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REPUBLIC OF THE PHILIPPINES
METROPOLITAN WATERWORKS AND SEWERAGE SYSTEM

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

VOLUME 1
SUMMARY REPORT

JUNE 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

REPUBLIC OF THE PHILIPPINES

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PREFACE

In response to a request from the Government of Republic of the Philippines the Government of Japan decided to conduct Study for the Groundwater Development in Metro Manila and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Philippines a study team headed by Mr. Toru Hayashi, Nippon Jogesuido Sekkei Co., Ltd. composed of members from the above company and Kokusai Kogyo Co., Ltd. from August, 1990 to March, 1992.

The team held discussions with the officials concerned of the Government of Philippines, and conducted field surveys at the study area. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of Republic of the Philippines for their close cooperation extended to the team.

JUNE, 1992

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency

June, 1992

Mr. Kensuke Yanagiya
President
Japan International Cooperation Agency
Tokyo, Japan

Dear Mr. Yanagiya

Letter of Transmittal

We are pleased to submit to you the final report of Study for the Groundwater Development in Metro Manila of Republic of the Philippines.

The field survey and analytical study were conducted during the period between August 1990 and March 1992.

The final report consists of four volumes: One - Summary report which succinctly describes the study and recommendations; Two - Main report which describes the results of the study and analysis; Three - Supporting report which contains the details of study and analysis; Four - Data report which contains the results of the field survey, well inventory, water quality analysis and computer output.

We hope that implementation of the proposed groundwater development scheme would greatly contribute to improve the water supply conditions in Metro Manila of the Philippines.

We wish to take this opportunity to express our sincere gratitude to your Agency, the Ministry of Foreign Affairs. We also wish to express our deep gratitude to the Metropolitan Waterworks and Sewerage System of Republic of the Philippines for the close cooperation and assistance extended to us during our investigations and study.

Very truly yours,

Toru Hayashi
Team Leader
Study for the Groundwater Development
in Metro Manila

CONTENTS

CHAPTER 1 INTRODUCTION

1.1 STUDY BACKGROUND

The National Capital Region or NCR, better known as Metro Manila, lies on an alluvial plain and terrace along Manila Bay, south of the island of Luzon. Containing a land area which is less than one percent (0.21 percent) of the country's total area and having thirteen percent (7.9 million) of the country's total population, the area is characterized by rapid urbanization posing serious problems in water supply, sewerage, transportation, housing, garbage disposal and other related issues.

The problem of water supply shortage in particular is of such seriousness as to spur the Metropolitan Waterworks and Sewerage System (MWSS), which has jurisdiction over Metro Manila's water supply services, to embark on implementing several projects to meet the increasing demand and to have under wraps plans for some more. Notwithstanding the amount of effort the MWSS is exerting to solve the problem, the water shortage in the metropolis remains as grave, even appearing as if it has been further compounded, considering the superannuation and leakage in the distribution pipes of the MWSS.

Metro Manila's water supply, historically, has depended on groundwater as an important source. The deep and shallow wells that were drilled provide water for industry and commerce and for the domestic supply of areas outside the coverage of the central distribution system (CDS) of the MWSS as well. Another source is the surface water of the Angat River in the Province of Bulacan which is a major one for the MWSS.

The uncontrolled development and excessive pumping of groundwater, however, had caused the widespread decline of water levels in artesian aquifers, this decline dating back as far as the Sixties. What had thus resulted was *the intrusion of salt water in the aquifers of coastal* areas. Many wells had to be abandoned, new ones have to be drilled, with this seeking of fresh water in deeper aquifers becoming a vicious cycle and in the process expanding more the area affected by the intrusion of salt water.

The above phenomenon has not spared the MWSS. A considerable number of the deep wells in its service area had been affected by the regional salinization and were therefore abandoned. Some of these wells form part of the well network that supplies groundwater through pipelines connected to the CDS.

To compensate for the losses from these salt-intruded wells and increase the water supply in areas covered by its central distribution system, the MWSS currently is implementing the Angat Water Supply Optimization Project (AWSOP). For areas where no future water supply plans using surface water as source exist, two projects using groundwater as source are currently under implementation. These are the Fringe Areas Water Supply Project (FAWSP) and the Rizal Province Water Supply Improvement Project (RPWSIP).

It is still projected, however, that even with the increment in supply brought forth by the above efforts, supply would not meet the increasing water demand as rapid urbanization has already taken place. The rational development and conservation of groundwater and the establishment of a system for its proper management must therefore be given greater and sustained attention.

The Philippine Government's concern, in the context of the above, prompted it to request the Government of Japan for technical assistance, which request the Japanese Government acceded to by sending a preliminary mission for the period 12-22 January 1990 to clarify the background and specifics of the request. An agreement was reached between the MWSS and the Japan International Cooperation Agency (JICA) on the Implementing Arrangement (IA) for a study. The agreement was signed on 18 January 1990 by representatives of both parties. Based on the IA, a Study Team was dispatched to carry out the study.

The Study Team stayed in the Philippines for the periods 26 August to 20 December 1990 (Stage I of the Study), 08 January to 26 March 1991 (Stage II of the Study) and 27 May to 20 December 1991 (from First to Third period of Stage III of the Study). In cooperation with MWSS personnel, the team conducted surveys on the groundwater resources of the MWSS service area (MSA).

1.2 STUDY OBJECTIVES AND AREA

1.2.1 Study Objectives

The Study aims to:

(1) Formulate a plan for the rehabilitation, operation, maintenance and development of MWSS-supervised wells in MSA.

(2) Evaluate the groundwater resources potential and formulate a groundwater development plan for the Antipolo Area.

(3) Come up with solutions or remedial measures and preventive schemes for areas with heavy saline water intrusion.

(4) Formulate a plan for the establishment of a groundwater monitoring system in Metro Manila.

1.2.2 Study Area

As shown in Figure 1.1, the Study Area covers the MSA. The MSA comprises five (5) cities and thirty two (32) municipalities (an area of 1,780 km^2), namely:

Metro Manila: 4 cities and 13 municipalities

The Cities of Manila, Pasay, Quezon and Caloocan; the Municipalities of Las Piñas, Makati, Malabon, Mandaluyong, Marikina, Muntinlupa, Navotas, Parañaque, Pasig, Pateros, San Juan, Taguig and Valenzuela.

Cavite Province: 1 city and 5 municipalities

The City of Cavite and the Municipalities of Bacoor, Imus, Kawit, Noveleta and Rosario.

Rizal Province: 14 municipalities

Antipolo, San Mateo, Taytay, Cainta and Montalban (BP 799: Angono, Baras, Binangonan, Cardona, Jala-Jala, Morong, Pililla, Tanay and Teresa).

1.3 ORGANIZATION OF THE STUDY

In carrying out the study, the Metropolitan Waterworks and Sewerage System (MWSS) of the Republic of the Philippines acted as the counterpart agency and the Japan International Cooperation Agency (JICA), the official agency in behalf of the Government of Japan.

The study period is from August 1990 to March 1992.

The Study was carried out by a joint study team composed of a JICA team and a MWSS team:

JICA Study Team

Toru HAYASHI	Team Leader/Water Supply Engineer
Akira KAMATA	Co-Team Leader/Hydrogeologist
Masaharu KINA	Urban Planner
Shoichi OOMORI	Geologist
Naoaki SHIBASAKI	Hydrogeologist
Kenji TAKAYANAGI	Hydrogeologist
Masuomi HIROYAMA	Water Quality Engineer
Reynaldo R. MEDINA	Hydrologist
Mitsuo TSUTSUMI	Drilling Supervisor
Yu AYUSAWA	Drilling Supervisor
Kakuji SUEMATSU	Well Engineer
Takafumi KIGUCHI	Water Supply Planner

MWSS Team

Rolando E. ROCA	Manager, Planning & Programming Dept.
Victor J. BALAGTAS	Project Manager C, MMGWDP

Ernesto V. ALCANTARA	Asst. Project Manager C, MMGWDP
Renee A. PINGOL	Sr. Statistician
Norma M. SANTIAGO	Sr. Hydrogeologist A
Godofredo C. CARPIO	Hydrogeologist A
Richard G. BURCE	Supervising Engineer
Romeo S. MANLAPIG	Sr. Engineer A
Rogelio G. OTIVAR	Sr. Engineer A
Enrico A. RUIDERA	Sr. Draftsman
Rodulfo M. NOVEDA	Engineering Assistant A
Rodolfo B. VICENTE	Engineering Assistant A
Oliver B. PADRON	Sr. Engineer A
Noel B. ZACARIAS	Engineering Assistant A
Daisy C. ARANAN	Data Encoder/Controller
Juliana F. VELADO	Data Encoder/Controller
Ramon N. MENDOZA	Engineering Assistant A
Lorenzo A. DUMANDAN	Engineering Assistant A
Judith S. CADAPAN	Draftsman A
Gemmalyn S. SANTOS	Administrative Service Assistant A
Olivia M. SANTIAGO	Clerk/Processor B

1.4 OUTLINE OF THE STUDY

The Study commenced in August 1990 and was completed in March 1992. The Study period of 20 months was divided into three stages: Stage I (Basic Survey), Stage II (Detailed Survey) and Stage III (Analysis and Planning).

The study procedure is flowcharted as shown in Figure 1.2.

(1) Stage I: Basic Survey

This stage involves the review and analysis of existing studies and data, field geological reconnaissance, arrangement of existing well inventory, questionnaire survey on groundwater use, preparation of the database system and appraisal survey on the ability and availability of local drilling contractors.

(2) Stage II: Detailed Survey

The Study at this stage includes investigation of MWSS wells, the electric resistivity survey of the Antipolo Area, drilling and pumping tests, installation of monitoring equipment, pumping tests of existing wells, simultaneous observation of water levels, survey on groundwater use (collection and analysis of questionnaires) and preparation of the database system.

(3) Stage III: Analysis and Planning

The Study at Stage III concerns the planning of the rehabilitation program for MWSS wells, the groundwater development and management program, the analysis of saltwater intrusion and the planning for the groundwater monitoring system in MSA.

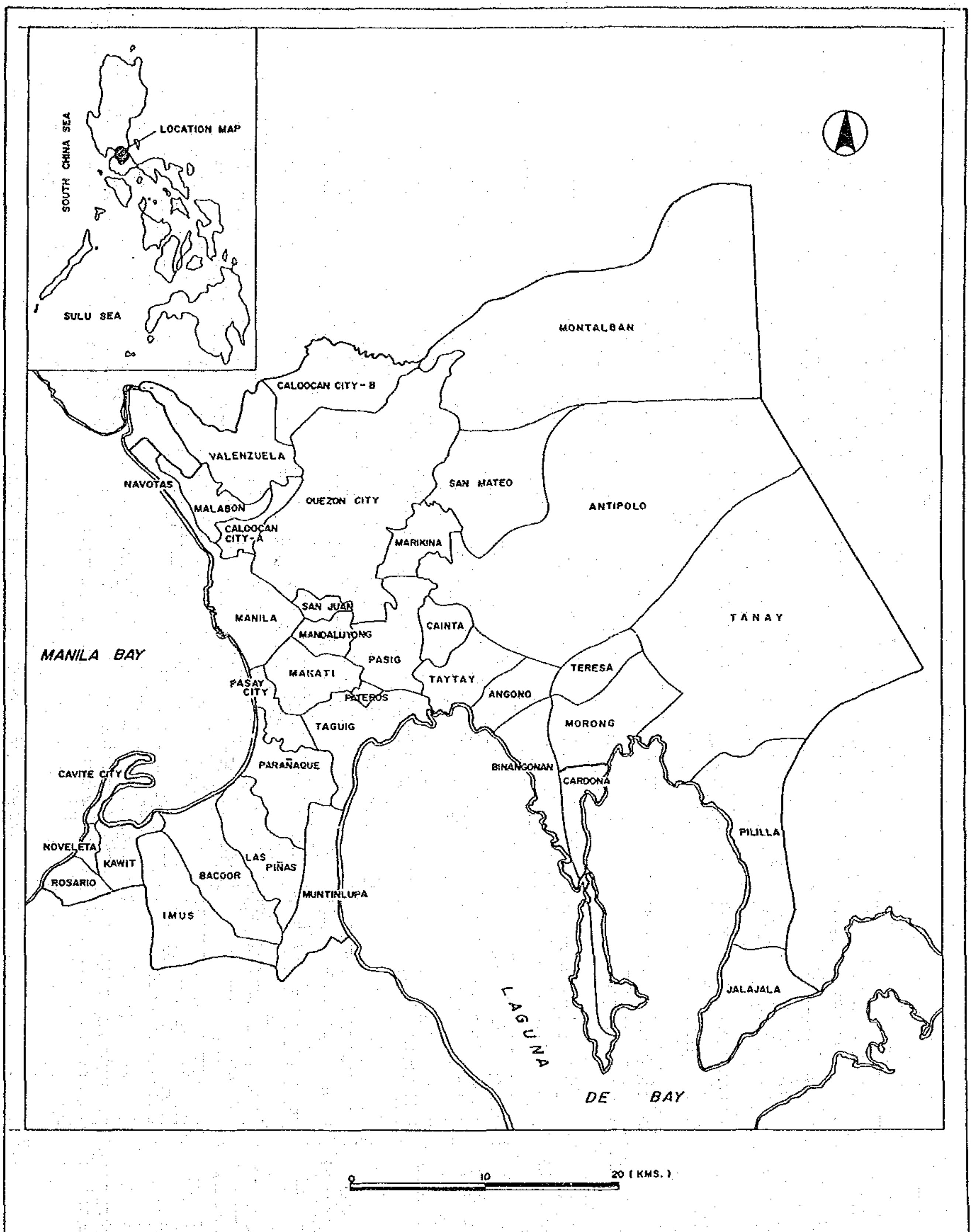
1.5 CONSTITUTION OF THE FINAL REPORT

The Final Report consists of five volumes: Summary Report, Main Report, Supporting Report and Data Report.

The Summary Report contains the summary of the study, conclusions and recommendations. The Main Report describes the results of the study on aquifer distribution, groundwater use, groundwater levels, water quality and rehabilitation of MWSS deep wells. In the Main Report is also contained the evaluation of the groundwater resource of Metro Manila based on the hydrogeologic analyses and computer groundwater simulations. It also contains the proposed groundwater development and management program. Conclusions and recommendations are summarized in the final chapter.

The Supporting Report contains the results of groundwater investigation, test borings,computer simulation, details of urban development planning, water supply systems and future water demand.

The results of electric resistivity survey, pumping tests, well rehabilitation, well inventory, water quality analysis and computer output are presented in the Data Report.



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 1.1 THE STUDY AREA

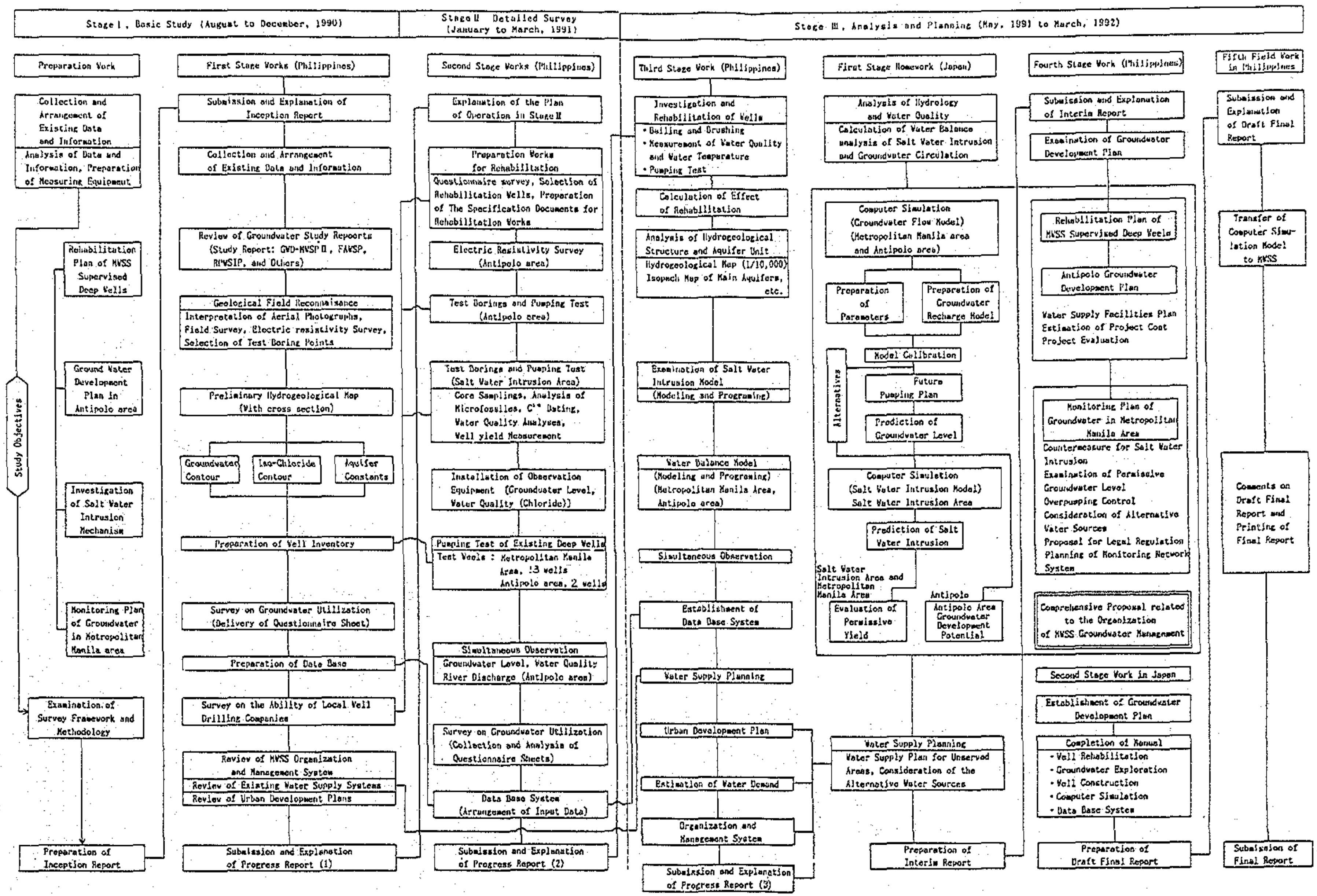


FIGURE 1.2 FLOWCHART OF THE STUDY

CHAPTER 2 SOCIO-ECONOMY AND WATER SUPPLY

2.1 SOCIO-ECONOMIC BACKGROUND

(1) Location

The Philippines consists of more than 7,000 islands located on the Western Pacific Ocean at latitudes 4°23'N to 21°25'N and longitudes 116°E to 126°30'E. Its eleven major islands occupy 90% of the country's total land area of about 300,000 km^2. Metro Manila, the capital region, lies at the center of Luzon Island at latitude 14°35'N and longitude 121°E.

(2) Area and Population

There are thirteen administrative regions in the Philippines including the National Capital Region (NCR). The Study Area includes the NCR and two provinces (Rizal and part of Cavite) of Region IV, a total of five cities and thirty-two municipalities. Its total land area is about 2,125km^2, of which NCR accounts for 636km^2, or 30% of the Study Area (Figures 2.1.1 and 2.1.2).

The 1990 Philippine Population Census placed the population of the country at 60,685,000. The total population of the Study Area was about 9.17 million (NCR: 7.83, Cavite: 0.46, and Rizal: 0.88) representing 15% of total population of the country (Table 2.1.1). Eighty-five percent (85%) of the Study Area's population is in the NCR. Population density in the NCR is around 123 persons per hectare.

(3) Social Background

The NCR and Region IV are the most urbanized and economically developed areas among the regions and have the major advantage in terms of social services, physical facilities, and those amenities associated with urban life. However, a large portion of its population still bears the brunt of poverty and its attendant ills. For Metro Manila, its labor force of the younger generation is abundant while the employment rate is relatively low and was recorded at 82.8% in 1988.

(4) Economic Background

The NCR is the country's center of trade, finance and commerce and education. It is also the seat of the National Government. The NCR accounts for 30% of the country's total Gross Domestic Product (GDP). GDP of the NCR reached 31,323 million pesos in 1988.

The average annual family income in the NCR is about 57,200 pesos, comparing favorably with the Philippine average of 31,000 pesos. Seventy-five percent (75%) of this income comes from non-agricultural sources.

(5) Land Use

Forty-seven percent (47%) of NCR's total land area is built-up area. Rizal's built-up area is only 11.7%. Cavite has its built-up area gradually increasing due to urbanization.

The recent years witnessed industries being located and/or relocated at cheaper sites to the north (Bulacan), east (Rizal) and south (Cavite) of the metropolis, along major transport routes. Agricultural and fishpond areas are converted to residential and/or commercial areas sporadically due to population growth.

2.2 WATER SUPPLY

(1) Present Water Supply Services

As of end-1987, around 63% of the country's total population have access to public water supply systems. The served population then was 86% for Metro Manila and its contiguous areas. Out of the 86% covered in Metro Manila, only 57% were directly served with MWSS water, 16% were served indirectly by MWSS through ambulant vendors, and the rest got their water through private wells and other undetermined sources (Table 2.2.1). The rest of the country's population, approximately 37%, depended on water from open dug wells, rainwater cisterns, lakes and streams.

In Metro Manila, water supply service consists of individual house connections, private wells, some public standpipes in blighted areas, and ambulant vendors. In large urban centers outside Metro Manila, majority of the people are served by Level III systems. In the rural areas, however, the most common water supply facilities are protected wells and Level I developed springs.

(2) Institutional Aspect

Water supply facilities are under the responsibility of the Department of Public Works and Highways (DPWH) and two of its attached agencies, namely, MWSS and the Local Water Utilities Administration (LWUA). The MWSS operates the water supply and sewerage systems in Metro Manila and its contiguous areas, while the LWUA handles the development and improvement of water and sewerage systems in areas not covered by MWSS.

The DPWH is concerned mainly with the development of Level I systems and is the lead agency in establishing national water supply plans and programs. Other agencies involved in the sector include the National Water Resources Board (NWRB) which is involved mainly in policies and regulations concerning the proper utilization and rights thereof of water resources all over the Philippines.

(3) Master Plan of the Philippines

The Water Supply, Sewerage, and Sanitation Master Plan for the period 1988-2000 was formulated in 1987. The Master Plan calls for a two-stage implementation of projects: the first stage covering the period 1988 to 1992; the second stage, the period 1993-2000.

The following activities are envisaged for the first stage. In Metro Manila and its contiguous areas, various projects are to be undertaken to expand and improve the service coverage of the MWSS to 87% of the Metro Manila's population. In other urban areas, population coverage shall be increased to 77% through the construction and rehabilitation of 450 and 250 piped systems (Levels II and III) respectively.

In the rural areas, about 933 piped systems and around 87,146 point sources (Level I) will be constructed. In addition, 21,620 facilities will be repaired or rehabilitated. Taken together, these rural projects should raise the service coverage to about 92% of the rural population.

The second stage of the Master Plan considers the complete water supply coverage of both urban and rural areas, with emphasis on proper operation and maintenance of facilities and the construction of sewerage systems.

In Metro Manila, the Manila Water Supply Project III is planned to boost the service coverage to 97%.

(4) Present Water Supply in MSA

The MWSS has jurisdiction (based on Republic Act No. 5234) over five cities and thirty-two municipalities.

Only specific areas of Metro Manila, plus some parts of Bacoor and Kawit of Cavite Province, are covered by the CDS of MWSS. Excluded from the CDS coverage in Metro Manila are those peripheral areas in the north, east and south of the metropolis. These excluded areas and the other areas in the Rizal and Cavite Provinces predominantly rely on isolated groundwater supply systems which are operated by MWSS and other public entities such as Water Districts, municipalities and barangays (Figure 2.2.1).

Currently under implementation, AWSOP targets an additional $15m^3$/sec of surface water supply. It also aims to expand the area covered by the CDS.

(5) Served Population and Water Amount

The total population served by MWSS in 1990 was 8.2 million, or 90% of the total population within MSA. Of this figure, 2.6 million or 29% of total MSA population was estimated as illegal users of the system (Table 2.2.2).

Surface water and groundwater production by MWSS in 1990 amounted to 876 MCM and 33.3 MCM, respectively.

Private groundwater use for industries, offices, schools, hotels and condominiums, etc. in 1990 was estimated at 307 MCM (see Section 3.3).

(6) Existing Water Supply Facilities

MWSS water sources consist of surface water and groundwater. Water is distributed through CDS. The drawn surface water is first stored in Angat Dam, afterwhich it flows through Angat river down to Ipo Dam. From Ipo dam, the water is conveyed via two tunnels to the Bicti Headworks. It is then diverted to four aqueducts connected to the La Mesa Dam, afterwhich it is conveyed to the Balara and La Mesa Treatment Plants. (See Figure 2.2.2.)

Most of the treated water from the Balara Treatment Plant is sent to the San Juan and Pasig Reservoirs and Balara Pumping Station. That from the La Mesa Treatment Plant is sent to the Bagbag Reservoir. Present capacity of these treatment systems is approximately 2.5 MCM per day. (Refer to Table 2.2.3.)

The groundwater drawn from MWSS deepwells is injected directly into the distribution systems after chlorination. Of the 258 MWSS deepwells, 52 wells are abandoned and 75 wells inactive as of March 1991. Capacity of groundwater source is approximately 90,000 CMD.

The total number of private deepwells is estimated to be more than 3,000.

(7) Ongoing and Proposed Projects

The MWSS is implementing several rehabilitation and expansion projects to reduce non-revenue water (NRW) and increase the service concessionaires. Among these are AWSOP, Manila Water Supply Rehabilitation Project I and II (MWSRP I and MWSRP II), and Metropolitan Manila Water Distribution Project (MMWDP). Several additional projects (e.g. RPWSIP and FAWSP) were also planned with the principal objectives of expanding the service area and augmenting the water production capacity.

(8) Future Water Source and Production Capacity

Based on the implementation plans of ongoing projects, only the AWSOP can be expected to augment the yield of water source by an annual average of 1.3 MCM/day. This increase in production capacity shall be achieved through construction of La Mesa Treatment Plant No. 2 with a capacity of 0.9 MCM/day.

MWSS is implementing several rehabilitation projects in order to recover non-revenue water (NRW). Targeted to be recovered by the MWSRP I and II are 0.765 MCM/day of NRW. As more than half of this amount is estimated to be accounted for by leakage from the distribution lines, around 0.4 MCM/day shall be left for consumption.

Several projects are lined up by the MWSS to augment the yield of its water sources. However, these projects are still on the feasibility study or detailed design stage, and financial sources for them have yet to be assured. As such, their implementation schedules are only tentative. The outlook therefore is for groundwater to supply the fringe areas of Metro Manila and Rizal over a long period of time.

Table 2.1.1 Population and Growth Rate by Region for Census Years

	POPULATION (THOUSANDS)												GROWTH RATE (%)				
	1960		1970		1975		1980		1985 (Estimate)		1990		1960/ 1970	1970/ 1975	1975/ 1980	1980/ 1985	1985/ 1990
Philippines	27,088	100.0	36,684	100.0	42,071	100.0	48,098	100.0	54,688	100.0	60,685	100.0	3.1	2.8	2.7	2.6	2.4
NCR (National Capital Region)	2,462	9.1	3,697	10.8	4,970	11.8	5,296	12.3	6,942	12.7	7,929	13.1	4.9	4.6	3.6	3.2	3.1
Region																	
1. Ilocos	2,428	9.0	2,991	8.1	3,269	7.8	3,541	7.4	3,903	7.1	3,551	5.9	2.1	1.8	1.6	2.0	1.6
2. Cagayan Valley	1,202	4.4	1,691	4.6	1,933	4.6	2,215	4.6	2,521	4.6	2,341	3.9	3.5	2.7	2.8	2.6	2.0
3. Central Luzon	2,525	9.3	3,615	9.9	4,210	10.0	4,803	10.0	5,456	10.0	6,199	10.2	3.7	3.1	2.7	2.6	2.5
4. Southern Tagalog	3,081	11.4	4,457	12.1	5,214	12.4	6,119	12.7	7,089	13.0	8,266	13.6	3.8	3.2	3.3	3.0	3.0
5. Bicol	2,363	8.7	2,967	8.1	3,194	7.6	3,477	7.2	3,922	7.2	3,910	6.4	2.3	1.5	1.7	2.4	1.3
6. Western Visayas	3,078	11.4	3,618	9.9	4,146	9.8	4,526	9.4	5,092	9.3	5,393	8.9	1.6	2.8	1.8	2.4	1.8
7. Central Visayas	2,523	9.3	3,033	8.3	3,387	7.9	3,787	7.9	4,195	7.7	4,593	7.6	1.9	2.2	2.3	2.1	1.9
8. Eastern Visayas	2,041	7.5	2,381	6.5	2,600	6.2	2,799	5.8	2,073	5.6	3,055	5.0	1.6	1.8	1.5	1.9	0.9
9. Western Visayas	1,351	5.0	1,869	5.1	2,048	4.9	2,528	5.3	2,863	5.2	3,159	5.2	3.3	1.8	4.3	2.1	2.3
10. Northern Mindanao	1,297	4.8	1,953	5.3	2,314	5.5	2,759	5.7	3,718	5.8	3,510	5.8	4.2	3.5	3.6	2.9	2.3
11. Southern Mindanao	1,353	5.0	2,201	6.0	2,715	6.5	3,347	7.0	3,836	7.0	4,457	7.3	5.0	4.3	4.3	2.8	2.9
12. Central Mindanao	1,383	5.1	1,941	5.3	2,070	4.9	2,271	4.7	2,598	4.8	3,171	5.2	3.4	1.3	1.9	2.7	3.5

Source: 1960-1980 Philippine Statistical Yearbook 1989 (NEDA)
1985 Philippine Yearbook 1989 (NSO)
1990 1990 Census of Population and Housing (NSO)

TABLE 2.1.2 GROSS REGIONAL DOMESTIC PRODUCT, FOR 1987-1988
(AT CONSTANT 1972 PRICES)

REGION	Actual (in PM)		Growth Rate	Per Capita GRDP (in P)	Growth Rate (in %)
	1987	1988*	1987-1988	1988	1987-1988
PHIL.	95,948	101,758	6.63	1,733	3.56
NCR	28,502	31,323	9.90	4,143	6.89
I	4,323	4,507	4.25	1,090	2.28
II	2,301	2,432	5.70	897	3.16
III	7,664	8,286	8.12	1,413	5.59
IV	14,221	14,929	4.97	1,941	2.19
V	3,120	3,257	4.41	776	2.09
VI	6,545	6,902	5.44	1,269	3.19
VII	6,905	7,421	7.48	1,669	5.45
VIII	2,323	2,383	2.60	735	0.76
IX	3,350	3,492	4.24	1,141	1.96
X	5,248	5,570	6.13	1,620	3.41
XI	7,082	7,186	1.47	1,739	-0.98
XII	3,844	4,064	5.74	1,451	3.14

(*) As of January 1989

Sources: Economic and Social Statistics Office
National Statistical Coordination Board

TABLE 2.2.1 EXISTING WATER SUPPLY COVERAGE

(million)

Area	Total Population	(%)	Population Served Total	(%)	Wells/Developed Spring	(%)	Piped System	(%)	Underserved/ Unserved Population	(%)
Philippines	57.36	100	36.17	63	17.92	31	18.25	32	21.19	37
Urban	23.53	100	15.39	65	12.52	53	2.87	12	8.14	35
Metro Manila and and its contiguous area*	8.16	100	7.01	86	6.84	84	0.17	2	1.15	14
Others	15.37	100	8.38	55	5.68	37	2.70	18	6.99	45
Rural	33.83	100	20.78	62	5.40	16	15.38	46	13.05	38

* Excluding the 303,433 population of the towns of Rizal province under BP 799.

Source: Department of Public Works and Highways, Water Supply, Sewerage, and Sanitation Master Plan of the Philippines: 1988-2000.

TABLE 2.2.2 MWSS WATER SUPPLY STATISTICS

Year	1984	1985	1986	1987	1988	1989	1990
1) Pop'n under MWSS (million)	7.480	7.712	7.938	8.167	8.405	8.651	9.133
2) Water Production							
a) Surface Water (million m3)	642.24	757.37	874.07	834.75	849.34	859.10	875.80
b) Groundwater (million m3)	25.56	29.45	30.43	27.87	29.48	28.96	33.33
Total	667.80	786.83	904.51	862.62	878.82	888.06	909.13
Increase	-	119.03	117.68	(41.89)	16.20	9.24	21.07
3) Water Consumption							
a) Volume Sold (million m3)	289.90	302.85	310.78	336.51	359.45	375.77	384.67
%	43.4%	38.5%	34.4%	39.0%	40.9%	42.3%	42.3%
b) NRW (million m3)	377.90	483.98	593.73	526.11	519.37	512.29	524.46
%	56.6%	61.5%	65.6%	61.0%	59.1%	57.7%	57.7%
Total	667.80	786.83	904.51	862.62	878.82	888.06	909.13
c) House Connection (mil. m3)	168.55	183.55	195.47	218.48	225.85	235.74	244.97
d) P.F. & Other Conn. (mil. m3)	121.35	119.30	115.31	118.03	133.60	140.03	139.70
e) Illegal Use (mil. m3)	151.16	193.59	237.49	210.44	207.75	204.92	209.78
Sub Total	441.06	496.44	548.27	546.95	567.20	580.69	594.45
%	66.0%	63.1%	60.6%	63.4%	64.5%	65.4%	65.4%
f) Leak, Meter Error (mil. m3)	226.74	290.39	356.24	315.67	311.62	307.37	314.68
%	34.0%	36.9%	39.4%	36.6%	35.5%	34.6%	34.6%
Total	667.80	786.83	904.51	862.62	878.82	888.06	909.13
4) Number of Connections							
a) House Connection	321,512	377,538	442,323	490,223	508,545	543,128	599,754
b) Public Faucet	1,020	1,080	1,160	1,230	1,300	1,420	1,490
c) Others	27,039	27,368	26,919	26,703	44,688	43,910	47,343
Total	349,571	405,986	470,402	518,156	554,533	588,458	648,587
Increase	-	56,415	64,416	47,754	36,377	33,925	60,129
5) Estimated Population Served							
a) House Connection (million)	2.604	3.058	3.583	3.971	4.119	4.399	4.858
b) Public Faucet (million)	0.496	0.525	0.564	0.598	0.632	0.690	0.724
Sub Total	3.100	3.583	4.147	4.569	4.751	5.089	5.582
Increase	-	0.483	0.564	0.422	0.182	0.338	0.493
c) Illegal Use (million)	1.358	1.955	2.738	2.483	2.381	2.399	2.649
Total	4.458	5.538	6.884	7.052	7.132	7.489	8.232
Increase	-	1.080	1.347	0.167	0.080	0.357	0.743
6) Per Capita Water Consumption (lpcd)							
a) for distributed water	410	389	360	335	338	325	303
b) for effective water	271	246	218	212	218	212	198
c) for domestic water	177	164	149	151	150	147	138

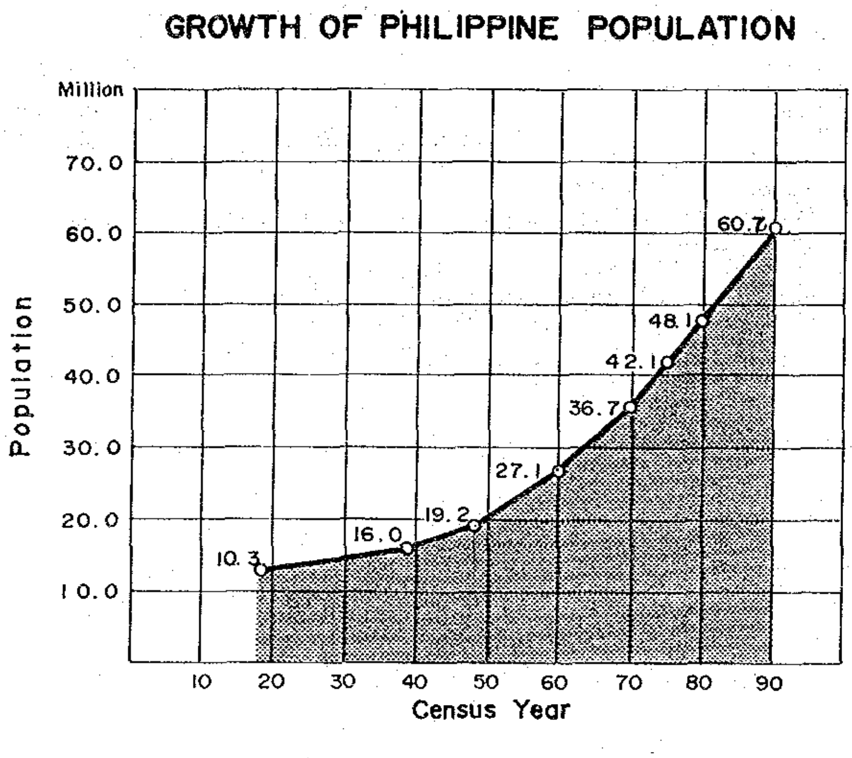
Note: 5a = 4a x 8.1, 5b = 4b x 486, 5c = (3b x 0.4 x (3c/3a)) / (3c/4a) x 8.1
6a = (3a+3b) / (5a+5b+5c), 6b = (3c+3d+3e) / (5a+5b+5c), 6c = 3c / 5a

Source: Corporate Planning Group

Table 2.2.3 Capacity of Water Sources

Source		Area of Watershed (km^2)	Water Right or Capacity (m^3/day)	Status
Angat Dam (Angat River)		568	1,901,000 1/	Used
Ipo Dam (Angat River, Ipo River)	Old	-	(Submerged by New Dam)	
	New	70	474,000 2/	Used
La Mesa Dam (Novaliches Watershed)		27	100,000 3/	Used
Alat Diversion Dam (Alat River)		14	20,000 4/	Used
Marikina River Pumping Stations 5/	1st	-	189,000	Abandoned
	2nd	-	189,000	Abandoned
Wawa Dam (Wawa River)		280	57,000	Abandoned
Groundwater			82,000 6/	Used
Total			3,012,000 m^3/day	
	Used w/o Groundwater		2,495,000 m^3/day	

1/: Allocated, 22 CMS
2/: AWSOP; derived from catchment area, rainfall, and permeability coefficient
3/: AWSOP; calculated based on water balance
4/: AWSOP; based on measurement
5/: Abandoned due to bad water quality
6/: Annual average pumpage of MWSS-owned deep wells



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 2.1.1
JAPAN INTERNATIONAL COOPERATION AGENCY	GROWTH OF THE PHILIPPINE POPULATION

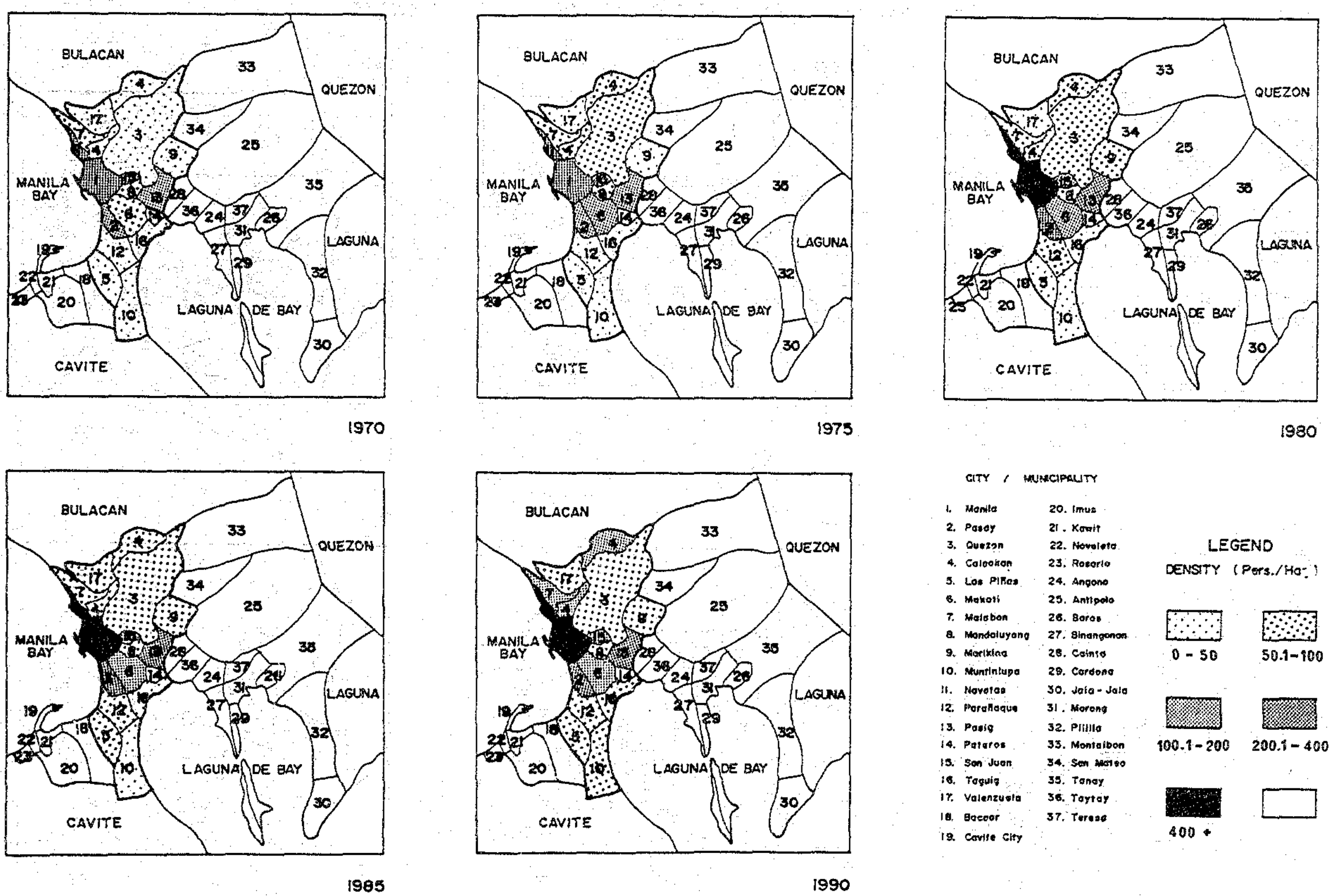


FIGURE 2.1.2(1) POPULATION DENSITY OF NCR

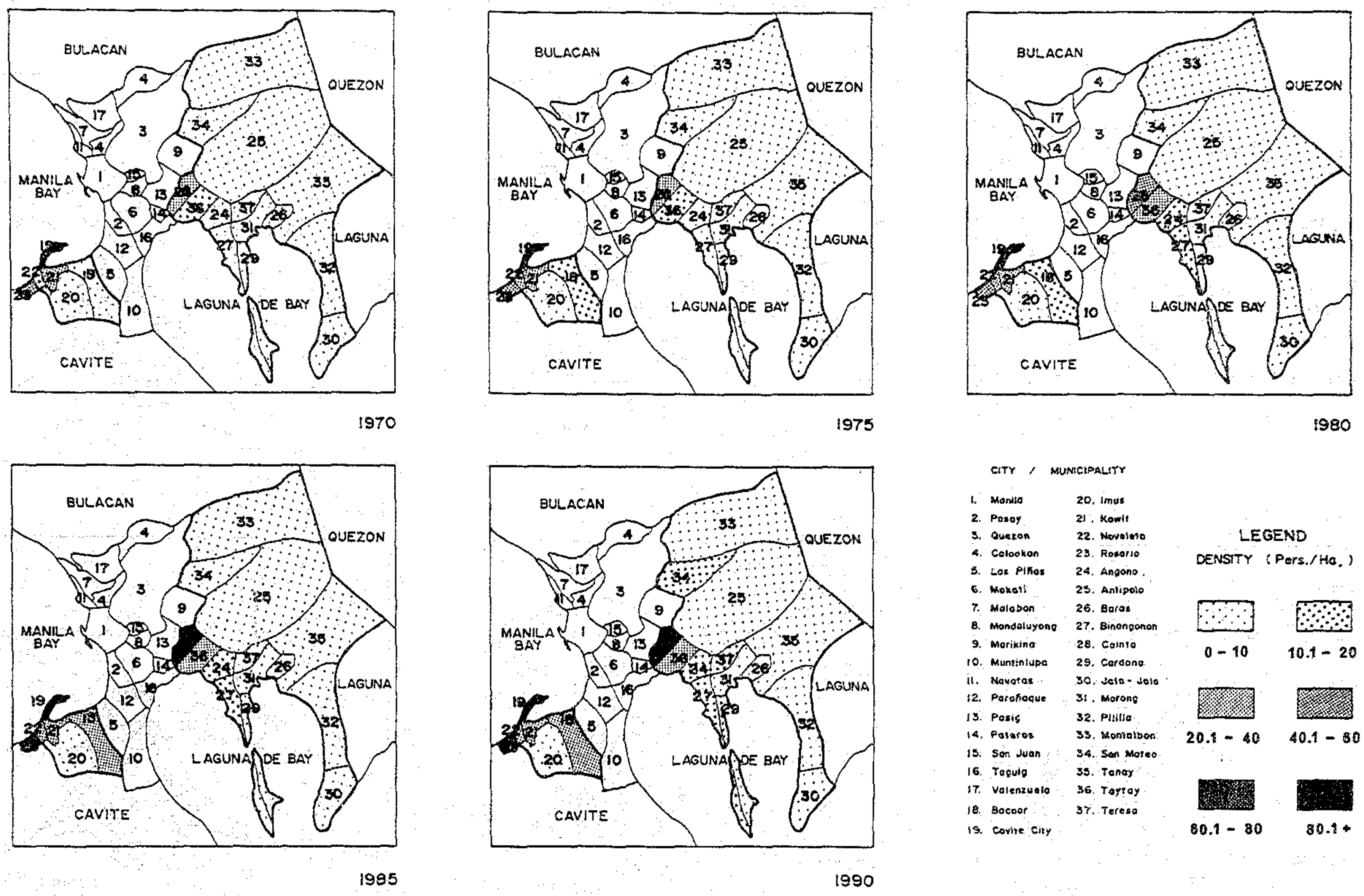
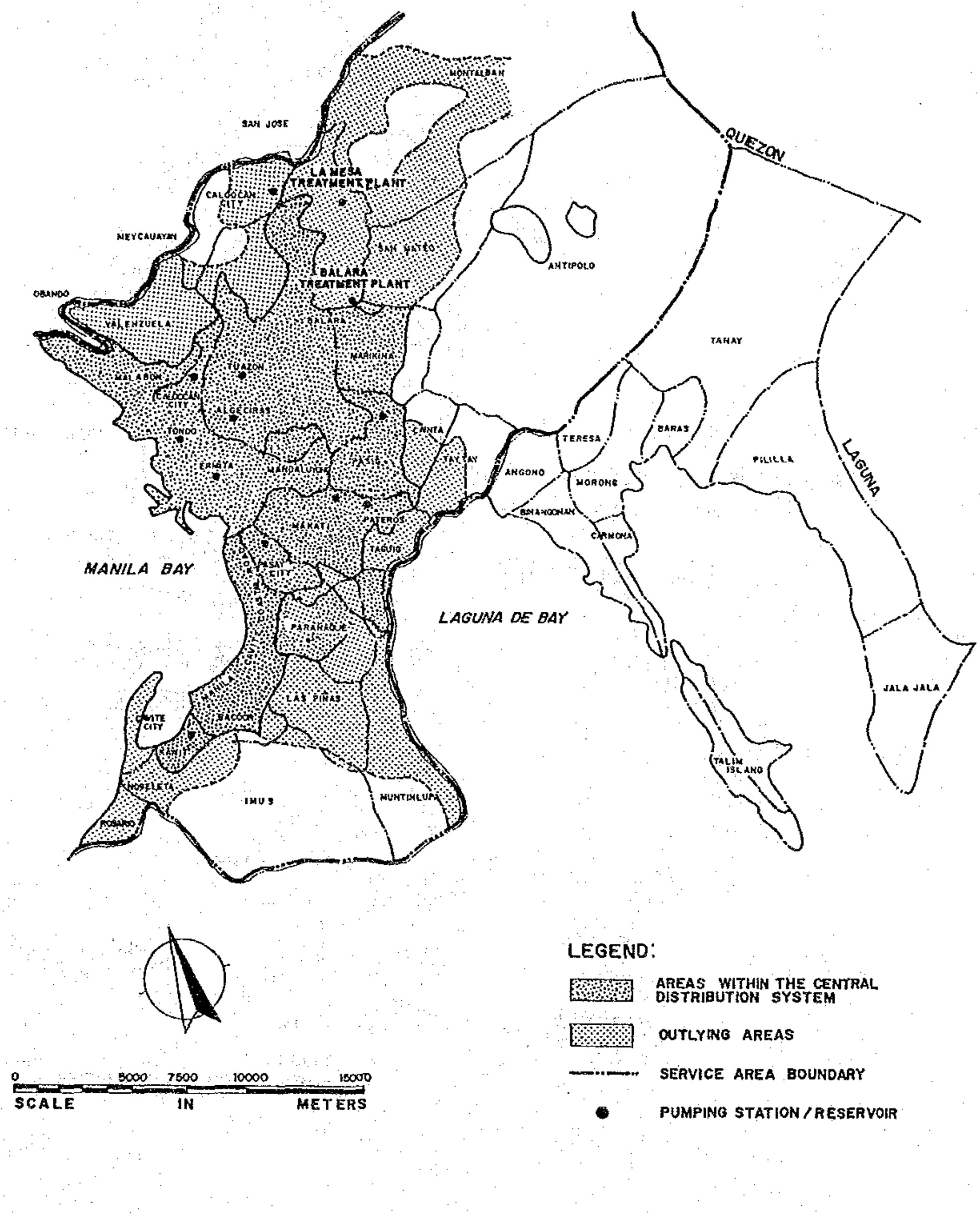
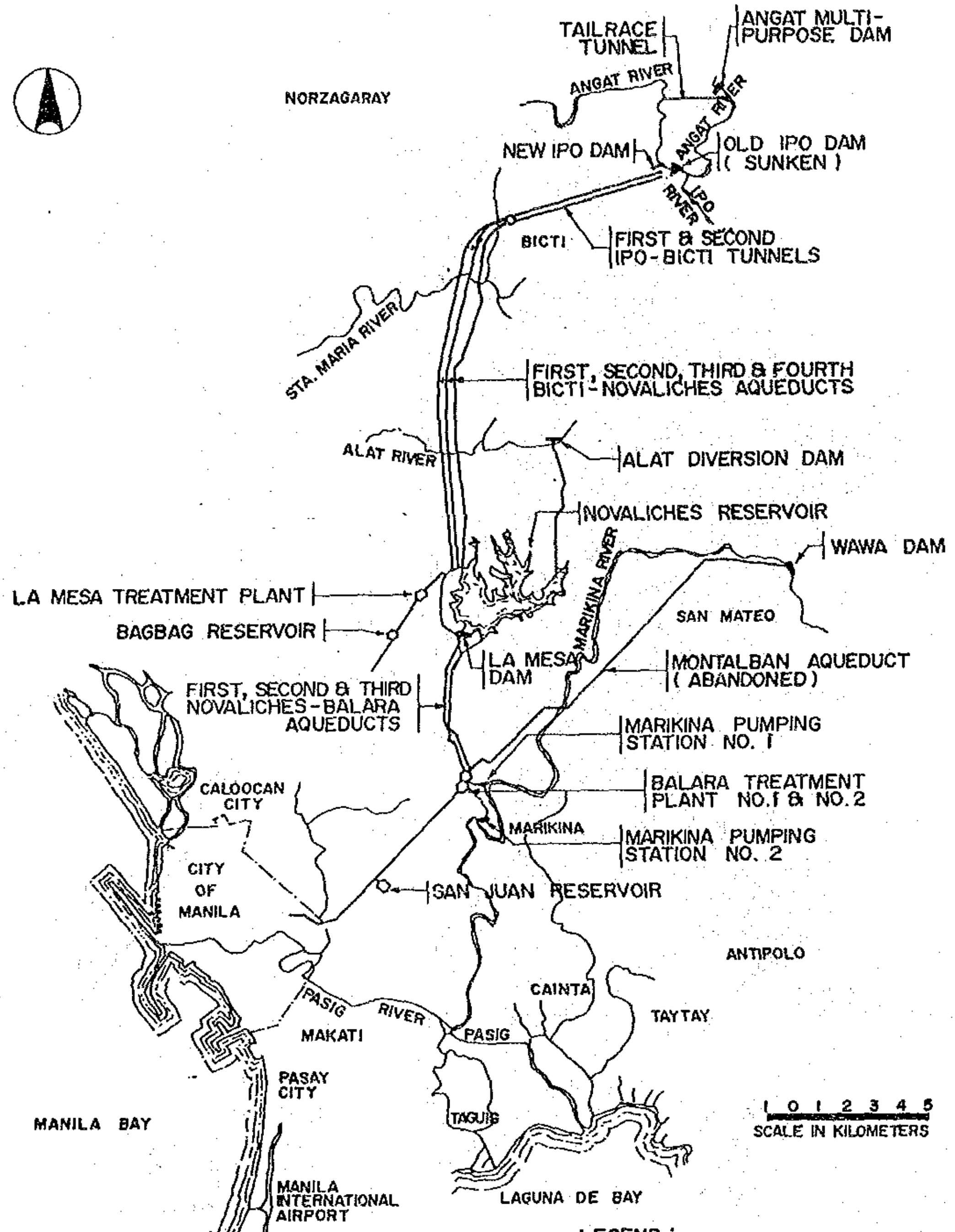


FIGURE 2.1.2(2) POPULATION DENSITY OF CAVITE AND RIZAL



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 2.2.1
JAPAN INTERNATIONAL COOPERATION AGENCY	PRESENT WATER SUPPLY SERVICE AREA BY MWSS



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 2.2.2
JAPAN INTERNATIONAL COOPERATION AGENCY	EXISTING AND MAJOR SUPPLY FACILITIES

CHAPTER 3 GROUNDWATER

3.1 HYDROLOGICAL ENVIRONMENT

3.1.1 Climate

The climate in the Study Area is divided into two seasons: the rainy season from May to October and the dry season from November to April. About 90 percent of annual rainfall occurs during the rainy season.

Average annual rainfall in the Study Area ranges from 1900mm to 2200mm. It is high in the eastern mountainous area, where it ranges from 2,200mm to 2,400mm, and gradually decreases from 2000mm to 1900mm westward. (See Figure 3.1.1.)

Mean monthly temperature varies from 25°C to 30°C. The coldest months are from December to February; the warmest months, April and May.

3.1.2 Topography and Hydrology

The Study Area faces Manila Bay in the west and the northern coast of Laguna de Bay in the south. The Antipolo Plateau is located in the east at an elevation of 250m. It extends in the north-south direction along Marikina Valley. The mountainous area of Montalban is located in the northeast.

Surface elevation ranges from 0m at the coast to 1400-1500m at the northeastern mountainous area. Most of the Study Area consists of coastal plains and hilly areas extending in the north-south direction along Manila Bay. Surface elevation ranges from 0-10m on the coastal plains and 20-70m on the hills.

Hydrologically, the Study Area is located within the Pasig-Laguna de Bay River Basin. This basin drains three (3) distinct and different sub-basins, namely, the Marikina River Basin, the Laguna de Bay Basin, and the urban watershed which includes the Greater Manila urban area.

Flowing east to west through central Manila is the Pasig River which is about 17 kilometers in length from the confluence of the Marikina River and Napindan Channel to Manila Bay.

Laguna de Bay is a shallow lake serving as a natural detention reservoir of discharges from the surrounding tributary streams. The lake's only outlet is via the Napindan Channel and Pasig River. The Napindan River normally flows from Laguna de Bay to Pasig, but it can and does flow in either direction, depending upon river and lake levels (Figure 3.1.2).

3.2 HYDROGEOLOGY

3.2.1 Metro Manila and Its Environs

(1) Outline of Geology

Geographically, the Study Area is situated in the southeastern part of the Luzon Central Plain and mainly constitutes the East Side Hill. The Luzon Central Plain extends in the north-south direction and faces Manila Bay in the south and the Lingayen Gulf in the north. (Refer to Figure 3.2.1.)

The plain is underlain by Alluvium, Guadalupe formation of the Pleistocene to the Pliocene age, and Neogene Tertiary system, in descending order. This sedimentary basin is named as the Luzon Central Valley Basin.

The East Side Hill ranges in the north-south direction in the east of the Luzon Central Plain at an elevation of 40-200m. It also extends from Palayan to Laguna de Bay. The hill almost coincides with the area where the Guadalupe formation is exposed. Most of Metro Manila is located on the hill.

The Southwest Luzon Upland is situated south of the Study Area. The elevation decreases towards the north. The southern piedmont area of Taal volcano is contiguous to Manila Bay and Laguna de Bay and is widely covered by thick volcanic materials and mud flows. The area constitutes a recharge zone of the lake water of Laguna de Bay and of the groundwater south of the Study Area.

South Sierra Madre presents a landform at the maturity stage with an elevation range of 300-1,500m. The area is underlain by pyroclastics, clastic rocks and limestone of Mesozoic to Neogene age and constitutes a part of the hydrogeological basement of the Study Area.

West of the Central Plain and extending north to east is the Zambales Range. This range is a mountainous region composed of volcanoes with heights of more than 1,200m. The basement of mountains consists of ultra-basic rocks. The volcanoes of the region range from north to south and form a row extending to the Bataan Peninsula, the Corregidor island, the Luzon upland and Mt. Batulao.

The volcanic row bounds the western Luzon Central Valley Basin and is considered to be a principal source of materials during the diluvial age of the sedimentary basin of the Guadalupe formation in the western part (Figure 3.2.2).

(2) Stratigraphy and Distribution

The Study Area is underlain by Kinabuan and Maybangain Formations of Cretaceous to Paleogene age, Angat and Madlum Formations of Neogene age, and Guadalupe Formation and Alluvium of Quaternary age (Figure 3.2.3).

Marikina Valley is situated at the center of the Study Area and it extends in the north-south direction. West of this valley, the Guadalupe formations and Alluvium underlie the area. In the east, the area is underlain by all the formations mentioned above.

(3) Geologic Formations as Aquifers

Consolidated clastic and volcanic rocks are deemed to be relatively impermeable. Weathered parts and fissure zone of rocks form an aquifer. However, most of these rocks yield very poor water or form aquifuges.

Clastic facies, such as tuffaceous sandstone, conglomerate and coarse tuff of Guadalupe formation form good aquifers in the Study Area. The Guadalupe formation distributes separately into three sedimentary basins. Each basin is surrounded by impermeable base rocks and forms isolated groundwater basin.

The Guadalupe Sedimentary Basin forms a part of the Luzon Central Valley Basin. Most of Metropolitan Manila is located in this latter basin. It is covered by Alluvium in the coastal areas of Manila Bay and the Marikina Valley. Generally, the strata gently dip westward in the east of the basin. The thickness of Guadalupe formation is also estimated to be more than 2,000m (3.2.4).

Antipolo Plateau is a small sedimentary basin surrounded by impermeable base rocks. Its center is in the town of Antipolo. The plateau forms a groundwater basin having an area of about $30km^2$ and contains exploitable water, quantity- and quality-wise. The thickness of the formation is about 230m.

North of the plateau, the Guadalupe formation forms a small sedimentary basin overlying the basaltic rocks of the Kinabuan formation.

The Alluvium is mainly composed of soft clay and thin loose sand and is distributed in the coastal areas of Manila Bay and Laguna de Bay, the Marikina Valley and the intramountain basins in the eastern mountain-area. The Alluvium forms a phreatic aquifer; however, water is salinized in the coastal area.

3.2.2 Antipolo Plateau

The Guadalupe formation may be divided into four members. The lowermost member, member I, consists of conglomerate and coarse sandstone and underlies the north of the plateau. Member II has two parts. The lower part is composed of consolidated medium sandstone and conglomerate while alternating beds of tuffaceous mudstone and sandstone compose the upper part. This member crops out at the steep cliff in the east of the plateau. Member III consists of alternating beds of mudstone and tuff. It covers the central area of the plateau. Member IV consists of deeply weathered tuff breccia and volcanic conglomerate. It overlies the north of the plateau (Figure 3.2.5).

The basement of Antipolo Plateau is composed of hard rocks of Pre-Neogene age. The basin is shaped like a ship-bottom with a depth-range of 180 to 230m at the center. The basement rocks are exposed in the east, west, and north of the plateau, in fault contact or unconformity with the Guadalupe formation. A number of springs are found along the marginal zone of the plateau, with water being discharged from the plateau.

Basing on JICA test wells and electric resistivity survey, hydrogeologic units can be defined as upper Gs and lower Gmd in terms of rock facies, formation resistivities and transmissivity values of the formations. Gs is mainly composed of coarse sandstone and tuff of member III and forms a fairly good confined aquifer. Its thickness is 100-120m. Gmd is mainly composed of tuffaceous mudstone of member II and forms an aquitard or aquifuge.

The Guadalupe formation is weathered at depths of 30-50m from the surface. The weathered unit contains unconfined water or perched water. From the flow condition of the spring, the Antipolo Plateau is considered to constitute an isolated groundwater basin (Figure 3.2.6).

Elevation of the water table at the center of Antipolo Plateau ranges from 160m to 170m, with groundwater level at about 30m to 40m below ground surface. A groundwater mound can be seen in the southern and eastern parts of the plateau. However, the water table becomes rather low at the center of the poblacion where it gradually descends westward.

The hydraulic gradient of the water table is steep in areas where escarpments are formed. These areas are located in the northeastern, eastern and southwestern edges of the plateau, at a relative height of about 200m. The hydraulic gradient of the water table in these places is steep such that the groundwater is discharged from the basin.

3.2.3 Las Piñas

The Las Piñas area is a flat land with an elevation range of 0-10m. It is located at the mouth of the Zapote and Las Piñas Rivers. Old rivers and marine ponds are found in this area. An alluvial plain extends inland at about 1.5-2.0km from the coast. A gently undulating hill is situated behind this plain at an elevation of 20-40m.

The lowland is covered by the Alluvium which is composed of sand and clay. The Guadalupe formation is exposed in the previously said undulating hill and is composed of alternating beds of sandstone, conglomerate, mudstone and tuff. The strata have strikes parallel to the coastal line and incline towards Manila Bay at 3-5 degrees. The thickness of the Guadalupe Formation possibly reaches to more than 2,000m.

In order to clarify the hydrogeology and saline water intrusion in Las Piñas, core borings and test well drillings were carried out. The thickness of Alluvium is less than 10m. The rest of the strata belongs to the Guadalupe Formation which is composed of tuffaceous silt, fine sand and medium to coarse sand. Significant thickness of clayey sediments that form the confining layer (CL) was traced at depths of about 60m to 90m. Four characteristic pumice-bearing layers (PM) occur at depths below 100m. These layers can be traced horizontally in the Las Piñas area (Figures 3.2.7 and 3.2.8).

The Guadalupe formation which is about 300m in thickness can be roughly divided into two aquifer units. The first aquifer has a thickness of about 60m and is confined. Since groundwater is highly salinized, no existing deep well taps this aquifer. The second aquifer has a thickness of more than 200m and is also confined. Existing deep wells have their screen sections at this aquifer. The CL--the first aquitard--particularly has an important role in saline water intrusion because of the high salinity of the first aquifer.

Groundwater level varies from aquifer to aquifer. Water levels of Las Piñas 100m-test wells are 4.6m and 3.7m for No.1 and No.2, respectively. In contrast, water levels of two 200m-test wells are 37.3m for No. 1 and 43.4m for No. 2. Water levels of 300m-test wells are 44.5m (No. 1) and 50.0m (No. 2), a little lower than those of 200m-test wells, indicating that groundwater is mainly pumped from the second aquifer.

The marked drop of the piezometric surface at the second aquifer to 60m below sea level near Pamplona points to the heavy pumping in this area as cause for the decline in piezometric head. Regional groundwater flows towards the depression in Pamplona, from the first aquifer towards the second aquifer through downward leakage.

3.3 GROUNDWATER USE

The total number of inventoried private deepwells in MSA is 3,434; of which, 2,216 were estimated as operational and 1,218 as abandoned wells. Private wells are concentrated in Parañaque, Las Piñas, Muntinlupa, Pasig, Quezon City, Caloocan City and Valenzuela.

Of the 258 MWSS-supervised wells, only 131 wells were active as of March 1991.

A groundwater use survey was conducted in the Study Area so that the average annual pumpage of private deep wells may be estimated. These wells were classified in terms of usage, area, and specific capacity. Of the 1063 sample-wells visited, only 542 were found valid for the estimation.

Pumpage of MWSS-supervised wells was determined using year-1990 pumping records.

The combined total withdrawal in 1990 was estimated at 339.6 MCM (private: 306.8 MCM; MWSS: 32.8 MCM). In terms of usage, the distribution was 26.34 MCM for commercial; 129.54 MCM for industrial and 150.97 MCM for public and institutional (Figure 3.3.1).

3.4 GROUNDWATER LEVELS

Three sets of simultaneous observations of groundwater levels of 231 deepwells were carried out in November 1990, April-May 1991 and August 1991. Groundwater contour maps were then prepared from the measurements (Figures 3.4.1 (1) and (2)).

The piezometric surface is higher in northern Caloocan City (from 20m to 60m above Mean Sea Level (MSL)) and in southern Bacoor and Imus (from 10m to 50m above MSL). However, a greater portion of Metro Manila has the piezometric surface below MSL: -70m to -80m in Las Piñas and Parañaque; -50m to -60m in Pasig and Quezon City; and -110m in Valenzuela.

The piezometric surface reveals that groundwater in the northern part of Metro Manila is flowing southward and westward, and in the southern part, northward. Both parts have groundwater flowing to areas of heavy pumpage, i.e., where the piezometric surface is below MSL. It also shows that Manila Bay and Laguna de Bay are recharging the depressions on their coastal areas.

Comparing the piezometric condition in 1981 and 1991, it may be noted that water levels have recovered at a maximum of more than 80m in the central part of Metro Manila, i.e., Manila, Makati and Mandaluyong (Figure 3.4.1 (3)). This recovery is considered as an outcome of the reduced pumpage arising from the completion of Manila Water Supply Project II (MWSP II).

The year-1991 fluctuation in Metro Manila of water levels between the dry and wet seasons indicates a rise of about one to six meters in the north sector and two to four meters in the south sector. In most of Metro Manila, however, water level was continuously declining due to pumping.

3.5 RECHARGE ANALYSIS

Direct recharge from rainfall over the Antipolo Groundwater Basin and the entire Study Area was estimated based on the following equation:

$$P = R + E + I$$

where, P: mean annual rainfall; R: runoff; E: evapotranspiration; and I: effective infiltration, all in mm.

The estimate of the direct recharge in the Antipolo basin is as follows.

Annual rainfall	:	2,720.8
Runoff	:	1,142.7
Evapotranspiration	:	958.8
Recharge	:	619.3 (23% of annual rainfall)

The estimate of the direct recharge over the Study Area had the present land use condition considered. It is as follows.

Annual rainfall	:	2,329.7
Runoff	:	1,397.8
Evapotranspiration	:	816.6
Recharge	:	115.3 (4.9% of annual rainfall)

The direct recharge over the Study Area is about 153.6mm (6.1% of 2498.8mm annual rainfall) and 114.7mm (5.0% of 2308.2mm annual rainfall) at its northern and southern parts.

3.6 AQUIFER PARAMETERS

The transmissivity and specific capacity maps (Figure 3.6.1) were prepared based on existing pumping test data plus those obtained from pumping tests conducted at MWSS deepwells. The average value of the transmissivity in the Metro Manila area is 58.3 m^2/d, with a range of 50 m^2/d to 100 m^2/d. High transmissivity zones are found in the coastal areas of Manila Bay, Laguna de Bay and Marikina Valley.

3.7 GROUNDWATER QUALITY

A total of 90 water samples were collected from operational deepwells. Seven major ions (Na^+, K^+, $Ca2^+$, $Mg2^+$, Cl^-, HCO_3, SO_4) were analyzed and plotted on the key diagram. (Refer to Figures 3.7.1 and 3.7.2.)

Most of the samples from the coastal area were plotted on domains III (carbonate alkali) and IV (noncarbonate alkali) of the diagram. Samples in domain IV are salinized and contain more than 200 mg/l of chloride. In two JICA 100m-test wells in Las Piñas, chloride concentration was extremely high and reached more than 17,000 mg/l. Samples in domain III are not salinized. Their chemical composition is thought to change from II to III along flow paths.

Samples from Guadalupe Hill were plotted on domains II (carbonate hardness) and III. They may have evolved geochemically from domain II. Chloride and sulfate concentrations of these samples are low and amount to less than 50 mg/l, suggesting groundwater of the Guadalupe aquifer in the hill to be not contaminated yet by saline water.

Samples from Marikina Valley were plotted on all the domains from I to IV. Two samples plotted on domains I and IV are remarkable. Chloride concentration of these samples show more than 140 mg/l. They are possibly contaminated by connate saline water contained in the deep aquifers.

All samples from the Antipolo Plateau were plotted on domain II. Surface water samples taken from Wawa Dam also belong to domain II. The chemical component of groundwater in the plateau is similar to that of surface water. Cation and anion characteristics of groundwater suggest that it has not been long since rain infiltrated through the soil into the aquifer system.

The groundwater quality of the Guadalupe aquifer is considered as originally belonging to domain II, but due to the saline water intrusion particularly in the coastal area, this quality was altered to the non-carbonate alkali type.

In Marikina Valley, connate water migrates into the shallow aquifer due to upconing.

3.8 SALINE WATER INTRUSION

Saline water intrusion of coastal areas in Metro Manila has been already observed in the late 1960s. Areas where saline water intruded were observed in Parañaque, in parts of Las Piñas and Cavite along Manila Bay, in Muntinlupa, in Pateros areas along Laguna de Bay and in parts of Cainta located downstream of the Marikina River.

Comparing the distribution of electric conductivity (EC) for years 1981 and 1991, a reduction of the saltwater intruded areas in Manila and Malabon may be noted. This reduction could be a result of the recovery of the groundwater level, which in turn was caused by the conversion of water source from groundwater to surface water. However, in an inland area within a few kilometers from the coast of Las Piñas and Bacoor, saline water has intruded (Figures 3.8.1 (1) and (2)).

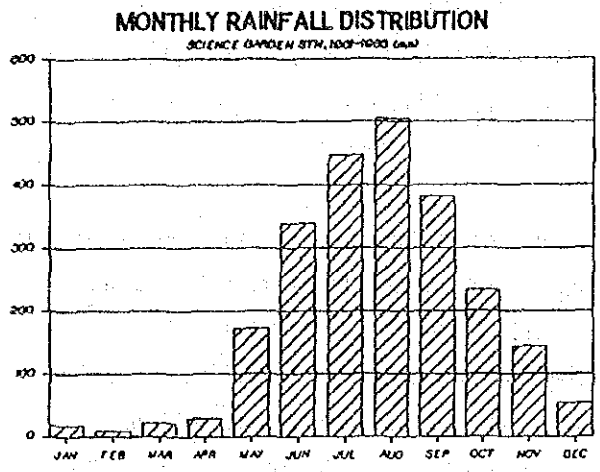
Electric conductivity and chloride concentration of the groundwater at the Las Piñas test wells show different values from aquifer to aquifer. At 100-m wells, Nos.1 and 2, high chloride concentrations of 17,144 mg/l and 21,100 mg/l were found. At the 200-m well at Las Piñas No.2, chloride concentration is 4,923 mg/l. However, groundwater is not salinized in the deep aquifer as seen in the 200-m and 300-m wells at Las Piñas No.1, and in the 300-m wells at Las Piñas Nos. 2 and 3. Chloride concentrations in these wells are less than 200 mg/l.

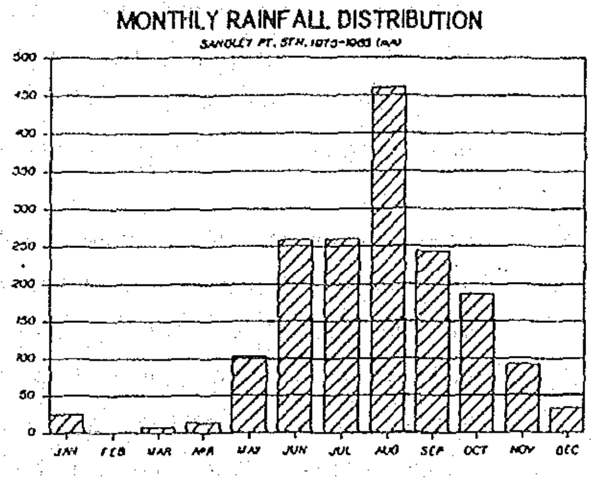
Considering the difference in chloride concentration at each aquifer, it is apparent that saline water migrates downward from the first aquifer to the second aquifer by leakage. The first aquifer may be salinized mainly by seawater encroachment from Manila Bay. Another cause of contamination may be the existence of the marine pond spreading 1.5 to 2.0km inland from the coast and the tidal inundation of the Zapote River.

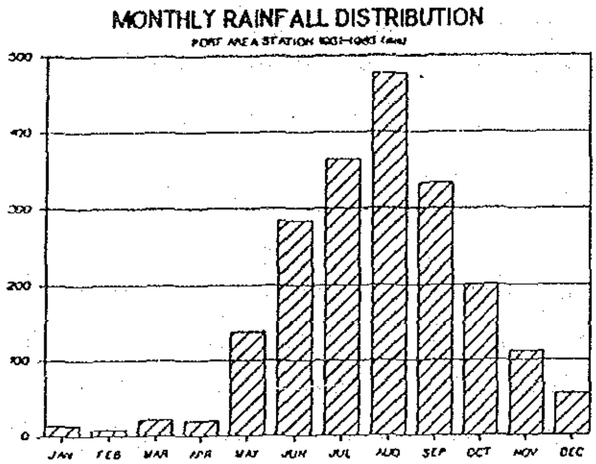
In the Marikina Valley, however, highly salinized groundwater was found in the deep Guadalupe aquifers--at the MGB PS-4 well that was drilled in the 1960s and whose recorded depth is 457.2m. This indicates the possible existence of fossil water in the Guadalupe aquifer. Saline water intrusion in shallow aquifers (100-200m) may be caused by upconing.

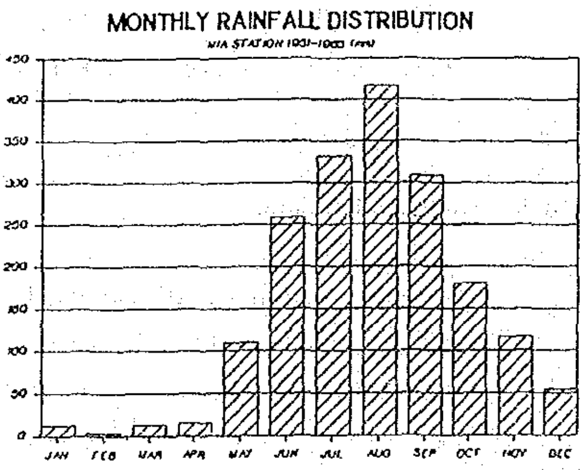
3.9 LAND SUBSIDENCE

The MSL measured at the Manila South Harbor tide station has markedly risen since the mid-Sixties. It may be noted that from 1965 to 1989 the MSL at Manila appears to have risen by 0.478m. However, no clear physical evidence of land subsidence was found in the coastal area. And because the Guadalupe formation is consolidated and the Alluvium clayey bed is thin, the probability of land subsidence occurring in this area is nil. Obtaining clear evidence of land subsidence therefore requires periodical regional leveling in Metro Manila.

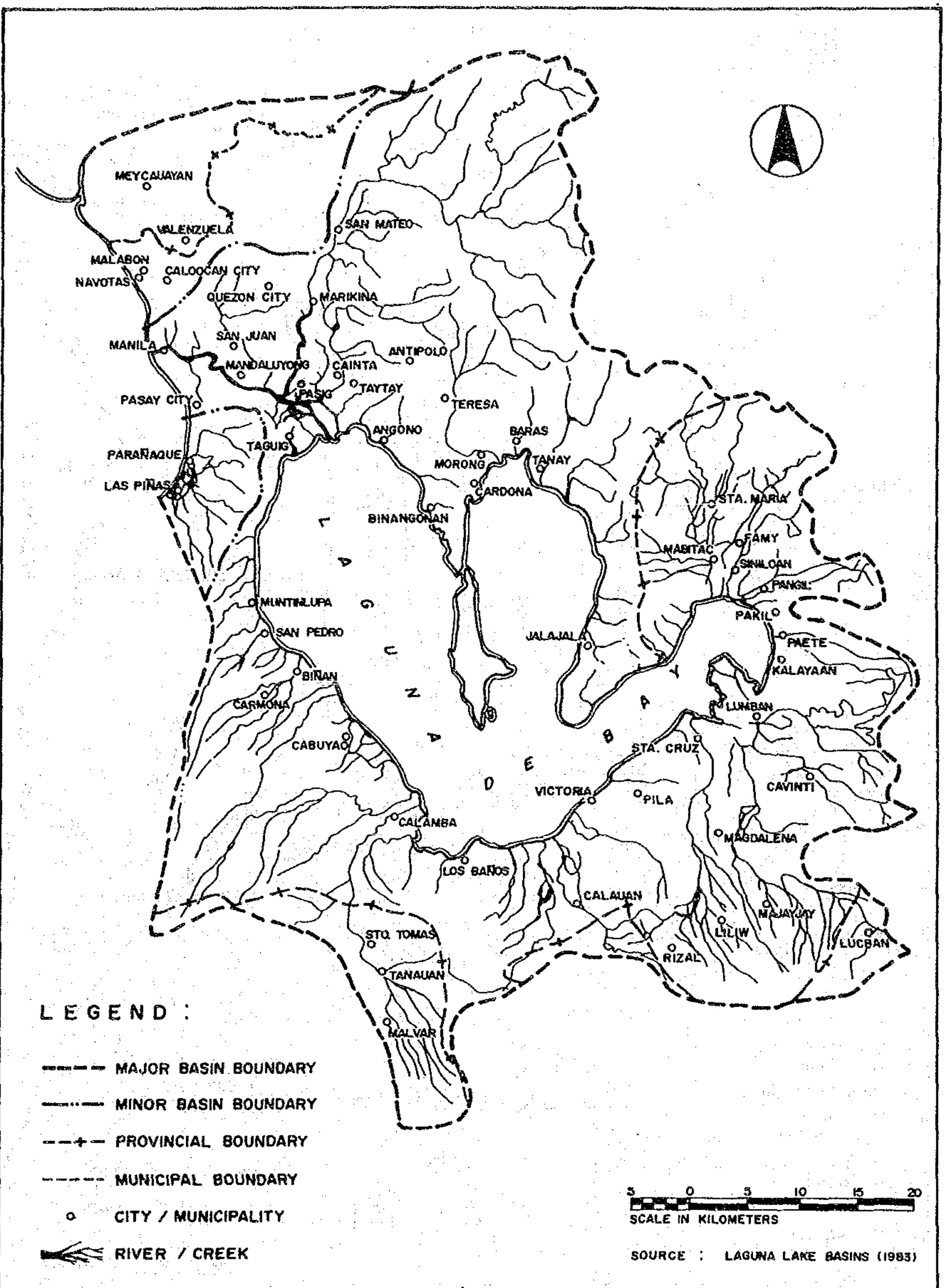




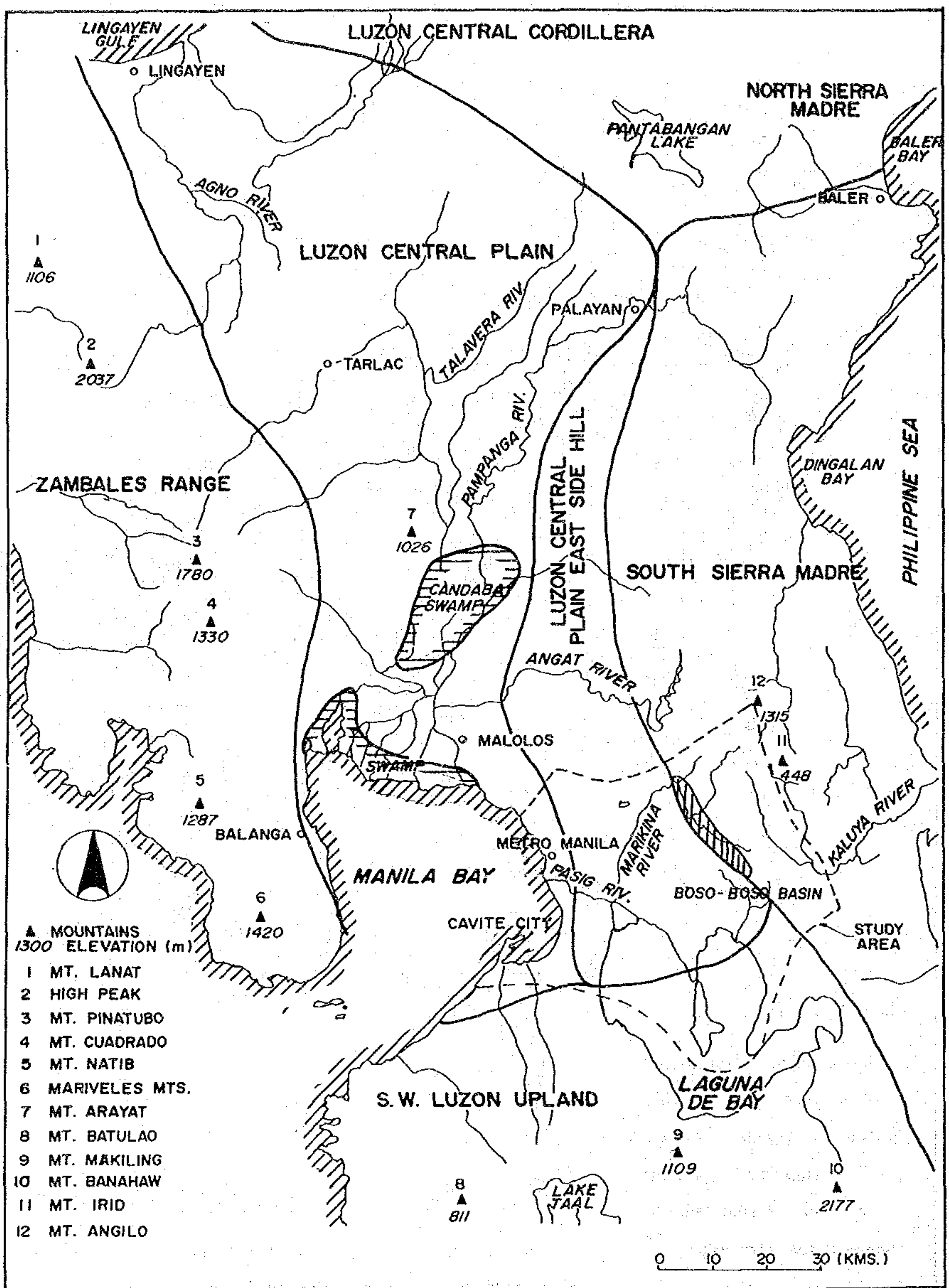




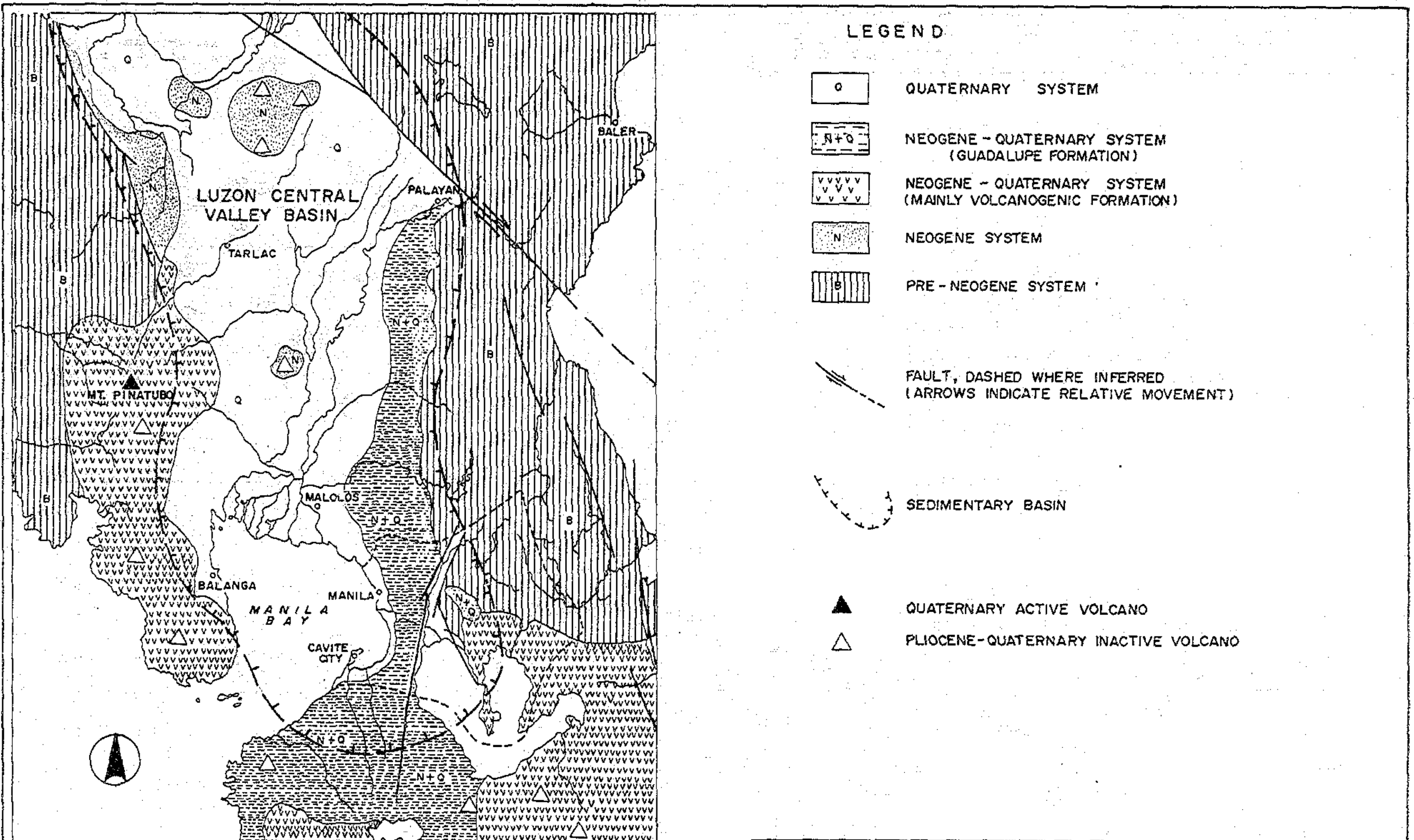
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.1.1
JAPAN INTERNATIONAL COOPERATION AGENCY	MONTHLY RAINFALL DISTRIBUTION



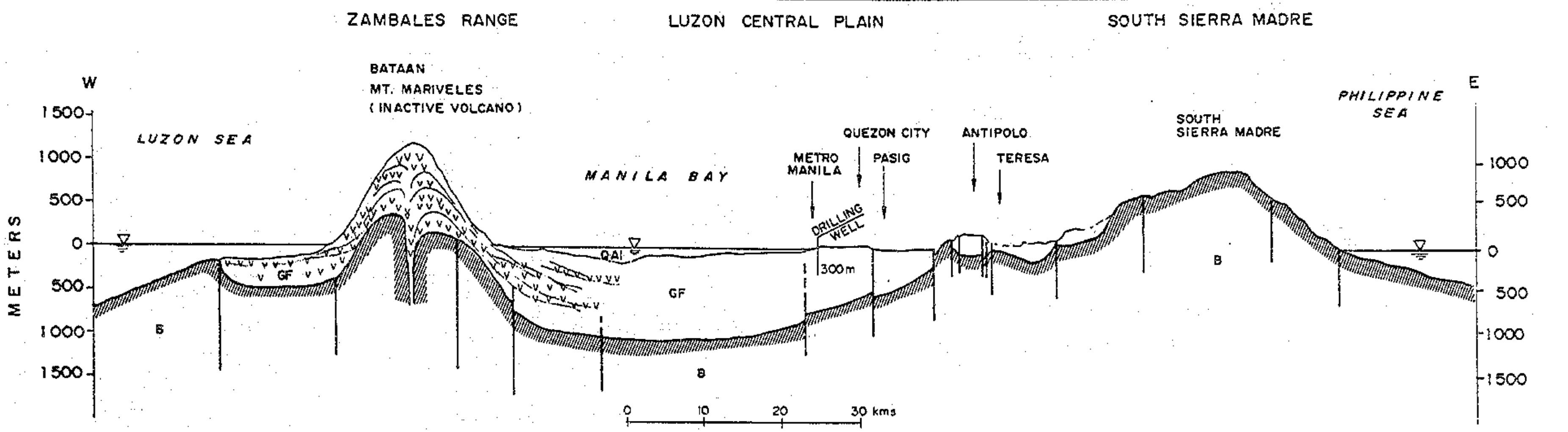
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.1.2
JAPAN INTERNATIONAL COOPERATION AGENCY	DRAINAGE MAP

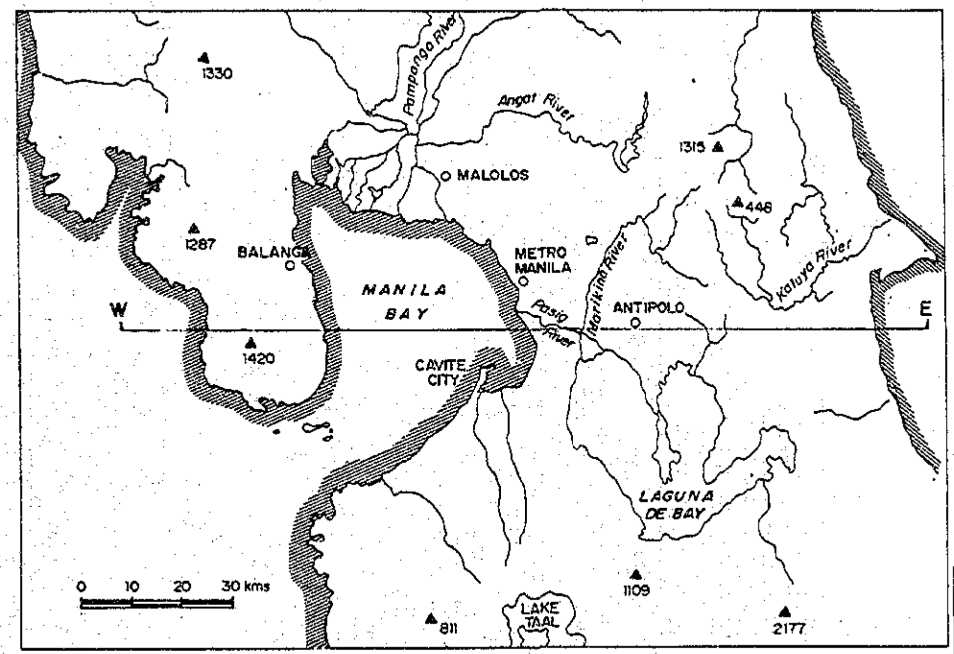


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.2.1 PHYSIOGRAPHIC PROVINCES OF CENTRAL LUZON
JAPAN INTERNATIONAL COOPERATION AGENCY	



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.2.2(1) GEOLOGIC STRUCTURE MAP OF CENTRAL LUZON
JAPAN INTERNATIONAL COOPERATION AGENCY	





LEGEND:

Q_{Al}	ALLUVIUM	QUATERNARY
	VOLCANICS	QUATERNARY
GF	GUADALUPE FORMATION	QUATERNARY
B	PRE-QUATERNARY (HYDROGEOLOGIC BASEMENT)	
	FAULT	

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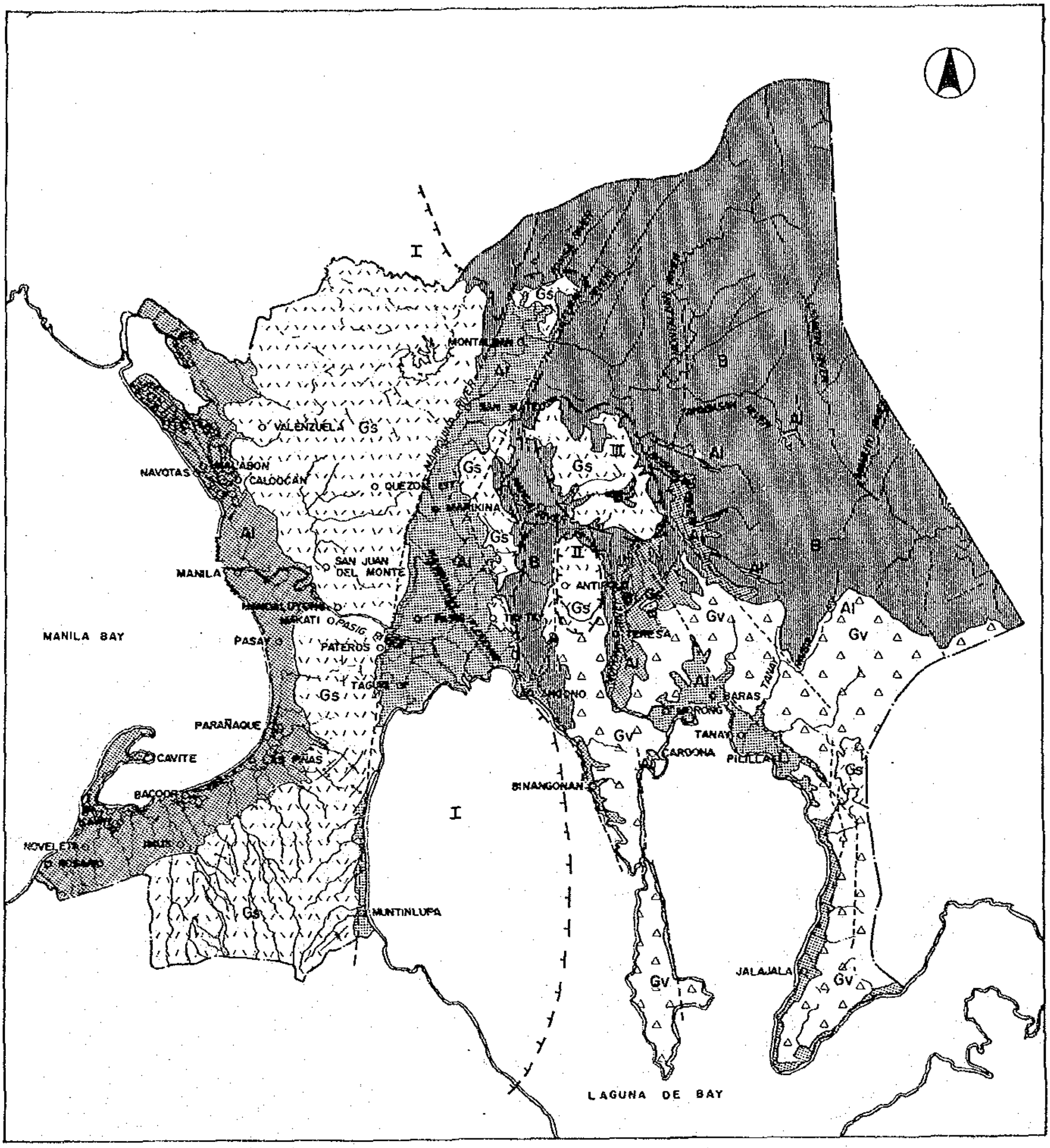
FIGURE 3.2.2(2) GEOLOGIC SECTION OF CENTRAL LUZON (W-E)



LEGEND:

Al : ALLUVIUM, TALUS, TERRACE	PLEISTOCENE - HOLOCENE
Gs : GUADALUPE FORMATION (SEDIMENTARY FACIES)	PLIOCENE - PLEISTOCENE
Gv : GUADALUPE FORMATION (VOLCANIC FACIES)	
B : BASEMENT ROCKS	PRE - QUATERNARY
GEOLOGICAL BOUNDARY	I. GUADALUPE SEDIMENTARY BASIN
FAULT	II. ANTIPOLO SEDIMENTARY BASIN
	III. NORTH ANTIPOLO SEDIMENTARY BASIN

0 10 20 (Kms.)

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FIGURE 3.2.3

SIMPLIFIED GEOLOGIC MAP
-STUDY AREA-

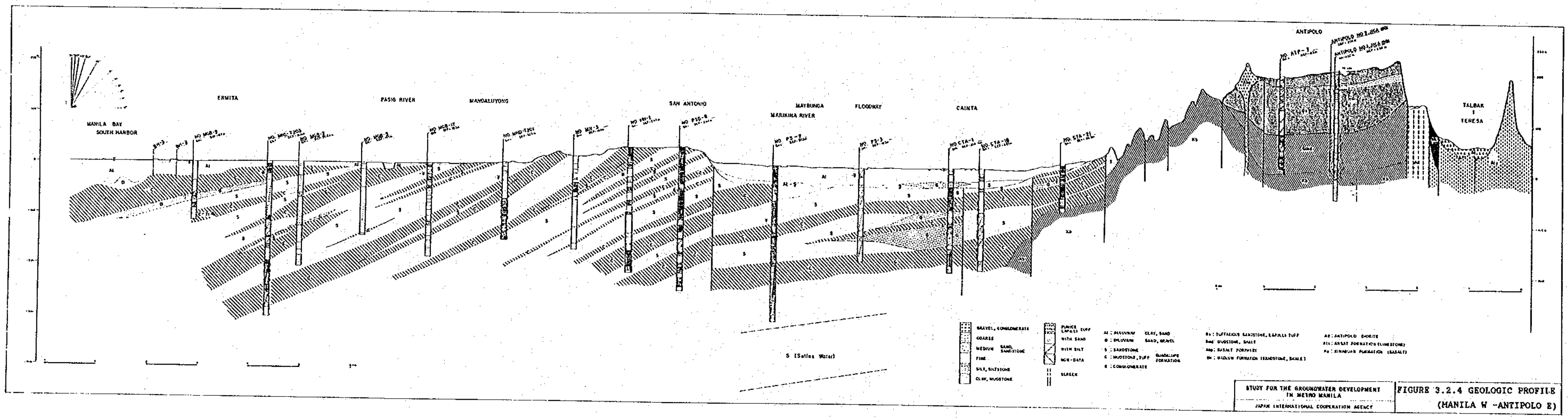

FIGURE 3.2.4 GEOLOGIC PROFILE (MANILA W - ANTIPOLO E)

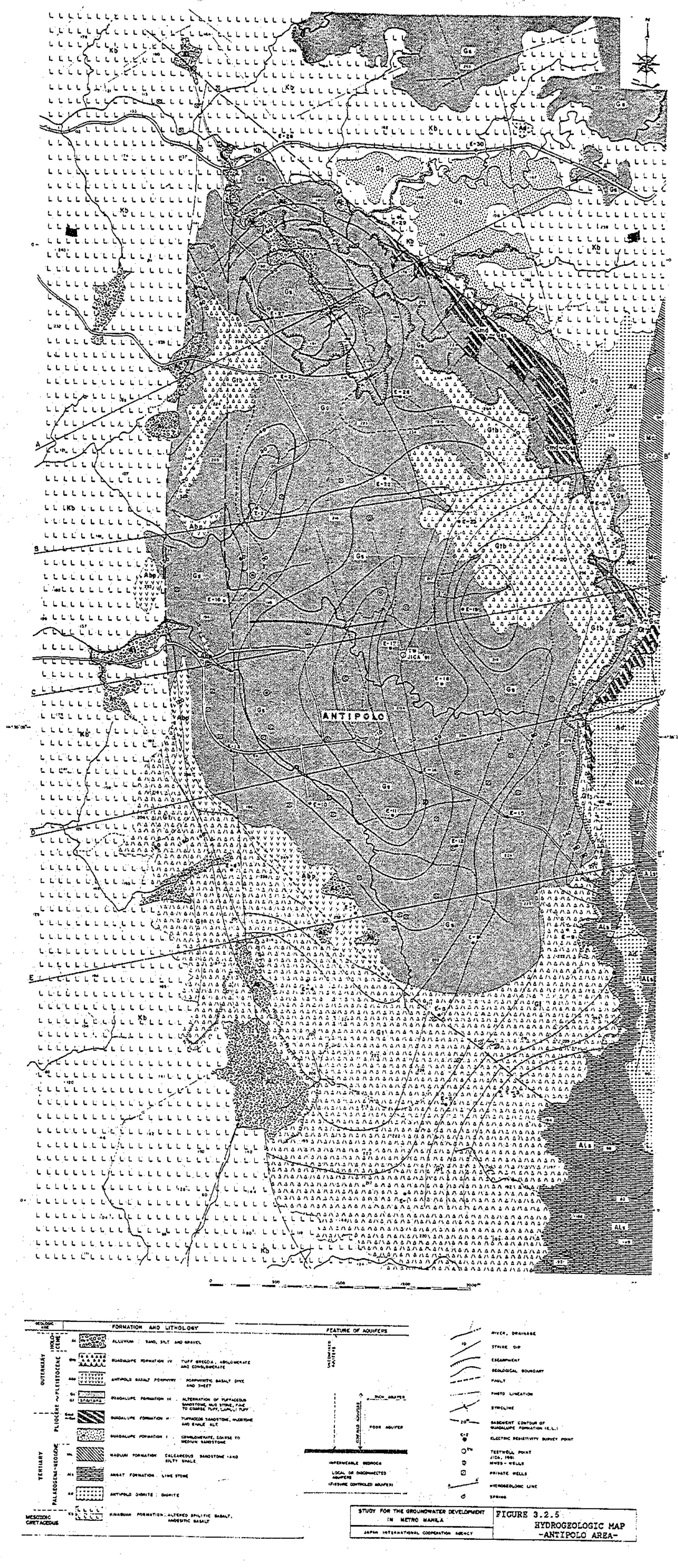

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FIGURE 3.2.5 HYDROGEOLOGIC MAP -ANTIPOLO AREA-

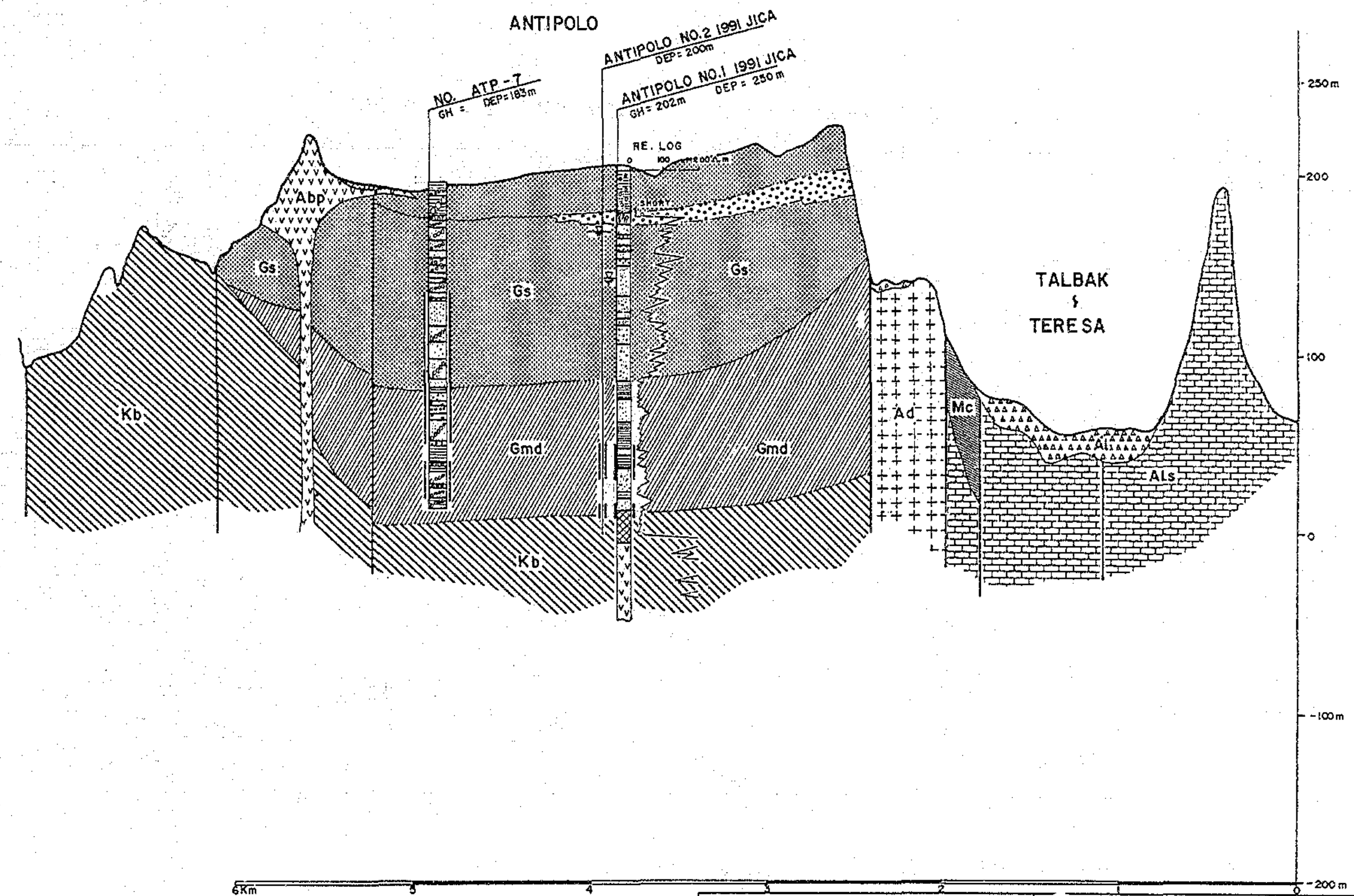

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FIGURE 3.2.6
HYDROGEOLOGIC PROFILE
-ANTIPOLO AREA-

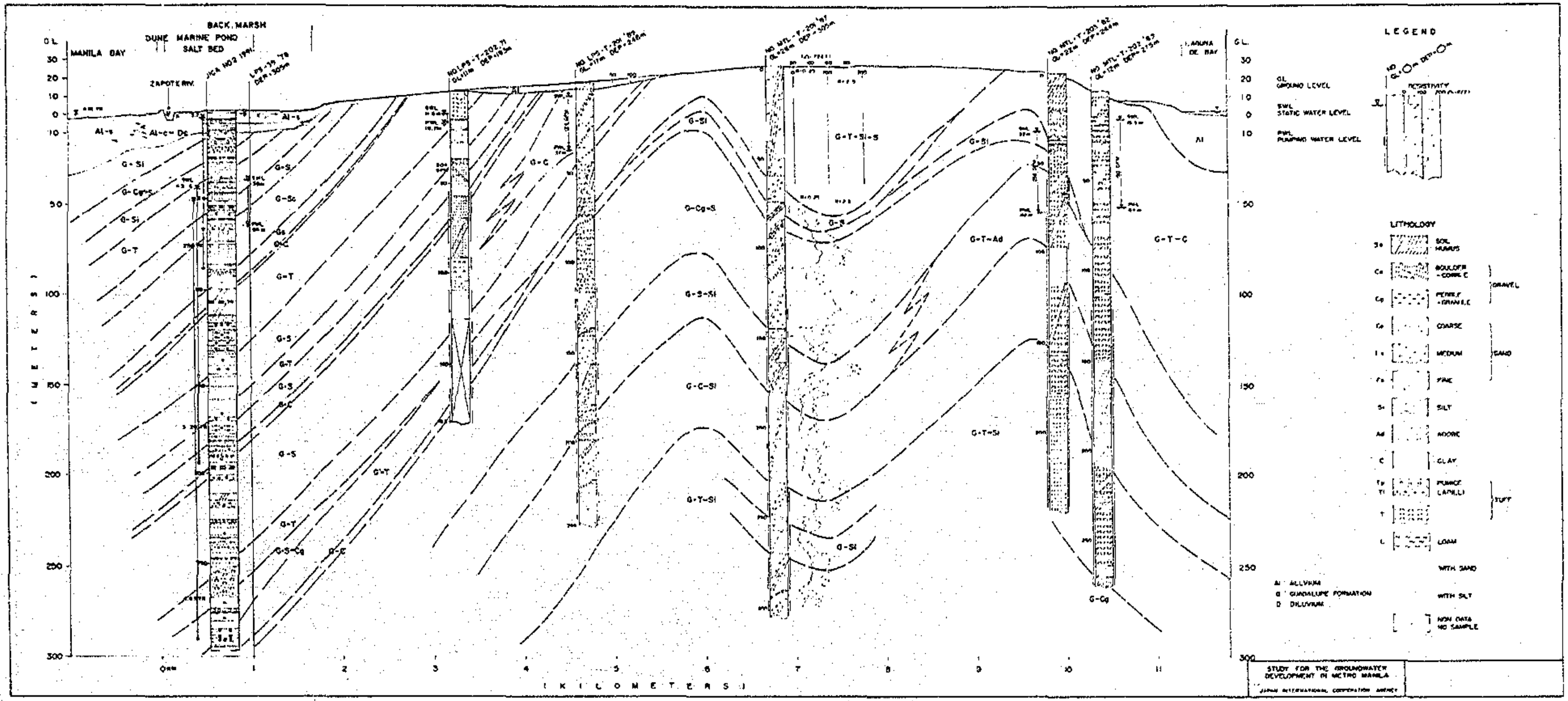
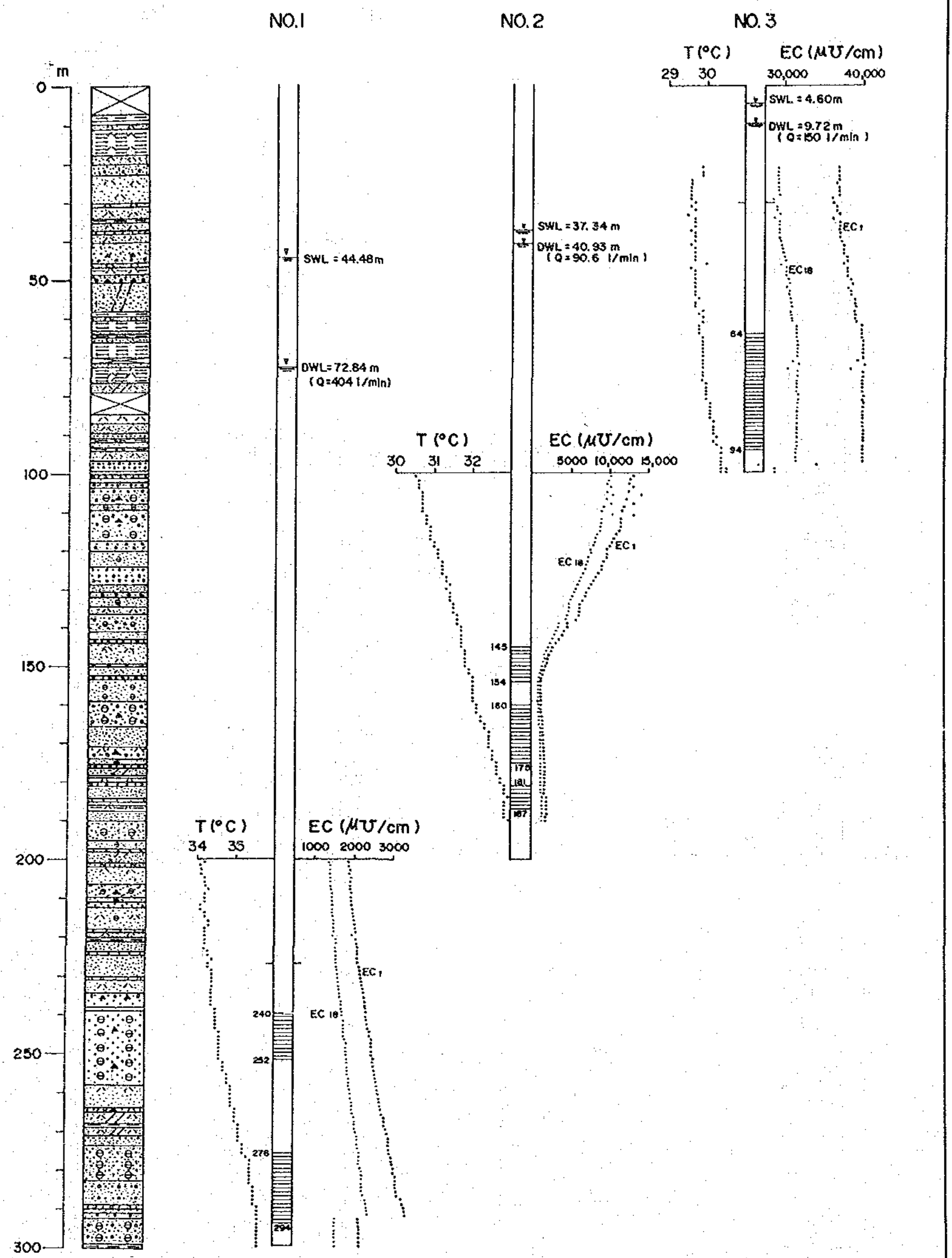


FIGURE 3.2.7 HYDROGEOLOGIC PROFILE -LAS PINAS AREA-



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.2.8(1) TEMPERATURE AND EC LOGS AT SITES NO.1 -LAS PINAS AREA-
JAPAN INTERNATIONAL COOPERATION AGENCY	

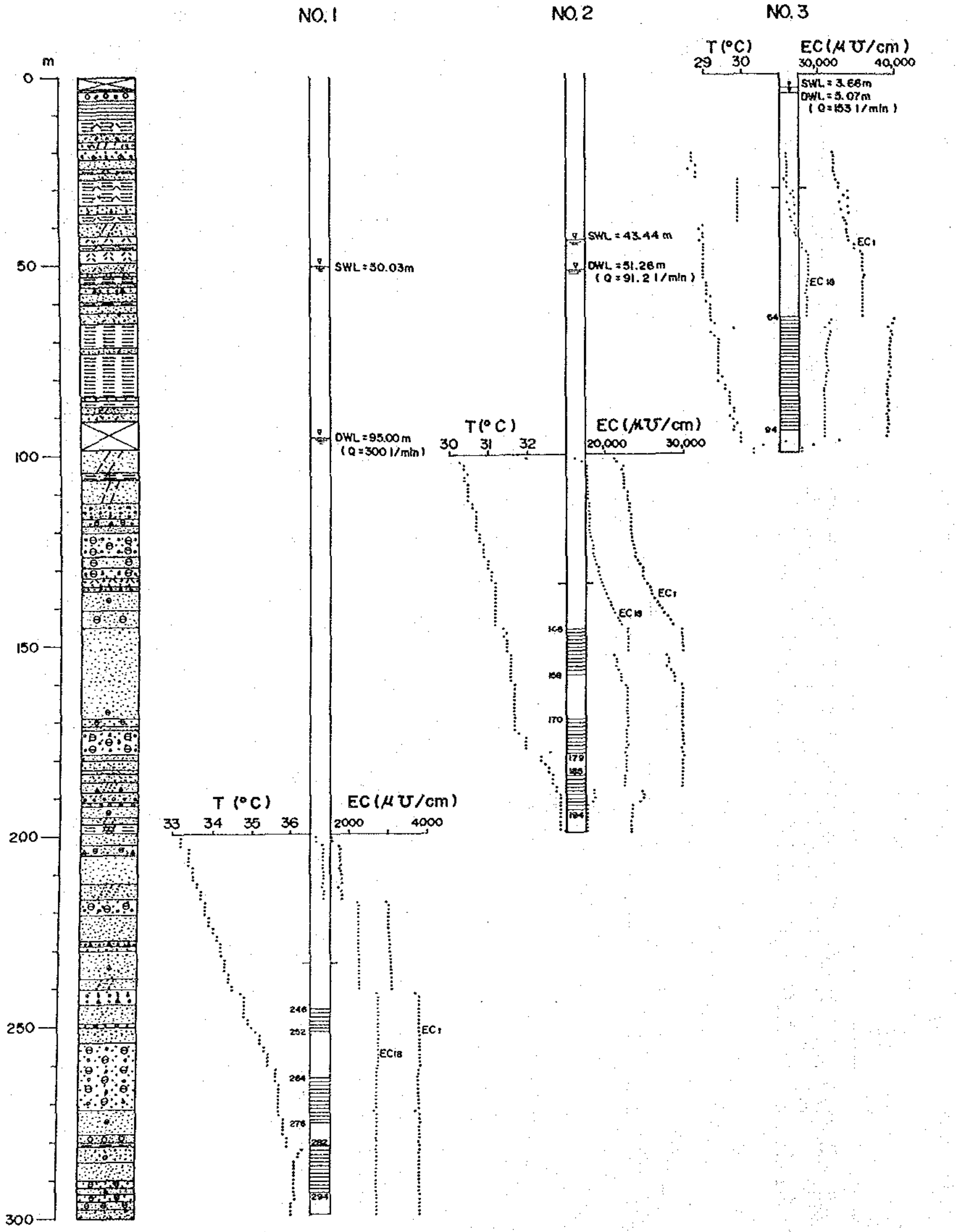


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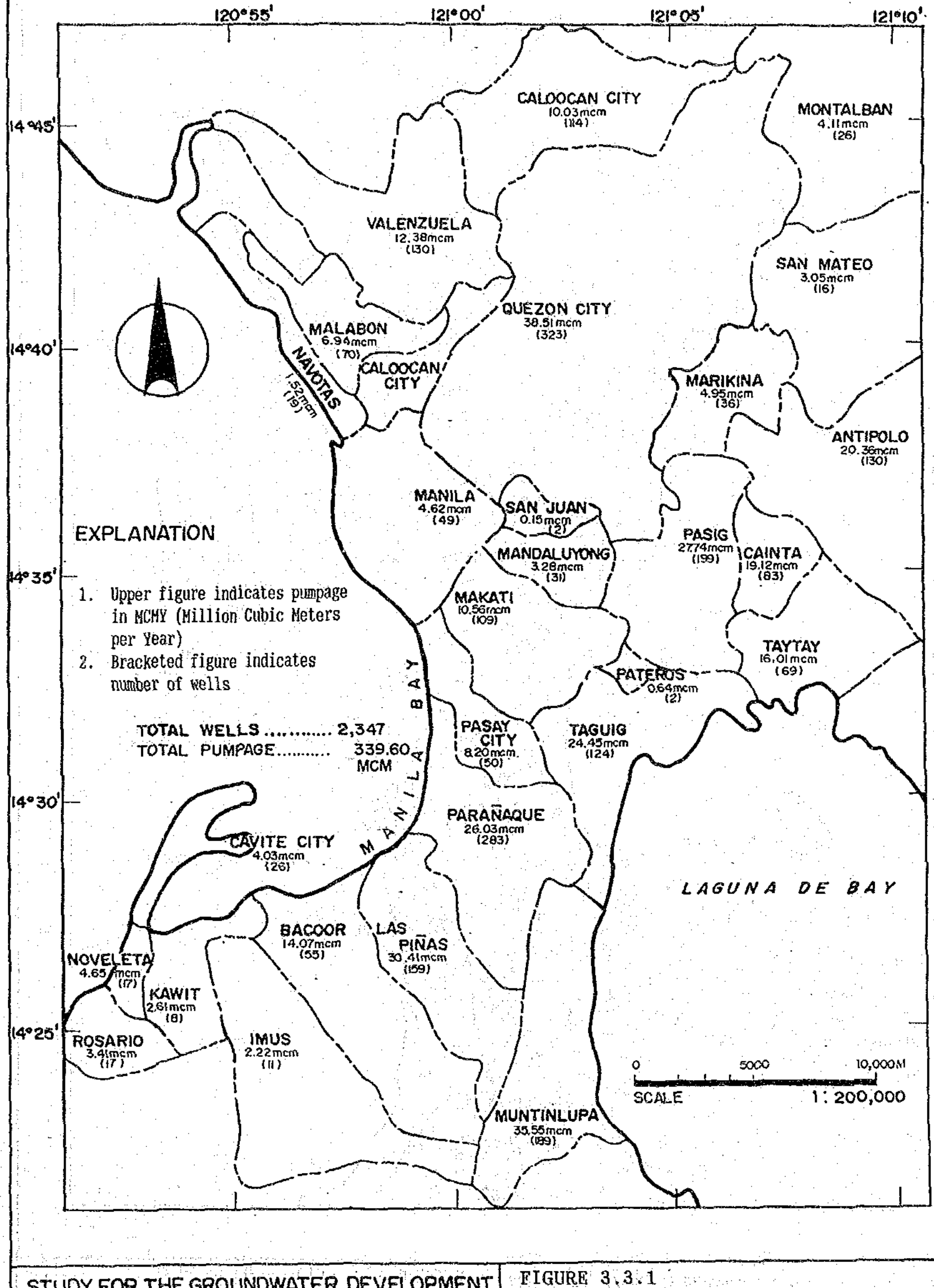
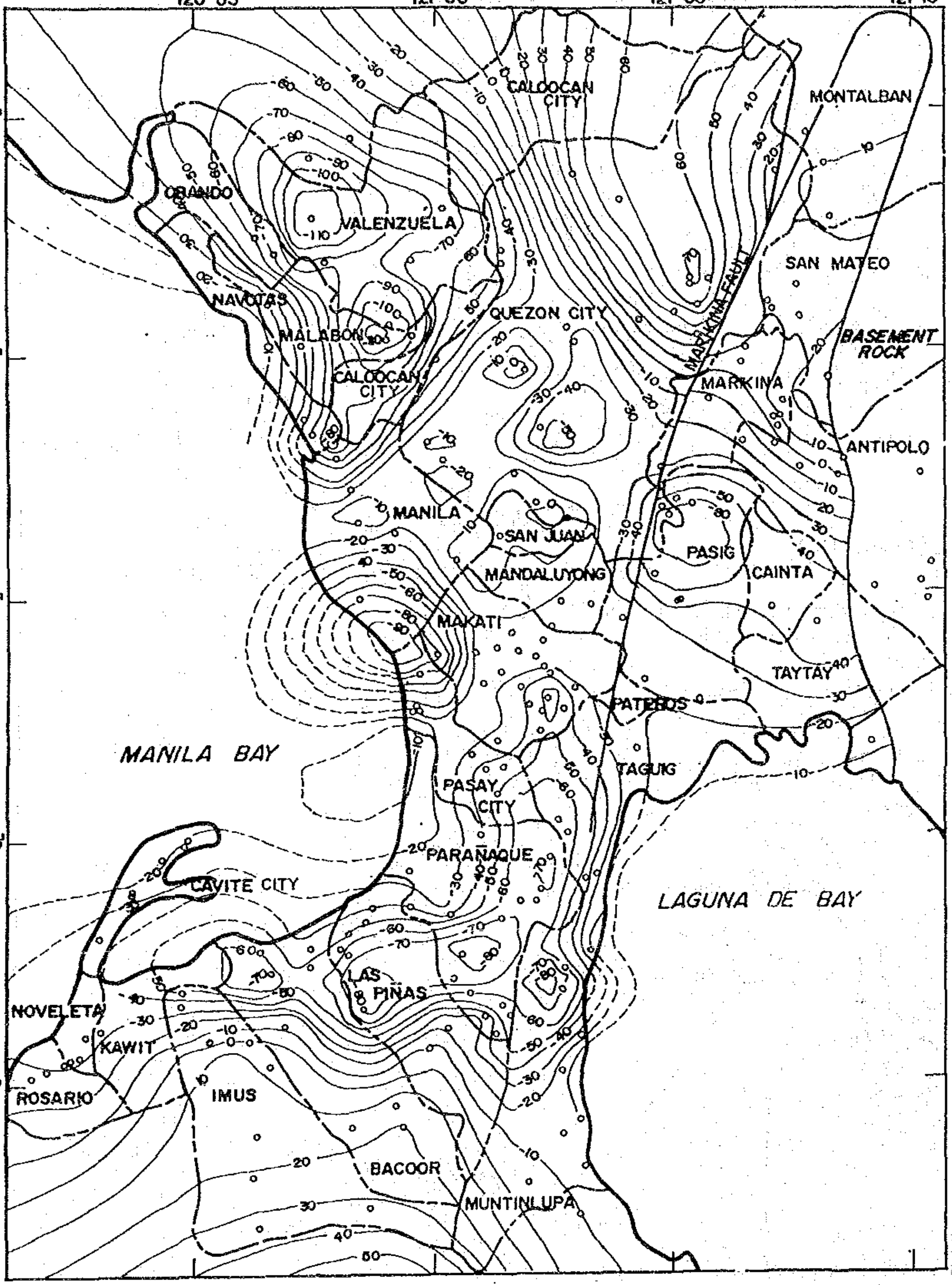
FIGURE 3.2.8(2)

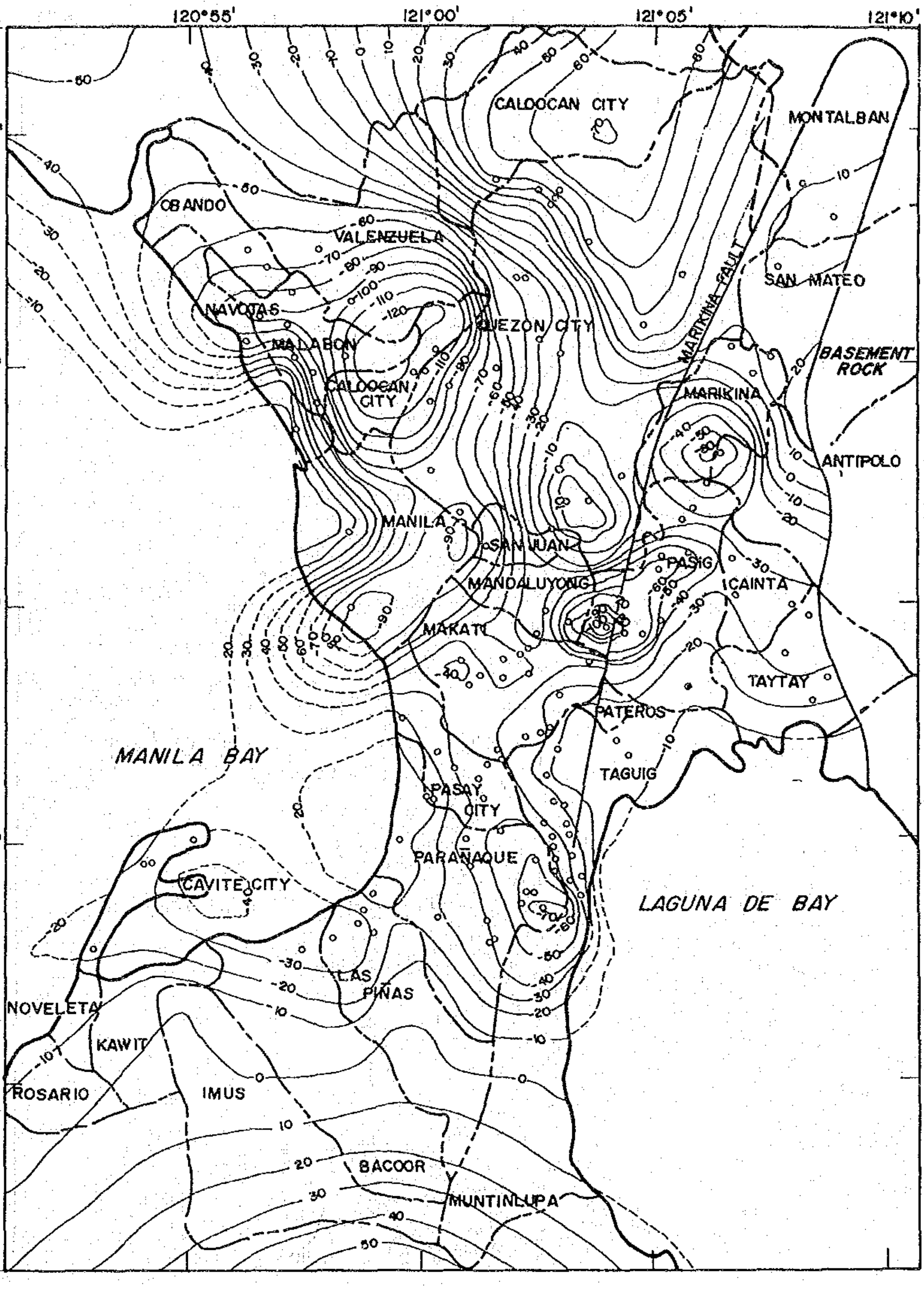
TEMPERATURE AND EC LOGS AT SITES NO.2
-LAS PINAS AREA-



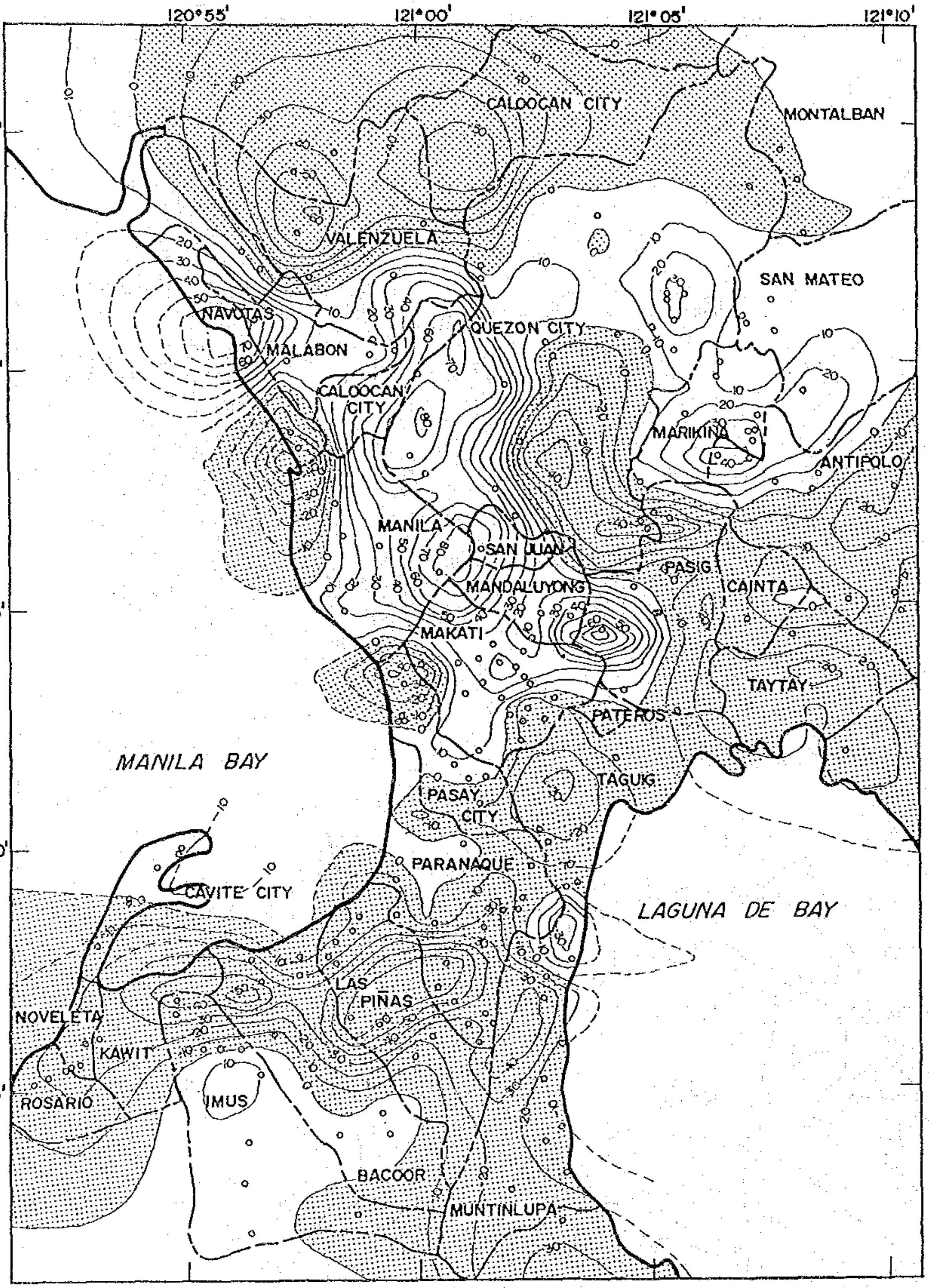
STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.3.1
JAPAN INTERNATIONAL COOPERATION AGENCY	GROUNDWATER PUMPAGE IN THE STUDY AREA, 1990



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.4.1(1) PIEZOMETRIC CONTOUR MAP OF THE STUDY AREA, 1990
JAPAN INTERNATIONAL COOPERATION AGENCY	



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.4.1(2)
JAPAN INTERNATIONAL COOPERATION AGENCY	PIEZOMETRIC CONTOUR MAP OF THE STUDY AREA, 1991



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.4.1(3) CHANGE IN PIEZOMETRIC CONTOURS IN THE STUDY AREA FROM 1981 TO 1990
JAPAN INTERNATIONAL COOPERATION AGENCY	

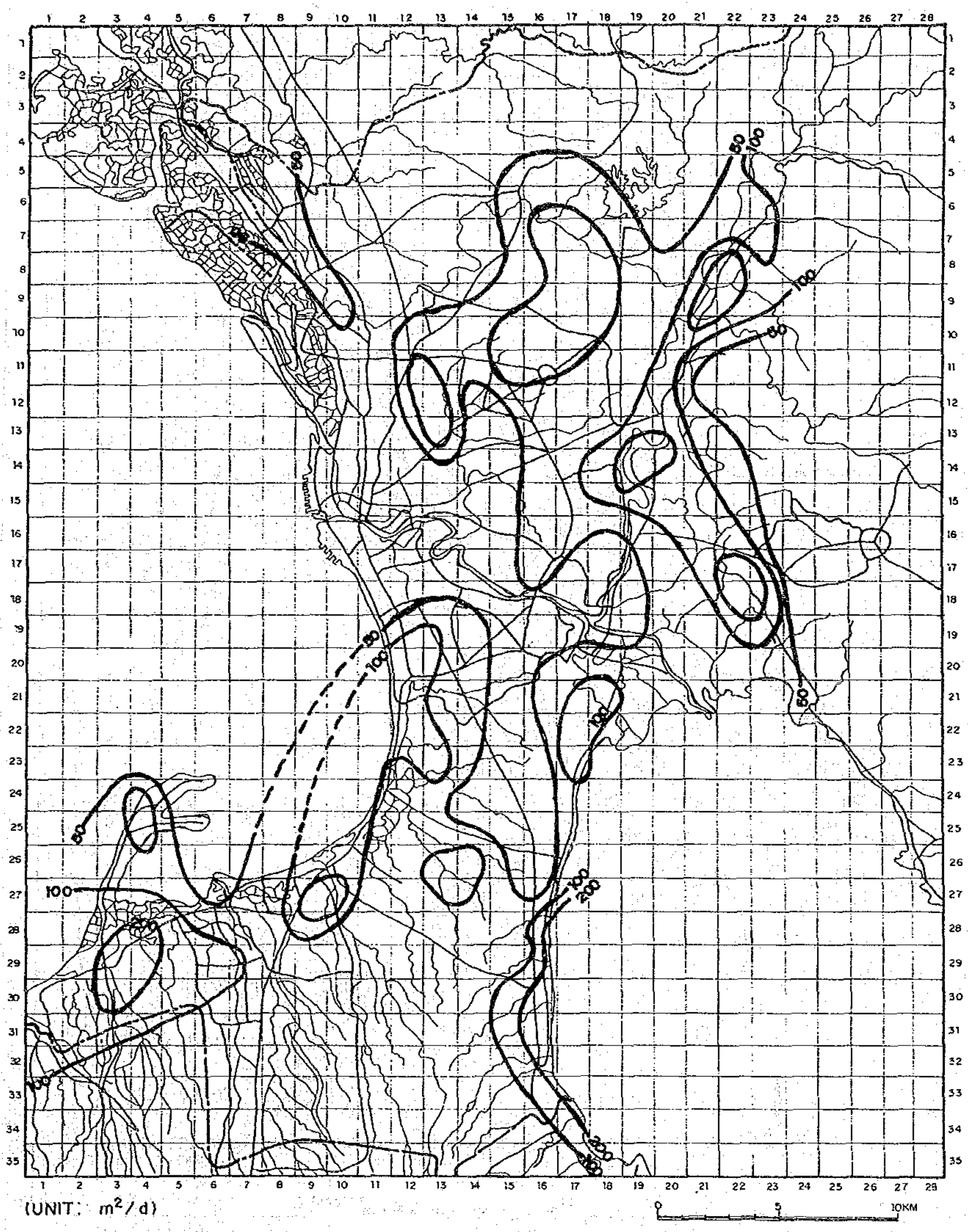


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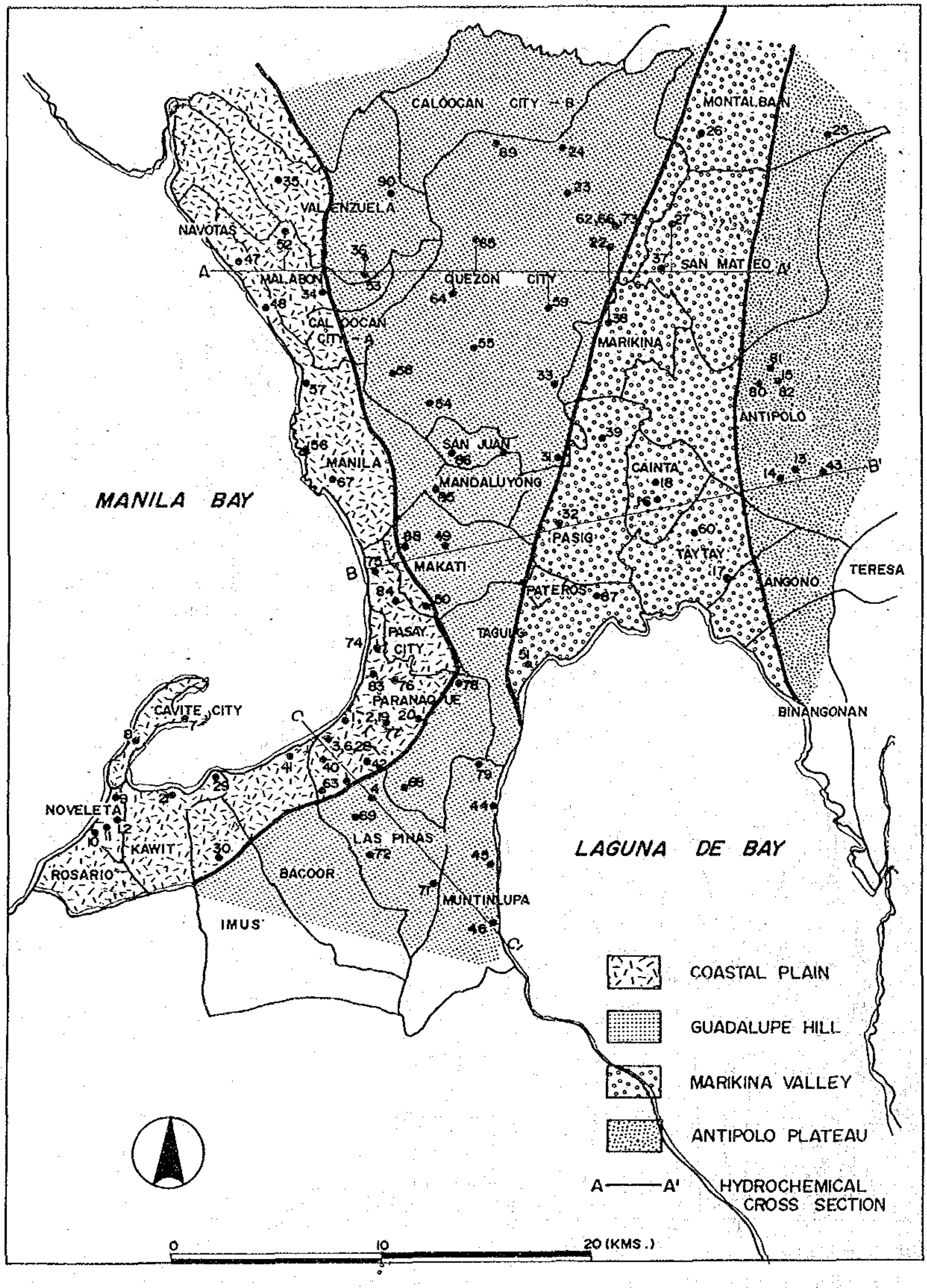
FIGURE 3.6.1 ESTIMATED TRANSMISSIVITY MAP FROM SPECIFIC CAPACITY



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

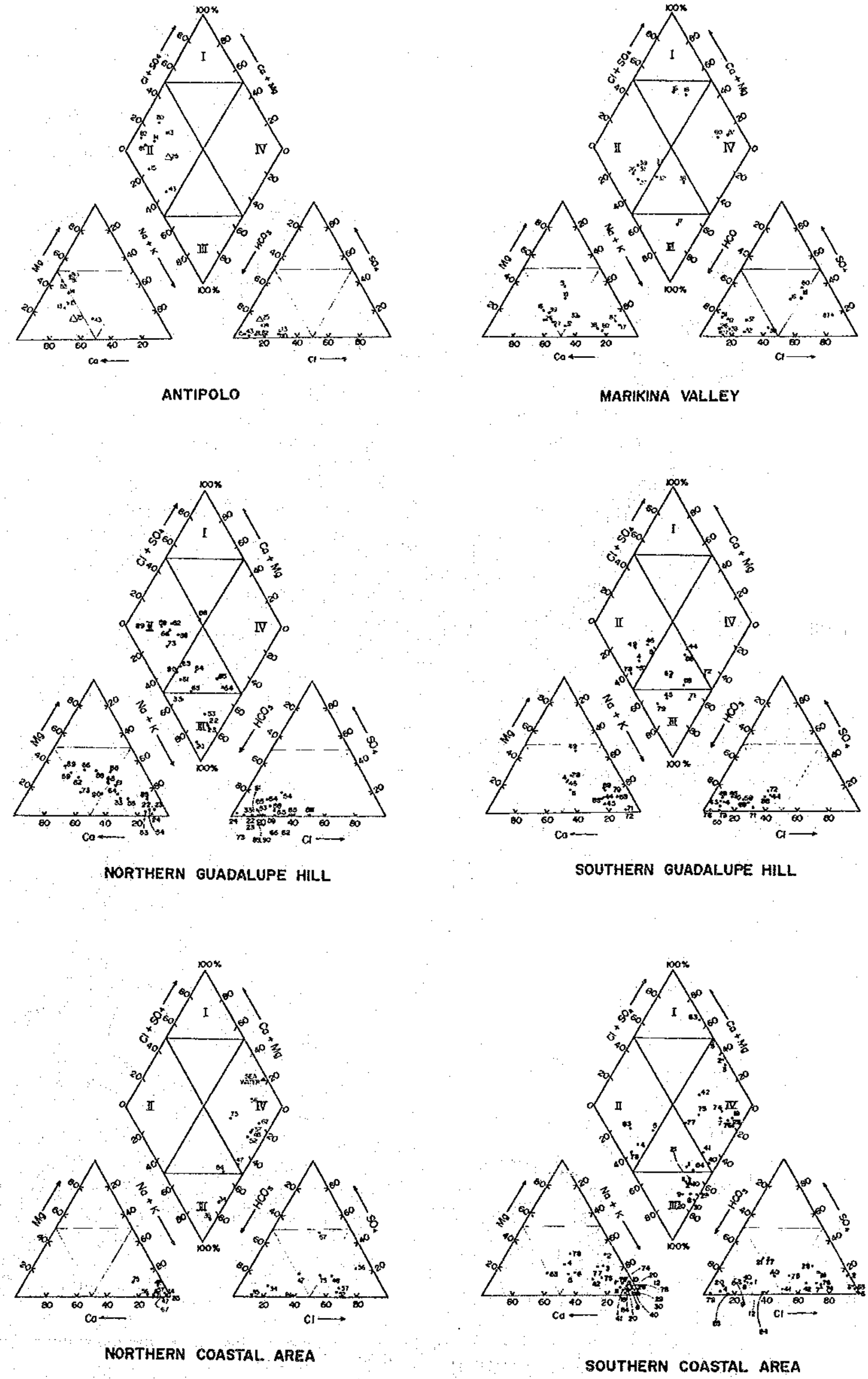
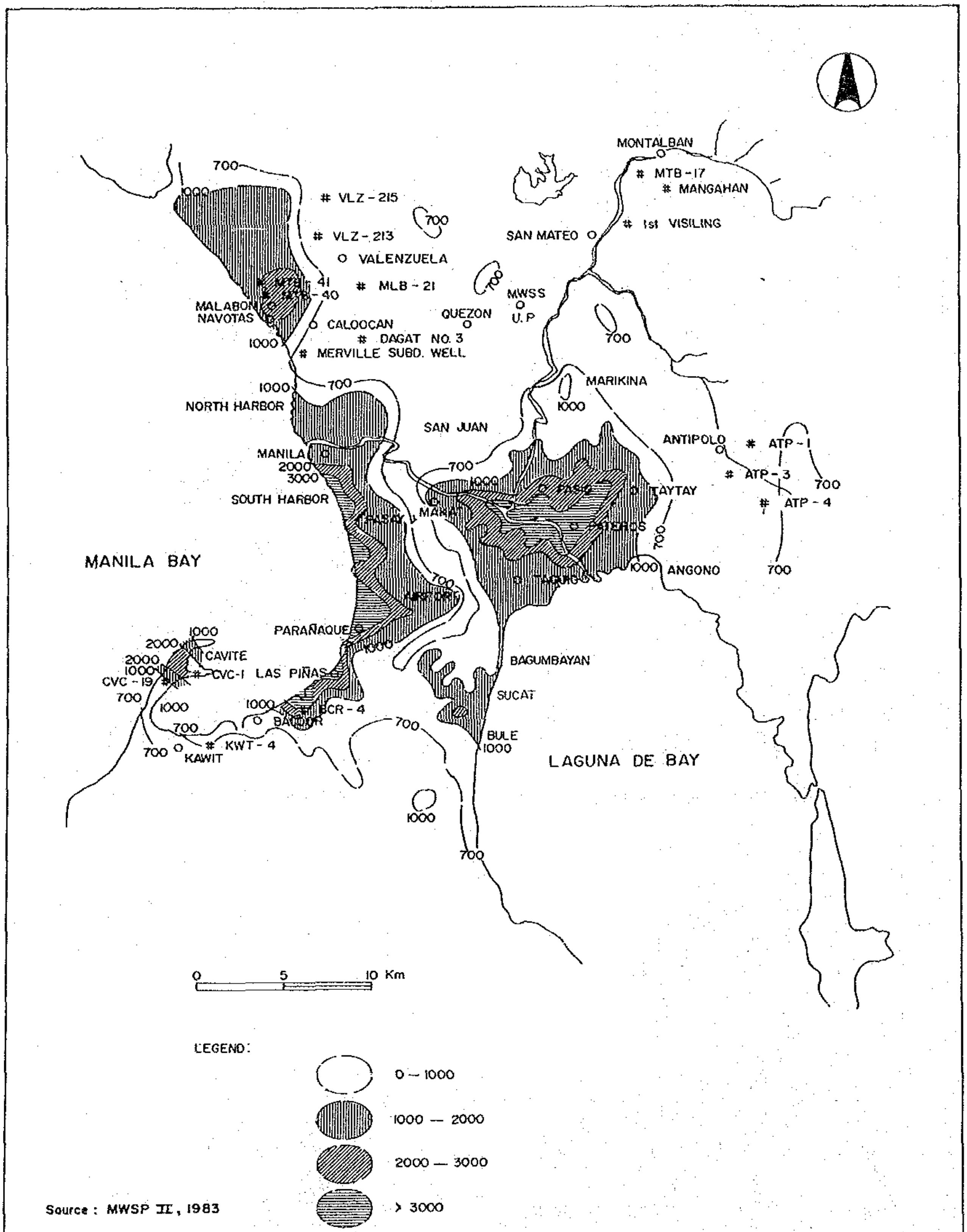


FIGURE 3.7.2 TRILINEAR DIAGRAM REPRESENTATION OF GROUNDWATER SAMPLES IN METRO MANILA



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.8.1(1) ELECTRIC CONDUCTIVITY OF GROUNDWATER IN METRO MANILA
JAPAN INTERNATIONAL COOPERATION AGENCY	

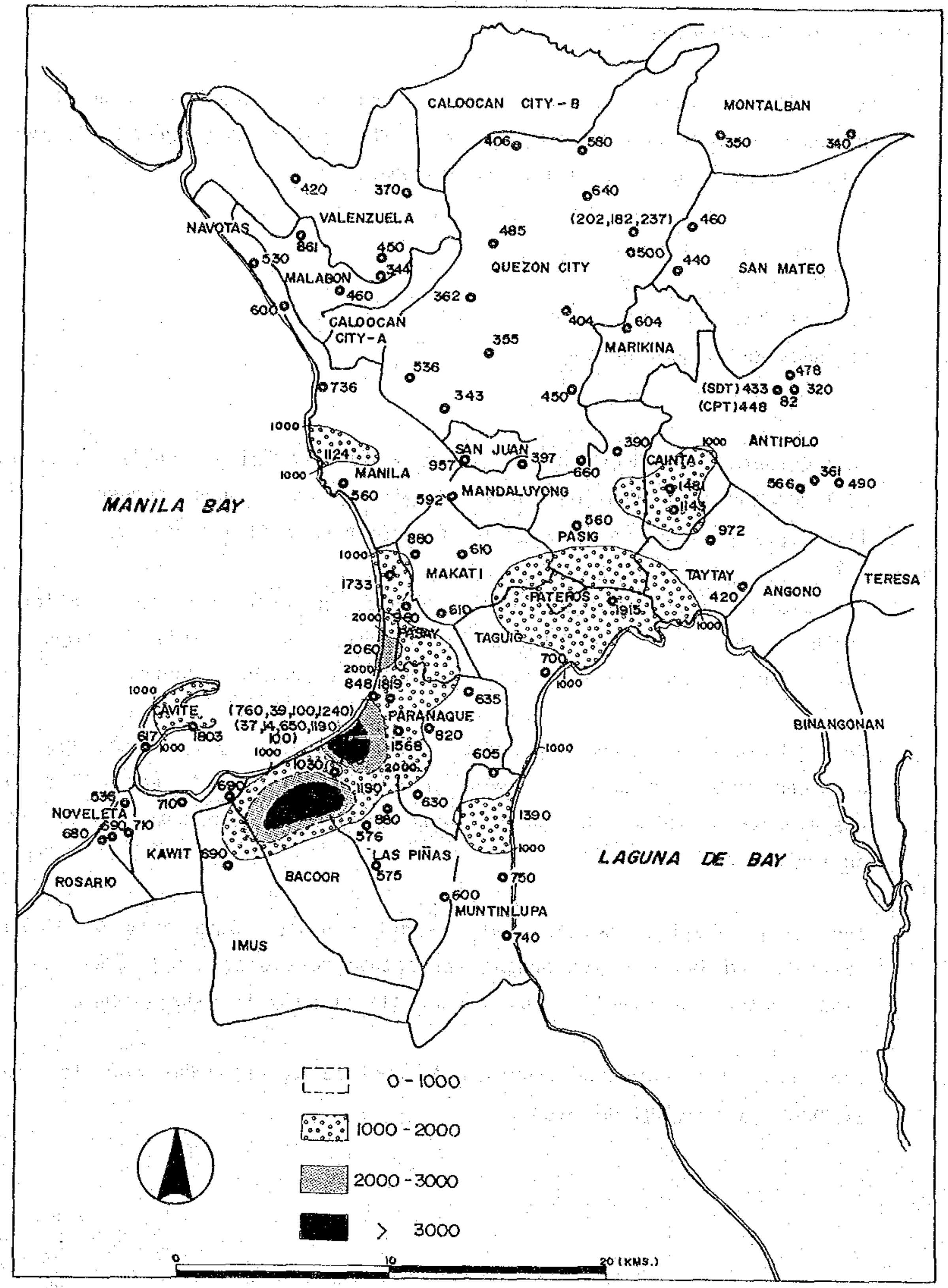


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FIGURE 3.8.1(2)

DISTRIBUTION OF ELECTRIC CONDUCTIVITY

CHAPTER 4 GROUNDWATER DATABASE

The groundwater database system aims to support the groundwater development and conservation program of MWSS. The system is composed of five databases containing the following information.

1) Well inventory data
2) Meteorological data
3) Hydrological data
4) Hydrogeological data
5) Related literature records

Well inventory includes MWSS-supervised wells and private wells. Various well data such as location, owner, depth, diameter, pump, screen, water level, pumping rate, etc. are stored in four related data files.

The meteorological database contains data on meteorological stations including the daily, monthly, and annual records of rainfall, temperature, evaporation, humidity, wind velocity and sunshine hours.

The hydrological database provides information on hydrological gaging stations including data on river discharge and gage height. It also contains the simultaneous observations on spring and stream flow in the Antipolo Area.

The hydrogeological database at present contains data only on those wells tested and measured during the actual test drillings, rehabilitation studies, pumping test and groundwater quality investigations.

The literature database provides literature records relevant to the groundwater development study.