes Antipolo, Caloocan-B, Imus, Montalban, Rosario and San Mateo)

b) 0 to -40m (includes Bacoor, Cainta, Cavite City, Kawit, Las Piñas, Mandaluyong, Noveleta, Pasay City, Pateros, Taguig and Taytay)

c) -40 to -80m (includes Makati, Manila, Marikina, Navotas, Parañaque, Pasig Quezon City and San Juan)

d) -80m to -120m (includes Caloocan-A, Malabon and Valenzuela)

(2) By type of user

a) Public: includes domestic (subdivisions, condominiums) and institutional (schools, public administration buildings, hospitals and military camps).

b) Commercial: includes office buildings, malls, department stores, restaurants, clubs, hotels and parks.

c) Industrial: users grouped by type of industries-- food and beverages; chemicals, distilleries and drugs; leather and footwear; textile, paper and pulp; and other industries.

(3) By specific capacity, based on pumping test results.

a) Small - < 0.5 lps/m

b) Medium - 0.5 - 1.0 lps/m

c) Large - > 1.0 lps/m

To allow readability of each sub-classification, the sample size was distributed as that given in Table 6.2.1.

Sample Selection

To ensure representativeness, the samples were selected randomly from the data file of the above-classified private wells using random numbers automatically generated by the computer.

o Substitution

A substitute under the same classification as the original sample was also selected randomly.

o Grounds for substitution

1) Outright refusal of the owner.
2) Chosen well could not be field-located.
3) Chosen well was abandoned or inactive at the time of the inter view.
4) Owner was not available for interview after two valid callbacks.

Well is usually termed abandoned when its screen has collapsed, has difficulty in pumping, or the quality of water it gives is not good. The term inactive or inoperational well is usually applied when there is an alternative water supply (surface water) or the well has very low yield.

Questionnaire

Questions directly addressed the wells' operation and capacity as well as the volume of groundwater required from the well. The questionnaire is shown in Annex 6A.

Field Work

To ensure the quality of data gathered in the field, the following measures were implemented:

o Orientation of interviewers

The survey had MWSS personnel as interviewers. Orientation of the field staff on the concept and guidelines of the survey was conducted to ensure the integrity of the data gathered.

Estimation of the Average Annual Pumpage of Well

Annual pumpage of the well surveyed was estimated using any of the following formula, depending upon which data were available during the interview.

(1) Use of Groundwater

$$P(ijkw) = Q(ijkw) \times Y(ijkw) \times 0.000001$$

where, P(ijkw) = pumpage of well w for sub-classification ijk,

in MCM

Q(ijkw) = total quantity of water use in a day, in m3

Y(ijkw) = number of days of operation in a year

w = sampled well

= 1,...., n(ijk); n(ijk) is the number of observations for sub-classification ijk

Sub-classification:

i = depth of depression

1 - +40m to 0
2 - 0 to -40m
3 - -40m to -80m
4 - -80m to -120m

j = specific capacity

1 - Small (<0.5 lps/m)
2 - Medium (0.5 - 1.0 lps/m)
3 - Large (>1.0 lps/m)

k = type of user

1 - Public, domestic
2 - Public, institution
3 - Commercial
4 - Industrial, food and beverages
5 - Industrial, chemicals and distilleries
6 - Industrial, leather and footwear
7 - Industrial, textile, paper and pulp
8 - Industrial, others

(2) Well production/Operation Data

P(ijkw) = DC(ijkw) x H (ijkw) x D(ijkw) x 0.0001872

where, P(ijkw) = as previously defined

DC(ijkw)= actual discharge of well w, in lps

H(ijkw) = number of hours of operation in a day
D(ijkw) = number of days of operation in a week
i,j,k,w = as previously defined

(3) Pump and Motor Data

P(ijkw) = RC(ijkw) x H(ijkw) x D(ijkw) x 0.0001872

where, P(ijkw) = as previously defined
RC(ijkw)= rated pump capacity, in lps
H(ijkw) = number of hours operation in a day
D(ijkw) = number of days operation in a week
i,j,k,w = as previously defined

Estimation of the Average Annual Pumpage of Wells by Sub-classification

(1) For sub-classification ijk (by area, type of user and specific capacity)

P(ijk) = P(ijkw) x W(ijk)

where, P(ijk) = total annual pumpage of wells for sub-classification ijk, in MCM
P(ijkw) = annual pumpage of well w for sub-classification ijk, in MCM
W(ijk) = weight for sub-classification ijk
= N(ijk)/n(ijk)
N(ijk) = number of inventoried wells for subclassification ijk
n(ijk) = number of observations for sub-classification ijk
i,j,k,w = as previously defined

(2) For sub-classification i (by area)

$$P(i) = \Sigma\Sigma\Sigma_{jkw} P(ijkw) \times n(ijk)$$

where, P(i) = total annual pumpage of wells for sub-classification i, in MCM

P(ijkw), n(ijk) = as previously defined

(3) For sub-classification j (by type of user)

$$P(j) = \sum_{ikw} \sum \sum P(ijkw) \times n(ijk)$$

where, P(i) = total annual pumpage of wells for sub-classification j, in MCM

P(ijkw),n(ijkw) = as previously defined

(4) For sub-classification k (by specific capacity)

$$P(k) = \sum_{ijw} \sum \sum P(ijkw) \times n(ijk)$$

where, P(k) = total annual pumpage of wells for sub-classification k, in MCM

P(ijkw), n(ijk) = as previously defined

Estimation of Groundwater Use for the Study Area

$$GWU = \sum_{ijkw} \sum \sum \sum P(ijkw) \times N(ijk)$$

where, GWU = groundwater use in MCM

P(ijkw), N(ijk) = as previously defined

Estimation of the Year-1990 Groundwater Pumpage by Groundwater Simulations

Since the actual number of abandoned wells in the 3,434 inventoried private deep wells was unknown and could not be derived through statistical means from the results of the groundwater use survey, estimation of the year-1990 groundwater pumpage was carried out by employing the groundwater flow model used for the Metro Manila groundwater basin simulations. The actual year-1990 piezometric surface in Metro Manila,

which was observed in this Study, was used as the controlling variable number of active private wells. The procedure for the estimation of the year-1990 pumpage is as follows:

1. Prepare nodal piezometric heads for years 1981 and 1990 from actual piezometric maps.

2. Compute actual nodal piezometric changes between 1981 and 1990.

3. Simulate piezometric heads in 1981 using preliminary pumpage of 1981 (30 time-steps steady-state calculation).

4. Compare simulated piezometric heads and actual piezometric heads.

5. Modify/Identify model parameters in order to adjust simulated heads to actual heads.

6. Repeat steps 3 to 5 until computed heads are almost equal to the actual heads.

7. Input preliminary pumpage data from 1981 to 1990 to the model.

8. Complete piezometric heads in 1990 by using 10 time-steps of non-steady-state simulation.

9. Compare simulated piezometric changes (1981-1990) with actual piezometric changes (1981-1990).

10. Compute pumpage modification coefficient at each element based on step 9.

11. Modify pumpage data and input to the model.

12. Repeat steps 8 to 11 until the computed piezometric changes are almost equal to the actual piezometric changes.

13. Compute final pumpage modification coefficient at each element.

14. Compute final pumpage data by type of user and by municipality.

The following assumptions were made for the estimation of the year-1990 pumpage:

1. Pumpage estimates in each element do not exceed the preliminary GWU estimates (previously defined) throughout the procedure.

2. Pumpage of MWSS wells remains constant.

3. Year-1981 pumpage is not modified.

4. Modification coefficients from 1982 to 1989 are increasing linearly.

When computed piezometric heads are almost the same as the actual heads, the modification of the preliminary pumpage estimates is then sufficiently satisfied.

Note that the preliminary pumpage estimates were made using a number of wells that was the difference between the 3,434 inventoried private wells and the known abandoned wells. The preliminary pumpage estimates were reported in Progress Report 3, while the final or modified estimates were presented in the Interim Report and the Main Report.

6.2.3 Survey Results

Table 6.2.2 shows the survey data on average annual pumpage for each sub-classification of the controlling variables (type of user, depth of depression, and specific capacity). Tables 6.2.3, 6.2.4 and 6.2.5 show the average discharge, the average number of hours of operation per day and the average number of days of operation per week. These results were used to obtain the average annual pumpage.

Discharge data of private wells were obtained from well inventory data, particularly from the pumping test results. The average yield per well of these wells is 7.9lps, very close to the 8.08lps average yield of the 542 sampled wells. The survey results also indicated some valid relationships among specific capacity, depth of depression and average well yield. As shown in the table below, the deeper the depression, the lower the average well yield. Also, the bigger the specific capacity,

the higher the average yield of well-- this holds true for all depths of depression. All these weighed, the results of the survey were considered reasonable.

AVERAGE YIELD PER WELL (in lps)

Specific capacity (lps/m)	Depth of Depression (m)			
	+40 to 0	0 to -40	-40 to -80	-80 to -120
<0.5	7.86	8.29	6.95	5.21
0.5 - 1.0	8.80	10.19	7.07	6.51
>1.0	9.01	10.65	8.30	7.47

TABLE 6.1.1 AVAILABILITY OF WELL DATA BY MUNICIPALITY
(AS OF MARCH 1991)

MUNICIPALITY	TOTAL NO. OF WELLS	ELECTRIC LOG	LITHOLOGIC LOG	WELL DESIGN	PUMPING TEST	WATER QUALITY
ATP	33	6	21	22	23	8
BIR	15	5	10	11	13	1
CLC	39	21	32	26	21	11
CTA	28	4	25	21	17	15
CVC	26	0	17	5	4	1
IMS	9	3	6	6	5	2
KWT	9	0	8	6	5	0
LPS	35	14	21	24	20	5
MDL	17	2	15	12	12	3
MKT	59	13	36	31	38	18
MLB	12	4	10	7	3	1
MNL	21	6	16	17	13	1
MRK	5	3	4	1	1	0
MTB	5	1	3	5	0	0
MTL	77	19	54	50	40	9
NAV	7	7	7	7	6	0
NOV	4	0	1	1	1	0
PRN	134	67	113	67	78	18
PSC	15	3	12	12	7	7
PSG	27	9	26	19	17	4
PTR	3	0	2	0	0	0
QCT	118	26	43	37	33	10
ROS	9	0	3	3	1	0
SJN	1	1	1	1	1	0
SMT	9	2	2	3	0	0
TGG	18	3	11	9	6	1
TYY	11	3	6	8	6	0
VLZ	42	25	42	37	22	1
TOTAL	788	247	547	448	393	116

TABLE 6.2.1 DISTRIBUTION OF SAMPLES

1. By Type of User and Area of Depression

Metro Manila	542
Public-Domestic	238
+40m to +0m	78
+0m to -40m	120
-40m to -80m	38
-80m to -120m	2
Public-Institution	61
+40m to +0m	9
+0m to -40m	45
-40m to -80m	5
-80m to -120m	2
Commercial	22
+40m to +0m	2
+0m to -40m	13
-40m to -80m	6
-80m to -120m	1
Industrial-Food & Beverages	27
+40m to +0m	4
+0m to -40m	12
-40m to -80m	8
-80m to -120m	3
Industrial-Chemicals	22
+40m to +0m	3
+0m to -40m	5
-40m to -80m	10
-80m to -120m	4
Industrial-Leather	2
-40m to -80m	2

TABLE 6.2.1 (CONTINUATION)

Industrial-Textile, Paper & Pulp	44
+40m to +0m	2
+0m to -40m	13
-40m to -80m	22
-80m to -120m	7
Industrial-Others	126
+40m to +0m	16
+0m to -40m	71
-40m to -80m	28
-80m to -120m	11

2. **By Type of User and Specific Depression**

Metro Manila	542
Public-Domestic	238
Small	105
Medium	74
Large	59
Public-Institution	61
Small	14
Medium	19
Large	28
Commercial	22
Small	9
Medium	3
Large	10
Industrial-Food & Beverages	27
Small	18
Medium	8
Large	1
Industrial-Chemicals	22
Small	10
Medium	2
Large	10

TABLE 6.2.1 (CONTINUATION)

Industrial-Leather	2
Medium	2
Industrial-Textile, Paper & Pulp	44
Small	11
Medium	22
Large	11
Industrial-Others	126
Small	50
Medium	26
Large	50

TABLE 6.2.2 AVERAGE ANNUAL PUMPAGE, BY TYPE OF USER, DEPTH OF DEPRESSION, AND SPECIFIC CAPACITY

(in MCM)

Type of User/ Specific Capacity	Depth of Depression			
	+40m to +0m	+0m to -40m	-40m to -80m	-80m to -120m
PUBLIC - DOMESTIC				
Specific Capacity				
Small	0.0978	0.1361	0.0868	0.0419
Medium	0.1304	0.1749	0.0714	0.0419
Large	0.2008	0.2582	0.1274	0.0689
PUBLIC - INSTITUTION				
Specific Capacity				
Small	0.0924	0.1046	0.0609	0.1488
Medium	0.1649	0.0701	0.0571	0.1488
Large	0.1225	0.1312	0.0571	0.1488
COMMERCIAL				
Specific Capacity				
Small	0.1271	0.1241	0.0944	0.0944
Medium	0.1271	0.1617	0.1517	0.1517
Large	0.1271	0.1254	0.1517	0.1517
INDUSTRIAL - FOOD & BEVERAGES				
Specific Capacity				
Small	0.1606	0.1274	0.1311	0.0754
Medium	0.1249	0.2364	0.1310	0.1310
Large	0.1249	0.2151	0.1310	0.1310
INDUSTRIAL - CHEMICALS				
Specific Capacity				
Small	0.2331	0.0461	0.1004	0.1061
Medium	0.2134	0.0461	0.0991	0.1061
Large	0.2134	0.0662	0.0991	0.1404

TABLE 6.2.2 (CONTINUATION)

Type of User/ Specific Capacity	Depth of Depression +40m to +0m	+0m to -40m	-40m to -80m	-80m to -120m
INDUSTRIAL - LEATHER				
Specific Capacity				
Small	0.3370	0.3370	0.3370	0.3370
Medium	0.3370	0.3370	0.3370	0.3370
Large	0.3370	0.3370	0.3370	0.3370
INDUSTRIAL - TEXTILE, PAPER & PULP				
Specific Capacity				
Small	0.2711	0.2144	0.3088	0.1960
Medium	0.3509	0.5451	0.2272	0.1991
Large	0.3145	0.4487	0.2923	0.1960
INDUSTRIAL - OTHERS				
Specific Capacity				
Small	0.0074	0.0778	0.0878	0.0158
Medium	0.1251	0.1173	0.0623	0.0788
Large	0.1936	0.3205	0.1076	0.2162

Source: Study Team's Survey Data

TABLE 6.2.3 ACTUAL DISCHARGE, BY TYPE OF USER, DEPTH OF DEPRESSION, AND SPECIFIC CAPACITY

(in LPS)

Type of User/ Specific Capacity	Depth of Depression			
	+10m to +0m	+0m to -40m	-40m to -80m	-80m to -120m
PUBLIC - DOMESTIC				
Specific Capacity				
Small	7.7478	5.7015	4.0321	2.0400
Medium	6.4470	9.7560	6.0767	2.0400
Large	10.5500	11.5176	8.3100	2.1900
PUBLIC - INSTITUTION				
Specific Capacity				
Small	5.0600	5.2220	3.2425	4.7300
Medium	6.0640	3.8262	2.9940	4.7300
Large	6.0859	6.8570	2.9940	4.7300
COMMERCIAL				
Specific Capacity				
Small	4.6500	14.5460	3.4525	3.4825
Medium	4.6500	12.3200	5.2100	8.2100
Large	4.6500	9.5314	8.2100	5.2100
INDUSTRIAL - FOOD & BEVERAGES				
Specific Capacity				
Small	7.3600	12.0760	5.2357	5.1167
Medium	5.7575	9.5400	5.4512	5.4512
Large	5.7575	11.1942	5.4512	5.4512
INDUSTRIAL - CHEMICALS				
Specific Capacity				
Small	11.0400	2.6350	6.1714	4.5925
Medium	9.8200	2.6350	6.1540	4.5925
Large	9.8200	3.0733	6.1540	5.9233
INDUSTRIAL - LEATHER				
Specific Capacity				
Small	12.5000	12.5000	12.5000	12.5000
Medium	12.5000	12.5000	12.5000	12.5000
Large	12.5000	12.5000	12.5000	12.5000

TABLE 6.2.3 (CONTINUATION)

Type of User/ Specific Capacity	Depth of Depression			
	+40m to +0m	+0m to -40m	-40m to -80m	-80m to -120m
INDUSTRIAL - TEXTILE, PAPER & PULP				
Specific Capacity				
Small	11.2862	8.7667	12.8543	7.4686
Medium	13.0456	20.1300	9.3633	7.5900
Large	13.7952	16.7162	13.5344	7.4656
INDUSTRIAL - OTHERS				
Specific Capacity				
Small	0.2350	4.5624	5.1125	1.1700
Medium	12.1360	10.7821	2.9400	3.9333
Large	9.1243	13.7975	6.2225	10.2600

Source: Study Team's Survey Data

TABLE 6.2.4 HOURS OF OPERATION PER DAY, BY TYPE OF USER, DEPTH OF DEPRESSION, AND SPECIFIC CAPACITY

Type of User/ Specific Capacity	Depth of Depression			
	+40m to +0m	+0m to -40m	-40m to -50m	-50m to -120m
PUBLIC - DOMESTIC				
Specific Capacity				
Small	11.3125	17.9773	17.5172	15.0000
Medium	14.1000	16.0333	12.6667	15.0000
Large	13.5000	16.6957	14.1667	24.0000
PUBLIC - INSTITUTION				
Specific Capacity				
Small	7.6667	16.2000	12.0000	24.0000
Medium	16.6000	14.9231	12.8000	24.0000
Large	12.0000	15.5926	12.8000	24.0000
COMMERCIAL				
Specific Capacity				
Small	17.6429	4.6000	17.5000	17.5000
Medium	17.6429	9.1535	15.0000	15.0000
Large	17.6429	10.2857	15.0000	15.0000
INDUSTRIAL - FOOD & BEVERAGES				
Specific Capacity				
Small	16.6667	10.6000	13.4286	11.3333
Medium	19.0000	20.6667	13.0000	13.0000
Large	19.0000	16.8333	13.0000	13.0000
INDUSTRIAL - CHEMICALS				
Specific Capacity				
Small	18.0000	13.0000	14.2857	16.5000
Medium	18.0000	13.0000	13.6000	16.5000
Large	18.0000	15.6667	13.6000	19.6667
INDUSTRIAL - LEATHER				
Specific Capacity				
Small	24.0000	24.0000	24.0000	24.0000
Medium	24.0000	24.0000	24.0000	24.0000
Large	24.0000	24.0000	24.0000	24.0000

TABLE 6.2.4 (CONTINUATION)

Type of User/ Specific Capacity	Depth of Depression			
	+10m to +0m	+0m to -40m	-40m to -50m	-50m to -120m
INDUSTRIAL - TEXTILE, PAPER & PULP				
Specific Capacity				
Small	19.4545	15.6667	19.7143	22.5571
Medium	22.0909	24.0000	17.6667	23.3333
Large	18.1515	22.7692	16.8869	22.5571
INDUSTRIAL - OTHERS				
Specific Capacity				
Small	24.0000	16.0345	16.5125	12.0000
Medium	8.4000	13.4256	16.5000	19.0000
Large	16.2857	17.9643	14.1250	10.5571

Source: Study Team's Survey Data

TABLE 6.2.5 DAYS OF OPERATION PER WEEK, BY TYPE OF USER, DEPTH OF DEPRESSION, AND SPECIFIC CAPACITY

Type of User/ Specific Capacity	Depth of Depression			
	+40m to +0m	+0m to -40m	-40m to -50m	-50m to -120m
PUBLIC - DOMESTIC				
Specific Capacity				
Small	6.9655	6.7273	6.6897	7.0000
Medium	6.8500	6.9697	6.6667	7.0000
Large	7.0000	6.7609	6.3333	7.0000
PUBLIC - INSTITUTION				
Specific Capacity				
Small	7.0000	7.0000	6.7500	7.0000
Medium	6.8000	7.0000	6.8000	7.0000
Large	6.3859	6.8519	6.8000	7.0000
COMMERCIAL				
Specific Capacity				
Small	7.0000	6.6000	6.7500	6.7500
Medium	7.0000	6.8462	6.6667	6.6667
Large	7.0000	7.0000	6.6667	6.6667
INDUSTRIAL - FOOD & BEVERAGES				
Specific Capacity				
Small	6.0000	5.6000	6.7143	5.6667
Medium	5.7500	5.6667	6.7500	6.7500
Large	5.7500	5.7500	6.7500	6.7500
INDUSTRIAL - CHEMICALS				
Specific Capacity				
Small	7.0000	6.6000	6.5714	6.2500
Medium	7.0000	6.6000	6.7000	6.2500
Large	7.0000	6.3333	6.7000	7.0000
INDUSTRIAL - LEATHER				
Specific Capacity				
Small	6.0000	6.0000	6.0000	6.0000
Medium	6.0000	6.0000	6.0000	6.0000
Large	6.0000	6.0000	6.0000	6.0000

TABLE 6.2.5 (CONTINUATION)

Type of User/ Specific Capacity	Depth of Depression +40m to +0m	+0m to -40m	-40m to -80m	-80m to -120m
INDUSTRIAL - TEXTILE, PAPER & PULP				
Specific Capacity				
Small	6.3636	7.0000	6.1429	6.2557
Medium	6.5000	6.3750	6.6667	6.3333
Large	6.1818	6.5385	6.1111	6.2857
INDUSTRIAL - OTHERS				
Specific Capacity				
Small	7.0000	6.8621	6.3750	6.0000
Medium	4.4000	6.2857	6.5000	6.6667
Large	6.8571	6.4286	6.8750	6.8571

Source: Study Team's Survey Data

Annex 6-A Groundwater Use Survey Questionnaire

METROPOLITAN WATERWORKS AND SEWERAGE SYSTEM
KATIPUNAN ROAD, BALARA, QUEZON CITY

GROUNDWATER USE SURVEY

JICA STUDY FOR GROUNDWATER DEVELOPMENT IN METRO MANILA

City/Municipality : _____
Address of Well Site : _____
Coordinates : LAT.: _____ LONG.: _____
Owner : _____
Present Status of Well : _____
(If abandoned, indicate reason for abandonment.)
Driller : _____ Year Constructed : _____
Total Well Depth : _____ M Casing Diameter : _____ CM
Quality (Taste, Odor, Color, Turbidity) : _____

WELL PRODUCTION/OPERATION DATA

Actual Discharge : _____ LPS
Method of Measurement : _____
Static Water Level : _____ M
Pumping Water Level : _____ M
No. of Hours of Operation per Day : _____
No. of Days of Operation per Week : _____
No. of Months of Operation per Year : _____
Observed Power Consumption : _____ KW
Average Power Consumption : _____ KW-HR/YR
Specific Capacity : _____ LPS/M

PUMP AND MOTOR DATA

Type of Pump : _____ Brand : _____
Pump HP Rating : _____ Rated Pump Capacity : _____ LPS
Total Dynamic Head (TDH) : _____ M Pump Setting : _____ M
Brand of Motor : _____ Motor HP Rating : _____

LOCATION MAP

Name of Respondent : _____ Position : _____
Date of Visit : _____ Investigator : _____

(PLEASE ANSWER NEXT PAGE AT THE BACK)

USE OF GROUNDWATER (CHECK THE TYPE OF USER)

____1 - PUBLIC: DOMESTIC (Subdivisions, Condominiums)
Number of Households : _____
Number of Persons in the Above Households: _____
Quantity of Water Used for
a) Sewage Treatment : _____M3/day
b) Boiler and Cooling System : _____M3/day
c) Others : _____M3/day
TOTAL (a+b+c) : _____M3/day

____2 - PUBLIC: INSTITUTION (Schools, Public Administration Bldgs, Hospitals, Military Camps)
Number of Employees : _____
Number of Enrollees/In-patients : _____
Quantity of Water Used for
a) Drinking and Sanitation : _____M3/day
b) Sewage Treatment : _____M3/day
c) Boiler and Cooling System : _____M3/day
d) Others : _____M3/day
TOTAL (a+b+c+d) : _____M3/day

____3 - COMMERCIAL (Office Bldgs, Malls, Department Stores, Restaurants, Clubs, Hotels, Parks)
Number of Employees : _____
Number of Guests/Customers per Day : _____
Quantity of Water Used for
a) Drinking and Sanitation : _____M3/day
b) Boiler and Cooling System : _____M3/day
c) Irrigation : _____M3/day
d) Others : _____M3/day
TOTAL (a+b+c+d) : _____M3/day

____4 - INDUSTRIAL: FOOD and BEVERAGES
____5 - INDUSTRIAL: CHEMICALS, DISTILLERIES, DRUGS
____6 - INDUSTRIAL: LEATHER AND FOOTWEAR
____7 - INDUSTRIAL: TEXTILE, PAPER and PULP
____8 - INDUSTRIAL: OTHERS (Specify: _____)

COMMON TO TYPES 4 -> 8 (INDUSTRIAL)
Output per Day in Tons : _____tons/day
(One Ton= 1000Kgs= One M3 of Water)
Quantity of Water Used per Ton of Output : _____M3/ton
Total Quantity of Water Used : _____M3/day
Number of Employees/Workers : _____
Quantity of Water Used for
a) Drinking and Sanitation : _____M3/day
b) Wastewater Treatment : _____M3/day
c) Boiler and Cooling System : _____M3/day
d) Irrigation : _____M3/day
e) Others : _____M3/day
TOTAL (a+b+c+d+e) : _____M3/day

CHAPTER 7

WELL REHABILITATION SURVEY

CHAPTER 7 WELL REHABILITATION SURVEY

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CHAPTER 7 WELL REHABILITATION SURVEY

7.1 SURVEY AT WELL SITES

7.1.1 Survey Methodology

There are at present two hundred fifty-eight (258) MWSS wells in MSA, and about half of these are inactive or abandoned. The figure is based on the list of active, inactive and abandoned MWSS deep wells prepared by the DeepWell Pumping Plant Section of MWSS (Table 7.1.1). Site survey of these wells was conducted, and the informations and data obtained were used to establish a rehabilitation program. Investigation items were:

- Site visit of all active and some inactive MWSS deep wells;
- Questionnaire survey at each area-cluster of deep wells;
- Collection and analysis of construction and pumping records of each well;
- Detailed survey of selected wells including the measurements of water levels, discharge rates and water qualities by pumping tests; and
- Preparation of the experimental rehabilitation program.

7.1.2 Present Condition of MWSS Wells

Obtained during the site visits and the interviews with the operators are the data on the present condition of MWSS wells (Tables 7.1.2). The well conditions are classified into four: "Good", "Damaged", "Standby" and "Others".

"Good": wells being operated are in good condition.
"Damaged": wells are damaged as indicated by any of the following:

a) Salty water output
b) Dirty water
c) Well caved-in
d) Well is almost dry
e) Defective pump/motor unit

"Standby": wells are on standby, under rehabilitation, or provides adequate water supply.

"Others": wells are abandoned, inactive, have broken distribution pipeline, etc.

Tables 7.1.2 and 7.1.3 show that ninety-nine (99) out of one hundred thirty (131) "active" wells are in good condition. The rest of the wells are practically inactive. However, this number of active wells may increase since some of the "inactive" wells are under rehabilitation and may be activated in the future. In addition, a considerable number of wells have not been operated since turn-over. These wells however could be operated when needed.

Under the active and inactive categories are 28 damaged wells. The causes of damage by municipality are shown in Table 7.1.4.

7.2 DETAILED SURVEY OF SELECTED WELLS

7.2.1 Scope and Specifications

Sixteen (16) out of twenty-eight (28) damaged wells were selected for detailed survey. This survey included pumping tests to obtain the data necessary for the well rehabilitation program. Those wells which were abandoned, or are very shallow, or have no original records were excluded. The scope and technical specifications of the rehabilitation are given as follows.

A. TWO WELLS

(1) COGEO No.1, ANTIPOLO (3 days)

- Addition of 2 pieces of riser pipes and lowering of the pump setting by about 12 meters
- Short pumping test (30 minutes)
- Removal of existing pumping facilities
- Measurement of well depth and static water level
- Installation of a pump test unit (pump setting - 78 meters)

- Pumping test (2 hours)
- Water sampling
- Removal of pump test unit
- Re-installation of the existing pumping facilities

(2) LAGRO No.5, QUEZON CITY (1 day)

- Measurement of pumping water level and discharge rate
- Addition of 3 pieces of riser pipes and lowering the pump setting by about 18 meters
- Pumping test (2 hours)
- Water sampling

B. TWELVE WELLS

- Removal of threaded-caps of sounding tube
- Measurement of static water level
- Pumping test (2 hours)
- Water sampling and measurement of pumping water level

C. TWO WELLS (Sumulong, Taytay and Forbes Park No. 12)

- Measurement of static water level

7.2.2 Results of the Survey

(1) Cogeo No.1, Antipolo

Due to low water output and frequent tripping of pump unit, this well has not been operated since July 1990.

The well and pumping unit have these following characteristics:

Existing pump setting	66m
Well depth	89.40m
Existing pump unit	Franklin Electric
	Model 2366016010 HP 7 1/2
	230 V PH3 MAX A 24.6
	3450 R.P.M.

Insulation resistivity 1.5 megaohms
(Low)

The new pump test unit which was used for the pump testing program has the following characteristics.

Pump Test Unit	RED JACKE 2130
	Serial No. DLE 6116 HP 15
	230 V 44.5 A, 3450 R.P.M.
	Insulation resistivity 130 megaohms
	(Good)

At first, the pump setting was changed to 78 meters by adding twelve (12) meters of riser pipes. Pumping started afterwards.

During the pumping test, the discharge rate is 3.08 lps and the pumping water level (PWL) is more than 67.06 m.

Another pump test unit which was installed at the same depth was also ran. Results show 3.22 lps of discharge and more than 67.06m of PWL and 6.0m of static water level (SWL). Results are almost the same as those on using the existing pump unit.

It is therefore noted that the low output of the well was improved by having the pump setting changed. But even with an increased discharge rate, the existing pump unit must still be repaired because of the low insulation resistance. It is also recommended that the pump setting be lowered by about 12 meters.

(2) Cogeo No. 6, Antipolo

As observed, this well has a reduced discharge rate. Results of the pumping test at Cogeo No.6 are as follows:

Existing pump setting	100.5m
Well depth	107.4m
Discharge rate	2.50 lps
Submersible pump	25 HP
Pumping Water Level	38.0m

It is recommended that the existing pump unit be removed so that pump setting and conditions can be checked. It seems that the pump setting was wrong or the impeller has worn out. Adjustment of pump setting to a more suitable position is recommended.

(3) Lagro No.5, Quezon City

This well was rehabilitated once in July 1990. However, water comes up intermittently.

Present condition of the well is as follows:

Existing pump	30 HP
Existing pump setting	96m
Discharge rate	3.75 lps
Pumping water level	50.60m

The pump setting was changed by adding three (3) pieces of 4" diameter riser pipes. Results of the pumping test are as follows:

Discharge rate	6.50 lps
Pumping water level	54.80m
Static water level	42.00m

The well produced water after the rehabilitation. It seems the existing pump setting was recorded incorrectly.

(4) IBP (Congress) No. 3, Quezon City

The condition of the well is as follows:

Well depth	208.20m
Submersible pump	30 HP
Pump setting	108m
Static water level	39m

This well was inactive since April 1990 because of the presence of iron bacteria. The existing pump should be pulled up and checked. The iron scales adhering to the pump and the riser pipes should be removed.

(5) Alabang Junction, Muntinlupa

The condition of the well is as follows:

Well depth	246.0m
Submersible pump	30 HP
Pump setting	72m
Pumping water level	74.45m
Discharge rate	(Flow meter was broken)

During the site visit made prior to the test, it was learned that the water that comes out from the well is dirty and contains sand. During the pumping test, however, clean water came up without sand. This well seemed to be in good condition. Pump setting was possibly wrong.

(6) Malanday, San Mateo

MWSS rehabilitated this well in 1989, but the well output is low. Results of the pumping test done by the Study Team are as follows:

Submersible pump	30 HP
Pump setting	78m
Flow rate	6.67 lps
Pumping water level	30.50m

Many iron bacteria appear to be present in the groundwater. The iron scales may be inside the riser pipes and the pump unit.

(7) Dulong Bayan, San Mateo

It was reported that the well had caved-in. The pumping test conducted by the Study Team showed that it has not.

Submersible pump	15 HP
Pump setting	57m
Flow rate	10.0 lps
Pumping water level	19.0m

No sandy materials were observed in the groundwater during pumping.

Pump operation is good. The groundwater flows directly into the distribution pipeline. Control of pumping rate is done by back pressure and thus could not be increased.

(8) Sumulong, Taytay

This well was inactive from September until the 3rd week of December 1990 due to defective electrical control. A 15-HP submersible pump was pulled out on December 27, 1990 and replaced by a 30-HP submersible pump the next day. The well condition is as follows:

Pump setting	75m
Static water level	58m
Submersible pump insulation resistance	0 ohm

The submersible pump needs repair because of zero (0) insulation resistance. Pump needs to be set deeper by adding three (3) pieces of 4" diameter riser pipes.

(9) Bangiad, Taytay

The well drilling was completed in March 1985. The pumping station was constructed in March 1987 and became operational in 1989.
Results of the pumping test:

Submersible pump	40 HP
Pump setting	90m
Flow rate	22.17 lps
Pumping water level	75.0m
40 HP submersible pump	Installed on Oct.3,1989.

The pump operation is good and groundwater is almost clean, except for some fine sand which sometimes comes out. The discharge rate should therefore be reduced.

(10) Zapote, Las Piñas

The pumping test results are as follows:

Submersible pump	25 HP
Flow rate	10.67 lps
Pumping water level	74.0m
Water quality	2,230 µS/cm; 30.9 deg. C; pH 7.95

Water coming from this well is salty. Considering the data obtained from the test wells drilled by the Study Team, the salty water may have originated from shallow aquifers in this area.

(11) Naga Road No.2, Las Piñas

The results of pumping test conducted by the Study Team are as follows:

Submersible pump	30 HP
Pump setting	132m
Flow rate	7.83 lps
Pumping water level	74.0m

The discharge rate was recorded at 23.03 lps in 1979. No rehabilitation work has been done during the last 12 years. It is therefore recommended that the existing pump unit be pulled out to check the setting and the pump's condition.

(12) Topacio Elementary School, Imus

The results are as follows:

Well depth	252m
Submersible pump	30 HP
Flow rate	14.5 lps
Pumping water level	81.0m

The report that the well had dried up was not true. This well seems to be in good condition. No sand came out during the test and the pump's operation was good.

(13) Dalahican, Cavite City

This well was also reported damaged. But the pumping test showed:

Well depth	189m
Submersible pump	15 HP
Pump setting	78m
Flow rate	6.67 lps
Pumping water level	52.45m

This well seems to be in good condition. No sand come out and the pump is still in good condition.

(14) Forbes Park No.12, Makati

The well characteristics are:

Well depth	304.80m
Static water level	48.50m

The pump unit was installed in September 1990.

(15) Forbes Park No.11, Makati

The well characteristics are:

Well depth	304.80m
Submersible pump	70 HP
Pump setting	210m
Pumping water level	139.0m

The discharge rate could not be measured because there was no flowmeter installed. Clean water came out from this well. The well is in good condition.

(16) Maricaban III, Pasay City

Results of pumping test show:

Well depth	237.74m
Submersible pump	30 HP
Pump setting	109m
Flow rate	11.22 lps
Pumping water level	110.40m
Water quality	1,421 µS/cm; 31.6 deg. C; pH 8.29

The well yields water that is a little salty. No sand came out. This well is still in good condition.

7.2.3 Summary of the Survey

(1) Recommended for well rehabilitation

Cogeo No.1, Antipolo
Cogeo No.6, Antipolo
IBP (Congress) No.3, Quezon City
Malanday, San Mateo
Sumulong, Taytay
Naga Road No.2, Las Piñas
Forbes Park No.12, Makati

(2) Well in good condition

Bangiad, Taytay

(3) Improvement in water quality could not be expected

Zapote, Las Piñas

(4) Increase the power rating of the pump or the total dynamic head

Dulong Bayan, San Mateo
Alabang Junction, Muntinlupa
Topacio Elementary School, Imus
Dalahican, Cavite City
Forbes Park No.11, Makati
Maricaban III, Pasay City

(5) Check and follow up the well condition

Lagro No.5, Quezon City

7.3 EXPERIMENTAL REHABILITATION WORK

7.3.1 Work Outline

The experimental work for rehabilitation was drawn up for five (5) MWSS deepwells in Metro Manila based on the survey results. The location and details of these wells are shown in Figures 5.3.1 to 5.3.6 and Table 5.3.1

The experimental work for rehabilitation involves the following activities:

1) Preparation and mobilization
2) Pulling out of existing pumping unit
3) Measuring of well depth and water level
4) Inspection of existing pumping unit
5) Installation of test pumping unit
6) First pumping test
7) Surging, bailing and airlifting
8) Second pumping test
9) Installation of existing pumping unit
10) Demobilization

After mobilization and preparatory work, the existing pumping unit well depth and static water level are then measured. The accumulation of sand, mud, rust and other materials at the bottom of the well are investigated throughout the measurement.

Electric conductivity and temperature logging are conducted just below the static water level down to the bottom of the well at one meter intervals.

The Study Team had the existing pumping units checked and the slight damages repaired. The scales adhering to the pumping units were removed

and the units cleaned up.

A test pumping unit was installed in the well together with a micro-flow meter in order to carry out the following pumping tests.

1) Step-drawdown test
2) Constant discharge test
3) Recovery test
4) Flow measurement at screen sections

Flow measurement was not conducted at Sumulong, Taytay and Cogeo No.1, Antipolo because the diameter of the casings of these wells is 6 inches and the clearance between the test pump and casing was so narrow for the installation of micro-flow meter unit. The flow meter was also not used at Cogeo No.6, Antipolo because the well was cased without screens from the ground surface to the depth of 100m, but was uncased below this depth down to the bottom. Instead of measuring the micro-flow at three wells -- IBP No.3, Cogeo No.6, Antipolo and Naga Road No.2 -- a television camera was lowered inside the wells and photographs were taken.

First Pumping Test

Pumping rate and pumping water level were measured continuously and checked by using a triangle notch weir and electrical sounding wire. The electric conductivity, temperature and pH were measured by using water quality meters.

(1) Step-drawdown Test

The step-drawdown test was conducted at five (5) steps with pumping duration of two (2) hours for each step. The pumping rate was decided at the site. The test was not completed at Cogeo No.1, Cogeo No.6, IBP No.3 and Naga Road No.2 wells because of large drawdowns or very low discharges.

(2) Constant Discharge Test

This test was continued for forty eight (48) hours. The pumping rate was decided and was directed to the Contractor.

(3) Recovery Test

After constant discharge test, the recovery of water level was measured for eight (8) hours.

(4) Flow Measurement

The flow rate at each screen section of the well was measured. The depth of setting was at the uppermost part of each screen section. Measurements were taken at one hour intervals during the conduct of the step drawdown.

Surging and Bailing

After the first pumping test, the wells were surged throughout the screen section. The wells are bailed when any accumulation are observed. Surging and bailing were performed for more than two (2) days, at eight (8) hours per day.

Airlifting

Upon completion of surging and bailing, the wells were discharged by airlifting for more than two (2) days, also at (8) hours per day. The compressor used for pumping by airlifting has a developing pressure of 8 kilograms per square centimeter (114 psi); the delivery rate was 17 cubic meter of air per minute. From time to time, the air flow was stopped to facilitate the loosening of trapped materials.

Airlifting was completed with the eductor pipes almost at the bottom of the well to ensure that all materials are cleaned out of the pipe.

Second Pumping Test

After airlifting, the second pumping test was conducted and flow measurements taken in the same manner as the first pumping test.

After completion of the second pumping test, the existing pumping unit was reinstalled in the well. Sounding tubes of 3/4-inch diameter were installed with the existing pumping unit to facilitate the measurement

of water level.

Actually, the existing pumping unit is damaged and therefore was not reinstalled at Sumulong, Cogeo No.6 and IBP No.3. But the riser pipes and submersible pumps for replacement were not available. IBP No.3 is recommended to be abandoned because of its low water output and the presence of many iron bacteria.

7.3.2 Effect of Rehabilitation

The results of experimental works are summarized in Table 5.3.2.

(1) Sumulong, Taytay Deepwell

For the first pumping test, a 30-HP submersible pump was used. It was installed at a depth of 78m below ground level. For the second, a 10-HP submersible pump was used and installed at a depth of 120m below ground level. The diameters of casing are 8 inches from ground level to 80.77m, and 6 inches below 80.77m. The diameter of riser pipes is 3 inches. Static water level before pumping was 58.00m for the first pumping test and 58.50m for the second pumping test.

The pumping tests were conducted at five steps with discharge rates of 60, 108, 144, 168 and 198 l/min for the first test; for the second, 78, 120, 162, 198 and 240 l/min. Each step has a duration of two hours.

From the results, well loss parameters were calculated using Jacob's equation. For the first pumping test, the values of B and C obtained from Q-s/Q graphs are 5.40×10^{-2} day/m^2 and 1.65×10^{-4} day^2/m^5, respectively; and for the second, 2.60×10^{-2} day/m^2 and 1.43×10^{-4} day^2/m^5, respectively. Well efficiencies were calculated as 51.3% when discharge rate is 198 l/min (285 m^3/day) at the first pumping test and as 34.0% when discharge rate is 240 l/min (328 m^3/day).

In order to determine the transmissivity T and storage coefficient S of the aquifer, the continuous pumping and recovery tests were carried out before and after rehabilitation work. The discharge rate determined from the step-drawdown test was 156 l/min at the first pumping test and 204 l/min at the second pumping test. Duration of pumping was 48 hours.

The discharge rates were small because the diameter of the casing pipes was reduced from 8 to 6 inches at depth of 80.77m and only a smaller submersible pump could be installed. The residual drawdown before and after rehabilitation work was measured for 8 hours after pumping has stopped.

The specific capacity was noted to have improved from 9.50 m^2/day to 13.07 m^2/day. Aquifer loss coefficient and well loss coefficient have also improved. This may indicate that the clogging of the well screen and aquifer were removed by rehabilitation work. EC values during pumping tests also support this idea.

(2) Cogeo Antipolo No. 1, Antipolo

A 10-HP submersible pump was installed at a depth of 78m below ground level. The diameter of casing and riser pipes were 6 and 3 inches, respectively. The static water level before pumping was 8.10m at the first pumping test and 6.55m at the second.

Step-drawdown tests were conducted at discharge rates of 42, 78, 120, 156 and 198 l/min before and after rehabilitation work. The duration of each step was two hours.

From the results, well loss parameters were calculated using Jacob's equation. For the first pumping test, the values of B and C obtained from Q-s/Q graphs are 8.00×10^{-3} day/m^2 and 2.55×10^{-4} day^2/m^5, respectively; and for the second, 2.00×10^{-3} day/m^2 and 2.10×10^{-4} day^2/m^5, respectively. Well efficiencies are calculated as 13.6% at the first pumping test and as 4.70% at the second pumping test. Discharge rate is 156 l/min (225 m^3/day).

The continuous pumping test was conducted at a discharge rate of 198 l/min. Duration of pumping at the first pumping test was 10 hours because the pumping water level declined to near the level of pump setting. Duration of the second pumping test was 48 hours. The discharge rate was small because the pumping water level declined rapidly to the level of pump setting.

The residual drawdown was measured for eight hours after the pumping has

stopped.

The specific capacity was noted to have improved from 17.0 m^2/day. Aquifer loss coefficient and well loss coefficient have also improved. This may indicate that the clogging of the well screen and aquifer were removed by rehabilitation work.

It was also observed that the pumping water level declined rapidly and did not become stable at the discharge rate of 198 l/min. This may indicate that the groundwater of this well come from the fissure of basalt and is unconfined. Storage coefficient S values and aquifer loss coefficient values B obtained from the pumping tests also support this idea.

(3) Cogeo No. 6, Antipolo

A 20-HP submersible pump was installed at a depth of 90m below ground level. The diameter of casing pipes and riser pipes were 8 and 3 inches, respectively. The 8" blank casing pipes were installed up to 91.44m below ground level and a 14" borehole was uncased from a depth of 91.44 to 117.35 meters. The static water level was 11.50m at the first pumping test and 10.49m at the second.

Step-drawdown test was performed at discharge rates of 49.2, 102, 150, 204 and 252 l/min. Although the planned duration of each step was two hours, the final step had only a duration of twenty (20) minutes, because the pumping water level had declined to the level of the pump setting.

For the first pumping test, the values of well loss parameters B and C obtained from Q-s/Q graphs are 0.00 day/m^2 and 8.00×10^{-4} day^2/m^5, respectively; and for the second, 0.00 day/m^2 and 7.35×10^{-4} day^2/m^5 respectively. Well efficiencies are calculated as 0.00% at the first pumping test and also as 0.00% at the second. Discharge rate was 204 l/min (294 m^3/day).

The continuous pumping test was conducted at a discharge rate of 150 l/min. Duration of pumping for the first pumping test was 22 hours. Although it was planned for forty eight (48) hours, pumping was aborted

due to power failure (brown out). Duration of the second pumping test was 48 hours. The discharge rate was small because the pumping water level declined rapidly and reached the pump setting position.

The specific capacity was noted to have improved a little from 4.30 m^2/day to 4.58 m^2/day. Well loss coefficient has also improved a little. This may indicate that the clogging of the well screen and aquifer were originally small.

It was also noted that the pumping water level declined continuously and was unstable when the discharge was 252 l/min. This may indicate that the groundwater of this well come from the fissure of basalt rocks, like that in Cogeo Deepwell No.1.

(4) IBP (Congress) No.3

The discharge from IBP No.3 was so small that the pumping test could not be carried out.

According to the lithologic log that was obtained at the time the well was completed on 23 May 1978, the geologic formation mainly consists of clayey layers and the screen section was set at very thin gravel beds. EC values at 18 degrees range from 136 to 156 µS/cm. Considering such low conductivities, this may indicate that water directly enters the well from surface sources such as rain or perched water. Very small amounts of groundwater may flow into the well through the screen section.

(5) Naga Road No.2

A 30-HP submersible pump was installed at a depth of 102m below ground level. The diameters of casing and riser pipes were 10 and 4 inches respectively. The static water level before pumping was 55.84m at the first pumping test and 55.42m at the second.

The step-drawdown test was conducted at discharge rates of 102, 204, 300 and 360 l/min. Although planned for five steps, testing was stopped at the final step because of the small dynamic head.

For the first pumping test, the values of well loss parameters B and C obtained from Q-s/Q graphs were 3.20×10^{-2} day/m^2 and 6.20×10^{-6} day^{-2}/m^5, respectively; for the second, 2.95×10^{-2} day/m^{-2} and 6.20×10^{-6} day^{-2}/m^5, respectively. Well efficiencies were calculated at 92.3% at the first pumping test and at 90.2% at the second. Discharge rate was 300 l/min (432 m^3/day).

The discharge rate determined from the step-drawdown test was 354 l/min. The continuous pumping test duration was 48 hours.

The discharge rate was not so high at the first pumping test because the existing 6-stage submersible pump that was used, after dismantling and removing the scales from the pump impeller, does not have high dynamic head. At the second pumping test, the discharge rate was also not so high because the existing pump was again used. A new 30-HP, 12-stage, submersible pump was then installed, but the motor conked out during the 20-minute test operation due to the intrusion of sand. Such being the case.

The residual drawdown was measured for eight hours after the pumping has stopped.

The specific capacity was noted to have improved from 28.9 m^2/day to 30.6 m^2/day at a discharge rate of 378 l/min. It was also noted that after rehabilitation the groundwater flowed into the well through lower screen sections. Well loss coefficient was the same. This may indicate that the clogging of the well screen and aquifer was very few.

7.3.3 Recommendations

Based on the result of the experimental work for rehabilitation of five (5) MWSS deepwells, the recommendation on the operation and maintenance of these wells are as follows.

(1) **Sumulong, Taytay**

The control panel of the submersible electric motor and all columns of riser pipes should be replaced. The submersible pump should have a smaller diameter and capacity than the existing one has. Pump should be

set deeper because the diameter of the well casing pipes was reduced from 8" to 6" at a depth of 80.77m, and the pumping water level is below this depth when the well was pumped at a discharge rate of 240 l/min. Submersible cable should be replaced because its insulation resistance reading is only 10 megaohms.

The submersible pump that should be installed must be 10 HP, 133mm in diameter, and it should have 115 meters of total dynamic head at 216 l/min of discharge. Twenty (20) columns of 3" x 20' riser pipes should also be installed.

(2) Cogeo No.1, Antipolo

Submersible pump should be replaced because its insulation resistance reading is only 0.5 megaohms, despite Contractor's not finding of any damage during inspection of the dismantled pump assembly.

In the course of the rehabilitation work, the pump setting has been changed from 66m to 78m by using two additional columns of 3" riser pipes and 12m additional submersible cable. The pumping water level was not stable and was still declining when the discharge was 198 l/min.

It is therefore recommended that this well should be operated on a half-day basis, at about 150 l/min of discharge and stopped for the rest of the day.

The pumping water level should always be monitored. Pump condition, especially the bolts, should be carefully maintained.

(3) Cogeo No.6, Antipolo

Submersible pump should be replaced because its insulation resistance reading is only 8 kiloohms and it has a 1x1 cm-size hole at the pump bowl. Two (2) pieces of 3"x20' riser pipes are usable, but 14 pieces of 3"x20' riser pipes and one 1 piece of 3"x20' riser pipe should be replaced. One hundred and one (101) meters of submersible cable are still usable. The pumping water level was not stable and still declining when the discharge was 204 l/min.

Submersible pump which has a capacity of 7.5 HP and 97 meters of total dynamic head at 200 l/min discharge rate should be installed with 16 pieces of 3"x20' riser pipes.

This well should be operated on a half-day basis at a discharge rate of about 150 l/min and be similarly maintained as the Cogeo Antipolo Deep-well No.1.

(4) IBP (Congress) No.3

This well should be abandoned after it has been plugged with cement.This well produces very low water output and has many iron bacteria inside the well. In order to avoid the spread of iron bacteria, and obviate the possibility of infection of another active well through the aquifer, the well should be completely plugged.

(5) Naga Road No.2

Seventeen (17) pcs. of 3"x20' riser pipes formerly used at Tuazon deep-well were installed to replace those of Naga Road Deepwell No.2. It is recommended that the pumping unit be pulled out and checked within two to three years. The pumping water level and discharge rate should be monitored regularly. Pumping facilities should be properly maintained.

TABLE 7.1.1A LIST OF ACTIVE MWSS DEEP WELLS
(AS OF MARCH 1991)

Well Name Municipality	Actual Condition	Group
ANTIPOLO		
1. M.L. Quezon (Pump #1)		
2. Sto. Nino (Pump #2)		
3. P. Burgos (Pump #3)		
4. Nursery (Pump #4)		
5. Circumferential Road (Pump #5)		
6. Road to Teresa (Pump #6)		
7. Sumulong Elementary School (Pump #7)		
8. San Isidro Elementary School (pump #8)		
9. Ang Tahanan (Pump #9)		
10. Saguinsin (Pump #10)		
11. Cogeo # 1	Defective pump unit	D-Pump
12. Cogeo # 2	Defective pump unit	D-Pump
13. Cogeo # 4		
14. Cogeo # 5	Defective pump unit	D-Pump
15. Cogeo # 6	Defective pump unit	D-Pump
CAINTA		
16. San Juan		
17. Gloria-Mariok		
18. San Fabian		
19. Magandan	Abandoned	Others
20. Sto. Domingo	Defective pump unit	D-Pump
TAYTAY		
21. Sumulong	Defective pump unit	D-Pump
22. San Isidro		
23. Sta. Ana Elementary School		
24. Taytay Elementary School		
25. San Victores		
26. Rosario		
27. Bangiad		
SAN MATEO		
28. San Mateo Public Market		
29. Banaba, Ampid		
30. Malanday	Abandoned	Dirty
31. Maly		
32. Dalong Bayan II	Well caved-in	Caved

TABLE 7.1.1A (CONTINUATION)

Well Name Municipality	Actual Condition	Group
MONTALBAN		
33. San Jose		
34. Manggahan		
35. Aranzazu		
VALENZUELA		
36. T. De Leon		
37. Pasolo Elementary School		
38. Arkong Bato	No operator	Others
MALABON		
39. Catmon	No operator	Others
40. Dampalit	No operation	Others
41. Dona Juana		
NAVOTAS		
42. Merville Subdivision		
43. Dagat Dagatan # 1	No operation	Others
MUNTINLUPA		
44. Muntinlupa Bliss		
45. Poblacion	Defective Pump unit	D-Pump
46. Tunasan		
47. Putatan		
48. Cupang Elementary School		
49. Alabang Junction	Dirty water yields	Dirty
50. Sucat Elementary School		
PARANAQUE		
51. MIA # 1		
52. mia # 3		
53. MIA # 4		
54. Sucat # 2		
55. La Huerta		
TAGUIG		
56. Signal Village 11		
57. Upper Bicutan	No operation	Others
58. Signal Village 1	No operation	Others

TABLE 7.1.1A (CONTINUATION)

Well Name Municipality	Actual Condition	Group
LAS PINAS		
59. Naga # 2	Defective Pump Unit	D-pump
60. Zapote, Las Pinas (under the supervision of Cavite pumping station)	Salty water yields	Salty
PASAY CITY		
61. Maricaban 1	Defective Pump Unit	D-pump
62. Maricaban 11		
63. Maricaban 111	Defective Pump Unit	D-pump
MAKATI		
64. Poblacion		
65. Ecology Village		
66. Ayala # 1	No operation	Others
67. Forbes Park # 2		
68. Forbes Park # 6	Defective Pump Unit	D-pump
69. Forbes park # 8		
70. Forbes Park # 9		
71. Forbes Park # 11	Defective Pump Unit	D-pump
72. Forbes Park # 12	Defective Pump Unit	D-pump
73. Dasmarinas # 39		
74. Dasmarinas # 17	Not yet in operation	Others
PASIG		
75. Barrio Capitolyo		
76. Valle Verde Phase 5	Not yet in operation	Others
QUEZON CITY		
77. Greenmeadows # 3		
78. Greenmeadows # 4		
79. Fairview # 1		
80. Fairview # 2		
81. Fairview # 3		
82. Fairview # 4		
83. Fairview # 5		
84. IBP Congress # 2		
85. IBP Cognress # 3	Recommended for abandon	Dirty
86. IBP Cognress # 4		
87. Lagro # 1		
88. Lagro # 2		
89. Lagro # 3		
90. Lagro # 5		
91. Escopa, Project 4		
92. Loyola Grand Villas	No operation	Others

TABLE 7.1.1A (CONTINUATION)

Well Name Municipality	Actual Condition	Group
CAVITE CITY		
93. Samonte Park	Salty water yields	Salty
94. Garita		
95. San Roque		
96. Manalac		
97. Calle Marino		
98. San Nicolas		
99. Bagong Pook	No operator	Others
100. Garcia Extension	No operation	Others
101. Crescini		
102. Rivero		
103. Magcauas		
104. Ejercito		
105. Militar		
106. Antonio		
107. J. Felipe		
BACOOR		
108. Daang Bukid		
109. Poblacion		
110. Balsahan		
111. Combalay		
112. Talaba		
113. Niog		
114. Bacoor Central School		
115. Dulong Bayan		
IMUS		
116. Plaza Garcia		
117. Yengco		
KAWIT		
118. Malamok		
119. Aguinaldo		
120. Josephine Resort		
121. Putol-Sta. Isabel		
ROSARIO		
122. Poblacion		
NOVELETA		
123. Noveleta Elementary School		
124. Noveleta Well Field # 1		
125. Noveleta Well Field # 2		
126. Noveleta Well Field # 3		
127. Noveleta Well Field # 4		
128. Noveleta Well Field # 5		
129. Noveleta Well Field # 6		
130. Noveleta Well Field # 7		
131. Noveleta Well Field # 8		

Notes: Blank of actual condition is good condition.

TABLE 7.1.1B LIST OF INACTIVE MWSS DEEP WELLS
(AS OF MARCH 1991)

Well Name Municipality	Actual Condition	Group
CAINTA		
1. Sumulong Highway	For rehab	Rehab
2. Poblacion	Frequent tripping of unit	D-pump
MARIKINA		
3. SSS Vill # 1	Test tun	Stand-by
4. SSS Vill # 2	Under rehabilitation program	Rehab
5. SSS Vill # 3	Test run	Stand-by
6. SSS Vill # 4	Test run	Stand-by
7. SSS Vill # 5.	Test run	Stand-by
8. SSS Vill # 6	Under rehabilitation program	Rehab
9. SSS Vill # 7	Under rehabilitation program	Rehab
10. SSS Vill # 8	Test run	Stand-by
11. SSS Vill # 9	Test run	Stand-by
12. SSS Vill # 10	Test run	Stand-by
13. East Drive, SSS Village	Test run	Stand-by
14. Industrial Valley	Insufficient water pressure	Adequate
15. Concepcion -	- do -	Adequate
MALABON		
16. Santolan	Adequate water supply	Adequate
17. Niogan	Stand-by	Stand-by
18. Panghulo	Stand-by	Stand-by
VALENZUELA		
19. Kadiwa Center	Sufficient surface water	Adequate
20. Tamaraw Hills	- do -	Adequate
21. Constantino	- do -	Adequate
22. Marulas Elem. School	- do -	Adequate
CALOOCAN CITY		
23. Banal St., Bagong Barrio	Stand-by	Stand-by
24. katarungan St., Bagong Barrio	Stand-by	Stand-by
NAVOTAS		
25. D. Dagatan # 2	Sufficient surface water	Adequate
26. D. Dagatan # 3	- do -	Adequate
27. D. Dagatan # 4	- do -	Adequate
28. D. Dagatan # 5	- do -	Adequate
29. D. Dagatan # 6	- do -	Adequate
30. D. Dagatan # 7	- do -	Adequate
31. D. Dagatan # 8	- do -	Adequate

TABLE 7.1.1B (CONTINUATION)

Well Name Municipality	Actual Condition	Group
PARANAQUE		
32. San Dionisio	Sufficient water pressure	Adequate
33. Sucat #1	Sufficient water pressure	Adequate
TAGUIG		
34. Maharlika	operated by Muslim	Others
LAS PINAS		
35. Poblacion	defective pumping unit since 8/19/86	D-pump
36. Manuyo	For Rehab	Rehab
37. Ilaya	For Rehab	Rehab
PASAY CITY		
38. Menares Cpd.	Sufficient surface water	Adequate
MAKATI		
39. Ayala # 8	defective unit	D-pump
40. Ayala # 10A	Under rehabilitation program	Rehab
41. Ayala # 11	Under rehabilitation program	Rehab
42. Ayala # 19	Under rehabilitation program	Rehab
43. Ayala # 20	Under rehabilitation program	Rehab
44. Ayala # 22	Under rehabilitation program	Rehab
45. Ayala # 25	Under rehabilitation program	Rehab
46. Ayala # 28	Under rehabilitation program	Rehab
47. Ayala # 29	Under rehabilitation program	Rehab
48. Ayala # 31	Under rehabilitation program	Rehab
49. Ayala # 33	Under rehabilitation program	Rehab
50. Ayala # 35	Under rehabilitation program	Rehab
51. Magallanes # 5	Under rehabilitation program	Rehab
52. Magallanes # 15	Under rehabilitation program	Rehab
53. Magallanes # 41	Under rehabilitation program	Rehab
54. Magallanes # 42	Under rehabilitation program	Rehab
55. Dasmarinas # 9	Under rehabilitation program	Rehab
56. Dasmarinas # 14	Under rehabilitation program	Rehab
57. Dasmarinas # 40	Under rehabilitation program	Rehab
58. Forbes Park # 3	Defective unit & Sufficient water pressure	D-pump
59. Forbes Park # 10	- do -	D-pump
60. Forbes Park # 13	- do -	D-pump
61. Forbes Park # 14	- do -	D-pump
PASIG		
62. Santolan	Sufficient surface water	Adequate

TABLE 7.1.1B (CONTINUATION)

Well Name Municipality	Actual Condition	Group
QUEZON CITY		
63. IBP # 1	Defective motor	D-pump
64. Congressional Village #3	For Rehab	Rehab
65. D. Tuazon Pumping Station	Sufficient water	Adequate
66. D. Tuazon Elem. School	Sufficient water	Adequate
67. Lagro #4	Defective motor	D-pump
68. GSIS Village	Sufficient water pressure	Adequate
69. Bagbag, Novaliches	- do -	Adequate
70. Poblacion, Novaliches	- do -	Adequate
71. North Fairview # 8		Others
KAWIT		
72. Binakayan, Kawit	Stand-by unit	Stand-by
73. Bo. Wawa	Stand-by unit	Stand-by
PASIG		
74. Wawa, Rosario, Cavite	Stand-by-unit	Stand-by
75. Bo. Sapa	- do -	Stand-by

TABLE 7.1.1C LIST OF ABANDONED MWSS DEEP WELLS
(AS OF MARCH 1991)

Well Name Municipality	Actual Condition	Group
ANTIPOLO		
1. Cogeo # 3	Well caved in	Caved-in
CAINTA		
2. Irma	Non potable water yields	Dirty
3. Felix	Non potable water yields	Dirty
TAYTAY		
4. Isagani	Very low water output	D-pump
MARIKINA		
5. San Roque	Adequate Water Supply	Adequate
6. Malanday	Availability of surface water	Adequate
SAN MATEO		
7. Ampid 1	Non potability water yields	Dirty
8. Sta. Ana	Now operational	Others
9. Ampid 11	Non potability water yields	Dirty
MONTALBAN		
10. Geronimo	Pumping unit was not installed	D-pump
11. Poblacion	Pumping unit was not installed	D-pump
VALENZUELA		
12. Malinta	No available data	Others
MALABON		
13. Bo. Hulong Duhat 1	No more existing well	Others
14. Bo. Hulong Duhat 11	No more existing well	Others
15. Dampalit, old well	Cemented, Salty	Salty
CALOOCAN CITY		
16. Pasmon Tala	Clogged	Caved-in
MANILA		
17. Baluto, Tondo	Salty water yields	Salty
18. Aduana, Intramuros	Old well/clogged	Caved-in
19. Muralla, Intramuros	Old well/clogged	Caved-in

TABLE 7.1.1C (CONTINUATION)

Well Name Municipality	Actual Condition	Group
PARANAQUE		
20. Sto. Nino	Salty water yields	Salty
21. Sukat # 3	Salty water yields	Salty
22. MIA # 2	Salty water yields	Salty
23. MIA # 3	Salty water yields	Salty
24. MIA # 4	Salty water yields	Salty
LAS PINAS		
25. Naga # 1	Salty water yields	Salty
26. Las Pinas Elem. School	Salty water yields	Salty
27. Pulang Lupa # 2	Salty water yields	Salty
PATEROS		
28. Fort Bonifacio	Salty water yields	Salty
29. San Pedro	Old well/cemented	Salty
TAGUIG		
30. Tipas	Salty water yields	Salty
31. Tuktukan	Salty water yields	Salty
32. Ususan	Salty water yields	Salty
PASAY CITY		
33. School of Deaf	Availability of surface water	Adequate
MAKATI		
34. Forbes Park # 15	Non potable water yields	Dirty
PASIG		
35. Pasig Market	Clogged/cemented	Caved-in
36. dela Paz	Clogged	Caved-in
MANDALUYONG		
37. National Mental Hospital # 1	Old well/ Availability of surface water	Adequate
38. National Mental Hospital # 2	Old well/ Availability of surface water	Adequate
39. MWSS Bilas. Sgt. Hulo	Availability of surface water	Adequate
CAVITE CITY		
40. R. Palma	Well caved-in	Caved-in
41. M. Castro	Salty water yields	Salty
42. Dalahican	Well is almost dry	Dry
43. Del Trabajo	Well caved-in	Caved-in
44. Paterno St.	Well caved-in	Caved-in
45. Public Market	Well caved-in	Caved-in
46. Hermanos St.	Well caved-in	Caved-in

TABLE 7.1.1C (CONTINUATION)

Well Name Municipality	Actual Condition	Group
BACOOR		
47. Banalo	Salty water yields	Salty
48. Wawa	Well is almost dry	Dry
IMUS		
49. Nueno	Well caved-in	Caved-in
50. Topacio Elem. School	Well is almost dry	Dry
51. Satorre St.	Clogged/Well caved-in	Caved-in
KAWIT		
52. Tirona	Well caved-in	Caved-in

TABLE 7.1.2 WELL CONDITIONS OF MWSS DEEP WELLS

(NUMBER OF WELLS)

WELL CONDITIONS	STATUS			
	ACTIVE WELLS	INACTIVE WELLS	ABANDONED WELLS	TOTAL
IN GOOD CONDITION	99	0	0	99
DAMAGED WELLS				
Defective unit	13	9	3	25
Yields salty water	2	0	17	19
Well caved-in	1	0	14	15
Yields dirty water	3	0	5	8
Well is almost dry	0	0	3	3
TOTAL	19	9	42	70
STAND BY				
Stand by	0	16	0	16
Under Rehabilitation Program	0	25	0	25
Adequate surface water supply	0	23	6	29
TOTAL	0	64	6	70
OTHERS	13	2	4	19
GRAND TOTAL	131	75	52	258

TABLE 7.1.3 PRESENT STATUS OF MWSS DEEP WELLS (31 MAY 1991)

UNIT: NUMBERS OF WELLS

MUNICIPALITY	Pumping Rate (l.p.s.)	ACTIVE WELLS			Inactive Wells	Abandoned Wells	EXISTING WELLS		
		Good	Damaged	Total			Good	No Good	Total
ANTIPOLO	153.29	11	4	15	0	1	11	5	16
BACOOR	74.00	8	0	8	0	2	8	2	10
CALOOCAN	0.00	0	0	0	2	1	0	3	3
CAINTA	56.36	3	2	5	2	2	3	6	9
CAVITE	92.59	12	3	15	0	7	12	10	22
IMUS	24.33	2	0	2	0	3	2	3	5
KAWIT	51.62	4	0	4	2	1	4	3	7
LAS PINAS	13.06	0	2	2	3	3	0	8	8
MANDALUYONG	0.00	0	0	0	0	3	0	3	3
MAKATI	95.77	6	5	11	23	1	6	29	35
MALABON	8.67	1	2	3	3	3	1	8	9
MANILA	0.00	0	0	0	0	3	0	3	3
MARIKINA	0.00	0	0	0	13	2	0	15	15
MONTALBAN	48.75	3	0	3	0	2	3	2	5
MUNTINLUPA	72.64	5	2	7	0	0	5	2	7
NAVOTAS	5.05	1	1	2	7	0	1	8	9
NOVELETA	68.36	9	0	9	0	0	9	0	9
PARANAQUE	33.00	5	0	5	2	5	5	7	12
PASAY	39.75	1	2	3	1	1	1	4	5
PASIG	3.25	1	1	2	1	2	1	4	5
PATEROS	0.00	0	0	0	0	2	0	2	2
QUEZON	191.24	14	2	16	9	0	14	11	25
ROSARIO	12.67	1	0	1	2	0	1	2	3
SAN JUAN	0.00	0	0	0	0	0	0	0	0
SAN MATEO	54.33	3	2	5	0	3	3	5	8
TAGUIG	10.00	1	2	3	1	3	1	6	7
TAYTAY	65.19	6	1	7	0	1	6	2	8
VALENZUELA	11.59	2	1	3	4	1	2	6	8
TOTAL	1210.84	99	32	131	75	52	99	159	258

Note: NO GOOD - No operational or no good conditioned wells

TABLE 7.1.4 NUMBER OF WELLS UNDER UNSATISFACTORY CONDITIONS, BY MUNICIPALITY

UNIT: NUMBER OF WELLS

MUNICIPALITY	TYPE OF CAUSE OF DAMAGE															ANOTHER REASON				OTHERS			TOTAL				Notes:
	D PUMP			SALTY			CAVED-IN			DIRTY			DRY			STAND	REHAB	ADEQUATE		OTHERS			TOTAL			GT	
	A	I	Ab	A	I	Ab	A	I	Ab	A	I	Ab	A	I	Ab	I	I	I	Ab	A	I	Ab	A	I	Ab		
ANTIPOLO	4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	1	5	
BACOOR	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	2	
CALOOCAN	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	1	3	D PUMP - Defective pump/ motor unit
CAINTA	1	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	1	0	0	2	2	2	6	
CAVITE	0	0	0	1	0	1	0	0	5	0	0	0	0	0	1	0	0	0	0	2	0	0	3	0	7	10	SALTY - Salty water yields
IMUS	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	3	CAVED-IN - Well caved-in
KAWIT	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	1	3	DIRTY - Dirty Water yields
LAS PINAS	1	1	0	1	0	3	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	3	3	8	DRY - Well is almost dry
MANDALUYONG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	3	3	STAND - Stand-by
MAKATI	3	5	0	0	0	0	0	0	0	0	0	1	0	0	0	0	18	0	0	2	0	0	5	23	1	29	REHAB - Recommended for rehabilitation
MALABON	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	1	0	2	0	2	2	3	3	8	
MANILA	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	ADEQUATE - Adequate water supply
MARIKINA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	3	2	2	0	0	0	0	13	2	15	
MONTALBAN	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	A - Active wells
MUNTINLUPA	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	I - Inactive wells
NAVOTAS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	1	0	0	1	7	0	8	Ab- Abandoned wells
NOVELETA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
PARANAQUE	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	5	7	
PASAY	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	2	1	1	4	
PASIG	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	2	4	
PATEROS	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	
QUEZON	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	5	0	1	1	0	2	9	0	11	
ROSARIO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	2	
SAN JUAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
SAN MATEO	0	0	0	0	0	0	1	0	0	1	0	2	0	0	0	0	0	0	0	0	0	1	2	0	3	5	
TAGUIG	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	2	1	3	6	
TAYTAY	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2	
VALENZUELA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	1	0	1	1	4	1	6	
TOTAL	13	9	3	2	0	17	1	0	14	3	0	5	0	0	3	16	25	23	6	13	2	4	32	75	52	159	
G.T.	25			19			15			8			3			16	25	29		19			159			159	

TABLE 7.3.1 WELL LIST OF THE EXPERIMENTAL WORK ON REHABILITATION

Well Name	Municipality	Status	Total Depth	Casing Pipe Position	Size	Well Screen Position	Exist. Pump Set.	Exist. Pump Cap.	Test Pump Set.	Test Pump Spec.	Pump After Rehab. Set.	Pump After Rehab. Spec.
Cogeo Antipolo No.1	Antipolo	In-active	91.44m	0m-9.75m 9.75-91.44	8" 6"	64m-87.78m	66m	7.5 Hp	78m	SP8-21 7.5HP OD 133	3" 78m	Existing Pump Installed
Sumulong	Taytay	In-active	202.69	0-80.77 80.77-202.7	8" 6"	Unknown	75	30	78m 120m	30 HP 10 HP OD 133mm	NO	No Pump Installed
Naga Road No.2	Las Pinas	Active	243.84	0-243.84	10"	103.63-121.91 128.01-158.49 164.59-170.68 182.88-213.36 219.45-237.74	78	30	120m 102m	SP45-12 30HP OD 150	3" 102m	Existing Pump Installed
IBP (Congress) No.3	Quezon City	In-Active	202.69	0-80 80-202.69	10" 8"	87-99 103-122 129-144 151-166 173-197	120	20	108	20 HP 9 stage OD 140	NO	No Pump Installed
Cogeo Antipolo No.6	Antipolo	In-Active	117.35	0-91.44	8"	91.44-117.35 bore hole	99	20	90	20 HP 9 stage OD 140	NO	No Pump installed

TABLE 7.3.2 EXPERIMENTAL REHABILITATION WORK RESULTS

	Sumulong Taytay	I B P #3	Cogeo ATP#1	Cogeo ATP#6	Naga Road #2
Well Depth (m)	202.68	202.69	91.44	117.35	243.84
Accumulation (m)	5.68	32.69	4.44	11.35	0
Static Water Level(m)	58.00	39.30	7.25	11.50	55.40
EC-T Logging	684-	92-	335-	316-	517-
ECt (uS/cm)	961	144	390	342	9585
T (. C)	30.2- 30.7	27.7- 28.1	25.8- 27.1	26.4- 27.5	30.0- 34.2
Micro Current	*	*	*	*	see Table 5.3.3
1st Pumping Test					
Discharge Rate(m3/d)	285	(25.9)	285	294	544
Drawdown (m)	30.00	(70.7)	48.80	68.40	17.70
Specific Capacity(m2/d)	9.50	(0.37)	5.84	4.30	30.70
Transmissivity (m2/d)					
Continuous- Theis	14.6	-	2.83	1.33	36.9
Continuous- Jacob	15.2	-	5.27	7.19	31.1
Recovery - Jacob	11.4	-	32.6	19.8	29.2
Storage Coeff.	7.65x10-5	-	1.19	2.26	3.18x10-4
Aquifer Loss Coeff. (day/m2)	5.40x10-2	-	8.00x10-3	0.0	3.2x10-2
Well Loss Coeff. (day2/m5)	1.65x10-4	-	2.55x10-4	8.0x10-4	6.2x10-6
2nd Pumping Test					
Discharge Rate(m3/d)	328	(54.4)	285	294	518
Drawdown (m)	25.10	(70.70)	19.50	64.20	17.07
Specific Capacity(m2/d)	13.07	(0.77)	14.6	4.58	31.9
Transmissivity (m2/d)					
Continuous- Theis	14.6	-	4.37	1.34	36.6
Continuous- Jacob	4.10	-	11.1	4.88	31.1
Recovery - Jacob	44.8	-	17.4	15.2	31.9
Storage Coeff.	1.03x10-4	-	2.05	3.32	3.90x10-4
Aquifer Loss Coeff. (day/m2)	2.6x10-2	-	2.0x10-3	0.0	2.95x10-2
Well Loss Coeff. (day2/m5)	1.43x10-4	-	2.10x10-4	7.35x10-4	6.2x10-6

TABLE 7.3.3 MEASUREMENT OF MICRO-CURRENT AT NAGA ROAD NUMBER 2, LAS PIÑAS WELL DEPTH 243.84 M, CASING SIZE 10" (O.D.25.4 cm)

	screen	F1	F2	F3	F4	F5	total
	position	103.63m	128.01m	164.59m	182.88m	219.45m	
	length	-121.91m	-158.49m	-170.68m	-213.36m	-237.74m	
step		18.28m	30.48m	6.09m	30.48m	18.29m	103.62m
1st step drawdown test							
	V cm/s	3.36	0.0	0.0	0.0	0.0	3.36
1	Q l/m	102	0	0	0	0	102
	%	100	0	0	0	0	100
	V cm/s	1.12	5.6	0.0	0.0	0.0	6.72
2	Q l/m	34.2	169.8	0	0	0	204
	%	16.7	83.3	0	0	0	100
	V cm	1.78	4.8	3.3	0.0	0.0	9.88
3	Q l/m	54	145.8	100.2	0	0	300
	%	18.0	48.6	33.4	0	0	100
	V cm	2.95	5.3	4.2	0.0	0.0	12.45
4	Q l/m	90	160.8	127.2	0	0	378
	%	23.7	42.6	33.7	0	0	100
2nd step drawdown test							
	V cm/s	0.56	2.80	0.0	0.0	0.0	3.36
1	Q l/m	17	85	0	0	0	102
	%	16.7	83.3	0	0	0	100
	V cm/s	1.42	2.3	0.9	2.1	0.0	6.72
2	Q l/m	43.1	69.8	27.3	63.8	0	204
	%	21.1	34.2	13.4	31.3	0	100
	V cm	0.98	6.0	1.1	1.8	0.0	9.88
3	Q l/m	29.8	182.2	33.4	54.6	0	300
	%	9.9	60.8	11.1	18.2	0	100
	V cm	2.15	6.3	3.4	0.0	0.0	11.85
4	Q l/m	65.3	191.4	103.3	0	0	360
	%	18.1	53.2	28.7	0	0	100

TABLE 7.3.4 STATUS OF EXISTING PUMPING FACILITIES

WELL NAME	SUMULONG TAYTAY	IBM #3	COGEO ATP #1	COGEO ATYP #6	NAGA ROAD #2
Control panel	Defective	Replaced some parts	Good	Good	Good
Submersible Cable	Low Resistance	good	Low Resistance	Good	Good
Riser Pipes	Rusted	Rusted	Good	2 pcs are good another 14.5 pcs were rusted	Rusted
Submersible Pump and	Good	Took out plastics from pump suction	Good	10x10 mm hole observed	Took out soft scales from pump impleller
Motor	Newly	Good	Low resistance	Low resistance	Good
Before Rehab.	Inactive	Inactive	Inactive	Inactive	Active
After Rehab.	No pump	No pump	Active	No pump	

Sumulong Taytay

Grundfos pump model - sp 25-20 (without 2 bowl assembly)
Century submiersible motor 30 Hp
11 pcs 3"Ø riser pipes and 1.5 pcs 4"Ø riser pipes

IBM #3

Gruppo Industriale Ercole pump
motor 20 Hp
20 pcs 3"Ø riser pipes

Cogeo Antipolo #1

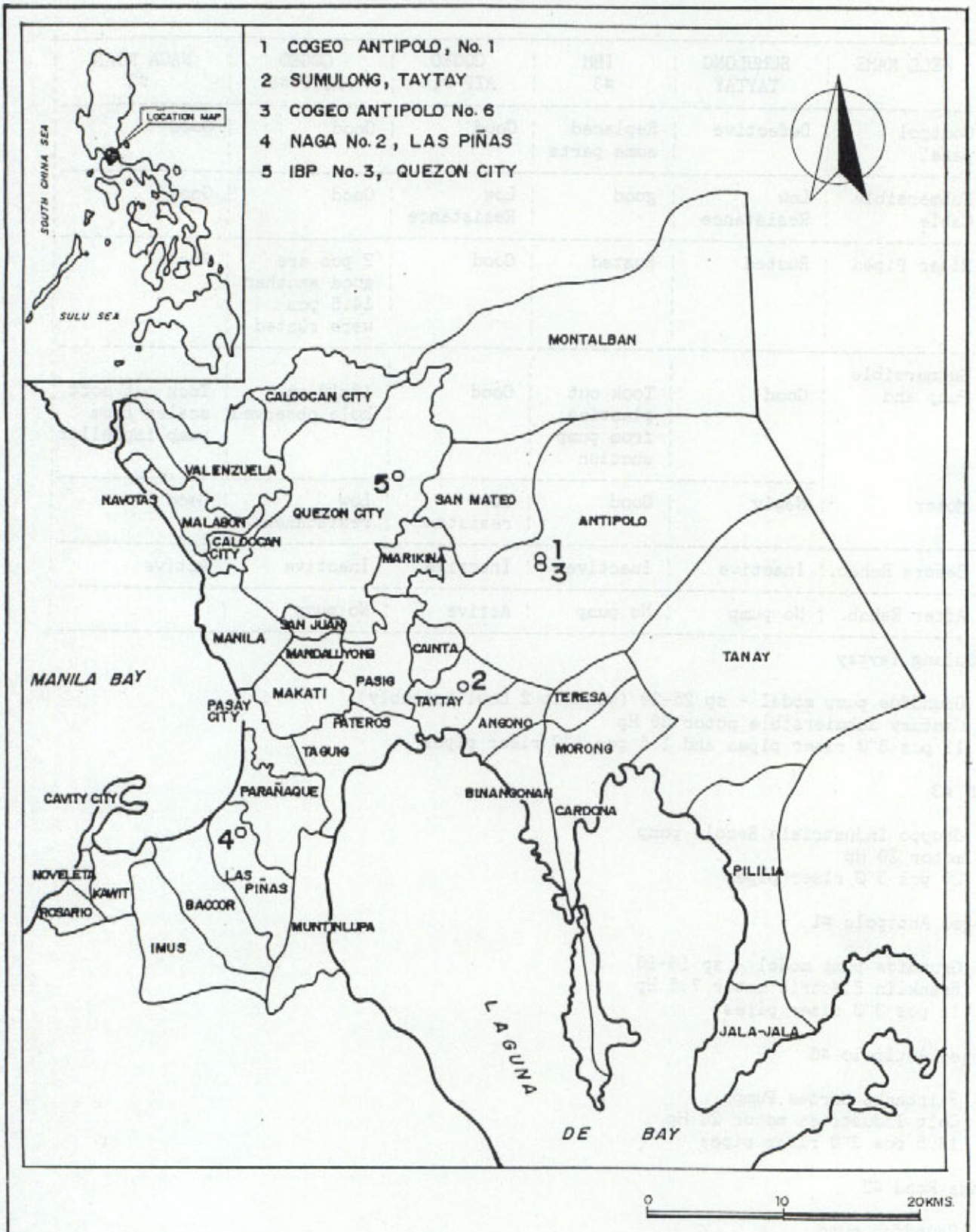
Grundfos pump model - sp 16-10
Franklin Electric motor 7.5 Hp
11 pcs 3"Ø riser pipes

Cogeo Antipolo #6

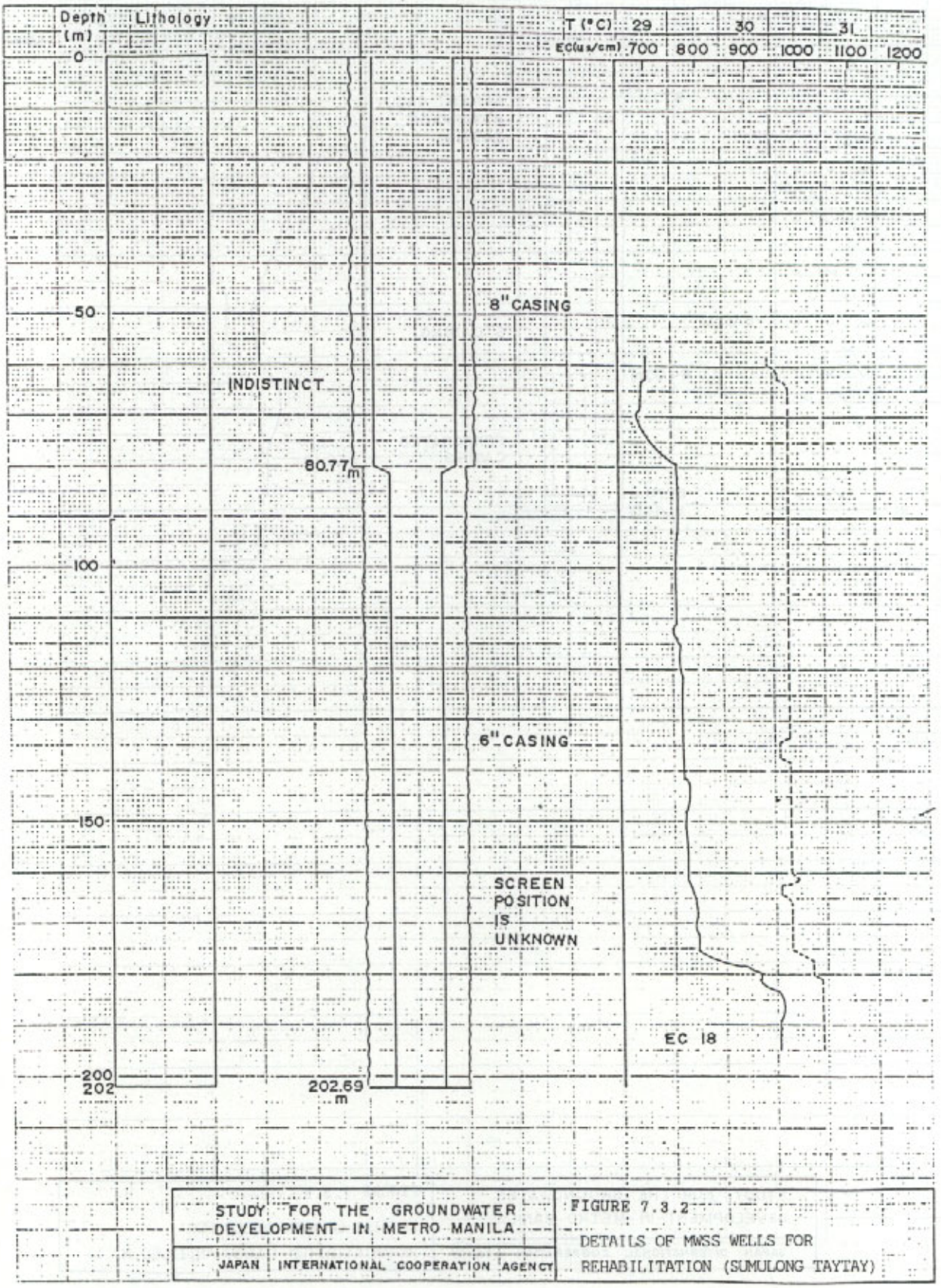
Fairbanks Morses Pumps
Colt Industries motor 20 Hp
16.5 pcs 3"Ø riser pipes

Naga Road #2

Grundfos pump
Franklin Electric motro 30 Hp
13 pcs 4"Ø riser pipes



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 7.3.1 LOCATION OF MWSS WELLS FOR REHABILITATION
JAPAN INTERNATIONAL COOPERATION AGENCY	

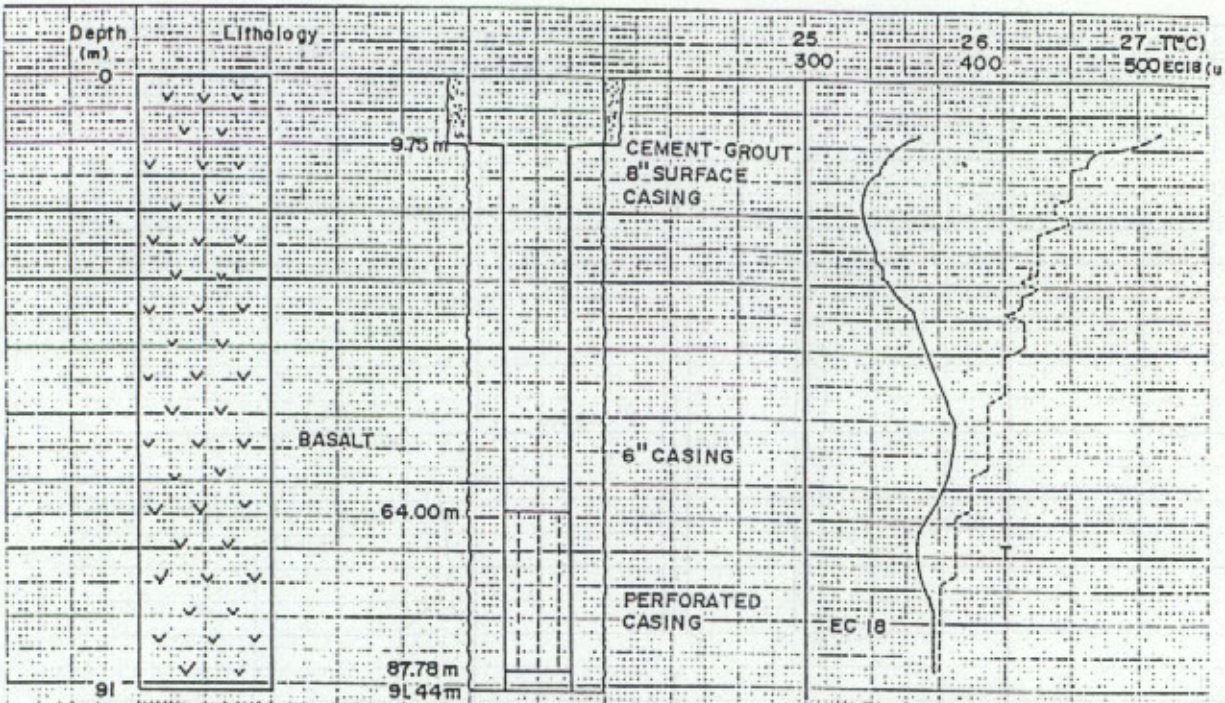


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

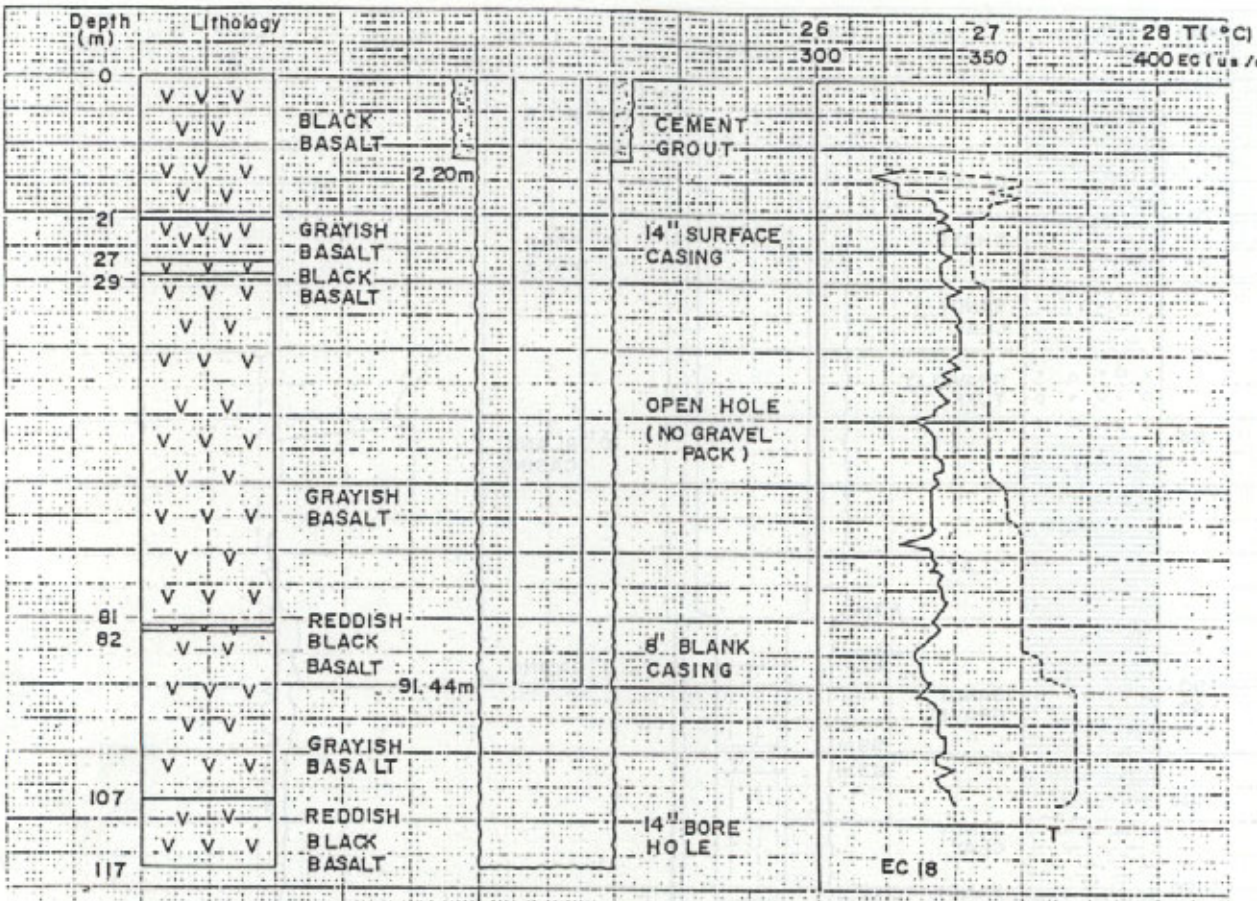
JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 7.3.2

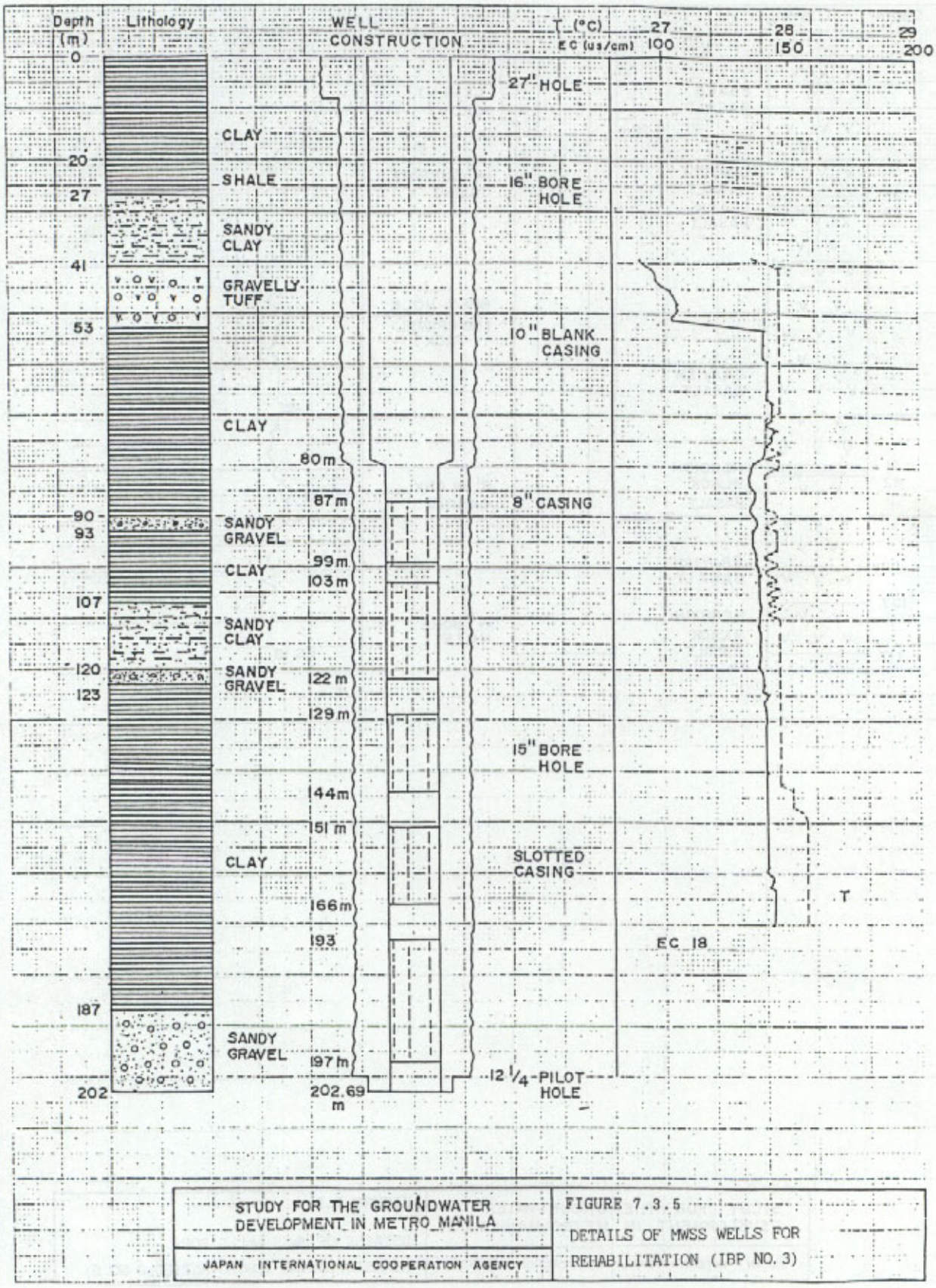
DETAILS OF MWSS WELLS FOR REHABILITATION (SUMULONG TAYTAY)



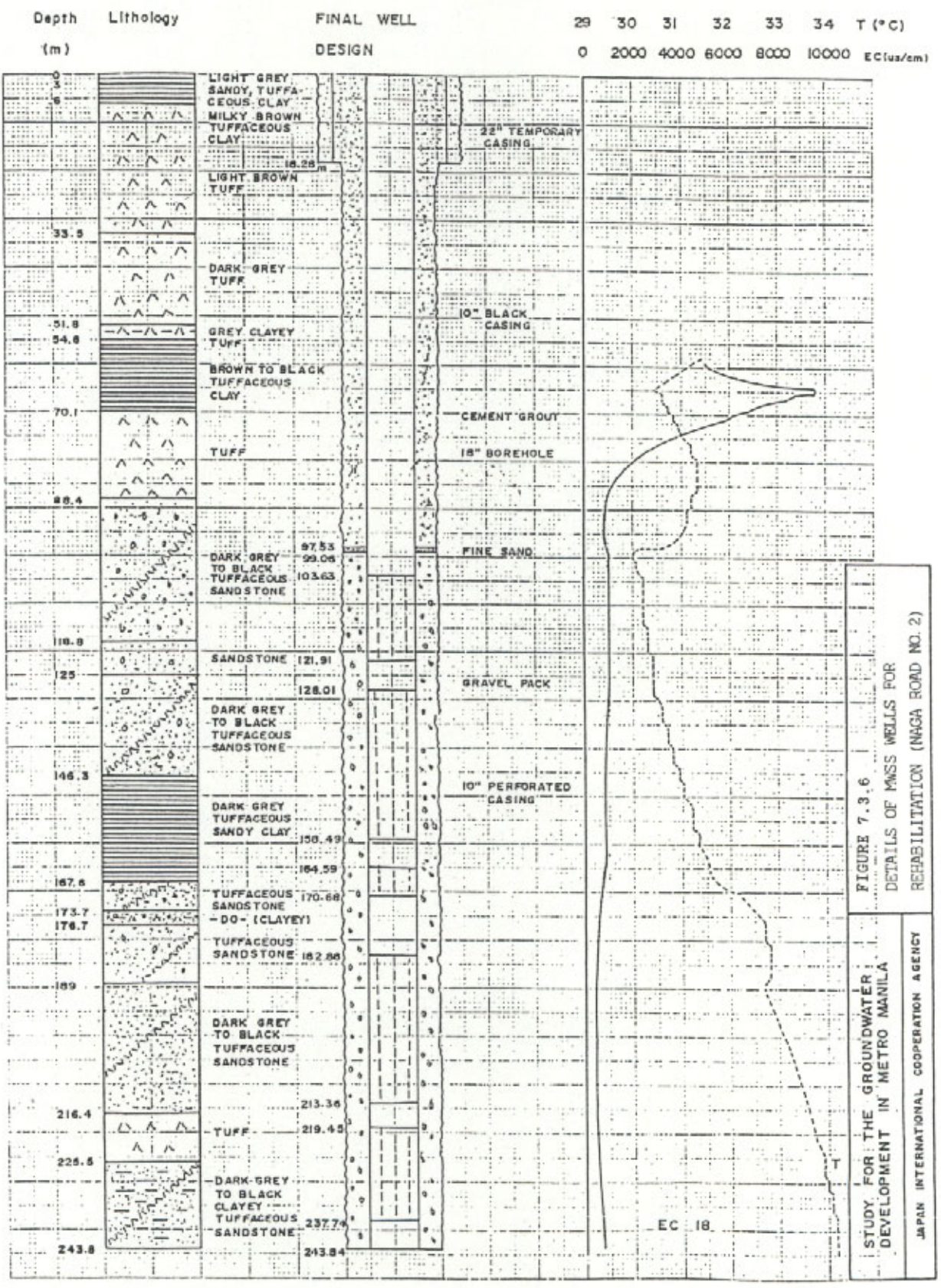
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA JAPAN INTERNATIONAL COOPERATION AGENCY	FIGURE 7.3.3 DETAILS OF MWSS WELLS FOR REHABILITATION (COGEO ANTIPOLO NO. 1)



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA JAPAN INTERNATIONAL COOPERATION AGENCY	FIGURE 7.3.4 DETAILS OF MWSS WELLS FOR REHABILITATION (COGEO ANTIPOLO NO. 6)



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 7.3.5
JAPAN INTERNATIONAL COOPERATION AGENCY	DETAILS OF MWSS WELLS FOR REHABILITATION (IBP NO. 3)


Depth (m)
Lithology
FINAL WELL DESIGN
29 30 31 32 33 34 T (°C)
0 2000 4000 6000 8000 10000 EC(us/cm)
LIGHT GREY SANDY, TUFFACEOUS CLAY
MILKY BROWN TUFFACEOUS CLAY
18.28
LIGHT BROWN TUFF
DARK GREY TUFF
GREY CLAYEY TUFF
BROWN TO BLACK TUFFACEOUS CLAY
TUFF
DARK GREY TO BLACK TUFFACEOUS SANDSTONE
97.53
99.06
103.63
SANDSTONE 121.91
128.01
DARK GREY TO BLACK TUFFACEOUS SANDSTONE
DARK GREY TUFFACEOUS SANDY CLAY
158.49
164.59
TUFFACEOUS SANDSTONE 170.68
-DO- (CLAYEY)
TUFFACEOUS SANDSTONE 182.88
DARK GREY TO BLACK TUFFACEOUS SANDSTONE
213.36
TUFF 219.45
DARK GREY TO BLACK CLAYEY TUFFACEOUS SANDSTONE 237.74
243.84
33.5
51.8
54.6
70.1
88.4
118.8
125
146.3
167.6
173.7
176.7
189
216.4
225.5
243.8
22" TEMPORARY CASING
10" BLACK CASING
CEMENT GROUT
18" BOREHOLE
FINE SAND
GRAVEL PACK
10" PERFORATED CASING
EC
T
FIGURE 7.3.6
DETAILS OF MWSS WELLS FOR REHABILITATION (NAGA ROAD NO. 2)
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA
JAPAN INTERNATIONAL COOPERATION AGENCY

CHAPTER 8

GROUNDWATER MODELING

CHAPTER 8 GROUNDWATER MODELING

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CHAPTER 8 GROUNDWATER MODELING

8.1 GENERAL

The construction of the groundwater flow model and solute transport model for confined aquifer systems in Metro Manila is based on hydrogeological analysis (Figure 8.1). This modeling activity is undertaken to predict future groundwater movement and specifically to:

(1) Describe the hydrogeologic conditions that led to heavy decline of groundwater head and saline water intrusion; and

(2) To estimate the movement of groundwater resulting from alternative schemes of future aquifer utilization or regulation.

Because groundwater is essentially an invisible resource, studies of groundwater movement under natural and artificial conditions require modeling techniques. Several types of models have been developed and used for this purpose. These models may be subdivided into four major categories: porous media models, miscellaneous analog models, electrical analog models, and digital computer models for numerical solution of aquifer flow equations.

In recent years, digital computer models have gained wider acceptance as they foster more efficient groundwater resource management. These tools have considerable capability to aid decision-making in relation to the various uses of both actual and potential groundwater systems.

Digital computer models may be further subdivided into flow models and mass transport models. Flow models consist of a set of differential equations that are known to govern the flow of groundwater. Mass transport models are based on a flow component and are coupled with the solute transport equations. They are used to predict the movement and concentration in the aquifers of various pollutants including saline water intrusion in coastal areas.

The reliability of prediction using a groundwater model depends on how

well the model approximates the field situation. As natural aquifer systems are inherently complex and uncertain, construction of the model always requires the making of assumptions and simplifications. It is very important to keep this awareness about the model, even though sophisticated numerical techniques and high-speed computers have already been developed.

8.2 GROUNDWATER FLOW MODEL

8.2.1 Model Concept

The digital model used for the Study is a quasi three-dimensional model (Q3P model). Its basic concept is that water in the main confined aquifer is supplied by lateral flow through the aquifer and by vertical flow through the aquitard from overlying phreatic aquifer.

Groundwater flow in a groundwater basin is by nature three-dimensional. But if the drawdown of piezometric heads by groundwater discharge is small, the groundwater flow can be treated as lateral in two dimensions, and this is because vertical flow such as leakage through confining layers and squeeze from clayey layers are negligible.

On the other hand, large drawdown of the piezometric heads makes the groundwater flow pattern more complicated and three-dimensional. The three-dimensional model is thus the best suited to simulate groundwater flow. It is difficult, however, to simulate three-dimensional groundwater flow given the complexity of the structure of a groundwater basin, the inadequacy of input data, and the limitations of numerical solution techniques and memory capacity of a computer. Therefore, the quasi three-dimensional model has been developed and widely used for practical purpose.

8.2.2 Groundwater Flow Equation

Neglecting the vertical flow component in the main confined aquifer and the horizontal flow component in aquitard, the basic equation of motion of the system is expressed as

$$T\left(\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2}\right) = S\frac{\partial h}{\partial t} + W(x,y,t) \qquad (8.2.1)$$

where,

T : transmissivity, L^2/T;
S : storage coefficient, dimensionless;
h : hydraulic head, L;
t : time, T;
x, y : spatial coordinates, L; and
$W(x,y,t)$: volume flux per unit area, L/T.

$W(x,y,t)$ can be expressed as:

$$W(x,y,t)=Qd(x,y,t)+k'/b'(h-H) \qquad (8.2.2)$$

where,

$Qd(x,y,t)$: the rate of withdrawal or recharge, L/T
k' : the permeability of the confining layer (aquitard), L;
b' : the thickness of the confining layer (aquitard), L; and
H : the phreatic water level, L.

The second term on the right hand side of Equation (8.2.2) is the leakage through the confining layer from the phreatic aquifer as defined by Hantush and Jacob (1955).

Equations (8.2.1) and (8.2.2) can be solved by the finite-difference method or finite-element method. A schematic cross section of the quasi three-dimensional groundwater model is illustrated in Figure 8.2.1.

This study employed the finite-element approximation using rectangular elements to simulate the Antipolo groundwater basin model and the Metro Manila groundwater basin model. Figure 8.2.2 shows a simplified flow chart of the computational procedure in Q3P model.

8.2.3 Required Input Data and Output Data

The required input data for the Q3P model are as follows:

for model framework

Element data
Node data
Boundary conditions
Model control card

for hydrogeological settings

Transmissivity
Storage coefficient
Aquitard thickness
Aquitard permeability
Phreatic water level
Initial piezometric heads
Direct recharge data

for groundwater use

Discharge data

The output data from the model are:

Piezometric heads distribution in each time-step
Changes of piezometric heads at specified nodes
Water balance components in specified area

8.2.4 Model Assumption

The model assumes that hydrogeologic parameters such as transmissivity, storage coefficient and leakance are not affected by changes in piezometric heads. Also, the model needs to assume that those parameters and boundary conditions do not change over time. The phreatic water levels are assumed to be constant over time.

8.2.5 Model Calibration

The model must be calibrated before starting actual calculations. The main procedure of model calibration is to specify boundary conditions and to identify some poorly reliable hydrogeologic parameters. Generally the model is verified by comparing calculated piezometric heads with actual piezometric heads. Figure 8.2.3 shows the general flow of model calibration.

After all parameters and boundary conditions have been fixed, the model can now compute future piezometric heads based on future groundwater pumpage plans and future recharge estimates.

8.3 SOLUTE TRANSPORT MODEL

8.3.1 Model Abstract

The two-dimensional solute transport and dispersion model (MOC model) used in the Study was originally devised by L. F. Konikow and J. D. Bredehoeft in 1978.

MOC is a two-dimensional model for the simulation of non-conservative solute transport in saturated groundwater systems. It computes changes in the spatial concentration and distribution over time caused by convective transport, hydrodynamic dispersion, mixing or dilution from recharge, and chemical reactions.

The chemical reactions include first-order irreversible rate reaction (such as radioactive decay), reversible equilibrium-controlled absorption with linear, Fruendlich or Langmuir isotherms, and reversible equilibrium controlled ion exchange for monovalent or divalent ions.

The model assumes that fluid density variations, viscosity changes, and temperature gradients do not affect the velocity distribution. MOC does allow modeling heterogeneous and/or anisotropic aquifers.

MOC couples the groundwater flow equation with the non-conservative solute-transport equation. The computer program uses the ADI or SIP

procedure to solve the finite-difference approximation of the groundwater flow equation. The SIP procedure for solving the groundwater flow equation is most useful when areal discontinuities in transmissivity exist or when the ADI solution does not converge.

MOC uses the method of characteristics to solve the solute transport equation. It uses a particle tracking procedure to represent convective transport and a two-step explicit procedure to solve the finite-difference equation that describes the effects of hydrodynamic dispersion, fluid sources and sinks, and divergence of velocity.

The explicit procedure is subject to stability criteria, but the program automatically determines and implements the time-step limitations necessary to satisfy the stability criteria.

MOC uses a rectangular, block-centered, finite-difference grid for flow and transport calculations. The grid size for flow calculations is limited to 40 rows and 40 columns. The grid size for transport calculations is limited to 20 rows and 20 columns which can be assigned to any area of the flow grid.

The program allows spatially varying diffuse recharge or discharge, saturated thickness, transmissivity, boundary conditions, initial heads and initial concentrations and an unlimited number of injection or withdrawal wells.

8.3.2 Theoretical Background

(1) Flow Equation

By following the derivation of Pinder and Bredehoeft (1968), the equation describing the transient two-dimensional areal flow of a homogeneous compressible fluid through a non-homogeneous anisotropic aquifer can be written in Cartesian tensor notation as

$$\frac{\partial}{\partial xi}\left(Tij\ \frac{\partial h}{\partial xj}\right) = S\ \frac{\partial h}{\partial t} + W \qquad i,j=1,2 \qquad (8.3.1)$$

where,

Tij : the transmissivity tensor, L^2/T;
h : the hydraulic head, L;
S : the storage coefficient, (dimensionless);
t : the time, T;
$W(x,y,t)$: the volume flux per unit area, L/T; and
xi and xj: the Cartesian coordinates, L.

If we only consider fluxes of (1) direct withdrawal or recharge, such as well pumpage, well injection, or evapotranspiration, and (2) steady leakage into or out of the aquifer through a confining layer, streambed, or lakebed, then $W(x,y,t)$ may be expressed as

$$W(x,y,t) = Q(x,y,t) - \frac{Kz}{m}(Hs-h) \qquad (8.3.2)$$

where,

$Q(x,y,t)$: the rate of withdrawal or recharge, L/T;
K : the vertical hydraulic conductivity of the confining layer, stream bed, or lakebed, L/T;
m : the thickness of the confining layer, streambed, or lakebed, L; and
Hs : the hydraulic head in the source bed, stream, or lake, L.

Lohman (1972) shows that an expression for the average seepage velocity of groundwater can be derived from Darcy's law. This expression can be written in Cartesian tensor notation as

$$Vi = -\frac{Kij}{\varepsilon}\frac{\partial h}{\partial xj} \qquad (8.3.3)$$

where,

Vi : the seepage velocity in the direction of xi, L/T;
Kij: the hydraulic conductivity tensor, L/T; and
ϵ : the effective porosity of the aquifer, (dimensionless).

(2) Transport Equation

The governing equation for the solute transport model considers flow and transport in two dimensions and assumes constant and uniform porosity and fluid density. The general governing equation for solute transport is (after Konikow and Grove, 1977)

$$\frac{\partial C}{\partial t} = \frac{1}{b}\frac{\partial}{\partial xi}\left[bDij\frac{\partial C}{\partial xj}\right] - Vi\frac{\partial C}{\partial xi} + \frac{W(C-C')}{\epsilon b} + \frac{CHEM}{\epsilon} \quad (8.3.4)$$

where,

C : the concentration of the solute, M/L^3;
t : the time, T;
b : the aquifer thickness, L;
Dij : the dispersion tensor, L^2/T, with implied summation for i=1,2, j=1,2;
xi : the spatial coordinates, L;
Vi : the fluid seepage velocity, L/T;
W : the source fluid flux into (W<0) the aquifer, L/T;
ϵ : the porosity, (dimensionless);
C' : the concentration of the solute in the source fluid, M/L^3; and
CHEM: the chemical reaction source (+) or sink (-) per unit volume of aquifer, $M/L^3/T$.

The first term on the right hand side of equation (8.3.4) represents the change in concentration due to hydrodynamic dispersion. The second term describes the effects of convective transport, while the third term represents a fluid source or sink.

The reaction term CHEM includes equilibrium-controlled absorption or exchange and first-order irreversible rate (decay) reactions. The general expression for the chemical reaction source or sink is (Grove and Stollenwerk, 1984)

$$CHEM = -\rho b \frac{d\bar{C}}{dt} - \lambda(\varepsilon C + \rho b \bar{C}) \qquad (8.3.5)$$

where,

$\bar{C}$: the concentration of solute (absorbed or exchanged) in the porous medium, M/M;
b: the porous medium bulk density, M/L; and
: the decay rate constant, 1/T.

Substituting equation (8.3.5) into the general governing equation (8.3.4), and rearranging the results yields

$$\frac{\partial C}{\partial t} + \frac{\rho b}{\varepsilon}\frac{d\bar{C}}{dt} = \frac{1}{b}\frac{\partial}{\partial x_i}\left[bD_{ij}\frac{\partial C}{\partial x_j}\right] - V_i\frac{\partial C}{\partial x_i} + \frac{W(C-C')}{\varepsilon b} - \lambda C - \frac{\rho b}{\varepsilon}\lambda\bar{C} \qquad (8.3.6)$$

(3) Dispersion Coefficient

Bear (1972) states that hydrodynamic dispersion is the macroscopic outcome of the actual movements of individual tracer particles through the pores and that it involves two processes. One process is mechanical dispersion, which depends upon both the flow of the fluid and the nature of the pore system through which the flow takes place. The second process is molecular and ionic diffusion, which because it depends on time, is more significant at low flow velocities.

Bear (1972) further states that the separation between the two processes

is artificial. In this model, it is assumed that for flowing groundwater systems the definable contribution of molecular and ionic diffusion to hydrodynamic dispersion is negligible. The dispersion coefficient may be related to the velocity of groundwater flow and to the nature of the aquifer by using Scheidegger's (1961) equation:

$$Dij = \alpha ijmn \frac{VmVn}{|V|} \qquad (8.3.7)$$

where,

ijmn : the dispersivity of the aquifer, L;

Vm and Vn: components of velocity in the m and n direction, respectively, L/T; and

$|V|$: the magnitude of the velocity, L/T.

Scheidegger (1961) further shows that for an isotropic aquifer the dispersivity tensor can be defined in terms of two constants. These are the longitudinal and transverse dispersivities of the aquifer (L and T, respectively). These are related to the longitudinal and transverse dispersion coefficients by

$$D_L = \alpha_L |V| \qquad (8.3.8)$$

and

$$D_T = \alpha_T |V| \qquad (8.3.9)$$

After expanding equation (8.3.7), substituting Scheidegger's identities, and eliminating terms with zero coefficients, the components of the dispersion coefficient for two-dimensional flow in an isotropic aquifer may be stated explicitly as

$$Dxx = D_L \frac{(Vx)^2}{|V|^2} + D_T \frac{(Vy)^2}{|V|^2} \quad ; \tag{8.3.10}$$

$$Dyy = D_T \frac{(Vx)^2}{|V|^2} + D_L \frac{(Vy)^2}{|V|^2} \quad ; \tag{8.3.11}$$

$$Dxy = Dyx = (D_L - D_T) \frac{VxVy}{|V|^2} \quad . \tag{8.3.12}$$

Note that while *Dxx* and *Dyy* must have positive values, it is possible for the cross-product terms (equation (8.3.12)) to have negative values if *Vx* and *Vy* have opposite signs.

8.3.3 Numerical Methods

Because aquifers have variable properties and complex boundary conditions, exact analytical solutions to the partial differential equations of flow and solute transport cannot be obtained directly. Therefore, approximate numerical methods must be employed.

The numerical methods require that the area of interest be grid-subdivided into a number of smaller sub-areas. This model utilizes a rectangular, uniformly-spaced, block-centered, finite-difference grid in which nodes are defined at the centers of the rectangular cells.

(1) Flow Equation

If the coordinate axes are aligned with the principal directions of the transmissivity tensor, equation (8.3.1) may be approximated by the following implicit finite-difference equation:

$$T_{xx}[i-1/2,j]\left[\frac{h_{i-1,j,k}-h_{i,j,k}}{(\Delta x)^2}\right]+T_{xx}[i+1/2,j]\left[\frac{h_{i+1,j,k}-h_{i,j,k}}{(\Delta x)^2}\right]$$

$$+T_{yy}[i,j-1/2]\left[\frac{h_{i,j-1,k}-h_{i,j,k}}{(\Delta y)^2}\right]+T_{yy}[i,j+1/2]\left[\frac{h_{i,j+1,k}-h_{i,j,k}}{(\Delta y)^2}\right]$$

$$=S\left[\frac{h_{i,j,k}-h_{i,j,k-1}}{\Delta t}\right]+\frac{q_w(i,j)}{\Delta x\Delta y}\quad\frac{Kz}{m}\quad[H_s(i,j)-h_{i,j,k}] \qquad (8.3.13)$$

where,

i,j,k : indices in the x, y, and time dimensions, respectively;

Wx, Wy, Wt: increments in the x, y, and time dimensions, respectively; and

qw : the volumetric rate of withdrawal or recharge at the (i,j) node, L^3/T.

The finite-difference equation (8.3.13) is solved numerically for each node in the grid using an iterative alternating implicit (ADI) procedure. After the head distribution has been computed for a given time-step, the velocity of groundwater flow is computed at each node using an explicit finite-difference form of equation (8.3.3).

(2) Transport Equation

The method of characteristics is used in this model to solve the solute transport equation. The approach taken by the method of characteristics is not to solve equation (8.3.4) directly, but rather to solve an equivalent system of ordinary differential equations. Konikow and Grove (1977) have shown that by considering saturated thickness as a variable and by expanding the convective transport term, equation (8.3.5) may be

written as

$$\frac{\partial C}{\partial t} = \frac{1}{b}\frac{\partial}{\partial x_i}\left[bD_{ij}\frac{\partial C}{\partial x_j}\right] - V_i\frac{\partial C}{\partial x_i} + \frac{C\left[S\frac{\partial h}{\partial t} + W - \varepsilon\frac{\partial b}{\partial t}\right] - C'W}{\varepsilon b}, \qquad (8.3.14)$$

Next, consider the representative fluid particles that are convected with flowing groundwater. Each point has a concentration and position associated with it and is moved through the flow field in proportion to the flow velocity at its location. Intuitively, the method may be visualized as tracking a number of fluid particles through a flow field and observing changes in chemical concentration in the fluid particles as they move.

The first step in the method of characteristics involves placing a number of traceable particles or points in each cell of the finite-difference grid to form a set of points that are distributed in a geometrically uniform pattern throughout the area of interest. The initial concentration assigned to each point is the initial concentration associated with the node of the cell containing the point.

For each time-step every point is moved a distance proportional to the length of the time increment and the velocity at the location of the point. After all points have been moved, the concentration at each node is temporarily assigned the average of the concentrations of all points then located within the area of that cell.

The total change in concentration caused by convective transport is computed by solving equation (8.3.14). The changes in concentration caused by hydrodynamic dispersion, fluid sources, divergence of velocity, and changes in saturated thickness are calculated using an explicit finite-difference approximation, which can be expressed as

$$\Delta C_{i,j,k} = \Delta t \left(\frac{1}{b} \frac{\partial}{\partial x_i} \left(b D_{ij} \frac{\partial C}{\partial x_j} \right) + F \right). \qquad (8.3.15)$$

where,

$$F = \frac{C \left(S \frac{\partial h}{\partial t} + W - \varepsilon \frac{\partial b}{\partial t} \right) - C' W}{\varepsilon b}. \qquad (8.3.16)$$

The major steps in the calculation procedures are summarized in Figure 8.3.1. It presents a simplified flow chart of the overall structure of the computer program. Figure 8.3.2 shows the particle tracking procedure and the treatment of particles at the various types of boundary conditions.

8.4 ANTIPOLO GROUNDWATER BASIN MODEL

The quasi three-dimensional groundwater model (Q3P model) was applied to the aquifer system in the Antipolo plateau (see Figure 8.1). The Antipolo plateau forms an independent groundwater basin at the place where the Guadalupe formation overlies the altered spilitic basalt of the Kinabuan formation.

Member III of the Guadalupe formation (Gs) forms fairly good aquifers. Groundwater in the uppermost weathered beds is in the phreatic condition. Groundwater in the lower part of member III is confined. With this lower part forming a main aquifer in the Antipolo plateau. Member IV (Gmd) forms an aquitard or aquifuge. The altered basaltic rocks form

a hydrogeological basement of the Antipolo groundwater basin.

The quasi three-dimensional model is used to examine the dynamic groundwater flow in the basin and the effect of groundwater development. Various hydrogeological data and parameters required for the model have to be prepared.

A number of simplifications have been made in the representation of the hydrogeological system in order to analyze the dynamic behavior of groundwater flow. The confined aquifer (Gs) has been modeled as a main confined aquifer which is hydraulically connected to the overlying phreatic aquifer through the confining layer.

The finite-element grid used in the model is shown in Figure 8.4.1. The model domain has an area of 24.56 km^2 and divided into 393 rectangular elements of 250m x 250m in size. The number of elements in the x and y coordinates are 34 and 16, respectively. The number of nodes in the domain where the heads are computed is 448.

8.4.1 Model Parameters and Boundary Conditions

(1) Boundary Conditions

Two different boundary conditions were specified based on the hydrogeological interpretations (Figure 8.4.2). The outlets of major valleys were modeled as constant-head boundaries. Also assigned as a constant-head boundary is the southern perimeter of the modeled area where the aquifer may extend south in the plateau towards Laguna de Bay. The head values of constant-head boundaries were assigned from the initial heads estimation.

The rest of the nodes along the modeled perimeter were modeled as no-flow boundaries.

(2) Model Parameters

Input parameters used in the model were collected/measured by the Study Team during study stages I to III. After data processing was completed, input data for the Q3P model were prepared. Those parameters were input-

ted 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

Because of inadequate pumping test data in the modeled area, the initial transmissivity value was modeled uniformly as 100m²/d. Throughout the steady-state calibration of the model, the transmissivity values from a minimum of 10 m²/d to a maximum of 2,000m²/d were identified as shown in Figure 8.4.3. High transmissivity values had to be assigned to the elements along the constant-head boundaries, rivers, and around the center part of the basin. On the other hand, low transmissivity values were assigned to the area where the basement rocks are exposed and/or where the topographic levels are higher.

(b) Storage coefficient

The values of storage coefficient were initially and uniformly assigned .sr0
as $1x10^{-3}$ because of the lack of actual data. During the nonsteady-state calculation, the values were modified by comparison of model results with field observations of piezometric heads.

Further, the Q3P model was arranged to simulate changes of piezometric heads in 1990 using estimated three-day recharge and discharge data for the identification of storage coefficient. Throughout the 120-step simulation, done with checking of range of piezometric heads, the values of storage coefficient were finally identified as 0.1 to 0.05 (Figure 8.4.4).

(c) Aquitard thickness and permeability

The thickness and permeability of aquitard control the leakage recharge to the confined aquifer. Based on the monitored piezometric heads, it was assumed that the recharge in the Antipolo basin occurs as the direct recharge. Therefore, the thickness of aquitard was uniformly modeled as

20m, with its permeability as 0m/d.

(d) Phreatic water level and initial heads

The phreatic water level is an important leakage recharge parameter. Since the Antipolo basin model assumes the recharge to be only the direct recharge from precipitation, dummy data were inputted to the model.

The initial piezometric heads were estimated from the steady-state simulation because the data on actual heads in 1981 were not available. For the steady-state simulation, the input initial heads were prepared based on geomorphological analyses. A river level map was made from topographic maps using the same grid to model the area. The initial heads were then assumed to be 10m below the river level.

After 30 steps (30 years) of steady-state calculation using the recharge and discharge data of 1981, the stabilized piezometric heads were used afterward as the initial heads of 1981 for the nonsteady-state simulation (Figure 8.4.5).

(e) Direct recharge

The direct recharge was estimated from the water balance computation. The daily rainfall measured at the Boso-boso station and the Science Garden station plus the daily pan-evaporation measured at Science garden were used to estimate direct recharge. The pan-evaporation data were used to compute the actual soil evaporation and evapotranspiration. The soil characteristics viz. soil type, moisture holding capacity and thickness of soil zone, as well as vegetation characteristics were taken into account in determining the surplus water from the soil zone.

Figure 8.4.6 shows the annual rainfall and computed recharge at Boso-boso station from 1981 to 1990. The annual recharge values were inputted to the model. Figure 8.4.7 shows the water balance components in the Antipolo basin using Science Garden's data from 1962 to 1989.

8.4.2 Verification of the Model

(1) Steady-state Simulation

Model verification is carried out to identify input parameters and assigned boundary conditions. This process is the most important and the most complicated work in groundwater modeling because areal quantification of various parameters which play significant roles in groundwater regime should be done under actual hydrogeological constraints. Thus done, the verification of the model yields a better insight on dynamic groundwater behavior in the area as well as on the limitations of the model.

The calibration of the model was initially carried out in steady-state conditions to identify the initial heads and transmissivity of the model. The simulated piezometric heads were observed at the selected points shown in Figure 8.4.8. By using a constant year-1981 pumping rate throughout the 30-year period (30 time-steps), computation of groundwater heads proceeded on a trial-and-error basis and stopped when the drops in head were approximately zero (Figure 8.4.9).

Throughout the steady-state simulation, transmissivity and boundary conditions were modified. The piezometric heads obtained from the 30-year steady-state calculation were extrapolated and used as the initial groundwater heads in 1981 for nonsteady-state simulation (Figure 8.4.10). Figure 8.4.11 shows the differences between the initial piezometric heads and the elevation of the bottom of the aquifer. The initial piezometric heads are located more than 100m above the bottom of the aquifer around the central part of the basin.

(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 storage coefficient was also 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. 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 de creasing 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 Mani la. 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 ground-

water 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 ground-

water 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 33.6m²/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:

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

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.

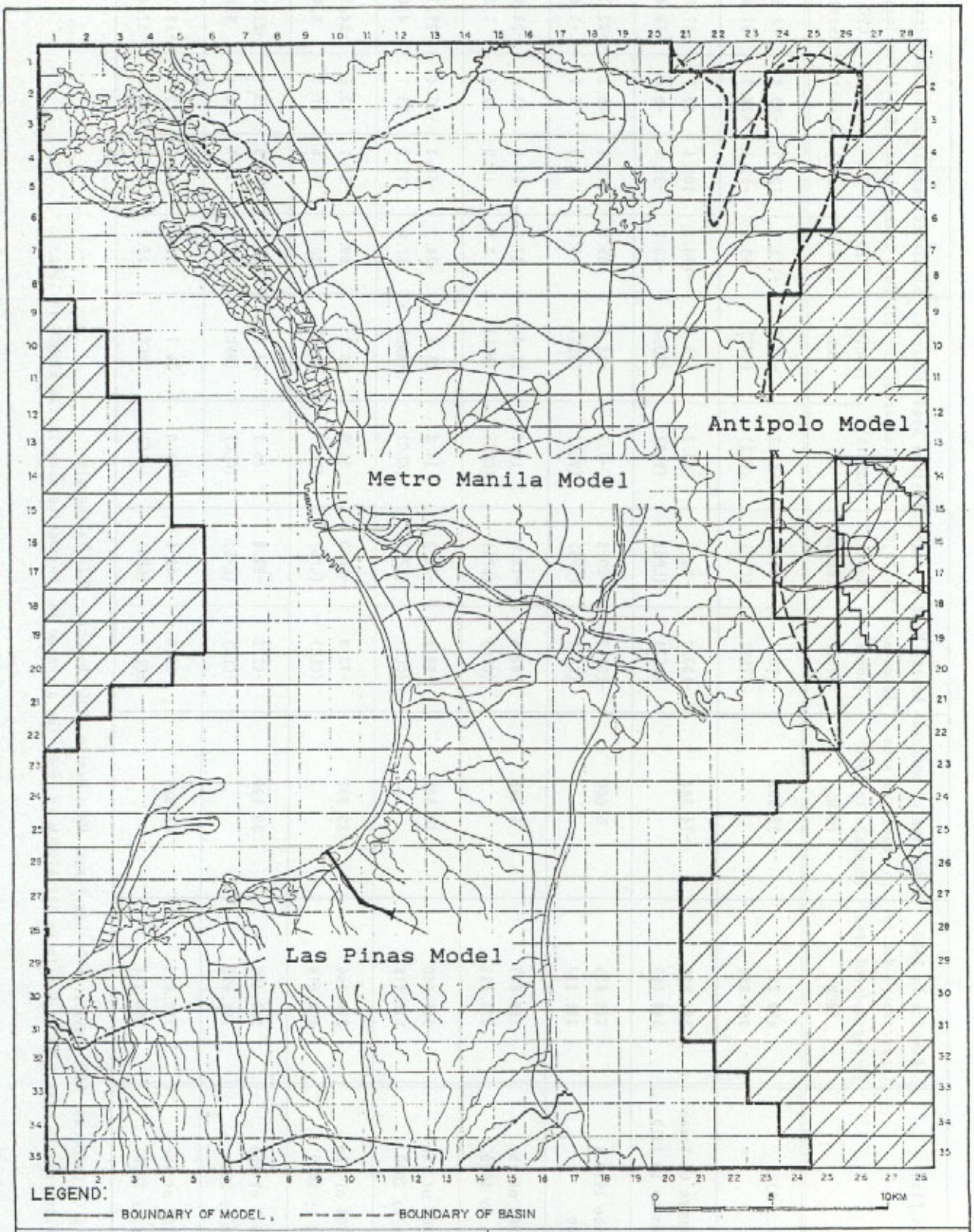
The model can simulate the future movement of saline water and its concentration, as well as future piezometric heads, after future plans of well locations and pumpage have been prepared.

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) (north) (masl)	(south) (masl)	Maximum head change in regulated area('10-'90) (north) (m)	(south) (m)	Simulated head in 2010(upper)(masl) Head change since 1990(lower)(masl) VLZ (masl)	CLC (masl)	MNL (masl)	CVC (masl)
(Scenario 1)	409.301 364.859	-39.553	-173.1 (VLZ)	-88.5 (CVC)	-83.1 (VLZ)	-57.4 (CVC)	-173.1 -83.1	-125.7 -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.	359.857 325.415	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.	350.060 315.618	19.595	-82.5 (CLC)	-72.2 (LPS)	24.8 (CLC)	15.7 (MNL)	-78.2 11.8	-58.3 17.3	-37.4 15.7	-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	-33.5 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 29.5	-43.9 31.7	-29.7 24.4	-21.5 9.5
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)	-51.5 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

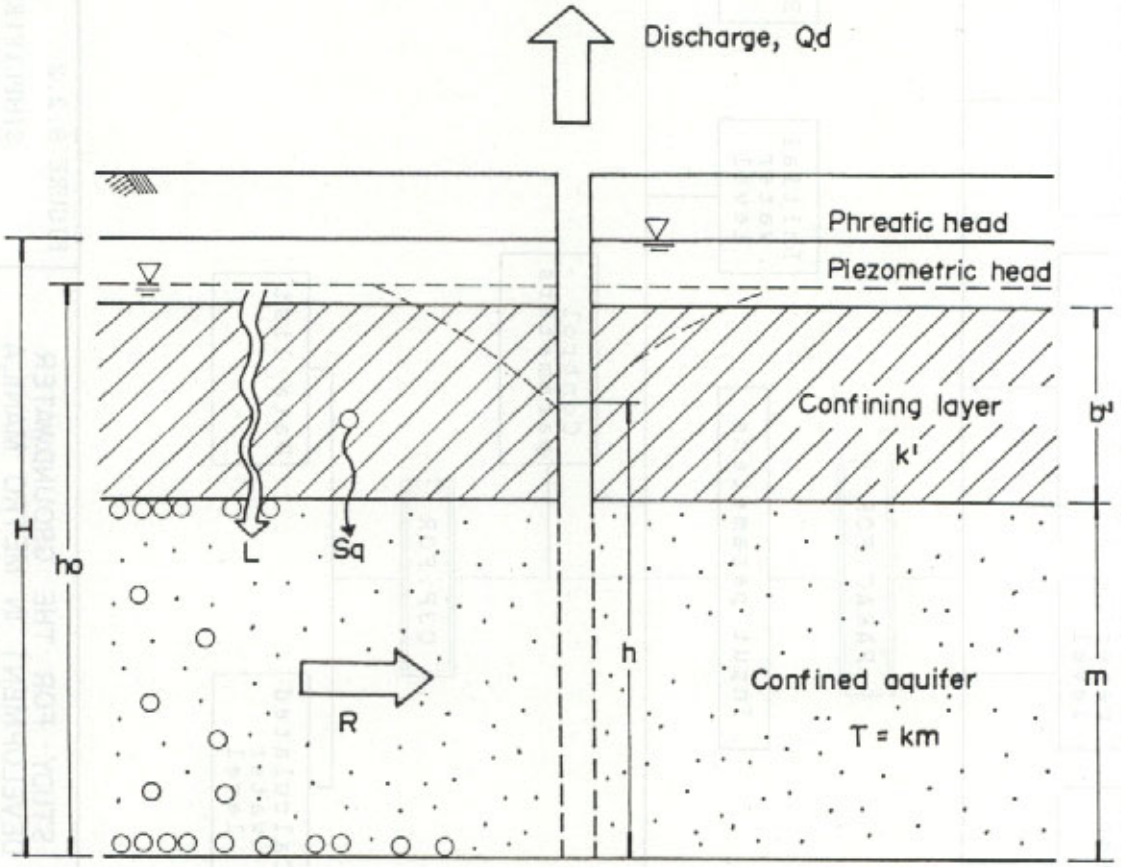
* The total discharge in entire Metro Manila is 339.611MCM in 1990, the dicharge in the modeled area is 316.572MCM in 1990.



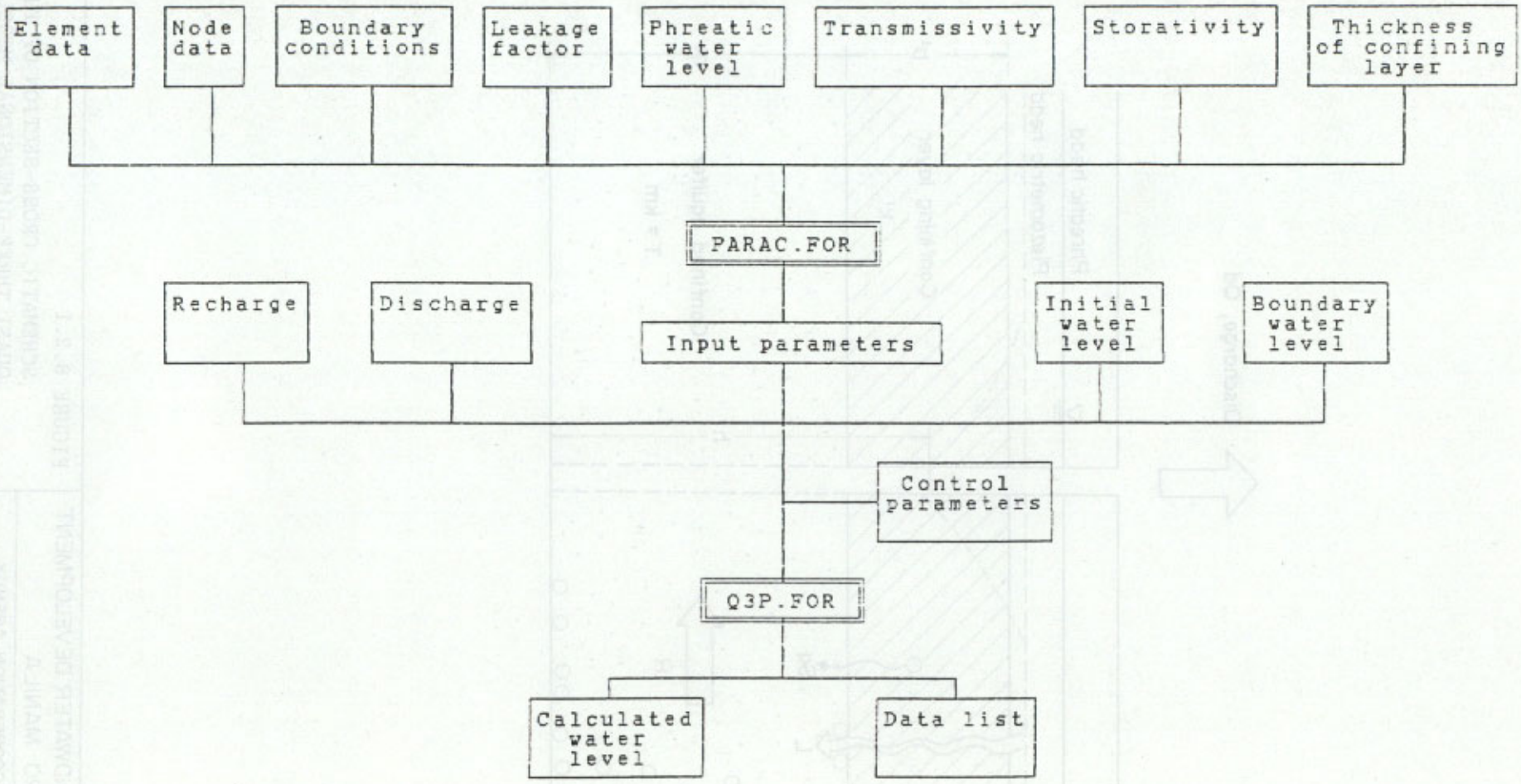
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

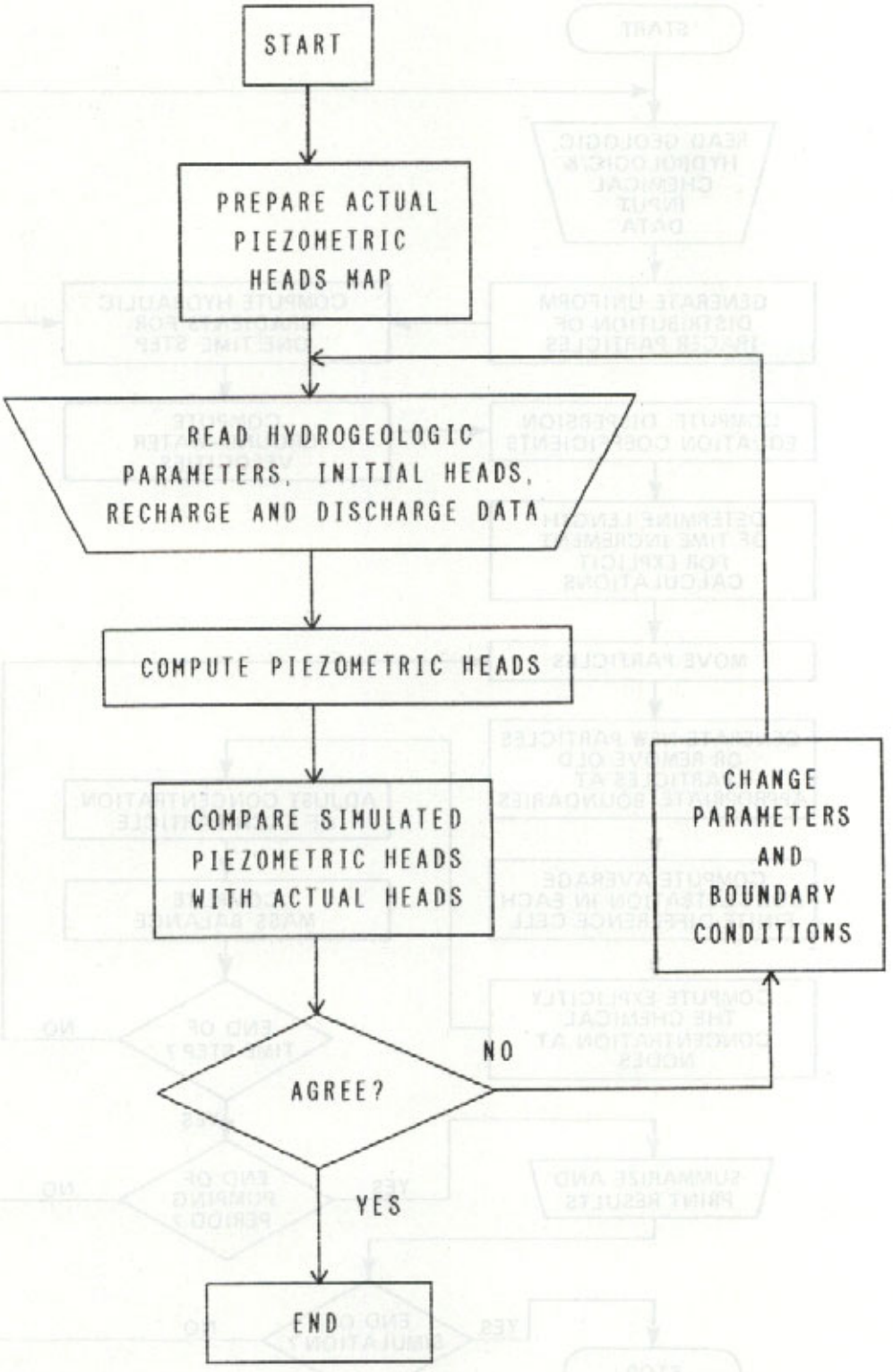
FIGURE 8.1
LOCATION OF GROUNDWATER MODELING



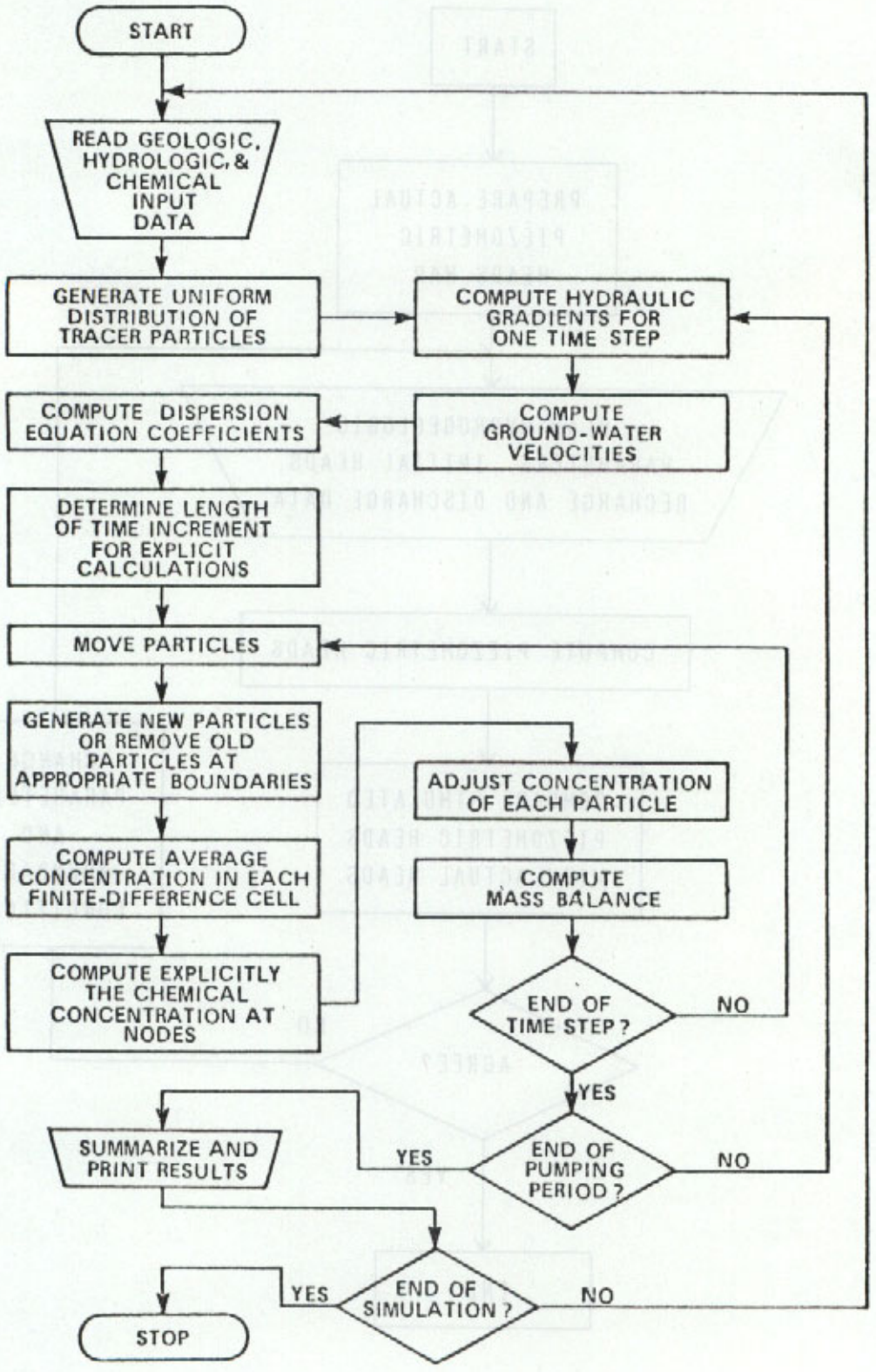
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA JAPAN INTERNATIONAL COOPERATION AGENCY	FIGURE 8.2.1 SCHEMATIC CROSS-SECTION OF THE QUASI THREE-DIMENSIONAL MODEL



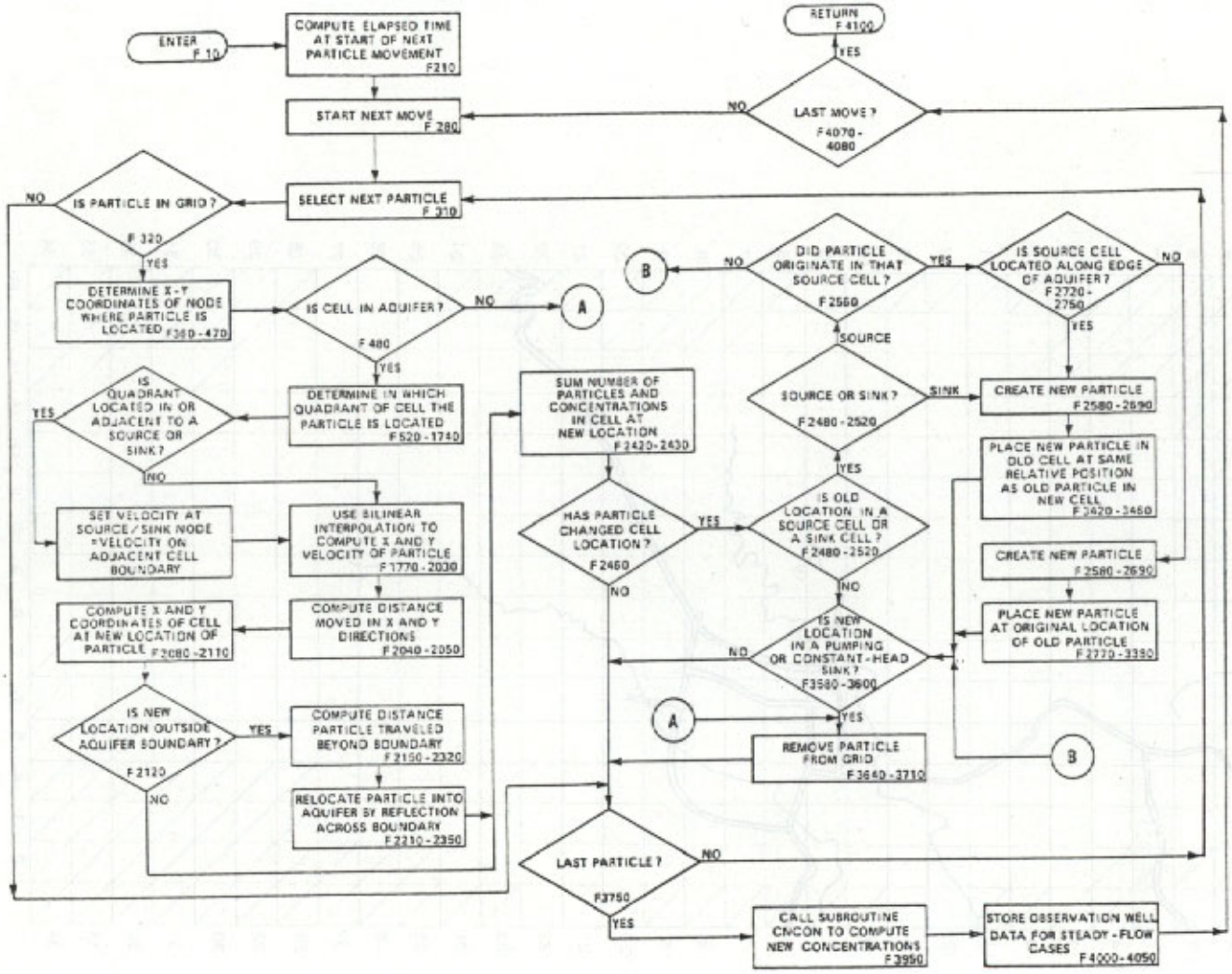
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.2.2 SIMPLIFIED FLOW CHART OF THE QUASI THREE-DIMENSIONAL FEM FLOW MODEL (Q3P)
JAPAN INTERNATIONAL COOPERATION AGENCY	



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



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

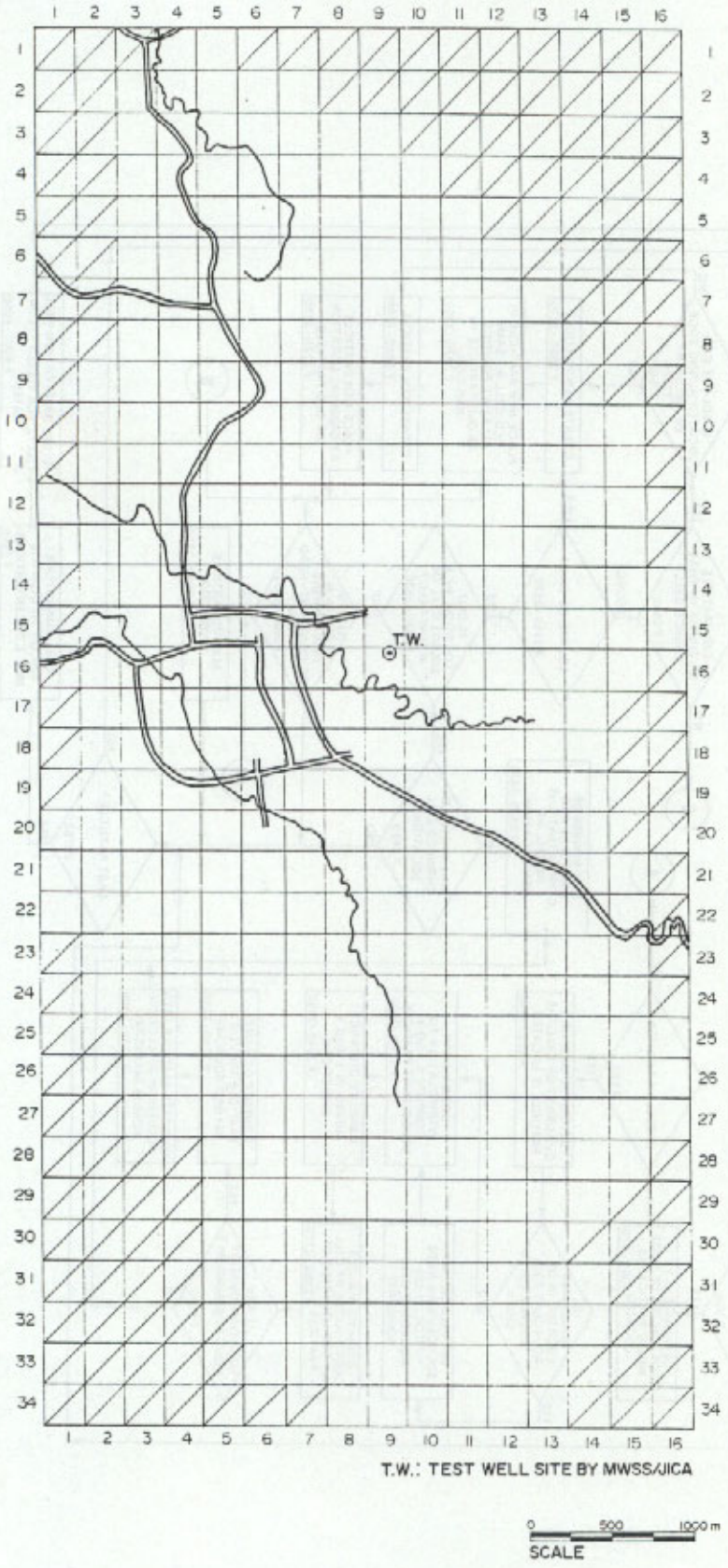


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.3.2

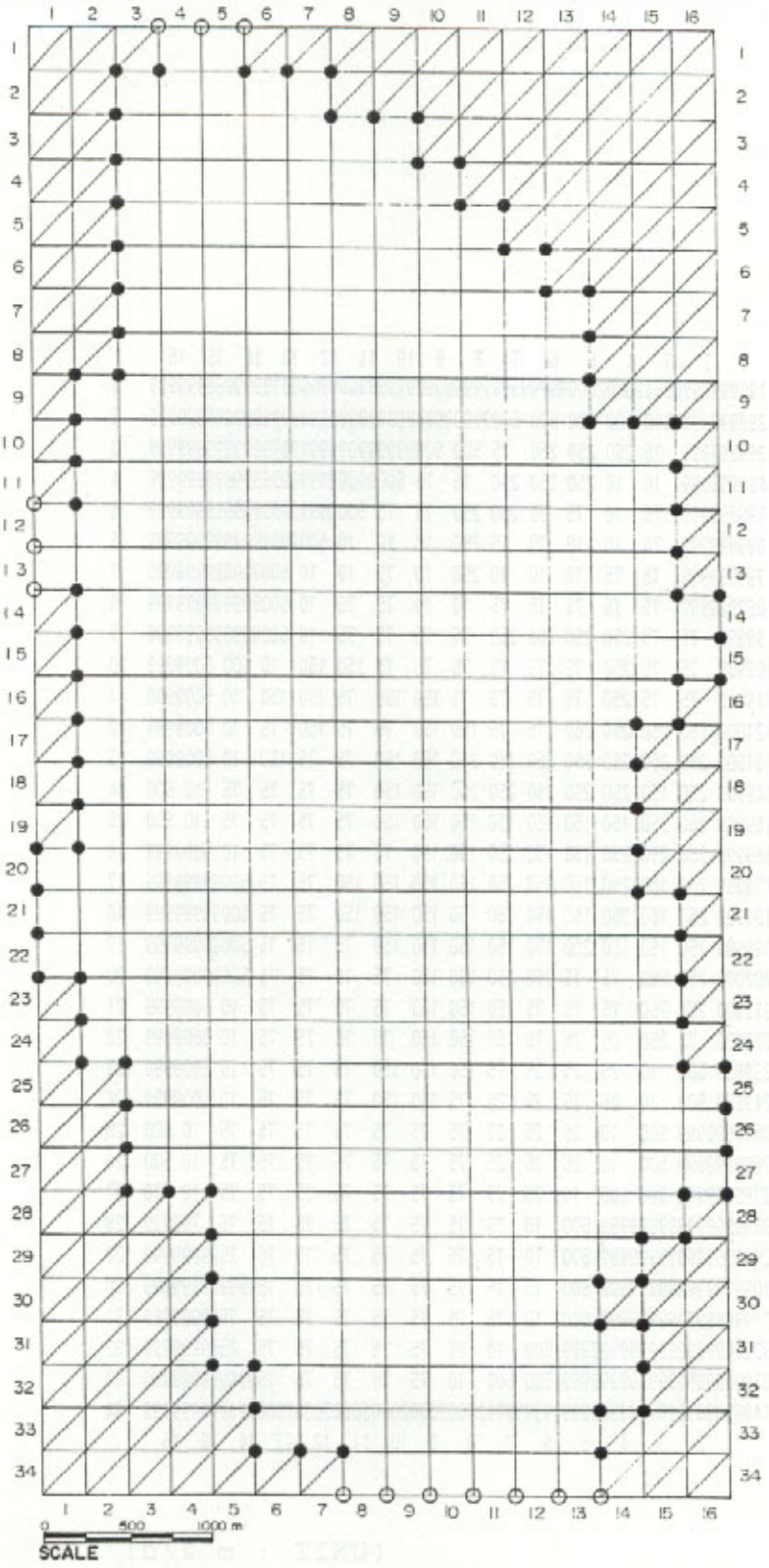
GENERALIZED FLOW CHART ILLUSTRATING THE PARTICLE TRACKING PROCEDURE IN THE SOLUTE TRANSPORT CALCULATION



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

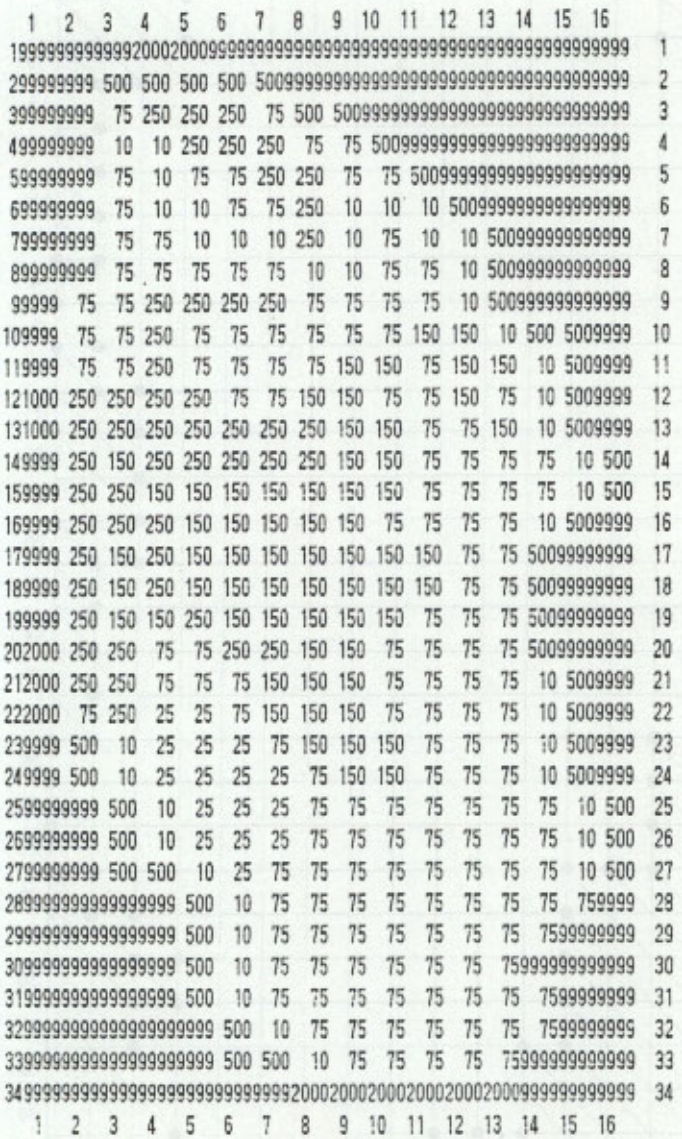


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

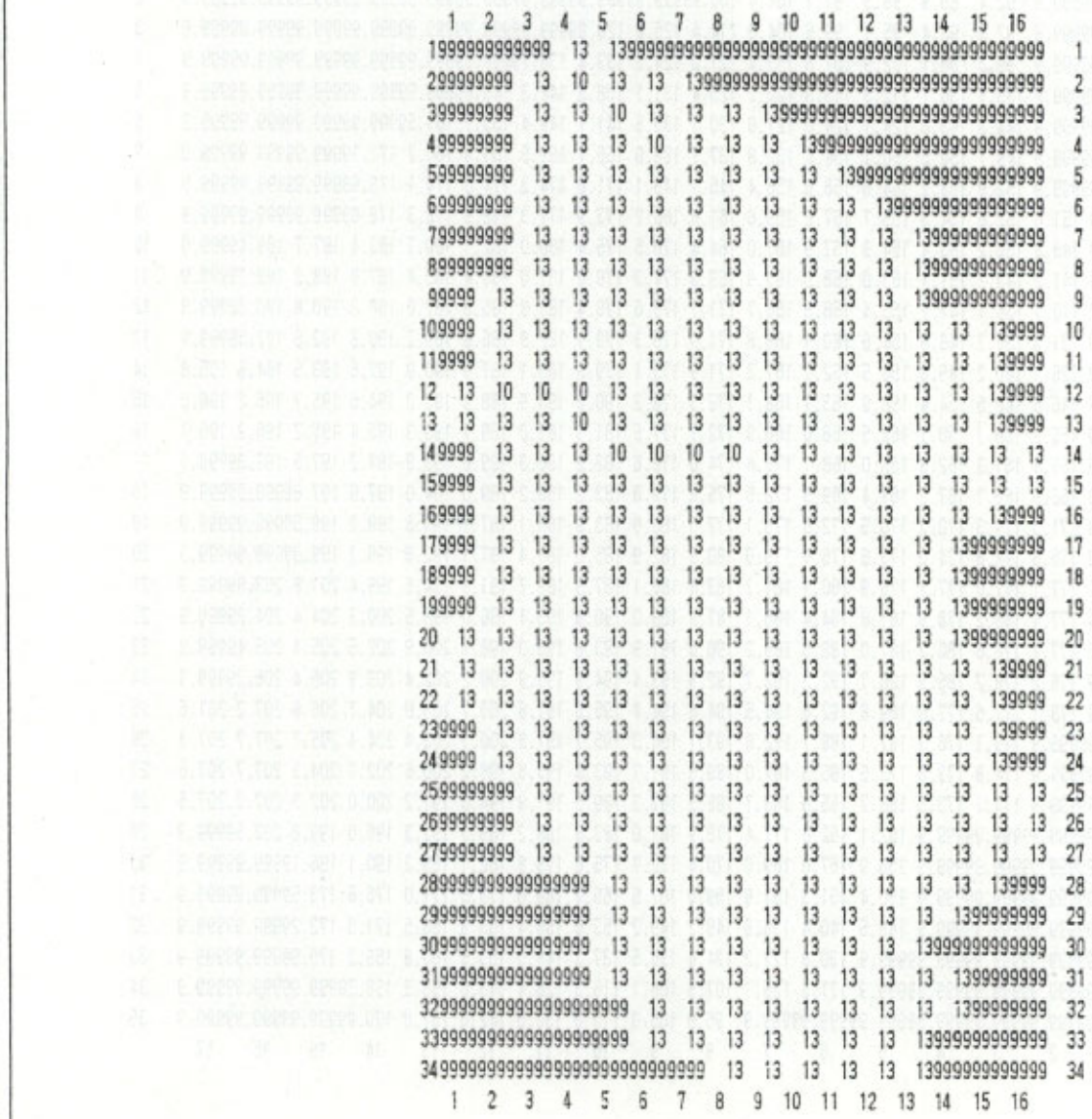
FIGURE 8.4.2

BOUNDARY CONDITIONS FOR THE ANTIPOLO GROUNDWATER BASIN MODEL



(UNIT : m^2/d)

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



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

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.4.4 FINAL DISTRIBUTION OF STORAGE COEFFICIENT
JAPAN INTERNATIONAL COOPERATION AGENCY	

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	85.0	9999.	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	196.3	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	185.3	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	FIGURE 8.4.5
JAPAN INTERNATIONAL COOPERATION AGENCY	COMPUTED INITIAL HEADS IN 1981

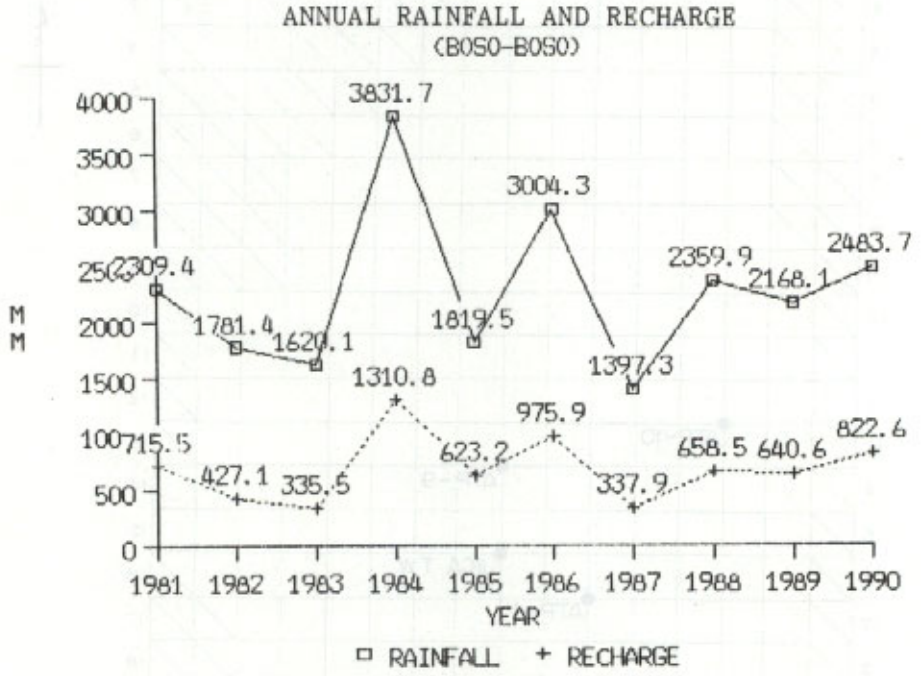


FIGURE 8.4.6 ANNUAL RAINFALL AND ESTIMATED RECHARGE AT BOSO-BOSO STATION

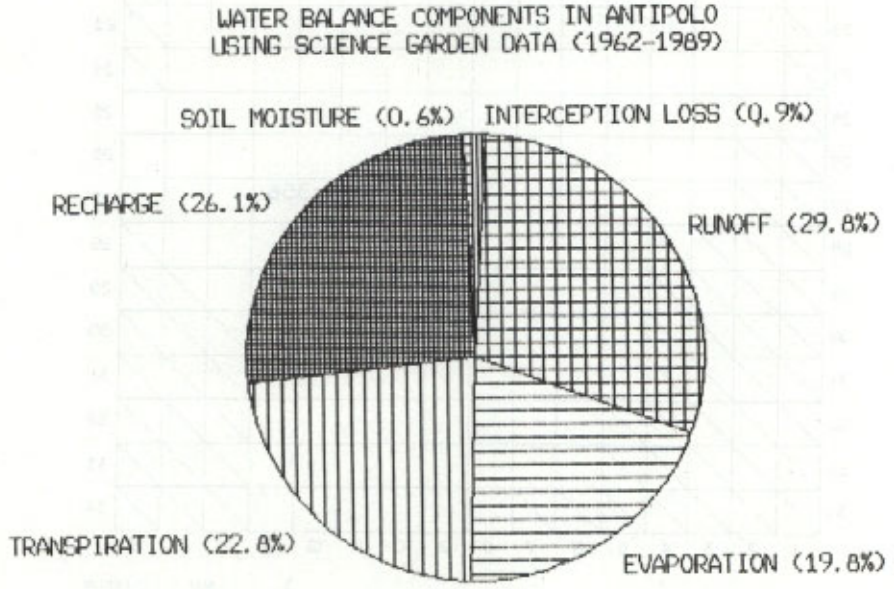
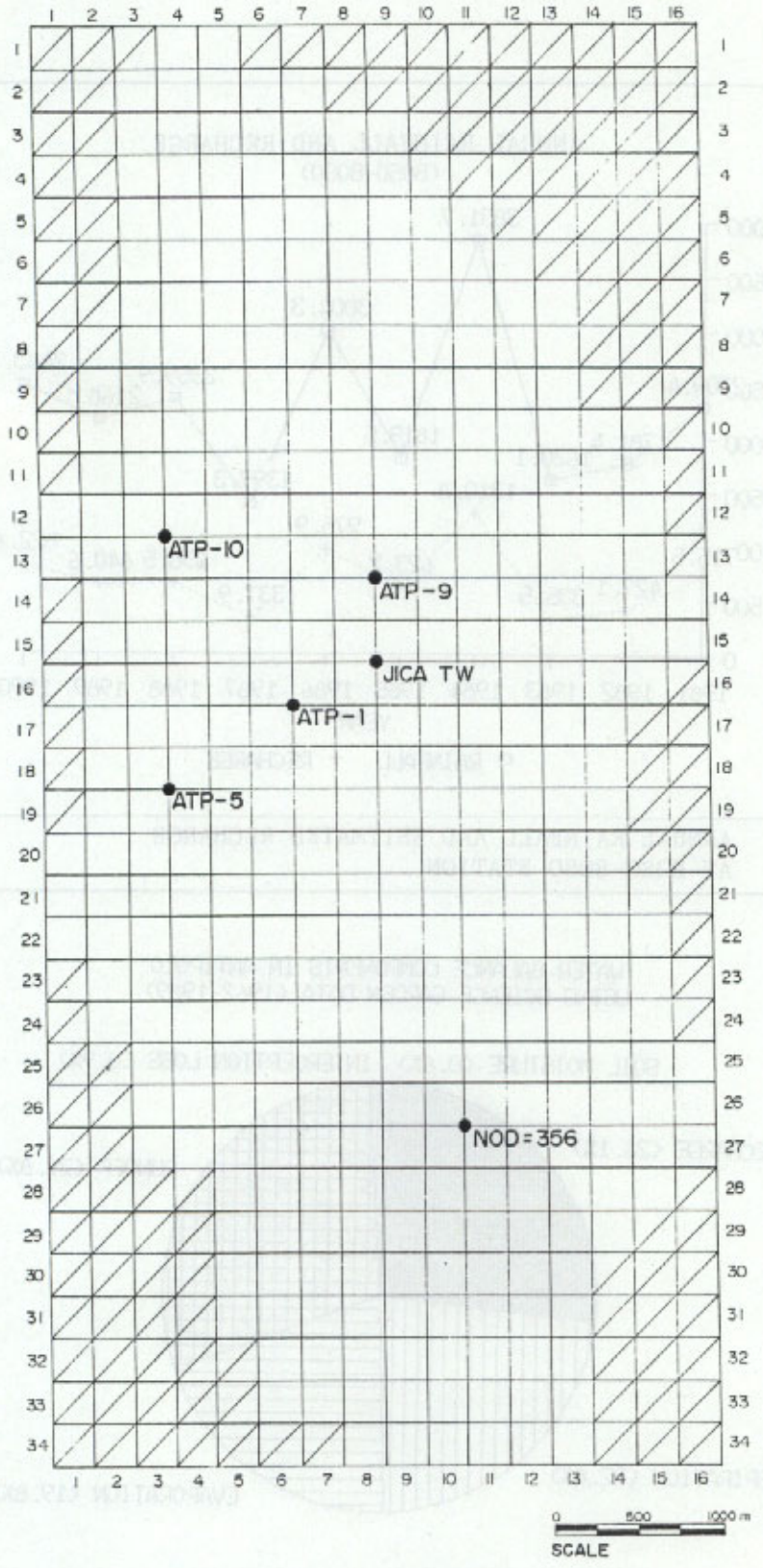


FIGURE 8.4.7 WATER BALANCE COMPONENTS IN THE ANTIPOLO BASIN USING SCIENCE GARDEN DATA

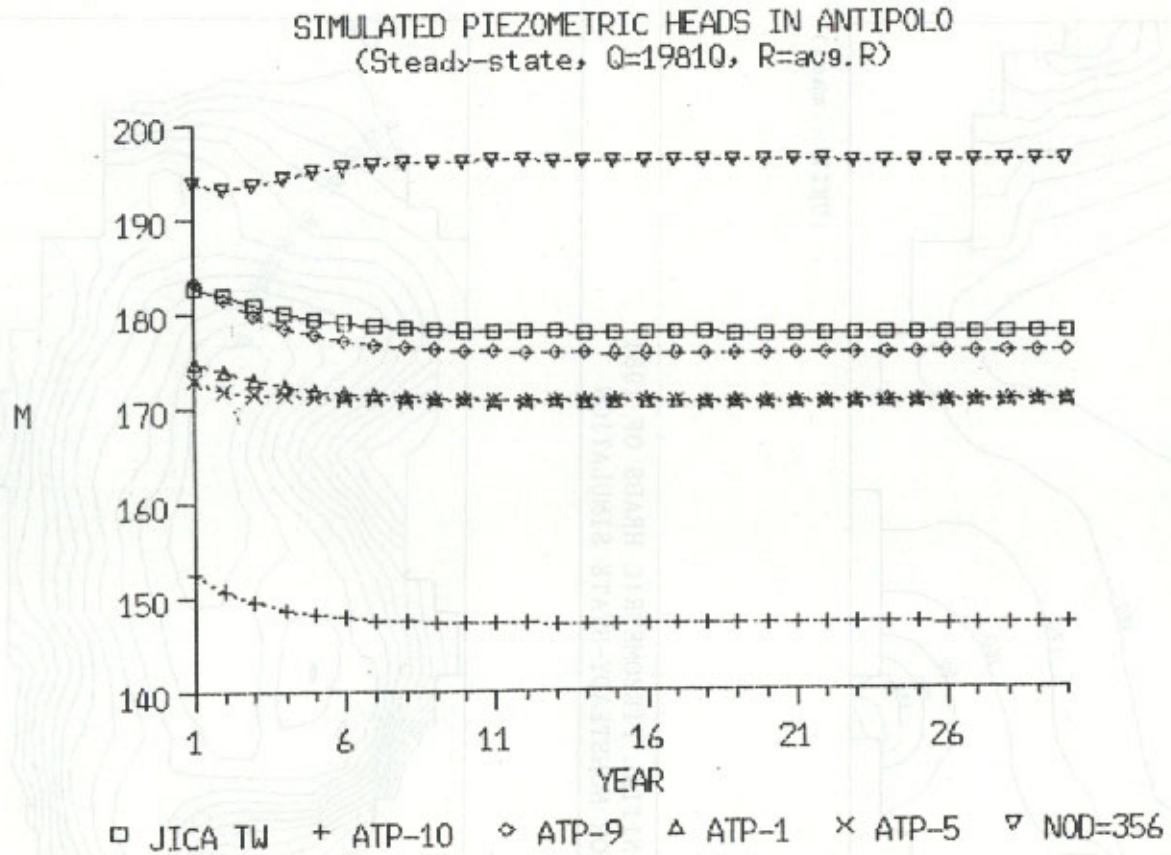


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

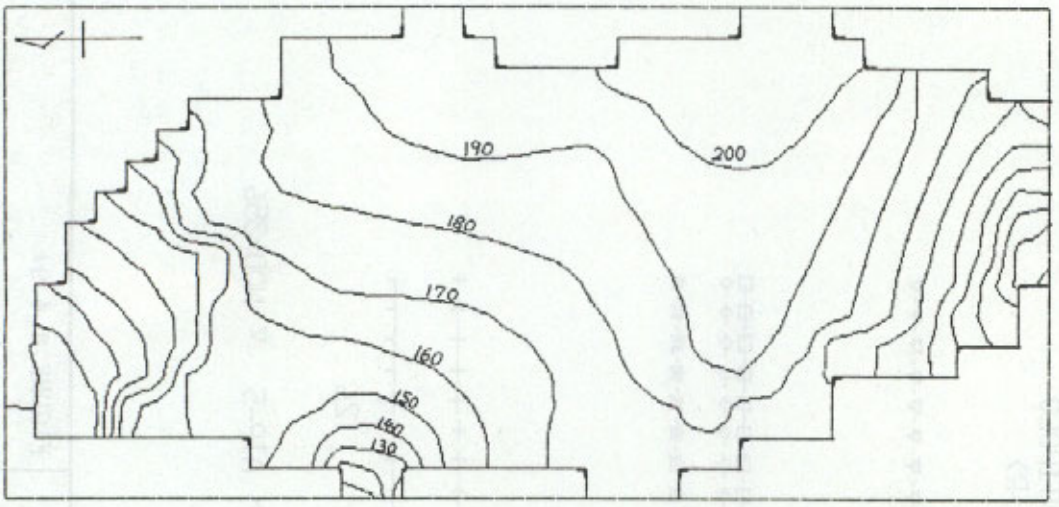
JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.4.8

LOCATION OF OBSERVATION POINTS

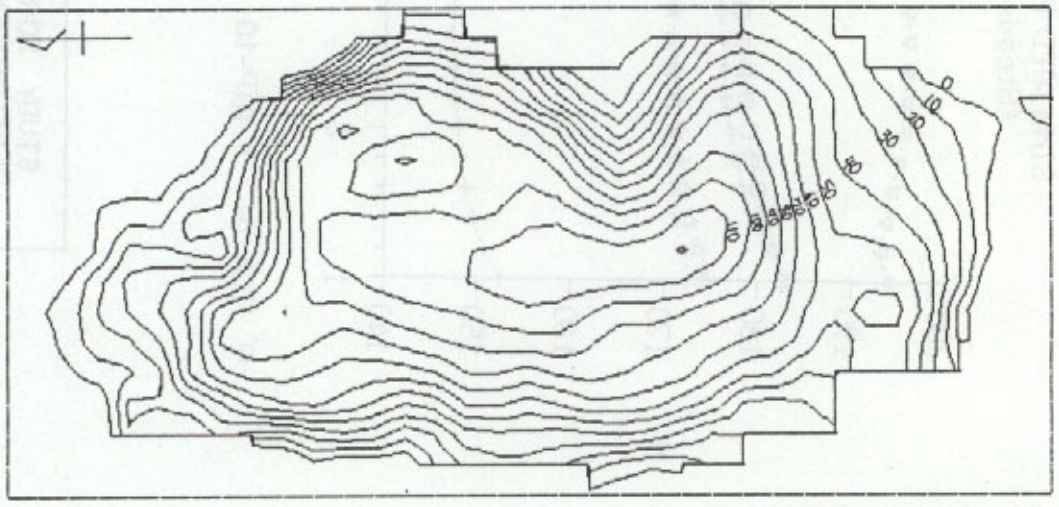


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.4.9
JAPAN INTERNATIONAL COOPERATION AGENCY	30-STEP STEADY-STATE CALCULATION TO MAKE INITIAL HEADS OF 1981



(UNIT : masl)

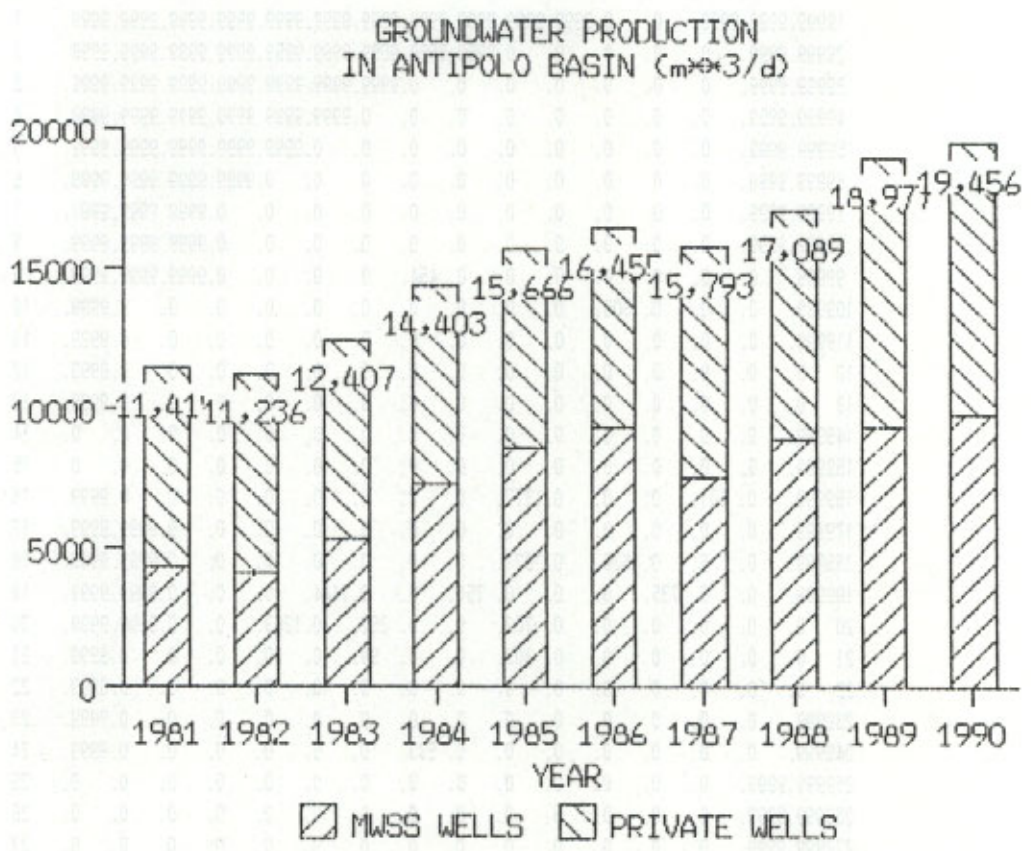
FIGURE 8.4.10 INITIAL PIEZOMETRIC HEADS OF 1981 FOR NONSTEADY-STATE SIMULATION



(UNIT : m)

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

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



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

ATP Q MAP (m^3/d)

YEAR: 1981

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1	9999.	9999.	9999.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	1
2	9999.	9999.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	2
3	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	3
4	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	4
5	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	5
6	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	6
7	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	7
8	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	8
9	9999.	0.	0.	0.	0.	0.	0.	0.	454.	0.	0.	0.	0.	9999.	9999.	9999.	9
10	9999.	0.	0.	0.	500.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	10
11	9999.	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
14	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	14
15	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	15
16	9999.	0.	601.	0.	0.	0.	1377.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	16
17	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	17
18	9999.	0.	6.	0.	1636.	0.	1021.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	18
19	9999.	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
23	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	23
24	9999.	0.	0.	0.	0.	0.	0.	0.	533.	0.	0.	0.	0.	0.	0.	9999.	24
25	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	25
26	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	26
27	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	27
28	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	38.	0.	0.	0.	9999.	28
29	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	29
30	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	30
31	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	31
32	9999.	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	32
33	9999.	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	33
34	9999.	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	FIGURE 8.4.13(1) DISCHARGE MAP IN 1981
JAPAN INTERNATIONAL COOPERATION AGENCY	

ATP Q MAP (m^3/d)

YEAR: 1982

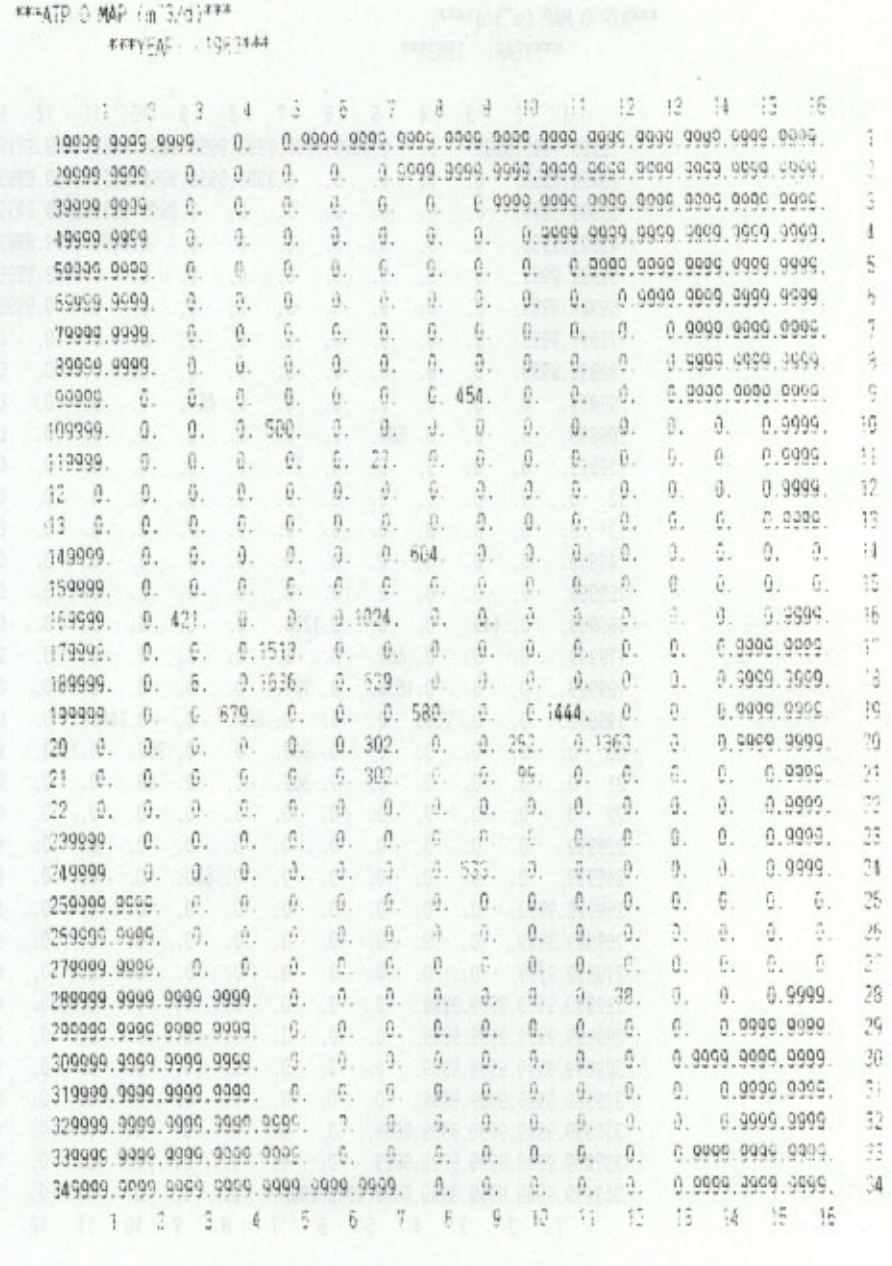
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1	9999.	9999.	9999.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	1
2	9999.	9999.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	2
3	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	3
4	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	4
5	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	5
6	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	6
7	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	7
8	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	8
9	9999.	0.	0.	0.	0.	0.	0.	0.	454.	0.	0.	0.	0.	9999.	9999.	9999.	9
10	9999.	0.	0.	0.	500.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	10
11	9999.	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
14	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	14
15	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	15
16	9999.	0.	449.	0.	0.	0.	1284.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	16
17	9999.	0.	0.	0.	466.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	17
18	9999.	0.	6.	0.	1636.	0.	737.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	18
19	9999.	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
23	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	23
24	9999.	0.	0.	0.	0.	0.	0.	0.	533.	0.	0.	0.	0.	0.	0.	9999.	24
25	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	25
26	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	26
27	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	27
28	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	38.	0.	0.	0.	9999.	28
29	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	29
30	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	30
31	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	31
32	9999.	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	32
33	9999.	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	33
34	9999.	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

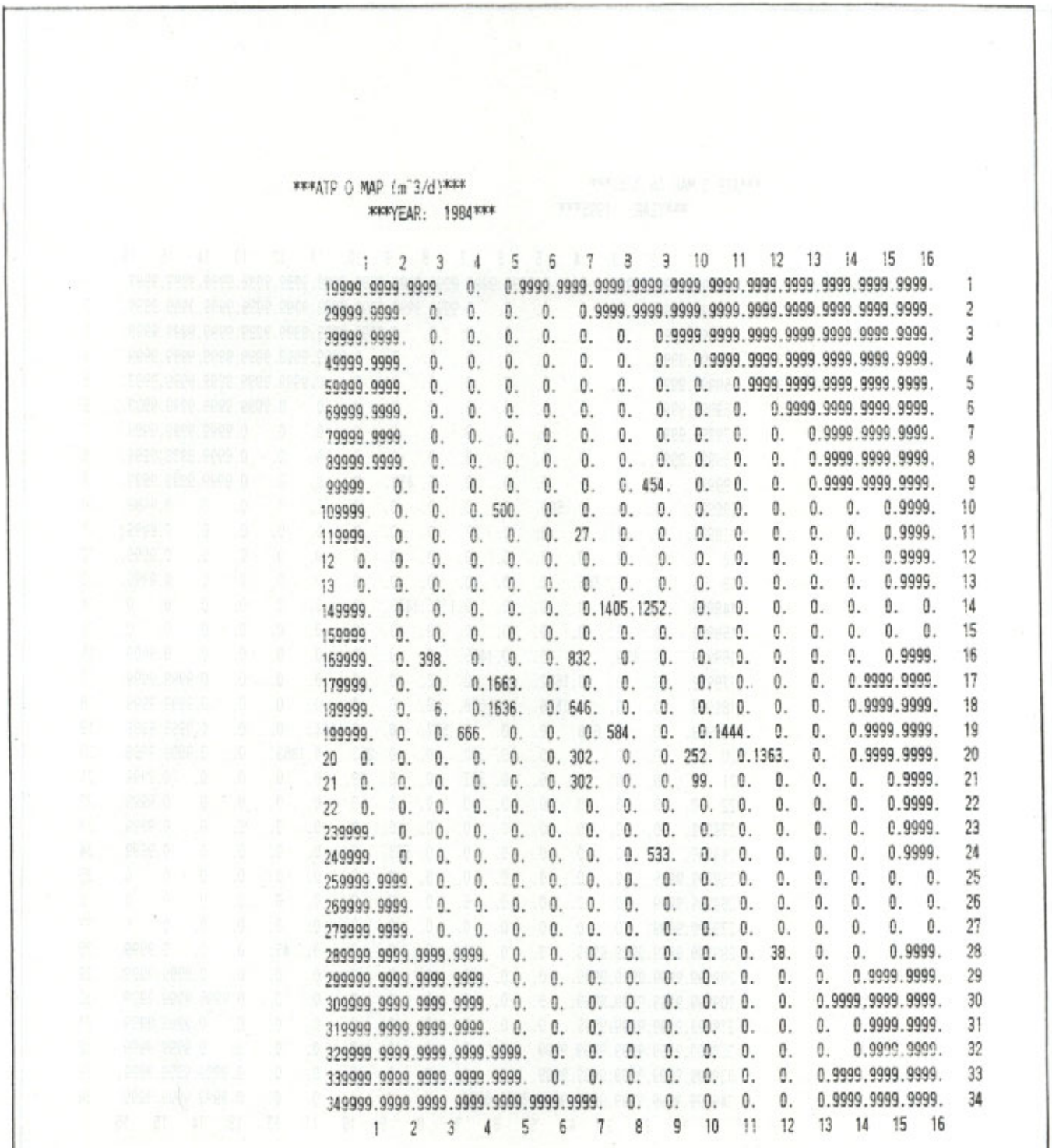
FIGURE 8.4.13(2)
DISCHARGE MAP IN 1982



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.4.13(3)
DISCHARGE MAP IN 1983



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.4.13(4) DISCHARGE MAP IN 1984
JAPAN INTERNATIONAL COOPERATION AGENCY	

ATP Q MAP (m^3/d)

YEAR: 1985

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1	9999.	9999.	9999.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	1
2	9999.	9999.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	2
3	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	3
4	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	4
5	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	5
6	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	6
7	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	7
8	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	8
9	9999.	0.	0.	0.	0.	0.	0.	0.	454.	0.	0.	0.	0.	9999.	9999.	9999.	9
10	9999.	0.	0.	0.	500.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	10
11	9999.	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
14	9999.	0.	0.	0.	0.	0.	0.	1132.	1435.	0.	0.	0.	0.	0.	0.	0.	14
15	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	15
16	9999.	0.	439.	0.	0.	0.	1465.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	16
17	9999.	0.	0.	0.	1652.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	17
18	9999.	0.	6.	0.	1636.	0.	678.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	18
19	9999.	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
23	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	23
24	9999.	0.	0.	0.	0.	0.	0.	0.	533.	0.	0.	0.	0.	0.	0.	9999.	24
25	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	25
26	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	26
27	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	27
28	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	45.	0.	0.	0.	9999.	28
29	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	29
30	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	30
31	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	31
32	9999.	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	32
33	9999.	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	33
34	9999.	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	FIGURE 8.4.13(5) DISCHARGE MAP IN 1985
JAPAN INTERNATIONAL COOPERATION AGENCY	

ATP O MAP (m^3/d)

YEAR: 1986

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1	9999.	9999.	9999.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	1
2	9999.	9999.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	2
3	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	3
4	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	4
5	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	5
6	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	6
7	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	7
8	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	8
9	9999.	0.	0.	0.	0.	0.	0.	0.	454.	0.	0.	0.	0.	9999.	9999.	9999.	9
10	9999.	0.	0.	0.	500.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	10
11	9999.	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
14	9999.	0.	0.	0.	0.	0.	0.	1203.	1434.	0.	0.	0.	0.	0.	0.	0.	14
15	9999.	0.	0:	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	15
16	9999.	0.	625.	0.	0.	1407.	0.	0.	0.	0.	0.	0.	0.	0.	9999.		16
17	9999.	0.	0.	1651.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.		17
18	9999.	0.	5.	1636.	0.	686.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.		18
19	9999.	0.	0.	589.	0.	0.	0.	403.	0.	1444.	0.	0.	9999.	9999.			19
20	0.	0.	0.	0.	0.	0.	302.	0.	0.	252.	1363.	0.	9999.	9999.			20
21	0.	0.	0.	0.	0.	0.	302.	0.	0.	99.	0.	0.	0.	0.	9999.		21
22	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.		22
23	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.		23
24	9999.	0.	0.	0.	0.	0.	0.	0.	533.	0.	0.	0.	0.	0.	9999.		24
25	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	25
26	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	26
27	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	27
28	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	45.	0.	0.	9999.		28
29	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.		29
30	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.		30
31	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.		31
32	9999.	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.		32
33	9999.	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.		33
34	9999.	9999.	9999.	9999.	9999.	9999.	9999.	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 = 16454.m^3/d

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.4.13(6) DISCHARGE MAP IN 1986
JAPAN INTERNATIONAL COOPERATION AGENCY	

ATP Q 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.	9999.	12
13	0.	0.	0.	1152.	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.	226.	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.	20
21	0.	0.	0.	0.	0.	0.	302.	0.	0.	99.	0.	0.	0.	0.	9999.	21
22	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 = 15790.m^3/d

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.4.13(7) DISCHARGE MAP IN 1987
JAPAN INTERNATIONAL COOPERATION AGENCY	

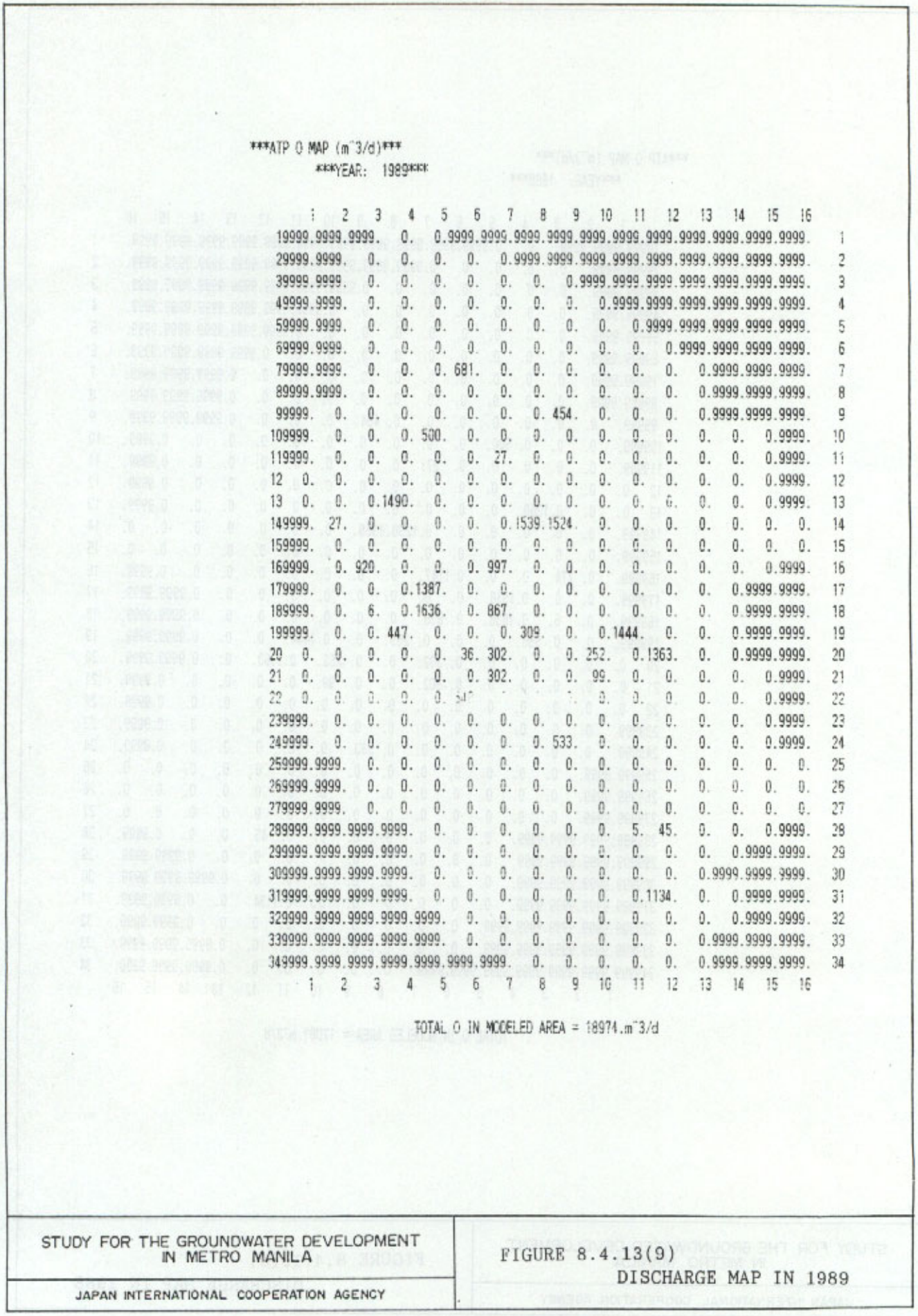
ATP Q MAP (m^3/d)

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.	9999.	12
13	0.	0.	1260.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	13
149999.	0.	0.	0.	0.	0.	1230.	1358.	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.	774.	0.	0.	1147.	0.	0.	0.	0.	0.	0.	0.	0.	9999.		16
179999.	0.	0.	1518.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.		17
189999.	0.	6.	1636.	0.	878.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.		18
199999.	0.	0.	556.	0.	0.	0.	269.	0.	1444.	0.	0.	0.	9999.	9999.		19
20	0.	0.	0.	0.	0.	0.	302.	0.	0.	252.	1363.	0.	0.	9999.	9999.	20
21	0.	0.	0.	0.	0.	0.	302.	0.	0.	99.	0.	0.	0.	0.	9999.	21
22	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	
1	9999.	9999.	9999.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	1
2	9999.	9999.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	2
3	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	9999.	3
4	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	9999.	4
5	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	9999.	5
6	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	9999.	6
7	9999.	9999.	0.	0.	0.	681.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	7
8	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	8
9	9999.	0.	0.	0.	0.	0.	0.	0.	454.	0.	0.	0.	0.	9999.	9999.	9999.	9
10	9999.	0.	0.	0.	500.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	10
11	9999.	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.	6.	0.	0.	0.	9999.	13
14	9999.	27.	0.	0.	0.	0.	0.	1539.	1524.	0.	0.	0.	0.	0.	0.	0.	14
15	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	15
16	9999.	0.	920.	0.	0.	0.	997.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	16
17	9999.	0.	0.	0.	1387.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	17
18	9999.	0.	6.	0.	1636.	0.	867.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	18
19	9999.	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			1.	0.	0.	0	0.	0.	0.	9999.	22
23	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	23
24	9999.	0.	0.	0.	0.	0.	0.	0.	533.	0.	0.	0.	0.	0.	0.	9999.	24
25	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	25
26	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	26
27	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	27
28	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	5.	45.	0.	0.	0.	9999.	28
29	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	29
30	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	30
31	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	1134.	0.	0.	9999.	9999.	31
32	9999.	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	32
33	9999.	9999.	9999.	9999.	9999.	0.	0.	0.	0.	0.	0.	0.	0.	9999.	9999.	9999.	33
34	9999.	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

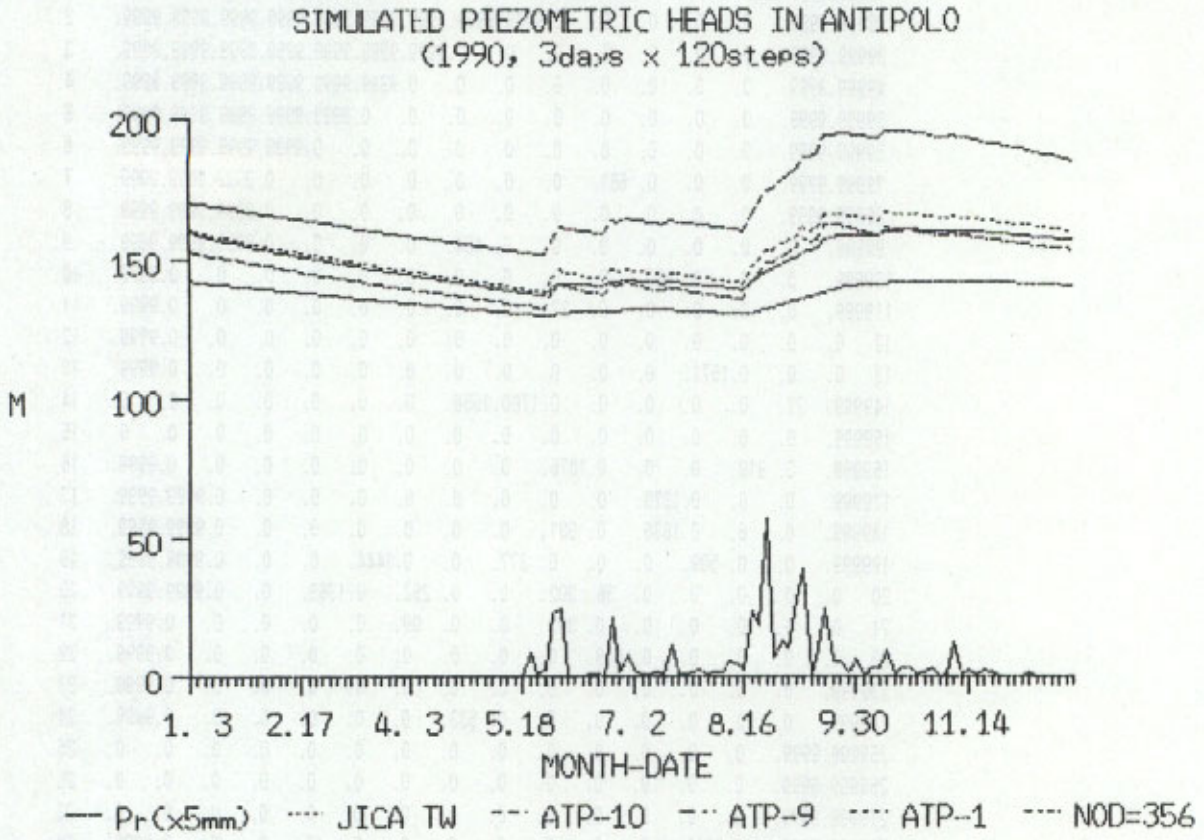
ATP Q MAP (m^3/d)

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.	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.	9999.	12
13	0.	0.	0.	1571.	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.	0.	881.	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.	0.	9999.	23
249999.	0.	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.	0.	25
269999.	9999.	0.	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.	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	FIGURE 8.4.13(10) DISCHARGE MAP IN 1990
JAPAN INTERNATIONAL COOPERATION AGENCY	



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	

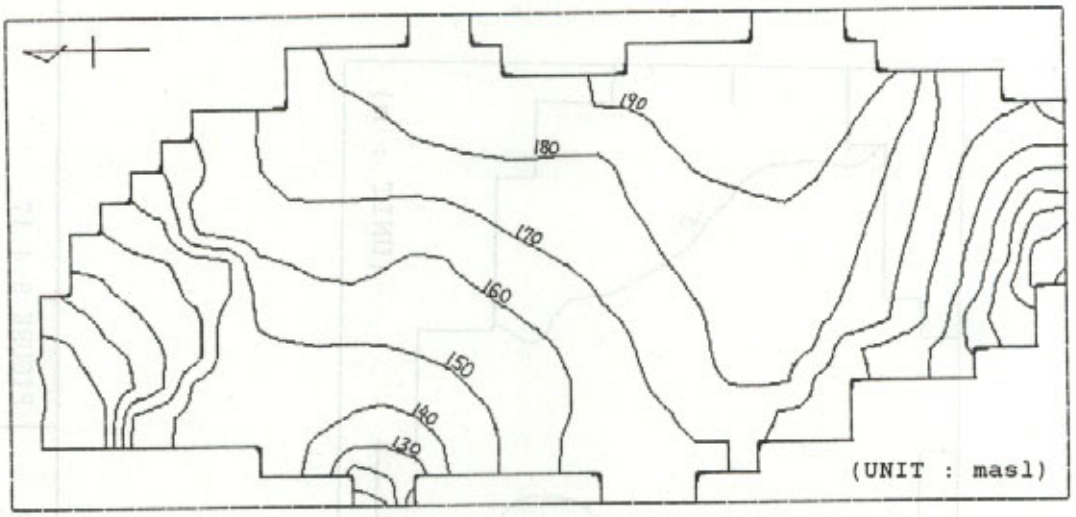


FIGURE 8.4.15 SIMULATED PIEZOMETRIC HEADS IN 1990

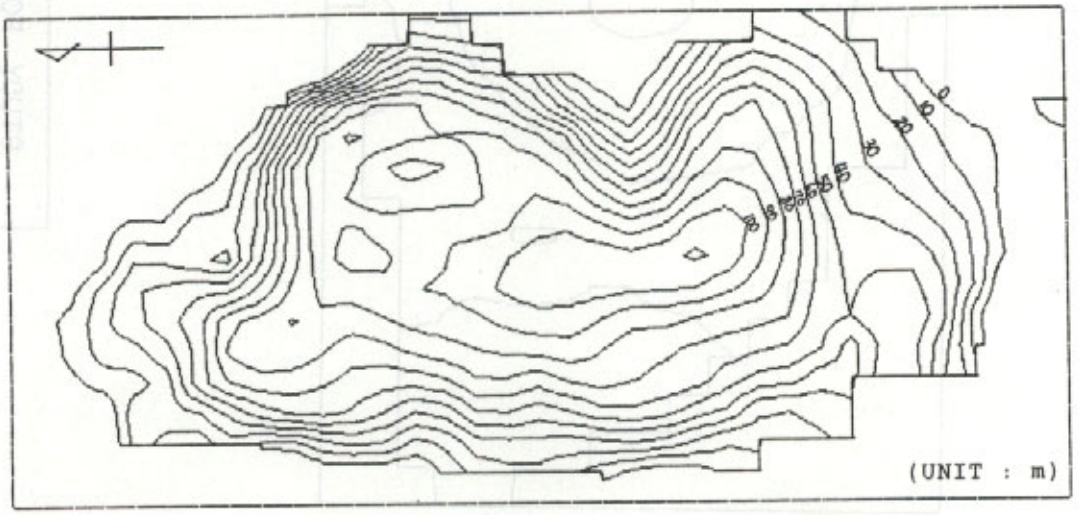
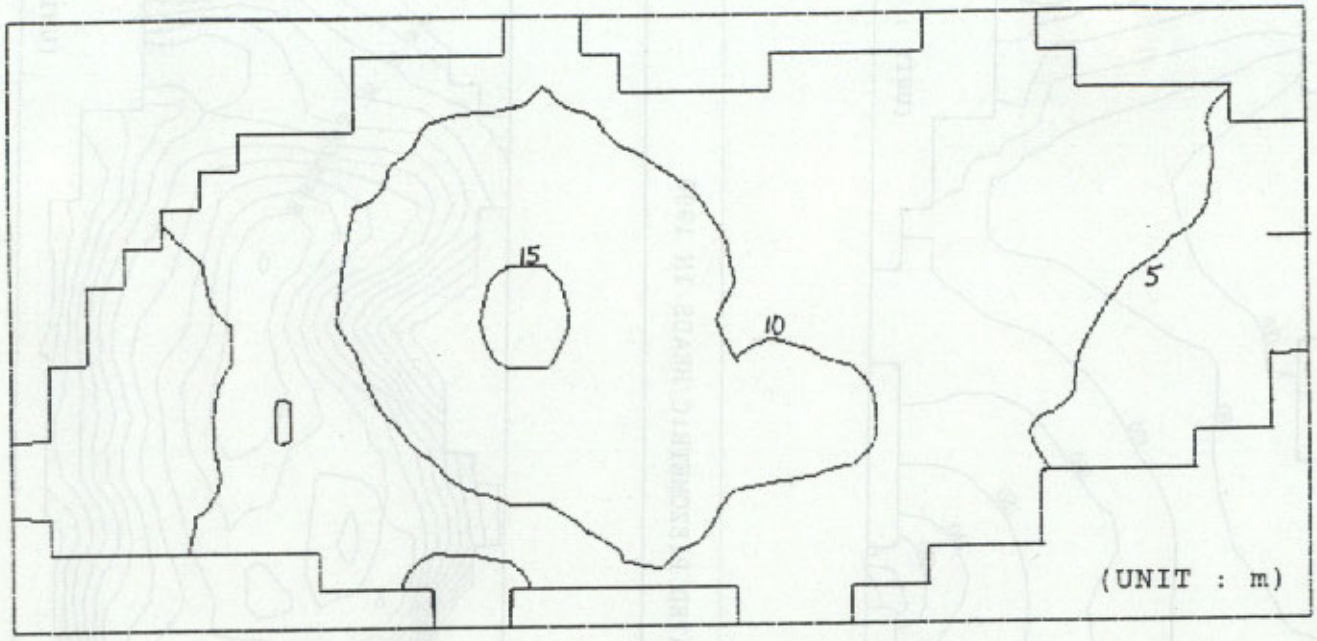


FIGURE 8.4.16 SIMULATED PIEZOMETRIC HEIGHTS FROM THE BOTTOM OF THE AQUIFER IN 1990

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



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.4.17
JAPAN INTERNATIONAL COOPERATION AGENCY	SIMULATED DRAWDOWN FROM 1981 TO 1990

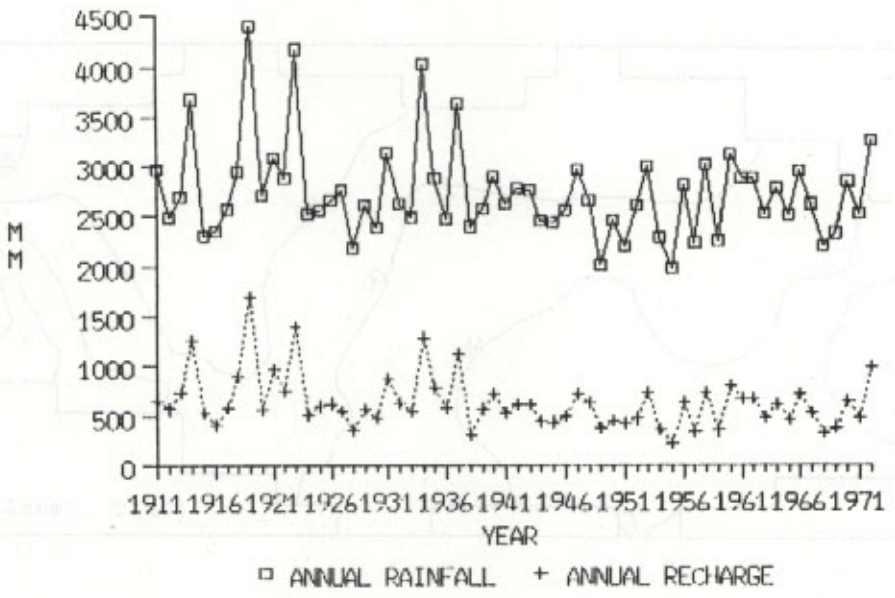


FIGURE 8.4.18 ANNUAL RAINFALL AND ESTIMATED RECHARGE IN ANTIPOLO USING SUMULONG STATION'S DATA (1911-1972)

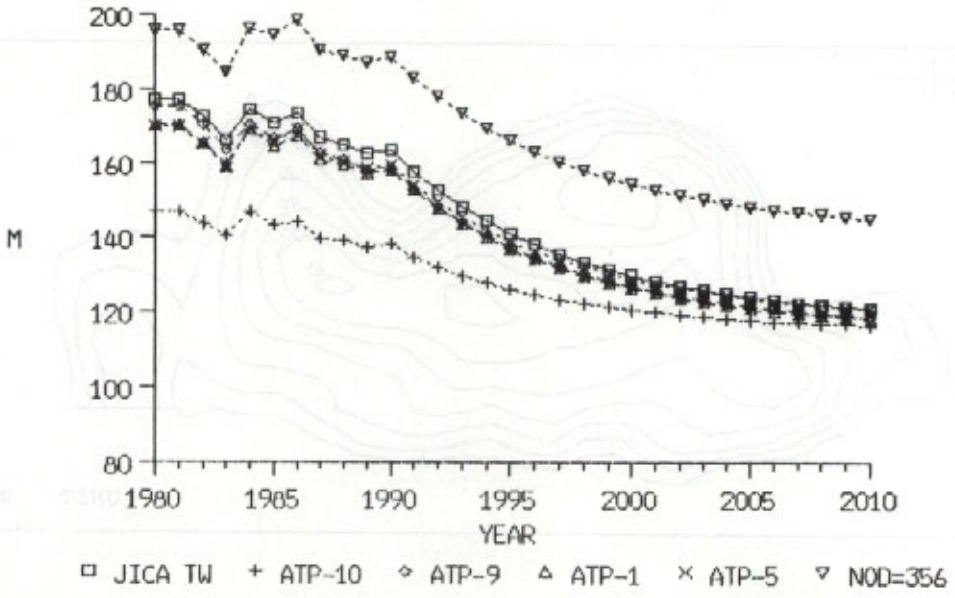


FIGURE 8.4.19 SIMULATED PIEZOMETRIC HEADS
(Discharge from 1991 to 2010 = Discharge of 1990)

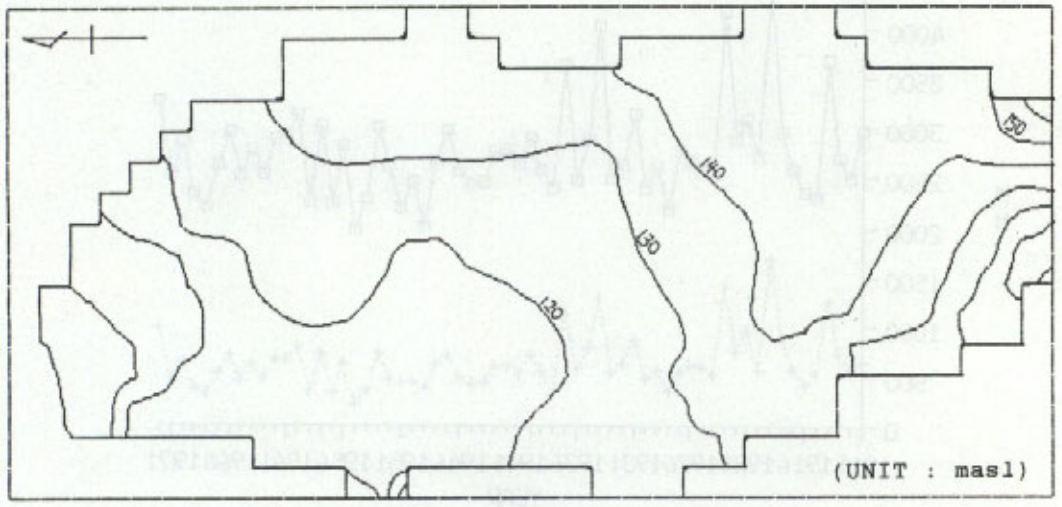


FIGURE 8.4.20 SIMULATED PIEZOMETRIC HEADS IN 2010
(Discharge from 1991 to 2010 = Discharge of 1990)

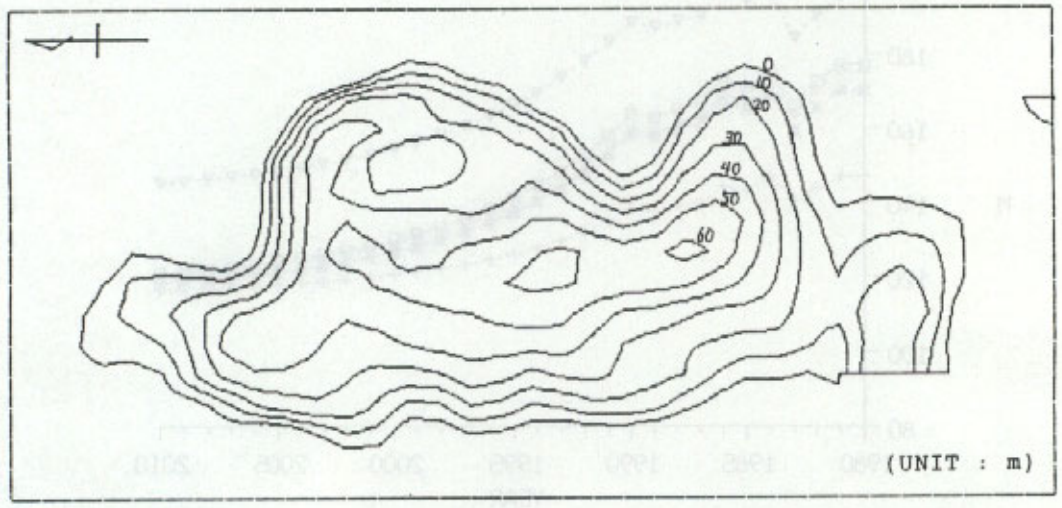
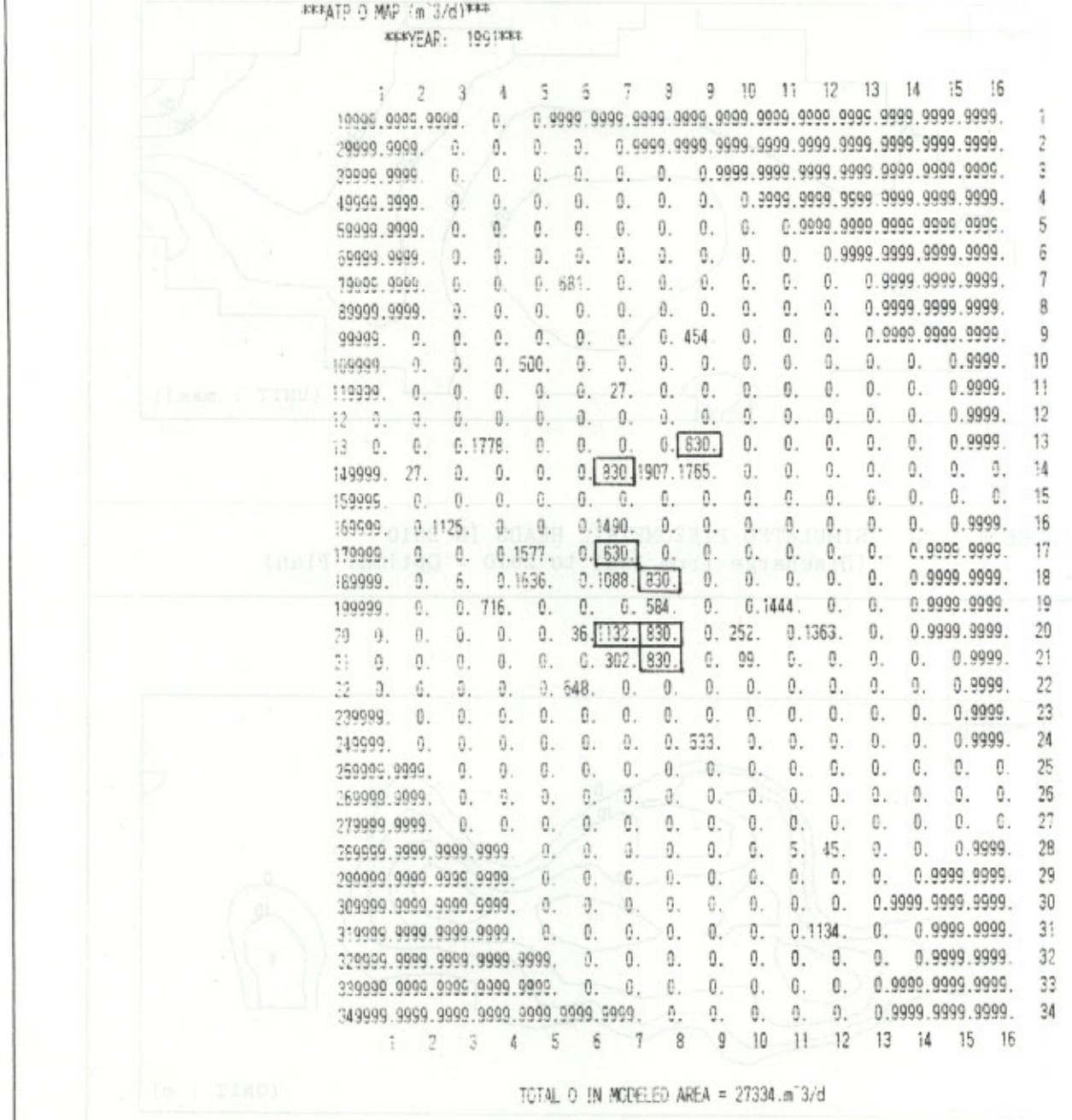


FIGURE 8.4.21 SIMULATED PIEZOMETRIC HEIGHTS FROM
THE BOTTOM OF THE AQUIFER IN 2010
(Discharge from 1991 to 2010 = Discharge of 1990)

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



ATP O MAP (m^3/d)

YEAR: 1991

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1	10000.	0000.	0000.	0.	0.	0000.	0000.	0000.	0000.	0000.	0000.	0000.	0000.	0000.	0000.		1
2	20000.	0000.	0.	0.	0.	0.	0.	0000.	0000.	0000.	0000.	0000.	0000.	0000.	0000.		2
3	30000.	0000.	0.	0.	0.	0.	0.	0.	0.	0000.	0000.	0000.	0000.	0000.	0000.		3
4	40000.	0000.	0.	0.	0.	0.	0.	0.	0.	0.	0000.	0000.	0000.	0000.	0000.		4
5	50000.	0000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0000.	0000.	0000.	0000.		5
6	60000.	0000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0000.	0000.	0000.		6
7	70000.	0000.	0.	0.	0.	681.	0.	0.	0.	0.	0.	0.	0.	0000.	0000.		7
8	80000.	0000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0000.	0000.		8
9	90000.	0.	0.	0.	0.	0.	0.	0.	454.	0.	0.	0.	0.	0000.	0000.		9
10	100000.	0.	0.	0.	500.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.		10
11	110000.	0.	0.	0.	0.	0.	27.	0.	0.	0.	0.	0.	0.	0.	0.		11
12	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.		12
13	0.	0.	0.	1776.	0.	0.	0.	0.	[630.]	0.	0.	0.	0.	0.	0.		13
14	149999.	27.	0.	0.	0.	0.	[830.]	1907.	1765.	0.	0.	0.	0.	0.	0.	0.	14
15	159999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	15
16	169999.	1125.	0.	0.	0.	1490.	0.	0.	0.	0.	0.	0.	0.	0.	0.		16
17	179999.	0.	0.	1577.	0.	[630.]	0.	0.	0.	0.	0.	0.	0.	0000.	0000.		17
18	189999.	0.	6.	1636.	0.	1088.	[830.]	0.	0.	0.	0.	0.	0.	0000.	0000.		18
19	199999.	0.	0.	716.	0.	0.	0.	584.	0.	0.	1444.	0.	0.	0000.	0000.		19
20	0.	0.	0.	0.	0.	36.	[132.]	[830.]	0.	252.	0.	1363.	0.	0000.	0000.		20
21	0.	0.	0.	0.	0.	0.	302.	[830.]	0.	99.	0.	0.	0.	0.	0000.		21
22	0.	0.	0.	0.	0.	648.	0.	0.	0.	0.	0.	0.	0.	0.	0000.		22
23	239999.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0000.		23
24	249999.	0.	0.	0.	0.	0.	0.	0.	533.	0.	0.	0.	0.	0.	0000.		24
25	259999.	0000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	25
26	269999.	0000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	26
27	279999.	0000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	27
28	289999.	0000.	0000.	0000.	0.	0.	0.	0.	0.	0.	5.	45.	0.	0.	0000.		28
29	299999.	0000.	0000.	0000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0000.	0000.		29
30	309999.	0000.	0000.	0000.	0.	0.	0.	0.	0.	0.	0.	0.	0000.	0000.	0000.		30
31	319999.	0000.	0000.	0000.	0.	0.	0.	0.	0.	0.	0.	1134.	0.	0.	0000.	0000.	31
32	329999.	0000.	0000.	0000.	0000.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0000.	0000.	32
33	339999.	0000.	0000.	0000.	0000.	0.	0.	0.	0.	0.	0.	0.	0.	0000.	0000.	0000.	33
34	349999.	0000.	0000.	0000.	0000.	0000.	0000.	0.	0.	0.	0.	0.	0.	0000.	0000.	0000.	34
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	

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

[ ] : Location of New MWSS Wells

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.4.22 OPTIMAL DISCHARGE PLAN IN THE ANTIPOLO BASIN
JAPAN INTERNATIONAL COOPERATION AGENCY	

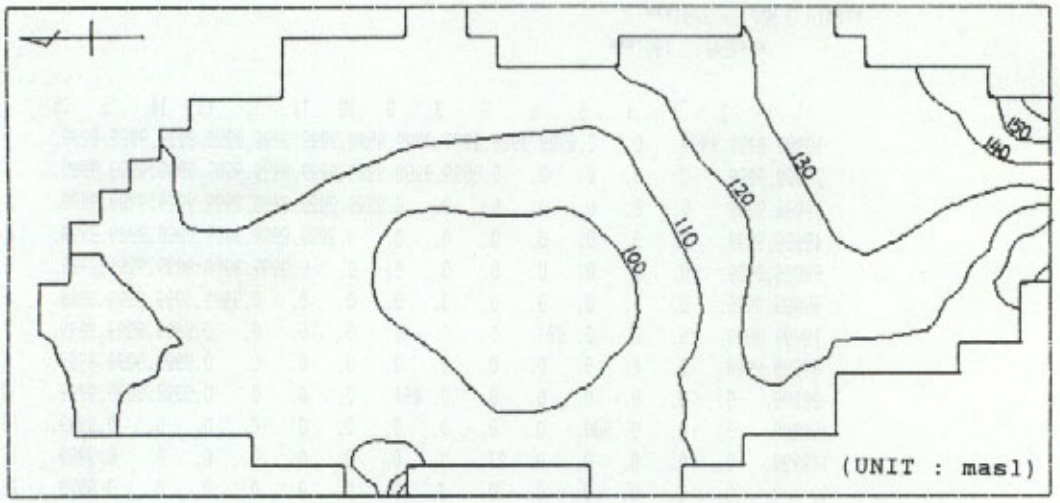


FIGURE 8.4.23 SIMULATED PIEZOMETRIC HEADS IN 2010
(Discharge from 1991 to 2010 = Optimal Plan)

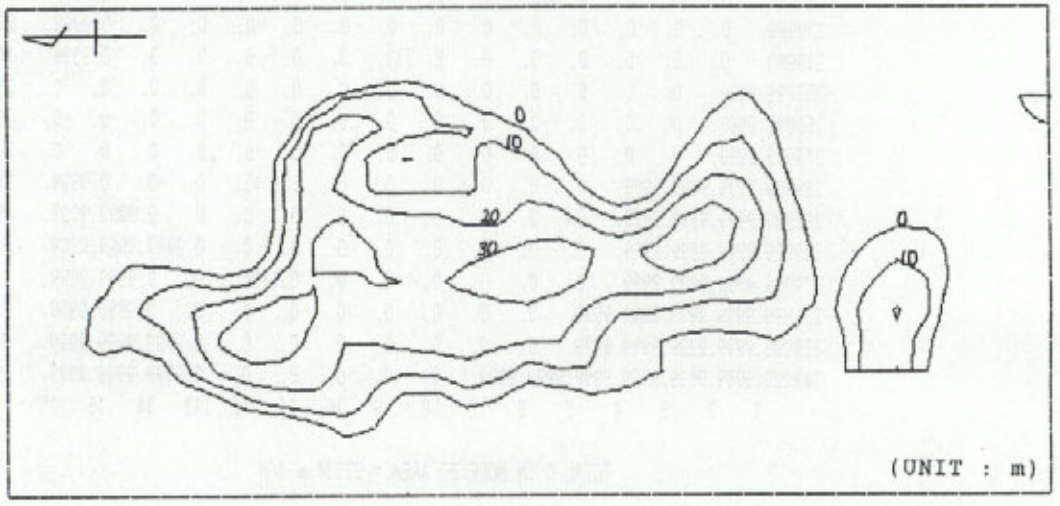
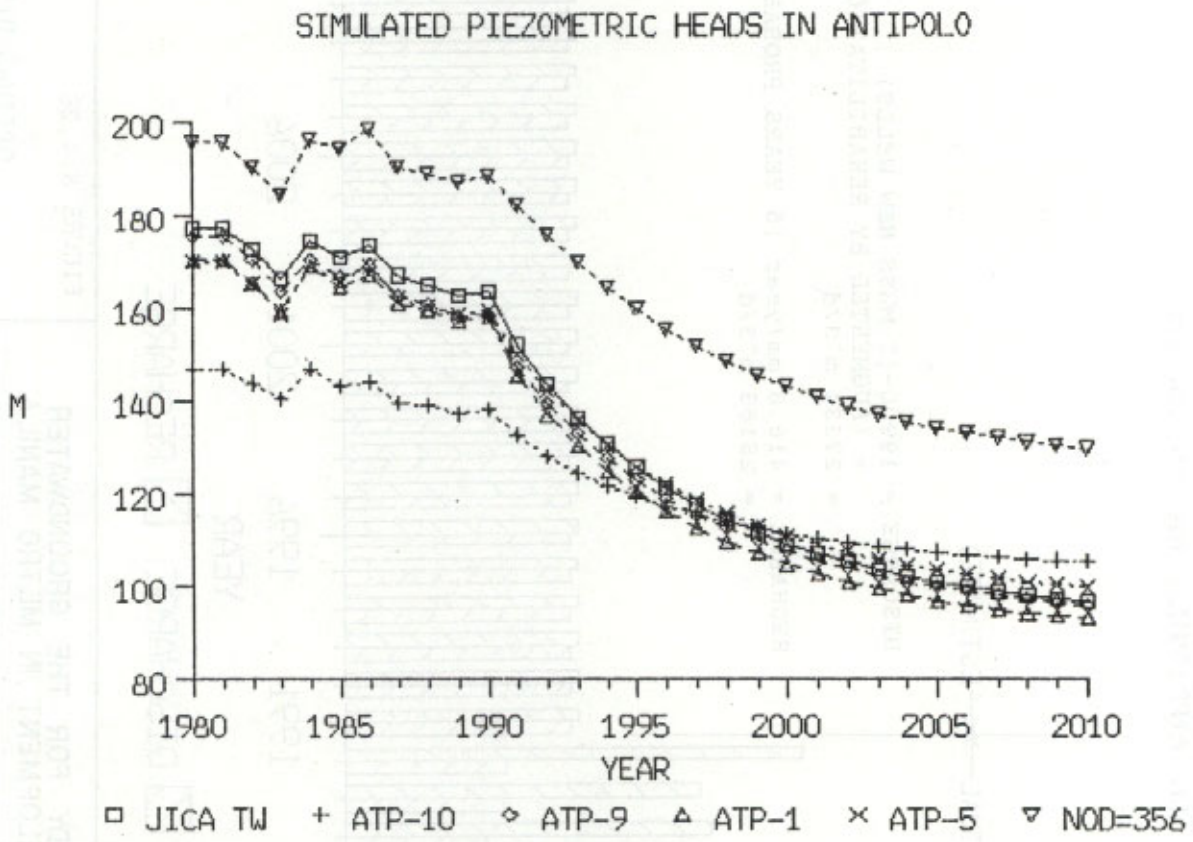
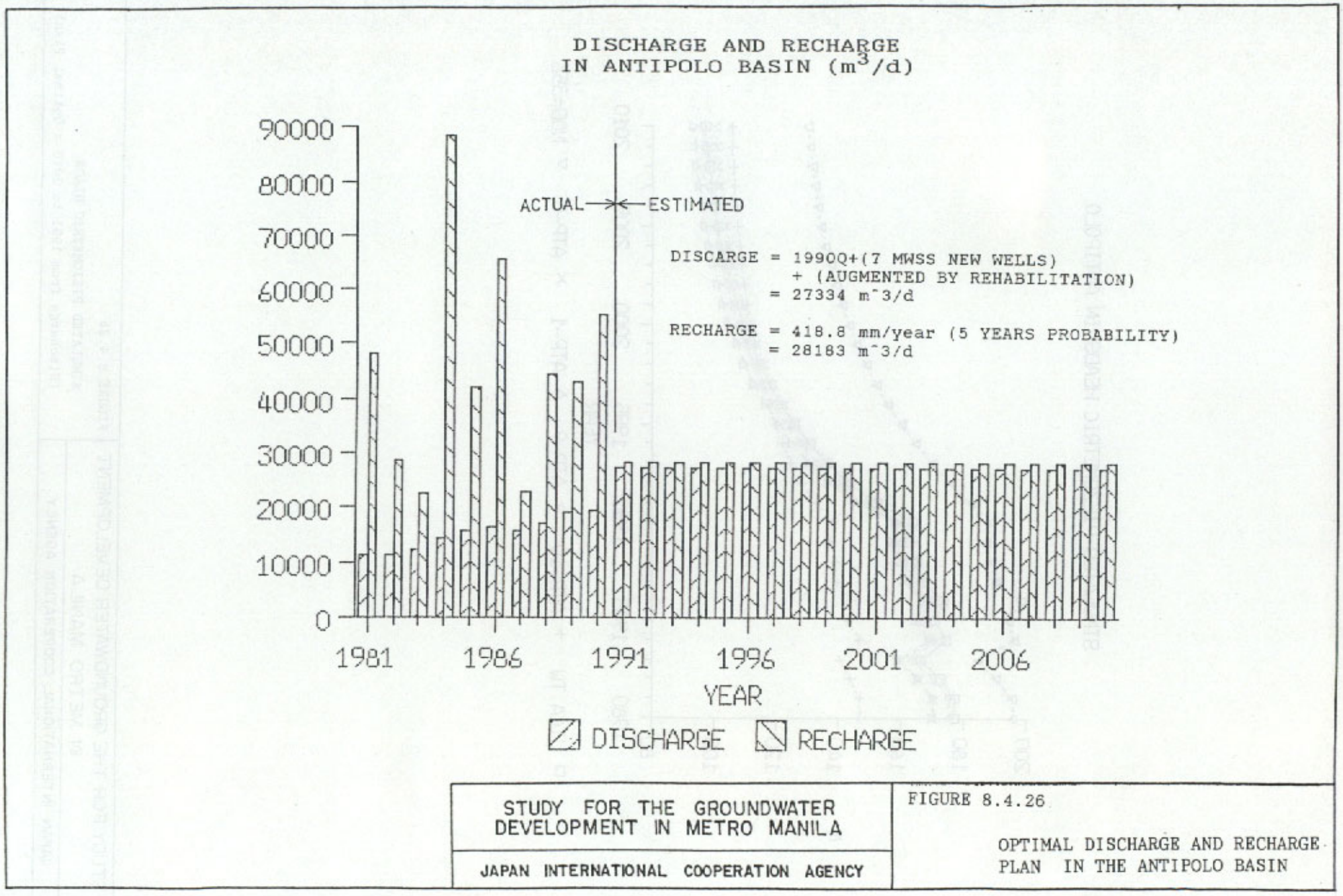


FIGURE 8.4.24 SIMULATED PIEZOMETRIC HEIGHTS FROM
THE BOTTOM OF THE AQUIFER IN 2010
(Discharge from 1991 to 2010 = Optimal Plan)

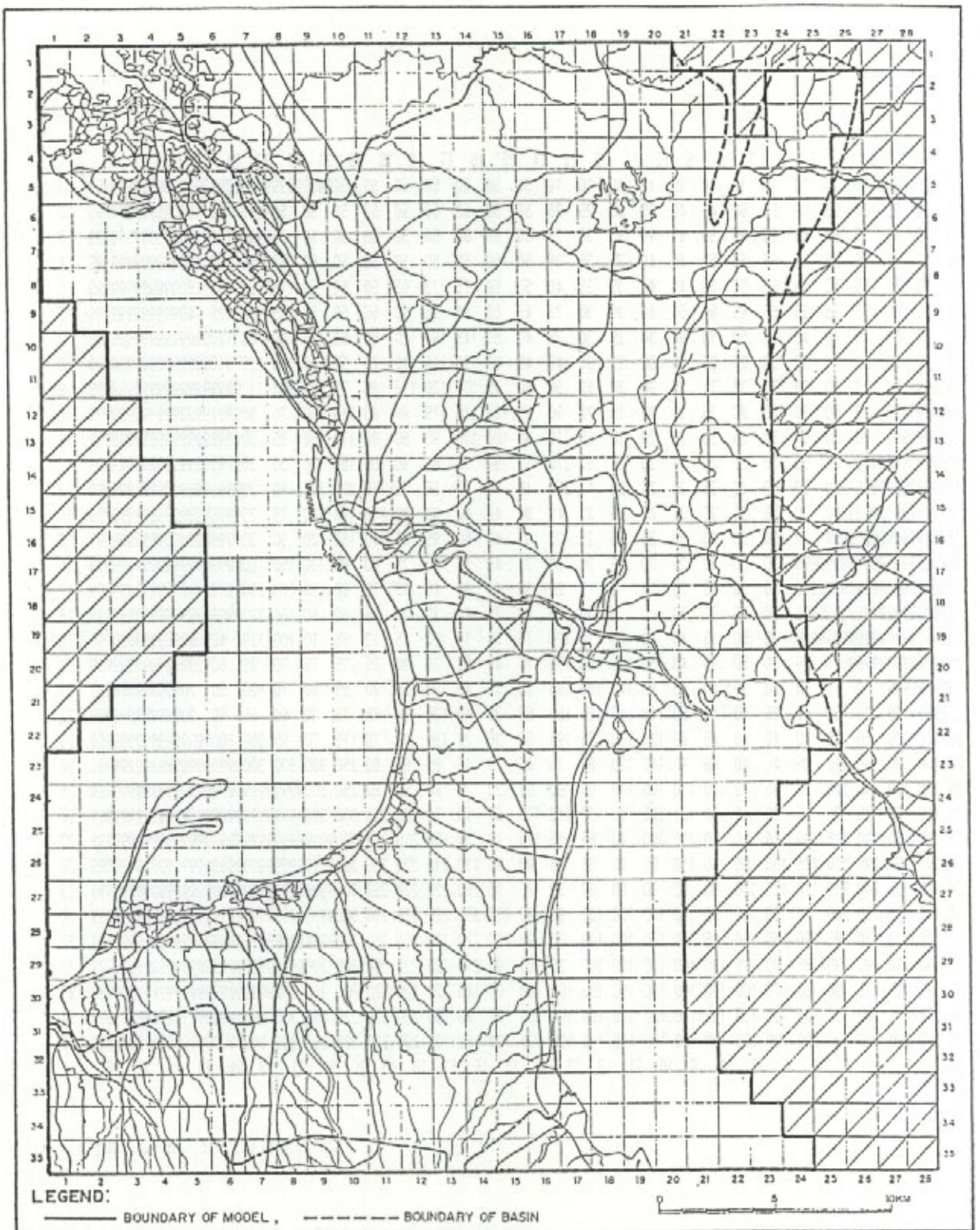
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	JAPAN INTERNATIONAL COOPERATION AGENCY



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.4.25 SIMULATED PIEZOMETRIC HEADS (Discharge from 1991 to 2010 = Optimal Plan)
JAPAN INTERNATIONAL COOPERATION AGENCY	



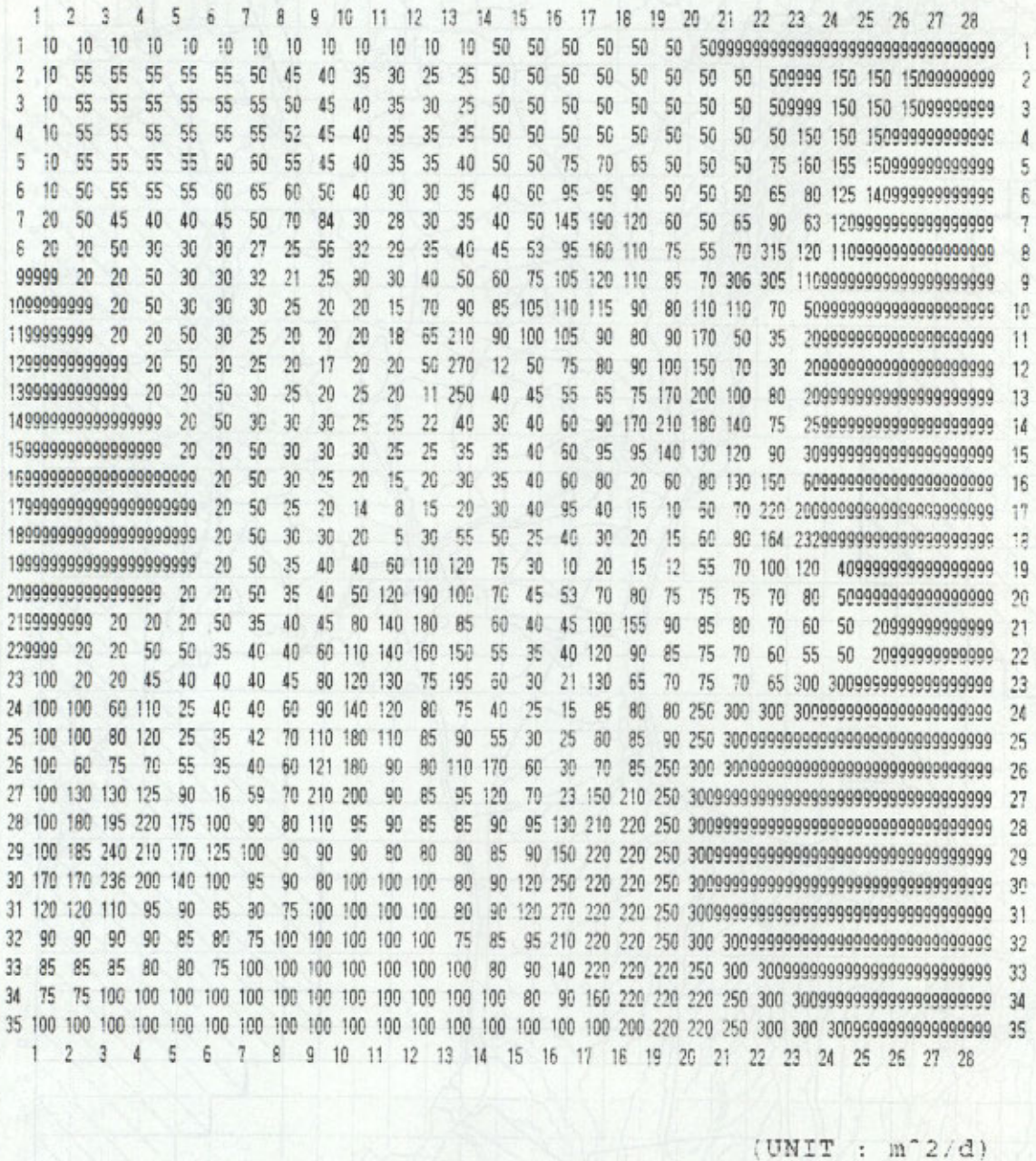
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.4.26
JAPAN INTERNATIONAL COOPERATION AGENCY	OPTIMAL DISCHARGE AND RECHARGE PLAN IN THE ANTIPOLO BASIN



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	50	999999999999999999999999999999999999								1
2	10	55	55	55	55	55	50	45	40	35	30	25	25	50	50	50	50	50	50	50	50	50	999999	150	150	150999999999			2
3	10	55	55	55	55	55	55	50	45	40	35	30	25	50	50	50	50	50	50	50	50	50	999999	150	150	150999999999			3
4	10	55	55	55	55	55	55	52	45	40	35	35	35	50	50	50	50	50	50	50	50	50	50	150	150	150999999999999			4
5	10	55	55	55	55	50	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
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11	999999999	20	20	50	30	25	20	20	20	18	65	210	90	100	105	90	80	90	170	50	35	2099999999999999999999							11	
12	9999999999999	20	50	30	25	20	17	20	20	50	270	12	50	75	80	90	100	150	70	30	2099999999999999999999								12	
13	999999999999	20	20	50	30	25	20	25	20	11	250	40	45	55	65	75	170	200	100	80	2099999999999999999999								13	
14	9999999999999999	20	50	30	30	30	25	25	22	40	30	40	60	90	170	210	180	140	75	2599999999999999999999									14	
15	9999999999999999	20	20	50	30	30	30	25	25	35	35	40	60	95	95	140	130	120	90	3099999999999999999999									15	
16	99999999999999999999	20	50	30	25	20	15	20	30	35	40	60	80	20	60	80	130	150	6099999999999999999999										16	
17	99999999999999999999	20	50	25	20	14	8	15	20	30	40	95	40	15	10	50	70	220	2009999999999999999999										17	
18	99999999999999999999	20	50	30	30	20	5	30	55	50	25	40	30	20	15	60	80	164	2329999999999999999999										18	
19	99999999999999999999	20	50	35	40	40	60	110	120	75	30	10	20	15	12	55	70	100	120	4099999999999999999									19	
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21	99999999	20	20	20	50	35	40	45	80	140	180	85	60	40	45	100	155	90	85	80	70	60	50	209999999999999					21	
22	999999	20	20	50	50	35	40	40	60	110	140	160	150	55	35	40	120	90	85	75	70	60	55	50	209999999999999				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	3099999999999999999999						24	
25	100	100	80	120	25	35	42	70	110	180	110	85	90	55	30	25	80	85	90	250	3099999999999999999999999999999999								25	
26	100	60	75	70	55	35	40	60	121	180	90	80	110	170	60	30	70	85	250	300	3099999999999999999999999999999999								26	
27	100	130	130	125	90	16	59	70	210	200	90	85	95	120	70	23	150	210	250	3099999999999999999999999999999999									27	
28	100	180	195	220	175	100	90	80	110	95	90	85	85	90	95	130	210	220	250	3099999999999999999999999999999999									28	
29	100	185	240	210	170	125	100	90	90	90	80	80	80	85	90	150	220	220	250	3099999999999999999999999999999999									29	
30	170	170	236	200	140	100	95	90	80	100	100	100	80	90	120	250	220	220	250	3099999999999999999999999999999999									30	
31	120	120	110	95	90	85	80	75	100	100	100	100	80	90	120	270	220	220	250	3099999999999999999999999999999999									31	
32	90	90	90	90	85	80	75	100	100	100	100	100	75	85	95	210	220	220	250	300	3099999999999999999999999999999999								32	
33	85	85	85	80	80	75	100	100	100	100	100	100	100	80	90	140	220	220	220	250	300	3099999999999999999999999999999999							33	
34	75	75	100	100	100	100	100	100	100	100	100	100	100	100	80	90	160	220	220	220	250	300	3099999999999999999999999999						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	3099999999999999999					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	

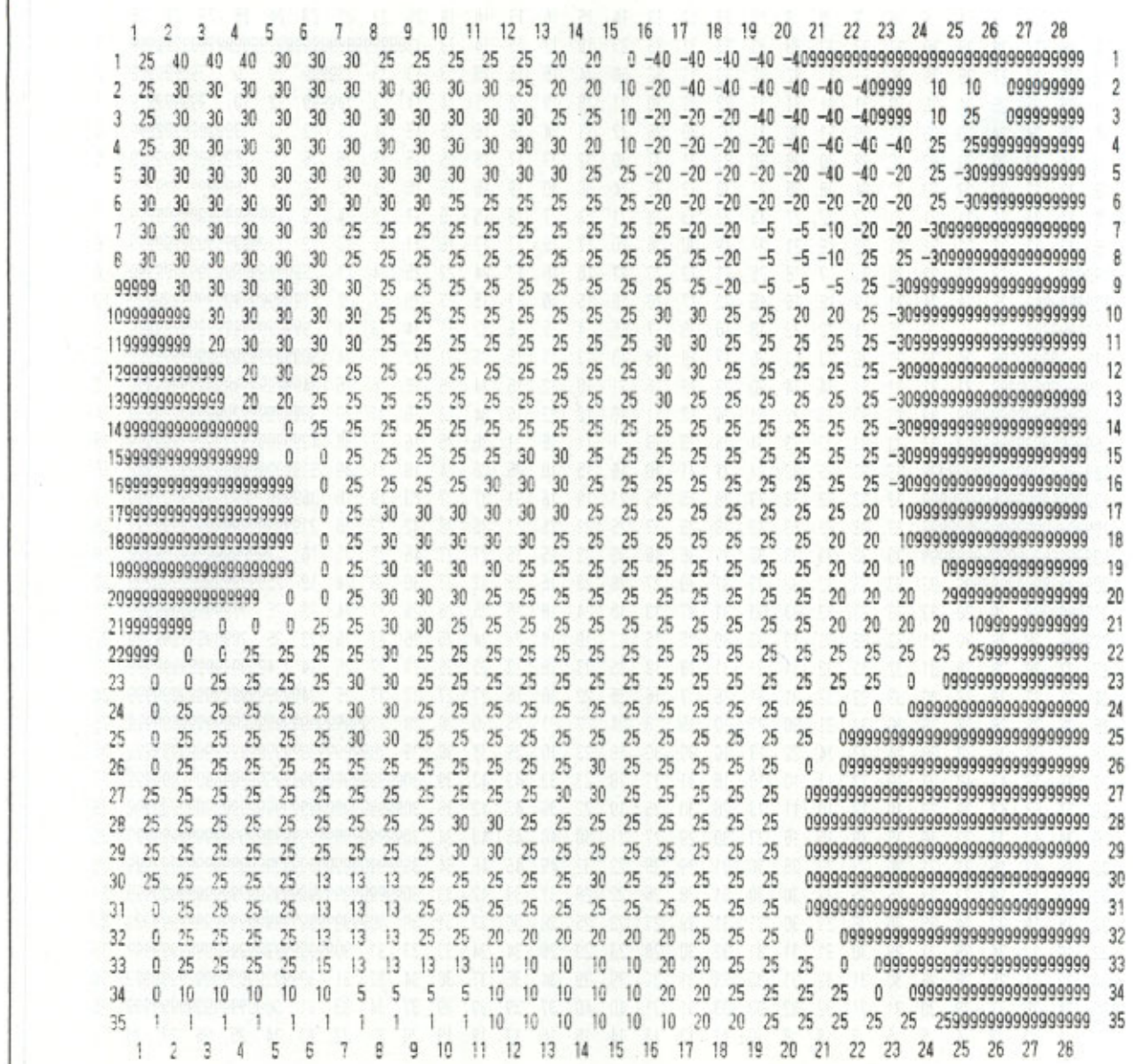
(UNIT : m^2/d)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

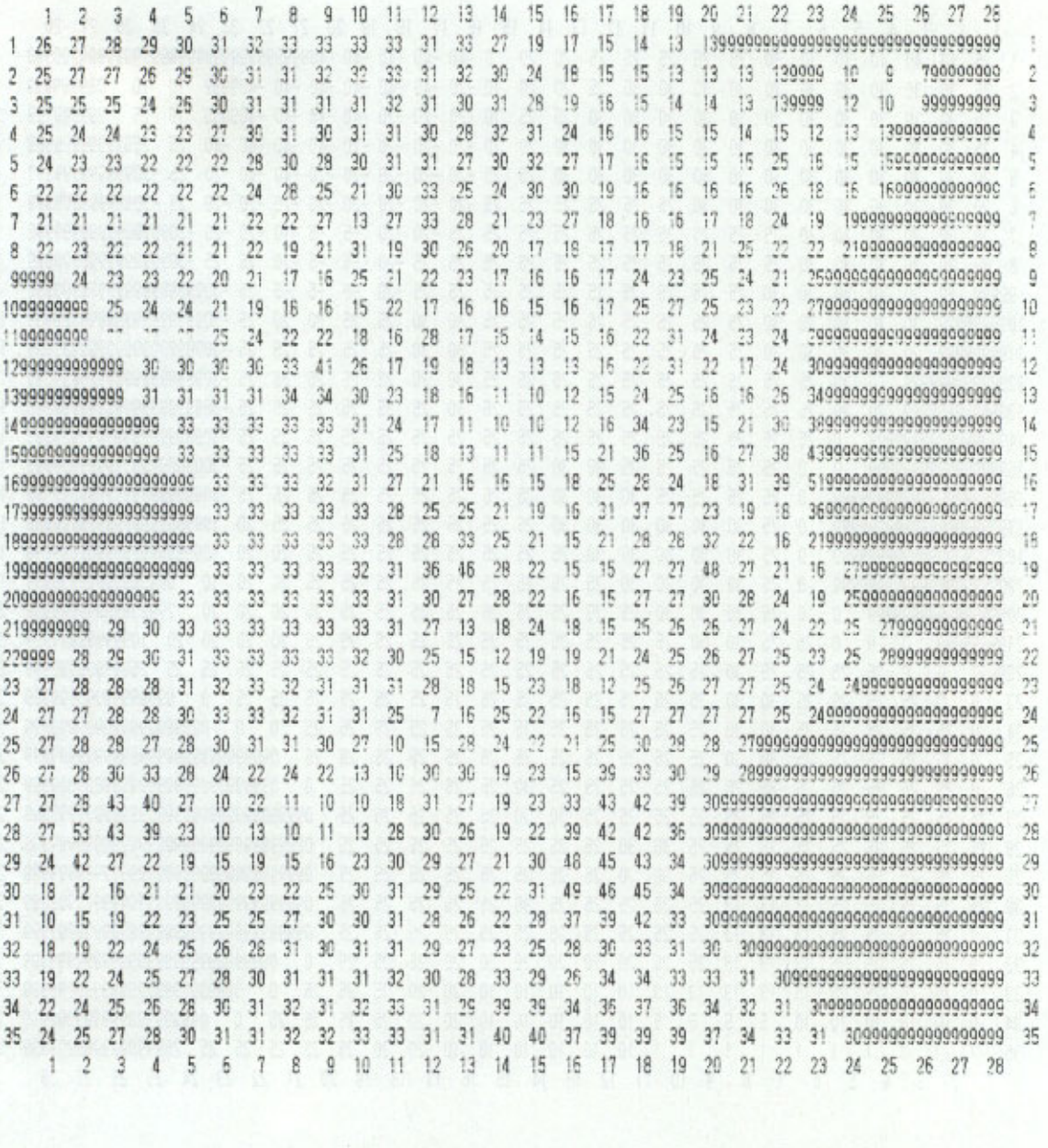
FIGURE 8.5.2

DISTRIBUTION OF TRANSMISSIVITY



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

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

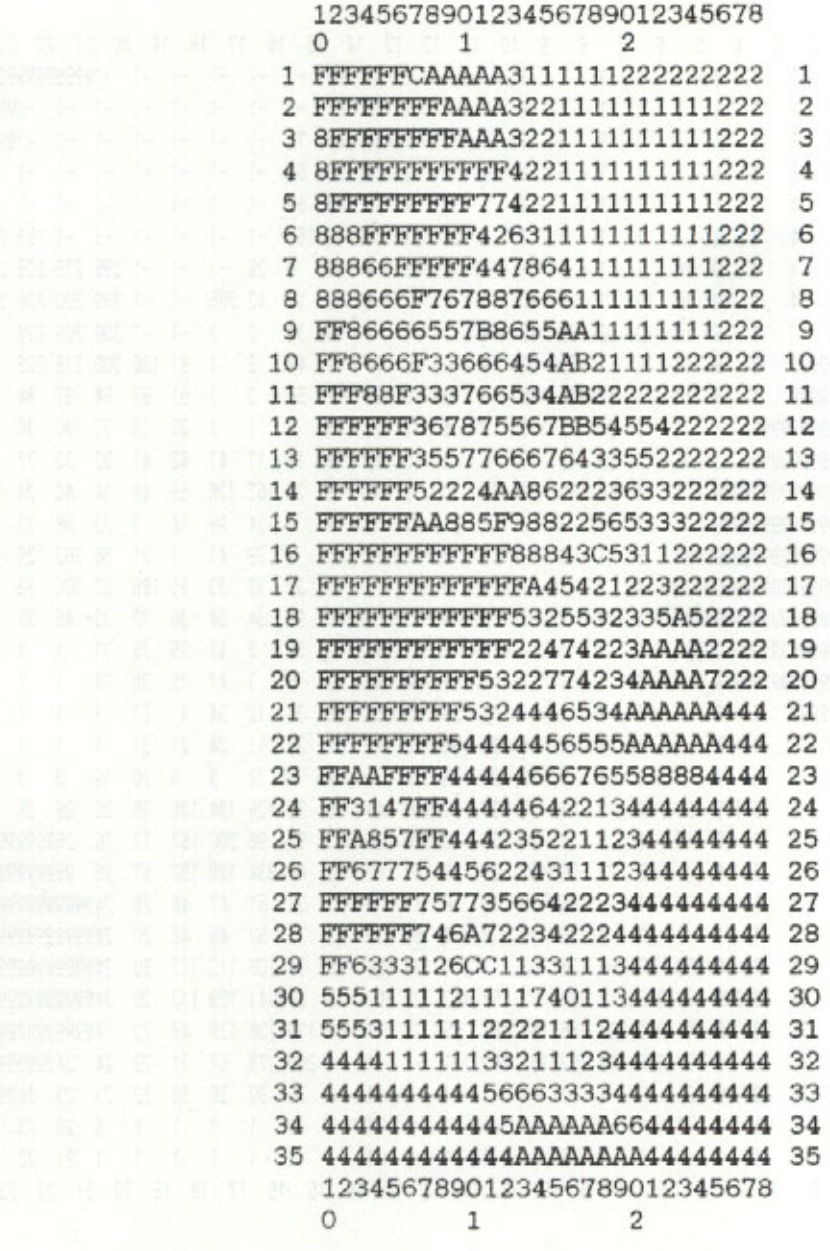


(UNIT : m)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

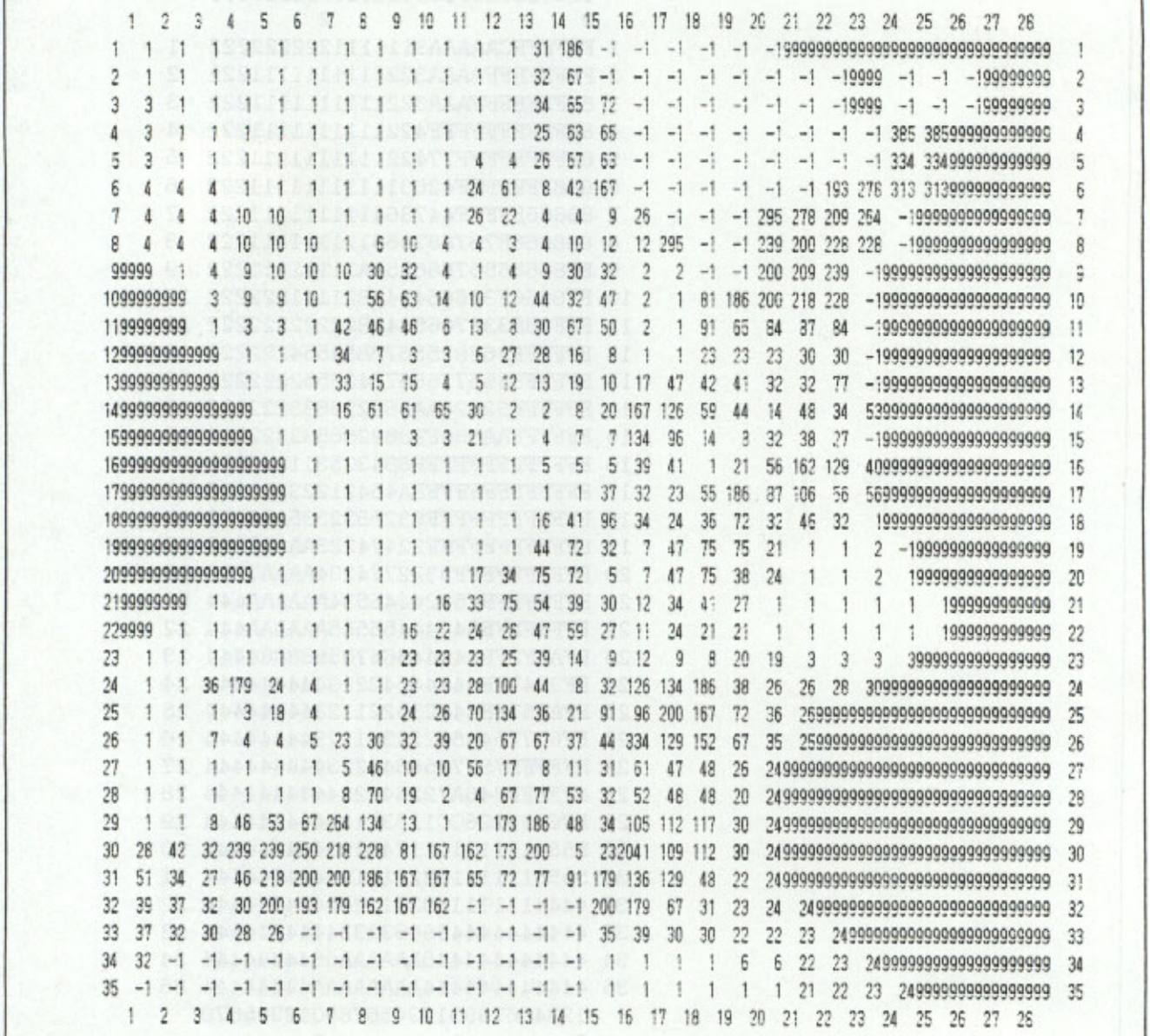
FIGURE 8.5.4
AQUITARD THICKNESS (b')



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	FIGURE 8.5.5 LABELS OF IDENTIFIED AQUITARD PERMEABILITY (k')
JAPAN INTERNATIONAL COOPERATION AGENCY	



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	-1999999999999999999999999999999999999								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	276	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	-199999999999999999				8
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1099999999		3	9	9	10	1	56	63	14	10	12	44	32	47	2	1	81	186	200	218	228	-199999999999999999999						10
1199999999		1	3	3	1	42	46	46	6	13	8	30	67	50	2	1	91	65	84	87	84	-199999999999999999999						11
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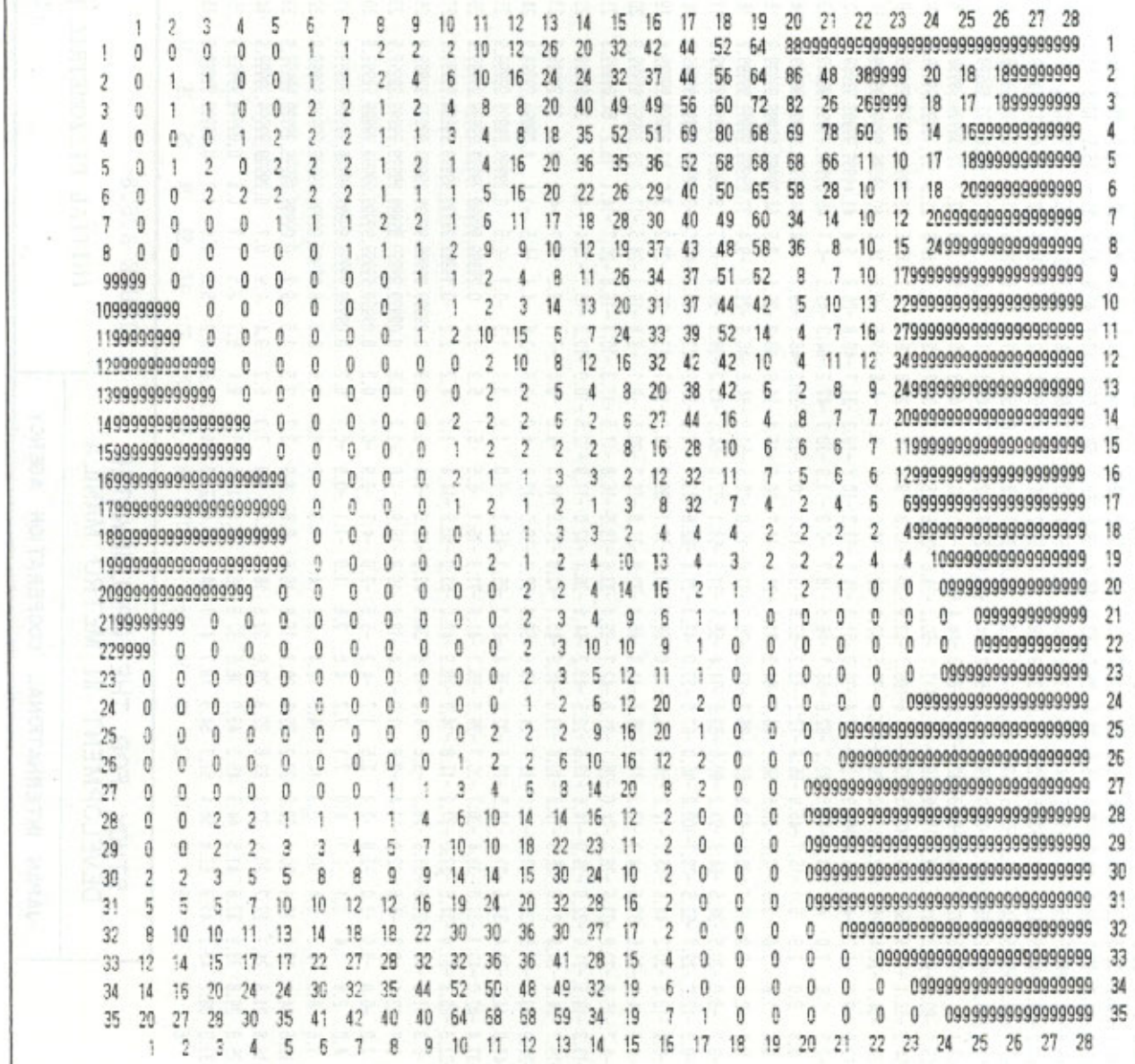
2199999999		1	1	1	1	1	1	1	16	33	75	54	39	30	12	34	41	27	1	1	1	1	1	19999999999999					21
229999		1	1	1	1	1	1	1	15	22	24	26	47	59	27	11	24	21	21	1	1	1	1	1	19999999999999				22
23	1	1	1	1	1	1	1	1	23	23	23	25	39	14	9	12	9	8	20	19	3	3	3	399999999999999999					23
24	1	1	36	179	24	4	1	1	23	23	28	100	44	8	32	126	134	186	38	26	26	28	309999999999999999999						24
25	1	1	1	3	18	4	1	1	24	26	70	134	36	21	91	96	200	167	72	36	269999999999999999999999999999								25
26	1	1	7	4	4	5	23	30	32	39	20	67	67	37	44	334	129	152	67	35	259999999999999999999999999999								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	49	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	249999999999999999999999999999999								32
33	37	32	30	28	26	-1	-1	-1	-1	-1	-1	-1	-1	-1	35	39	30	30	22	22	23	249999999999999999999999999							33
34	32	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	6	6	22	23	249999999999999999999						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	249999999999999999					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

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.6 COMPUTED LEAKANCE
JAPAN INTERNATIONAL COOPERATION AGENCY	



(UNIT : m)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.7 PHREATIC WATER LEVEL
JAPAN INTERNATIONAL COOPERATION AGENCY	

	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	53.9	65.7	60.1	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	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	56.5	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	60.5	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	12.4	9999.9	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	15.9	9999.9	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	22.5	9999.9	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	22.3	9999.9	9999.9	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	35.1	9999.9	9999.9	9
10	9999.9	-0.1	-10.1	-23.7	-38.9	-54.3	-68.1	-72.4	-58.1	-93.5	-125.5	-123.8	-116.5	-105.7	-63.9	-30.8	-15.3	9.5	28.2	20.8	5.2	5.2	18.5	32.8	9999.9	9999.9	9999.9	10
11	9999.9	9999.9	-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	40.1	9999.9	9999.9	9999.9	11
12	9999.9	9999.9	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	41.4	9999.9	9999.9	9999.9	12
13	9999.9	9999.9	9999.9	-0.4	-3.2	-2.5	1.6	7.0	4.1	-43.9	-87.5	-92.2	-82.6	-56.7	-46.6	-18.7	-0.9	-11.9	-30.7	-47.2	-64.3	-49.5	-4.7	45.0	9999.9	9999.9	9999.9	13
14	9999.9	9999.9	9999.9	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	54.0	9999.9	9999.9	9999.9	14
15	9999.9	9999.9	9999.9	9999.9	9999.9	0.1	0.8	1.8	3.0	5.5	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	54.7	9999.9	9999.9	15
16	9999.9	9999.9	9999.9	9999.9	9999.9	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	-74.3	-45.9	-29.9	-9.4	37.0	9999.9	9999.9	16
17	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	-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	8.0	9999.9	9999.9	17
18	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	-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	-6.0	9999.9	9999.9	18
19	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	-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	52.3	9999.9	19
20	9999.9	9999.9	9999.9	9999.9	9999.9	0.2	-4.8	-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	28.3	9999.9	20
21	9999.9	9999.9	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	54.0	9999.9	21
22	9999.9	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	39.0	9999.9	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	29.2	9999.9	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	-43.5	-56.0	-57.7	-39.0	-13.0	-4.2	-1.8	-2.5	-4.4	-4.5	-1.4	8.0	9999.9	9999.9	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	0.3	9999.9	9999.9	9999.9	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	0.2	9999.9	9999.9	9999.9	9999.9	9999.9	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	0.1	9999.9	9999.9	9999.9	9999.9	9999.9	27
28	-19.2	-18.3	-16.8	-13.3	-8.5	-5.3	-11.9	-16.4	-21.6	-27.5	-28.3	-8.6	-4.2	-19.5	-34.9	-43.0	-25.0	-9.4	-0.3	1.9	0.3	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	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	0.0	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	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	0.0	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	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	0.0	9999.9	9999.9	9999.9	9999.9	9999.9	9999.9	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	-8.0	9999.9	9999.9	9999.9	9999.9	9999.9	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	0.0	9999.9	9999.9	9999.9	9999.9	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	0.0	9999.9	9999.9	9999.9	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	0.0	9999.9	9999.9	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	0.0	9999.9	9999.9	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	

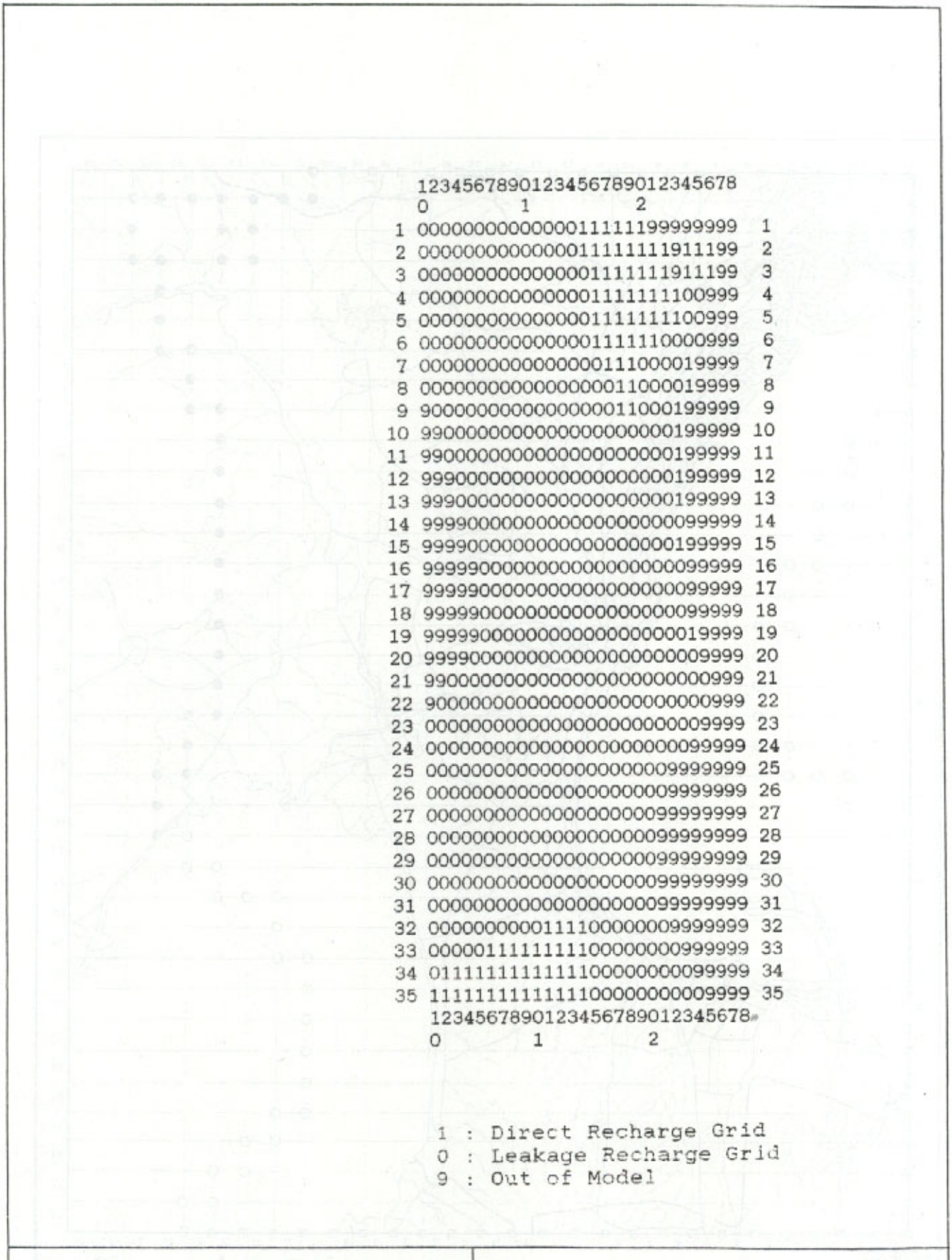
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

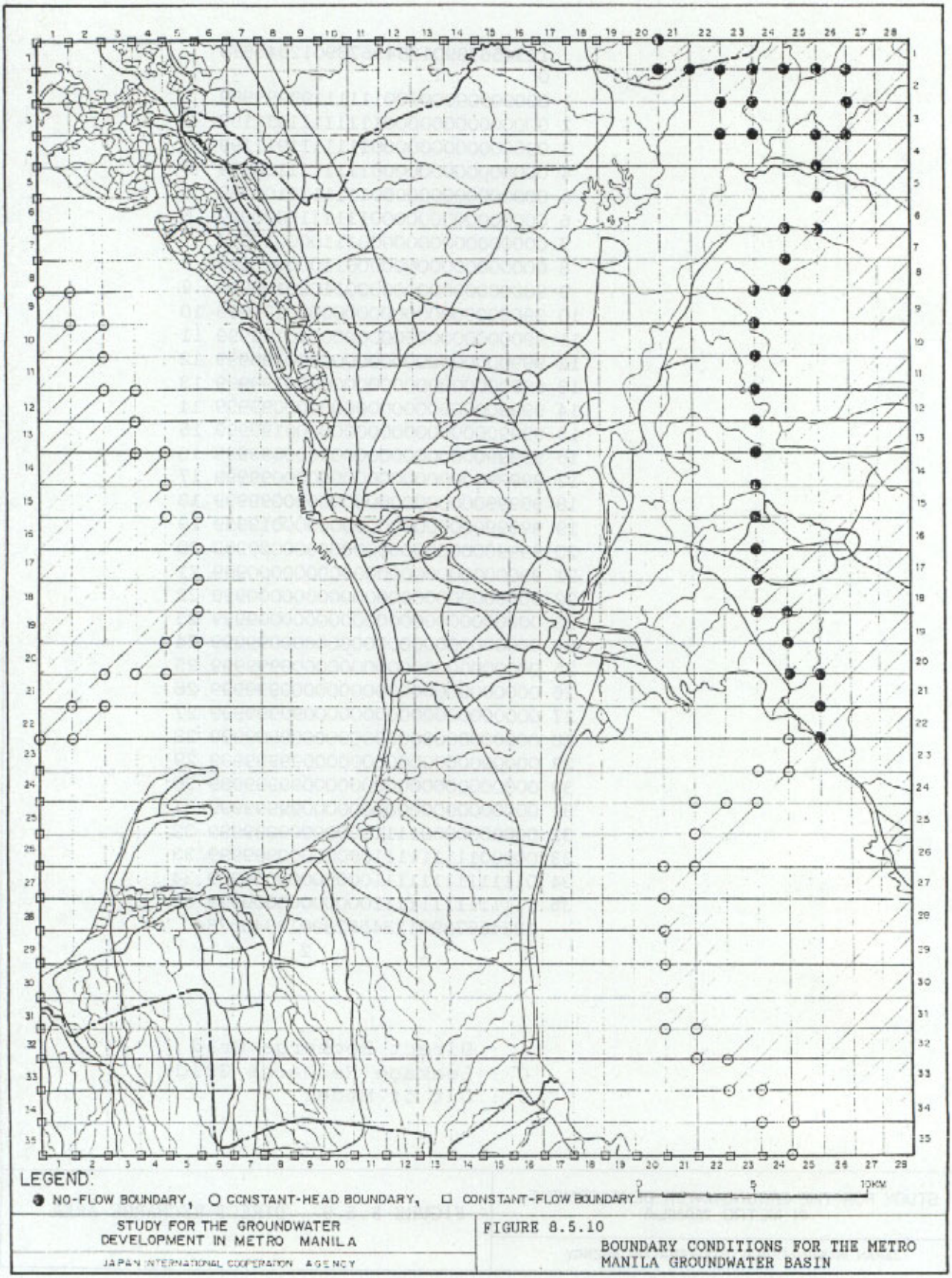
FIGURE 8.5.8

INITIAL PIEZOMETRIC HEADS IN 1981

(UNIT : masl)



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.9 DIRECT RECHARGE AREA
JAPAN INTERNATIONAL COOPERATION AGENCY	

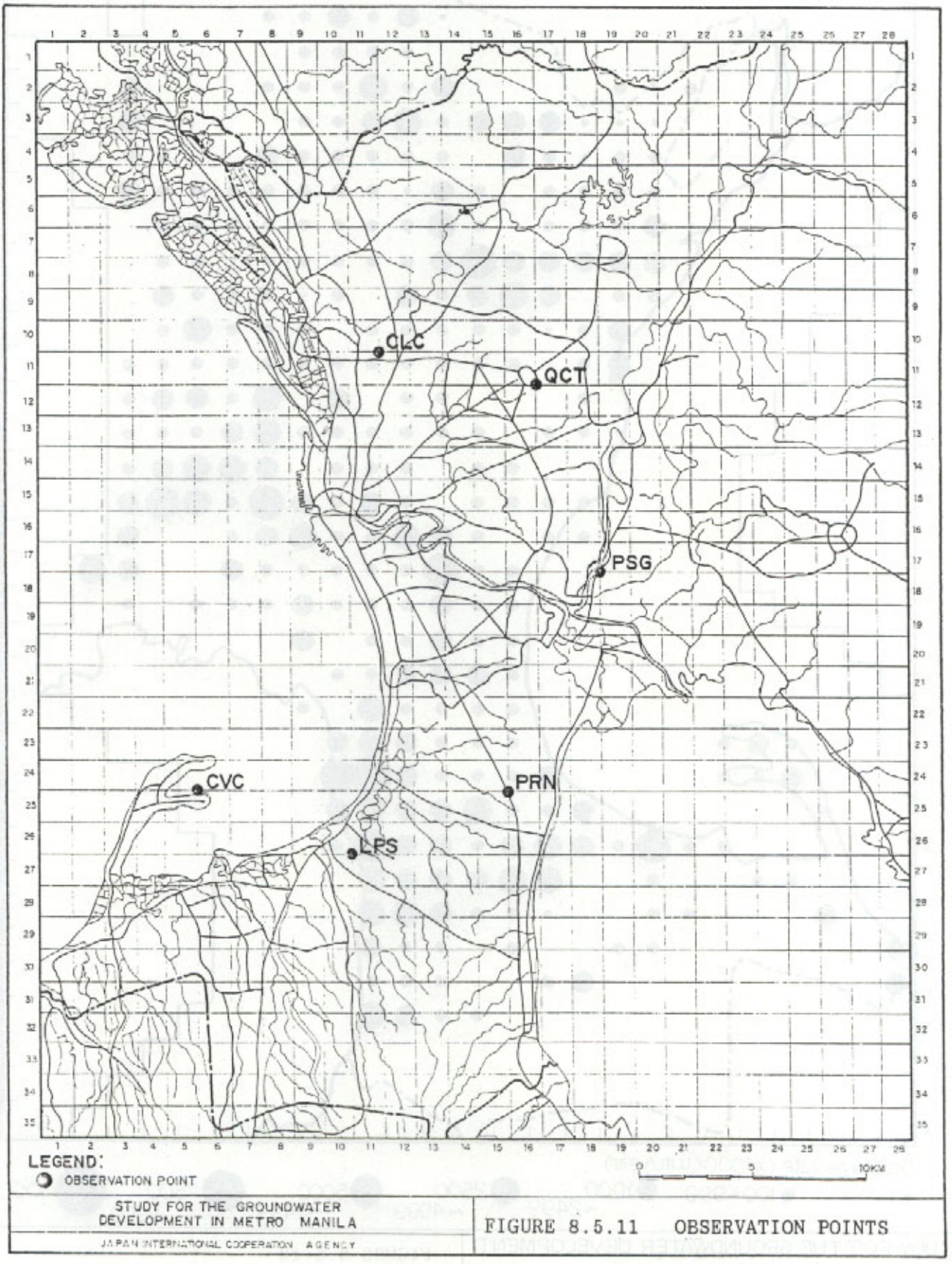


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.10

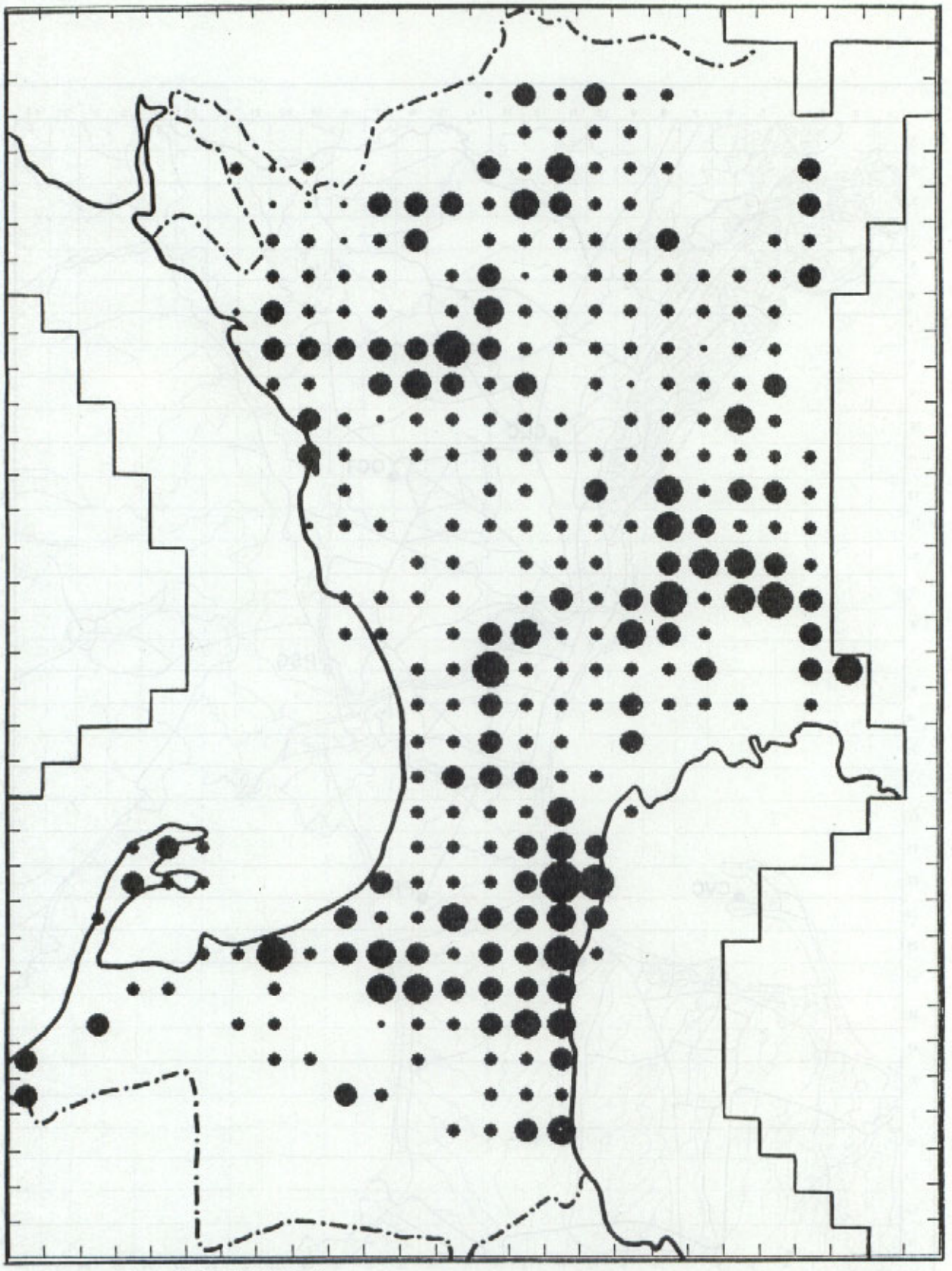
BOUNDARY CONDITIONS FOR THE METRO MANILA GROUNDWATER BASIN



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.11 OBSERVATION POINTS

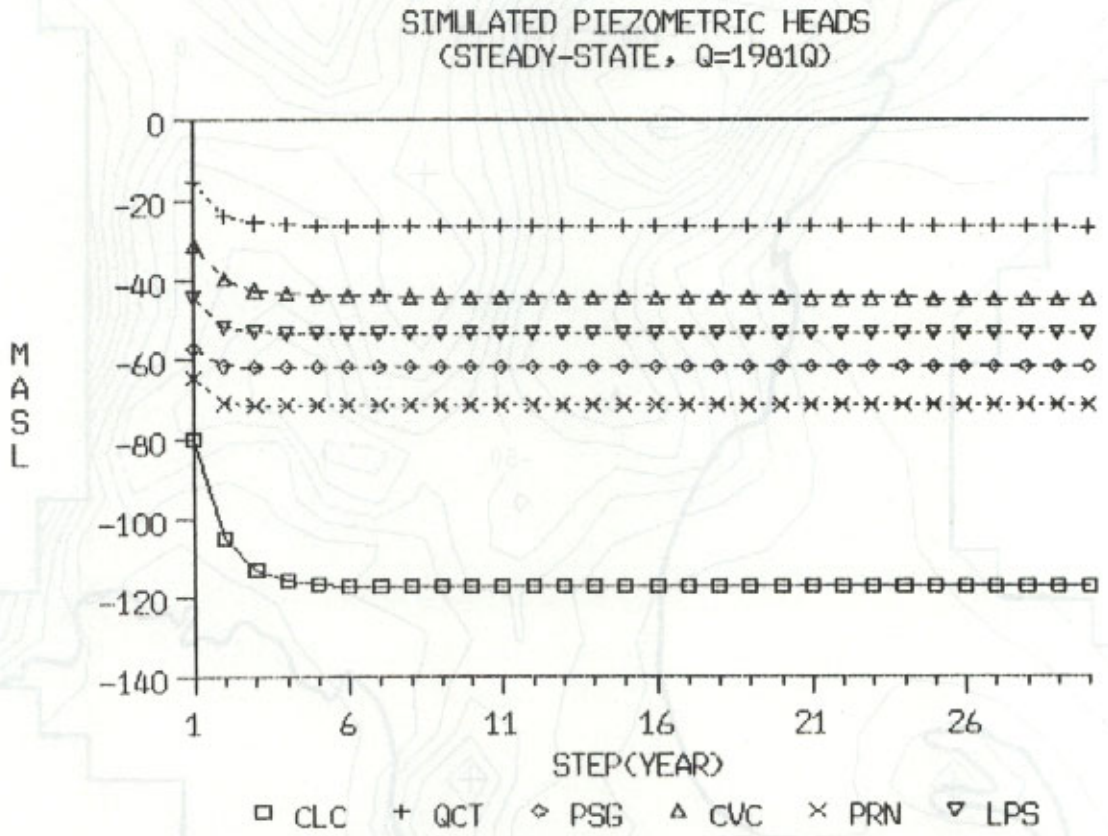


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

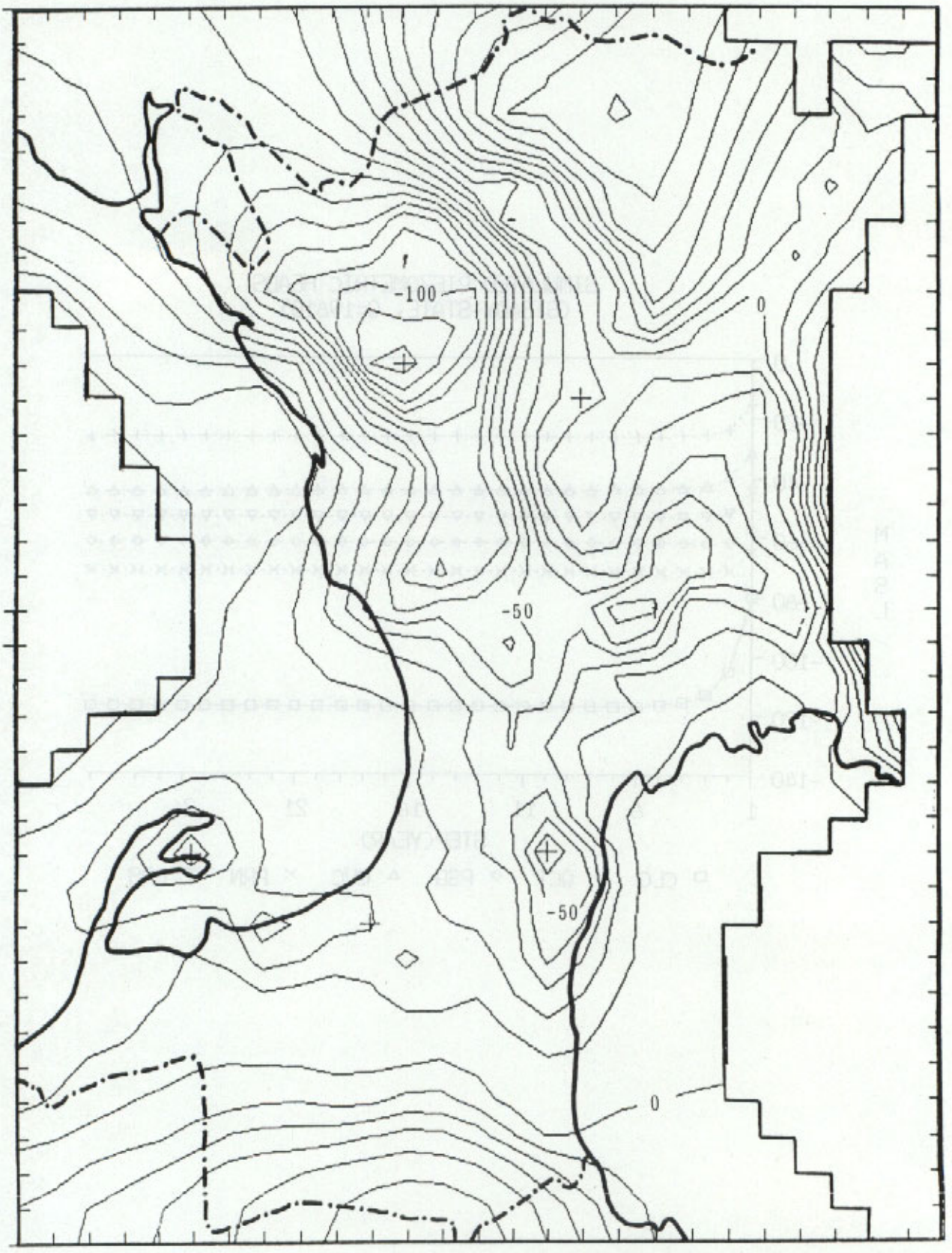
JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.12

DISCHARGE DISTRIBUTION IN 1981



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.13 SIMULATED PIEZOMETRIC HEADS BY 30-STEP STEADY-STATE CALCULATION
JAPAN INTERNATIONAL COOPERATION AGENCY	



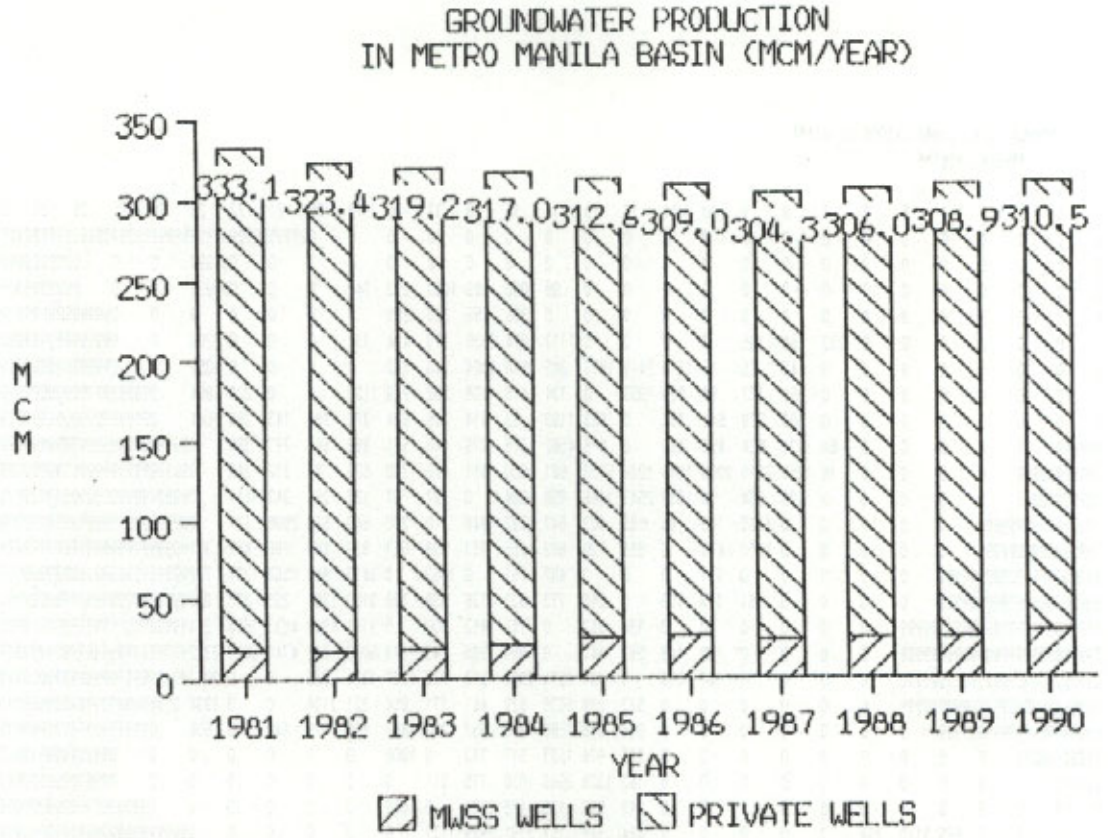
(Contour Interval: 10m, Unit: masl)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.14

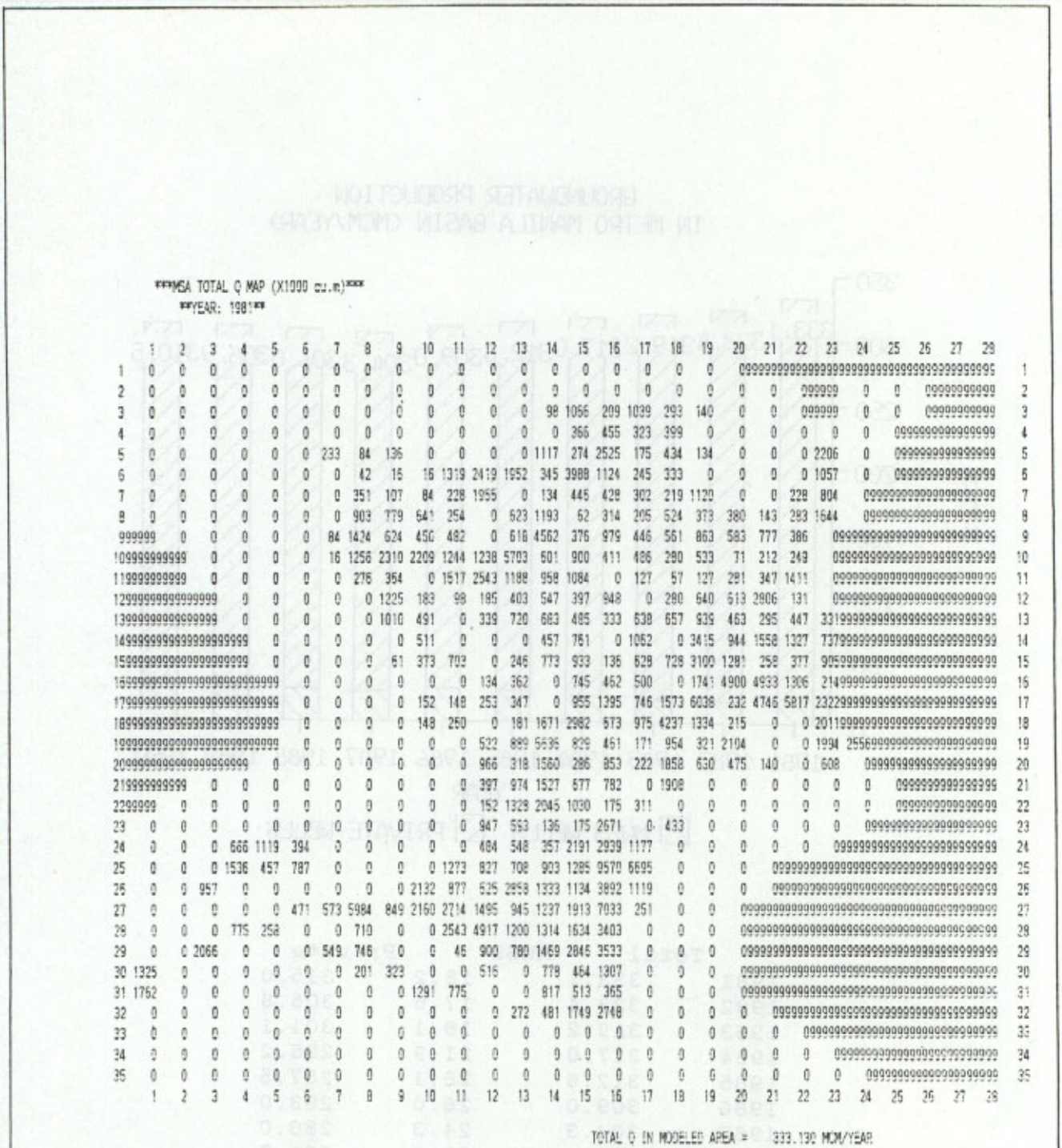
SIMULATED PIEZOMETRIC HEADS IN 1981



	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)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.15 GROUNDWATER PRODUCTION IN THE METRO MANILA BASIN
JAPAN INTERNATIONAL COOPERATION AGENCY	



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.16(1) DISCHARGE MAP IN 1981
JAPAN INTERNATIONAL COOPERATION AGENCY	

MSA TOTAL Q MAP (X1000 cu.m)

YEAR: 1982

	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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9999999999999999999999999999999999999999									1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	099999		0	0	09999999999			2
3	0	0	0	0	0	0	0	0	0	0	0	0	0	98	1066	339	1039	293	182	0	0	099999		0	0	09999999999			3
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	366	455	323	399	0	0	0	0	0	0	0999999999999999				4
5	0	0	0	0	0	0	233	84	136	0	0	0	0	1117	274	2525	172	434	129	0	0	0	2207	0	0999999999999999				5
6	0	0	0	0	0	0	0	42	16	16	1319	2435	1994	345	4059	950	222	312	0	0	0	0	1215	0	0999999999999999				6
7	0	0	0	0	0	0	0	351	107	84	216	1582	0	134	446	394	259	185	734	0	0	198	773	0999999999999999999999					7
8	0	0	0	0	0	0	0	757	759	679	254	0	614	1291	26	314	176	430	226	219	96	197	1462	0999999999999999999999					8
999999	0	0	0	0	0	44	949	488	445	568	0	597	3952	376	979	445	561	633	301	424	342	17999999999999999999999999							9
109999999999		0	0	0	0	11	1059	2524	2201	1250	1254	4638	400	660	411	486	280	445	49	157	205	099999999999999999999999999							10	
119999999999		0	0	0	0	0	276	354	0	1488	2201	822	639	1084	0	127	57	121	264	285	958	099999999999999999999999999							11	
129999999999999999			0	0	0	0	0	1313	183	98	130	271	482	397	948	0	280	640	593	2425	83	099999999999999999999999999							12	
139999999999999999			0	0	0	0	0	1098	491	0	268	564	587	556	333	538	695	988	453	295	391	27399999999999999999999999999							13	
149999999999999999999				0	0	0	0	0	502	0	0	0	322	621	71	1062	0	3363	927	1685	1327	73799999999999999999999999999							14	
159999999999999999999				0	0	0	0	61	340	623	0	160	499	697	129	628	728	3100	1281	258	377	90599999999999999999999999999							15	
169999999999999999999999					0	0	0	0	0	0	120	220	0	600	455	500	0	1868	5028	4933	1528	21499999999999999999999999999							16	
179999999999999999999999					0	0	0	0	152	148	253	311	0	857	1302	746	1405	5995	232	4746	5635	22219999999999999999999999999							17	
189999999999999999999999					0	0	0	0	148	260	0	181	1401	2750	630	843	3579	1334	215	0	0	18199999999999999999999999999							18	
199999999999999999999999					0	0	0	0	0	0	522	1040	4939	821	461	168	954	321	2104	0	0	1994	25559999999999999999999999							19
209999999999999999999					0	0	0	0	0	0	966	318	1449	286	853	222	1789	512	475	140	0	608	099999999999999999999							20	
219999999999		0	0	0	0	0	0	0	0	0	337	1350	1434	677	782	0	1884	0	0	0	0	0	0	0	09999999999999999				21
2299999	0	0	0	0	0	0	0	0	0	0	132	1506	2259	1030	175	486	0	0	0	0	0	0	0	0	09999999999999999				22
23	0	0	0	0	0	0	0	0	0	0	0	757	680	136	175	2678	0	433	0	0	0	0	0	0999999999999999999					23	
24	0	0	0	661	935	354	0	0	0	0	0	479	548	357	2512	3097	1177	0	0	0	0	0	0	0999999999999999999999999					24	
25	0	0	0	1513	443	787	0	0	0	0	1250	827	795	903	1285	9456	6410	0	0	0	099999999999999999999999999999999999								25
26	0	0	902	0	0	0	0	0	0	2161	646	525	2830	1506	1221	3905	962	0	0	0	099999999999999999999999999999999999								26
27	0	0	0	0	0	424	565	5787	1050	2160	2714	1495	945	1364	1975	7033	245	0	0	0999999999999999999999999999999999999999									27
28	0	0	0	775	258	0	0	710	0	0	2543	4917	1375	1314	1892	3539	0	0	0	0999999999999999999999999999999999999999									28
29	0	0	2066	0	0	0	684	654	0	0	46	900	780	1469	3021	3927	0	0	0	0999999999999999999999999999999999999999									29
30	1325	0	0	0	0	0	0	159	323	0	0	501	0	778	464	1230	0	0	0	0999999999999999999999999999999999999999									30
31	1762	0	0	0	0	0	0	0	0	1175	666	0	0	817	513	354	0	0	0	0999999999999999999999999999999999999999									31
32	0	0	0	0	0	0	0	0	0	0	0	0	272	617	2021	2666	0	0	0	0	0999999999999999999999999999999999999								32
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0999999999999999999999999999999999999						33
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0999999999999999999999999999					34
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0999999999999999999				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	

TOTAL Q IN MODELED AREA = 323.402 MCM/YEAR

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.16(2)
DISCHARGE MAP IN 1982

MSA TOTAL Q MAP (X1000 cu.m)

YEAR: 1983

	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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					2
3	0	0	0	0	0	0	0	0	0	0	0	0	0	98	1164	470	1169	391	182	0	0	0	0	0					3
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	366	455	323	399	0	0	0	0	0	0					4
5	0	0	0	0	0	0	233	84	136	0	0	0	0	1311	274	2525	167	431	126	0	0	0	2216	0					5
6	0	0	0	0	0	0	0	42	16	16	1319	2435	2092	345	4101	804	201	295	0	0	0	0	1236	0					6
7	0	0	0	0	0	0	0	351	107	84	377	1271	0	134	446	363	223	157	474	0	0	172	714						7
8	0	0	0	0	0	0	7	532	780	688	254	0	601	1291	9	314	193	352	135	107	65	146	1299						8
9	0	0	0	0	0	0	22	616	380	439	531	0	572	3422	376	979	446	561	461	150	280	305							9
10	0	0	0	0	0	0	7	892	2531	2192	1652	1254	3779	252	569	411	557	280	370	33	115	168							10
11	0	0	0	0	0	0	0	276	364	0	1455	1869	560	451	1084	0	127	57	114	217	337	642							11
12	0	0	0	0	0	0	0	1411	183	98	95	179	423	397	948	0	280	640	575	1997	52								12
13	0	0	0	0	0	0	0	1098	491	0	208	437	503	556	333	638	571	983	463	295	450								13
14	0	0	0	0	0	0	0	0	494	0	0	0	224	504	71	1062	0	3473	914	1685	1327								14
15	0	0	0	0	0	0	61	309	550	0	102	317	503	123	628	729	3100	1573	258	377									15
16	0	0	0	0	0	0	0	0	0	106	130	0	569	448	500	0	1996	5028	4933	1533									16
17	0	0	0	0	0	0	152	149	253	277	0	767	1187	746	1401	6077	232	5262	5679										17
18	0	0	0	0	0	0	148	260	0	181	1221	2532	587	727	3001	1334	215	0	0										18
19	0	0	0	0	0	0	0	0	522	1135	4453	848	461	164	954	321	2104	0	0										19
20	0	0	0	0	0	0	0	0	966	318	1453	286	853	222	1746	533	475	140	0										20
21	0	0	0	0	0	0	0	0	285	1429	1346	677	782	0	1784	0	0	0	0										21
22	0	0	0	0	0	0	0	0	114	1557	2705	1030	175	486	0	0	0	0	0										22
23	0	0	0	0	0	0	0	0	729	757	136	175	3036	0	433	0	0	0	0										23
24	0	0	0	619	973	317	0	0	0	0	0	588	548	357	2512	3324	1177	0	0										24
25	0	0	0	1647	439	787	0	0	0	0	1191	827	795	903	1484	9859	5689	0	0										25
26	0	0	872	0	0	0	0	0	0	2174	544	525	2967	1562	1380	3679	660	0	0										26
27	0	0	0	0	0	440	553	5785	1086	2150	3035	1495	945	1553	2225	7033	240	0	0										27
28	0	0	0	775	258	0	0	710	0	0	2543	4917	1375	1314	1892	3539	0	0	0										28
29	0	0	2065	0	0	0	329	553	0	0	46	900	780	1469	3196	5006	0	0	0										29
30	1325	0	0	0	0	0	0	125	323	0	0	485	0	778	464	1158	0	0	0										30
31	1762	0	0	0	0	0	0	0	0	1068	573	0	0	817	513	345	0	0	0										31
32	0	0	0	0	0	0	0	0	0	0	0	0	272	617	2157	2770	0	0	0	0									32
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0								33
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0							34
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						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	

TOTAL Q IN MODELED AREA = 319.181 MCM/YEAR

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.16(3) DISCHARGE MAP IN 1983
JAPAN INTERNATIONAL COOPERATION AGENCY	

MSA TOTAL Q MAP (X1000 cu.m)
YEAR: 1984

	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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	9	9	9	9	9	9	9	1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	9	9	9	9	9	2
3	0	0	0	0	0	0	0	0	0	0	0	0	0	98	1235	470	1169	391	182	0	0	0	9	9	9	9	9	9	3
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	506	455	323	399	0	0	0	0	0	0	9	9	9	9	4
5	0	0	0	0	0	0	233	84	136	0	0	0	0	1311	274	2677	165	431	121	0	0	0	2361	0	9	9	9	9	5
6	0	0	0	0	0	0	0	42	16	16	1319	2435	2134	345	4244	658	182	277	0	0	0	0	1251	0	9	9	9	9	6
7	0	0	0	0	0	0	0	351	107	84	353	1009	0	134	446	334	504	1091	302	0	0	149	782	9	9	9	9	9	7
8	0	0	0	0	0	0	9	525	756	679	254	0	585	1291	5	371	165	287	78	44	42	123	1152	9	9	9	9	9	8
9	9	0	0	0	0	0	11	386	293	432	520	0	546	2939	376	979	446	561	333	72	163	270	9	9	9	9	9	9	9
10	9	9	9	9	9	0	0	0	4	748	2531	2184	1652	1254	3041	169	485	411	557	290	308	23	83	139	9	9	9	9	10
11	9	9	9	9	9	9	0	0	0	276	364	0	1416	1649	375	292	1084	0	127	57	108	18	292	425	9	9	9	9	11
12	9	9	9	9	9	9	9	0	0	0	0	1495	183	98	122	116	370	397	948	0	280	540	558	1641	32	9	9	9	12
13	9	9	9	9	9	9	9	0	0	0	0	1186	491	0	162	337	429	556	333	638	560	939	463	295	391	2769	9	9	13
14	9	9	9	9	9	9	9	9	0	0	0	0	485	0	0	0	154	407	71	1062	0	3465	906	1685	1327	7379	9	9	14
15	9	9	9	9	9	9	9	9	0	0	0	61	282	495	0	84	197	364	116	628	728	3100	1681	258	377	9059	9	9	15
16	9	9	9	9	9	9	9	9	9	0	0	0	0	0	94	75	0	454	442	500	0	1996	5028	4933	1652	2149	9	9	16
17	9	9	9	9	9	9	9	9	9	0	0	0	152	148	253	246	0	685	1125	746	1321	6033	232	5262	5749	2423	9	9	17
18	9	9	9	9	9	9	9	9	9	0	0	0	148	260	0	181	1033	2275	549	625	2513	1334	215	0	0	2126	9	9	18
19	9	9	9	9	9	9	9	9	9	0	0	0	0	0	522	1135	4012	770	461	160	954	321	2104	0	0	1994	2556	9	19
20	9	9	9	9	9	9	9	9	0	0	0	0	0	1090	319	1347	286	853	222	1724	643	475	140	0	608	9	9	9	20
21	9	9	9	0	0	0	0	0	0	0	0	0	241	1516	1264	677	782	0	1706	0	0	0	0	0	0	9	9	9	21
22	9	9	9	0	0	0	0	0	0	0	0	0	99	1692	3345	1030	175	486	0	0	0	0	0	0	0	9	9	9	22
23	0	0	0	0	0	0	0	0	0	0	0	0	638	767	136	175	3042	0	433	0	0	0	0	0	9	9	9	9	23
24	0	0	0	536	837	284	0	0	0	0	0	0	671	548	357	2600	3324	1177	0	0	0	0	0	0	9	9	9	9	24
25	0	0	0	1495	468	787	0	0	0	0	0	1187	827	795	903	1484	9986	5044	0	0	0	0	9	9	9	9	9	9	25
26	0	0	926	0	0	0	0	0	0	2154	645	525	2897	1947	1380	3391	502	0	0	0	9	9	9	9	9	9	9	9	26
27	0	0	0	0	0	411	659	5950	1015	2160	3035	1753	945	1625	2312	7096	392	0	0	9	9	9	9	9	9	9	9	9	27
28	0	0	0	775	256	0	0	710	0	0	2543	5238	1375	1314	2106	3990	0	0	0	9	9	9	9	9	9	9	9	9	28
29	0	0	2066	0	0	0	386	511	0	0	46	900	780	1469	3196	6101	0	0	0	9	9	9	9	9	9	9	9	9	29
30	1325	0	0	0	0	0	0	98	323	0	0	470	0	778	464	1089	0	0	0	9	9	9	9	9	9	9	9	9	30
31	1762	0	0	0	0	0	0	0	0	971	490	0	0	817	771	358	0	0	0	9	9	9	9	9	9	9	9	9	31
32	0	0	0	0	0	0	0	0	0	0	0	0	272	617	2157	2992	0	0	0	0	9	9	9	9	9	9	9	9	32
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	318	0	0	0	0	9	9	9	9	9	9	9	33
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	9	9	9	9	34
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	9	9	9	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	

TOTAL Q IN MODELED AREA = 317.041 MCM/YEAR

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.16(4)
DISCHARGE MAP IN 1984

MSA TOTAL Q MAP (X1000 cu.m)
YEAR: 1985

	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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
3	0	0	0	0	0	0	0	0	0	0	0	0	0	98	1235	470	1169	489	182	0	0	0	0	0	0	0	0	0	3
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	506	455	323	557	0	0	0	0	0	0	0	0	0	0	4
5	0	0	0	0	0	0	233	84	136	0	0	0	0	1311	274	2677	160	431	117	0	0	0	2508	263	0	0	0	0	5
6	0	0	0	0	0	0	0	42	16	16	1319	2435	2218	497	4286	548	165	261	0	0	0	0	1201	0	0	0	0	0	6
7	0	0	0	0	0	0	0	351	107	84	329	793	0	134	446	357	648	1349	188	0	0	128	964	0	0	0	0	0	7
8	0	0	0	0	0	0	14	433	733	668	349	0	568	1291	0	371	141	233	44	22	27	126	1022	0	0	0	0	0	8
9	0	0	0	0	0	0	10	243	225	424	180	0	513	2507	376	979	446	561	262	32	109	239	1269	0	0	0	0	0	9
10	0	0	0	0	0	0	3	625	2524	2176	1652	1254	2380	107	415	411	557	280	255	15	60	113	0	0	0	0	0	0	10
11	0	0	0	0	0	0	0	276	364	0	1374	1383	246	185	1084	0	127	57	103	0	223	277	0	0	0	0	0	0	11
12	0	0	0	0	0	0	0	1517	183	98	89	74	375	397	948	0	280	640	540	1344	19	0	0	0	0	0	0	0	12
13	0	0	0	0	0	0	0	1186	491	0	125	256	364	556	333	638	597	926	463	295	505	2259	0	0	0	0	0	0	13
14	0	0	0	0	0	0	0	478	0	0	0	104	328	71	1062	0	3294	839	1685	1523	737	0	0	0	0	0	0	0	14
15	0	0	0	0	0	0	61	256	427	0	39	120	262	111	626	728	3100	1808	258	377	905	0	0	0	0	0	0	0	15
16	0	0	0	0	0	0	0	0	0	0	83	42	0	361	435	500	0	1996	5029	4933	1686	2149	0	0	0	0	0	0	16
17	0	0	0	0	0	0	152	148	253	218	0	611	1050	746	1244	5988	232	5262	6037	2358	0	0	0	0	0	0	0	0	17
18	0	0	0	0	0	0	148	260	0	181	846	1929	512	536	2097	1334	215	0	265	2628	0	0	0	0	0	0	0	0	18
19	0	0	0	0	0	0	0	0	522	1135	3223	750	451	157	954	321	2104	0	0	1994	2556	0	0	0	0	0	0	0	19
20	0	0	0	0	0	0	0	0	1090	318	1279	286	853	222	1698	527	475	140	0	508	0	0	0	0	0	0	0	0	20
21	0	0	0	0	0	0	0	0	0	0	203	1481	1185	677	782	0	1505	0	0	0	0	0	0	0	0	0	0	0	21
22	0	0	0	0	0	0	0	0	0	0	85	1914	3450	1030	175	486	0	0	0	0	0	0	0	0	0	0	0	0	22
23	0	0	0	0	0	0	0	0	0	0	574	767	136	175	3111	0	433	0	0	0	0	0	0	0	0	0	0	0	23
24	0	0	0	395	723	254	0	0	0	0	0	652	548	357	2500	3402	1177	0	0	0	0	0	0	0	0	0	0	0	24
25	0	0	0	1355	364	787	0	0	0	0	1083	827	795	903	1650	9853	4664	0	0	0	0	0	0	0	0	0	0	0	25
26	0	0	875	0	0	0	0	0	0	2040	587	525	2882	1932	1380	3168	381	0	0	0	0	0	0	0	0	0	0	0	26
27	0	0	0	0	0	381	819	5968	950	2160	3035	1753	945	1625	2312	7096	497	0	0	0	0	0	0	0	0	0	0	0	27
28	0	0	0	833	262	0	0	710	0	0	2543	5558	1375	1314	2106	4125	0	0	0	0	0	0	0	0	0	0	0	0	28
29	0	0	2236	0	0	0	230	496	0	0	46	900	780	1469	3196	6456	0	0	0	0	0	0	0	0	0	0	0	0	29
30	1325	0	0	0	0	0	0	77	323	0	0	456	0	778	484	1423	0	0	0	0	0	0	0	0	0	0	0	0	30
31	1762	0	0	0	0	0	0	0	0	881	420	0	0	817	771	847	0	0	0	0	0	0	0	0	0	0	0	0	31
32	0	0	0	0	0	0	0	0	0	0	0	0	272	617	2157	3007	0	0	0	0	0	0	0	0	0	0	0	0	32
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	460	0	0	0	0	0	0	0	0	0	0	0	33
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	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	

TOTAL Q IN MODELED AREA = 312.599 MCM/YEAR

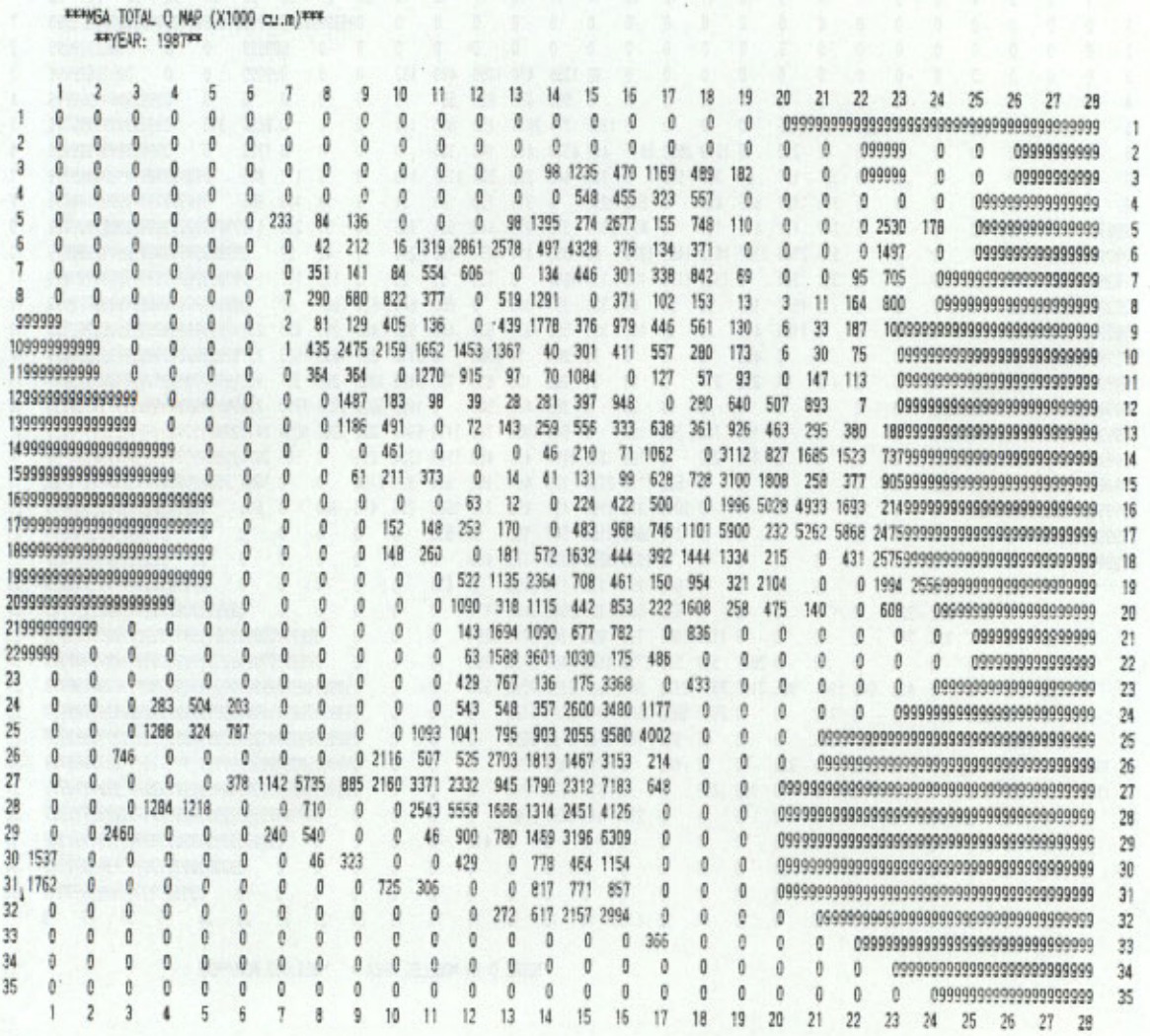
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.16(5) DISCHARGE MAP IN 1985
JAPAN INTERNATIONAL COOPERATION AGENCY	

MSA TOTAL Q MAP (X1000 cu.m)
YEAR: 1986

	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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	999	0	0	9			2
3	0	0	0	0	0	0	0	0	0	0	0	0	0	98	1235	470	1169	489	182	0	0	0	999	0	0	9			3
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	506	455	323	557	0	0	0	0	0	0	0	9			4
5	0	0	0	0	0	0	233	84	136	0	0	0	0	1395	274	2677	158	865	112	0	0	0	2490	310	0	9			5
6	0	0	0	0	0	0	0	42	212	16	1319	2650	2417	497	4328	455	148	396	0	0	0	0	1226	0	0	9			6
7	0	0	0	0	0	0	0	351	107	84	303	675	0	134	446	328	604	1102	116	0	0	111	806	0	0	9			7
8	0	0	0	0	0	0	10	356	707	656	406	0	545	1291	0	371	120	189	24	9	18	140	905	0	0	9			8
9	9	0	0	0	0	0	5	147	171	415	136	0	479	2122	376	979	446	561	185	14	57	212	1129	0	0	9			9
10	9	0	0	0	0	1	523	2508	2167	1652	1453	1826	66	353	411	557	280	211	9	43	92	0	0	0	0	9			10
11	9	0	0	0	0	0	364	364	0	1325	1139	157	115	1084	0	127	57	98	0	178	179	0	0	0	0	9			11
12	9	0	0	0	0	0	0	1517	183	98	56	46	324	397	948	0	280	640	524	1098	12	0	0	0	0	9			12
13	9	0	0	0	0	0	0	1186	491	0	95	193	309	556	333	638	488	926	453	295	420	23	1999	0	0	9			13
14	9	0	0	0	0	0	0	0	469	0	0	0	70	264	71	1062	0	3112	827	1685	1523	73	7999	0	0	9			14
15	9	0	0	0	0	0	61	233	375	0	23	71	186	105	628	728	3100	1808	258	377	90	5999	0	0	0	9			15
16	9	0	0	0	0	0	0	0	0	73	23	0	285	429	500	0	1996	5028	4933	1710	214	9999	0	0	0	9			16
17	9	0	0	0	0	0	152	148	253	193	0	544	1002	746	1170	5944	232	5262	6058	241	9999	0	0	0	0	9			17
18	9	0	0	0	0	0	148	260	0	181	712	1794	477	459	1743	1334	215	0	565	287	4999	0	0	0	0	9			18
19	9	0	0	0	0	0	0	0	522	1135	2732	729	461	153	954	321	2104	0	0	1994	255	9999	0	0	0	9			19
20	9	0	0	0	0	0	0	0	0	1090	318	1199	461	853	222	1608	258	475	140	0	608	0	0	0	0	9			20
21	9	0	0	0	0	0	0	0	0	170	1689	1163	677	782	0	836	0	0	0	0	0	0	0	0	0	9			21
22	9	9	0	0	0	0	0	0	0	73	1935	3262	1030	175	486	0	0	0	0	0	0	0	0	0	0	9			22
23	0	0	0	0	0	0	0	0	0	0	0	540	757	136	175	3100	0	433	0	0	0	0	0	0	0	9			23
24	0	0	0	333	602	227	0	0	0	0	0	630	548	357	2500	3402	1177	0	0	0	0	0	0	0	0	9			24
25	0	0	0	1471	335	787	0	0	0	0	1121	1041	795	903	1746	9717	4297	0	0	0	0	0	0	0	0	9			25
26	0	0	708	0	0	0	0	0	0	2011	518	525	2752	1689	1467	3129	286	0	0	0	0	0	0	0	0	9			26
27	0	0	0	0	0	422	948	5947	905	2160	3371	2332	945	1625	2312	7096	528	0	0	0	0	0	0	0	0	9			27
28	0	0	0	1229	934	0	0	710	0	0	2543	5558	1686	1314	2106	4126	0	0	0	0	0	0	0	0	0	9			28
29	0	0	2400	0	0	0	257	553	0	0	46	900	780	1469	3196	6556	0	0	0	0	0	0	0	0	0	9			29
30	1325	0	0	0	0	0	0	59	323	0	0	442	0	778	464	1277	0	0	0	0	0	0	0	0	0	9			30
31	1762	0	0	0	0	0	0	0	0	799	359	0	0	817	771	796	0	0	0	0	0	0	0	0	0	9			31
32	0	0	0	0	0	0	0	0	0	0	0	0	272	617	2157	3061	0	0	0	0	0	0	0	0	0	9			32
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	412	0	0	0	0	0	0	0	0	9			33
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9			34
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9			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	

TOTAL Q IN MODELED AREA = 309.028 MCM/YEAR

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.16(6) DISCHARGE MAP IN 1986
JAPAN INTERNATIONAL COOPERATION AGENCY	



MGA TOTAL Q MAP (X1000 cu.m)
YEAR: 1987

	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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0999999999999999999999999999999999999999									1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	099999	0	0	099999999999				2
3	0	0	0	0	0	0	0	0	0	0	0	0	0	98	1235	470	1169	499	182	0	0	099999	0	0	099999999999				3
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	548	455	323	557	0	0	0	0	0	0	099999999999999				4
5	0	0	0	0	0	0	233	84	136	0	0	0	98	1395	274	2677	155	748	110	0	0	0	2530	178	099999999999999				5
6	0	0	0	0	0	0	0	42	212	16	1319	2861	2578	497	4328	376	134	371	0	0	0	0	1497	0	099999999999999				6
7	0	0	0	0	0	0	0	351	141	84	554	606	0	134	446	301	338	842	69	0	0	95	705	099999999999999999999					7
8	0	0	0	0	0	0	7	290	680	822	377	0	519	1291	0	371	102	153	13	3	11	164	800	099999999999999999999					8
999999	0	0	0	0	0	2	81	129	405	136	0	439	1778	376	979	446	561	130	6	33	187	1009999999999999999999999999							9
109999999999		0	0	0	0	1	435	2475	2159	1652	1453	1367	40	301	411	557	280	173	6	30	75	099999999999999999999999999								10
119999999999		0	0	0	0	0	364	364	0	1270	915	97	70	1084	0	127	57	93	0	147	113	099999999999999999999999999								11
1299999999999999			0	0	0	0	0	1487	183	98	39	28	281	397	948	0	280	640	507	893	7	099999999999999999999999999								12
1399999999999999			0	0	0	0	0	1186	491	0	72	143	259	556	333	638	361	926	463	295	380	188999999999999999999999999								13
14999999999999999999			0	0	0	0	0	461	0	0	0	46	210	71	1062	0	3112	827	1685	1523	737999999999999999999999999								14
15999999999999999999			0	0	0	0	61	211	373	0	14	41	131	99	628	728	3100	1808	258	377	905999999999999999999999999								15
169999999999999999999999			0	0	0	0	0	0	63	12	0	224	422	500	0	1996	5028	4933	1693	214999999999999999999999999									16
179999999999999999999999			0	0	0	0	152	148	253	170	0	483	968	746	1101	5900	232	5262	5868	247599999999999999999999999									17
189999999999999999999999			0	0	0	0	148	260	0	181	572	1632	444	392	1444	1334	215	0	431	257599999999999999999999999									18
199999999999999999999999			0	0	0	0	0	0	522	1135	2354	708	461	150	954	321	2104	0	0	1994	255699999999999999999999999									19
209999999999999999999			0	0	0	0	0	0	0	1090	318	1115	442	853	222	1608	258	475	140	0	608	099999999999999999999									20
219999999999		0	0	0	0	0	0	0	0	0	0	143	1694	1090	677	782	0	836	0	0	0	0	0	0	099999999999999					21
2299999	0	0	0	0	0	0	0	0	0	0	0	63	1588	3601	1030	175	486	0	0	0	0	0	0	0	099999999999999					22
23	0	0	0	0	0	0	0	0	0	0	0	0	429	767	136	175	3368	0	433	0	0	0	0	0	099999999999999999999					23
24	0	0	0	283	504	203	0	0	0	0	0	0	543	548	357	2600	3480	1177	0	0	0	0	0	0	099999999999999999999999					24
25	0	0	0	1288	324	787	0	0	0	0	1093	1041	795	903	2055	9580	4002	0	0	0	099999999999999999999999999999999999									25
26	0	0	746	0	0	0	0	0	0	2116	507	525	2703	1813	1467	3153	214	0	0	0	099999999999999999999999999999999999									26
27	0	0	0	0	0	378	1142	5735	885	2150	3371	2332	945	1790	2312	7183	648	0	0	0999999999999999999999999999999999999999										27
28	0	0	0	1284	1218	0	0	710	0	0	2543	5558	1586	1314	2451	4125	0	0	0	0999999999999999999999999999999999999999										28
29	0	0	2460	0	0	0	240	540	0	0	46	900	780	1459	3196	6309	0	0	0	0999999999999999999999999999999999999999										29
30	1537	0	0	0	0	0	0	46	323	0	0	429	0	778	464	1154	0	0	0	0999999999999999999999999999999999999999										30
31	1762	0	0	0	0	0	0	0	0	725	306	0	0	817	771	857	0	0	0	0999999999999999999999999999999999999999										31
32	0	0	0	0	0	0	0	0	0	0	0	0	0	272	617	2157	2994	0	0	0	0	0999999999999999999999999999999999999									32
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	366	0	0	0	0	0	099999999999999999999999999999						33
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	099999999999999999999999999				34
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	099999999999999999999			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	

TOTAL Q IN MODELED AREA = 304.330 MCM/YEAR

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

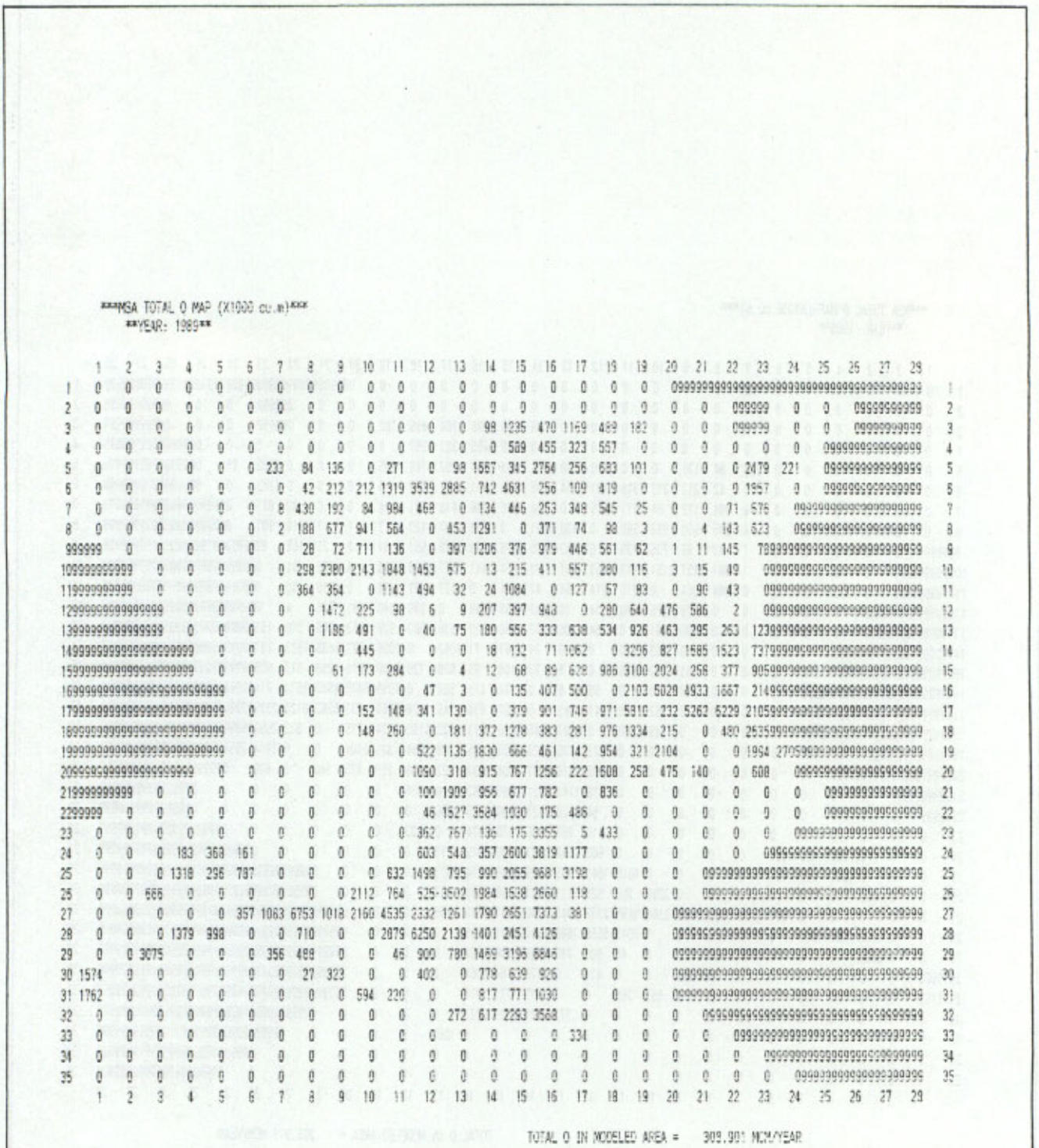
FIGURE 8.5.16(7)
DISCHARGE MAP IN 1987

MSA TOTAL Q MAP (X1000 cu.m)
YEAR: 1988

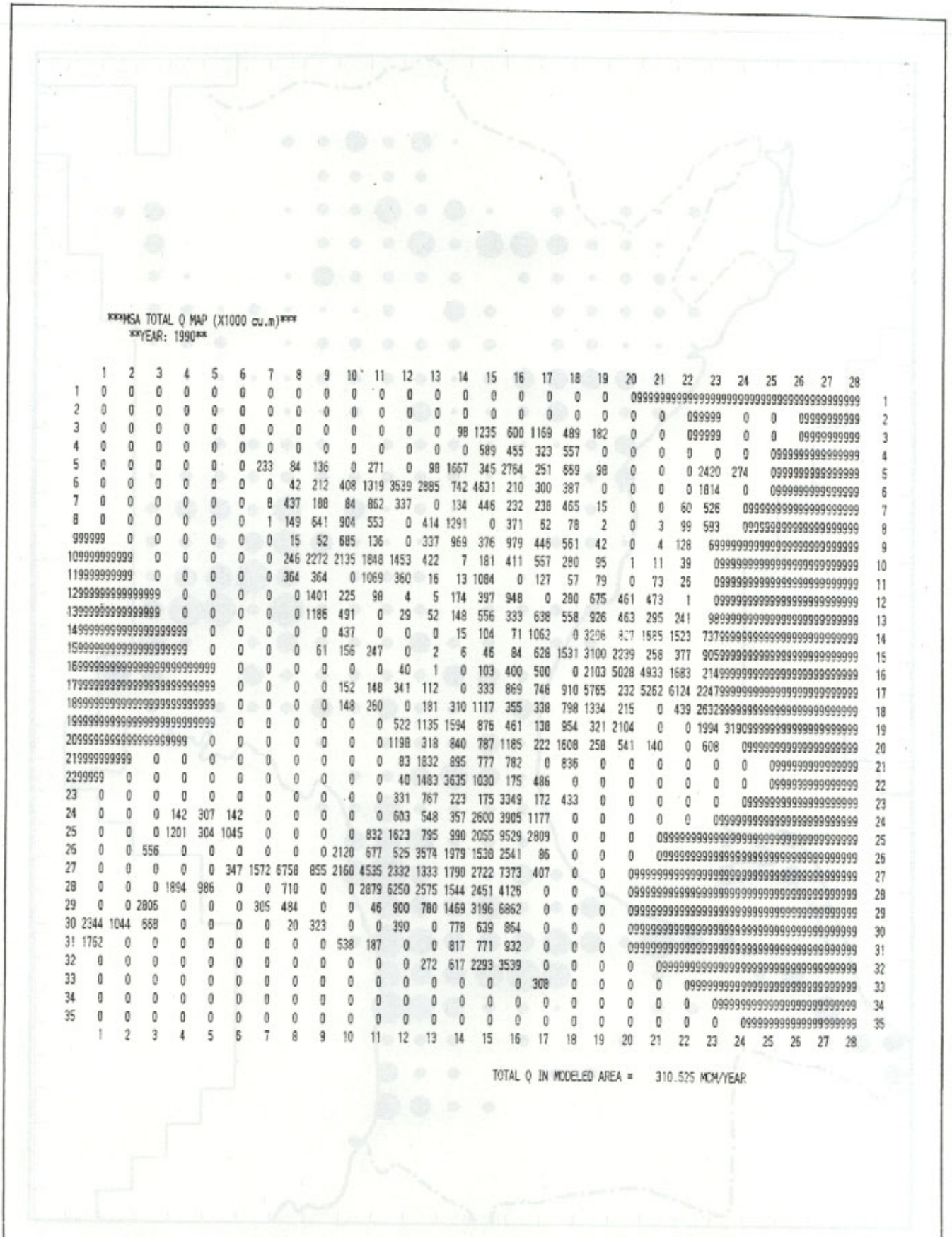
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
3	0	0	0	0	0	0	0	0	0	0	0	0	0	98	1235	470	1169	489	182	0	0	0	0	0	0	0	0	0	3
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	589	455	323	557	0	0	0	0	0	0	0	0	0	0	4
5	0	0	0	0	0	0	233	84	136	0	0	0	98	1474	345	2764	262	748	105	0	0	0	2532	91	0	0	0	0	5
6	0	0	0	0	0	0	0	42	212	212	1319	3131	2754	655	4416	311	121	472	0	0	0	0	1767	0	0	0	0	0	6
7	0	0	0	0	0	0	9	394	173	84	617	505	0	134	446	276	418	641	44	0	0	82	677	0	0	0	0	0	7
8	0	0	0	0	0	0	4	235	650	973	560	0	488	1291	0	371	87	122	7	1	7	119	707	0	0	0	0	0	8
9	0	0	0	0	0	0	1	49	95	736	136	0	452	1475	376	979	446	561	91	2	21	165	899	0	0	0	0	0	9
10	0	0	0	0	0	0	1	361	2457	2151	1848	1453	987	23	254	411	557	280	143	4	22	61	0	0	0	0	0	0	10
11	0	0	0	0	0	0	0	364	364	0	1210	674	58	42	1084	0	127	57	88	0	110	70	0	0	0	0	0	0	11
12	0	0	0	0	0	0	0	0	1478	225	98	14	16	241	397	948	0	280	640	491	725	4	0	0	0	0	0	0	12
13	0	0	0	0	0	0	0	0	1186	491	0	54	105	217	556	333	638	560	926	463	295	308	151	0	0	0	0	0	13
14	0	0	0	0	0	0	0	0	0	453	0	0	0	29	167	71	1062	0	3206	927	1685	1523	737	0	0	0	0	0	14
15	0	0	0	0	0	0	0	61	192	326	0	8	23	100	95	628	728	3100	1916	258	377	905	0	0	0	0	0	0	15
16	0	0	0	0	0	0	0	0	0	55	6	0	174	415	500	0	1996	5028	4933	1672	214	0	0	0	0	0	0	0	16
17	0	0	0	0	0	0	0	152	148	341	149	0	427	934	746	1228	5856	232	5262	6125	2335	0	0	0	0	0	0	0	17
18	0	0	0	0	0	0	0	148	260	0	181	445	1460	413	332	1190	1334	215	0	322	295	0	0	0	0	0	0	0	18
19	0	0	0	0	0	0	0	0	0	522	1135	2128	703	465	146	954	321	2104	0	0	1994	2556	0	0	0	0	0	0	19
20	0	0	0	0	0	0	0	0	0	1090	318	987	604	1097	222	1608	258	475	140	0	608	0	0	0	0	0	0	0	20
21	0	0	0	0	0	0	0	0	0	0	119	1748	1021	960	782	0	836	0	0	0	0	0	0	0	0	0	0	0	21
22	0	0	0	0	0	0	0	0	0	0	54	1508	3721	1030	175	486	0	0	0	0	0	0	0	0	0	0	0	0	22
23	0	0	0	0	0	0	0	0	0	0	0	410	757	136	175	3374	0	433	0	0	0	0	0	0	0	0	0	0	23
24	0	0	0	232	455	180	0	0	0	0	0	603	548	357	2600	3819	1177	0	0	0	0	0	0	0	0	0	0	0	24
25	0	0	0	1337	312	787	0	0	0	0	1018	1041	795	903	2055	9694	3527	0	0	0	0	0	0	0	0	0	0	0	25
26	0	0	698	0	0	0	0	0	0	2099	752	525	3111	1997	1538	2898	159	0	0	0	0	0	0	0	0	0	0	0	26
27	0	0	0	0	0	372	1102	5983	885	2160	3495	2332	945	1790	2651	7246	496	0	0	0	0	0	0	0	0	0	0	0	27
28	0	0	0	1457	1111	0	0	710	0	0	2543	5558	1686	1314	2451	4126	0	0	0	0	0	0	0	0	0	0	0	0	28
29	0	0	2595	0	0	0	314	556	0	0	46	900	780	1469	3196	6374	0	0	0	0	0	0	0	0	0	0	0	0	29
30	1600	0	0	0	0	0	0	35	323	0	0	415	0	778	464	1064	0	0	0	0	0	0	0	0	0	0	0	0	30
31	1762	0	0	0	0	0	0	0	0	557	260	0	0	817	771	919	0	0	0	0	0	0	0	0	0	0	0	0	31
32	0	0	0	0	0	0	0	0	0	0	0	0	272	617	2293	3213	0	0	0	0	0	0	0	0	0	0	0	0	32
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	280	0	0	0	0	0	0	0	0	0	0	0	33
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	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	

TOTAL Q IN MODELED AREA = 305.976 MCM/YEAR

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.16(8) DISCHARGE MAP IN 1988
JAPAN INTERNATIONAL COOPERATION AGENCY	



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.16(9) DISCHARGE MAP IN 1989
JAPAN INTERNATIONAL COOPERATION AGENCY	

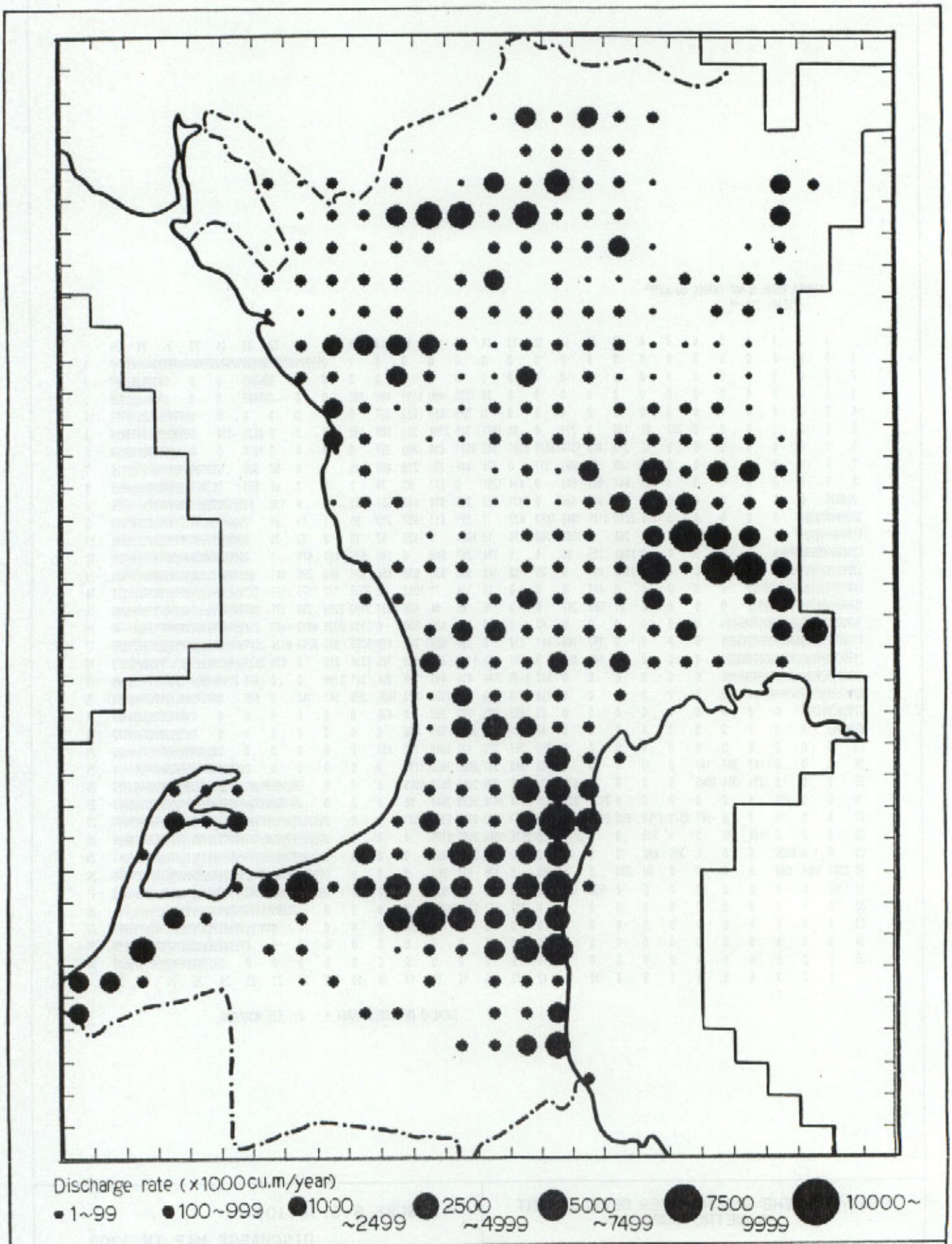


MSA TOTAL Q MAP (X1000 cu.m)
YEAR: 1990

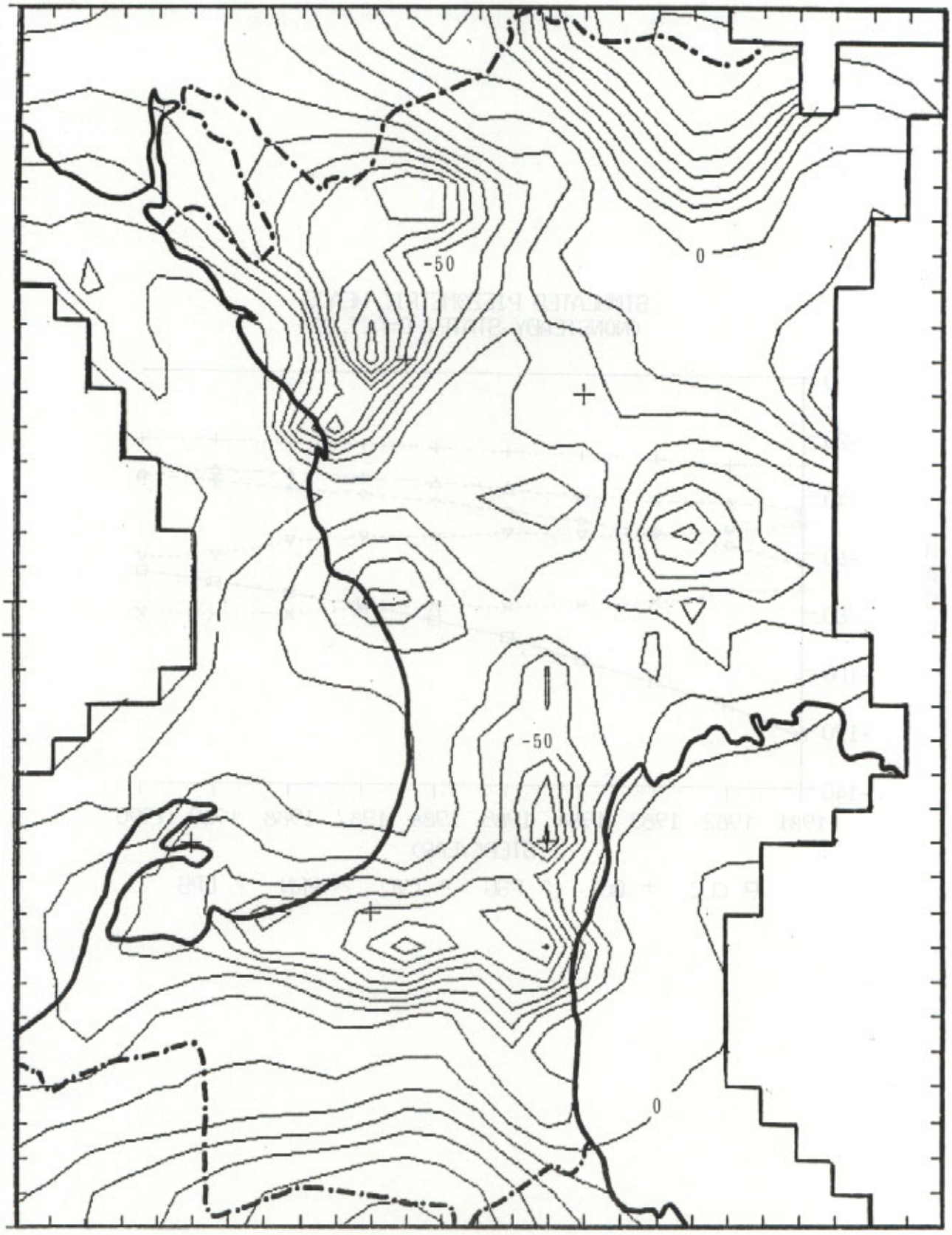
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0999999999999999999999999999999999999999999									1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	099999		0	0	099999999999			2
3	0	0	0	0	0	0	0	0	0	0	0	0	0	98	1235	600	1169	489	182	0	0	099999		0	0	099999999999			3
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	589	455	323	557	0	0	0	0	0	0	0999999999999999				4
5	0	0	0	0	0	0	233	84	136	0	271	0	98	1667	345	2764	251	659	98	0	0	0	2420	274	0999999999999999				5
6	0	0	0	0	0	0	0	42	212	408	1319	3539	2885	742	4631	210	300	387	0	0	0	0	1814	0	0999999999999999				6
7	0	0	0	0	0	0	8	437	188	84	862	337	0	134	446	232	238	465	15	0	0	60	526	0999999999999999999						7
8	0	0	0	0	0	0	1	149	641	904	553	0	414	1291	0	371	82	78	2	0	3	99	593	0999999999999999999						8
999999	0	0	0	0	0	0	15	52	685	136	0	337	969	376	979	445	561	42	0	4	128	6999999999999999999999999999								9
109999999999		0	0	0	0	0	246	2272	2135	1848	1453	422	7	181	411	557	280	95	1	11	39	0999999999999999999999999999								10
119999999999		0	0	0	0	0	364	364	0	1069	360	16	13	1084	0	127	57	79	0	73	26	0999999999999999999999999999								11
12999999999999999			0	0	0	0	0	1401	225	98	4	5	174	397	948	0	280	675	461	473	1	0999999999999999999999999999								12
13999999999999999			0	0	0	0	0	1186	491	0	29	52	148	556	333	638	558	926	463	295	241	9899999999999999999999999999								13
149999999999999999999			0	0	0	0	0	437	0	0	0	15	104	71	1062	0	3296	827	1585	1523	737999999999999999999999999								14
159999999999999999999			0	0	0	0	61	156	247	0	2	6	46	84	628	1531	3100	2239	258	377	905999999999999999999999999								15
169999999999999999999999			0	0	0	0	0	0	40	1	0	103	400	500	0	2103	5028	4933	1683	2149999999999999999999999999									16
179999999999999999999999			0	0	0	0	152	148	341	112	0	333	869	746	910	5765	232	5252	6124	2247999999999999999999999999									17
189999999999999999999999			0	0	0	0	148	260	0	191	310	1117	355	338	798	1334	215	0	439	2632999999999999999999999999									18
199999999999999999999999			0	0	0	0	0	0	522	1135	1594	876	461	138	954	321	2104	0	0	1994	3190999999999999999999999									19
209999999999999999999			0	0	0	0	0	0	0	1198	318	840	787	1185	222	1608	258	541	140	0	608	0999999999999999999									20
219999999999		0	0	0	0	0	0	0	0	0	83	1832	895	777	782	0	836	0	0	0	0	0	0	0999999999999999						21
2299999	0	0	0	0	0	0	0	0	0	0	40	1483	3635	1030	175	486	0	0	0	0	0	0	0	0999999999999999						22
23	0	0	0	0	0	0	0	0	0	0	0	331	767	223	175	3349	172	433	0	0	0	0	0	0	0999999999999999999					23
24	0	0	0	142	307	142	0	0	0	0	0	603	548	357	2600	3905	1177	0	0	0	0	0	0999999999999999999999999							24
25	0	0	0	1201	304	1045	0	0	0	0	832	1623	795	990	2055	9529	2809	0	0	0	0999999999999999999999999999999999									25
26	0	0	556	0	0	0	0	0	0	2120	677	525	3574	1979	1538	2541	86	0	0	0	0999999999999999999999999999999999									26
27	0	0	0	0	0	347	1572	6758	855	2160	4535	2332	1333	1790	2722	7373	407	0	0	0999999999999999999999999999999999999										27
28	0	0	0	1894	986	0	0	710	0	0	2879	6250	2575	1544	2451	4126	0	0	0	0999999999999999999999999999999999999										28
29	0	0	2806	0	0	0	305	484	0	0	46	900	780	1469	3196	6862	0	0	0	0999999999999999999999999999999999999										29
30	2344	1044	568	0	0	0	0	20	323	0	0	390	0	778	639	864	0	0	0	0999999999999999999999999999999999999										30
31	1762	0	0	0	0	0	0	0	0	538	187	0	0	817	771	932	0	0	0	0999999999999999999999999999999999999										31
32	0	0	0	0	0	0	0	0	0	0	0	0	272	617	2293	3539	0	0	0	0	0999999999999999999999999999999999									32
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	308	0	0	0	0	0999999999999999999999999999999999									33
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0999999999999999999999999								34
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0999999999999999999						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	

TOTAL Q IN MODELED AREA = 310.525 MCM/YEAR

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.16(10) DISCHARGE MAP IN 1990
JAPAN INTERNATIONAL COOPERATION AGENCY	

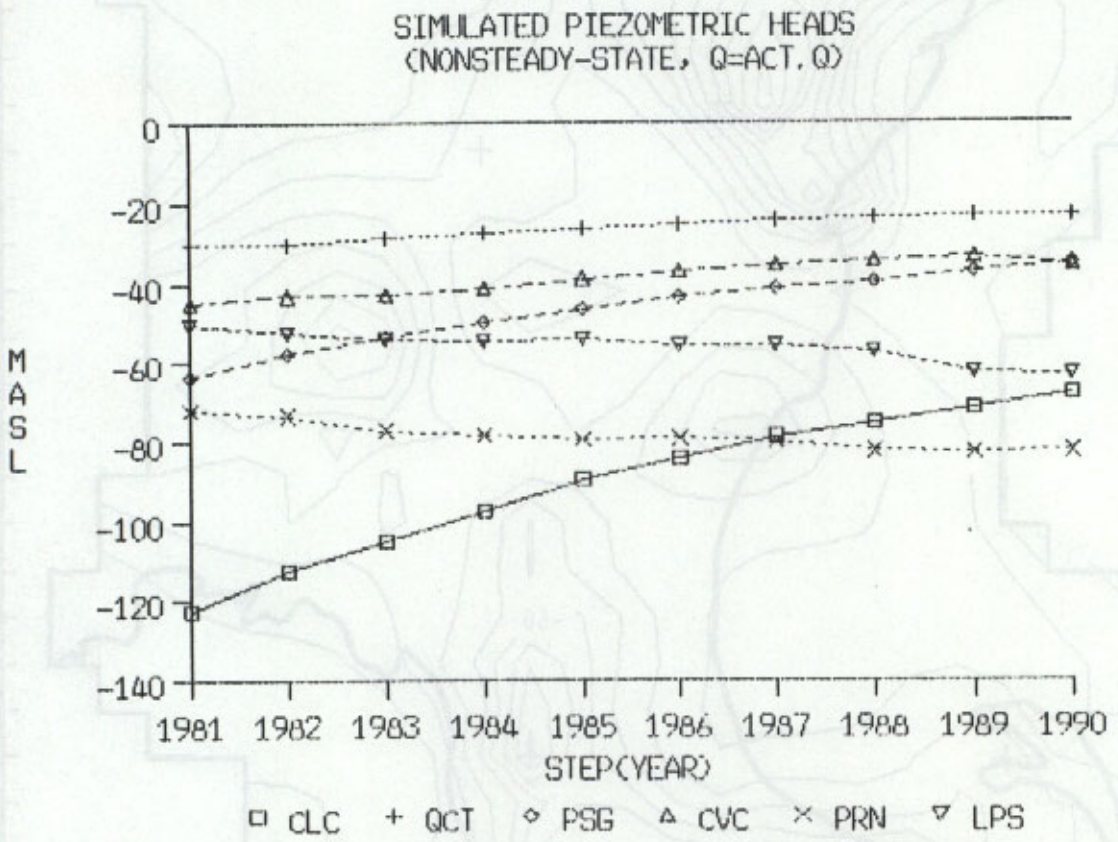


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.17
JAPAN INTERNATIONAL COOPERATION AGENCY	DISCHARGE DISTRIBUTION IN 1990

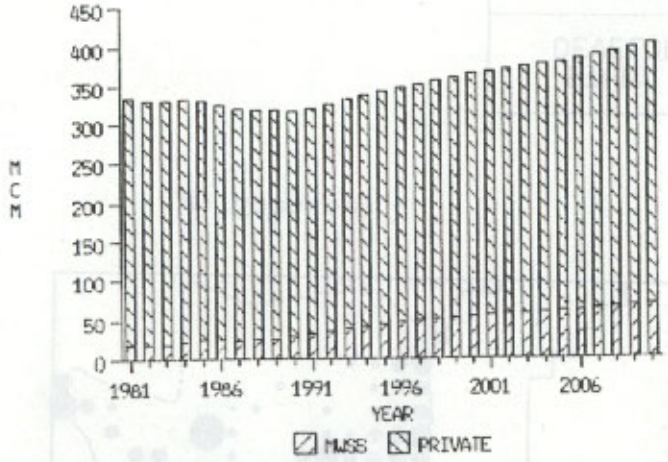


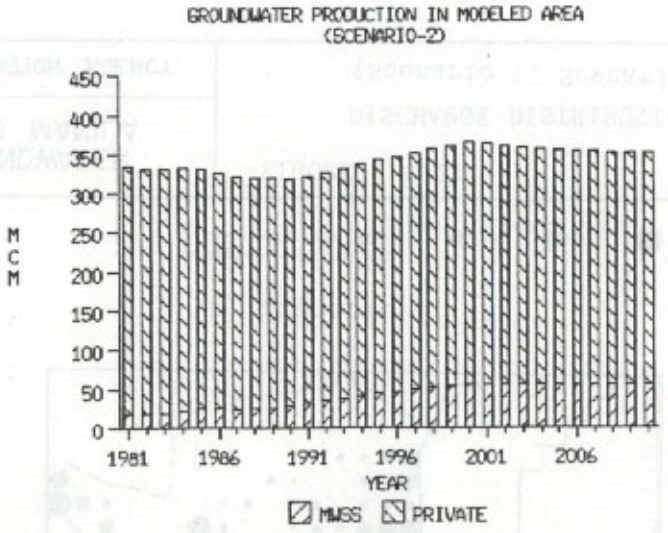
(Contour Interval: 10m, Unit: masl)

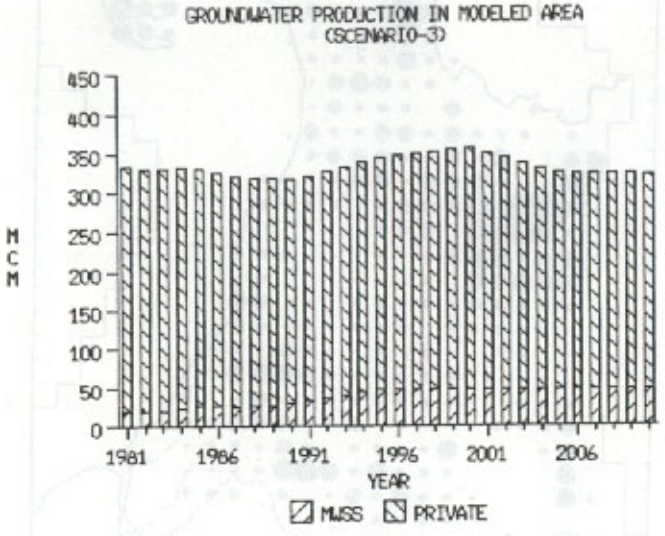
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.188
JAPAN INTERNATIONAL COOPERATION AGENCY	SIMULATED PIEZOMETRIC HEADS IN 1990

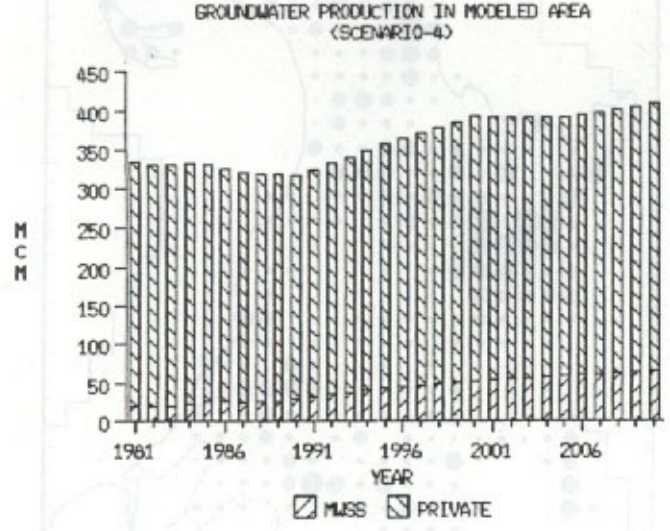


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.19 SIMULATED PIEZOMETRIC HEADS BY NONSTEADY-STATE CALCULATION
JAPAN INTERNATIONAL COOPERATION AGENCY	





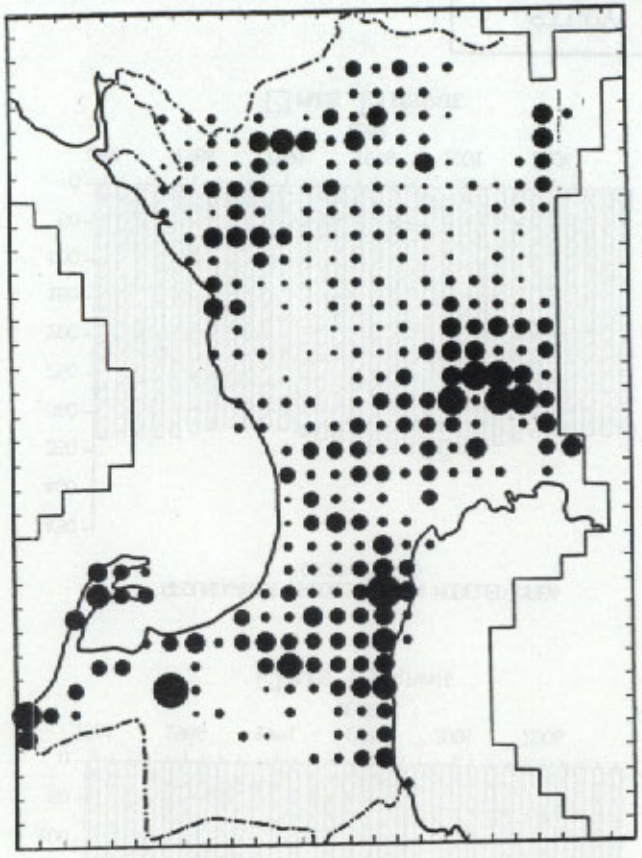




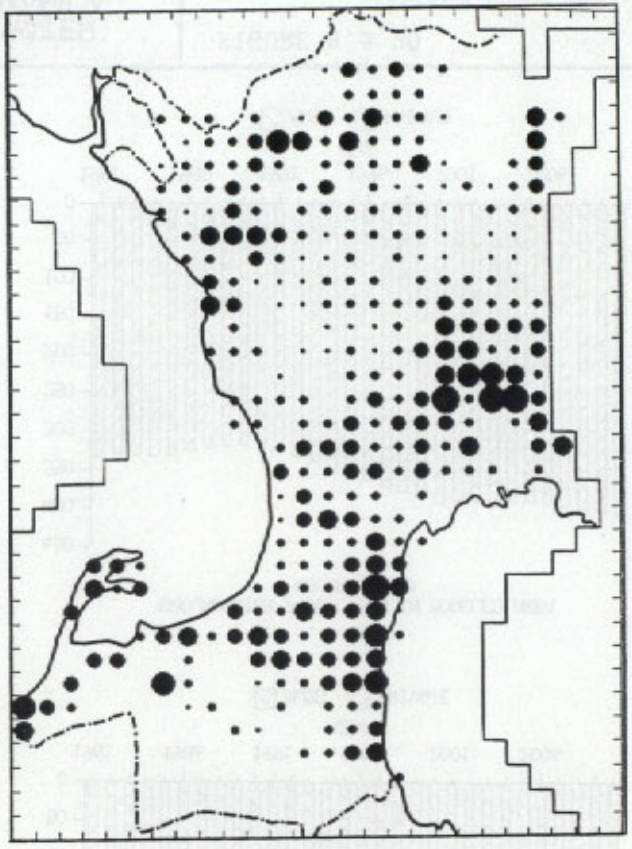
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.20
GROUNDWATER PRODUCTION OF EACH SCENARIO



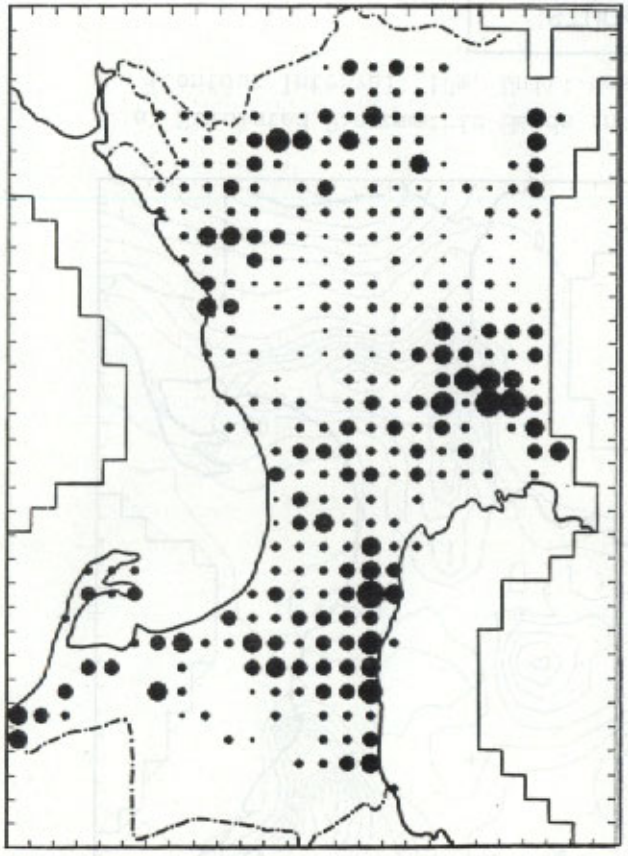
a) Scenario 1



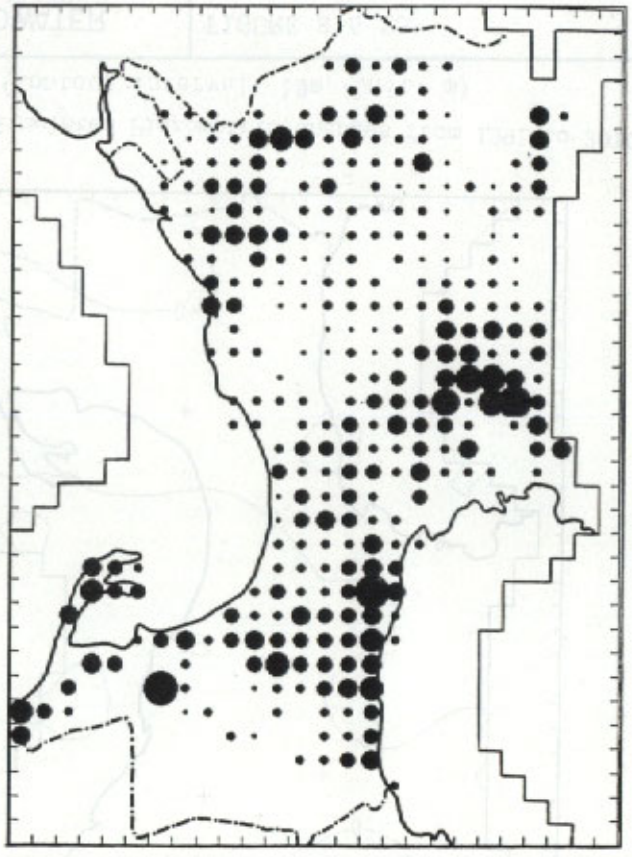
b) Scenario 2

Discharge rate (x1000cu.m/year)
1~99 100~999 1000~2499 2500~4999 5000~7499 7500~9999 10000~

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.21 DISCHARGE DISTRIBUTION IN 2010 (Scenario 1, Scenario 2)
JAPAN INTERNATIONAL COOPERATION AGENCY	



a) Scenario 3



b) Scenario 4

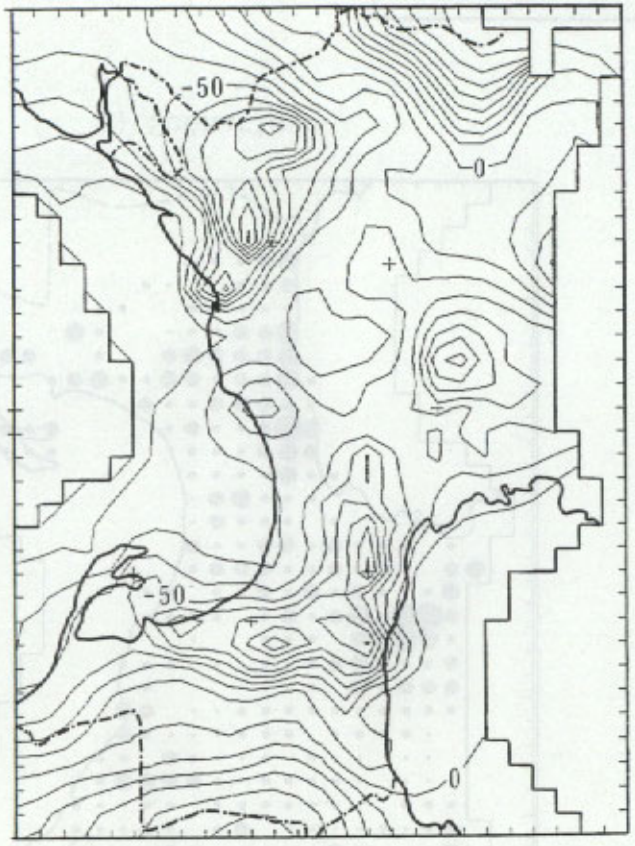
Discharge rate (x1000cum/year)
1~99 100~999 1000~2499 2500~4999 5000~7499 7500~9999 10000~

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

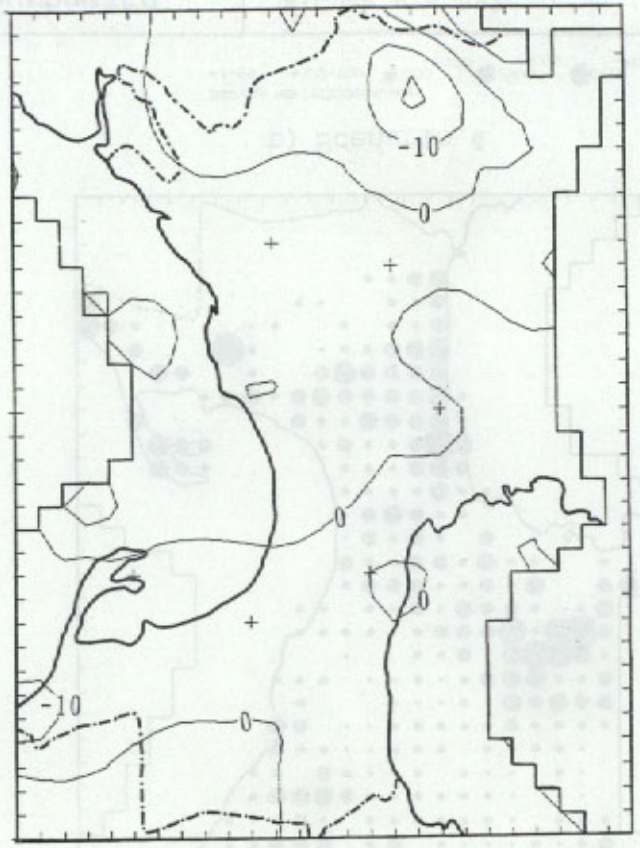
JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.222

DISCHARGE DISTRIBUTION IN 2010
(Scenario 3, Scenario 4)



a) Simulated Piezometric Heads in 2010
(Contour Interval: 10m, Unit: masl)



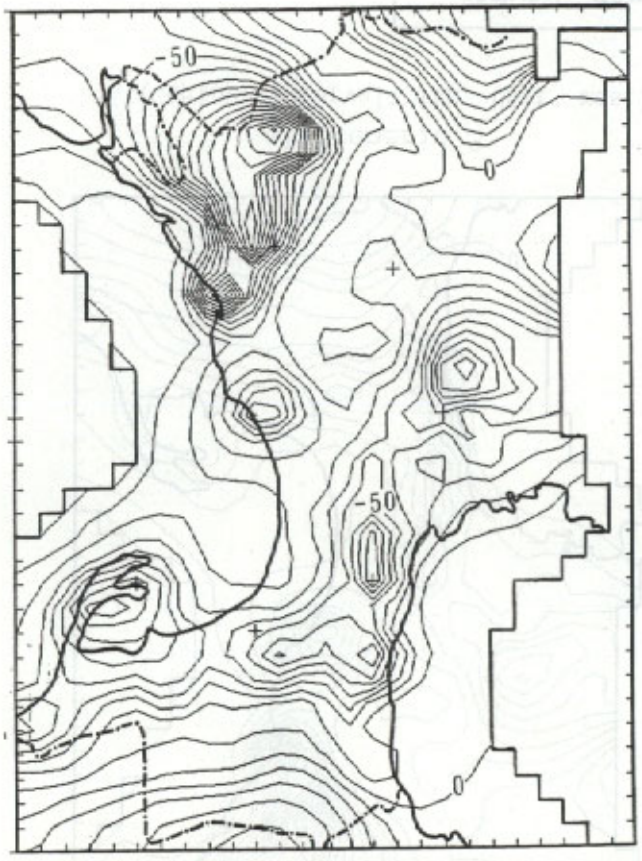
b) Simulated Piezometric Changes from 1991 to 2010
(Contour Interval: 10m, Unit: m)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

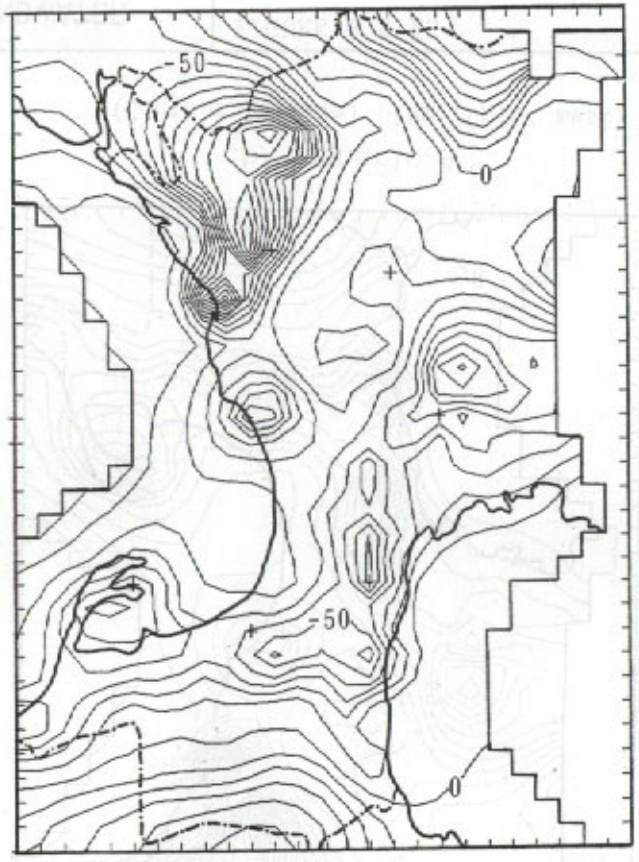
FIGURE 8.5.23

SIMULATED PIEZOMETRIC HEADS AND CHANGES



a) Scenario 1

(Contour Interval: 10m, Unit: masl)



b) Scenario 2

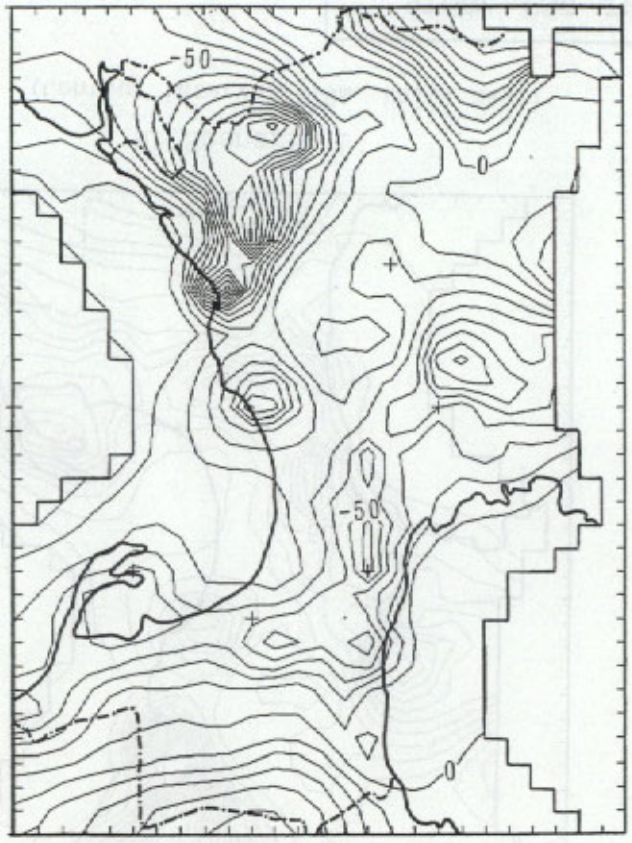
(Contour Interval: 10m, Unit: masl)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

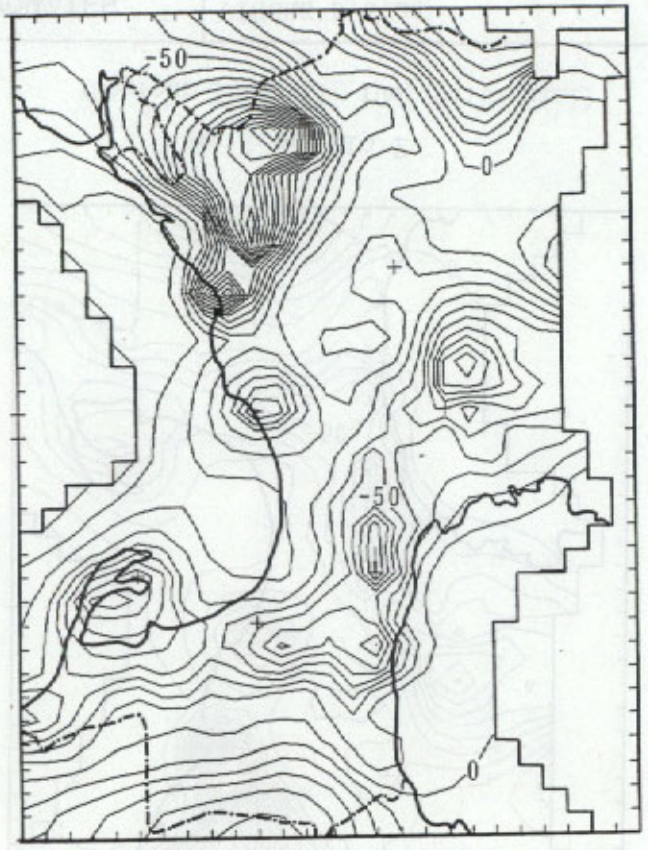
JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.24

SIMULATED PIEZOMETRIC HEADS IN 2010
(Scenario 1, Scenario 2)



a) Scenario 3
(Contour Interval: 10m, Unit: masl)



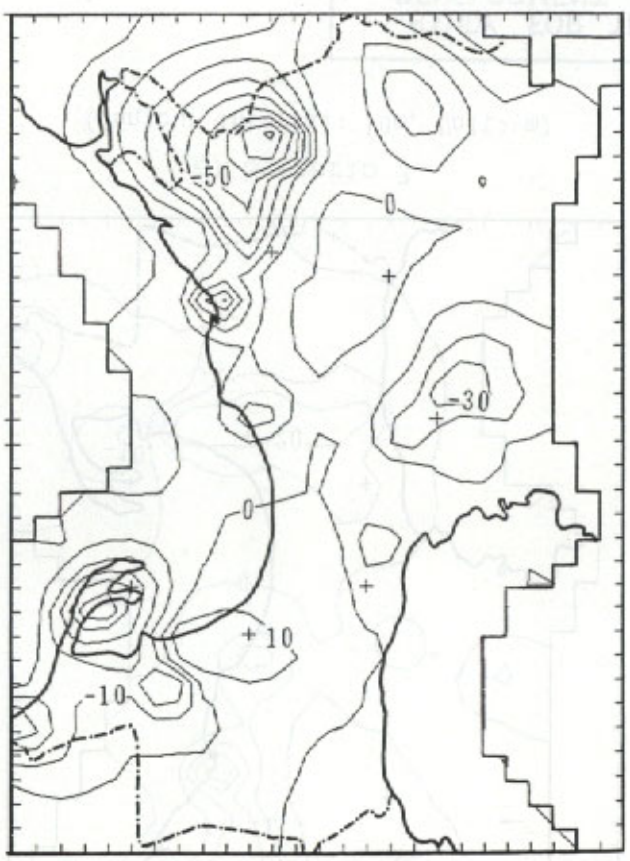
b) Scenario 4
(Contour Interval: 10m, Unit: masl)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

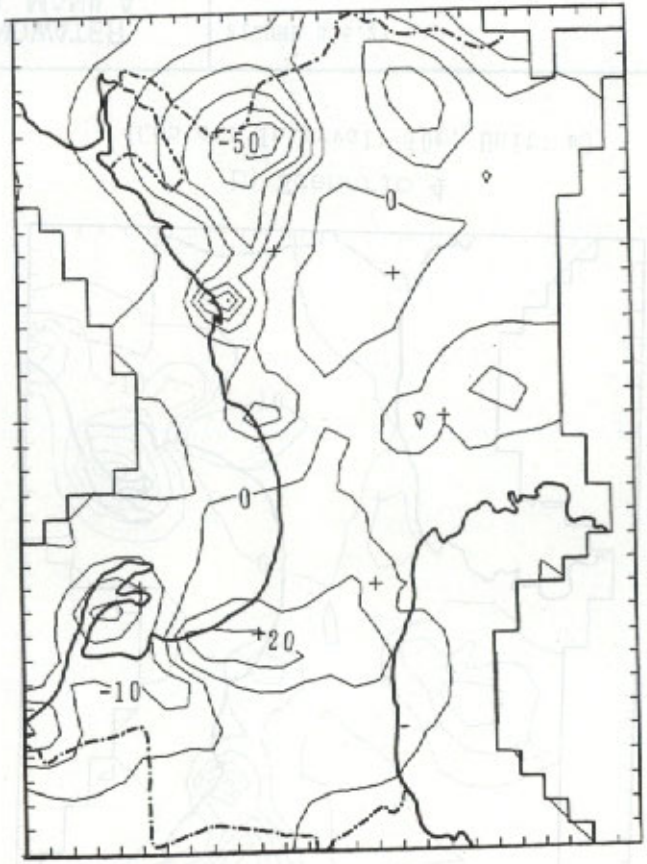
FIGURE 8.5.255

SIMULATED PIEZOMETRIC HEADS IN 2010
(Scenario 3, Scenario 4)



a) Scenario 1

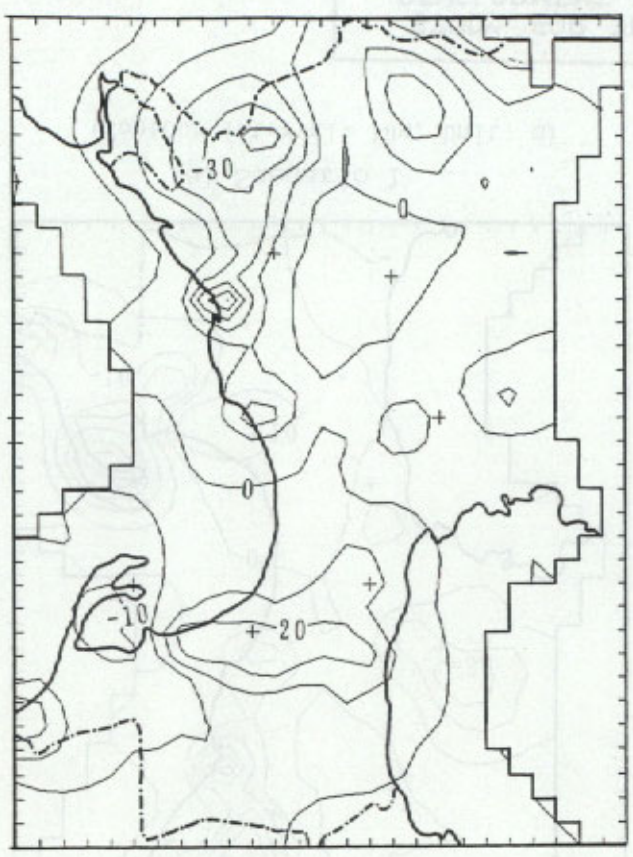
(Contour Interval: 10m, Unit: m)



b) Scenario 2

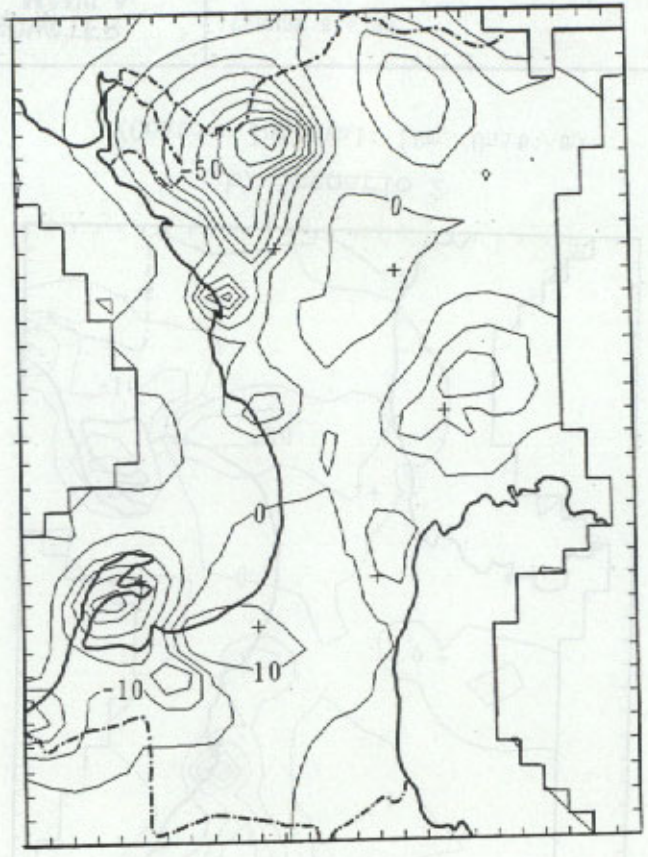
(Contour Interval: 10m, Unit: m)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.26 SIMULATED PIEZOMETRIC CHANGES FROM 1991 TO 2010 (Scenario 1, Scenario 2)
JAPAN INTERNATIONAL COOPERATION AGENCY	



a) Scenario 3

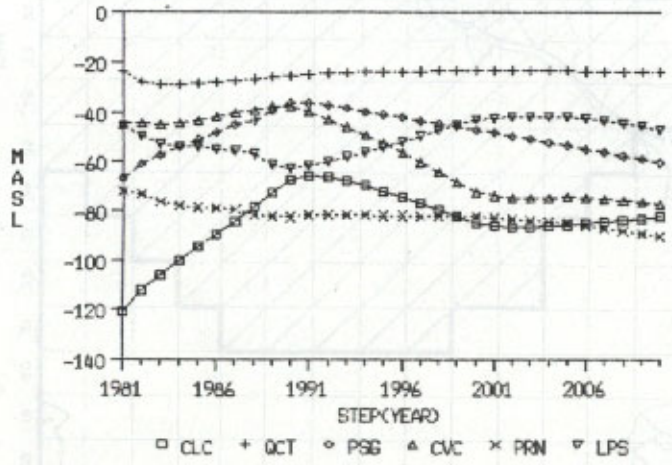
(Contour Interval: 10m, Unit: m)

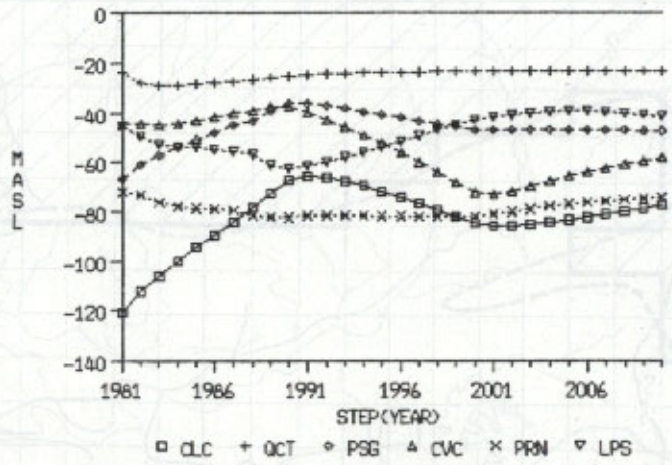


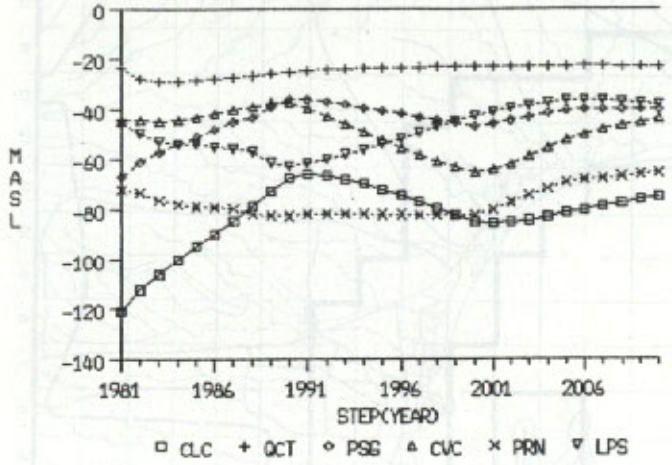
b) Scenario 4

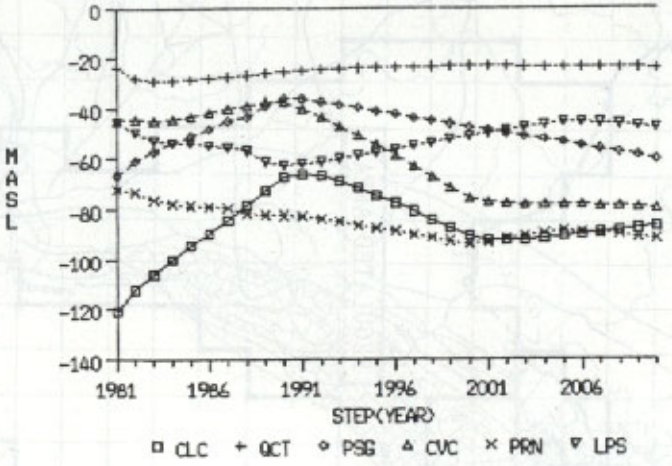
(Contour Interval: 10m, Unit: m)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.27 SIMULATED PIEZOMETRIC CHANGES FROM 1991 TO 2010 (Scenario 3, Scenario 4)
JAPAN INTERNATIONAL COOPERATION AGENCY	







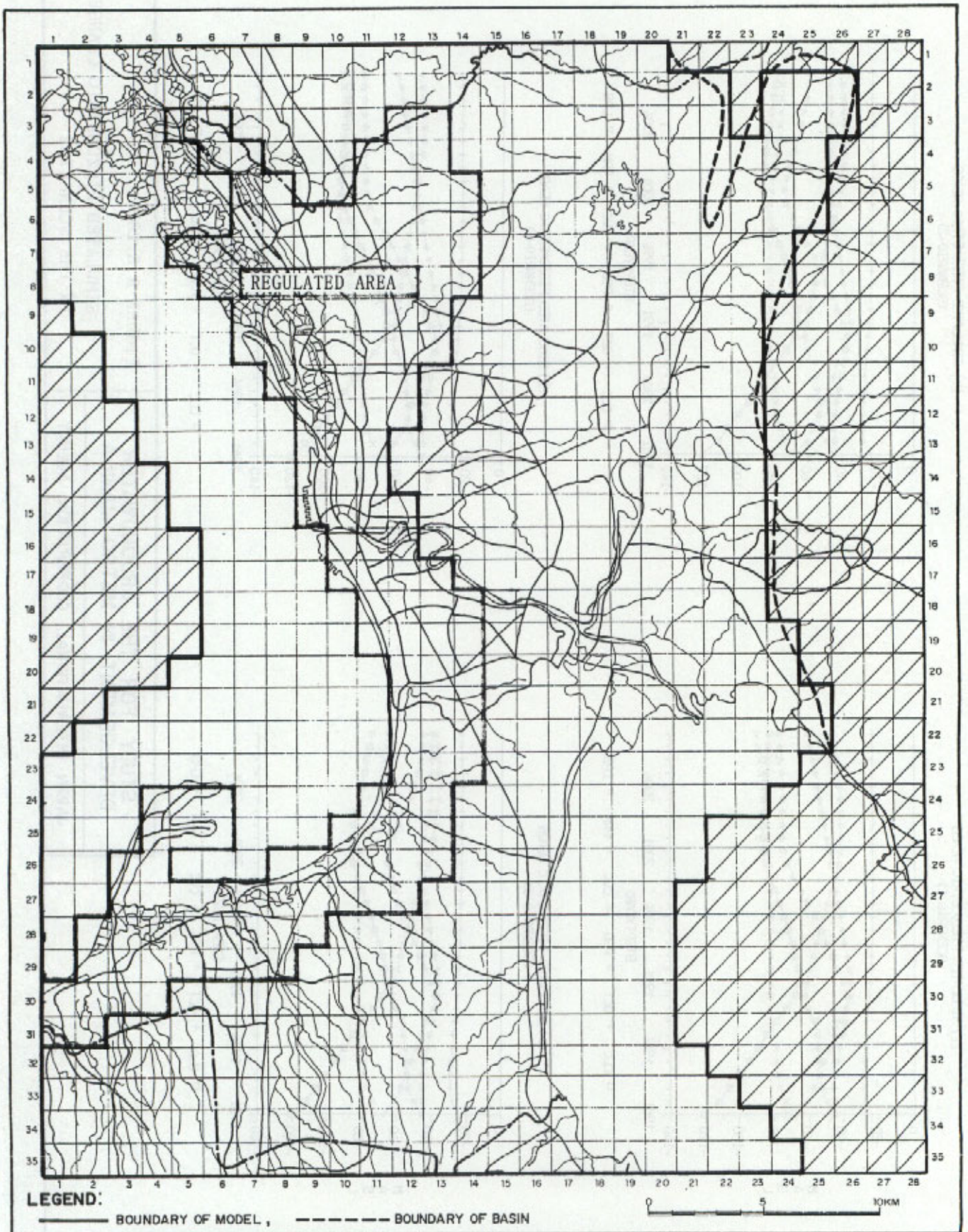


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.28

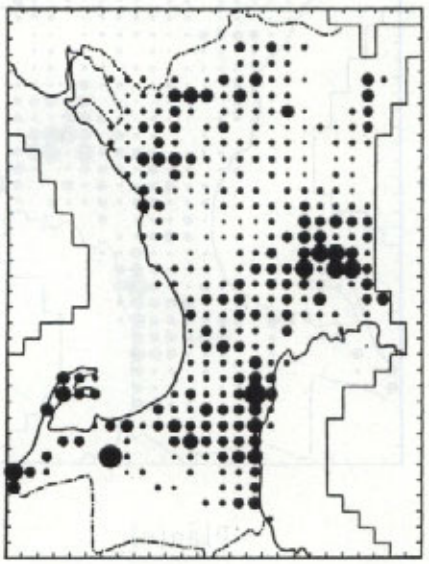
SIMULATED PIEZOMETRIC CHANGES IN THE SCENARIOS



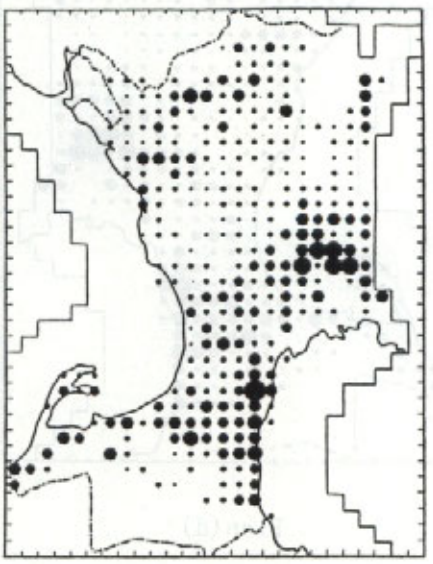
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

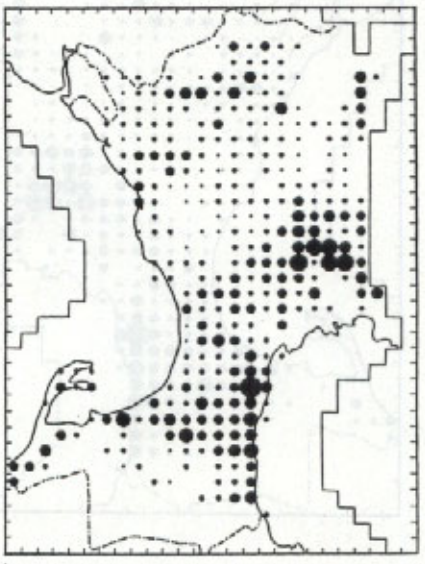
FIGURE 8.5.29
REGULATED AREA FOR GROUNDWATER PUMPAGE



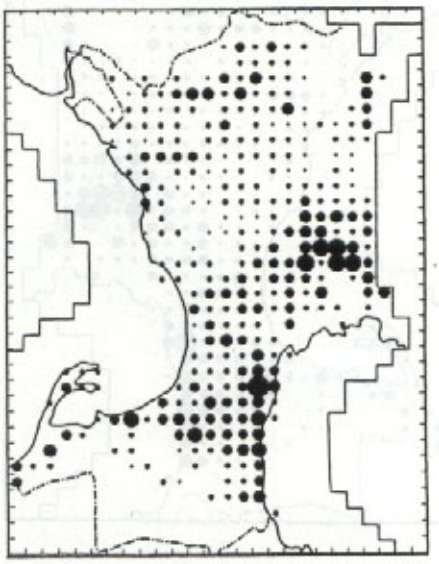
Scenario 1



Plan(a)

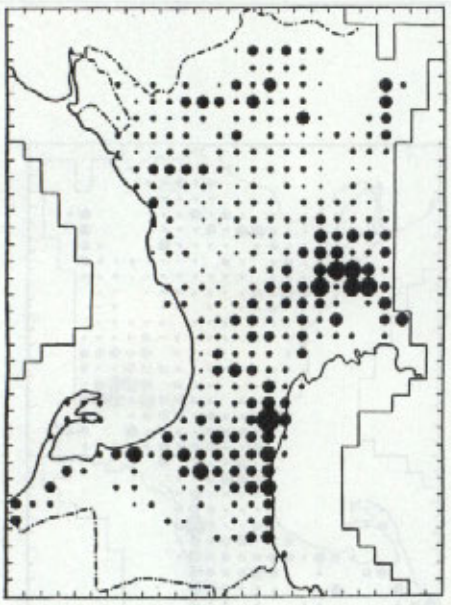


Plan(b)

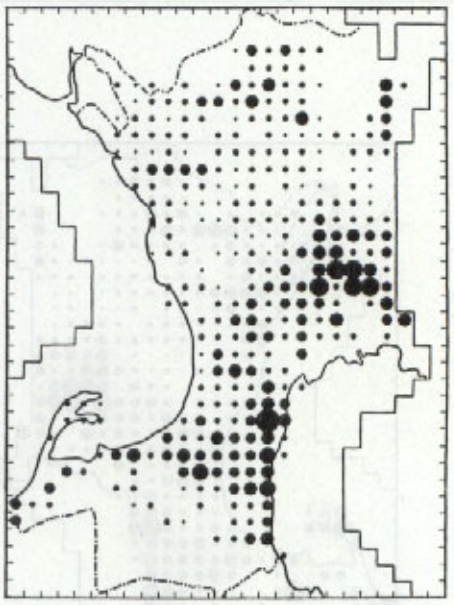


Plan(c)

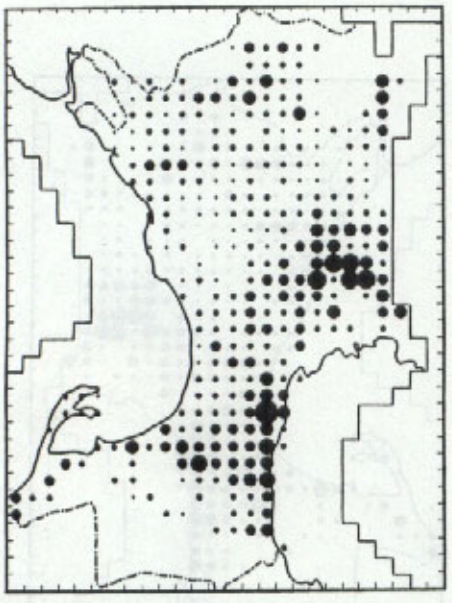
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA JAPAN INTERNATIONAL COOPERATION AGENCY	FIGURE 8.5.30 DISCHARGE DISTRIBUTION OF FUTURE PLANS IN 2010 (1)



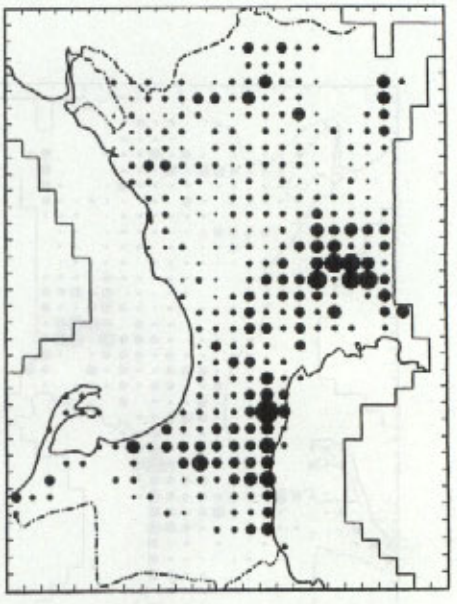
Plan(d)



Plan(e)



Plan(f)

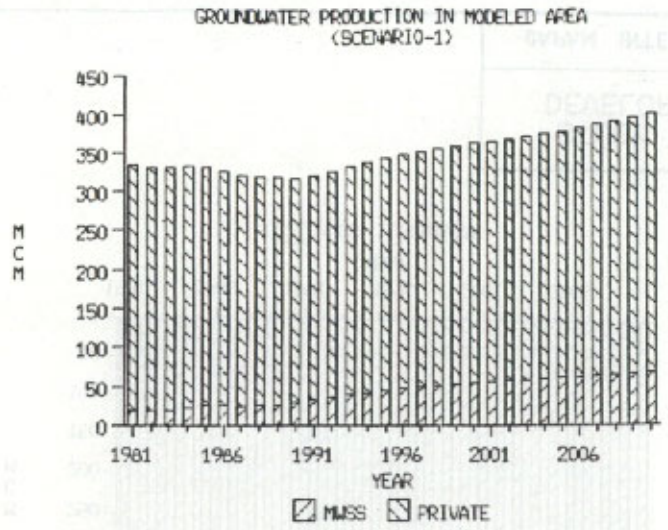


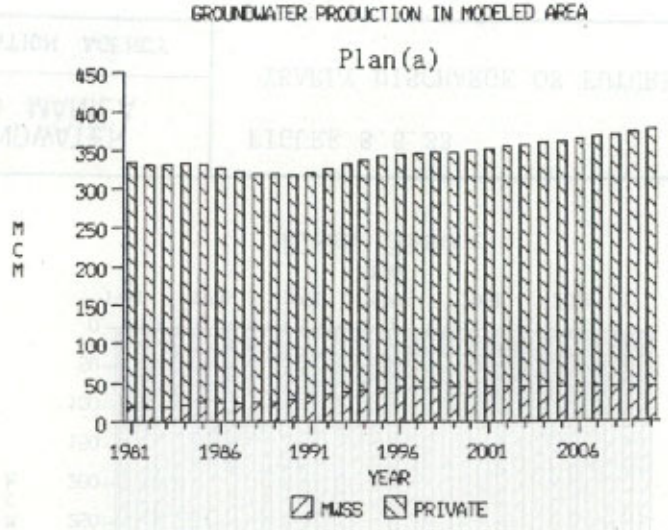
Plan(g)

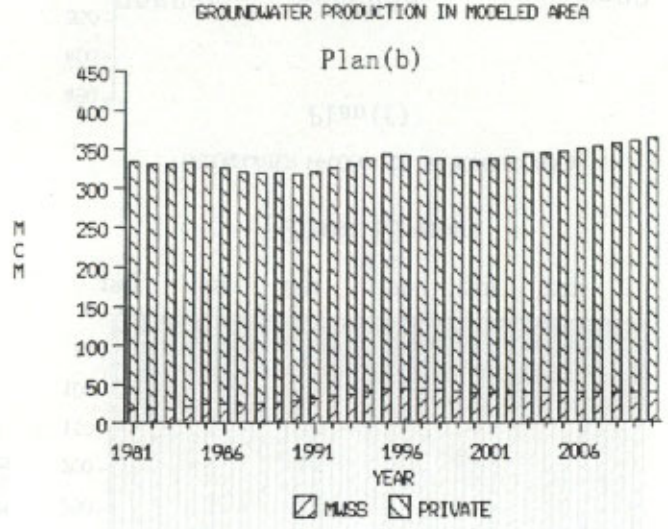
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

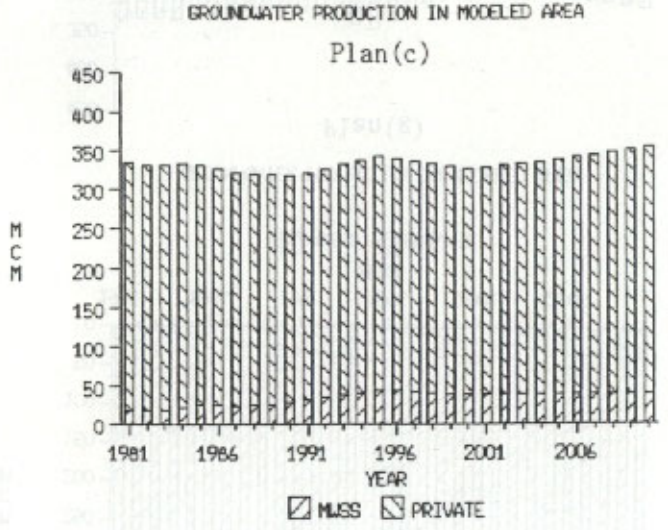
JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.5.31
DISCHARGE DISTRIBUTION OF FUTURE PLANS IN 2010 (2)









STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

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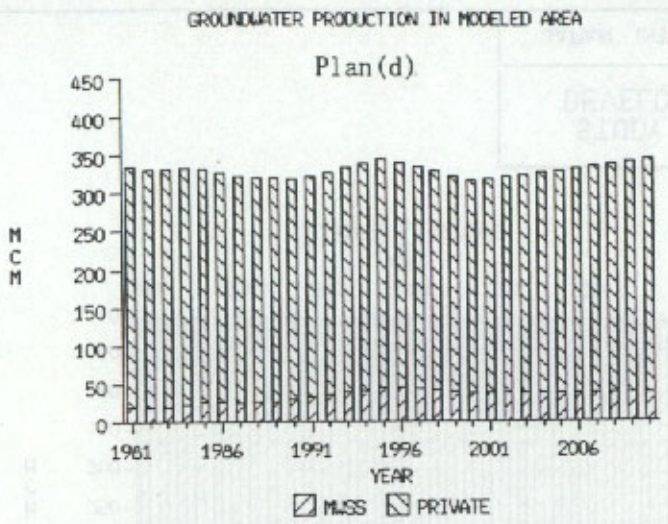
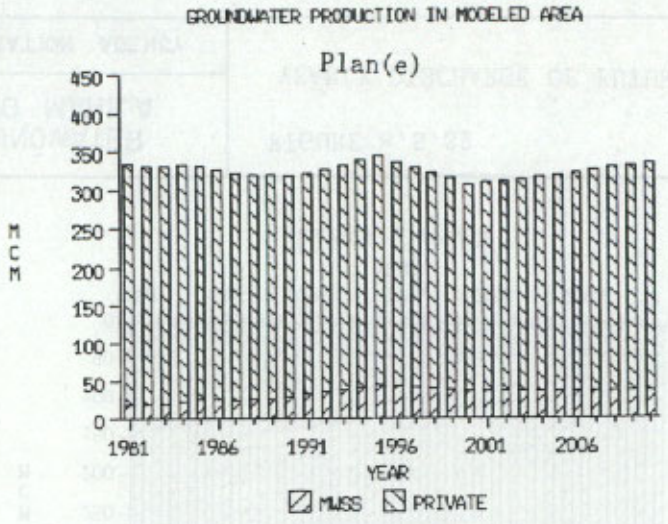
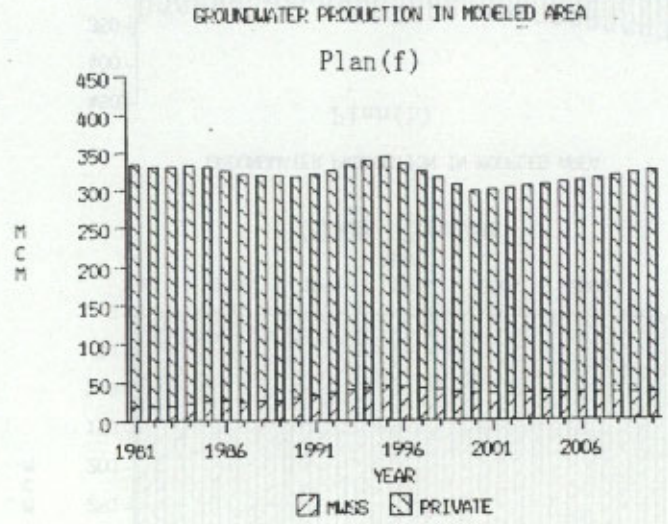
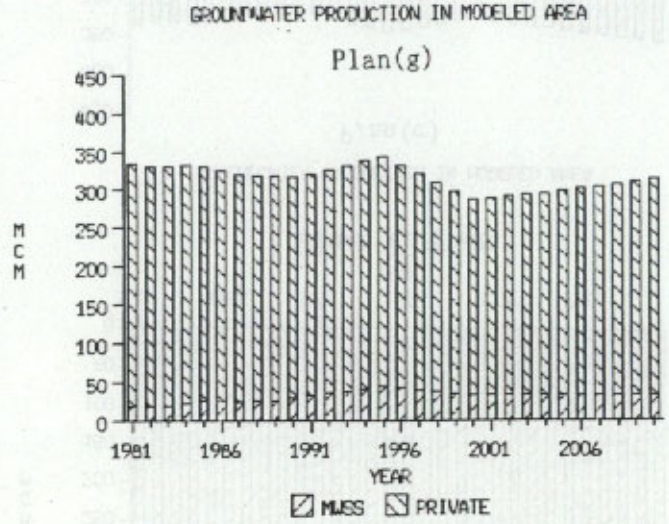
FIGURE 8.5.32

YEARLY DISCHARGE OF FUTURE PLANS (1)

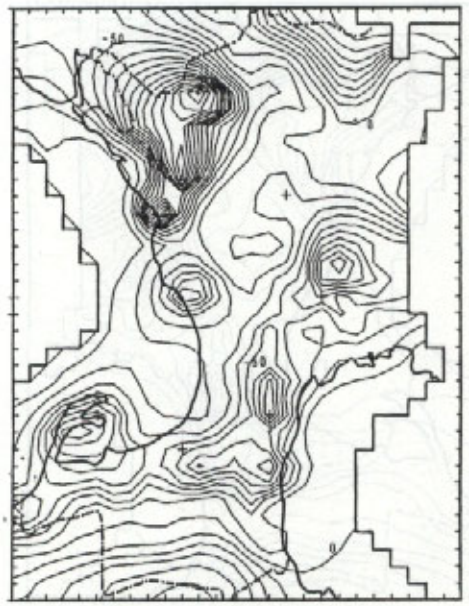




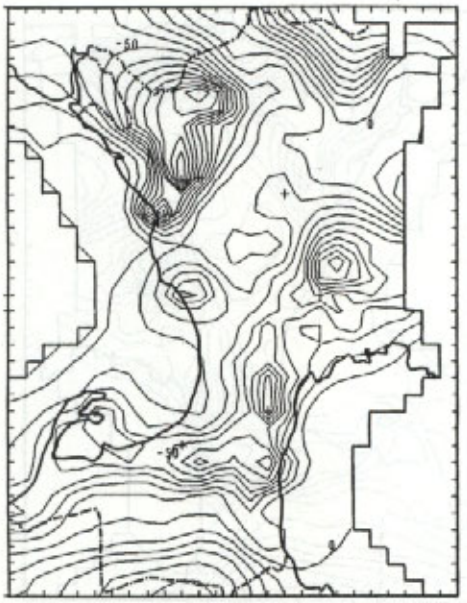




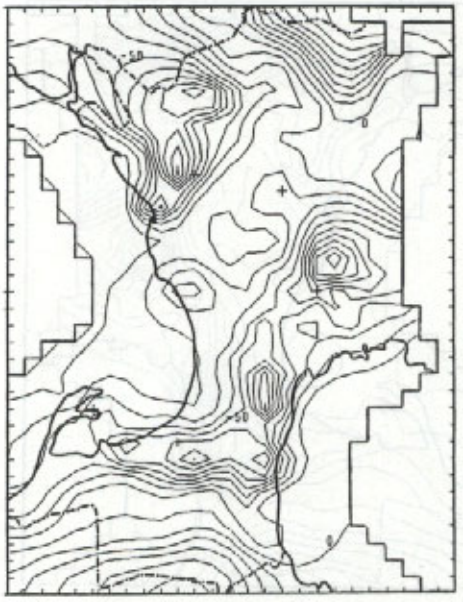
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.33
JAPAN INTERNATIONAL COOPERATION AGENCY	YEARLY DISCHARGE OF FUTURE PLANS (2)



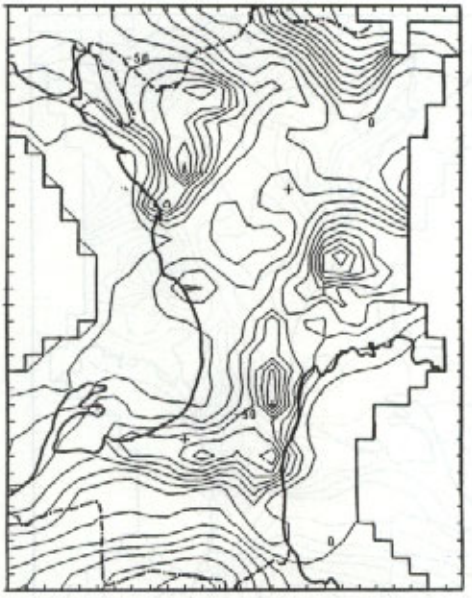
Scenario 1



Plan(a)



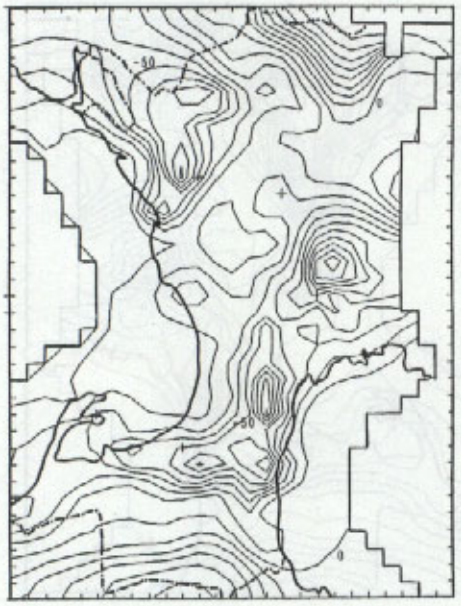
Plan(b)



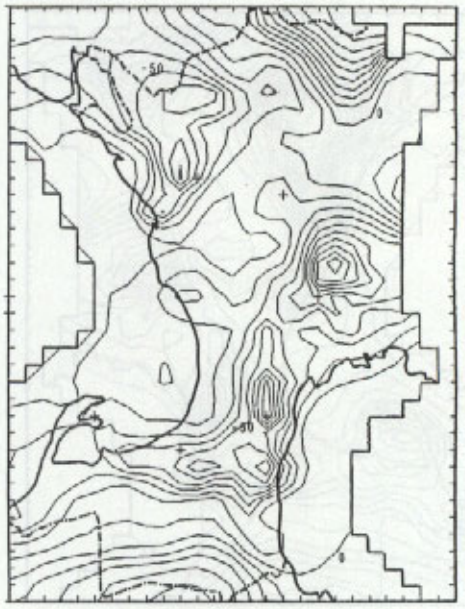
Plan(c)

(Contour Interval: 10m, Unit: masl)

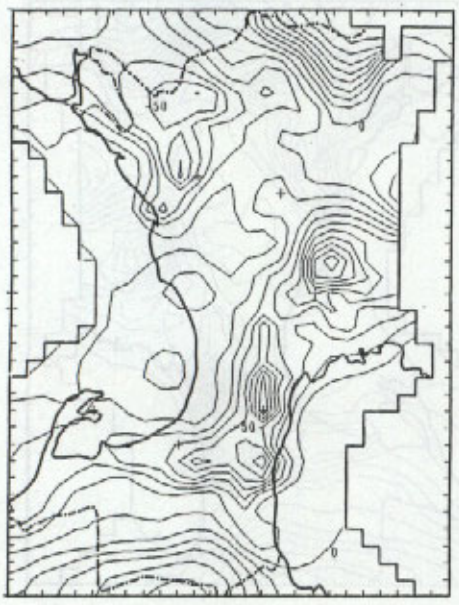
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.34 SIMULATED PIEZOMETRIC HEADS IN 2010 BY THE FUTURE DISCHARGE PLANS (1)
JAPAN INTERNATIONAL COOPERATION AGENCY	



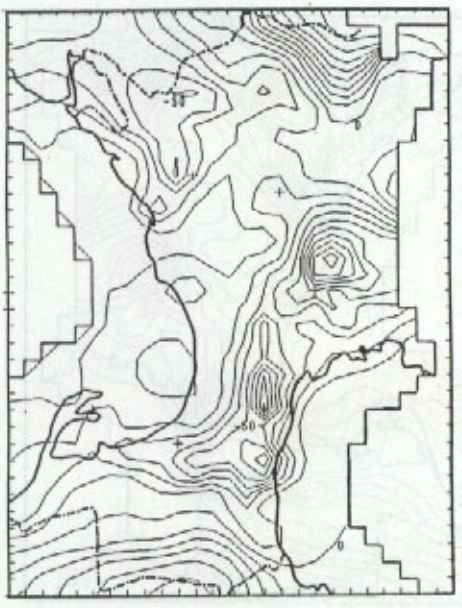
Plan(d)



Plan(e)



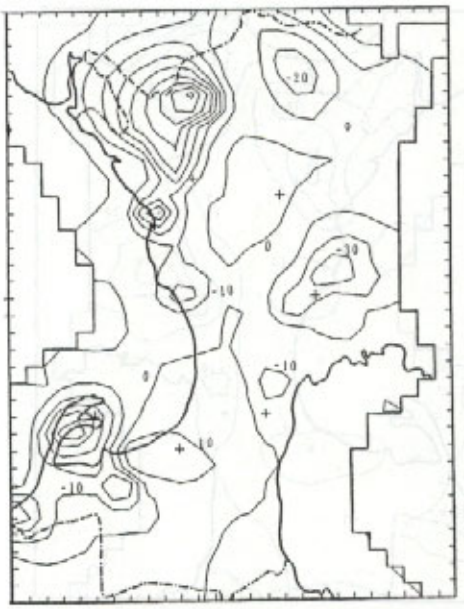
Plan(f)



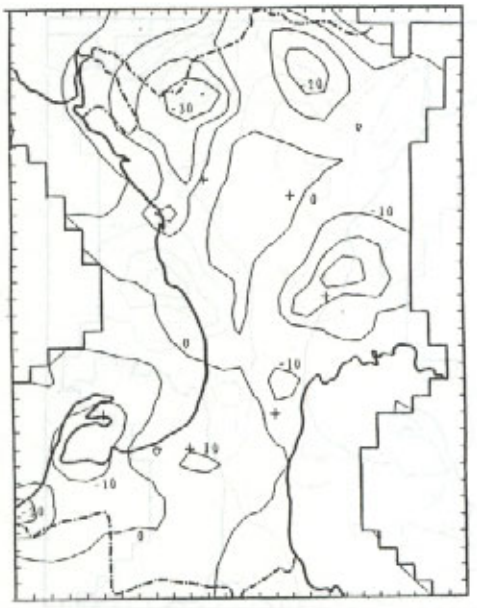
Plan(g)

(Contour Interval: 10m, Unit: masl)

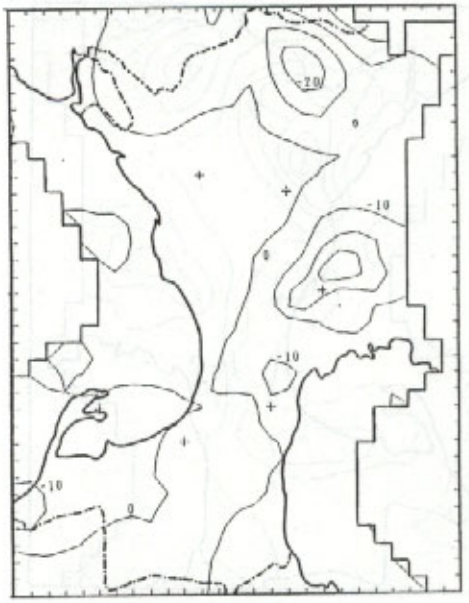
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.35 SIMULATED PIEZOMETRIC HEADS IN 2010 BY THE FUTURE DISCHARGE PLANS (2)
JAPAN INTERNATIONAL COOPERATION AGENCY	



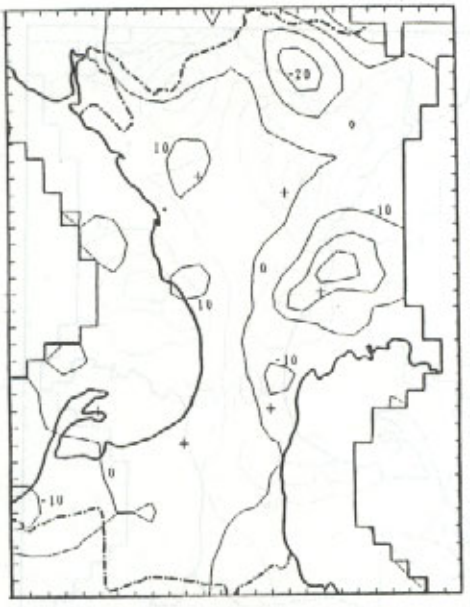
Scenario 1



Plan(a)



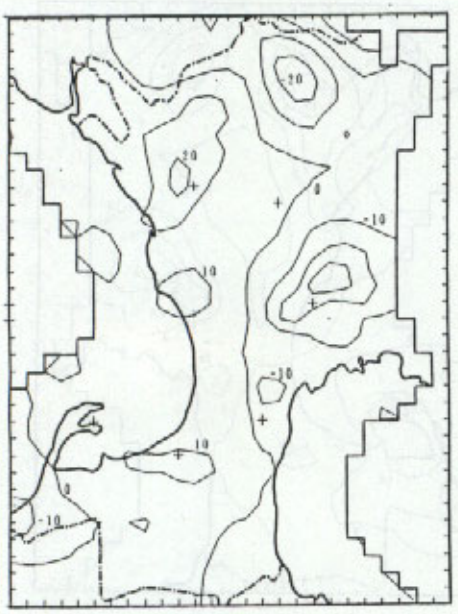
Plan(b)



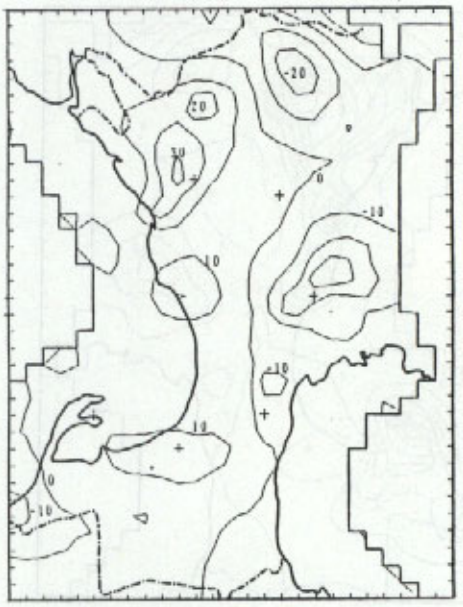
Plan(c)

(Contour Interval: 10m, Unit: m)

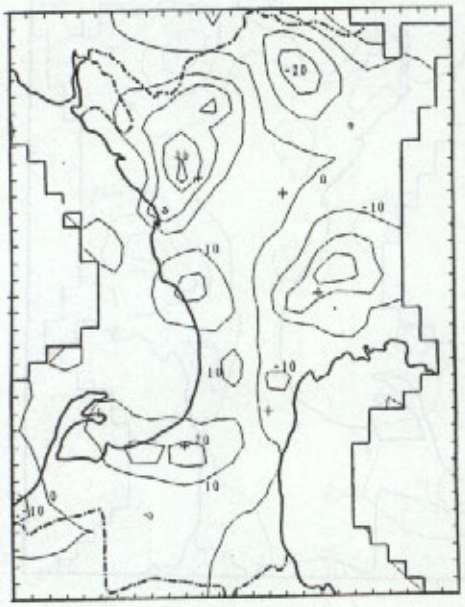
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.36 SIMULATED PIEZOMETRIC CHANGES FROM 1991 TO 2010 BY THE FUTURE DISCHARGE PLANS (1)
JAPAN INTERNATIONAL COOPERATION AGENCY	



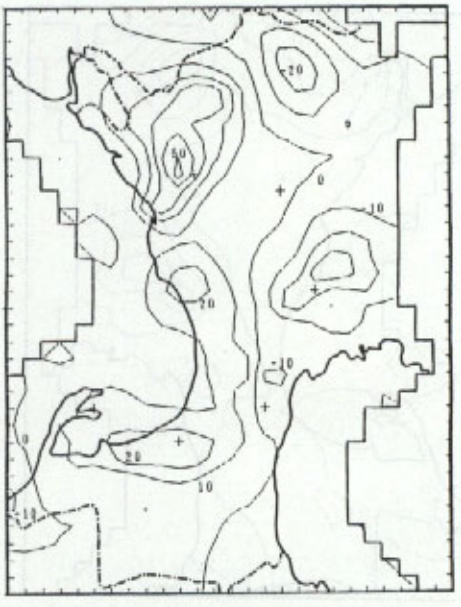
Plan(d)



Plan(e)



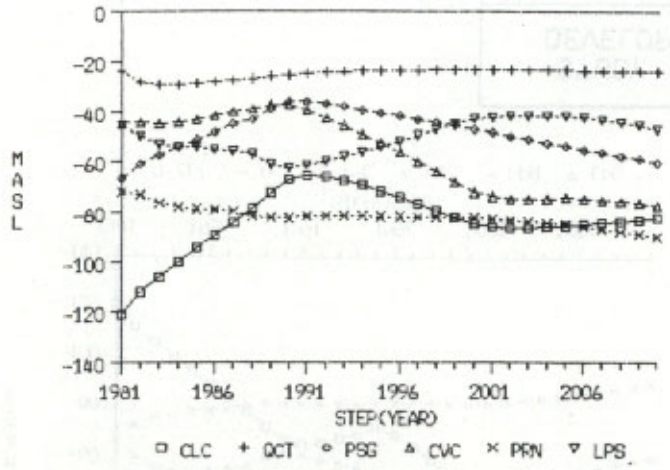
Plan(f)

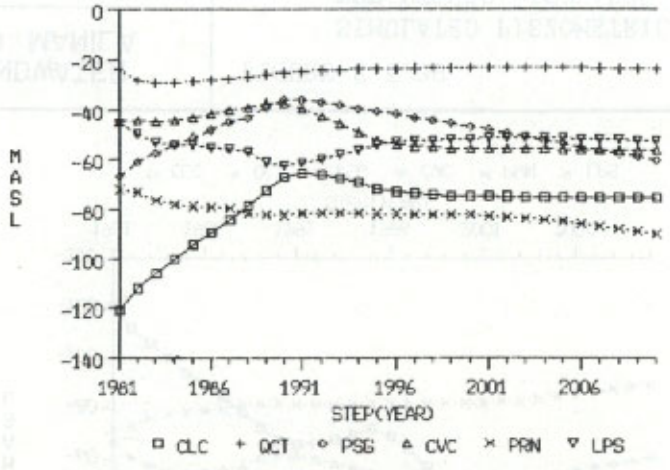


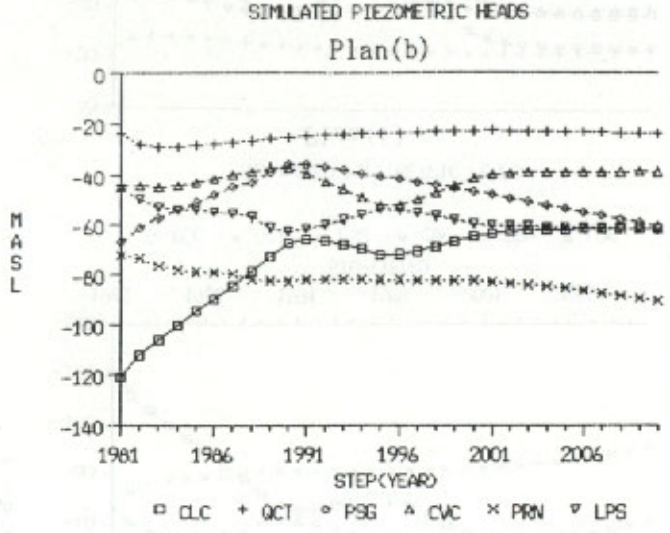
Plan(g)

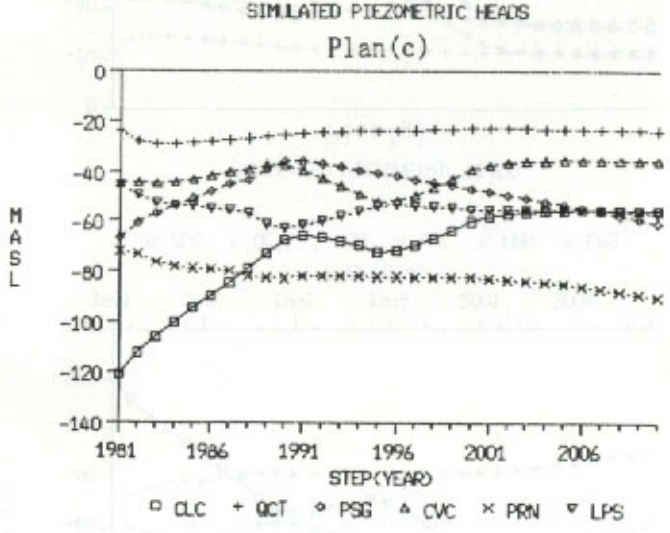
(Contour Interval: 10m, Unit: m)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.37 SIMULATED PIEZOMETRIC CHANGES FROM 1991 TO 2010 BY THE FUTURE DISCHARGE PLANS (2)
JAPAN INTERNATIONAL COOPERATION AGENCY	

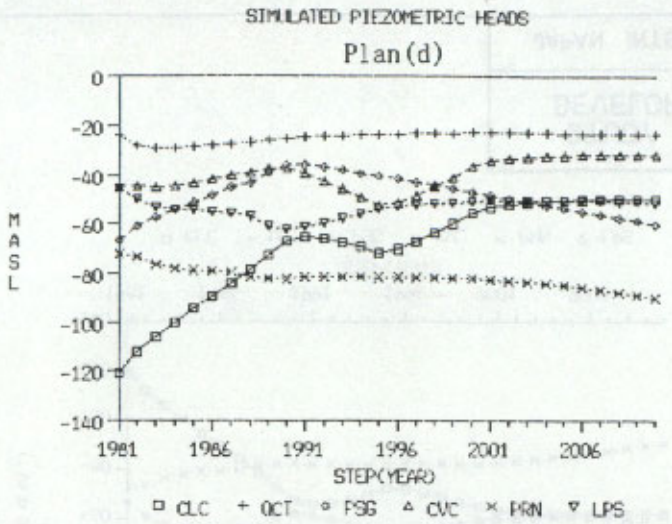


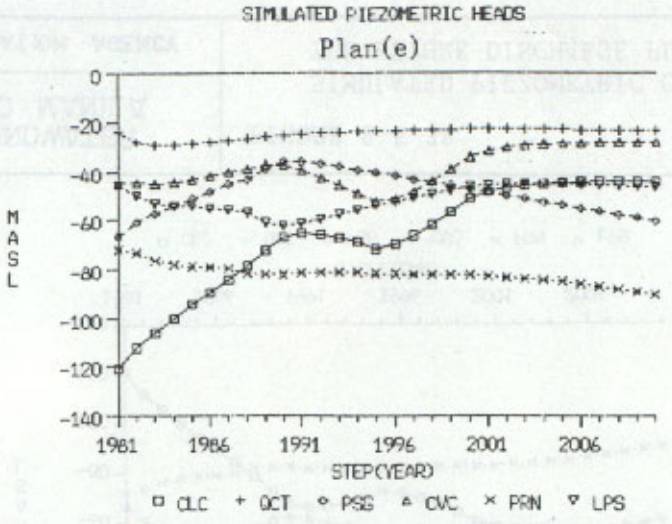


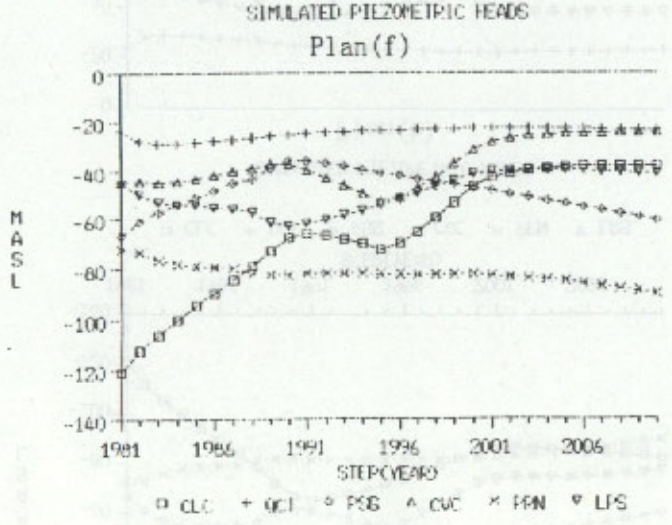


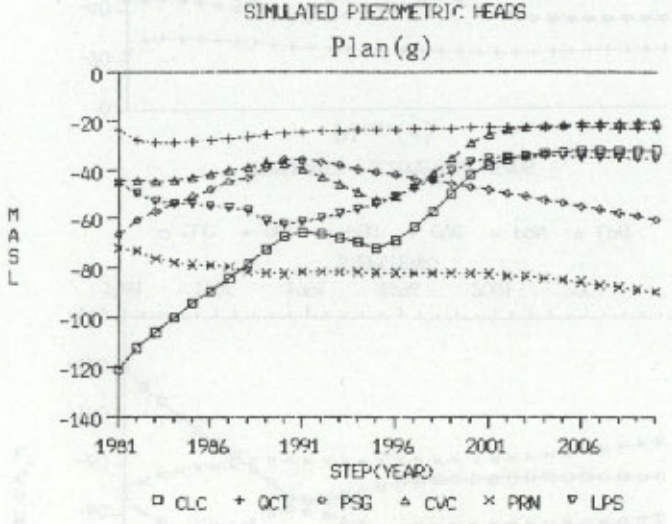


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.38 SIMULATED PIEZOMETRIC CHANGES BY THE FUTURE DISCHARGE PLANS (1)
JAPAN INTERNATIONAL COOPERATION AGENCY	

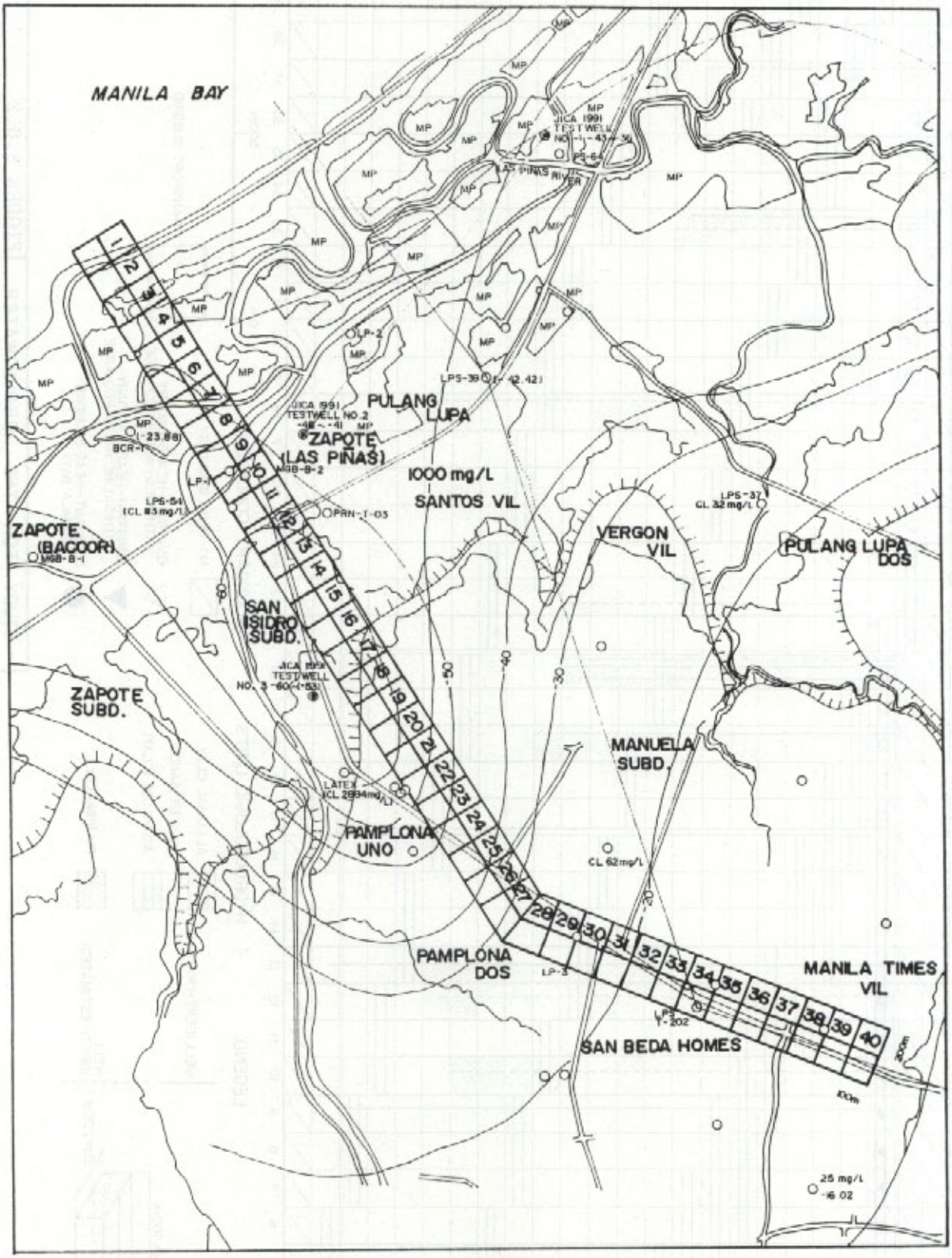








STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.5.39 SIMULATED PIEZOMETRIC CHANGES BY THE FUTURE DISCHARGE PLANS (2)
JAPAN INTERNATIONAL COOPERATION AGENCY	



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

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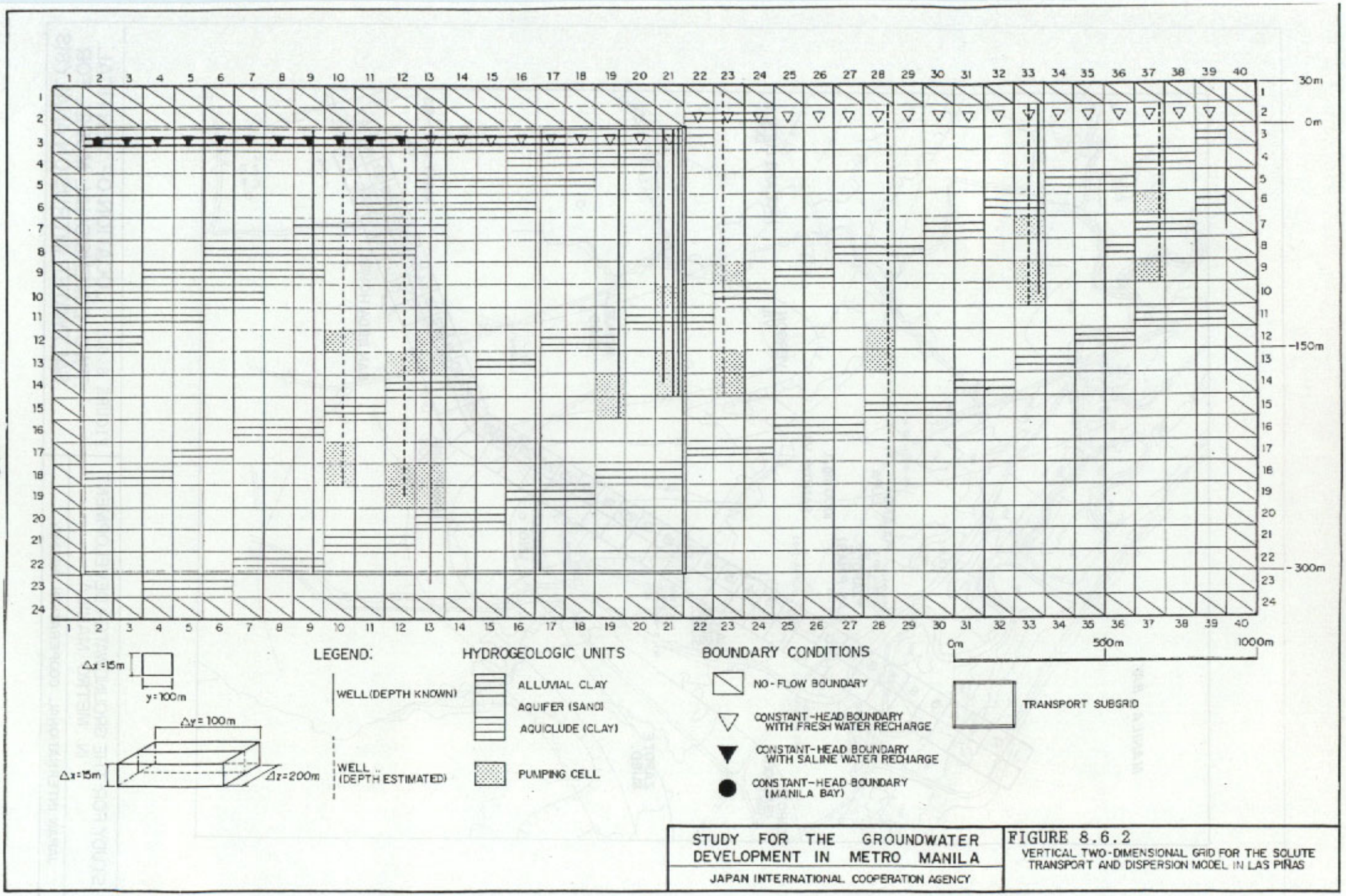
FIGURE 8.6.1 **LOCATION OF VERTICAL TWO-DIMENSIONAL MODEL FOR SALTWATER INTRUSION ANALYSIS**



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

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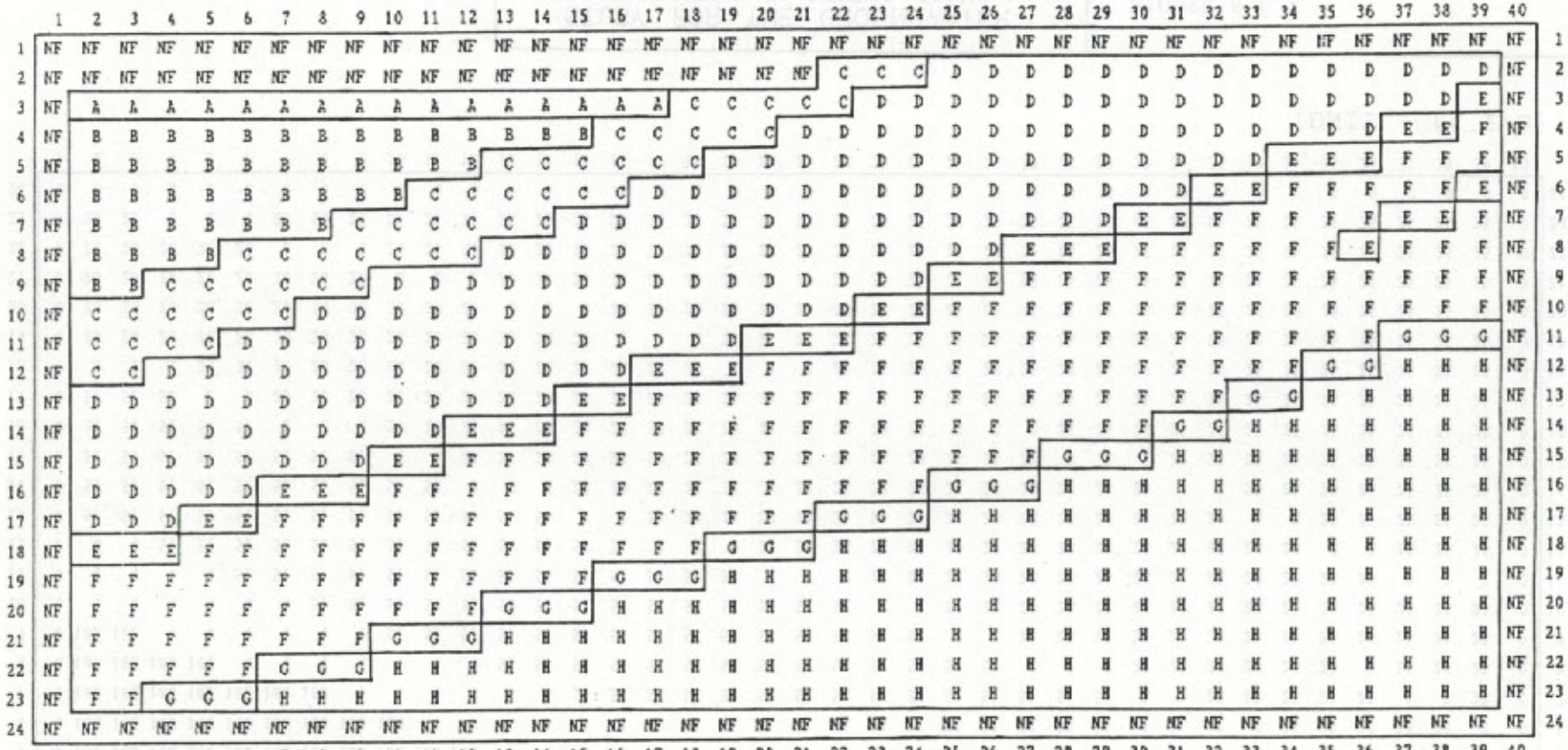
FIGURE 8.6.2
VERTICAL TWO-DIMENSIONAL GRID FOR THE SOLUTE TRANSPORT AND DISPERSION MODEL IN LAS PIÑAS



Label	Hydrogeologic Unit
A	Alluvium
B	Aquifer-1
C	Aquiclude-1
D	Aquifer-2
E	Aquiclude-2
F	Aquifer-3
G	Aquiclude-3
H	Aquifer-4
NF	No-Flow Boundary

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FIGURE 8.6.3
MODELED HYDROGEOLOGIC UNIT

	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	29	30	31	32	33	34	35	36	37	38	39	40	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	0	2
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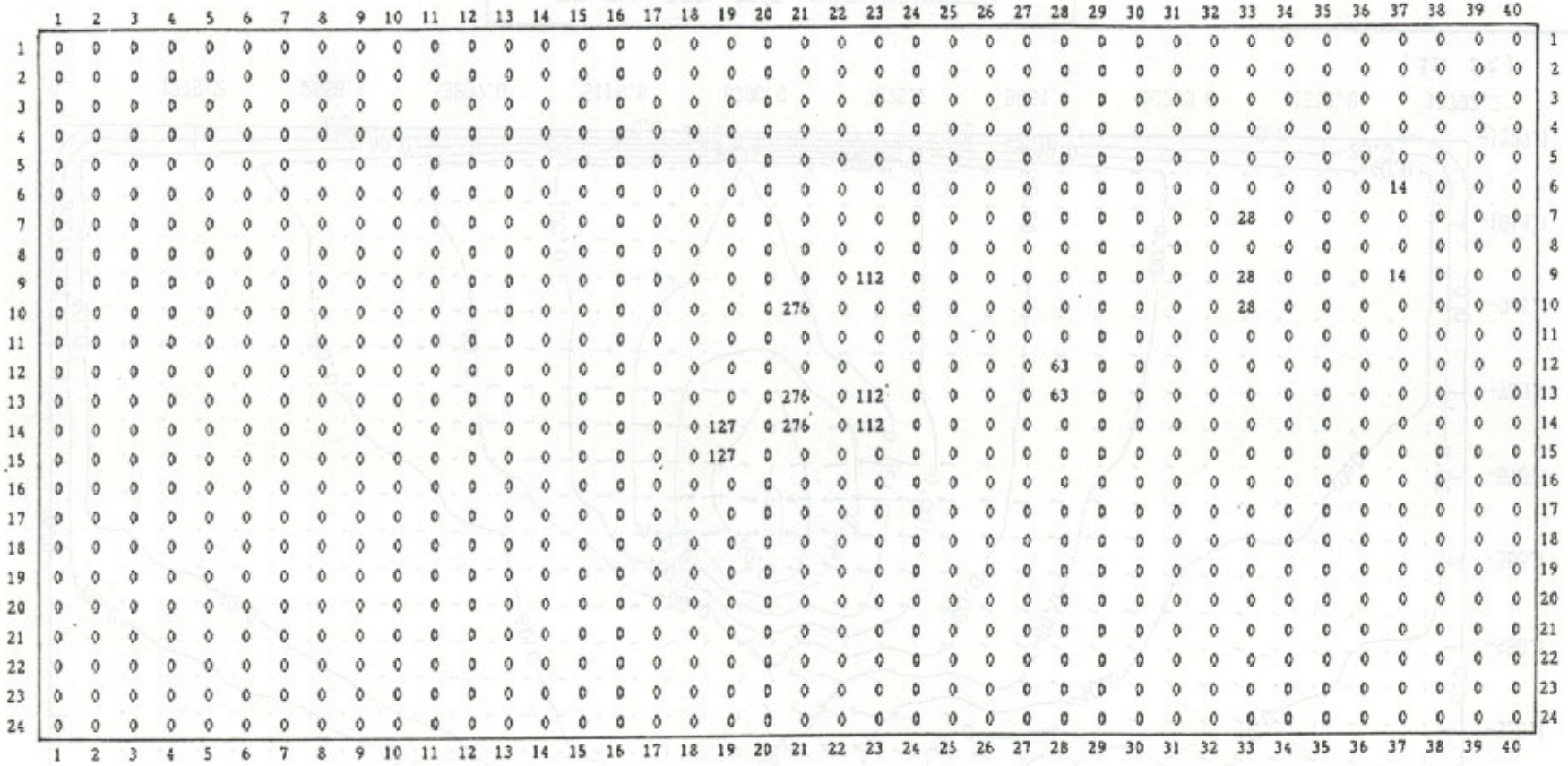
(UNIT : ft^2/s)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.6.4

TRANSMISSIVITY MAP OF LAS PIÑAS MODEL



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1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	0	6
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	0	0	0	0	0	0	7
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	112	0	0	0	0	0	0	0	0	0	28	0	0	0	14	0	0	0	9
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	276	0	0	0	0	0	0	0	0	0	0	0	28	0	0	0	0	0	0	0	10
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14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	127	0	276	0	112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	127	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
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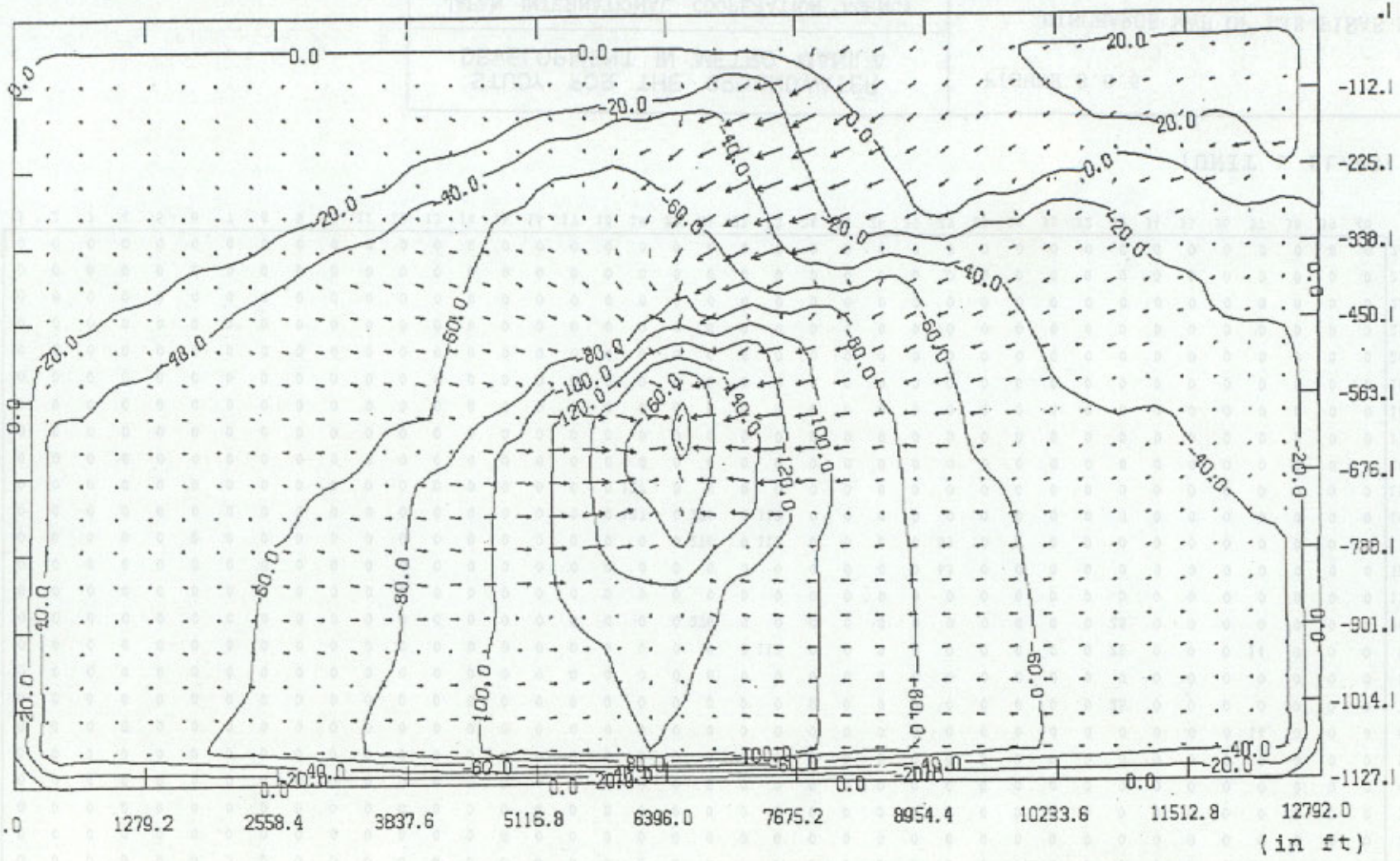
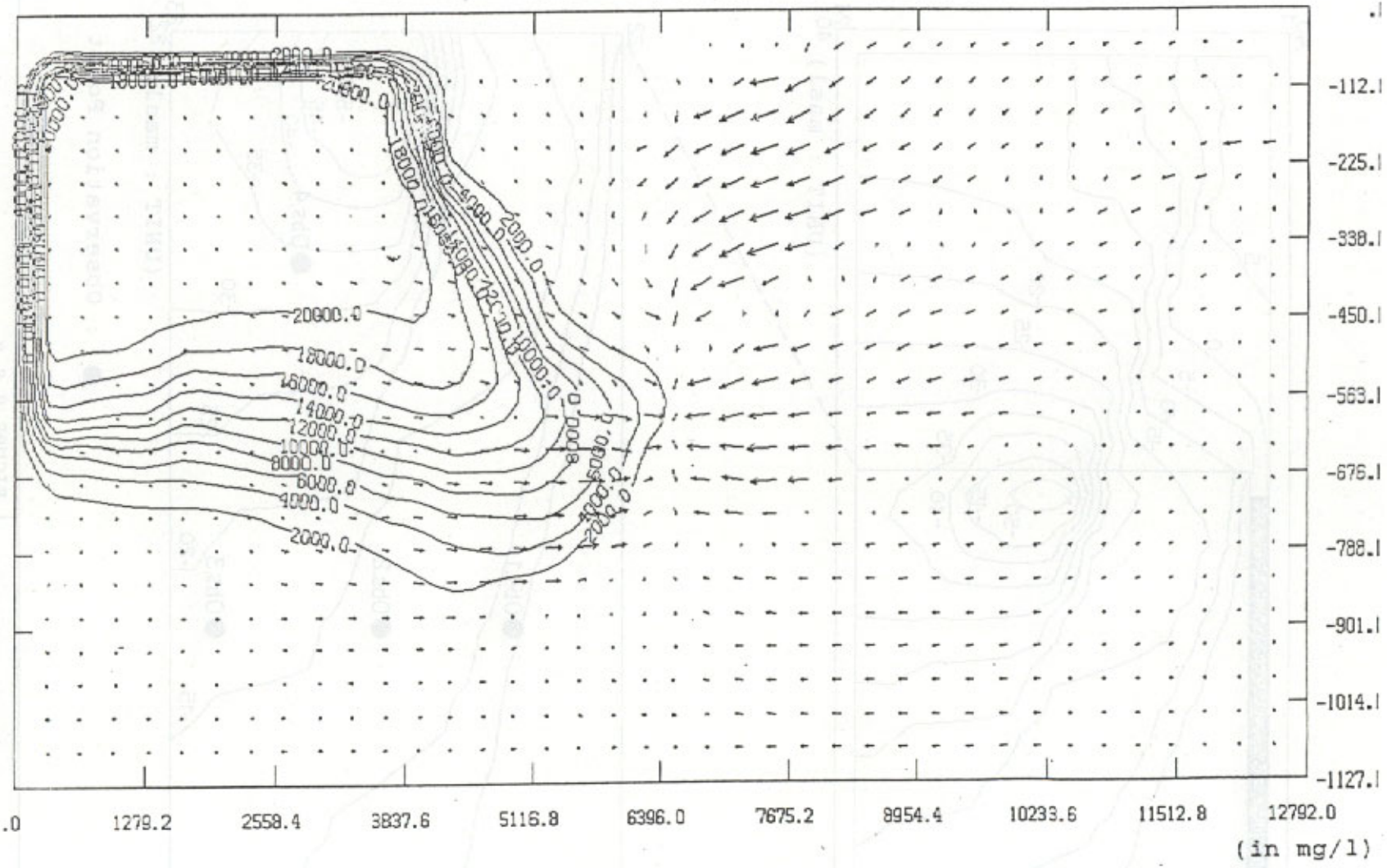
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24
	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	29	30	31	32	33	34	35	36	37	38	39	40	

(UNIT : ft/s)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.6.5
JAPAN INTERNATIONAL COOPERATION AGENCY	DISCHARGE MAP OF LAS PIÑAS MODEL



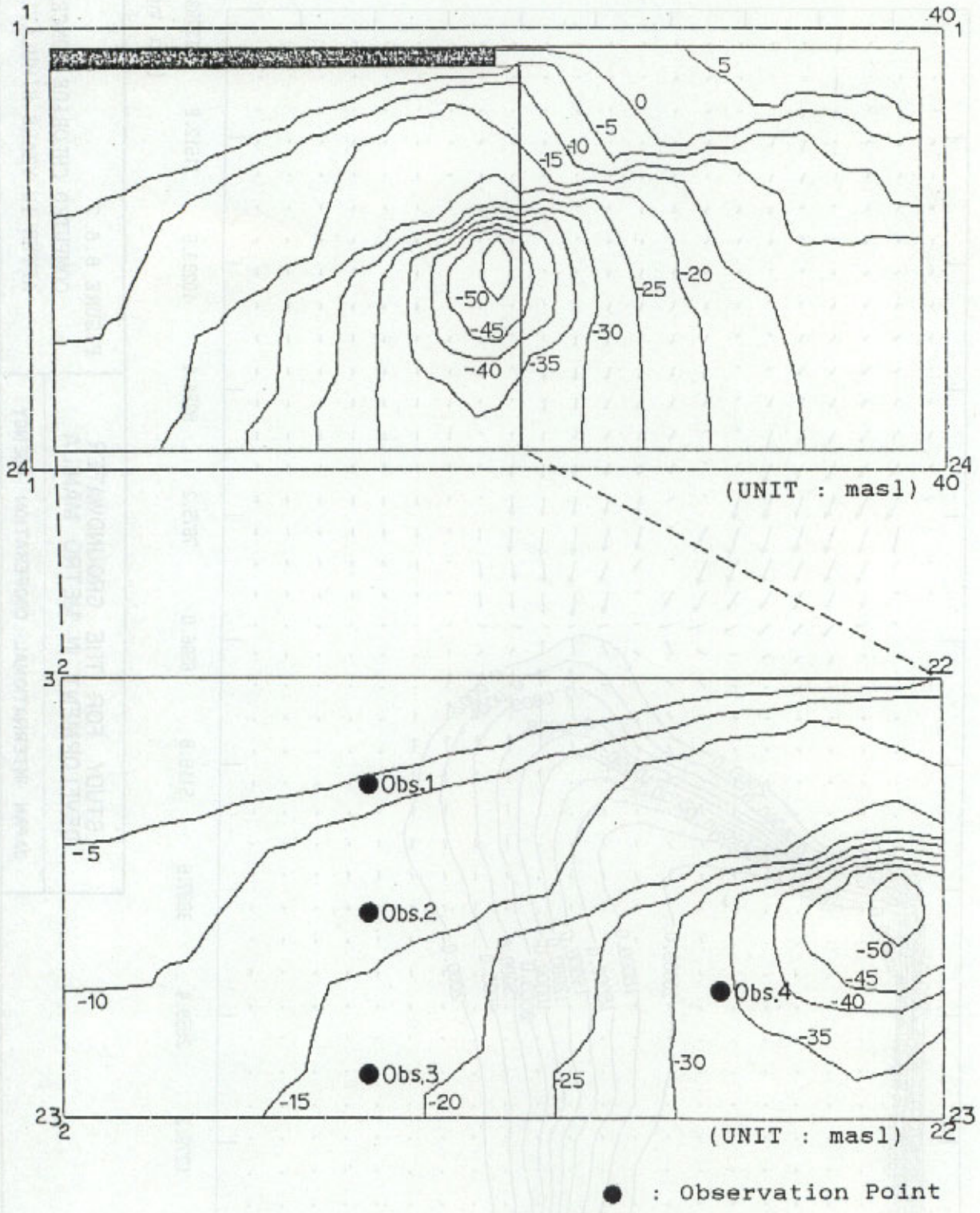
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.6.6 SIMULATED PIEZOMETRIC HEADS IN STEADY-STATE CONDITION
JAPAN INTERNATIONAL COOPERATION AGENCY	



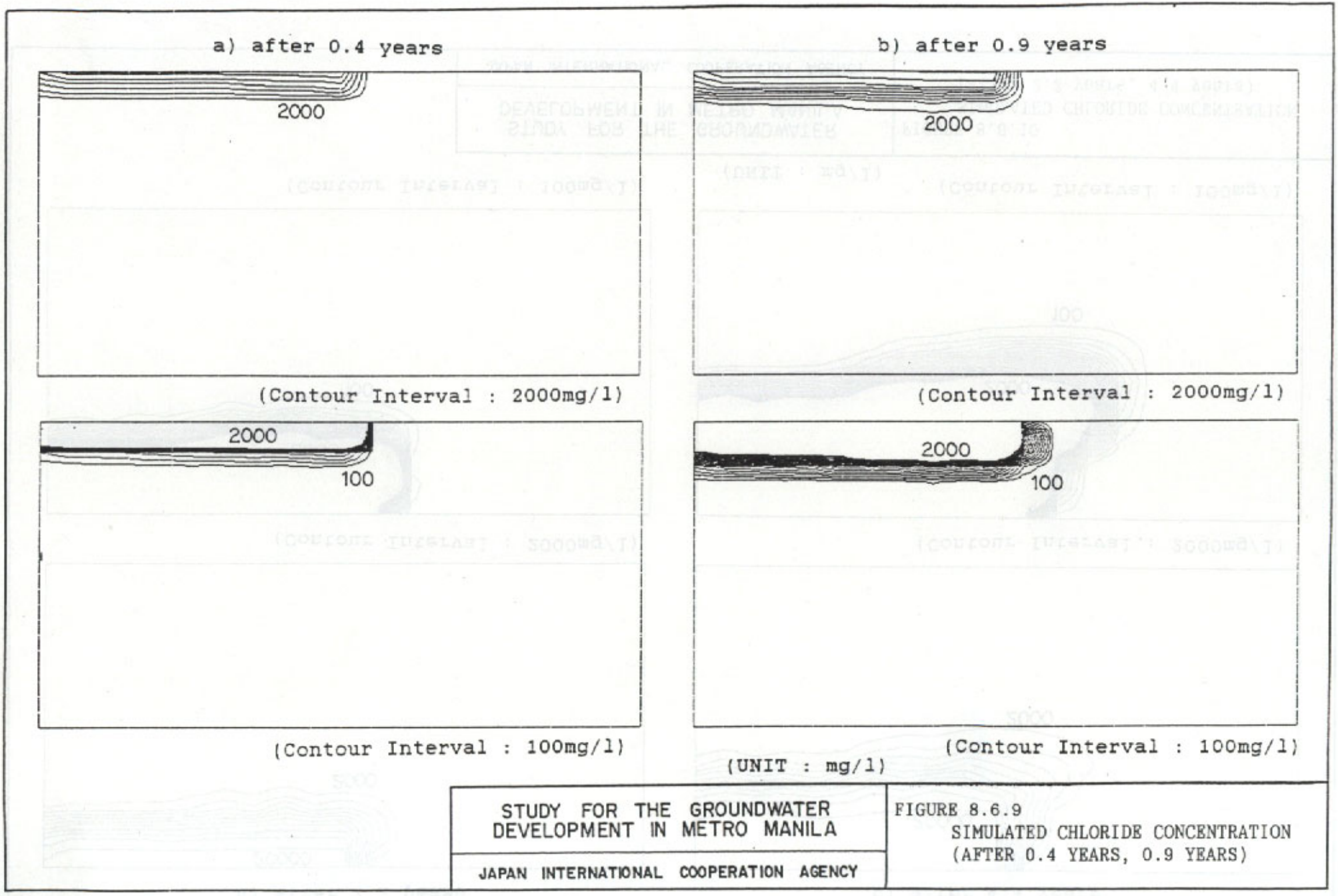
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.6.7
COMPUTED CHLORIDE CONCENTRATIONn
AFTER 10 YEARS SIMULATION



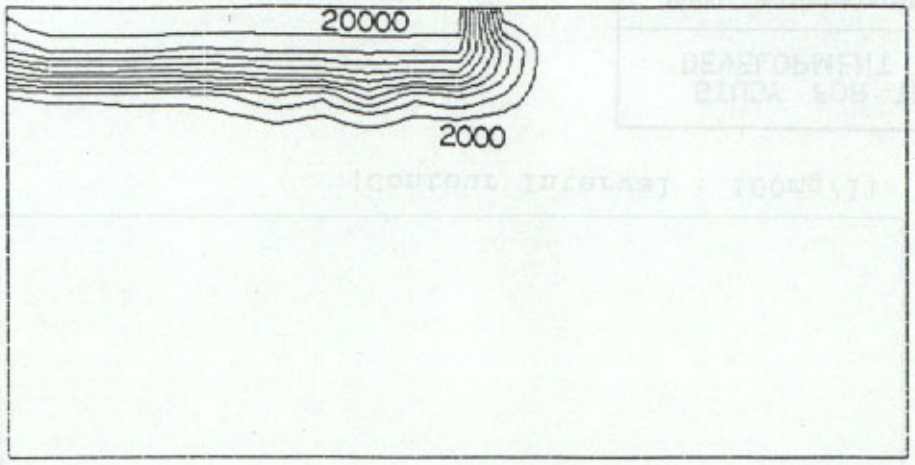
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA JAPAN INTERNATIONAL COOPERATION AGENCY	FIGURE 8.6.8 SIMULATED PIEZOMETRIC HEADS IN TRANSPORT GRID



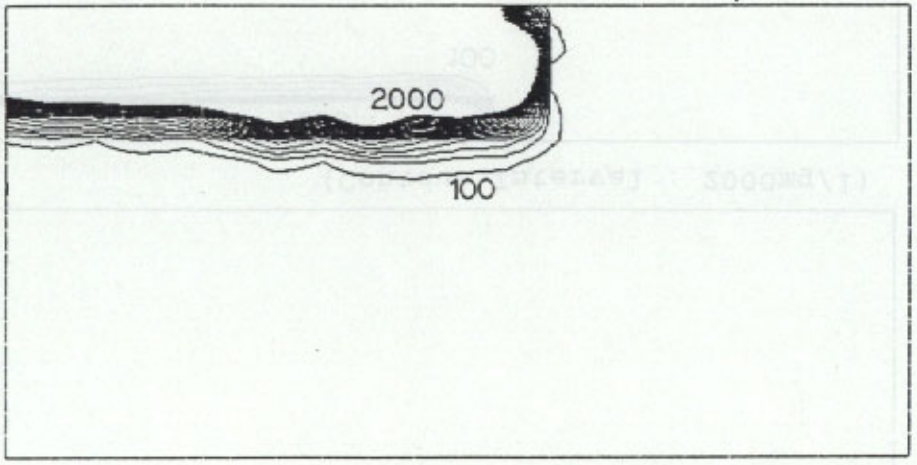
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

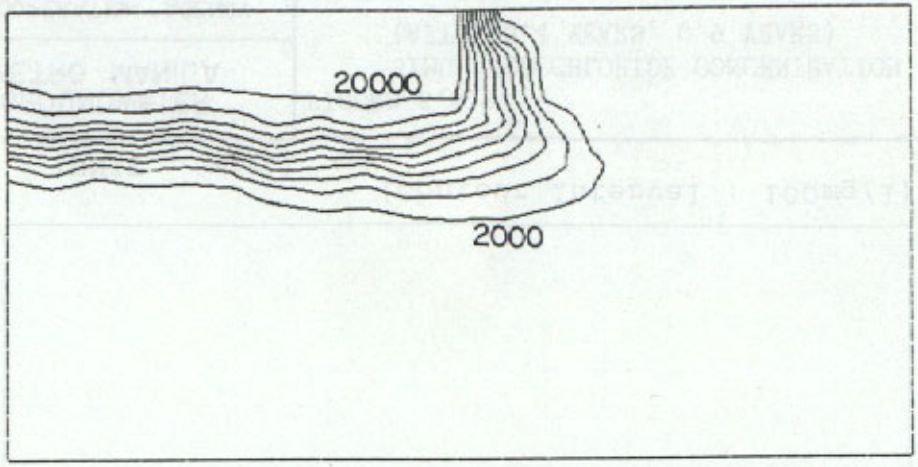
FIGURE 8.6.9
SIMULATED CHLORIDE CONCENTRATION
(AFTER 0.4 YEARS, 0.9 YEARS)



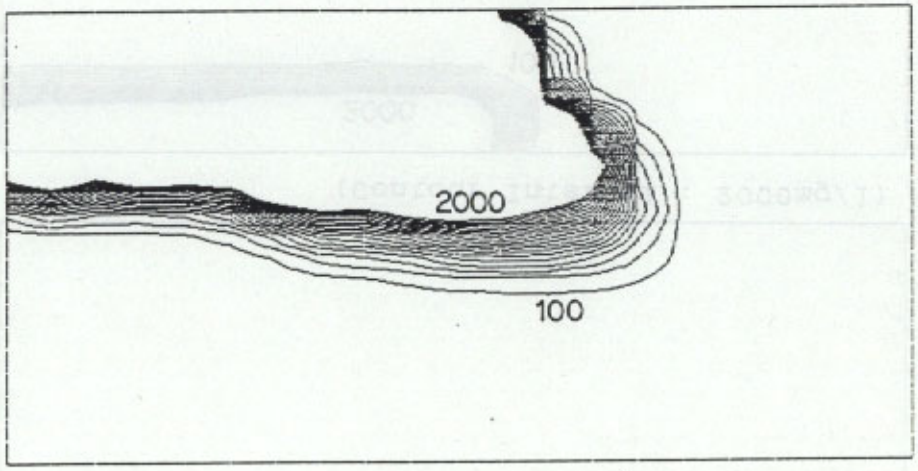
(Contour Interval : 2000mg/l)



(Contour Interval : 100mg/l)



(Contour Interval : 2000mg/l)



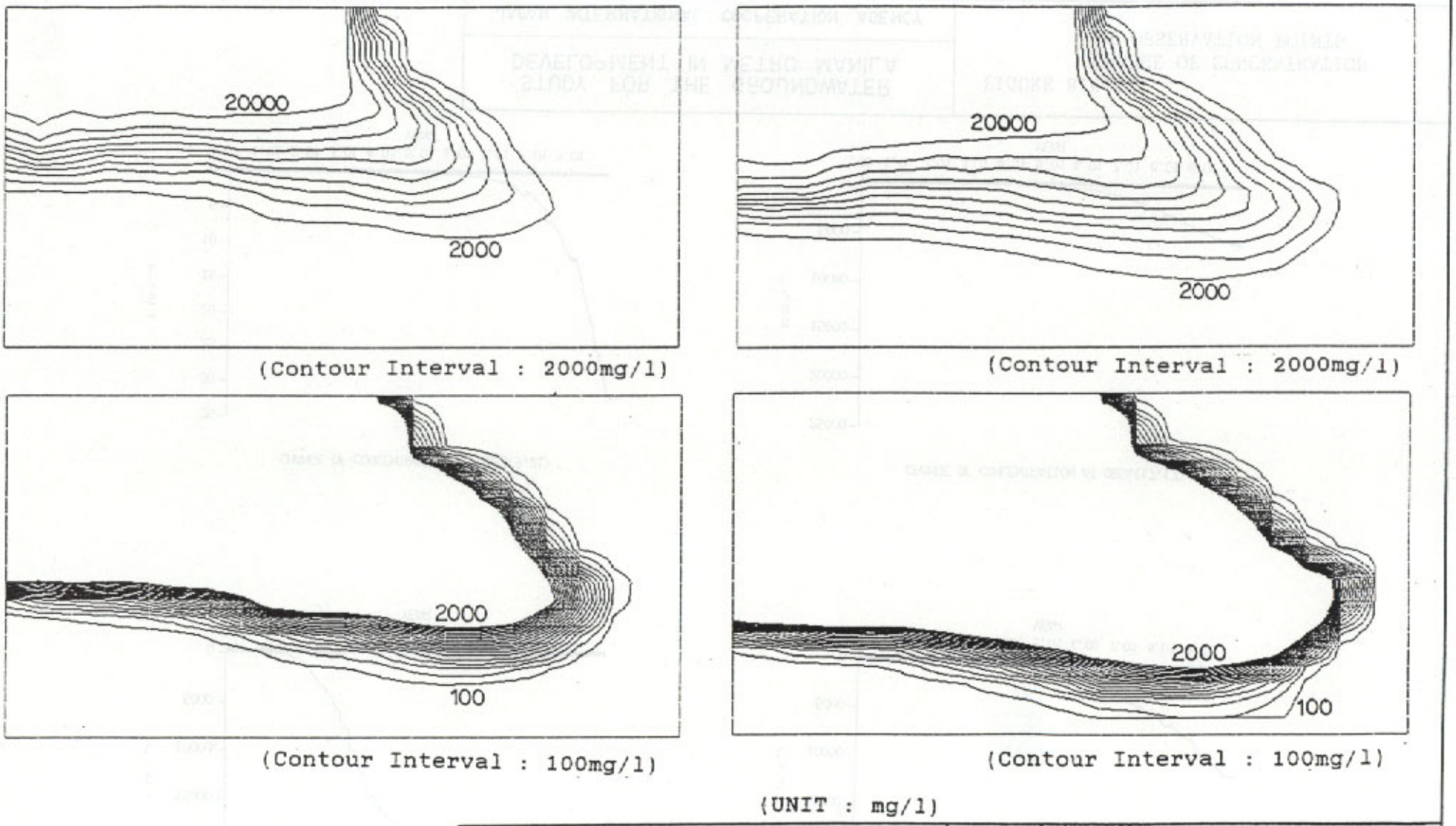
(Contour Interval : 100mg/l)

(UNIT : mg/l)

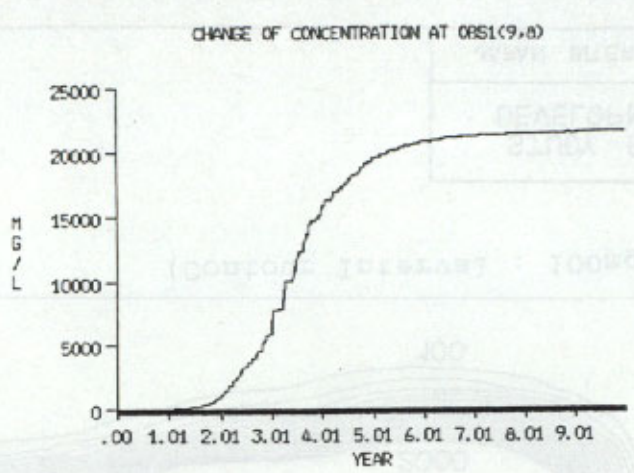
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

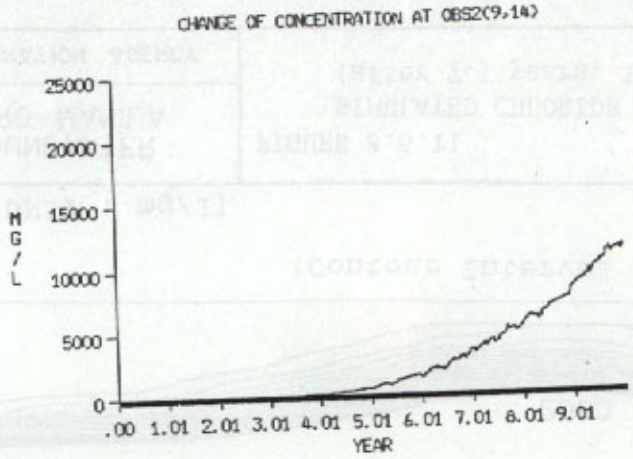
JAPAN INTERNATIONAL COOPERATION AGENCY

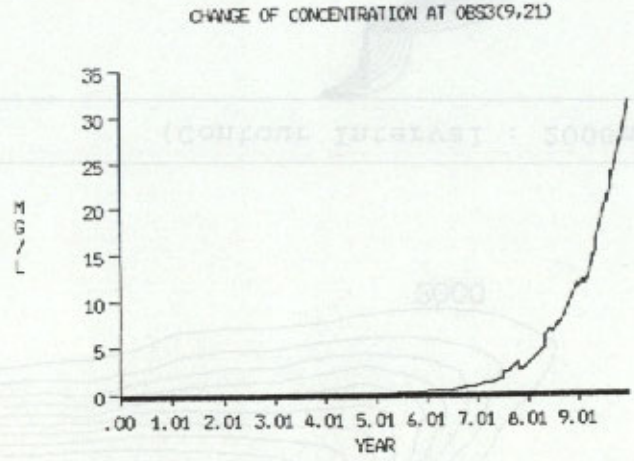
FIGURE 8.6.10
SIMULATED CHLORIDE CONCENTRATION
(after 2.2 years, 4.4 years)

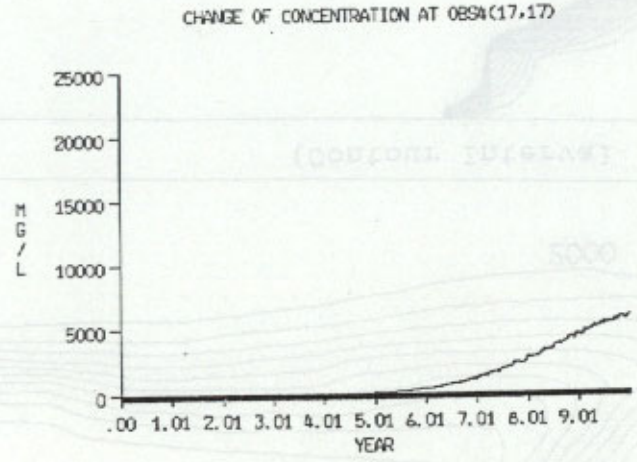


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 8.6.11 SIMULATED CHLORIDE CONCENTRATION (after 7.1 years, 10.0 years)
JAPAN INTERNATIONAL COOPERATION AGENCY	





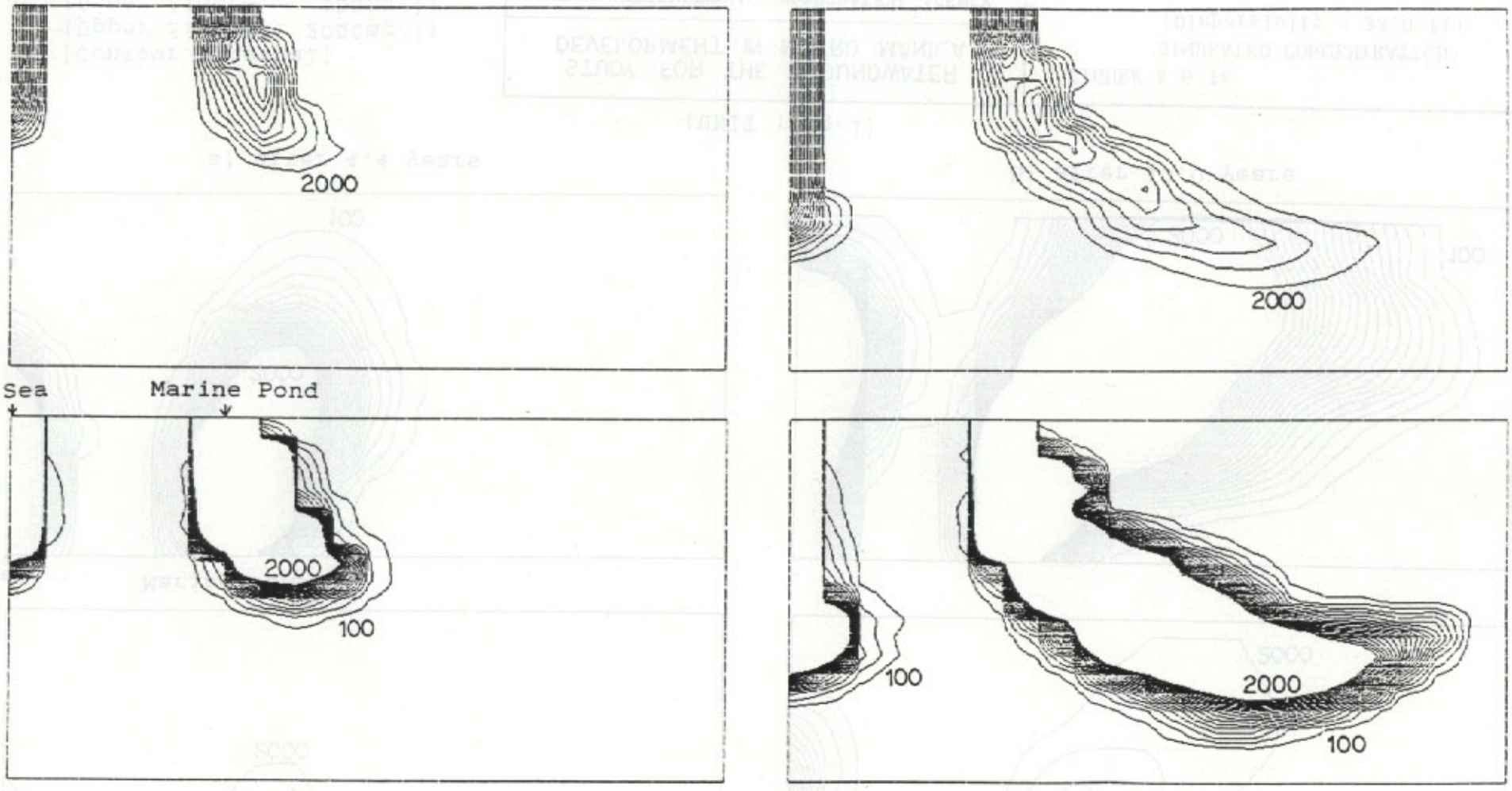




STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.6.12
CHANGE OF CONCENTRATION AT OBSERVATION POINTS



a) after 4.4 years

b) after 10.0 years

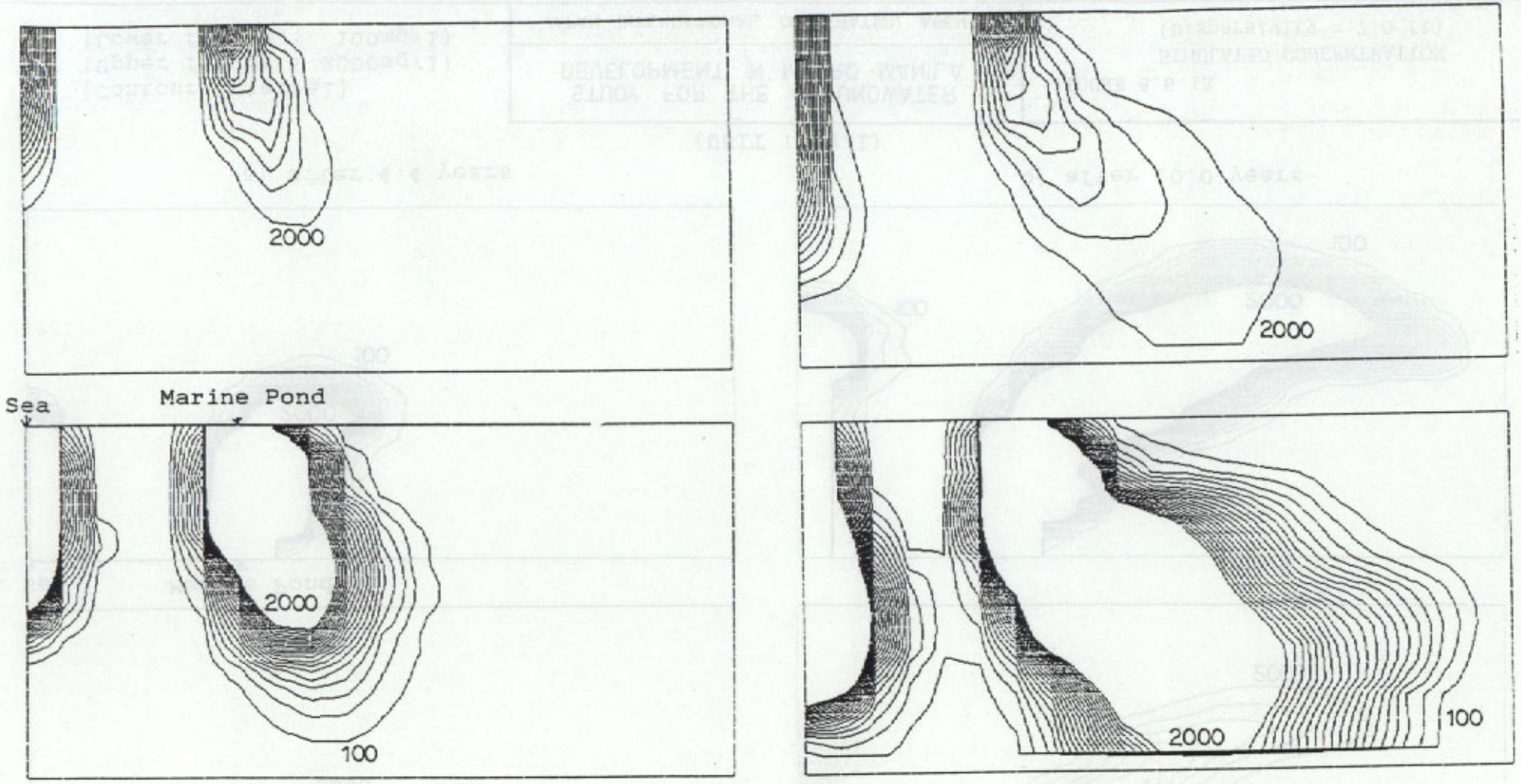
(UNIT : mg/l)

[Contour Interval]
(Upper figure : 2000mg/l)
(Lower figure : 100mg/l)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.6.13
SIMULATED CONCENTRATION
(Dispersivity = 7.0 ft)



a) after 4.4 years

b) after 10.0 years

(UNIT : mg/l)

[Contour Interval]
(Upper figure : 2000mg/l)
(Lower figure : 100mg/l)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 8.6.14
SIMULATED CONCENTRATION
(Dispersivity = 33.0 ft)

CHAPTER 9

LAND SUBSIDENCE IN METRO MANILA

CHAPTER 9 LAND SUBSIDENCE IN METRO MANILA

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CHAPTER 9 LAND SUBSIDENCE IN METRO MANILA

9.1 INTRODUCTION

The rapid and heavy decline of groundwater levels 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 mainly caused by the withdrawal of groundwater, particularly in the alluvial plain. As the coastal areas of Manila Bay, Laguna de Bay and the area of Marikina River are covered by soft, clayey deposits of Alluvium age, the lowering of the groundwater head of underlying aquifers may cause the consolidation of these clayey deposits. Metro Manila in this sense has the requisite condition for land subsidence.

9.2 FIELD OBSERVATION

Indications of land subsidence are generally found at well sites, on roads, dikes, buildings, bridges, etc. They could 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 easily be identified. Inclination and cracks on walls of buildings due to unequal at-place subsidence rates may often be observed.

So that evidence regarding land subsidence in Metro Manila may be gathered, the Study Team conducted a field observation in the downstream area of the Pasig River and the coastal areas of Manila and Navotas. Several tall buildings and bridges located along the Pasig River -- from Nagtahan Bridge near Malacañang Palace to Jones 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. 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 low elevation, not to land subsidence.

9.3 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 those as shown in Figure 9.2.1 and Table 9.2.1. The data indicate that the alluvial clay is in normally consolidated condition. The range of consolidation parameters is basically the same as those of alluvial clays found in the world's coastal plains.

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

As mentioned earlier, the alluvial clay is generally thin with its distribution being limited to the coastal areas of Metro Manila. In addition, 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.

9.4 RISE OF MEAN SEA LEVEL

The Mean Sea Level (MSL) data at the Manila South Harbor tide station seem to provide evidence of land subsidence. Table 9.3.1 lists the data and variations. The data came from NAMRIA (National Mapping and Resource Information Authority), formerly Bureau of Coast and Geodetic Survey (BCGS)).

Tides at the Manila South Harbor are measured and logged automatically on a recorder with a corresponding tide staff. The recorder and tide staff installed at Pier 13 of the Manila South Harbor were used till 1969. They were moved to Pier 15 in 1970.

The MSL of Manila has marked by risen since the mid-Sixties (Figure 9.3.1). Though not as marked, the same rising tendency and fluctuation of the MSL can be observed at Legaspi, Cebu and Davao. Worth noting too, and if a tectonic movement of the islands is imagined, is the

similarity between the steep rise of the MSL in Manila and those in Legaspi, Cebu and Davao for the period 1987-89.

From Table 9.3.1, it may be noted that from 1965 to 1989 the MSL at Manila appears to have risen by 0.478 m. Therefore, and assuming the MSL does not change, it may be inferred that land subsidence is occurring in the vicinity of the tide staff.

9.5 ELEVATION OF BENCHMARKS

NAMRIA established benchmarks of first, second and third order levelings in Metro Manila. The location map of benchmarks is given in Figure 9.4.1.

BM4 was used before as the reference benchmark until its loss in 1969. It was replaced by BM4a in 1970, which then became the reference benchmark throughout the 1970s up to the time of its loss in 1980.

BM4b is a benchmark located at Intramuros, Manila and is used as the reference benchmark for the elevation of all benchmarks established in Metro Manila and nearby provinces. The elevation of BM4b is reckoned from MLLW (Mean Lower Low Water). The height of MLLW is reckoned from OTS (Zero of Tide Staff). The height of BM4b reckoned from the OTS that was established in 1901 is maintained at 5.3065m.

Since the location and elevation of the reference benchmark changed thrice, a comparison between the old and new elevations is virtually impossible. Besides, and even if the elevation of BM4b can be adjusted, making such comparison is difficult because BM4b itself may be sinking, perhaps due to land subsidence in the vicinity.

Though elevation of the reference benchmark is different, several benchmarks were compared in order to know the vertical tendency of the displacements of land in Metro Manila.

Figure 9.4.2 shows the location of leveling routes for comparison. One route is located along the coast in the north-south direction. Another traverses Metro Manila in the east-west direction.

Presented in Table 9.4.1 are the elevations of the recovered benchmarks located along the year-1987 route. The table also presents the elevation of the same benchmarks surveyed before 1966. Differences in elevation of these benchmarks between years 1966 and 1987 appear to indicate land subsidence at almost all benchmarks.

Several benchmarks, for instance, OS-2, GM-R4 and GM-S9, are located on a hill composed of consolidated Guadalupe formation. From the viewpoint of the mechanical properties of the rock, this kind of location may not subside in response to the abstraction of groundwater. Therefore, if these benchmarks are immovable and the differences can be ignored, elevations in 1987 can be made the same as the elevations before 1966. Assuming that GM-S9 is the reference benchmark of the levelings in 1987 and those before 1966, the differences in elevation of other benchmarks become almost negligible errors. There is no definitive evidence therefore of land subsidence occurring.

Obtaining clear evidence of land subsidence thus 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 in order to properly evaluate the difference in elevation of two different levelings.

TABLE 9.2.1 RANGES OF CONSOLIDATION CHARACTERISTICS

Area	Py (kg/cm^2)	Cv (cm^2/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^{-2} to 2.4×10^{-1}	1.4×10^{-2}	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 9.3.1 ANNUAL MEAN SEA LEVELS AND VARIATIONS

Page 1 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.
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 1.932	0.066	2.024	0.053		
1963	2.195	-0.039	1.571	-0.042	1.693	-0.062	[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 9.3.1 (CONTINUATION)

Page 2 DATA SOURCE: NAMRIA

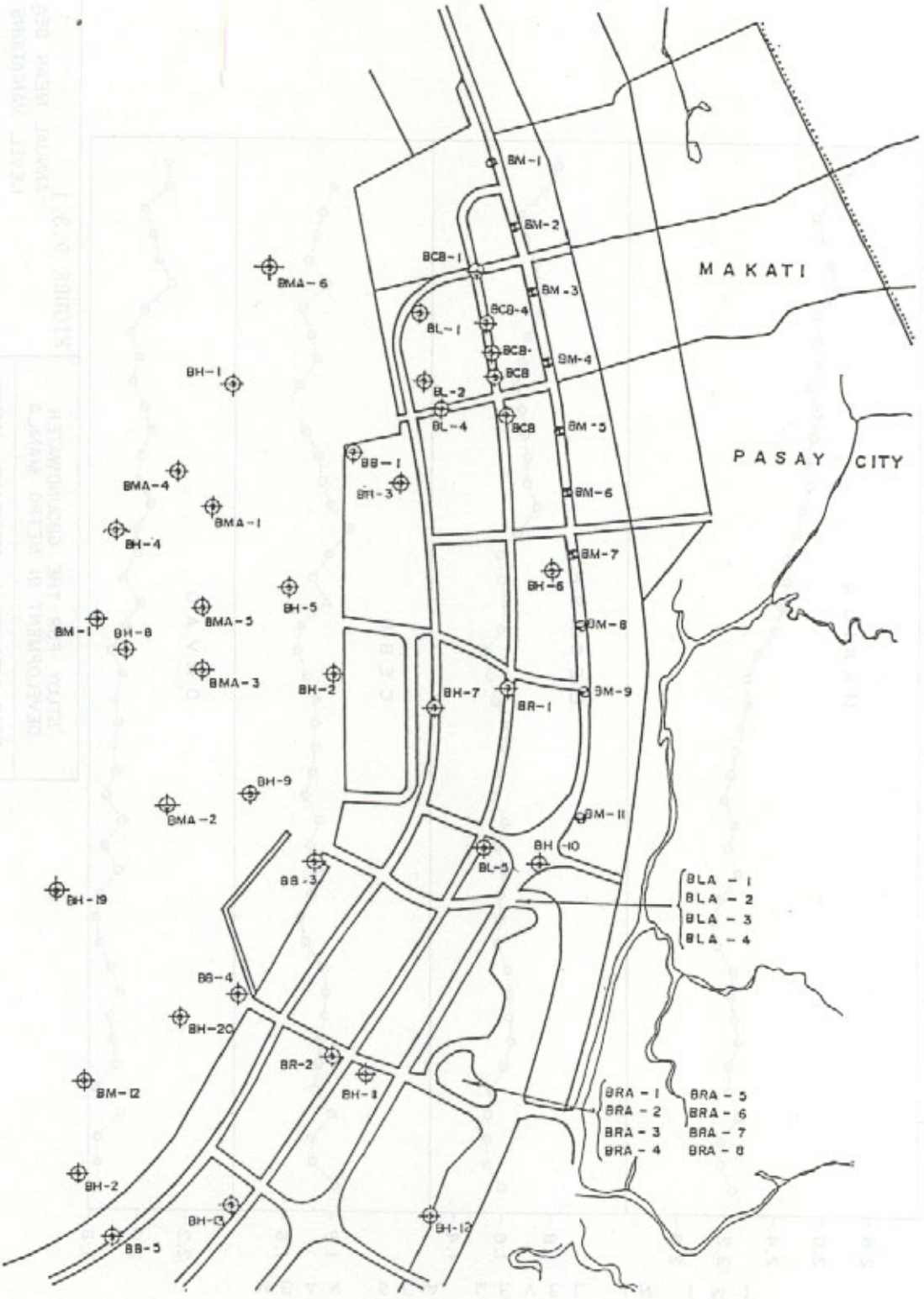
Year	MANILA OTS (1901) Mean m.	Divergence m.	LEGASPI OTS (1947) Mean m.	Divergence m.	CEBU OTS (1935) Mean m.	Divergence m.	DAVAO OTS (1947) Mean m.	Divergence m.	JOLO OTS (1947) Mean m.	Divergence m.	SAN FERNANDO OTS (1947) Mean m.	Divergence m.
1969	2.328	0.045	1.533	-0.015	1.657	-0.040	1.888	-0.044	1.938	-0.014		
					4		1					
1970	2.400	0.072	1.593	0.060	[1.678]	0.021	[1.952]	0.064	2.008	0.070		
			1		3							
1971	2.431	0.031	[1.612]	0.019	[1.773]	0.095	2.022	0.070	2.019	0.011		
							6					
1972	2.441	0.010	1.588	-0.024	1.712	-0.061	[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		
									2			
1974	2.488	0.065	1.652	0.073	1.871	0.090	1.994	-0.004	[2.031]	0.040		
					1				1			
1975	2.514	0.026	1.738	0.086	[1.788]	-0.083	2.056	0.062	[2.048]	0.017		
	1											
1976	[2.541]	0.027	1.698	-0.040	1.752	-0.036	1.979	-0.077	1.972	-0.076		
	1											
1977	[2.538]	-0.003	1.697	-0.001	1.745	-0.007	2.008	0.029	2.008	0.036		
					7				2			
1978	2.561	0.023	1.680	-0.017	[1.692]	-0.053	2.051	0.043	[2.004]	-0.004		
	2											
1979	[2.583]	0.022	1.668	-0.012	-		2.021	-0.030	-			
					6							
1980	2.536	-0.047	1.653	-0.015	[1.663]		1.956	-0.065	1.973			
									1			
1981	2.575	0.039	1.675	0.022	1.726	0.063	1.992	0.036	[1.991]	0.018		
							1					
1982	2.575	0.000	1.692	0.017	1.711	-0.015	[1.959]	-0.033	1.929	-0.062		
	1											
1983	[2.578]	0.003	1.745	0.053	1.668	-0.043	2.017	0.058	1.932	0.003		
									1			
1984	2.658	0.080	1.738	-0.008	1.769	0.101	2.130	0.113	[2.035]	0.103	1.484	
					6				4		2	
1985	2.632	-0.024	1.715	-0.022	[1.693]	-0.076	2.078	-0.052	[1.985]	-0.050	[1.461]	-0.023
					1						2	
1986	2.606	-0.026	1.682	-0.033	[1.726]	0.033	2.061	-0.017	1.980	-0.005	[1.397]	-0.064
					4				3		6	
1987	2.568	-0.038	1.657	-0.025	[1.745]	0.019	2.012	-0.049	[1.947]	-0.033	[1.433]	0.036
											1	
1988	2.647	0.079	1.762	0.105	1.787	0.042	2.113	0.101	2.022	0.075	[1.430]	0.057
1989	2.716	0.069	1.818	0.056			2.115	0.002			1.469	-0.001

[ ] Number of months due to instrument breakdown.

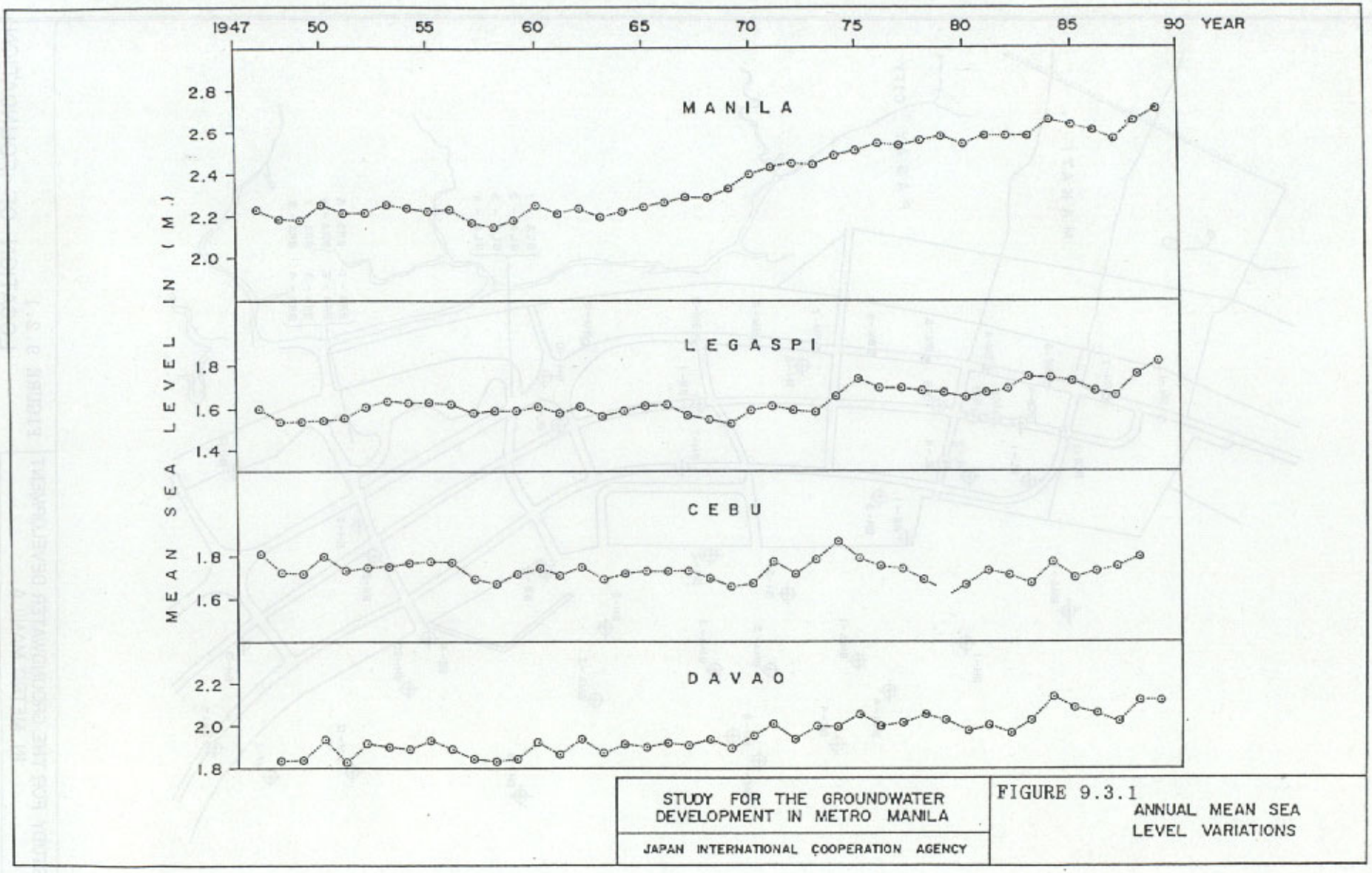
The integer above the bracket means the number of months.

TABLE 9.4.1 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 9.2.1 LOCATION OF FOUNDATION DRILLING (DPWH, 1977)
JAPAN INTERNATIONAL COOPERATION AGENCY	

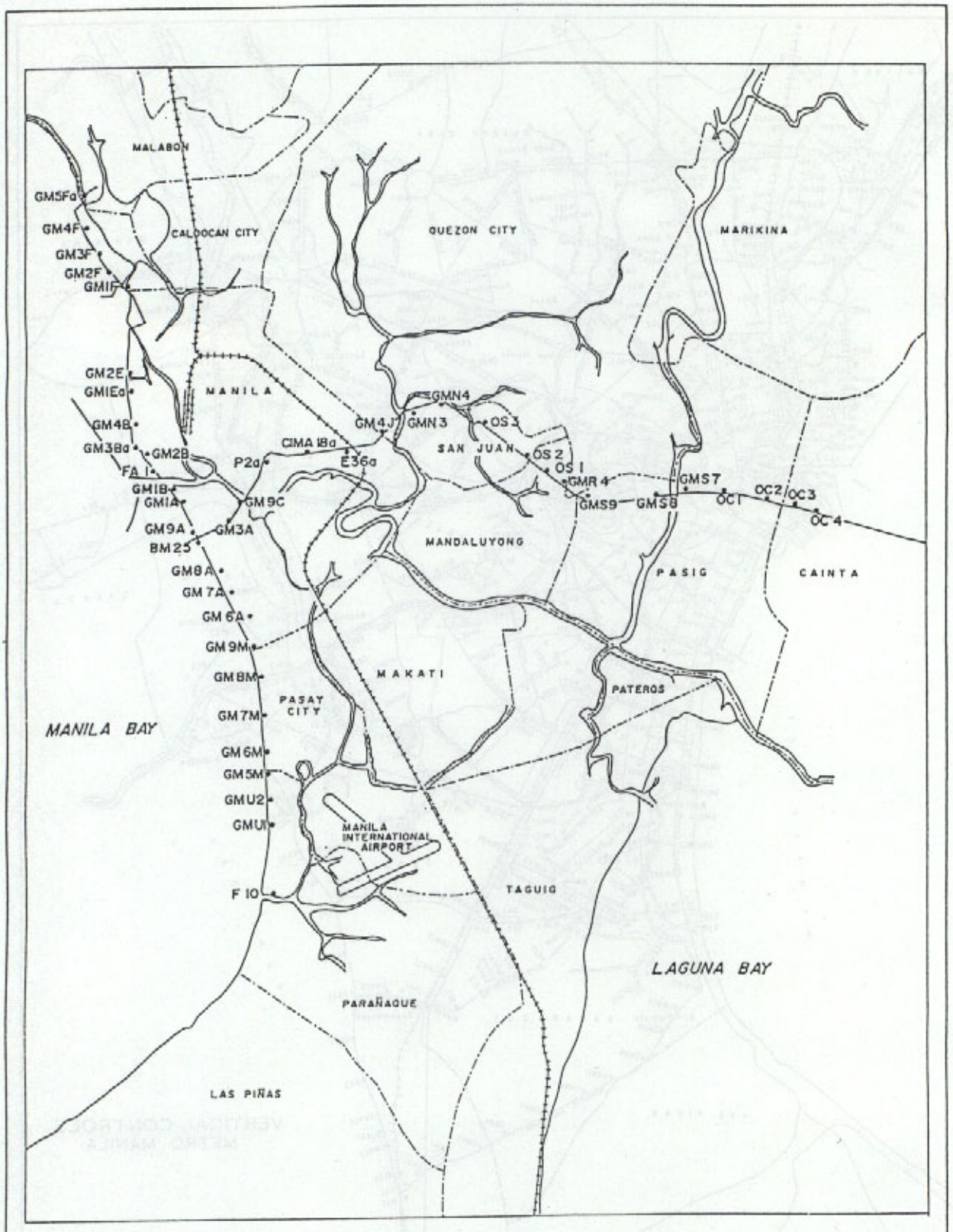


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 9.3.1 ANNUAL MEAN SEA LEVEL VARIATIONS

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 9.4.1
JAPAN INTERNATIONAL COOPERATION AGENCY	VERTICAL CONTROLS - METRO MANILA



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 9.4.2 SURVEY ROUTE FOR COMPARISON
JAPAN INTERNATIONAL COOPERATION AGENCY	

CHAPTER 10

ORGANIZATION AND MANAGEMENT

CHAPTER 10 ORGANIZATION AND MANAGEMENT

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CHAPTER 10 ORGANIZATION AND MANAGEMENT

10.1 MWSS ORGANIZATION

10.1.1 Introduction

The primary object of this chapter is to describe how the MWSS is organized, and then to examine, especially how the offices directly responsible for the operation, monitoring and maintenance of MWSS wells are managed.

The history of the modern water supply system in Metropolitan Manila has its roots in 1878 with the construction of the "Carriedo Waterworks", named after a retired Spanish Captain General, Don Francisco Carriedo y Pedro, who in 1743 bequeathed his entire fortune of ₱10,000 to Manila as the nucleus of a fund for the City's public water supply . This donation plus its accumulated interest was used in 1878 for the construction of said waterworks.

The "Carriedo Waterworks" which was completed in 1882 was the first properly-designed water supply system in the Far East. Its capacity of 15 Mlpd at the beginning was increased to 87 Mlpd in 1909, i.e., when its intake from the Marikina River in Santolan was transferred further upstream north to the town of Montalban.

In 1919, the Metropolitan Water District (MWD) was created by Republic Act No. 2832, to supply water for Manila and suburbs. Under its jurisdiction, the service area was expanded to include fourteen (14) adjoining cities and municipalities. With the Angat River as the new source of water supply, the construction of the Angat-Novaliches System was begun in 1925, with all the works completed in 1939. The first Balara treatment plant was constructed then, and this new system supplied 300 Mlpd.

After the World War II, on 18 June 1955, the National Waterworks and Sewerage Authority (NWSA) was created to take over the functions of the Metropolitan Water District, and at the same time, to centralize and consolidate under its administration all waterwoks and sewerage systems

throughout the country, and so that the rehabilitation of water supply systems which were devastated during the war may be accelerated and the increasing demand met. During the NWSA period, the supply capacity of Metropolitan Manila Waterworks was increased to a total of 1,137 Ml/d.

On 19 June 1971, however, the Government of the Philippines set a policy goal to supply safe drinking water to every household throughout the country. NWSA was thus reorganized into two organizations, namely, MWSS and LWUA (Republic Act No. 6234, "An Act Creating the Metropolitan Waterworks and Sewerage System and Dissolving the National Waterworks and Sewerage Authority, and for Other Purposes").

Through its long history, MWSS has now become one of the largest water supply systems in the world. It supplies 2,500 Ml/d to 9.3 million inhabitants in Metropolitan Manila and its environs (served population is 5.3 million). At present, the MWSS Service Area (MSA) totals about 150,000 hectares and covers five (5) cities and thirty two (32) municipalities.

In addition to these five cities and thirty two municipalities, "Lungsod Silangan" was legally included as a proposed supply area, i.e., when the time for it becomes opportune. Also, MWSS can annex other areas which are deemed as appropriate expansion areas of MSA, by mutual agreement between the concerned national and local authorities, subject to the approval of the President of the Philippines.

10.1.2 Organization of MWSS

The organization of the MWSS is shown in Figure 10.1.1. The Board of Trustees formulates policy, determines staffing levels and remuneration, considers and approves budgets, approves large scale contracts, appoints MWSS's Deputy Administrators, and recommends tariff adjustment for the President's approval.

The Secretary of Public Works and Highways as a rule is the Chairman of MWSS Board of Trustees, unless the President of the Philippines designates another person. Also according to this rule, the Undersecre tary (for Construction) of Public Works and Highways is the Administrator, unless another is designated by the President of the Philippines.

The Administrator is supported by a Senior Deputy Administrator and six Deputy Administrators whose respective areas are:

Engineering; Construction Management; Operation; Customers Services; Finance; Administration

The number of MWSS personnel is approximately nine (9) thousand, of which four thousand eight hundred is regular staff and the rest casual.

Table 10.1.1 and Table 10.1.2. show the number of MWSS personnel by area and by department, respectively.

10.1.3 Management of MWSS Deep Wells

(1) Responsibility on Operation

The actual operation of MWSS-owned/supervised wells are handled by the Water Distribution and Maintenance Department (WDMD) through its Pumping Plants Division down to the Deepwell Pumping Plants Section. This office is wholly responsible for the operation and monitoring of both existing and non-operational deepwells. The number of personnel assigned to every well station is scheduled by rotation. Data and information on the water production of each well are recorded daily.

(2) Responsibility on Maintenance

The maintenance of all MWSS-owned wells is the responsibility of the Central Maintenance Department (CMD) through its General Control and Repair Division and General Workshop Section. The cost of maintenance and repair of small damages and minor engine troubles are all handled by the CMD for this office has the budget for this purpose.

(3) Responsibility on Rehabilitation/Construction

Based on the recommendation of the Central Maintenance Department (CMD) and the Water Distribution and Maintenance Department (WDMD), the rehabilitation of existing MWSS wells are undertaken by the Groundwater Monitoring Unit of the Hydrology and Research Division (HARD) under the Planning and Programming Department (PPD).

For the drilling of new wells, it is the Groundwater Monitoring Unit,

Hydrology and Research Division (HARD) under the Planning and Programming Department (PPD) which initiates the feasibility study for well specification and location.

10.2 ISSUES ON MANAGEMENT

10.2.1 Personnel and Training

MWSS staff are competent and hard working generally, and many of the technical staff, especially those in the senior-management and middle-management class, have served in their respective positions for several years, providing valuable continuity and making good use of their experience and in-depth knowledge of the system.

Also, MWSS's internal training system on human resource development is one of the most praiseworthy and successful training system in this field. MWSS's Human Resources Development Department (HRDD) is carrying out an extensive program, for all staff levels, from laborers to top management.

The program of training for 1990 as shown in Appendix C.3 includes 23 different courses for about 1,440 persons. In this program, training for the pump operators-WDMD is carried out in the course on "Plant Electrical Circuits and Motor Control." But this course focused mainly on the electrical aspect of pump operation, and not on the "well" itself. It may be recalled that as efforts in the past were largely focused on expansion projects, the maintenance of existing distribution facilities, especially of deep wells which supply water to outlying areas (those wells not connected to the CDS), received insufficient attention. Considering the serious state of MWSS deep wells, some program/seminar on basic strategies of deep well management in the MWSS should be planned.

10.2.2 Problem of Trimdown of Number of Personnel

Since the early 1980s, recommendations have been made in the MWSS regarding the relative highness of staff levels in relation to the number of connections and services provided. An appreciation of this problem

may be gleaned from the increment in the ratio of number of staff per thousand water connections during 1986-1987 when the ratio rose from 10.1 to 12.7, presumably reflecting the social turmoil in those times.

A significant reduction of such ratio has been made since then, and as of end-April 1991 this ratio was already at 8.9. On the basis of world-wide statistics however, this figure is still higher than the ratio of 4 staff per thousand connections which were achieved in very efficient water utilities. In Japan, for instance, the contracting out of meter reading and bill collection to appropriate public entities had this ratio even reduced to about 2.5 in large water utilities.

The crux of the matter therefore appears to be the way the number of personnel can be reduced. There are existing administrative orders, executive orders, national budget circulars, and related economy measures that are supposed to address this problem. But such behests in the main are aimed at the cutting down of overhead expenses, and may, in their implementation, be counterproductive because necessary personnel could be sacrificed; and justifications for the exemption of such personnel would involve tedious processes and lost manhours. To obviate the loss of precious personnel, and to have an efficient organization in place, an organizational audit of the MWSS may be pursued.

It is necessary to ensure the required number of capable and competent personnel, particularly in the area of Engineering and Construction Management, to cope with the ever-continuing expansion of MWSS's area coverage. The salary schedule in the MWSS may also be worth reconsidering, especially when seen with the aim of bringing the MWSS the status of an attractive public body where the most capable characters are employed.

The experience in most of the large towns and cities may be worth looking into: For domestic customers, 80 to 90 % of bill collection is carried out by withdrawing the due amount from the customer's bank accounts in accordance with the agreement between the customers and the water supply authorities. This minimizes the number of personnel for bill collection.

10.3 ORGANIZATIONS OF MUNICIPALITIES OUTSIDE CDS

Municipalities outside the CDS mostly belong to the 4th and 5th income classes, based on Executive Order No. 249, issued on July 25, 1987. These municipalities are:

Cavite City	4th
Bacoor	4th
Imus	3rd
Kawit	4th
Noveleta	5th
Rosario	4th
Antipolo	3rd
Cainta	2nd
Rodriguez (Montalban)	5th
San Mateo	5th
Taytay	3rd
(Excluding 9 municipalities of B. P. 799)	

From the Bureau of Local Government Finance of the Department of Finance, the income brackets for the classification of provinces and cities are as follows:

First Class : Average annual income of P30,000,000 or more;

Second Class: Average annual income of P20,000,000 or more but less than P30,000.000;

Third Class : Average annual income of P15,000,000 or more but less than P20,000.000;

Fourth Class: Average annual income of P10,000,000 or more but less than P15,000.000;

Fifth Class : Average annual income of P5,000,000 or more but less than P10,000.000;

Sixth Class : Average annual income of P5,000,000.

The income brackets for the classification of municipalities are:

First Class : Average annual income of P15,000,000 or more;
Second Class: Average annual income of P10,000,000 or more but less than P15,000.000;
Third Class : Average annual income of P5,000,000 or more but less than P10,000.000;
Fourth Class: Average annual income of P3,000,000 or more but less than P5,000.000;
Fifth Class : Average annual income of P1,000,000 or more but less than P3,000.000;
Sixth Class : Average annual income of P1,000,000.

The elective officials of the municipality are the Municipal Mayor, Vice Mayor and Sangguniang Bayan members; the appointive officials are the Municipal Secretary, Treasurer, Municipal Assessor, Budget Officer and a Planning and Development Coordinator. The last position takes charge of matters related to planning and development, including these water supply utilities.

In addition to the abovementioned positions, the following positions may be allowed on need basis; Municipal Attorney, Personnel Officer, Bookkeeper and a Civil Security Officer.

At any rate, there is no particular division/section which takes charge of water supply exclusively in each municipality. Generally, in these municipalities, the number of personnel which belongs to the Office of the Municipal Planning and Development Coordinator is strictly limited, and it is very difficult to find personnel whose expertise lie in the field of sanitary engineering.

Figure 10.3.1 to Figure 10.3.4 show the organizations of Cavite City and the other municipalities respectively.

TABLE 10.1.1 TOTAL NUMBER OF MWSS PERSONNEL

(AS OF MAY 31, 1991)

AREA	TOTAL	REGULAR	CASUAL
TOTAL	9,087	4,833	4,254
MWSS Board	14	14	0
Office of the Administrator	280	256	25
Engineering	386	231	155 /a
Construction Management	3,060	196	2,864 /b
Operations	1,872	1,589	283
Customers's Service	2,753	1,847	906
Finance	393	383	10
Administration	328	317	11

/a Engineering Area

BDED (Main)	13
PPD (Main)	7
MSWSP (Main)	14
Fringe Area (Main)	10
Rizal Province (Main)	16
AWSOP (Eng'g)	95
TOTAL	155

/b Construction Management Area

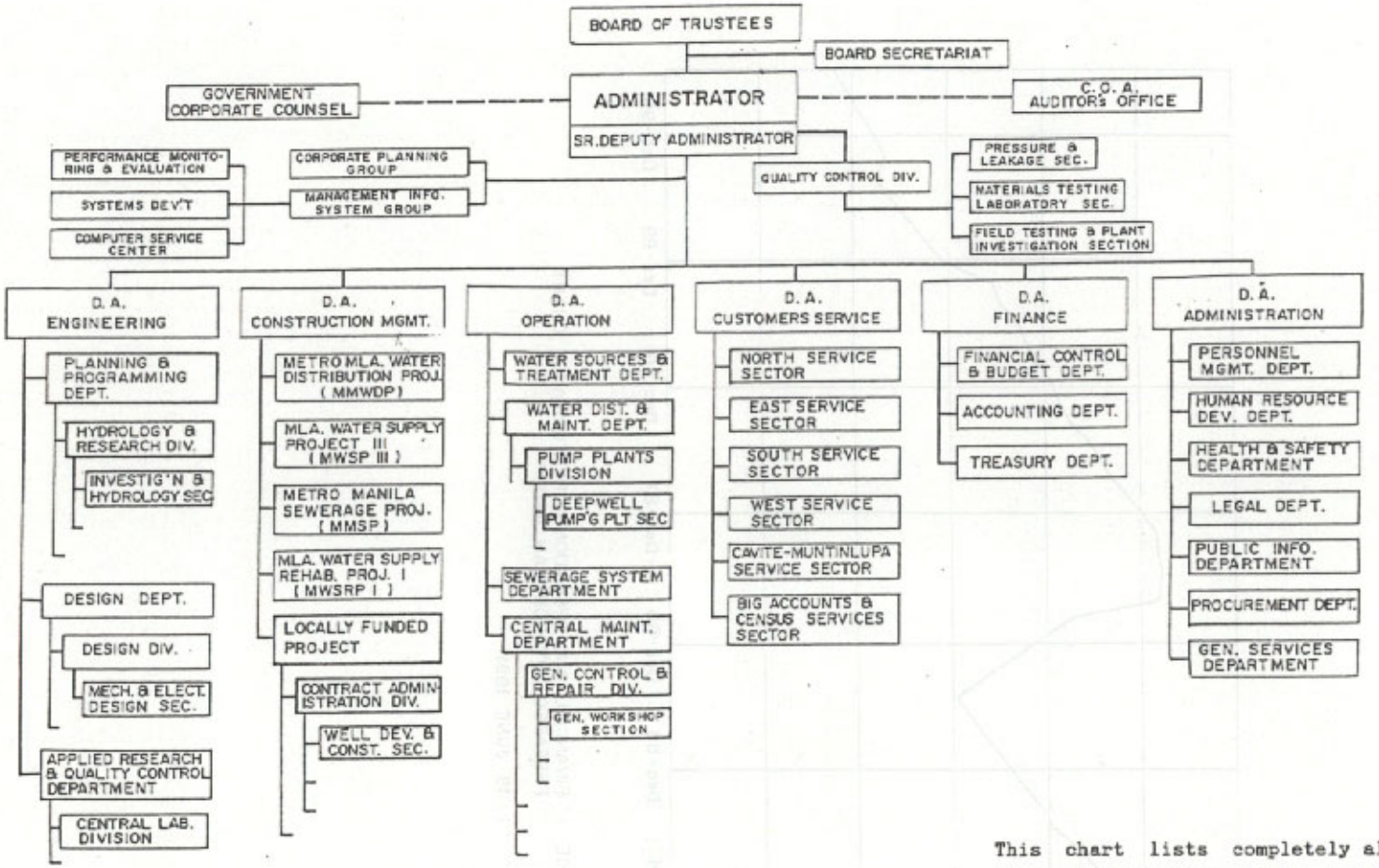
Restoration Task Force (Main)	56
LFPD (Main)	11
MMWDP	428
MWSP III (Skeletal Group)	14
MMSSP - AWSOP I	175
MWSRP I	1,377
MWSRP II	739
AWSOP I	64
TOTAL	2,864

TABLE 10.1.2 NO. OF MWSS PERSONNEL, BY DEPARTMENT
(AS OF MAY 31, 1991)

AREA/DEPARTMENT	REGULAR			CASUAL			GRAND TOTAL
	MALE	FEMALE	TOTAL	MALE	FEMALE	TOTAL	
TOTAL	3667	1166	4833	3584	670	4254	9087
Office of the Board of Trustees	4	10	14	0	0	0	14
Office of the Administrator	18	23	41	0	0	0	41
Public Information	14	20	34	1	0	1	35
Inspectorate Group			0	10	2	12	12
CORPLAN Group	4	11	15	0	0	0	15
MIS Group	2	2	4	0	1	1	5
PMED	10	16	26	0	0	0	26
Systems Development	3	11	14	0	1	1	15
Computer Service Center	56	66	122	7	3	10	132
Engineering	3	3	6	0	0	0	6
BDED	11	9	20	8	5	13	33
* Fringe Area			0	8	2	10	10
* Rizal Province			0	8	8	16	16
* Planning & Programming	44	20	64	6	1	7	71
Design	76	29	105	0	0	0	105
Applied Res. & Quality Con.	10	26	36	0	0	0	36
AWSOP			0	80	15	95	95
* MSWSP			0	12	2	14	14
Construction Management	3	4	7	0	0	0	7
Restoration Task Force			0	53	3	56	56
MMWDP	14	1	15	295	133	428	443
MWSP III - Skeletal Group	3	2	5	11	3	14	19
MMSSP - AWSOP II	6	1	7	127	48	175	182
MWSRP I	4	4	8	1206	171	1377	1385
MWSRP II	7	1	8	630	109	739	747
Locally Funded	134	12	146	9	2	11	157
AWSOP I	0	0	0	40	24	64	64
Operations	3	3	6	0	0	0	6
Water Sources & Treatment	238	25	263	0	0	0	263
Water Distribution & Maint.	791	25	816	241	7	248	1064
Sewerage Systems	262	22	284	13	5	18	302
Central Maintenance	206	14	220	17	0	17	237

TABLE 10.1.2 (CONTINUATION)

AREA/DEPARTMENT	REGULAR			CASUAL			GRAND TOTAL
	MALE	FEMALE	TOTAL	MALE	FEMALE	TOTAL	
Customers Service	3	3	6	0	0	0	6
North Sector	249	67	316	104	7	111	427
East Sector	280	86	366	144	10	154	520
South Sector	289	80	369	141	15	156	525
West Sector	284	79	363	194	8	202	565
Cavite-Munti Sector	218	82	300	72	8	80	380
Big Accounts & Census Sector	89	38	127	130	73	203	330
Finance	3	2	5	0	0	0	5
Financial Control & Management	20	51	71	0	0	0	71
Accounting	34	111	145	0	0	0	145
Treasury	98	64	162	6	4	10	172
Administration	2	3	5	0	0	0	5
Personnel Management	7	39	46	0	0	0	46
Human Resource Dev't	14	19	33	0	0	0	33
Health & Safety	10	29	39	0	0	0	39
Procurement	12	7	19	0	0	0	19
Legal	18	10	28	0	0	0	28
General Services	111	36	147	11	0	11	158



This chart lists completely all offices of MWSS up to the Department level, however, only particular divisions and sections involved in groundwater activities are included in the chart.

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

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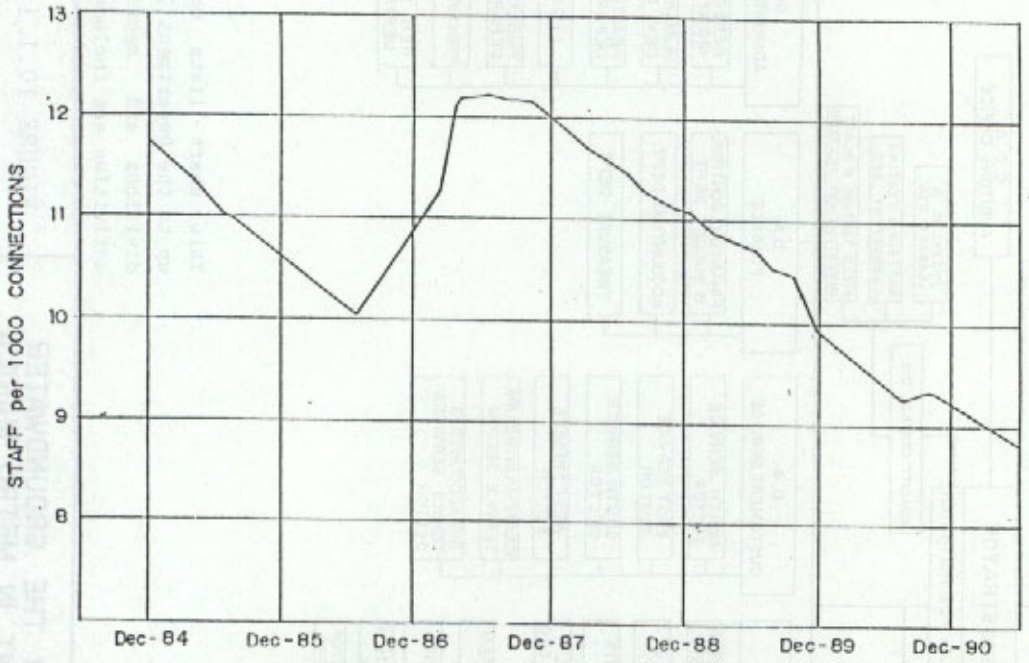
FIGURE 10.1.1

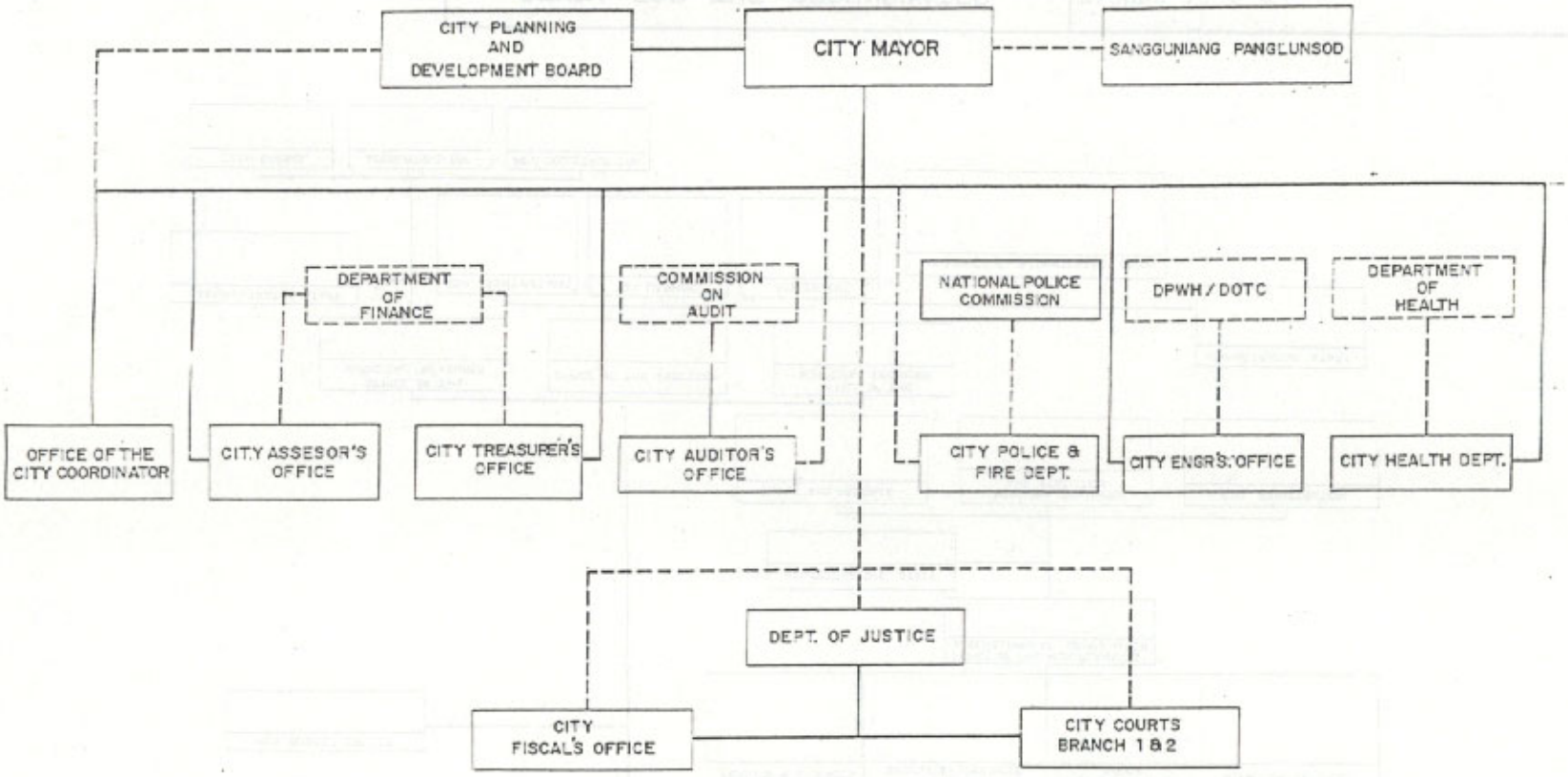
MWSS ORGANIZATION CHART



SOURCE : FINANCIAL AND OPERATIONAL PERFORMANCE CHART PREPARED BY CORPLAN GROUP

DATE : 18 JUNE 1991

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 10.2.1 STAFF PER 1000 CONNECTIONS (PERMANENT & CASUAL OF WATER SECTOR)
JAPAN INTERNATIONAL COOPERATION AGENCY	



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 10.3.1 ORGANIZATION CHART OF CAVITE CITY, CAVITE
JAPAN INTERNATIONAL COOPERATION AGENCY	

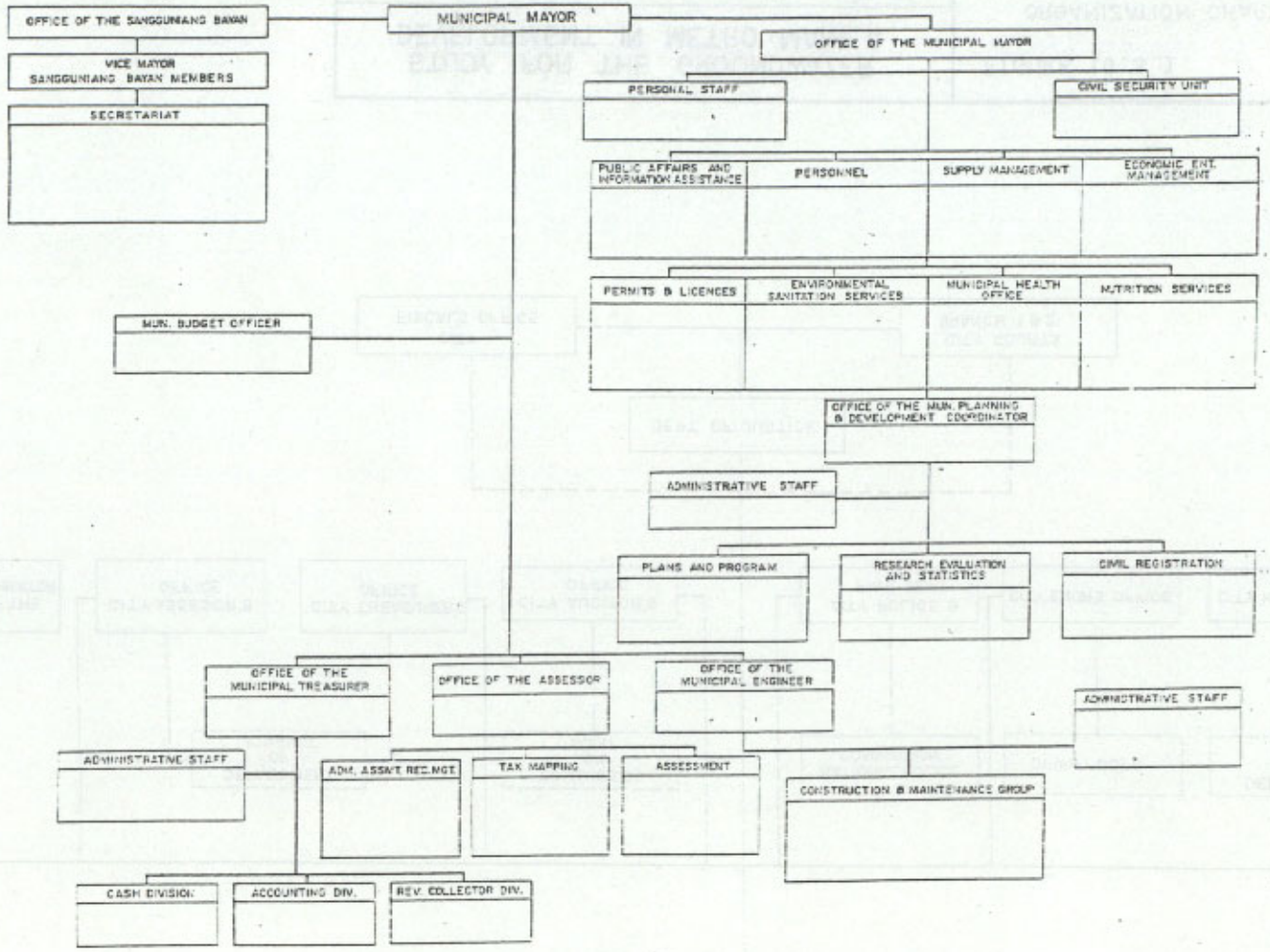


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FIGURE 10.3.2

ORGANIZATION CHART OF MUNICIPALITY OF CAINTA, RIZAL

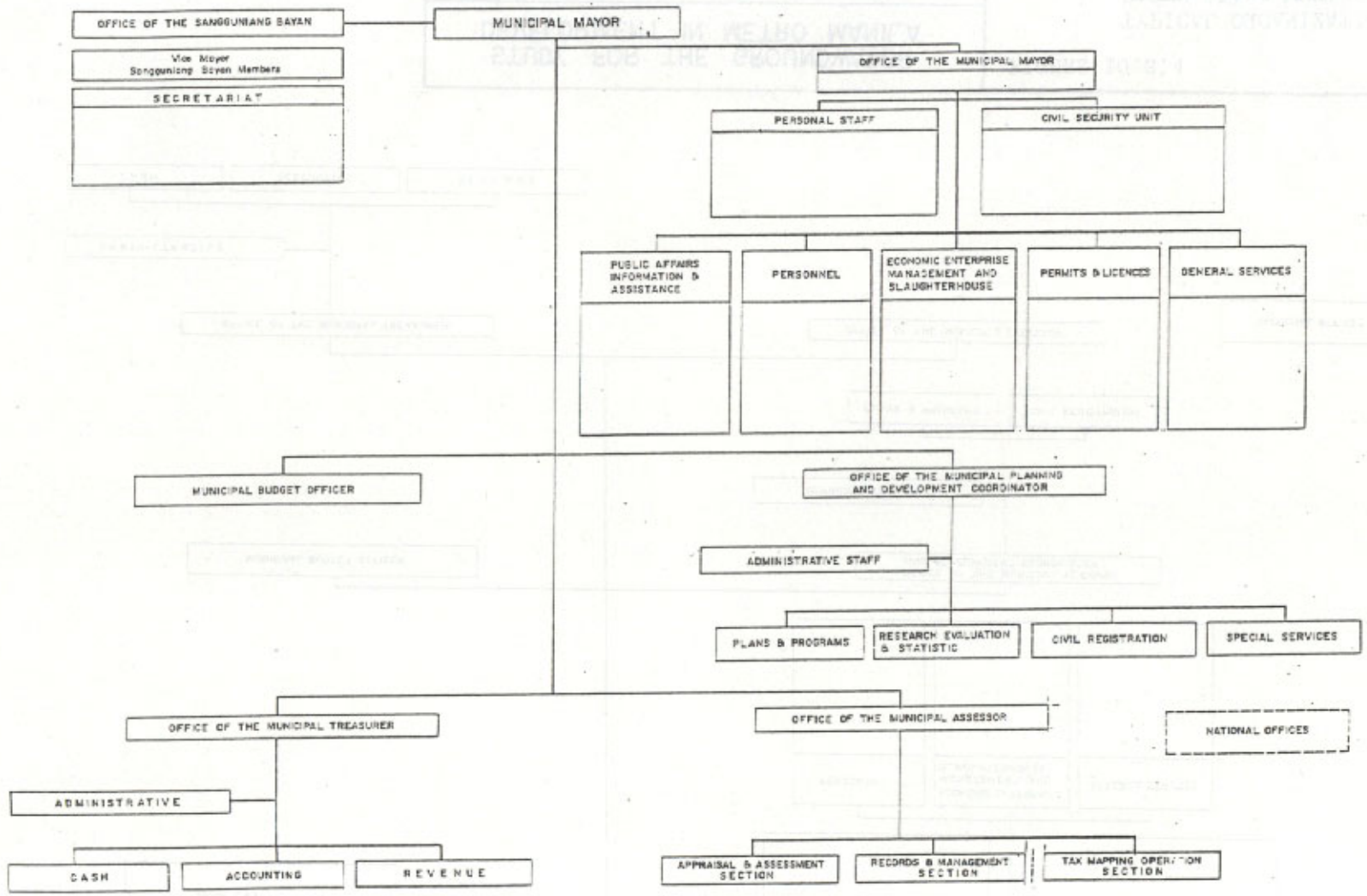

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FIGURE 10.3.3

TYPICAL ORGANIZATION CHART OF THE THIRD AND FOURTH CLASS MUNICIPALITIES

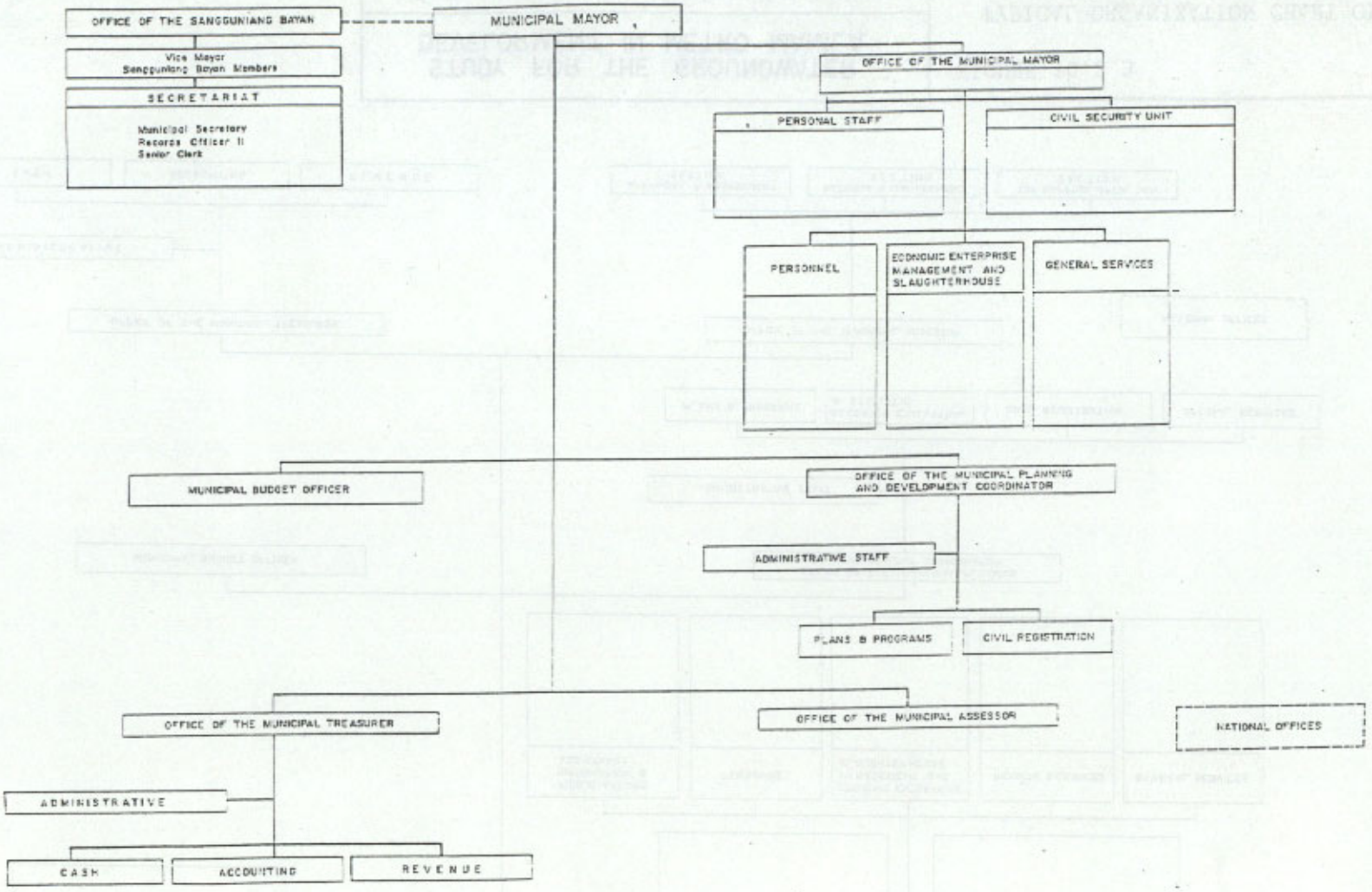

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FIGURE 10.3.4

TYPICAL ORGANIZATION CHART OF FIFTH CLASS MUNICIPALITIES