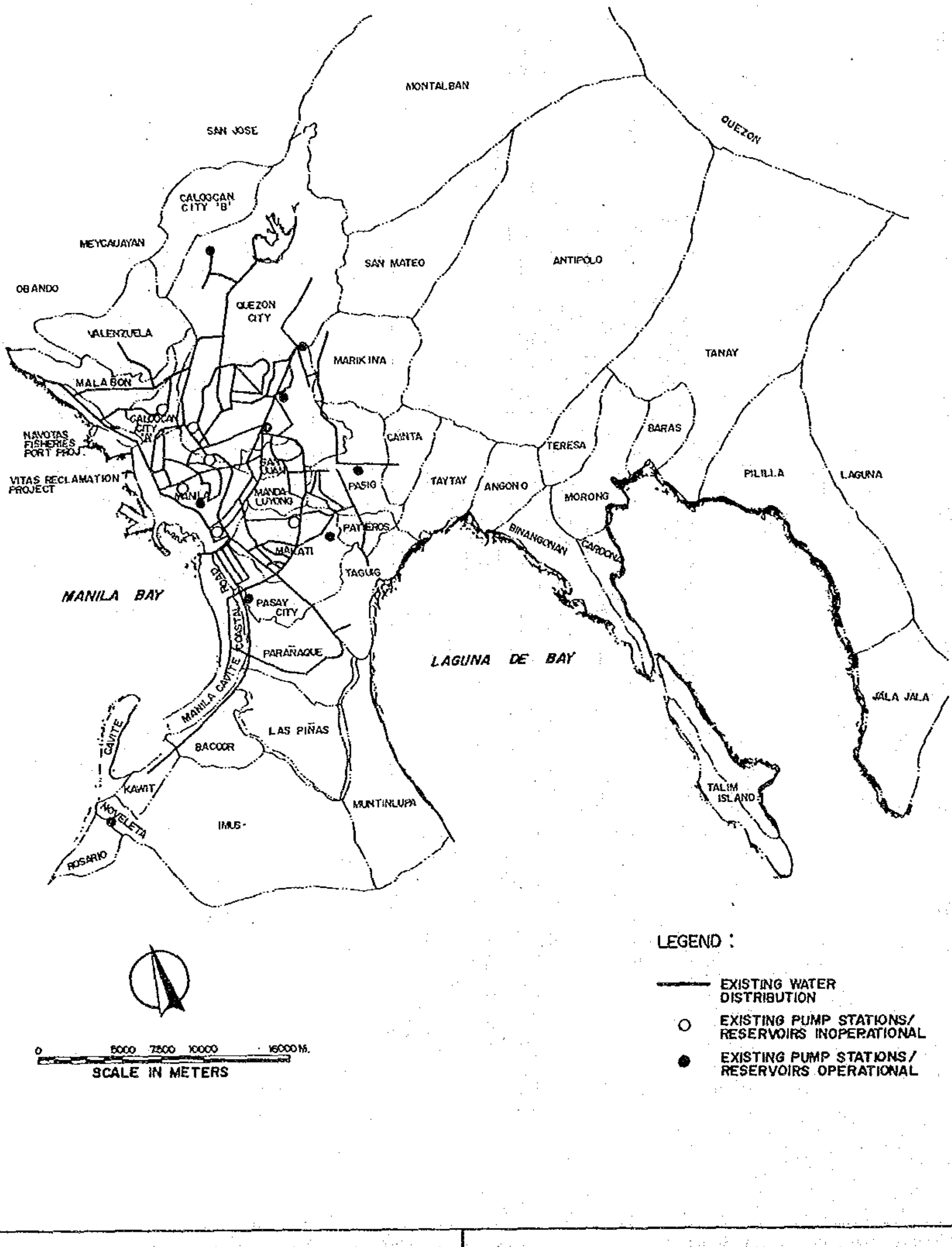

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 2.2.9 **EXISTING PRIMARY DISTRIBUTION SYSTEM**
JAPAN INTERNATIONAL COOPERATION AGENCY	

CHAPTER 3

GROUNDWATER

CHAPTER 3 GROUNDWATER

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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. During the period of the dry season from January to April, rainfall drops to 10-30mm/month.

From the mean annual rainfall map of the Laguna Lake Basin, the Study Area's rainfall ranges from 1900mm to 2200mm. The Cavite and Diliman stations of PAGASA record an annual rainfall range of 1684mm to 2356mm. Rainfall gradually decreases westward as shown in Figures 3.1.1 and 3.1.2.

Monthly temperatures in the Study Area range from 20°C to 35°C. Mean monthly temperature varies from 25°C to 30°C. The coldest months are from December to February while the warmest months are April and May. Mean annual temperature is placed at 27°C. Plots of the minimum, mean and maximum monthly temperatures are shown in Figure 3.1.3.

Monthly pan evaporation at the Diliman station registered a minimum of 62mm in July 1977 and a maximum of 246mm in May 1978. Estimated annual mean is set at 1469mm (Figure 3.1.3).

3.1.2 Topography and Hydrology

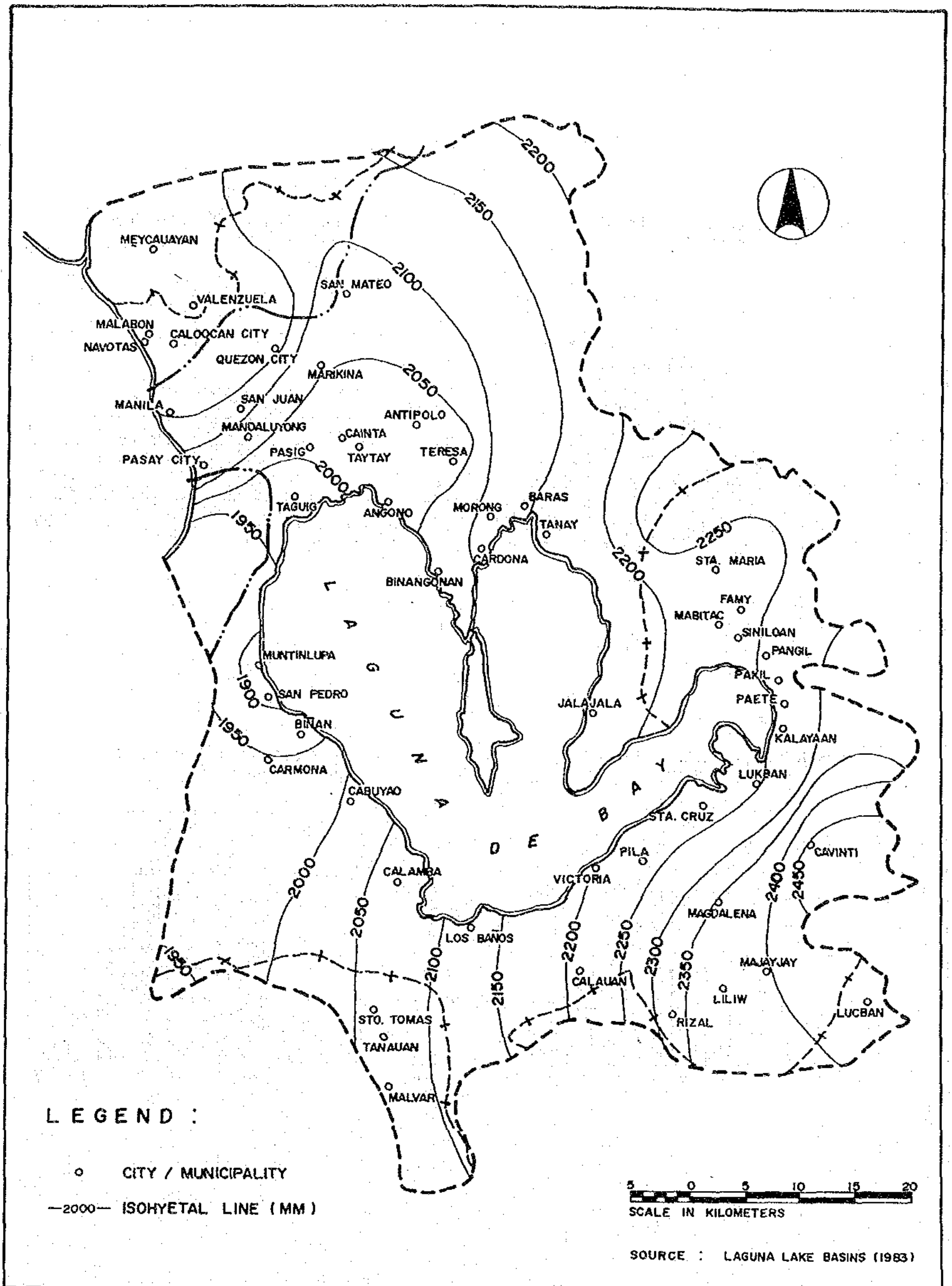
The Study Area faces Manila Bay in the west and the northern coast of Laguna de Bay in the south. This area includes a part of Sierra Madre in the east and the mountainous area of Valenzuela and Montalban in the north.

Surface elevation in the Study Area 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 0m to 10m on the coastal plains and from 20m to 70m on the hills.

Hydrologically, the Study Area is located within the Pasig-Laguna de Bay river basin (4,678 km^2; Figure 3.1.4). This basin has an area of 4,678 km^2 and it 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, i.e., the Cities of Manila, Pasay, Caloocan, Quezon and the Municipalities of Makati, San Juan, Mandaluyong and Parañaque.

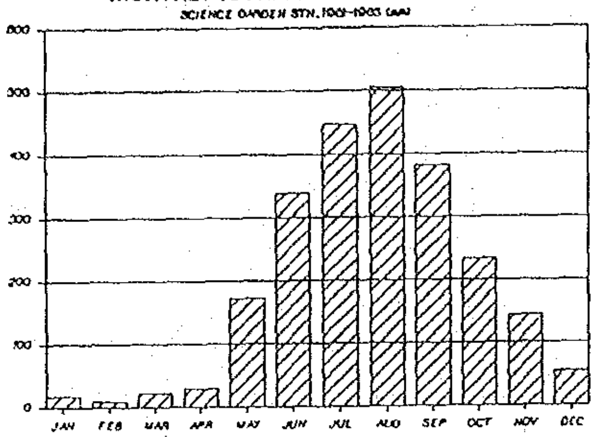
Flowing east to west through central Manila is the Pasig River. It is about 17 kilometers in length from the confluence of the Marikina and Napindan Channel to Manila Bay. One of its principal tributaries is the San Juan River. Its discharge depends upon the elevation of the water surface at the Pasig-Napindan junction, the lake stages of Laguna de Bay, the elevation of tides in Manila Bay, and the discharge from the San Juan River. At certain periods of high tide in the Bay and of low-water lake stage during the dry season, the Pasig River reverses its flow. During high tide conditions and high flows from the San Juan River, a backwater effect slows down the flow of the Pasig River and this causes overbanking.

Immediately inland from the Metro Manila area is Laguna de Bay. It is a shallow lake serving as a natural detention reservoir of discharges from the surrounding tributary streams (Pila-Santa Cruz, San Juan, San Cristobal, Pagsanjan and Romero-Sta. Maria Rivers). 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. The lake stages of Laguna de Bay depend upon the seasonal variation in rainfall and the yearly inflow of surface water, the interaction between the lake level and tidal stage in Manila Bay, and the annual evaporation from the lake.

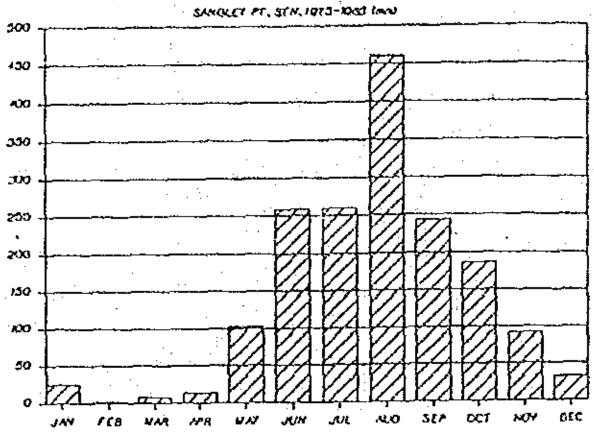


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.1.1 MEAN ANNUAL RAINFALL (MM) LAGUNA LAKE BASINS
JAPAN INTERNATIONAL COOPERATION AGENCY	

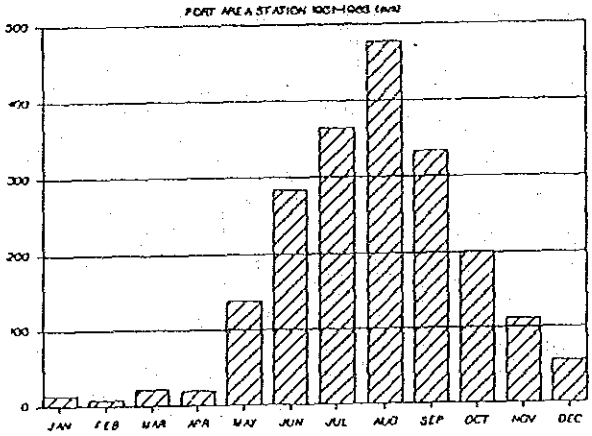
MONTHLY RAINFALL DISTRIBUTION



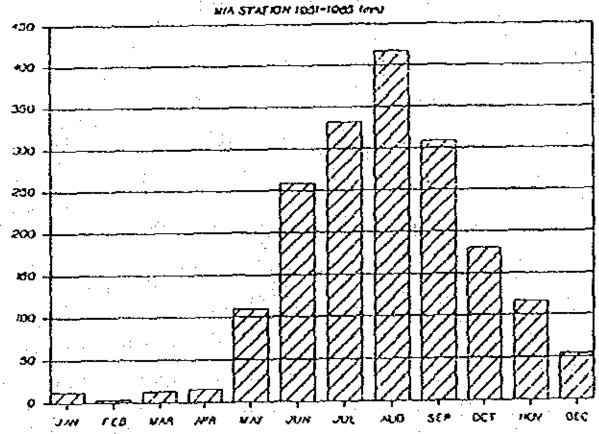
MONTHLY RAINFALL DISTRIBUTION



MONTHLY RAINFALL DISTRIBUTION

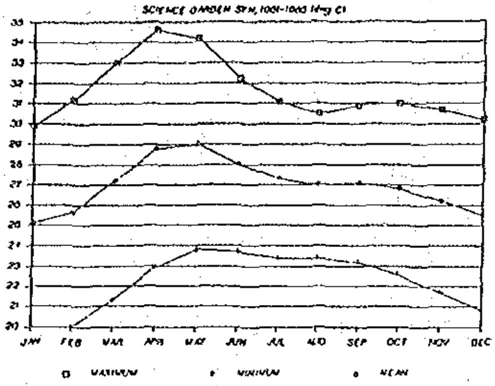


MONTHLY RAINFALL DISTRIBUTION

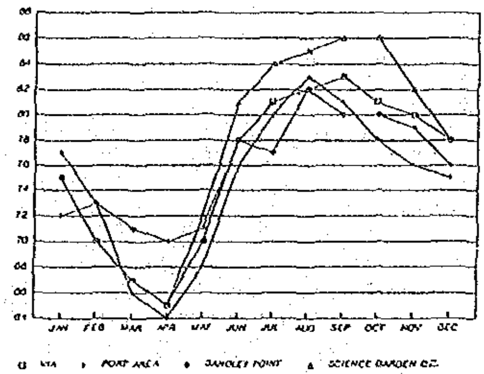


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.1.2 MONTHLY RAINFALL DISTRIBUTION
JAPAN INTERNATIONAL COOPERATION AGENCY	

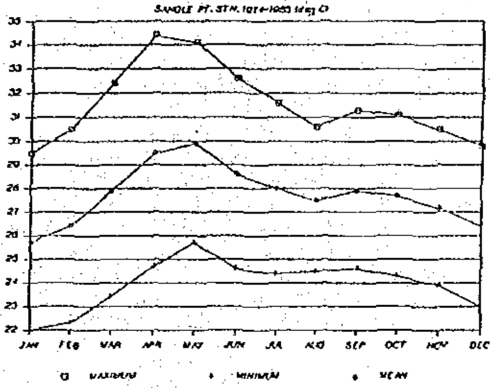
MONTHLY TEMPERATURE DISTRIBUTION



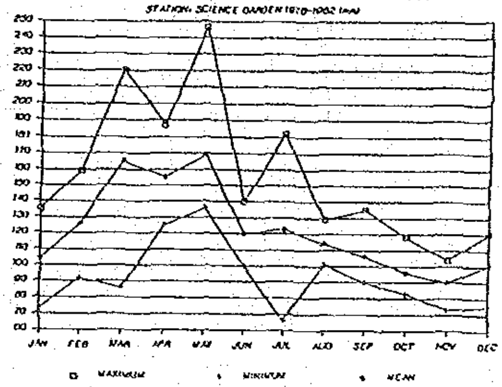
MONTHLY RELATIVE HUMIDITY DISTRIBUTION



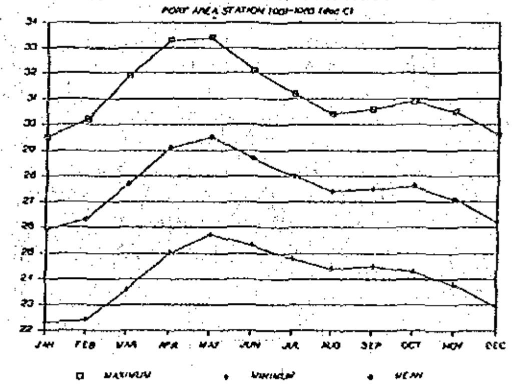
MONTHLY TEMPERATURE DISTRIBUTION



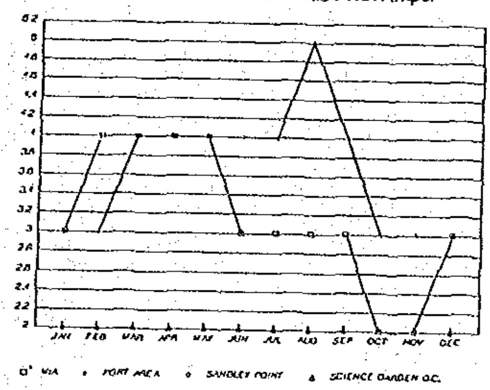
MONTHLY EVAPORATION DISTRIBUTION



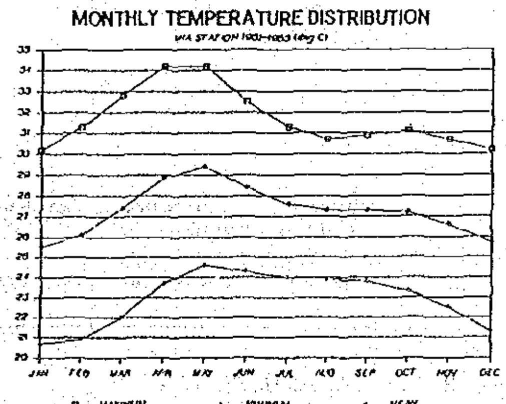
MONTHLY TEMPERATURE DISTRIBUTION



MONTHLY WIND SPEED DISTRIBUTION (mps)



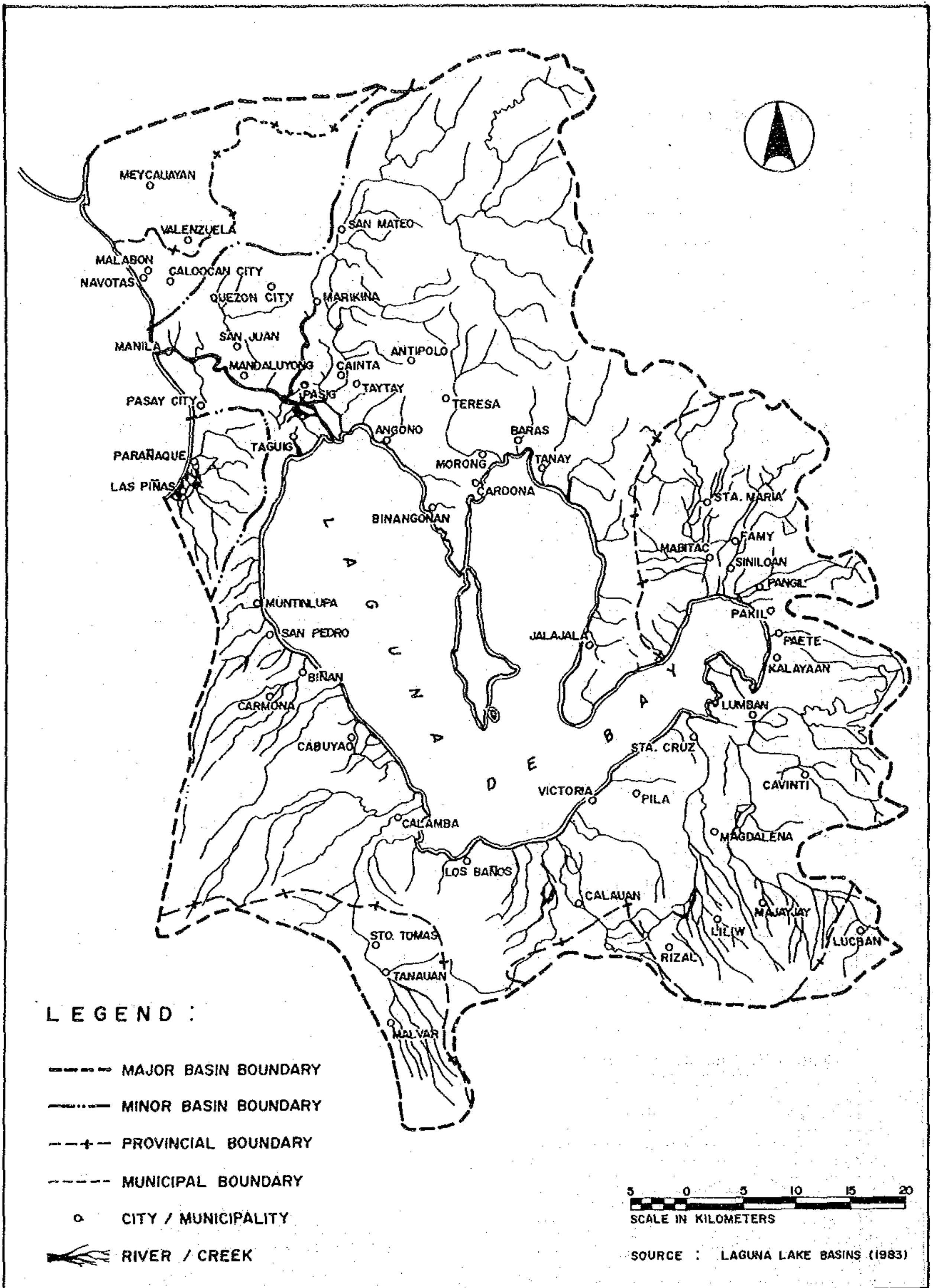
MONTHLY TEMPERATURE DISTRIBUTION



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 3.1.3 METEOROLOGICAL DATA



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 3.1.4 DRAINAGE MAP LAGUNA LAKE BASINS
JAPAN INTERNATIONAL COOPERATION AGENCY	

3.2 HYDROGEOLOGY

3.2.1 Metro Manila and Its Environs

3.2.1.1 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 (Figure 3.2.1). It is mountainous east of the Boso-Boso Basin and is contiguous to the South Luzon Upland in the south. East of Manila Bay lies the Zambales Range which extends in the north-south direction.

The Luzon Central Plain extends in the north-south direction and faces Manila Bay in the south and the Lingayen Gulf in the north. The plain has an average length and width of 150km and 60km, respectively. It is bounded by the Philippine Fault on the northeastern part which is contiguous to the Luzon Central Cordillera.

Through the northern part of the plain flows the Agno River which empties into the Lingayen Gulf. The Pampanga and Angat rivers flow through the plain's southern part and both empty into the Manila Bay.

The plain is widely covered by Alluvial deposits. An old inactive volcano (0.53 + 0.05 million years), Mt. Arayat (1,026m), is located prominently in the central part of the plain. The plain is underlain by Alluvium, Guadalupe formation of the Pleistocene to the Pliocene age, and Neogene Tertiary system, in descending order. The thickness of the Guadalupe formation is estimated to be 2,000m in the central part. This sedimentary basin is named as the Luzon Central Valley Basin (Mines and Geosciences Bureau, 1982).

The Study Area is situated southeast of the basin where the Guadalupe formation is exposed. Extending north to south in the marginal zone of the basin are several faults, which indicate tectonic activity up to the Quaternary age (Figures 3.2.2 and 3.2.3). Since volcanoes in the marginal zone were also active during the Quaternary age, most of the sediments have materials of volcanic origin.

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.

The Southwest Luzon Upland is situated south of the Study Area. The prominent peaks of Mt. Banahaw (2,177m) and Mt. Makiling (1,109m) of this upland constitute two volcanoes--Taal volcano and Mt. Batulao (811m). The elevation of these mountains decreases towards the north. Accordingly, the southern edges of the piedmont are contiguous to Manila Bay and Laguna de Bay.

The piedmont area is widely covered by thick volcanic materials such as basalt, andesite lava, pyroclastic rocks and mud flows. The area constitutes a recharge zone of the lake water of Laguna de Bay and the groundwater in Imus.

South Sierra Madre presents a landform at the maturity stage with an elevation range of 300m to 1,500m. A steep slope is present and deep valleys are formed. There is no flat plain.

This Sierra Madre area is underlain by pyroclastics, clastic rocks and limestone of Mesozoic to Neogene age. It constitutes a part of the hydrogeologic 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. These volcanoes, Mt. Pinatubo (1,780m), Mt. Natib (1,287m) and Mt. Mariveles (1,420m) range from north to south and constitute a volcanic row extending to the Corregidor Island, the Luzon Upland and the Mt. Batulao.

Volcanic rocks are composed of lavas of tholeiite basalt, andesite and dacite, and pyroclastics. The volcanic row bounds the western Luzon Central Valley Basin and is considered to be a principal source of materials for the sedimentary basin of the Guadalupe formation in the western part. A previous study (MGB, 1982) considered these volcanoes to have been active for about a million years. One which violently erupted on June 15, 1991 covered parts of Metro Manila with layers of volcanic ash.

3.2.1.2 Lithology and Stratigraphy

The Study Area is underlain by the basement rocks of Pre-Quaternary age and Guadalupe formation and Alluvium of Quaternary age (Table 3.2.1 and Figure 3.2.4).

Marikina Valley is situated at the center of the Study Area and is about 3-7 km wide. It extends in the north-south direction. Bounding the east of the valley, the Binangonan Fault separates the distribution and the structure of geology.

In the west, the Guadalupe formation and Alluvium underlie the area. In the east, the area is underlain by all the formations previously mentioned. However, in the northeastern part, there locates only formations of Pre-Quaternary age.

The Guadalupe formation distributed in the east is lithologically divided into two sections. One is mainly composed of sedimentary rocks; the other, by pyroclastic rocks.

While sedimentary rocks are distributed in the northern part of the Antipolo Plateau, the southern part has a distribution of pyroclastic rocks. These pyroclastic rocks indicate the contemporaneous heterotopic facies and mainly constitute a lower portion of the formation.

The sequence between the Guadalupe formations east and west of the Marikina Valley is not clear as the formations are separated by basaltic rocks that are distributed east of the fault. However, two formations can be identified as sediments from the same period because of the similarity in facies.

The period of sedimentation of the Guadalupe formation is thought to be Quaternary (MGB, 1982). However, a lower part of the sediments might be correlated with the Pliocene age, considering the maximum thickness of 2,000m, the degree of consolidation and alteration of rocks, and the existence of intrusive dyke rocks.

3.2.1.3 Geologic Formations as Aquifers

(1) Basement Rocks

The Madlum formation, Angat formation, Maybangin formation, and Kinabuan formation of Pre-Quaternary age constitute the basement rocks of the Study Area (Figure 3.2.15). Such rocks consist of consolidated clastic and volcanic rocks and are deemed to be relatively impermeable. In some parts where rocks are exposed and weathered, the abovesaid rocks locally form an aquifer. Groundwater can also be found in the fissure zone of rocks which are near faults and limestone caves. However, most of these rocks yield very poor water or form aquifuges.

(2) Guadalupe Formation

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 (Figure 3.2.4), namely, the Guadalupe Sedimentary Basin (GSB), the Antipolo Sedimentary Basin (ASB), and the North Antipolo Sedimentary Basin (NASB). Each basin is surrounded by impermeable base rocks and forms an isolated groundwater basin.

The GSB is situated at a part of the Luzon Central Valley Basin and is composed of thick Guadalupe formation. It is covered by Alluvium in the coastal areas of Manila Bay and the Marikina Valley.

The GSB at the center of Manila Bay has a synclinal axis in the north-south direction. Therefore, the strata in the east of the basin generally dip gently westward. However, there are anticlinal and synclinal axes south of the basin. These folds are affected by the tectonic movement of the Southwest Luzon Upland.

The GSB forms a huge groundwater basin containing several connected and interrelated aquifers composed of tuffaceous sandstone and conglomerate (Figures 3.2.5, 3.2.6 and 3.2.7). Clayey and sandy belts extend in the north-south direction as shown on the facies map of the GSB (Figure 3.2.8).

The thickness of Guadalupe formation is also estimated to range from 1,300 to 2,000m, according to the previously mentioned study (MGB, 1982). In Metro Manila, however, most of the deep wells drilled to exploit fresh groundwater have an average depth of 300 m.

As shown in Figure 3.2.6, the strata of the GSB in Metro Manila tilt monoclinally towards the west. Five to six aquifers can be identified up to a depth of about 300m. The Guadalupe formation is considered to be discontinuous from west to east of the western boundary of the Marikina Valley because the Valley has the features of a graben and is bounded by faults on both sides.

The Guadalupe aquifers strike NW-SE in the northern area of the hill, N-S in the vicinity of the Pasig River, and NNE-SSW in Parañaque. The Guadalupe formation consists of conglomerates in the northern area where non-volcanic sediments are dominant. Secondary volcanic sediments are dominant in the south of Parañaque.

The clay content distribution of the formation is illustrated in Figure 3.2.9. Aquifer transmissivity and productivity may be indicated by this distribution.

Groundwater recharge occurs in the northern area of Novaliches, the northern and eastern areas of Montalban, the western area of the Antipolo plateau, and the southern terrace which is composed of lahar and is contiguous to Tagaytay.

The Guadalupe aquifers in Metro Manila can be considered as the "Metro Manila Groundwater Basin". The Basin constitutes a part of the GSB.

The ASB is a small sedimentary basin surrounded by impermeable base rocks. Its center is in Antipolo and it 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. Details are explained in Subsection 3.2.2.

The NASB is situated north of Antipolo. It is underlain by thin tuffaceous sandstone and silt stone and the Kinabuan formation. The thickness of Guadalupe formation is estimated to range from several tens of meters to 100m. Its thickness is lower than that of ASB, although the area is bigger. The thin sediments and deep valley in the area suggest that the NASB forms seasonal aquifers because of the presence of a small volume of interspaces in the strata.

Pyroclastics of Guadalupe formation around Laguna de Bay are mainly composed of tuff breccia and partly contains sandstone. These rocks are generally thought to be impermeable, but they contain some exploitable water in the fracture and in the concentrated zone of gravel and sand. Since the sediments were laid down irregularly, the aquifer is locally distributed.

(3) Alluvium

The Alluvium is distributed in the coastal areas of Manila Bay and Laguna de Bay, in the Marikina Valley and the intramountain basins in the eastern mountain area. The Alluvium generally forms a phreatic aquifer in the coastal area of Manila Bay and Marikina Valley. The thickness of Alluvium is estimated to range from 5 to 10m in the coastal areas of Manila Bay and Laguna de Bay, based on drilling data and JICA test well data (Figure 3.2.10).

The Alluvium is mainly composed of soft clay and thin loose sand and overlies Diluvial clay or Guadalupe formation. The sandy layer of the Alluvium forms a phreatic aquifer. Groundwater may be used for domestic purpose; however, water is salinized in the coastal area.

Figure 3.2.11 shows geologic profiles at the Manila South Harbor (JICA, 1987). Based on the N-value, the thickness of Alluvial sediments exceeds 30m at Pier-5. However, and as mentioned previously, the thickness of alluvial sediments in the coastal area from Navotas to Obando is generally small, as shown in Figure 3.2.12 (JICA, 1990). A thick area though is found off-shore.

Diluvial clay consists of clay and silt with N-value range of 5-20 and is partly consolidated. The thickness of the clay layer range from 10-20m in the coastal area. However, the identification of diluvial clay is based only on the foundation drillings at the Manila port and the coastal plain. Further classification is still needed to determine the geologic age, the distribution and thickness of Diluvial clay.

The recent drilling carried out by MWSS indicates the sand and gravel of alluvial fan deposit and the underlying Guadalupe formation to form aquifers in the coastal area of Laguna de Bay from Baras to Jala-Jala. The thickness of Alluvium in the inland basins, such as Teresa and Boso-Boso, is estimated to be minimal as the impermeable basement rock is sporadically exposed. This could suggest that aquifers in these areas yield poor quantities of groundwater.

Based on the geologic data and the above interpretation, the transgression in Alluvium age may be as illustrated in Figure 3.2.13. This figure suggests that the deep erosional valley was not formed in the glacial time that is more than 10,000 years past. The decline of the sea level at the Wurm glacial stage is thought to be a maximum of 140m. But old Manila Bay then might be a huge lake, with its water table level remaining relatively high.

(4) Hydrogeologic Assessment

The groundwater potentials of the Study Area were initially assessed qualitatively, based on the distribution and the facies of rocks, and are illustrated in Figure 3.2.14. Aquifer systems can be classified according to the formations. Six categories were made.

(1) Al/G : Alluvium overlying Guadalupe Formation
(2) G : Guadalupe Formation
(3) G/B : Guadalupe Formation overlying Basement
(4) Al/Gv : Alluvium overlying Guadalupe Formation of volcanic facies
(5) Al/B : Alluvium overlying Basement
(6) B : Basement

Groundwater potential is high at categories 1, 2 and 3, and relatively low at 4 and 5. Category 6 is thought to be the lowest.

3.2.2 Antipolo Plateau

3.2.2.1 Geology

The Antipolo Plateau is located east of Marikina Valley. Its area is about $30km^2$; elevation, about 200m above mean sea level. The main rivers of the plateau flow into the poblacion of Antipolo and then flow out westward to Marikina Valley or cascade through cliffs. Rivers in the east and north of the plateau originate from springs at piedmont.

The plateau is underlain by the Kinabuan formation and the Antipolo diorite of Cretaceous to Oligocene age, by the Angat formation and Madlum formation of Miocene age, and by the Guadalupe formation and Alluvium of Quaternary age (Table 3.2.2, Figures 3.2.15 and 3.2.16).

The Kinabuan formation is distributed west and north of the plateau and is composed of altered basalt, basaltic andesite lava, pillow lava and pyroclastics. These volcanic rocks are dark greenish in color due to chloritization, indicating them to be products of marine volcanoes.

The Antipolo diorite is distributed in the north-south direction along the eastern edge of the plateau. The rock has a fine- and even-grained texture and is deeply weathered. Recent K-A dating (MGB, 1982) reveals that the rock is of Oligocene age.

The Angat formation is mainly composed of partly crystalline limestone and is distributed in contiguity with the Antipolo diorite in the eastern edge of the plateau. The formation is dated Lower Miocene, based on the occurrence of larger Foraminifera.

The Madlum formation consists of consolidated limey sandstone and silty shale. The formation is distributed in a limited area at the eastern edge of the plateau. Geological age of the formation is considered to be Upper Miocene.

The Guadalupe formation has a total thickness of about 230m, and it may be divided into four members based on logs of existing wells and JICA test wells and field observation of outcrops.

The lowermost member, member I, consists of conglomerate and coarse sandstone and underlies the north of the plateau.

Member II is composed of consolidated medium sandstone and conglomerate in the lower part, and alternating beds of tuffaceous mudstone and sandstone in the upper part. The strike and dip of the formation are N20°W and 6S°W, respectively. The formation gently inclines towards the center of the Antipolo Sedimentary Basin (ASB).

Member III consists of alternating beds of mudstone and tuff. Tuffaceous sandstone is predominant in the member and covers the central area of the plateau. The member intercalates a lappili tuff that is widely distributed south of the ASB and which is considered to be continuous up to the pyroclastics of the Laguna formation.

Member IV consists of deeply weathered tuff breccia and volcanic conglomerate. It overlies the north of the plateau.

Black basalt porphyry intrudes into member III at the western and southern edges of the plateau. The rock is considered to be formed in sheets.

The time stratigraphic classification of the Guadalupe formation is still undetermined by the fossils. It is generally thought that the formation is made up of Quaternary sediments, considering the rock facies. However, judging from the degree of consolidation, the low resistivity and the existence of intrusive basalt porphyry, members I and II are possibly Pliocene. These members are less tuffaceous than upper members III and IV. The rock facies also indicate that the formation was deposited in the bay or the lake environment.

The Antipolo plateau is underlain by the Guadalupe formation with its basement composed by hard rocks of pre-Neogene age. The basin has the shape of a ship-bottom with a depth-range of 180 to 230m at the center (Figure 3.2.15)

The basement rocks are exposed in the east, west, and north of the plateau, in fault contact or unconformity with the Guadalupe formation. Major faults run in the north-south direction on both sides of the plateau, but in the north, a fault in the north-west direction bounds the plateau.

For the southern plateau, a massive lapilli tuff of member III shows a flat landform. Considering the distribution of basement rock, the depth of the sediment is shallow in the southern part.

3.2.2.2 Hydrogeologic Unit and Structure

Pre-Quaternary rocks generally form a hydrogeologic basement of the plateau. The Guadalupe formation overlies the basement. This formation constitutes good aquifers, particularly the coarse sandstone and tuff of its upper member.

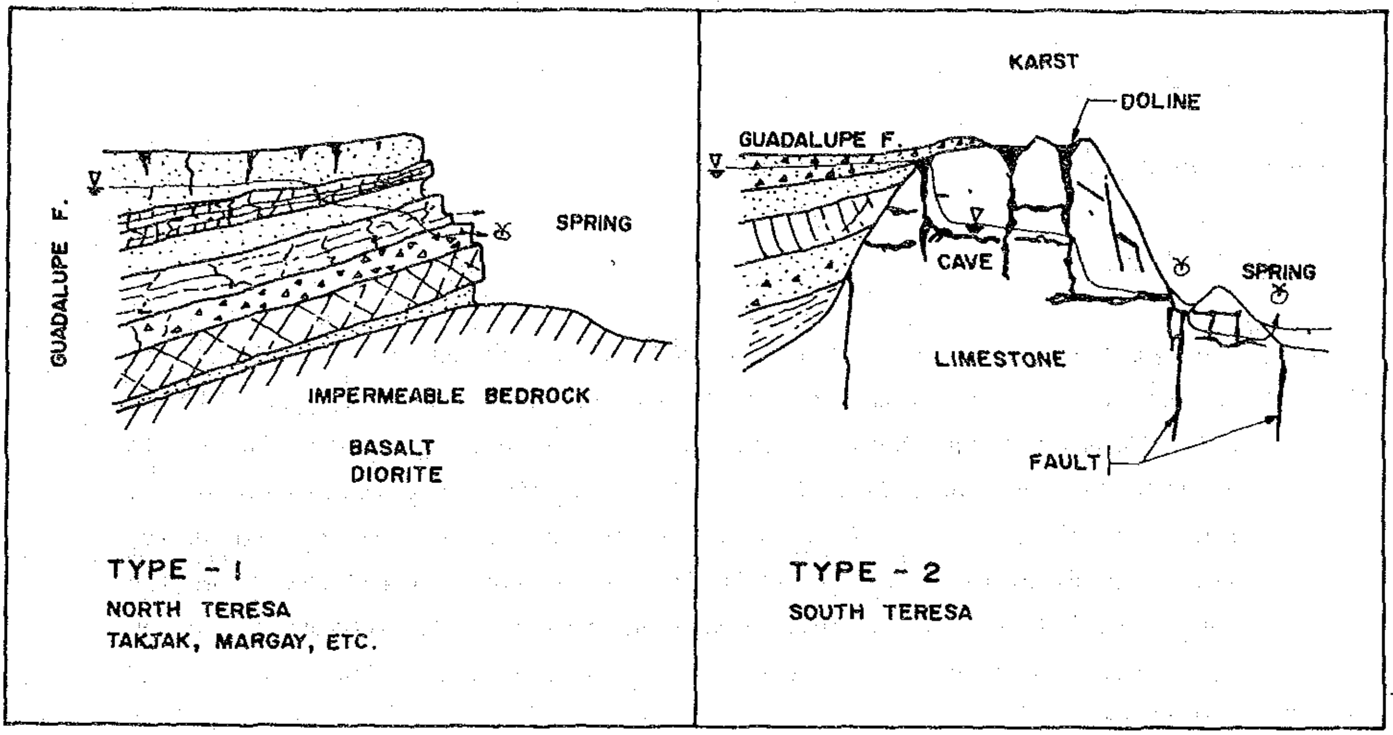
The Guadalupe formation is weathered at a depth of 30-50m from the surface. The weathered section contains unconfined water or perched water especially during the rainy season.

Hydrogeologic units can be defined as upper Gs and lower Gmd in terms of rock facies, resistivity and transmissivity of the formation. Gs is mainly composed of coarse sandstone and tuff of member III and forms a fairly good confined aquifer. Gmd is mainly composed of tuffaceous mudstone of member II and forms an aquitard or aquifuge (Figure 3.2.18).

The type of formation was verified by the pumping test result of JICA 200m test well in Barangay San Jose, Antipolo. Transmissivity of muddy layer (at depths of 152m to 173m and 185m to 194m) was only $9m/d^2$. The discharge rate was 51.6 l/min.

Although the maximum thickness of the Guadalupe formation is estimated to be about 230m, only the upper member of the Guadalupe formation forms an aquifer, with its depth as measured from the surface varying from 100m to 120m (Figure 3.2.17). Some existing wells in Antipolo are tapped at depths of 180m to 245m. However, groundwater is thought to be supplied mainly by Gs aquifer shallower than 120m.

A number of springs are found along the marginal zone of the plateau, with water being discharged from the plateau. Flow systems are categrized into two types and are shown below.



From the flow condition of the spring, the Antipolo Plateau is considered to constitute an isolated groundwater basin.

3.2.2.3 Groundwater Table

The groundwater table as measured in May 1991 is illustrated in Figure 3.2.19. Elevation of the water table at the center of the 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 where escarpments are formed. These areas are located in the northeastern, the eastern and the southwestern edges of the plateau at a relative height of about 200m. The hydraulic gradient of the water table is steep in these places such that the groundwater flows out of the basin as mentioned in 2.3.2.

3.2.3 Las Piñas

3.2.3.1 Geology

(1) Outline

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, both of which flow into the Manila Bay. Rivers meander in an area which is about 500-1,000m away from the coast. Old river and marine ponds are found in this area wherein both surface water and groundwater are salinized. An alluvial plain extends inland at about 1.5-2.0km from the coast. Behind this plain is a gently undulating hill with an elevation of 20-40m. Only about 7.54km separate the coasts of Laguna de Bay and Manila Bay.

The Guadalupe formation is exposed in the above undulating hill and it is composed of alternating beds of sandstone, conglomerate, mudstone and tuff. The strata have a strike parallel to the coastal line and dip at 3-5 degrees.

Downstream of the Zapote river, the strata are composed of alternating beds of fine to medium tuffaceous sandstone and mudstone, the tuffaceous sandstone being prominent. The strata intercalate pumice tuff and incline towards Manila Bay at about 3 degrees.

The thickness of the Guadalupe formation possibly reaches to more than 2,000m. The thickness of Alluvium might be 10m to 20m, basing on existing well logs and core boring data at JICA test well sites. The alluvial bed consists of sand and clay with shell fragments (Figures 3.2.20, 3.2.21 and 3.2.23).

(2) Lithologic Description of JICA Test Well Sites

Seven test wells were drilled at three locations in the coastal area of Las Piñas. Prior to the drilling of test wells, two 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 is 300m.

Las Piñas No.1 and No.2 are located inland at a distance of about 500m to 800m from the coast. The distance between the two well sites is about 1,300m. The facies and thickness of the formation are very similar to each other and are briefly described as follows (Figure 3.2.23).

LAS PIÑAS NO.1

The site is near the coastal line where the alluvium is less than seven-meter thick. The rest of the strata 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, namely CL, was traced at depths of 58m to 76m. This clayey layer may be associated with Las Piñas No.2. The formation overlain by this clayey layer consists mainly of alternating beds of 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, thus making the resistivity curves indicate high anomalies.

LAS PIÑAS NO.2

Geology of Las Piñas No.2 can be classified into Alluvium and the Guadalupe formation. The Alluvium which is 11.1-m thick consists of soft clay and loose gravel layers and is underlain by well-consolidated Guadalupe formation.

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 in Las Piñas No.1.

3.2.3.2 Analysis of Core Samples

Core samples taken at Las Piñas No.1 were analyzed from the stratigraphical, chronological and geochemical points of view.

(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 3.2.3. 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 could have been disturbed by water flow during their transport and deposition, judging from the grain shape, lamina, wooden fragment and roundness of conglomerate.

Accordingly, the result of dating may 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.

(2) Diatom Analysis

Most of the diatoms found in the core samples (obtained at depths of 7.7 to 10.5m) are marine or marine to brackish. In contrast, only limnetic diatoms were identified in the core samples taken at depths of 24.8m to 298m (Table 3.2.4).

This finding suggests that the uppermost sediments were laid down in the shallow sea of Holocene age while the 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, was discovered during the 1960s by MGB through a drilling it carried out downstream of the Marikina River. This could indicate that the deeper formation was deposited in a marine environment.

(3) Analysis of Heavy Minerals

The 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 dominant in heavy minerals. Hornblende was found in samples taken at shallow depths reaching up to 165m. The amount of hyperthene was very small--below 265m.

The difference of 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 were found in the samples instead of a small content 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 exceeded 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 3.2.5.

(4) Analysis of Chloride Content

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

The findings show that samples from shallow aquifers which were taken at depths of 10m, 27m and 52.5m yield much higher chloride content than those from deep aquifers. This could indicate that the saltwater mainly encroaches on the shallow aquifer from Manila Bay and the surface (Table 3.2.6).

(5) Carbon Dating

The carbon dating was carried out for Las Piñas Site No.2 using 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 years, plus or minus 150 years. That of sample No.2 is 7360 years, 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").

3.2.3.3 Hydrogeologic Unit and Structure

Good aquifers in the area are constituted by tuffaceous sand and gravelly layers of the Guadalupe formation. Groundwater is abstracted by deep wells which tap at a depth of about 300m. A thick clayey layer was