## 3.4 HYDROGEOLOGICAL FEATURES OF AQUIFERS

### 3.4.1 Objective Aquifers to the Existing Wells

Most of the screens of existing wells in the Study Area are installed in the layers of scoria, sand and gravel intercalated in Kaybubutong Formation and the layers of sandstone or conglomerate intercalated in Talisay Formation.

In case of the well located in the low elevation zone (lower than 50 m), the screens are installed in the conglomerate layer intercalated in the lower horizon of Kaybubutong Formation and in conglomerate or sandstone layer intercalated in Talisay Formation.

In case of the well located in the middle elevation zone (50 - 200 m), the screens are installed in the layers of scoria or gravel intercalated in the middle and lower horizons of Kaybubutong Formation and Talisay Formation.

In case of the well located in the high elevation zone (higher than 200 m), the screens are installed in the andesite lava or scoria bed intercalated in the middle of Kaybubutong Formation. The major springs in the Study Area also gush out from these layers.

### 3.4.2 Hydrogeological Characteristics of Main Aquifers

**Table 3.4.1** shows the hydrogeological constants obtained from electric logging and pumping test conducted on the four test wells.

According to the drilling results of the four test wells, three aquifers, shown in **Table 3.4-2,** were distinguished.

Middle Aquifer is the best aquifer among the three judging from its large specific capacity (Sc) and transmissivity (T). The sediments consisting this aquifer were deposited at the end of Cavite Slope as alluvial fan conglomerate.

Electric conductivity is low in Upper Aquifer and Middle Aquifer but high in Lower Aquifer. Usually, confined groundwater shows high electric conductivity because pressure holds dissolved minerals in solution. Consequently, groundwater in Upper and Middle Aquifers is considered as unconfined and that in the Lower Aquifer is as confined.

### 3.4.3 Distribution of Specific Capacity

**Fig. 3.4-1** shows the distribution pattern of specific capacity based on existing well data and the results of the pumping test carried out in this Study.

## TABLE 3.4-1 DETAILS OF THE TEST WELLS

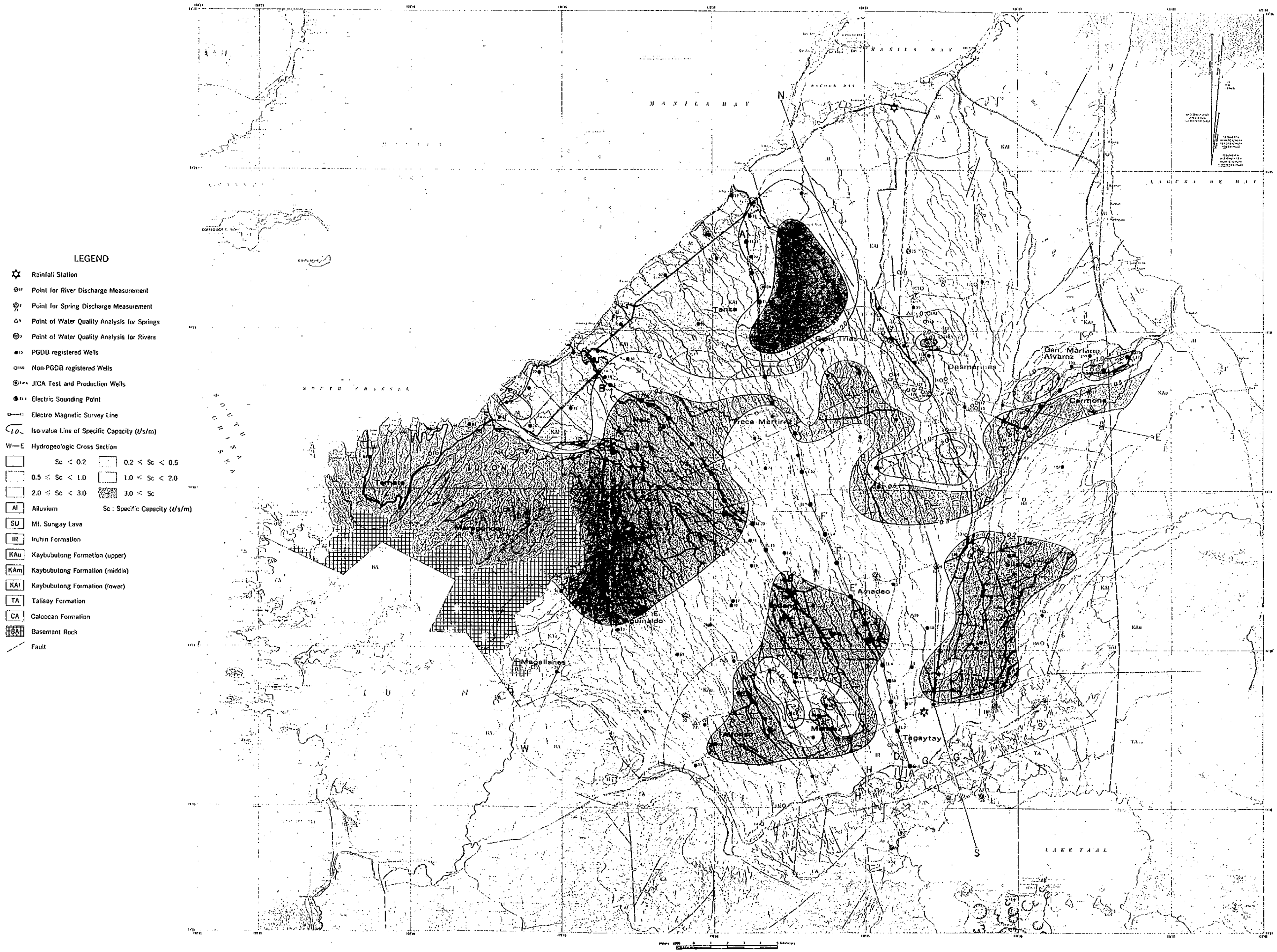
| No. | LOCATION: Site | LOCATION: Ground Level (m) | WELL STRUCTURE: Borehole Depth (m) | Borehole Ø (mm) | Casing Depth (m) | Casing Ø (mm) | Screen Ø (mm) | Screen TOP GL-m | Screen BOTTOM GL-m | SWL GL-m | PUMPING TEST DATA: STEP DRAWDOWN TEST Qmax (l/s) | Drawd. (m) | Sc (l/s/m) | CONSTANT DISCHARGE TEST Q (l/s) | Drawd. (m) | Sc (l/s/m) | (T) ($cm^2/s$) | WELL LOGGING DATA: Temp (℃) | Cond. (S/cm) | Main Aquifer | Resistivity (ohm-m) | Stratigraphic Horizon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | GMA | 163.65 | 100 | 350 | 100 | 200 | 150 | 106 | 154 | 99.45 | 1.88 | 1.59 | 1.18 | 1.74 | 1.62 | 1.07 | 34.00 | 26.5 | 370 | Scoria tuff | 30~50 | Kaybubutong Formation (lower) |
| | | | 220 | 320 | 160 | 150 | | (Total 48 m) | | | | | | | | | | | | ~C.S.S (Scoria rich) | 20~30 | |
| B | TANZA | 30.65 | 60 | 400 | 60 | 250 | 200 | 66 | 84 | 10.45 | 34.10 | 19.43 | 1.76 | 14.54 | 9.06 | 1.60 | 35.95 | 29.5 | 450 | (Upper) Conglomerate ~Gravely C.S.S | 20~60 | Kaybubutong Formation (lower) |
| | | | | | | | 200 | 96 | 102 | | | | | | | | | | | | | |
| | | | | | | | 200 | 108 | 120 | | | | | | | | | | | | | |
| | | | | | | | 200 | 126 | 130 | | | | | | | | | | | | | |
| | | | 150 | 390 | 150 | 200 | 200 | 138 | 144 | | | | | | | | | | | (Lower) Gravely C.S.S ~Pumice tuff | 20~30 | Talisay Formation |
| | | | | | | | | (Total 48 m) | | | | | | | | | | | | | | |
| C | NAIC | 5.40 | 60 | 400 | 60 | 250 | 200 | 66 | 72 | 6.28 | 36.00 | 33.20 | 1.08 | 33.08 | 36.38 | 1.05 | 22.20 | 30.2 | 510 | MSS ~FSS (scoria rich) | 30~50 | Talisay Formation |
| | | | | | | | 200 | 78 | 84 | | | | | | | | | | | | | |
| | | | | | | | 200 | 102 | 114 | | | | | | | | | | | | | |
| | | | | | | | 200 | 102 | 114 | | | | | | | | | | | | | |
| | | | 150 | 370 | 150 | 200 | 200 | 120 | 128 | | | | | | | | | | | | | |
| | | | | | | | | (Total 48 m) | | | | | | | | | | | | | | |
| D | MENDEZ | 542.00 | 200 | 350 | 200 | 200 | 150 | 206 | 212 | 112.19 | 8.24 | 12.60 | 0.65 | 8.27 | 9.85 | 0.84 | 15.30 | 24.5 | 272 | Scoria tuff ~Volcanic conglomerate | 100~180 | Kaybubutong Formation (middle) |
| | | | | | | | 150 | 218 | 221 | | | | | | | | | | | | | |
| | | | | | | | 150 | 251 | 257 | | | | | | | | | | | | | |
| | | | 290 | 320 | 270 | 150 | 150 | 251 | 257 | | | | | | | | | | | | | |
| | | | | | | | 150 | 275 | 284 | | | | | | | | | | | | | |
| | | | | | | | | (Total 30 m) | | | | | | | | | | | | | | |

C.S.S.: Coarse Sandstone

## TABLE 3.4-2 CLASSIFICATION OF THE AQUIFERS DISTINGUISHED IN THE STUDY AREA

| | Stratigraphic Horizon | Lithology | Sc (1/s/m) | T ($cm^2$/s) | Temperature (℃) | Conductivity (μ s/cm) | Resistivity (ohm-m) | Test Well |
|---|---|---|---|---|---|---|---|---|
| Upper Aquifer | Middle horizon of Kaybubutong Formation | Scoria, Tuff, Volcanic Conglomerate lava | 0.84 | 15.30 | 24.5 | 272 | 100~180 | Mendez |
| Middle Aquifer | Lower horizon of Kaybubutong Formation | Conglomerate ~Coarse sand | 1.60 | 36.0 | 29.5 | 450 | 20~60 | Tanza |
| | | | 1.007 | 34.0 | 26.5 | 370 | 20~40 | G.M.A |
| Lower Aquifer | Talisay Formation | Coarse sandstone with gravel ~Medium Sandstone | 1.05 | 22.2 | 30.2 | 510 | 30~50 | Naic |

# Fig. 3.4-1 EVALUATION MAP OF GROUNDWATER RESOURCES



Specific capacity is as high as more than 0.5 l/s/m in the low elevation zone, the northern part of Cavite Slope, while it is as low as less than 0.5 l/s/m in the middle to high elevation zone in general.

In the areas along the National Road between Dasmarinas and Silang and around Mendez, specific capacity rarely exceeds more than 1.01 l/s/m.

The high specific capacity zone around Tanza roughly coincide with the valley on the surface plane of Talisay Formation. High specific capacity in this zone may reflect thick fan deposits (lower horizon of Kaybubutong Formation) supplied from the high elevation zone of Cavite Slope.

The wells tend to be deeper in the middle to high elevation zone with high specific capacity. For example, the wells deeper than 120 m in Mendez and 200 m in Silang show more than 1.0 l/s/m in specific capacity. This indicates that the aquifer consisted of coarse-grain sediments of Kaybubutong Formation which lies in the depth of the middle to high elevation zone.

# CHAPTER 4

# WATER BALANCE AND GROUNDWATER POTENTIAL

# CHAPTER 4

# WATER BALANCE AND GROUNDWATER POTENTIAL


Using the records of seven PAGASA rainfall stations in and near the Study Area, mean annual areal rainfall was determined at 2,505 mm.

Many springs are distributed in the Study Area, especially between 300 m and 400 m in elevation and their total discharge amounts to 580 lps which is equivalent to 4.6% of the annual rainfall.

Based on the results of river survey, annual total surface runoff was estimated as 1,082 mm in depth, of which about 70% is discharged in wet season and 30% is in dry season.

Actual evapotranspiration was estimated as 931 mm/yr from pan evaporation value obtained from the existing data and the modified Blaney–Criddle Method.

Using the results of the well inventory survey and the pumping discharge survey, the present annual groundwater withdrawals in the Study Area was estimated as 32.573 x $10^6$ cum.

As for the whole Study Area, 37.2% of the annual rainfall is consumed as actual evapotranspiration, 43.2% as surface runoff, 15.7% as groundwater discharge and 3.9% is groundwater recharge. In addition, about 33% of the total groundwater is pumped up for human activities. Water balance was also computed for some major river basins.


## 4.1 STUDY METHODS

In its general form, the water balance equation may be represented by

$$P = Et + R + O + \Delta G + \Delta S + I + M$$

where $P$ is precipitation, $Et$ is evapotranspiration, $R$ is surface runoff, $O$ is the groundwater from aquifers, $\Delta G$ is the groundwater storage increment, $\Delta S$ is the soil moisture increment, $I$ is the amount of water intercepted and $M$ is the water recharge or depletion due to human activity, all values are in millimeters.

$P$, $R$, $I$ and $M$ were measured or surveyed in this Study as outlined below. Other variables were lumped or estimated empirically.

### 4.1.1 Rainfall Measurement

Though an automatic rain gage (STAGELOG 2D) was installed at Malinta Elementary School, Brgy. Malinta, Dasmarinas, it malfunctioned and was not used in the Study. Therefore, rainfall data observed during the Study period were obtained from seven (7) PAGASA stations in and near the Study Area.

### 4.1.2 River Survey

The river survey measured the dry season and wet season discharge, Ph, EC and temperature, and sampled the river for water quality analysis. A total of 30 measurement points were established in the six (6) major river basins in the Study Area: Maragondon, Labac, Canas, San Juan, Imus and Binan. Of which, at least five (5) were in the basin selected for groundwater simulation. The measurement points are plotted in **Fig. 4.1-1**.

### 4.1.3 Spring Survey

The spring discharge measurement aims to estimate quantitatively the groundwater outflow in the Study Area. As in the river survey, this estimate shall be used in making a detailed water balance analysis of the area.

Twenty (20) representative springs were selected and measured for discharge, temperature, pH and EC. Of which, 10 were sampled for water quality analysis. The measurement points are plotted in **Fig. 4.1-2.**

A questionnaire survey was also conducted to determine the utility condition of the springs.

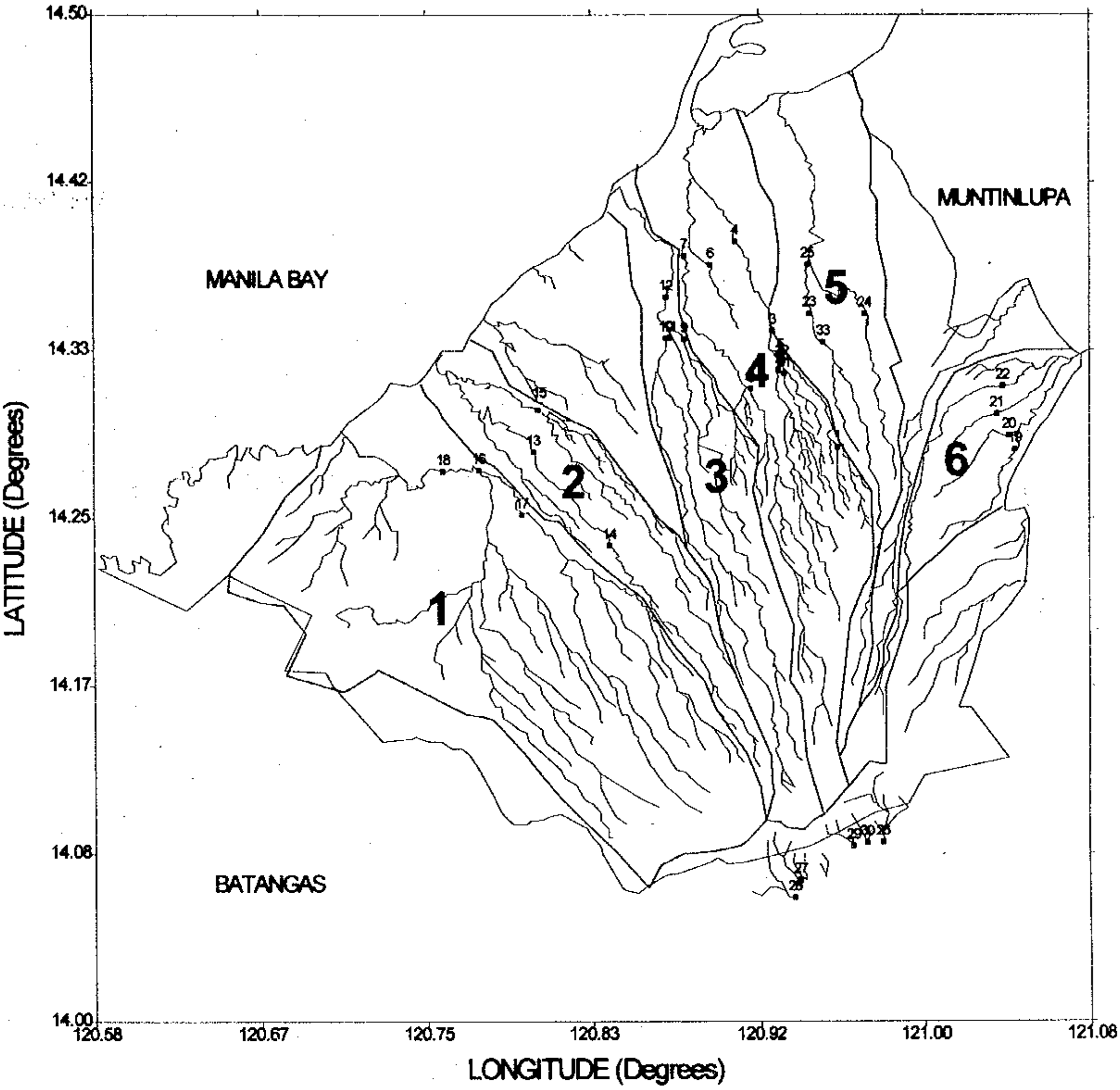
### 4.1.4 Well Inventory Survey

Well inventory provides the basic data to carry out the various investigations and surveys of this Study, e.g., selection of sites for test wells and core drilling, measurement and monitoring of groundwater levels and quality, and conduct of geological and geophysical surveys. It involves the collection of all available data on existing wells including: location, well design and construction, static water level, pumping test results, electric logs, lithologic logs and water quality. In this Study, the well inventory survey specifies collection and arrangement or transcription of data and information on existing 150 deep wells with sufficient hydrogeological information. This number represents 10% of the total number of deep wells believed to be drilled in the Study Area.

Through a UNDP grant, LWUA, together with other government agencies, had established the Philippine Groundwater Data Bank (PGDB). At present, about 639 wells located in the Study Area are registered in this PGDB. **Table 4.1-1** details the availability of well data from the data bank.

The well inventory survey has retrieved 81 new deep well data which shall be supplemented to the data bank to form an updated well inventory database for Cavite. These new well data were arranged using PGDB's well inventory form and the use of which was confirmed and fixed during the survey.

Considering not only the sufficiency of hydrogeological data but also the distribution over the Study Area, 167 deep wells were selected from both PGDB-registered wells and the 81 non-PGDB-




**MAJOR RIVER BASIN**

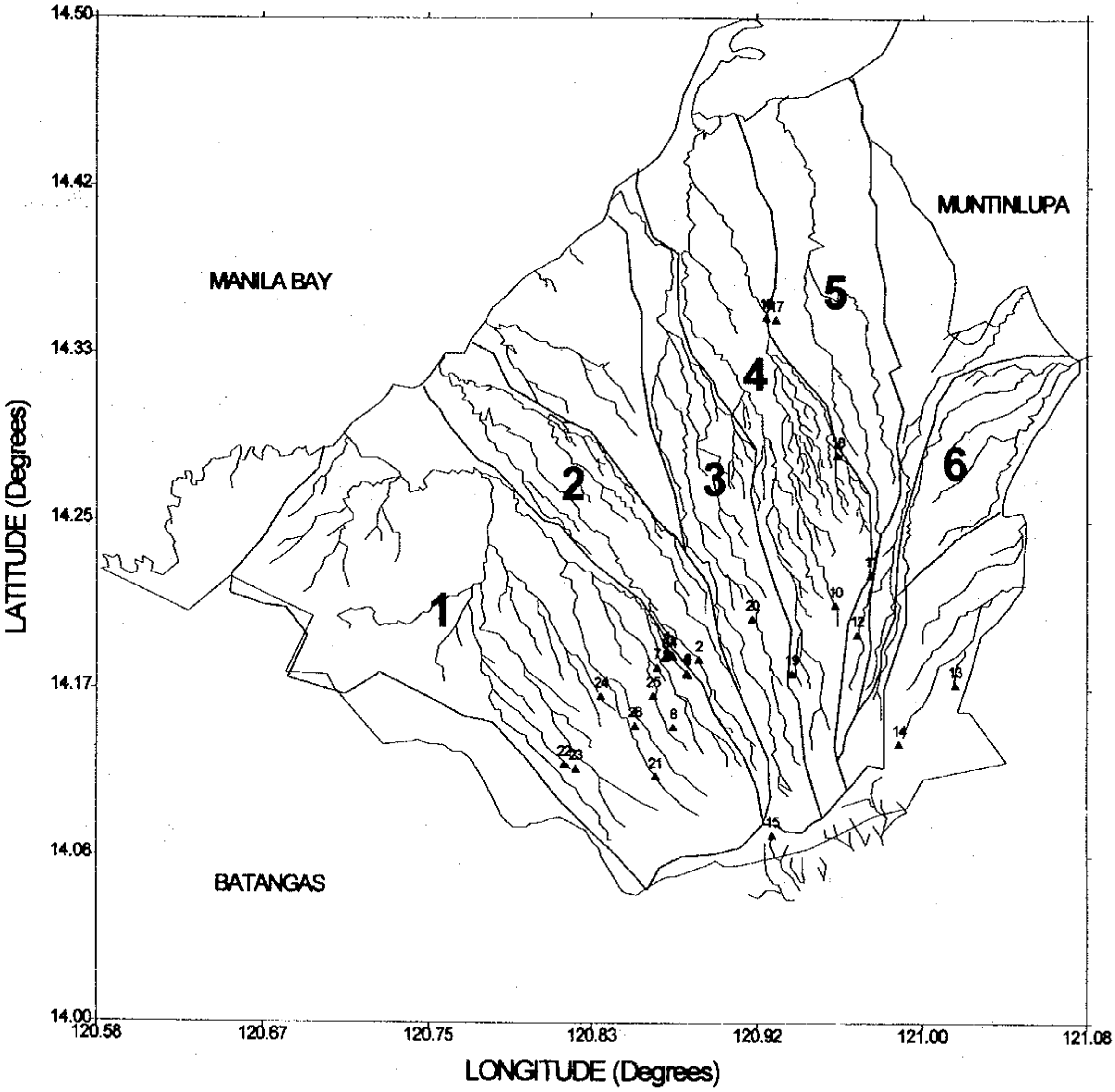
1 MARAGONDON RIVER BASIN
2 LABAC RIVER BASIN
3 CAÑAS RIVER BASIN
4 SAN JUAN RIVER BASIN
5 IMUS RIVER BASIN
6 BIÑAN RIVER BASIN

LEGEND :

RIVER DISCHARGE MEASUREMENT STATION

DRAINAGE BOUNDARY

| CAVITE WATER SUPPLY DEVELOPMENT STUDY | Fig. 4.1-1 |
| --- | --- |
| JAPAN INTERNATIONAL COOPERATION AGENCY | LOCATIONS OF RIVER SURVEY STATIONS |




**MAJOR RIVER BASIN**

1 MARAGONDON RIVER BASIN
2 LABAC RIVER BASIN
3 CAÑAS RIVER BASIN
4 SAN JUAN RIVER BASIN
5 IMUS RIVER BASIN
6 BIÑAN RIVER BASIN

**LEGEND :**

12 ▲ SPRING NO.
— DRAINAGE BOUNDARY

| CAVITE WATER SUPPLY DEVELOPMENT STUDY | Fig. 4.1-2 |
| --- | --- |
| JAPAN INTERNATIONAL COOPERATION AGENCY | LOCATIONS OF SPRING SURVEY STATIONS |

Table 4.1-1 EXISTING PGDB AND NON-PGDB WELL DATA

| No. | MUNICIPALITY | NUMBER OF WELLS | | LOCATION DATA (1) | | (1) + WELL CONSTRUCTION DATA | | (1) + LITHOLOGIC LOG DATA | | (1) + PUMPING TEST DATA | | (1) + WATER QUALITY DATA | | (1) + ELECTRIC LOG DATA | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PGDB | NON-PGDB | PGDB | NON-PGDB | PGDB | NON-PGDB | PGDB | NON-PGDB | PGDB | NON-PGDB | PGDB | NON-PGDB | PGDB | NON-PGDB |
| 1 | DASMARIÑAS | 67 | 36 | 49 | 27 | 6 | 24 | 22 | 16 | 22 | 12 | 9 | 7 | | 23 |
| 2 | INDANG | 65 | | 43 | | 9 | | 32 | | 23 | | 5 | | | |
| 3 | GMA | 2 | 3 | 2 | 3 | 1 | 3 | 1 | 3 | 0 | 2 | 0 | | | 2 |
| 4 | MENDEZ | 24 | 1 | 22 | 1 | 2 | 1 | 20 | 1 | 17 | 1 | 3 | | | |
| 5 | SILANG | 70 | 13 | 44 | 13 | 4 | 10 | 32 | 13 | 17 | 12 | 1 | 1 | | 5 |
| 6 | TANZA | 52 | 1 | 40 | 1 | 5 | 1 | 26 | 1 | 10 | | 8 | | | 1 |
| 7 | TAGAYTAY CITY | 13 | 5 | 12 | 4 | 0 | 3 | 3 | 2 | 1 | | 1 | | | 1 |
| 8 | AMADEO | 19 | | 12 | | 2 | | 8 | | 5 | | 1 | | | |
| 9 | MAGALLANES | 14 | | 4 | | 0 | | 3 | | 2 | | 0 | | | |
| 10 | MARAGONDON | 39 | 1 | 30 | 1 | 0 | 1 | 14 | 1 | 6 | 1 | 6 | 1 | | 1 |
| 11 | TERNATE | 23 | 2 | 11 | 2 | 0 | 2 | 8 | 2 | 3 | 1 | 0 | 2 | | 1 |
| 12 | ALFONSO | 51 | 1 | 44 | 1 | 3 | 1 | 41 | 1 | 19 | | 5 | | | 1 |
| 13 | NAIC | 54 | | 41 | | 2 | | 30 | | 6 | | 5 | | | |
| 14 | GEN. E. AGUINALDO | 5 | | 2 | | 0 | | 0 | | 0 | | 0 | | | |
| 15 | CARMONA | 78 | 12 | 77 | 6 | 1 | 4 | 44 | 6 | 12 | 2 | 5 | | | 4 |
| 16 | TRECE MARTIRES CITY | 17 | 5 | 6 | 2 | 1 | 2 | 4 | 1 | 4 | 1 | 3 | 1 | | 2 |
| 17 | GEN. TRIAS | 46 | 1 | 33 | 1 | 4 | 1 | 19 | 1 | 8 | 1 | 3 | 1 | | 1 |
| | TOTAL | 639 | 81 | 472 | 62 | 40 | 53 | 307 | 48 | 155 | 33 | 55 | 13 | | 42 |

registered wells (or supplementary wells). Of these 167 wells, 20 wells were chosen for simultaneous groundwater leveling and water quality sampling.

### 4.1.5 Groundwater Level Monitoring

(1) Simultaneous groundwater leveling

The purposes of simultaneous groundwater leveling or measurements of static water levels are as follows: to prepare a groundwater contour map of the Study Area and analyze regional groundwater flow and to investigate the short-term and long-term changes in groundwater levels for groundwater modeling and water balance analysis. The fluctuation of groundwater level is the best indicator of groundwater storage development.

**Fig. 4.1-3** shows the approximate locations of the 20 wells measured for static water levels. These active wells were selected from the 166 deep wells of the well inventory survey. Static water levels were measured at least 6 hours after the operation stops to allow the water level to recover. Just after the restart of the operation, water sample is taken from the blow-off pipe or tap of the same well.

(2) Continuous groundwater level monitoring

Five (5) automatic water level gages (STAGELOG 40) were installed in five (5) existing deep wells in the simulation area to measure water pressure in mBar. The groundwater level monitoring points are plotted in **Fig. 5.2-1**. The behavior of groundwater levels in the simulation area was monitored for six month, from June to November, 1994. After the measuring period, the logger was taken out from the well, connected to the PC to read the measured groundwater level data. **Fig. 4.1-4** presents the groundwater level hydrographs measured at JICA monitoring stations.

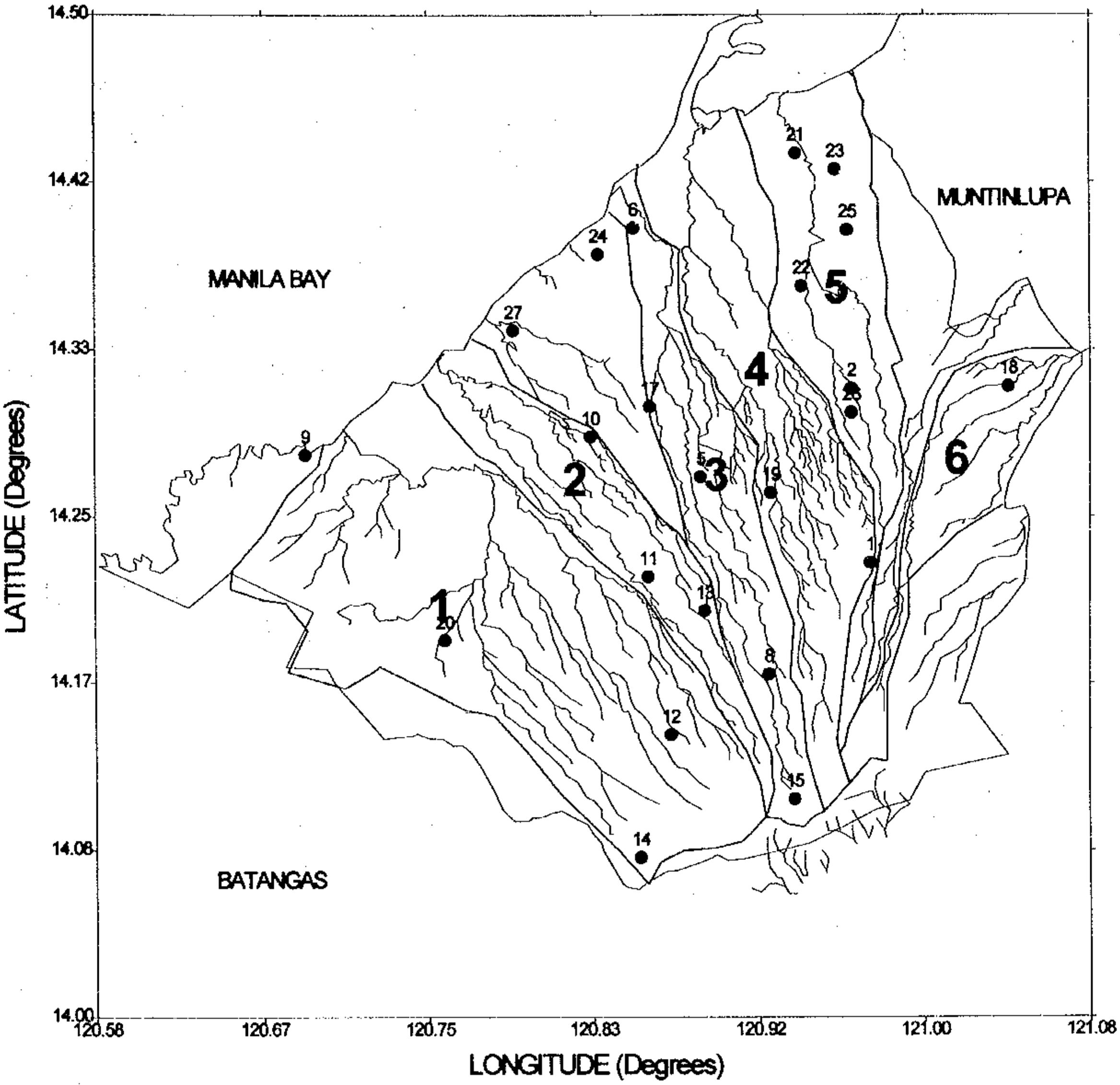
### 4.1.6 Pumping Discharge Survey

Pumping discharge survey was conducted to estimate the amount of groundwater use in the Study Area. Locations of the surveyed wells are shown in **Fig.4.1-5**.

## 4.2 WATER BALANCE IN THE STUDY AREA

### 4.2.1 Rainfall

**Fig. 4.2-1** exhibits the isoyethal map of mean annual rainfall for the Study Area based on the records of seven (7) PAGASA rainfall stations. Annual rainfall varies from 2,000 mm to 3,800 mm with the southern part experiencing much rainfall. Mean annual areal rainfall was determined at 2,505 mm.



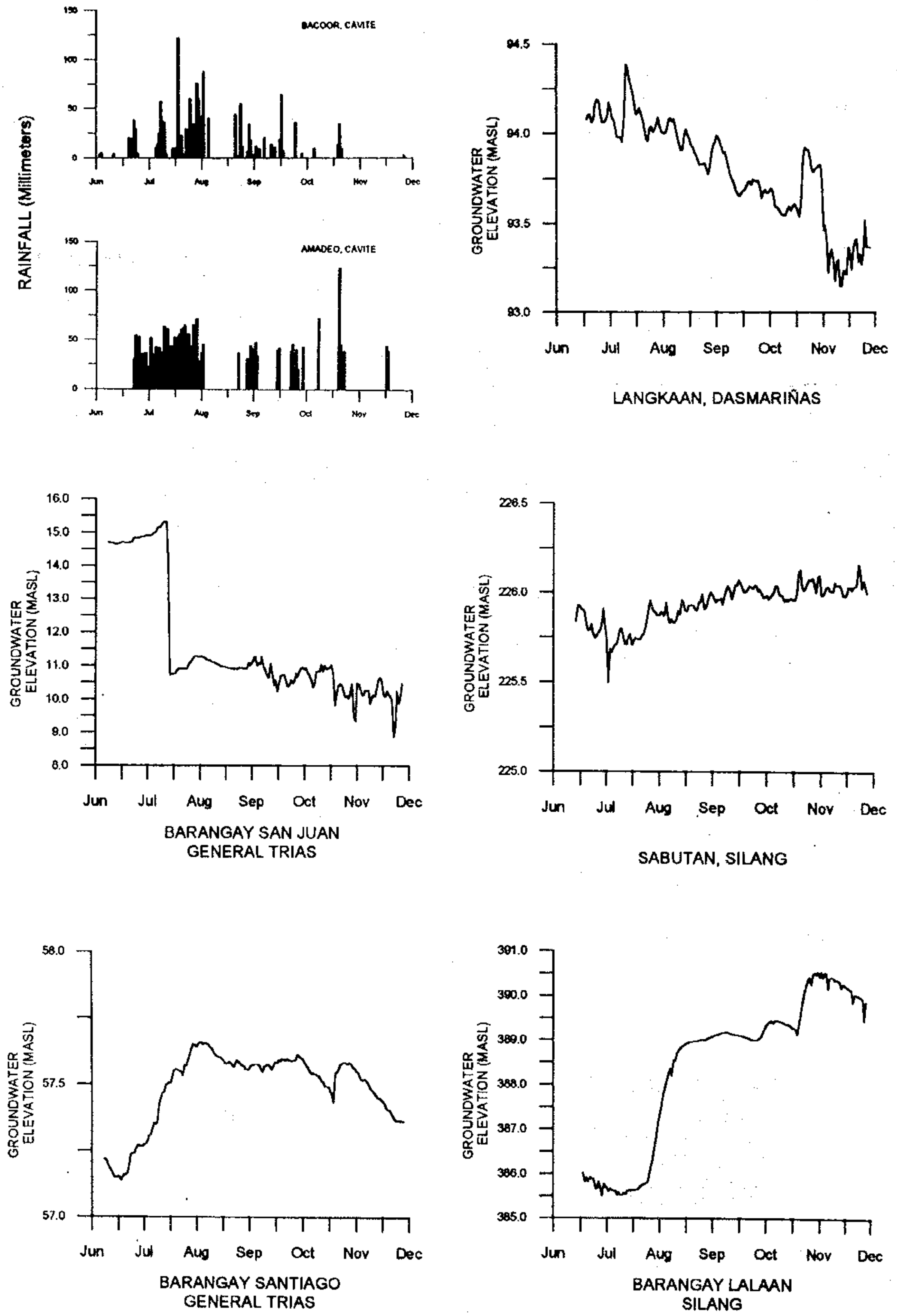

**MAJOR RIVER BASIN**

1 MARAGONDON RIVER BASIN
2 LABAC RIVER BASIN
3 CAÑAS RIVER BASIN
4 SAN JUAN RIVER BASIN
5 IMUS RIVER BASIN
6 BIÑAN RIVER BASIN

**LEGEND :**

● WELL I.D. NO.
— DRAINAGE BOUNDARY

| CAVITE WATER SUPPLY DEVELOPMENT STUDY | Fig. 4.1-3 |
|---|---|
| JAPAN INTERNATIONAL COOPERATION AGENCY | LOCATIONS OF GROUNDWATER LEVEL MONITORING STATIONS |

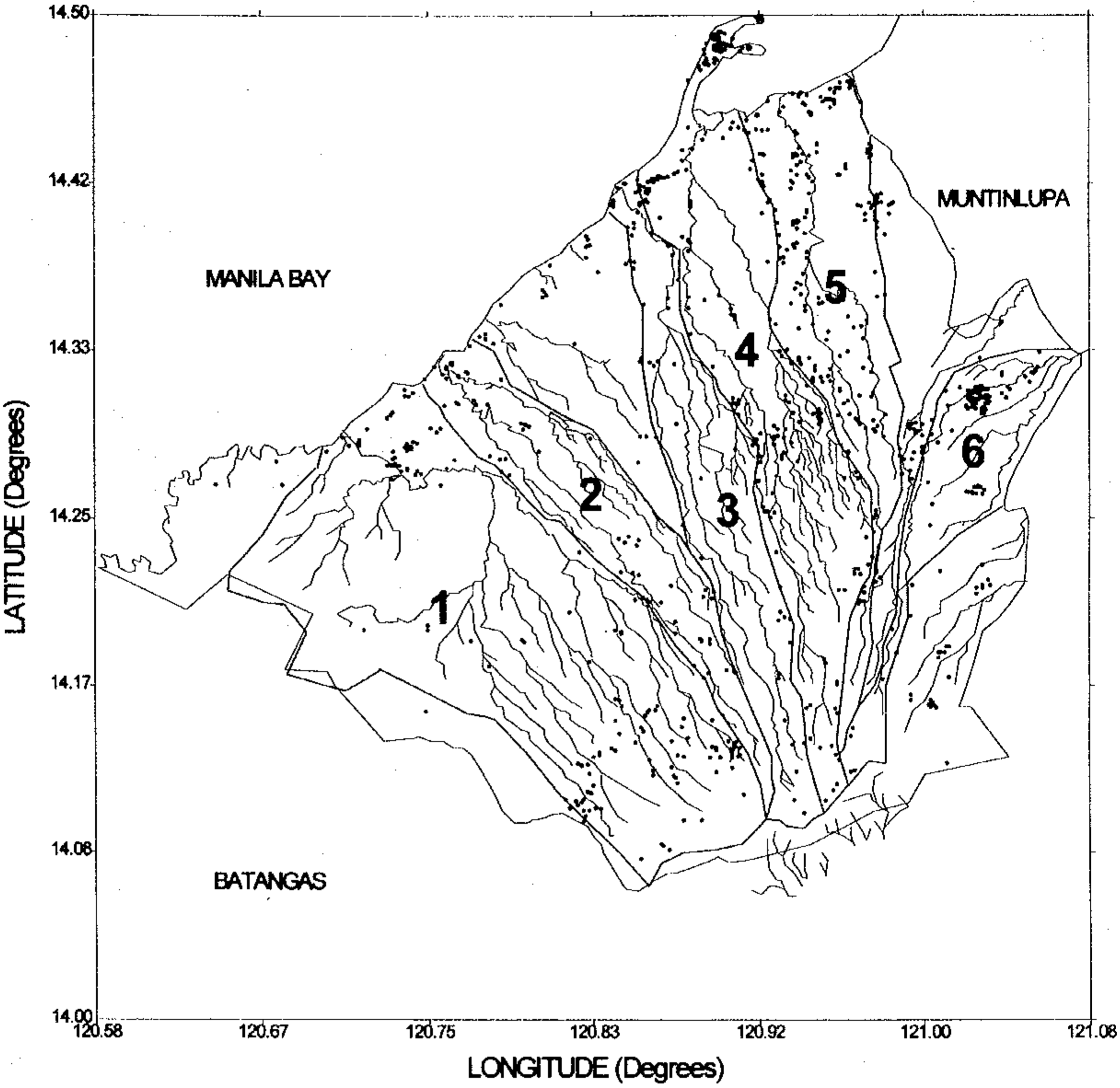



**CAVITE WATER SUPPLY DEVELOPMENT STUDY**

JAPAN INTERNATIONAL COOPERATION AGENCY

**Fig. 4.1–4**

**GROUNDWATER LEVEL HYDROGRAPHS OF JICA MONITORING STATIONS**

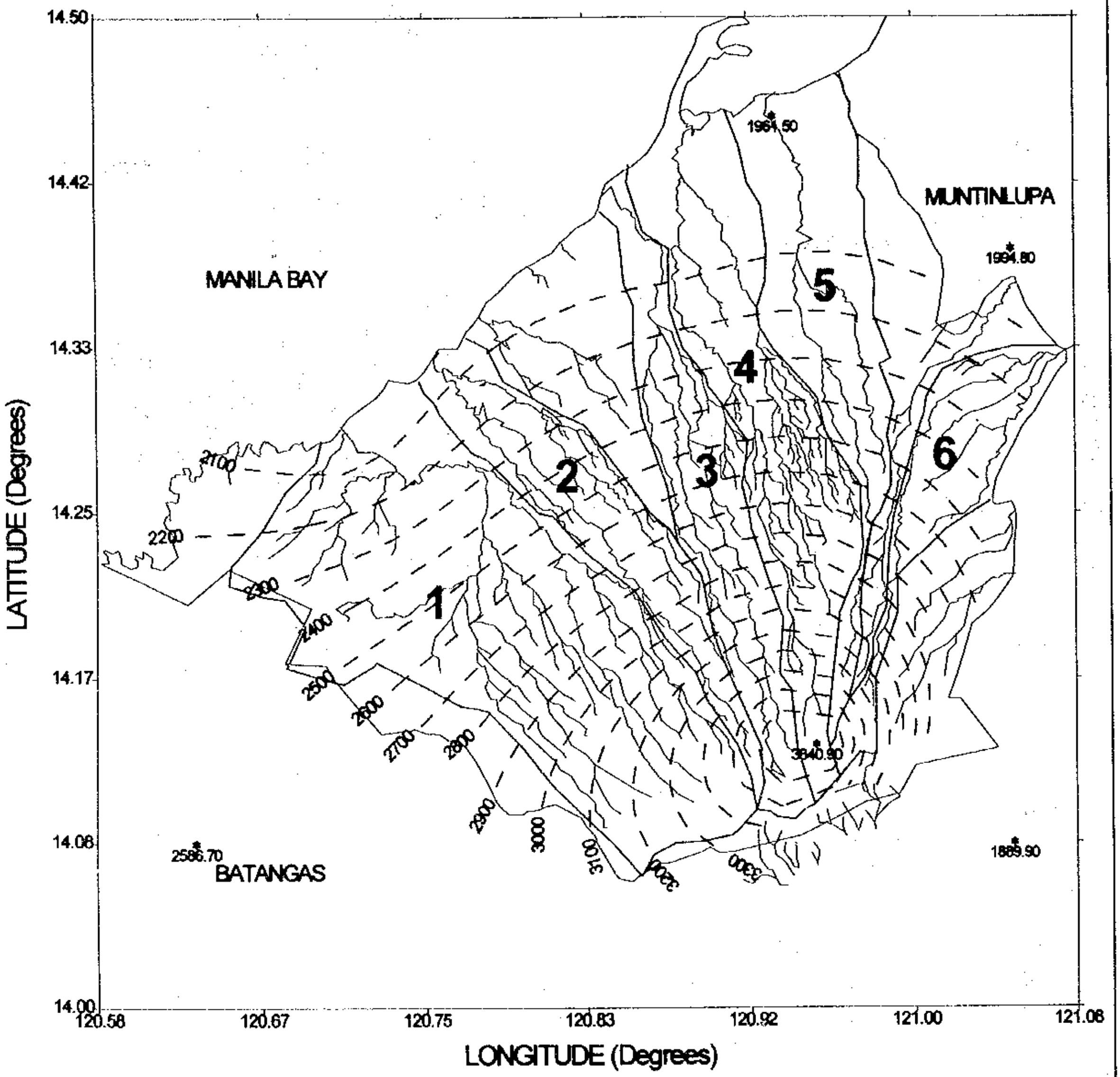



**MAJOR RIVER BASIN**

1 MARAGONDON RIVER BASIN
2 LABAC RIVER BASIN
3 CAÑAS RIVER BASIN
4 SAN JUAN RIVER BASIN
5 IMUS RIVER BASIN
6 BIÑAN RIVER BASIN

NOTE : EXCLUDES WELLS WITHOUT COORDINATES

| | |
|---|---|
| **CAVITE WATER SUPPLY DEVELOPMENT STUDY** | **Fig. 4.1-5** |
| JAPAN INTERNATIONAL COOPERATION AGENCY | **LOCATIONS OF WELLS FOR PUMPING DISCHARGE SURVEY** |




**MAJOR RIVER BASIN**

1 MARAGONDON RIVER BASIN
2 LABAC RIVER BASIN
3 CAÑAS RIVER BASIN
4 SAN JUAN RIVER BASIN
5 IMUS RIVER BASIN
6 BIÑAN RIVER BASIN

**LEGEND :**

- -2500- ANNUAL RAINFALL IN MILLIMETERS
- — DRAINAGE BOUNDARY
- * PAGASA RAINFALL STATION

| CAVITE WATER SUPPLY DEVELOPMENT STUDY | Fig. 4.2-1 |
|---|---|
| JAPAN INTERNATIONAL COOPERATION AGENCY | ANNUAL RAINFALL DISTRIBUTION IN THE STUDY AREA |

### 4.2.2 Runoff through Rivers

Many springs recharge rivers in the Study Area. Discharge amount and the utility condition of these springs obtained from the spring survey are summarized in **Tables 4.2-1** and **4.2-2**. **Table 4.2-3** shows the results of the river discharge survey.

**Fig. 4.2-2** illustrates the measurement results in the flow scheme for each river basin. In general, almost all rivers have higher discharge in wet season than in dry season, except for three (3) rivers namely, Ilang-Ilang River (R-2), Cañas River (R-10) and Balsahan River (R-13). This is due to the NIA diversions (for irrigation) located upstream of the measurement points. The dry season discharge is only 28% of the annual river discharge, while wet season discharge is 72%. The Electric Conductivity (EC) and pH values obtained for wet season are lower compared to the measured values during dry season.

Streamflow of the major rivers is being diverted as irrigation water for paddy fields by NIA. The water requirement for irrigation in the Study Area amounts to 185 x $10^6$ cum per year, of which about 77% is required in the wet season. Diversion capacity, irrigated area and water requirement for each river are shown in the **S/R**.

As shown in **Table 4.2-4**, these data were needed to adjust the discharge records to obtain a better estimates of surface runoff for water balance analysis.

### 4.2.3 Evapotranspiration

In this Study, the pan evaporation is considered as the potential evapotranspiration and assumed to include 75 mm from residual wet season soil moisture.

The pan evaporation data from Ambulong, Tanauan, Batangas was considered for the Study Area. The data consist of records from 1959 to 1975. Monthly mean evaporation values range from 97 mm to 153 mm over a 16-year period. The observed pan evaporation at this station is 1,401 mm/yr.

In the FRAMEWORK PLAN SOUTHERN TAGALOG TAAL LAKE BASINS (NWRC,1983), evapotranspiration rates were also computed using the modified Blaney-Criddle Method. Temperature data of Ambulong as well as relative humidity, sunshine and wind conditions were considered. Evapotranspiration was estimated at 1,400 mm/yr.

### 4.2.4 Amount of Water Use

The annual amount of water use by type of user in the Study Area as a whole in 1993, which totals 173.427 x $10^6$ cum, is summarized as:

Table 4.2-1 SPRING SURVEY STATIONS AND SURVEY RESULTS FOR DRY AND WET SEASONS

| SPRING NO. | NAME OF SPRING | BASIN NO. | LOCATION | DISCHARGE (lps) | | WATER QUALITY SAMPLING POINT |
|---|---|---|---|---|---|---|
| | | | | DRY | WET | |
| S-1 | Ikloy | 1 | Kaytambog, Indang | 181.2 | 209.0 | Y |
| S-2 | Niyog | 2 | Buna Cerca, Indang | 6.6 | 11.7 | Y |
| S-3 | Ipie I | 1 | Kaytambog, Indang | 57.8 | 70.0 | N |
| S-4 | Ipie II | 1 | Kaytambog, Indang | 17.5 | 159.0 | N |
| S-5 | Ulo | 1 | Kayquit, Indang | 15.3 | 21.5 | N |
| S-6 | Buho | 1 | Kaytambog, Indang | 9.8 | 16.0 | N |
| S-7 | Pulo | 1 | Pulo, Indang | 3.0 | 44.8 | N |
| S-8 | Siloy | 1 | Carasuchi, Indang | 38.7 | 68.5 | N |
| S-9 | Silid-siliran | 1 | Kayquit, Indang | 6.0 | 16.3 | N |
| S-10 | Lucsuhin | 4 | Lucsuhin, Silang | 11.7 | 11.7 | Y |
| S-11 | Ilog ng Bayan | 5 | Ilog Bayan, Silang | 3.0 | 6.8 | Y |
| S-12 | Sulsugin | 5 | Balete II, Silang | 0.8 | 0.9 | N |
| S-13 | Pulong Usiw | 7 | Iruhin, Tagaytay City | 0.6 | 0.6 | N |
| S-14 | Matang Tubig | 7 | Francisco, Tagaytay City | 8.2 | 26.3 | Y |
| S-15 | Kaybubutong | 7 | Sambong, Tagaytay City | 168.4 | 177.0 | Y |
| S-16 | Sabang I | 4 | Sabang, Dasmariñas | 1.0 | 1.0 | N |
| S-17 | Sabang III | 5 | Sabang, Dasmariñas | 0.2 | 0.8 | N |
| S-18 | Bucal | 4 | Bucal, Dasmariñas | 3.5 | 5.0 | Y |
| S-19 | Bucal | 4 | Bucal, Amadeo | 0.2 | 0.6 | N |
| S-20 | Balete | 3 | Halang, Amadeo | 42.5 | 44.8 | Y |
| S-21 | Alibandog | 1 | Mangas I, Alfonso | 2.2 | 4.0 | Y |
| S-22 | Sta. Theresa I | 1 | Sta. Theresa, Alfonso | 11.4 | 18.7 | Y |
| S-23 | Sta. Theresa II | 1 | Sta. Theresa, Alfonso | 0.2 | 1.6 | N |
| S-24 | Salvacion | 1 | Taywanak Ilaya, Alfonso | 1.1 | 5.2 | N |
| S-25 | Taywanak II | 1 | Taywanak Ilaya, Alfonso | 0.4 | 4.3 | N |
| S-26 | Taywanak I | 1 | Taywanak Ilaya, Alfonso | 0.7 | 2.5 | N |
| S-27 | Kaybubutong II | 7 | | 72.6 | | N |
| S-28 | Kaybagal | 3 | | 49.8 | | N |

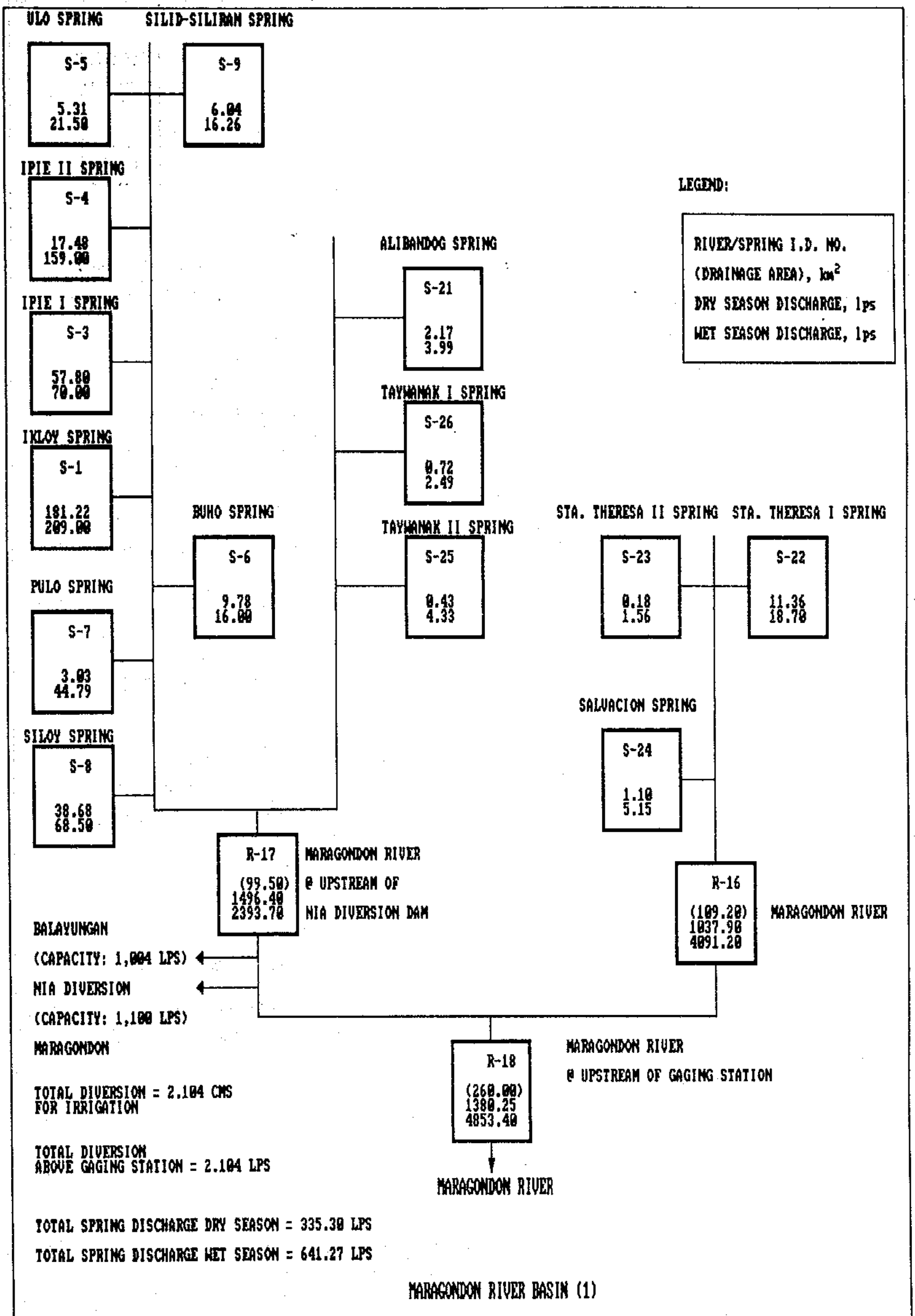
## Table 4.2-2 UTILITY CONDITION OF THE MAJOR SPRINGS

| SPRING NUMBER | NAME OF SPRING | LOCATION | ELEVATION ABOVE POBLACION, m | TYPE OF SPRING | USER | POPULATION SERVED | FACILITIES |
|---|---|---|---|---|---|---|---|
| S-1 | IKLOY** | Kaytambog, Indang | 27 | Depression | Indang Water District | 6,490 (1990) | Spring Box with 18" dia. pipe to Pumping Station, 2" dia. and 4" dia. transmission pipes |
| S-2 | NIYOG** | Buna Cerca, Indang | 60 | Depression | Privately Owned Factory | | Spring Box with 3/4" dia. intake pipe (2) 2" dia. and 6" dia. overflow pipes |
| S-3 | IPIE I | Kaytambog, Indang | 30 | Depression | Indang Water District | 590 (1990) | Spring Box with 4" dia. intake pipe |
| S-4 | IPIE II | Kaytambog, Indang | 24 | Depression | Indang Water District | 5,900 (1990) | Spring Box with 4" dia. supply pipe to Ikloy and 4" dia. overflow pipe |
| S-5 | ULO | Kayquit, Indang | 70 | Contact | Brgy. Kayquit | 3,670 (1990) | None |
| S-6 | BUHO | Kaytambog, Indang | 30 | Depression | Brgy. Kaytambog | 590 (1990) | Spring Box with 4" dia. overflow pipe |
| S-7 | PULO | Pulo, Indang | 80 | Depression | Brgy. Pulo | 470 (1990) | 3" dia. and 4" dia. intake pipes |
| S-8 | SILOY | Carasuchi, Indang | 140 | Depression | Brgy. Banaba | 890 (1990) | Spring Box with 6" dia. supply pipe and (2) 6" dia. overflow pipes |
| S-9 | SILID-SILIRAN | Kayquit, Indang | 70 | Depression | Brgy. Kayquit | 3,670 (1990) | None |
| S-10 | LUCSUHIN** | Lucsuhin, Silang | 23 | Depression | Silang Water District | 23,746 (1994) | Pumping Station |
| S-11 | ILOG NG BAYAN** | Ilog Bayan, Silang | -7 | Depression | Brgy. Ilog Bayan | 1,922 (1994) | Spring Box with (3) 3" dia. overflow pipes |
| S-12 | SULSUGIN | Balete II, Silang | 105 | Depression | Brgy. Balete II | | None |
| S-13 | PULONG USIW | Iruhin, Tagaytay City | -122 | Depression | Tagaytay City Water District | | Pumping Station |
| S-14 | MATANG TUBIG** | Francisco, Tagaytay Cit | -142 | Depression | Tagaytay City Water District | | Pumping Station |
| S-15 | KAYBUBUTUNG** | Sambong, Tagaytay City | -348 | Impervious Rock | Tagaytay City Water District | | Reservoir and Pumping Station |
| S-16 | SABANG I | Sabang, Dasmariñas | -30 | Artesian | Brgy. Sabang | 2,174 (1994) | 2" and 1" dia. overflow pipes |
| S-17 | SABANG III | Sabang, Dasmariñas | -32 | Artesian | Brgy. Sabang | 2,174 (1994) | None |
| S-18 | BUCAL** | Bucal, Dasmariñas | 50 | Depression | Dasmariñas Water District | 705 (1994) | Spring Box with 6" dia. transmission pipe, (3) 4" dia. overflow pipes and (2) 4" dia. drain pipes |
| S-19 | BUCAL | Bucal, Amadeo | -40 | Depression | Brgy. Bucal | | None |
| S-20 | BALETE** | Halang, Amadeo | -90 | Depression | Brgy. Halang | | None |
| S-21 | ALIBANDOG** | Mangas I, Alfonso | 75 | Depression | Poblacion | | Spring Box with 6" dia. supply pipe and 3" dia. overflow pipe |
| S-22 | STA. THERESA I** | Sta. Theresa, Alfonso | -30 | Depression | Brgy. Sta. Theresa | | Spring Box with 4" dia. supply pipe and 3" dia. overflow pipe |
| S-23 | STA. THERESA II | Sta. Theresa, Alfonso | -20 | Depression | Brgy. Sta. Theresa | | None |
| S-24 | SALVACION | Taywanak Ilaya, Alfonso | -65 | Depression | Brgy. Taywanak | | Spring box with 4" dia. intake pipe |
| S-25 | TAYWANAK II | Taywanak Ilaya, Alfonso | -50 | Depression | Brgy. Taywanak | | None |
| S-26 | TAYWANAK I | Taywanak Ilaya, Alfonso | -80 | Depression | Brgy. Taywanak | | Spring box with 3" dia. intake pipe |
| S-27 | KAYBUBUTONG II | | | | | | |
| S-28 | KAYBAGAL | | | | | | |

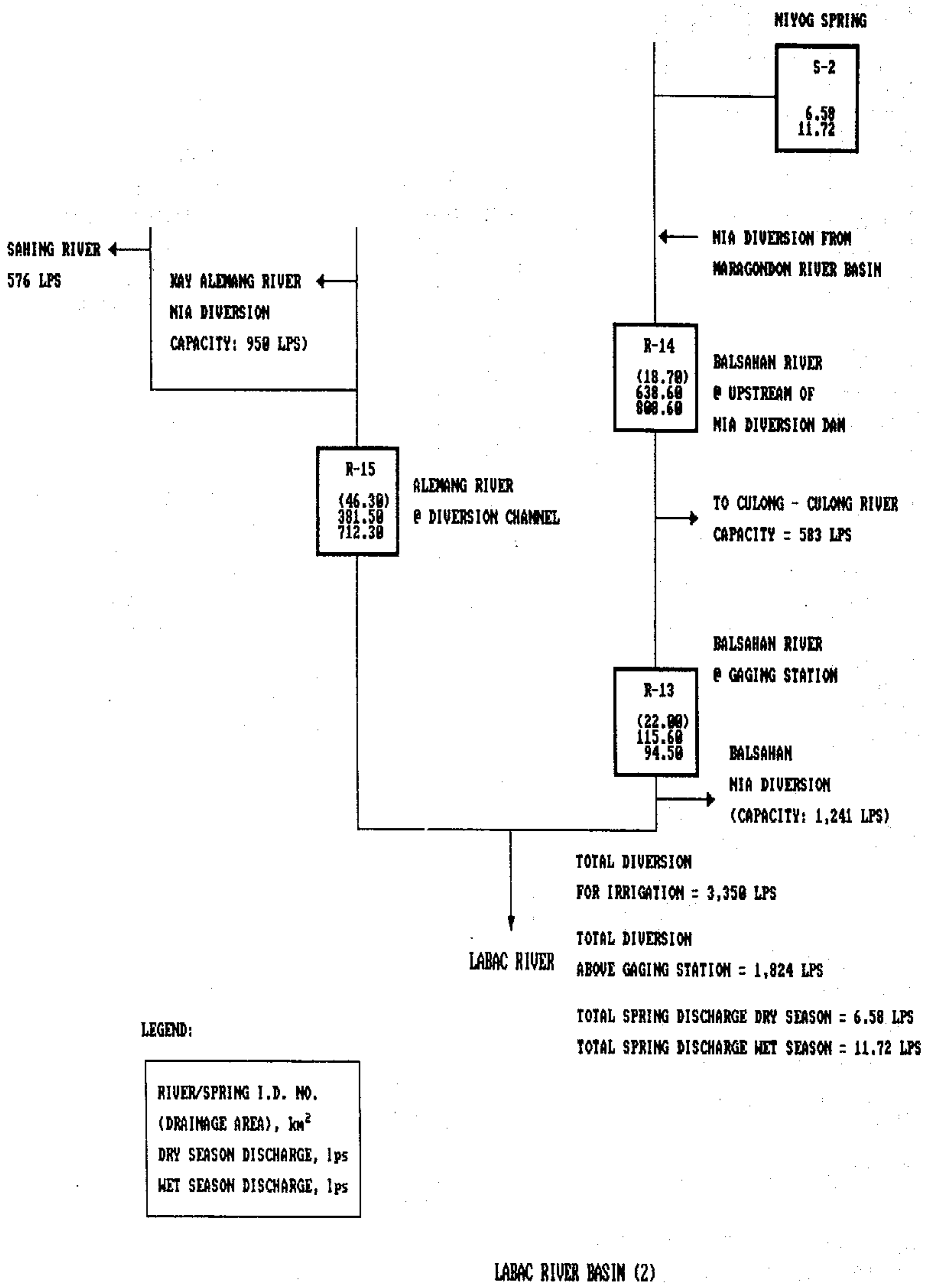
* VALUES TAKEN FROM PREVIOUS STUDIES
** SAMPLING POINTS FOR WATER QUALITY ANALYSIS
( ) MINOR SPRINGS
LATITUDE, LONGITUDE, ELEVATIONS AND DISTANCE WERE BASED FROM THE TOPOGRAPHIC MAP

Table 4.2-3 RIVER SURVEY STATIONS AND SURVEY RESULTS FOR DRY AND WET SEASONS

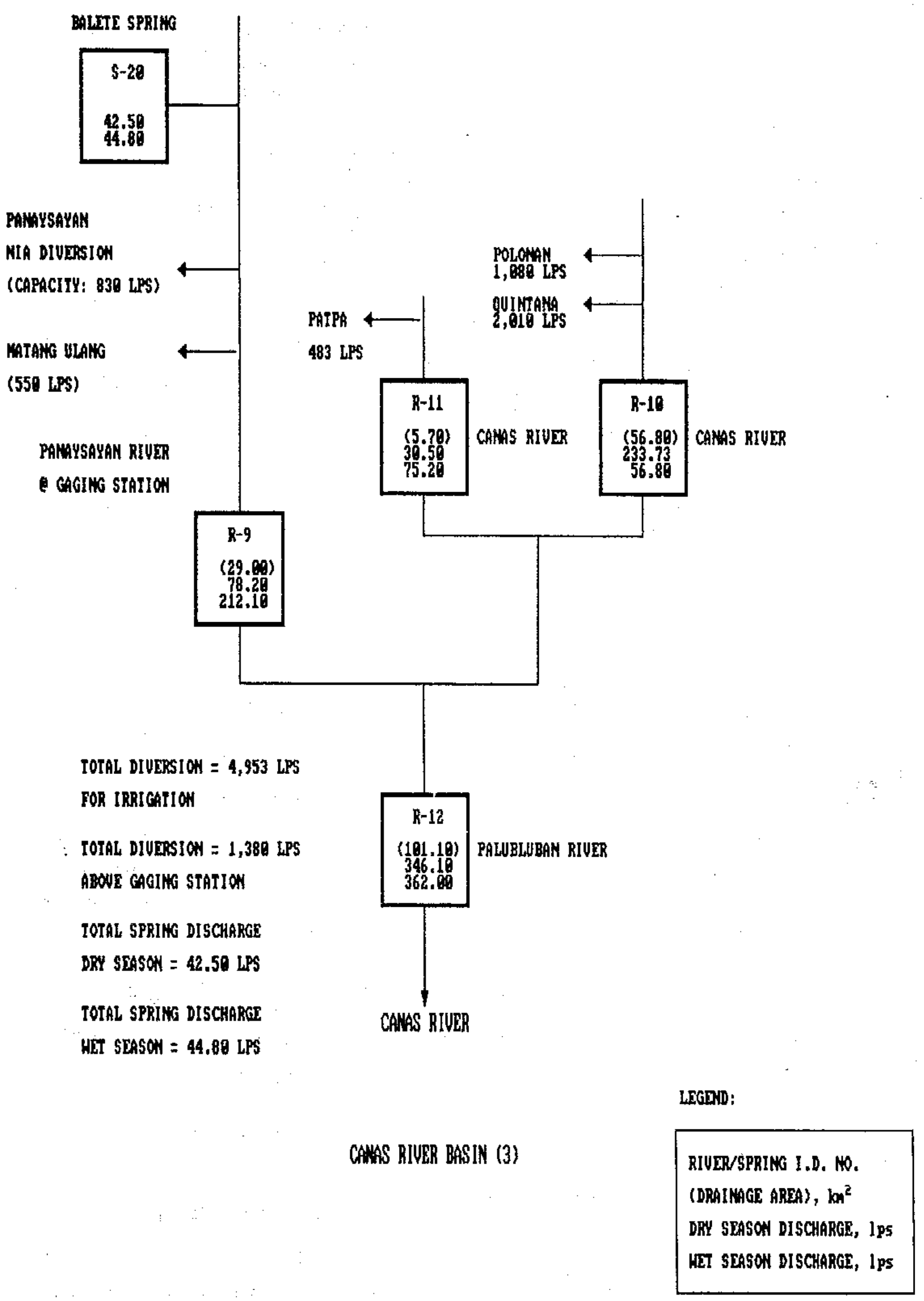
| STA. NO. | RIVER_NAME | BASIN NO. | LOCATION | DRAINAGE AREA (km²) | DISCHARGE (lps) | | WATER QUALITY SAMPLING POINT | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | | | | | DRY | WET | | |
| R-1 | Dasmarinas | 4 | Bucal, Dasmarinas | 9.4 | 123.7 | 269.9 | N | |
| R-2 | Ilang-Ilang | 4 | San Francisco, General Trias | 30.4 | 88.0 | 38.3 | N | Diversion Channel |
| R-3 | Ilang-Ilang | 4 | San Jose, Dasmarinas | 53.1 | 10.0 | 171.9 | Y | |
| R-4 | Ilang-Ilang | 4 | Alapan, Imus | 60.0 | 35.6 | 69.7 | N | |
| R-5 | Dasmariñas | 4 | Fiesta Subd., San Jose, Dasmariñas | 12.2 | 182.0 | 421.5 | N | Kasundu Dam |
| R-6 | Pasong Camachile | 4 | Pasong Camachile, General Trias | 12.2 | 49.5 | 388.9 | N | Pasong Camachile Dam |
| R-7 | Rio Grande | 4 | Prinza, General Trias | 50.4 | 157.4 | 557.9 | N | Bayan Dam |
| R-8 | Rio Grande | 4 | Buenavista, General Trias | 38.9 | 544.3 | 969.6 | Y | |
| R-9 | Panaysayan | 3 | Pasong Cawayan II, General Trias | 29.0 | 78.2 | 212.1 | Y | BRS Gaging Station |
| R-10 | Cañas | 3 | Pasong Cawayan II, General Trias | 56.8 | 233.7 | 56.9 | N | |
| R-11 | Cañas | 3 | Pasong Cawayan II, General Trias | 5.7 | 30.5 | 75.2 | N | |
| R-12 | Palubluban | 3 | Pinagtipunan, General Trias | 101.1 | 346.1 | 362.0 | N | Placenta Dam |
| R-13 | Balsahan | 2 | Palangui, Naic | 22.0 | 115.6 | 94.5 | N | BRS Gaging Station |
| R-14 | Balsahan | 2 | Calumpang Lejos, Indang | 18.7 | 638.6 | 808.6 | Y | Culong-Culong Dam |
| R-15 | Alemang | 2 | Sabang, Naic | 46.3 | 381.5 | 712.3 | N | Sahing Dam |
| R-16 | Maragondon | 1 | Mabacao, Maragondon | 109.2 | 1037.9 | 4091.2 | Y | |
| R-17 | Maragondon | 1 | Pantijan, Maragondon | 99.5 | 1496.4 | 2393.7 | N | |
| R-18 | Maragondon | 1 | Bucal, Maragondon | 260.0 | 1380.9 | 4853.4 | Y | BRS Gaging Station |
| R-19 | Biñan | 6 | Timbao, Carmona | 12.7 | 12.8 | 137.5 | N | |
| R-20 | Biñan | 6 | Lantic, Carmona | 9.5 | 13.0 | 31.2 | Y | |
| R-21 | Biñan | 6 | Lantic, Carmona | 3.8 | 11.4 | 49.3 | N | |
| R-22 | Biñan | 6 | Mabuhay, Carmona | 20.5 | 8.6 | 131.4 | N | |
| R-23 | Imus | 5 | Salitran III, Dasmariñas | 32.3 | 67.1 | 407.6 | Y | Salitran Dam |
| R-24 | Baluctot | 5 | Salawag, Dasmari,,as | 9.6 | 16.0 | 402.8 | N | |
| R-25 | Imus | 5 | Anabu Segunda, Imus | 50.7 | 50.7 | 810.4 | N | |
| R-26 | Unknown Creek | 7 | Caloocan, Talisay | 9.4 | 38.3 | 73.2 | N | |
| R-27 | Bubutong | 7 | Leviste, Laurel | 2.1 | 76.0 | 78.6 | N | Diversion Dam |
| R-28 | Pata Creek | 7 | Pata, Laurel | 5.9 | 16.6 | 26.2 | N | |
| R-29 | Benirayan Creek | 7 | Benirayan, Talisay | 3.7 | 11.7 | 14.4 | N | |
| R-30 | Caloocan | 7 | Sampaloc, Talisay | 1.8 | 11.9 | 25.3 | N | |
| R-31 | Hasaan Creek | 5 | San Francisco, General Trias | 9.1 | 0.0 | 504.5 | N | Hasaan Dam |
| R-32 | Ilang-Ilang | 4 | San Francisco, General Trias | 9.3 | 0.0 | 212.7 | N | |
| R-33 | Imus | 5 | San Manuel, Dasmariñas | 28.7 | 0.0 | 465.3 | N | Justo Dam |




| CAVITE WATER SUPPLY DEVELOPMENT STUDY | Fig. 4.2-2(A) |
|---|---|
| JAPAN INTERNATIONAL COOPERATION AGENCY | FLOW SCHEME OF MARAGONDON RIVER BASIN |




| CAVITE WATER SUPPLY DEVELOPMENT STUDY | Fig. 4.2-2(B) |
|---|---|
| JAPAN INTERNATIONAL COOPERATION AGENCY | FLOW SCHEME OF LABAC RIVER BASIN |

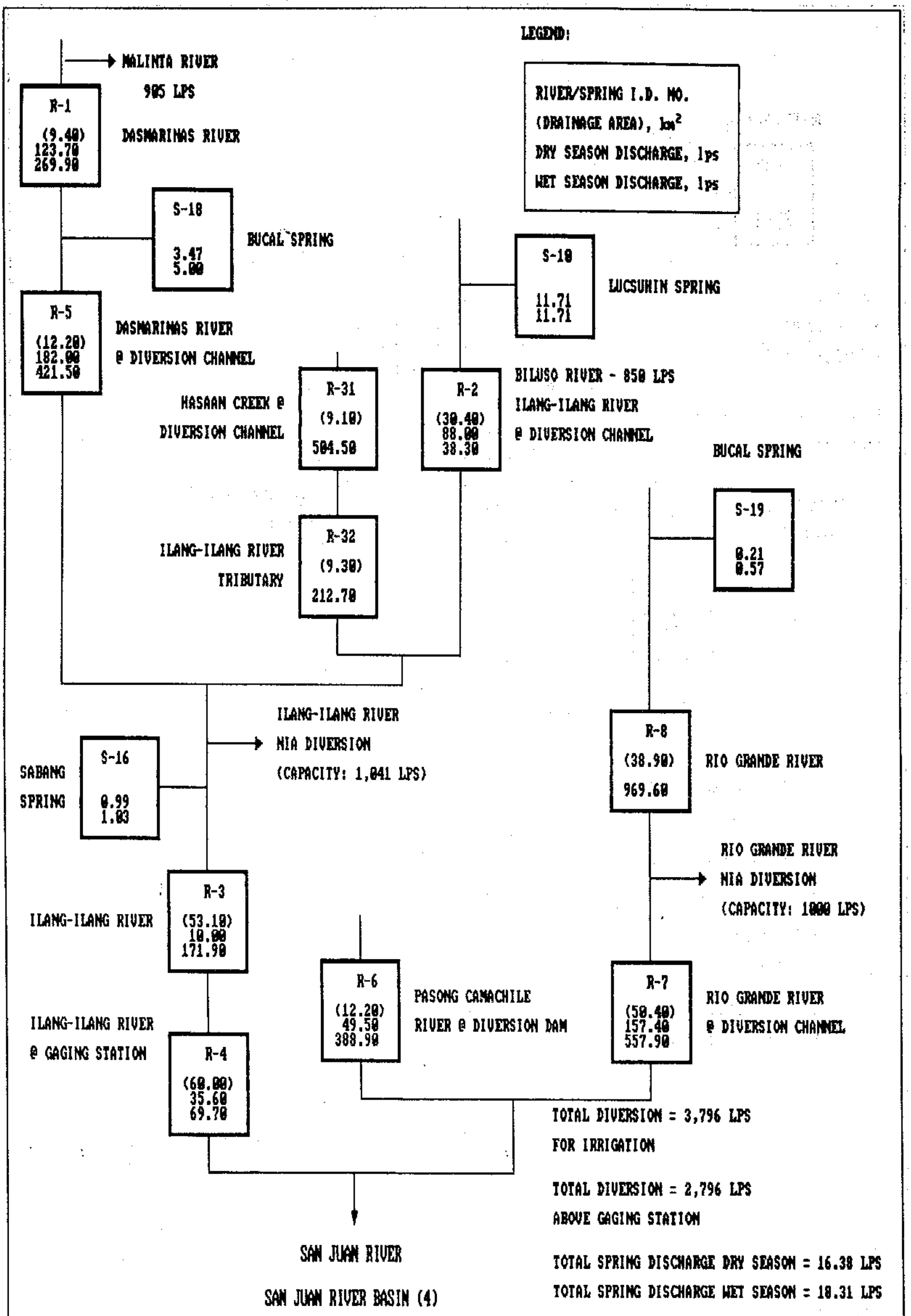



CAVITE WATER SUPPLY DEVELOPMENT STUDY

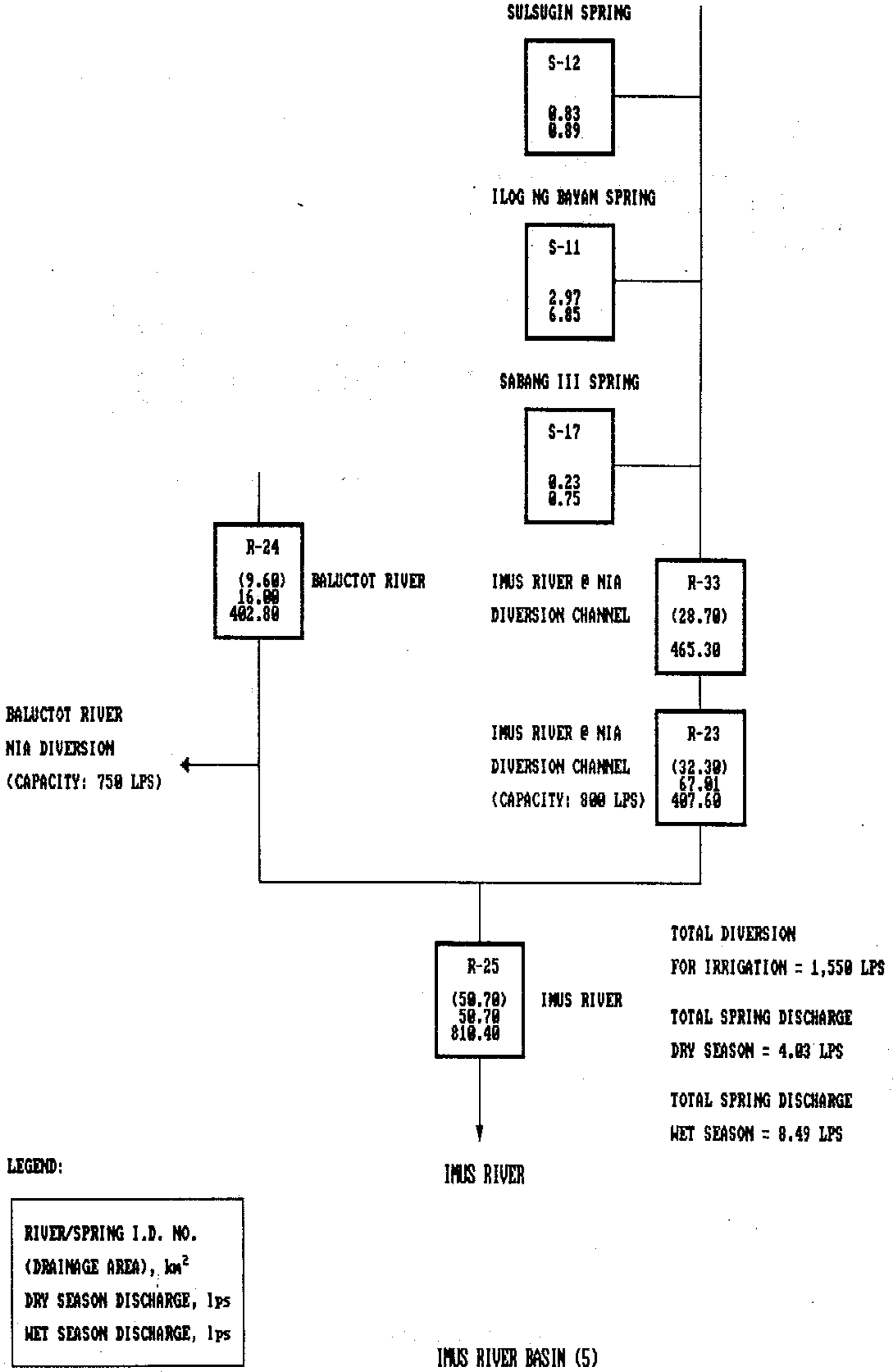
JAPAN INTERNATIONAL COOPERATION AGENCY

**Fig. 4.2-2(C)**

**FLOW SCHEME OF CAÑAS RIVER BASIN**

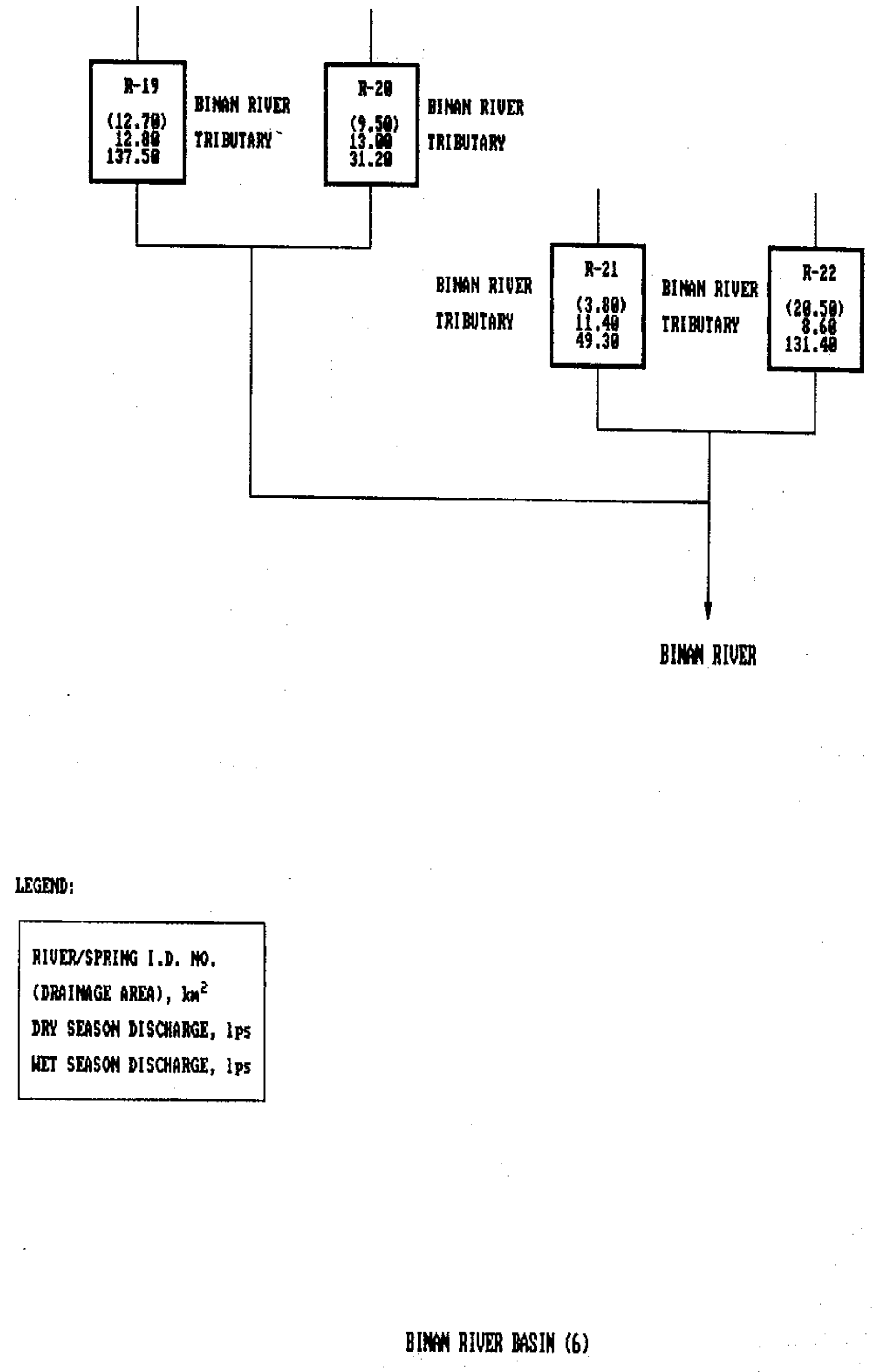



| CAVITE WATER SUPPLY DEVELOPMENT STUDY | **Fig. 4.2-2(D)** |
|---|---|
| JAPAN INTERNATIONAL COOPERATION AGENCY | **FLOW SCHEME OF SAN JUAN RIVER BASIN** |

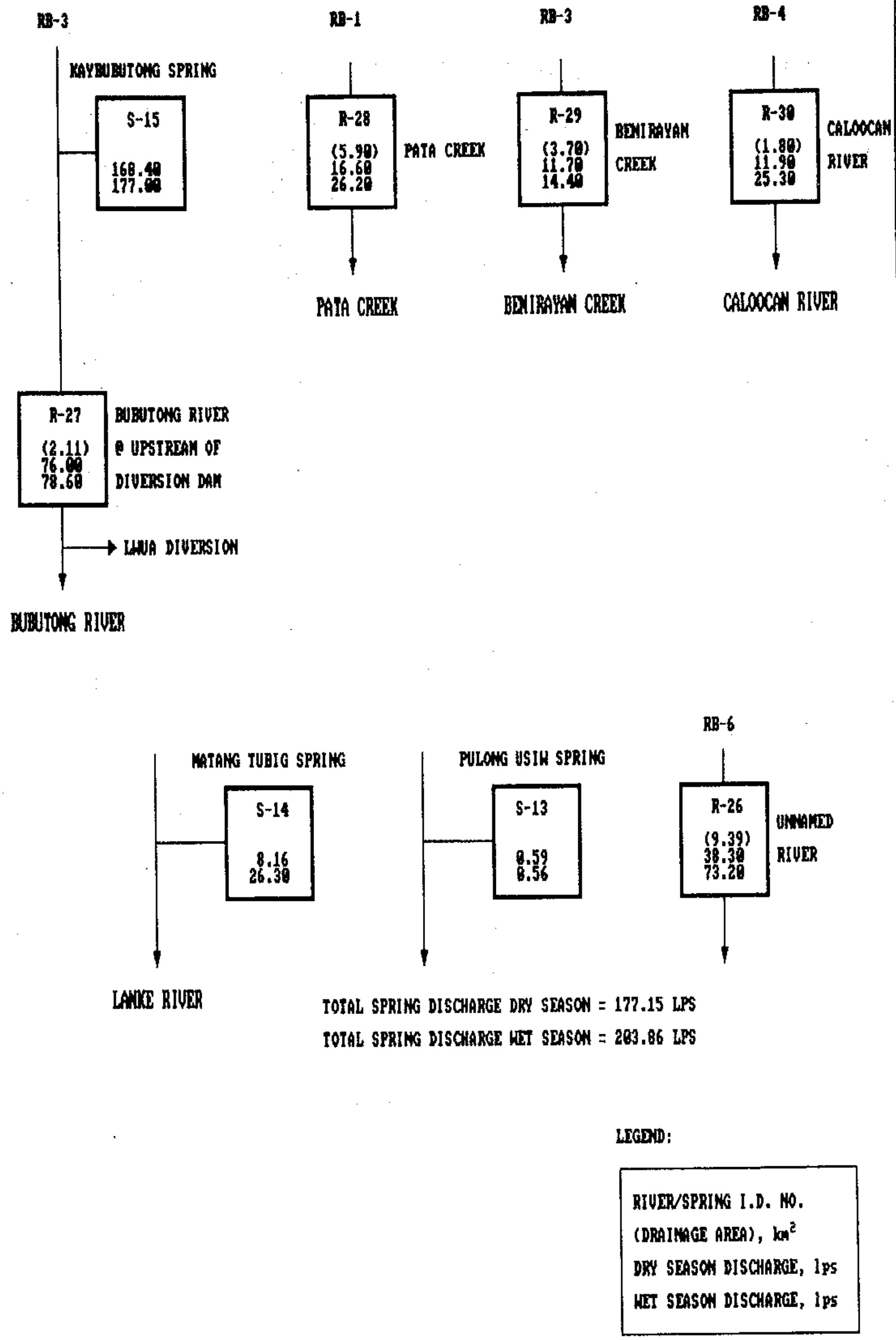



IMUS RIVER BASIN (5)

| CAVITE WATER SUPPLY DEVELOPMENT STUDY | Fig. 4.2-2(E) |
| --- | --- |
| JAPAN INTERNATIONAL COOPERATION AGENCY | FLOW SCHEME OF IMUS RIVER BASIN |




| CAVITE WATER SUPPLY DEVELOPMENT STUDY | Fig. 4.2-2(F) |
|---|---|
| JAPAN INTERNATIONAL COOPERATION AGENCY | FLOW SCHEME OF BIÑAN RIVER BASIN |




| | |
|---|---|
| **CAVITE WATER SUPPLY DEVELOPMENT STUDY** | **Fig. 4.2-2(G)** |
| JAPAN INTERNATIONAL COOPERATION AGENCY | **FLOW SCHEMES OF RIVER SYSTEMS BELOW TAGAYTAY RIDGE ON BATANGAS SIDE** |

Table 4.2-4 SURFACE RUNOFF ESTIMATES BY RIVER BASIN

| River Basin | MARAGONDON | LABAC | CAÑAS | SAN JUAN |
|---|---|---|---|---|
| River | Maragondon | Balsahan | Panaysayan | Ilang-Ilang |
| Drainage Area | 260 km^2 | 22 km^2 | 29 km^2 | 60 km^2 |
| | (mm) | (mm) | (mm) | (mm) |
| JAN | 27.1 | 31.7 | 17.5 | 20.8 |
| FEB | 26.8 | 13.2 | 12.5 | 29.6 |
| MAR | 25.5 | 11.0 | 18.5 | 399.4 |
| APR | 22.3 | 8.2 | 17.9 | 166.6 |
| MAY | 98.1 | 67.0 | 24.9 | 24.9 |
| JUN | 149.2 | 205.0 | 139.4 | 492.6 |
| JUL | 237.3 | 438.3 | 215.2 | 53.4 |
| AUG | 474.2 | 303.1 | 234.6 | 44.1 |
| SEP | 283.5 | 453.6 | 241.3 | 23.3 |
| OCT | 180.8 | 174.1 | 106.2 | 16.6 |
| NOV | 141.1 | 180.3 | 37.5 | 17.2 |
| DEC | 87.9 | 63.3 | 24.0 | 11.9 |
| ANNUAL, mm | 1753.8 | 1948.8 | 1089.5 | 1300.4 |
| MEAN, mm | 146.15 | 162.40 | 90.79 | 108.37 |
| Irrigation Diversion, mm | 79.8 | 0.00 | 470.00 | 0.00 |
| TOTAL RUNOFF, mm | 1234.8 | 1571.10 | 1182.70 | 991.00 |
| BASEFLOW, mm | 598.8 | 377.7 | 376.8 | 309.4 |
| SURFACE RUNOFF, mm | 636.00 | 1193.40 | 805.90 | 681.60 |

Unit: x $10^6$ cum

| Type of User | Annual amount |
|---|---|
| Domestic | 18.089 |
| Commercial | 2.909 |
| Institutional | 0.436 |
| Industrial | 6.993 |
| Agricultural (Irrigation) | 145.000 |
| Total | 173.427 |

As for domestic use, the amount is calculated based on the estimated 1993-population and the unit consumption rate by level (I, II and III) of water supply facilities. Commercial (including cottage and small-scale industries) and institutional uses are estimated using the connection density ratio method. Industrial water use is estimated based on information gathered directly from interviews made in the industrial estates and in the local government units. Agricultural water use is calculated using the data supplied by NIA, i.e. the irrigable land area within the Study Area, and the pattern of water requirement shown in THE MASTER PLAN STUDY ON THE PROJECT CALABARZON (JICA, 1991).

**Table 4.2-5** and **Table 4.2.6** show the details of domestic and industrial water use respectively, and **Table 4.2-7** summarizes the amount of water use by type of user in the Study Area and by municipality or city.

Using the results of the well inventory survey and the pumping discharge survey, the present annual groundwater withdrawals in the Study Area and in each river basin were estimated. **Table 4.2-8** shows an annual total pumpage of 32.573 x $10^6$ cum for the Study Area, and 53.724 x $10^6$ cum for the water balance area. Among the six (6) river basins considered for water balance analysis, San Juan River Basin and Imus River Basin have the highest groundwater withdrawal of 12.221 x $10^6$ cum and 11.657 x $10^6$ cum, respectively. The total pumpage in the six (6) river basins is 31.415 x $10^6$ cum within the Study Area and 52.464 x $10^6$ cum within the water balance area.

## 4.3 GROUNDWATER LEVEL AND GROUNDWATER POTENTIAL

### 4.3.1 Estimation for the Whole Study Area

**Table 4.3-1** arranges the results of simultaneous groundwater level measurements for dry and wet seasons. **Figs. 4.3-1** and **4.3-2** show the groundwater level distributions in dry and wet seasons, respectively.

The groundwater level contours show steep to flat gradient reflecting the general topography of the Study Area. Groundwater gradient around or near Tagaytay Ridge is steeper, and it becomes flat towards the lower reach near Manila Bay.

Table 4.2-5 ESTIMATED DOMESTIC WATER USE BY WATER SUPPLY LEVEL BY MUNICIPALITY IN1993

Unit: 1000 cum

| No. | City/Municipality | Total Demand | Level I Demand | Level I % | Level II Demand | Level II % | Level III Demand | Level III % | Doubtful Sources Demand | Doubtful Sources % |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Dasmarinas | 6,142 | 136 | 2.2 | 519 | 8.5 | 5,486 | 89.3 | 0 | 0.0 |
| 2 | Indang | 1,038 | 19 | 1.8 | 618 | 59.6 | 401 | 38.6 | 0 | 0.0 |
| 3 | G. M. A. | 1,921 | 32 | 1.7 | 954 | 49.7 | 935 | 48.7 | 0 | 0.0 |
| 4 | Mendez | 465 | 70 | 15.1 | 62 | 13.2 | 334 | 71.7 | 0 | 0.0 |
| 5 | Silang | 2,530 | 202 | 8.0 | 912 | 36.0 | 1,370 | 54.1 | 47 | 1.8 |
| 6 | Tanza | 711 | 632 | 88.9 | 0 | 0.0 | 0 | 0.0 | 79 | 11.1 |
| 7 | Tagaytay City | 911 | 8 | 0.8 | 27 | 2.9 | 856 | 93.9 | 21 | 2.3 |
| 8 | Amadeo | 509 | 110 | 21.6 | 67 | 13.1 | 330 | 64.9 | 2 | 0.4 |
| 9 | Magallanes | 212 | 48 | 22.7 | 142 | 67.1 | 0 | 0.0 | 22 | 10.2 |
| 10 | Maragondon | 461 | 168 | 36.4 | 0 | 0.0 | 285 | 61.8 | 8 | 1.8 |
| 11 | Ternate | 132 | 132 | 100.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 12 | Alfonso | 853 | 59 | 6.9 | 214 | 25.0 | 578 | 67.8 | 2 | 0.3 |
| 13 | Naic | 669 | 539 | 80.5 | 50 | 7.4 | 81 | 12.1 | 0 | 0.0 |
| 14 | Gen. Aguinaldo | 231 | 48 | 21.0 | 79 | 34.4 | 100 | 43.4 | 3 | 1.2 |
| 15 | Carmona | 329 | 327 | 99.2 | 0 | 0.0 | 0 | 0.0 | 3 | 0.8 |
| 16 | Trece Martirez City | 348 | 118 | 34.0 | 61 | 17.7 | 168 | 48.4 | 0 | 0.0 |
| 17 | Gen. Trias | 625 | 587 | 93.9 | 0 | 0.0 | 38 | 6.1 | 0 | 0.0 |
| | Study Area Total | 18,089 | 3,235 | 17.9 | 3,705 | 20.5 | 10,962 | 60.6 | 187 | 1.0 |

Source: JICA Study Team

Note: Unit water consumption; 30 lpcd for Level I and doubtful sources, 60 lpcd for Level II and 110 lpcd for Level III

Table 4.2-6 INDUSTRIAL WATER USE IN 1993

| No. | Name of Industrial Estate | Location | Number of Industries | Estimated Water Demand x1000cum/year |
|---|---|---|---|---|
| 1 | Gateway Business Park | Gen. Trias | 2 | 180 |
| 2 | First Cavite Industrial Estate | Dasmarinas | 21 | 364 |
| 3 | Dasmarinas Bagong Bayan-NHA Industrial Estate | Dasmarinas | 4 | 182 |
| 4 | G. M. A.-NHA Industrial Estate | G. M. A. | 3 | 59 |
| 5 | Cavite-Carmona Industrial Estate (PTC) | Carmona | 46 | 432 |
| 6 | New Cavite Industrial Center | Gen. Trias | 5 | 17 |
| 7 | First Cityland Heavy Industrial Center | Dasmarinas | 3 | 7 |
| 8 | Bulihan-NHA Industrial Estate | Silang | 4 | 55 |
| 9 | Cavite Export Processing Zone (CEPZ) | Gen. Trias/Rosario | 6 *1) | 55 |
| 10 | Others 2) | | 97 | 5,644 |
| | Study Area Total | | 191 | 6,993 |

Source:

JICA Study Team; Basic data come from Environment Impact Assessment Report (Draft Final) for the Cavite Water Supply Development Study in November 1994 and interviews to the industrial estates and municipalities.

Notes:

1) Industries located in Gen. Trias Municipality
2) Major industries which are located outside the industrial estates shown above in the Study Area

Table 4.2-7 ESTIMATED WATER USE IN THE STUDY AREA BY MUNICIPALITY IN 1993

Unit: 1000 cum

| No. | City/Municipality | Population | Domestic | | Commercial *1) | | Institutional | | Industrial *2) | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (Person) | Consumption | (%) | Consumption | (%) | Consumption | (%) | Consumption | (%) | |
| 1 | Dasmarinas | 182,550 | 6,142 | 64.9 | 666 | 7.0 | 100 | 1.1 | 2,556 | 27.0 | 9,464 |
| 2 | Indang | 42,204 | 1,038 | 85.4 | 154 | 12.7 | 23 | 1.9 | | 0.0 | 1,216 |
| 3 | G. M. A. | 73,703 | 1,921 | 51.5 | 269 | 7.2 | 40 | 1.1 | 1,499 | 40.2 | 3,730 |
| 4 | Mendez | 18,518 | 465 | 85.7 | 68 | 12.4 | 10 | 1.9 | | 0.0 | 543 |
| 5 | Silang | 103,990 | 2,530 | 80.4 | 380 | 12.1 | 57 | 1.8 | 181 | 5.8 | 3,148 |
| 6 | Tanza | 68,542 | 711 | 56.0 | 250 | 19.7 | 38 | 3.0 | 271 | 21.4 | 1,269 |
| 7 | Tagaytay City | 26,565 | 911 | 80.2 | 97 | 8.5 | 15 | 1.3 | 113 | 10.0 | 1,136 |
| 8 | Amadeo | 22,718 | 509 | 84.2 | 83 | 13.7 | 12 | 2.1 | | 0.0 | 605 |
| 9 | Magallanes | 13,569 | 212 | 70.0 | 50 | 16.4 | 7 | 2.5 | 34 | 11.2 | 303 |
| 10 | Maragondon | 24,489 | 461 | 81.8 | 89 | 15.9 | 13 | 2.4 | | 0.0 | 564 |
| 11 | Ternate | 12,748 | 132 | 71.2 | 47 | 25.1 | 7 | 3.8 | | 0.0 | 186 |
| 12 | Alfonso | 31,435 | 853 | 77.3 | 115 | 10.4 | 17 | 1.6 | 118 | 10.7 | 1,103 |
| 13 | Naic | 56,482 | 669 | 72.6 | 206 | 22.4 | 31 | 3.4 | 16 | 1.7 | 922 |
| 14 | Gen. Aguinaldo | 11,407 | 231 | 82.8 | 42 | 14.9 | 6 | 2.2 | | 0.0 | 279 |
| 15 | Carmona | 31,765 | 329 | 26.2 | 116 | 9.2 | 17 | 1.4 | 794 | 63.2 | 1,257 |
| 16 | Trece Martirez City | 18,799 | 348 | 26.6 | 69 | 5.2 | 10 | 0.8 | 881 | 67.3 | 1,308 |
| 17 | Gen. Trias | 57,624 | 625 | 44.7 | 210 | 15.0 | 32 | 2.3 | 530 | 38.0 | 1,398 |
| | Study Area Total | 797,108 | 18,089 | 63.6 | 2,909 | 10.2 | 436 | 1.5 | 6,993 | 24.6 | 28,428 |

Source: JICA Study Team

Notes:

1) Including small industries based on LWUA methodology manual

2) Large water users

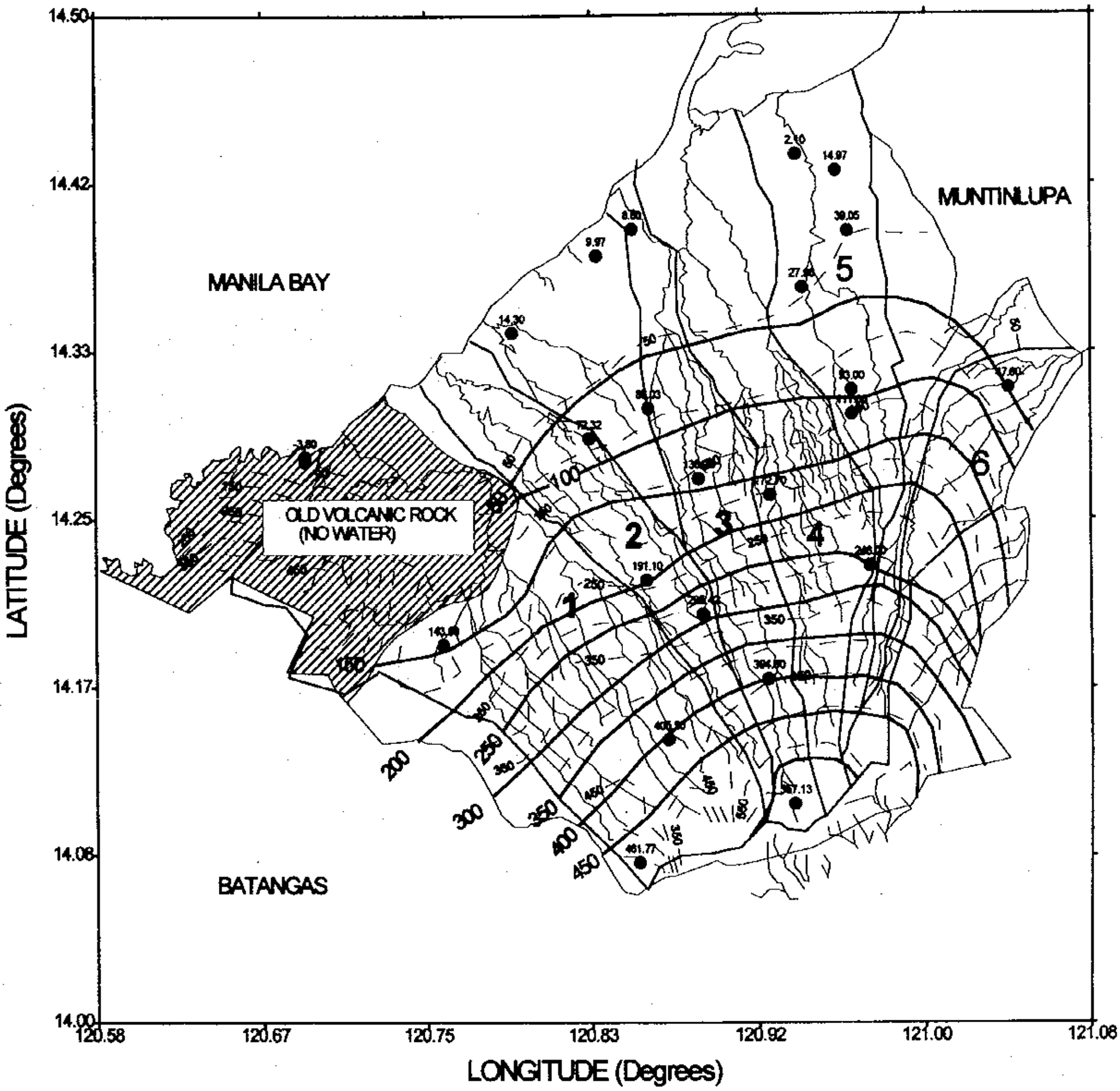
Table 4.2-8 PRESENT GROUNDWATER PUMPAGE (MCM/YEAR) BY TYPE OF USE AND BY RIVER BASIN

| GROUNDWATER USE | WITHIN STUDY AREA | WITHIN WATER BALANCE AREA |
|---|---|---|
| Domestic | 18.09 | 32.298 |
| Institutional | 0.436 | 0.436 |
| Commercial | 2.909 | 3.345 |
| Agricultural | 4.144 | 4.896 |
| Industrial | 6.993 | 12.748 |
| TOTAL | 32.573 | 53.724 |

| RIVER BASIN | WITHIN STUDY AREA | WITHIN WATER BALANCE AREA |
|---|---|---|
| Maragondon | 1.155 | 1.155 |
| Labac | 0.32 | 0.32 |
| Canas | 0.782 | 4.574 |
| San Juan | 12.221 | 20.153 |
| Imus | 11.057 | 20.383 |
| Binan | 5.879 | 5.879 |
| TOTAL | 31.415 | 52.464 |

Table 4.3-1 RESULTS OF SIMULTANEOUS GROUNDWATER LEVEL MEASUREMENT FOR DRY AND WET SEASONS

| I.D. NO. | WELL INVENTORY NO. | LATITUDE | LONGITUDE | RIVER BASIN NO. | LOCATION | GROUND ELEV. (masl) | WELL DEPTH (m) | GW_DEPTH (mbgs) | | GW_ELEV. (masl) | | WATER QUALITY SAMPLING POINT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | DRY | WET | DRY | WET | |
| 01 | SIL-130 | 14 13 37 | 120 58 19 | 4 | Poblacion, Silang PS #1 | 317 | 188.00 | 71.00 | 72.68 | 246.00 | 244.32 | Y |
| 02 | | 14 18 49 | 120 57 47 | 5 | San Luis, Dasmariñas PS#6 | 130 | | 36.20 | 36.45 | 93.00 | 93.55 | Y |
| 03 | GEN-162 | 14 17 30 | 120 00 16 | 6 | Teacher's Village,GMA #1 | 180 | 213.41 | | | | | Y |
| 04 | MEN-142 | 14 07 32 | 120 54 08 | 1 | Payapa Mendez | 522 | 243.90 | | | | | Y |
| 05 | TRE-140 | 14 16 12 | 120 53 13 | 3 | Trece Martirez | 168 | 242.00 | 29.80 | 23.60 | 138.20 | 144.40 | Y |
| 06 | TAN-94 | 14 23 39 | 120 51 13 | 3 | Poblacion, Tanza | 13 | 115.00 | 4.40 | 5.13 | 8.60 | 7.87 | Y |
| 07 | | 14 16 32 | 120 44 03 | 1 | Poblacion, Maragondon | 20 | 33.84 | | | | | Y |
| 08 | | 14 10 14 | 120 55 14 | 3 | Poblacion, Amadeo | 452 | 73.17 | 57.40 | 45.23 | 394.60 | 406.77 | Y |
| 09 | | 14 16 53 | 120 41 17 | 1 | Camandag, Puerto Azul | 20 | 92.00 | 23.80 | 22.70 | -3.80 | -2.70 | Y |
| 10 | TAN-139 | 14 17 23 | 120 49 55 | 7 | Tanauan, Tanza | 90 | 122.00 | 17.68 | 19.40 | 72.32 | 70.60 | Y |
| 11 | | 14 13 12 | 120 51 38 | 2 | Agos-os, Indang | 223 | 76.22 | 31.90 | 31.25 | 191.10 | 191.75 | Y |
| 12 | | 14 08 26 | 120 52 18 | 1 | Guyam na Munti, Indang | 447 | 91.46 | 41.50 | 40.15 | 405.50 | 406.85 | Y |
| 13 | | 14 12 12 | 120 53 23 | 2 | Alulod, Indang | 318 | 33.54 | 22.58 | 20.43 | 295.42 | 297.57 | Y |
| 14 | ALF-167 | 14 04 48 | 120 51 25 | 1 | Esperanza, Alfonzo | 363 | 240.00 | 101.23 | 93.50 | 461.77 | 469.50 | Y |
| 15 | TAG-143 | 14 06 34 | 120 56 01 | 4 | Tagaytay City | 652 | 213.41 | 67.87 | 65.00 | 557.13 | 560.00 | Y |
| 16 | | 14 09 03 | 120 59 14 | 7 | Ulat, Silang | 510 | 157.00 | | | | | Y |
| 17 | | 14 18 19 | 120 51 45 | 7 | De Ocampo, Trece Martirez City | 105 | 121.95 | 18.97 | 17.40 | 86.03 | 87.60 | Y |
| 18 | CAR-160 | 14 18 53 | 121 02 31 | 6 | Mla. Southwoods, Carmona | 60 | 250.00 | 12.40 | 9.32 | 47.60 | 50.68 | Y |
| 19 | TRI-10 | 14 15 45 | 120 55 21 | 4 | Javalera, Gen. Trias | 210 | 200.00 | 37.30 | 36.30 | 172.70 | 173.70 | Y |
| 20 | | 14 11 17 | 120 45 27 | 1 | Poblacion, Magallanes | 172 | 51.83 | 28.10 | 25.20 | 143.90 | 146.80 | Y |
| 21 | | 14 25 52 | 120 56 07 | 5 | Poblacion, Imus | 8 | 121.95 | 5.90 | 3.83 | 2.10 | 4.17 | N |
| 22 | | 14 21 55 | 120 56 17 | 5 | Anabu II, Imus | 38 | 121.95 | 10.02 | 10.38 | 27.98 | 27.62 | N |
| 23 | | 14 25 24 | 120 57 18 | 5 | Vista Verde, Bacoor | 20 | | 5.03 | 4.93 | 14.97 | 15.07 | N |
| 24 | | 14 22 53 | 120 50 09 | 7 | Amaya, Tanza | 15 | | 4.28 | 8.33 | 10.72 | 6.67 | N |
| 25 | | 14 23 55 | 120 57 41 | 5 | Molino, Bacoor | 55 | 182.93 | 15.95 | 12.95 | 39.05 | 42.05 | N |
| 26 | | 14 18 06 | 120 57 48 | 5 | St. Charbel, Dasmariñas | 157 | 152.00 | 46.00 | 46.93 | 111.00 | 110.07 | N |
| 27 | | 14 20 34 | 120 47 34 | 7 | Timalan, Naic | 20 | | 5.70 | 5.10 | 14.30 | 14.90 | N |
| 28 | | 14 07 34 | 120 59 32 | 7 | Sungay, Tagaytay City | 578 | 140.24 | | | | | N |
| 29 | | 14 18 49 | 121 01 08 | 6 | Area-D, GMA | 100 | 120.00 | | | | | N |
| 30 | | 14 08 07 | 121 00 05 | 7 | Iruhin, Tagaytay City | 620 | | | | | | N |



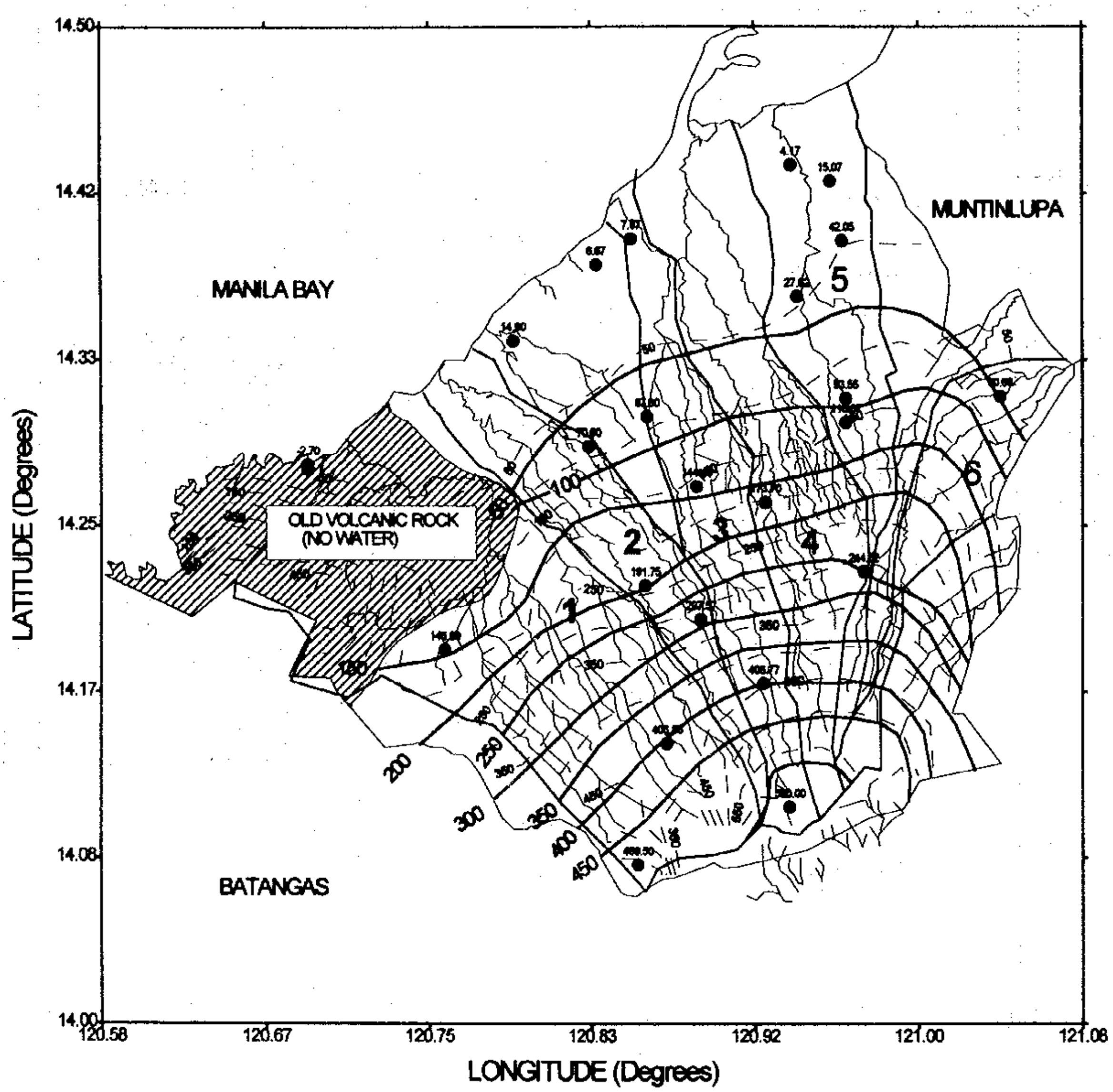

**MAJOR RIVER BASIN**

1 MARAGONDON RIVER BASIN
2 LABAC RIVER BASIN
3 CAÑAS RIVER BASIN
4 SAN JUAN RIVER BASIN
5 IMUS RIVER BASIN
6 BIÑAN RIVER BASIN

**LEGEND:**

| | |
|---|---|
| -- 100 -- | TOPOGRAPHIC ELEVATION (Masl) |
| —— 100 —— | GROUNDWATER LEVEL ELEVATION (Masl) |
| ////////// | OLD VOLCANIC ROCK |

| | |
|---|---|
| **CAVITE WATER SUPPLY DEVELOPMENT STUDY** | **Fig. 4.3-1** |
| JAPAN INTERNATIONAL COOPERATION AGENCY | **DRY SEASON GROUNDWATER LEVEL** |




**MAJOR RIVER BASIN**

1 MARAGONDON RIVER BASIN
2 LABAC RIVER BASIN
3 CAÑAS RIVER BASIN
4 SAN JUAN RIVER BASIN
5 IMUS RIVER BASIN
6 BIÑAN RIVER BASIN

**LEGEND:**

-- 100 -- TOPOGRAPHIC ELEVATION (Masl)
— 100 — GROUNDWATER LEVEL ELEVATION (Masl)
OLD VOLCANIC ROCK

| CAVITE WATER SUPPLY DEVELOPMENT STUDY | Fig. 4.3-2 WET SEASON GROUNDWATER LEVEL |
|---|---|
| JAPAN INTERNATIONAL COOPERATION AGENCY | |

The measured static water level varies from more than 450 above MSL as in Tagaytay, Mendez and Alfonso to less than 50 m above MSL as in Tanza, Maragondon, Ternate and Carmona. Lowest measured static water level was 3.8 m below MSL in Ternate.

In general, groundwater moves in the northeast direction from Tagaytay Ridge towards Laguna Lake and north, northwest direction towards Manila Bay.

In **Fig. 4.3-3** the year-1994 fluctuation of groundwater levels between wet and dry seasons indicates a rise of about 7.5 meters in the south sector in Alfonso. In Silang, Dasmarinas, Tanza and Imus, groundwater level was continuously declining due to pumping.

The average annual water balance for the whole Study Area is presented schematically in **Fig. 4.3-4(a)**. The water balance analysis involves the calculation of direct recharge or infiltration from rainfall. As discussed in 4.2, the annual rainfall depth over the Study Area is 2,504.9 mm; annual surface runoff depth is 1,475.3 mm; actual evapotranspiration is 931.0 mm, and the groundwater discharge is 393.2 mm. Hence, the annual recharge is estimated at 98.6 mm or 3.9% of the annual rainfall.

It could also be noted that the surveyed spring discharges shown in **Table 4.2-1**, which total 579.9 lps, seem to indicate a high recharge rate upstream of these springs. Converting this discharge into depth using 158.7 $km^2$, which is the computed area above the 400-meter contour line, gives 115.2 mm. It means that 115.2 mm or 4.6% of the annual rainfall is given off by these springs. However, this amount is part of the groundwater discharge mentioned above.

Comparing the present annual groundwater use of 32.6 x $10^6$ cum as presented in **Table 4.2-8** with the estimated groundwater recharge of 113.8 x $10^6$ cum, the tentative estimate of the groundwater surplus of the Study Area is placed at 81.2 x $10^6$ cum.

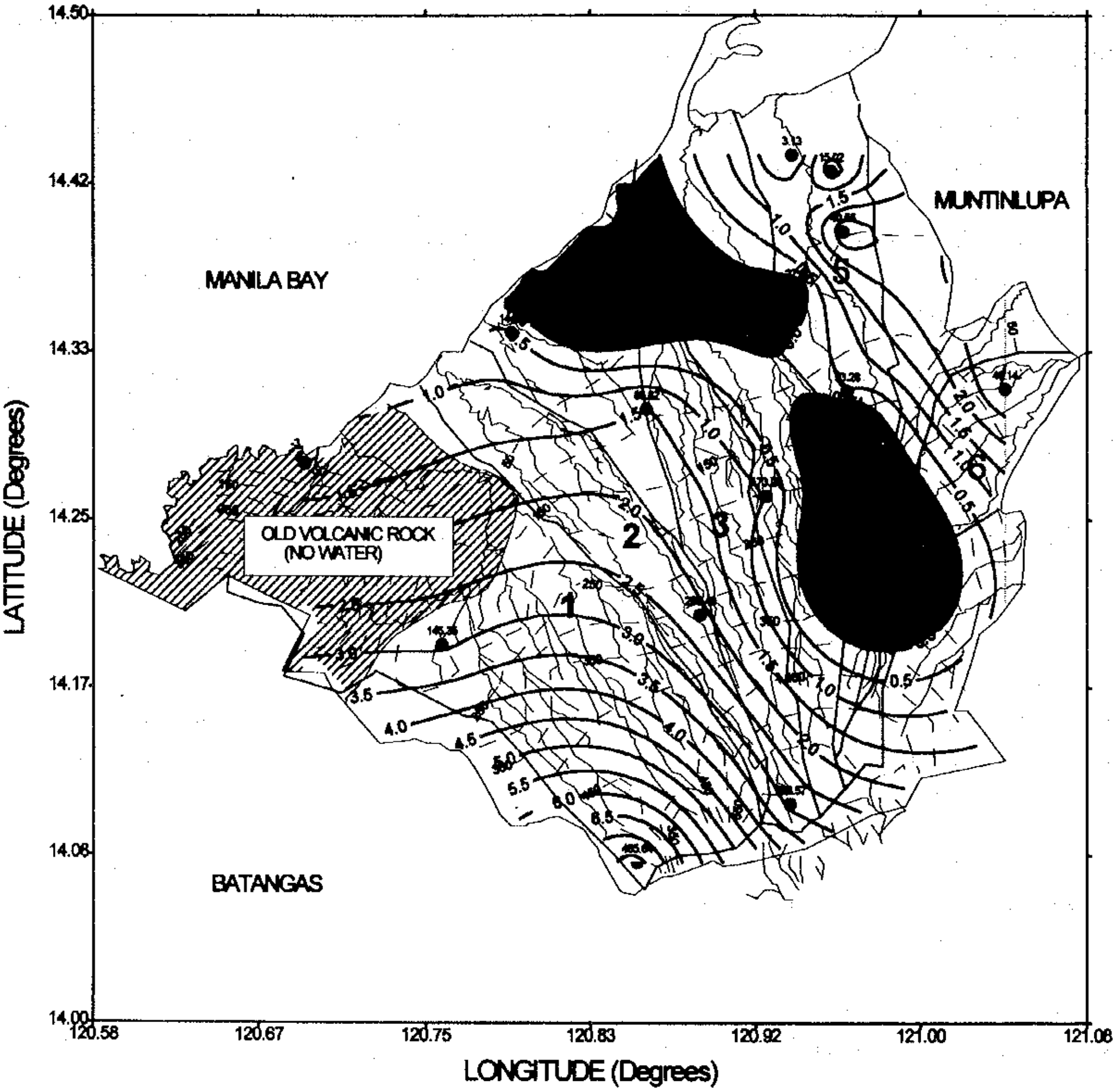
### 4.3.2 Estimation for Each River Basin

The results of annual average water balance computations are given for the following six (6) river basins.

(1) MARAGONDON RIVER BASIN

The basin has an area of 329 $km^2$. As presented schematically in **Fig. 4.3-4(b)**, the annual rainfall depth over the basin is 2,605.2 mm; the annual surface runoff depth is 1,084.4 mm; actual evapotranspiration is 929.9 mm, and the groundwater discharge is 526.0 mm. Hence, the annual recharge is estimated at 64.9 mm or 2.5% of the annual rainfall.

Comparing the present annual groundwater use of 1.2 x $10^6$ cum as presented in **Table 4.2-8** with the estimated groundwater recharge of 15.8 x $10^6$ cum, the tentative estimate of the groundwater surplus of the basin is placed at 14.6 x $10^6$ cum. It may also be noted that the measured spring discharge (15.4 x $10^6$ cum) in the basin is almost equal in magnitude to the net



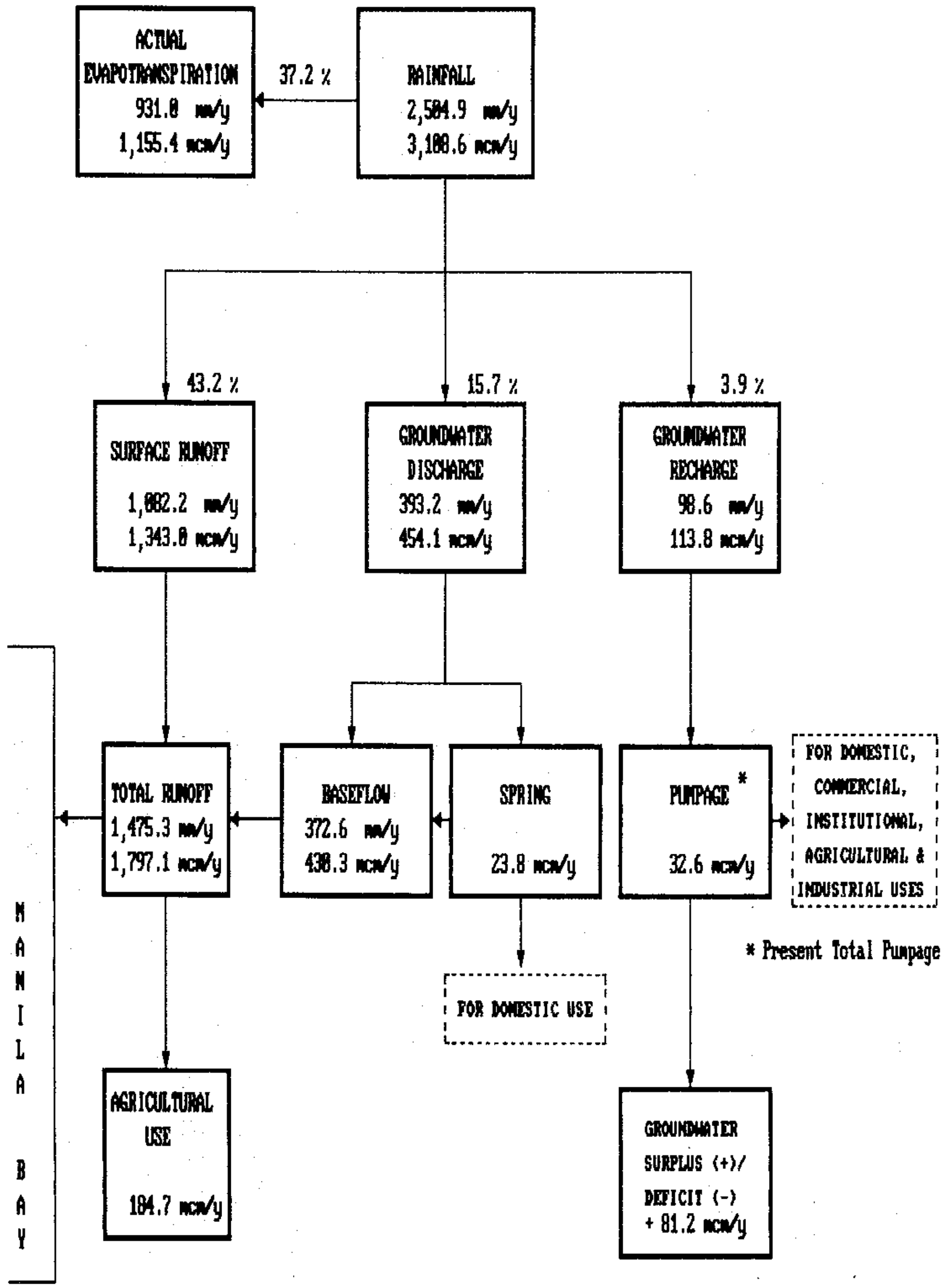

**MAJOR RIVER BASIN**

1 MARAGONDON RIVER BASIN
2 LABAC RIVER BASIN
3 CAÑAS RIVER BASIN
4 SAN JUAN RIVER BASIN
5 IMUS RIVER BASIN
6 BIÑAN RIVER BASIN

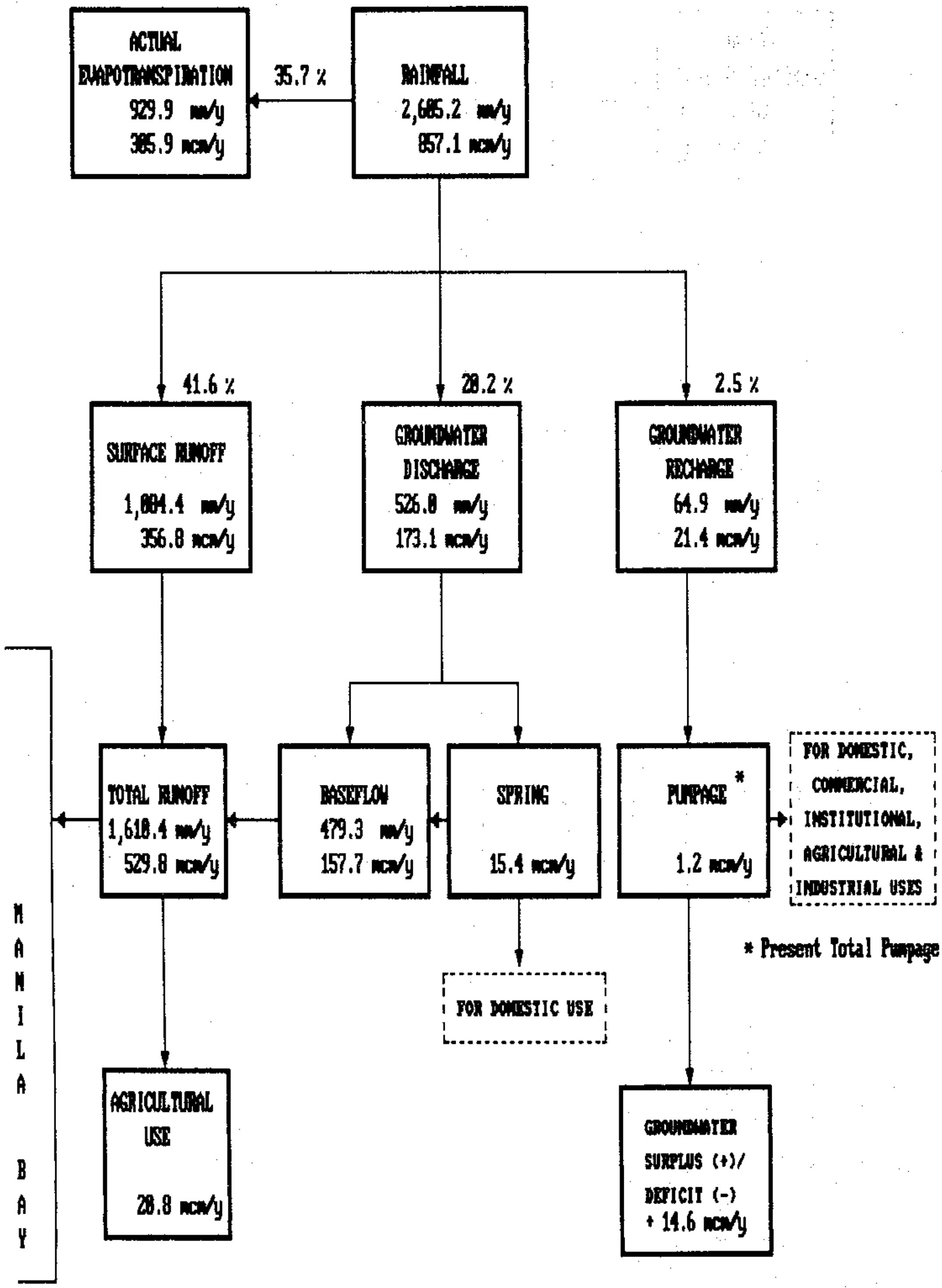
**LEGEND:**

| | |
|---|---|
| -- 100 -- | TOPOGRAPHIC ELEVATION (Masl) |
| —— 100 —— | GROUNDWATER LEVEL ELEVATION (Masl) |
| ▨ | OLD VOLCANIC ROCK |

| | |
|---|---|
| **CAVITE WATER SUPPLY DEVELOPMENT STUDY** | **Fig. 4.3-3** |
| JAPAN INTERNATIONAL COOPERATION AGENCY | **GROUNDWATER LEVEL DIFFERENCE BETWEEN WET SEASON AND DRY SEASON** |




| CAVITE WATER SUPPLY DEVELOPMENT STUDY | Fig. 4.3-4(A) |
|---|---|
| JAPAN INTERNATIONAL COOPERATION AGENCY | ANNUAL AVERAGE WATER BALANCE FOR THE STUDY |




| | |
|---|---|
| CAVITE WATER SUPPLY DEVELOPMENT STUDY | Fig. 4.3-4(B) |
| JAPAN INTERNATIONAL COOPERATION AGENCY | ANNUAL AVERAGE WATER BALANCE FOR MARAGONDON RIVER BASIN (D.A.=329 $KM^2$) |

recharge to its aquifers (15.8 x $10^6$ cum). This may offer a promising type of water supply potential coming from springs, better than the recharge to its aquifers.

(2) LABAC RIVER BASIN

The basin has an area of 106 $km^2$. The Balsahan River (22 $km^2$) is the representative sub-basin for the water balance analysis. As presented schematically in **Fig. 4.3-4(c)**, the annual rainfall depth over the basin is 2,766.2 mm; the annual surface runoff depth is 1,402.6 mm; the actual evapotranspiration is 949.5 mm, and the groundwater discharge is 337.1 mm. Hence, the annual recharge is estimated at 77.6 mm or 2.8% of the annual rainfall.

Comparing the present annual groundwater use of 0.3 x $10^6$ cum as presented in **Table 4.2-8** with the estimated groundwater recharge of 8.2 x $10^6$ cum the tentative estimate of the groundwater surplus of the basin is placed at 7.9 x $10^6$ cum.

(3) CANAS RIVER BASIN

This basin has an area of 111 $km^2$ and is represented by Panaysayan River (29 $km^2$) for the water balance analysis. As presented schematically in **Fig. 4.3-4(d)**, the annual rainfall depth over the basin is 2,699.9 mm; annual surface runoff depth is 1,231.1 mm; the actual evapotranspiration is 945.6 mm and the groundwater discharge is 392.0 mm. Hence, the annual recharge is estimated at 131.2 mm or 4.9% of the annual rainfall.

Comparing the present annual groundwater use of 4.6 x $10^6$ cum as presented in **Table 4.2-8** with the estimated groundwater recharge of 14.6 x $10^6$ cum, the tentative estimate of the groundwater surplus of the basin is placed at 10.0 x $10^6$ cum.

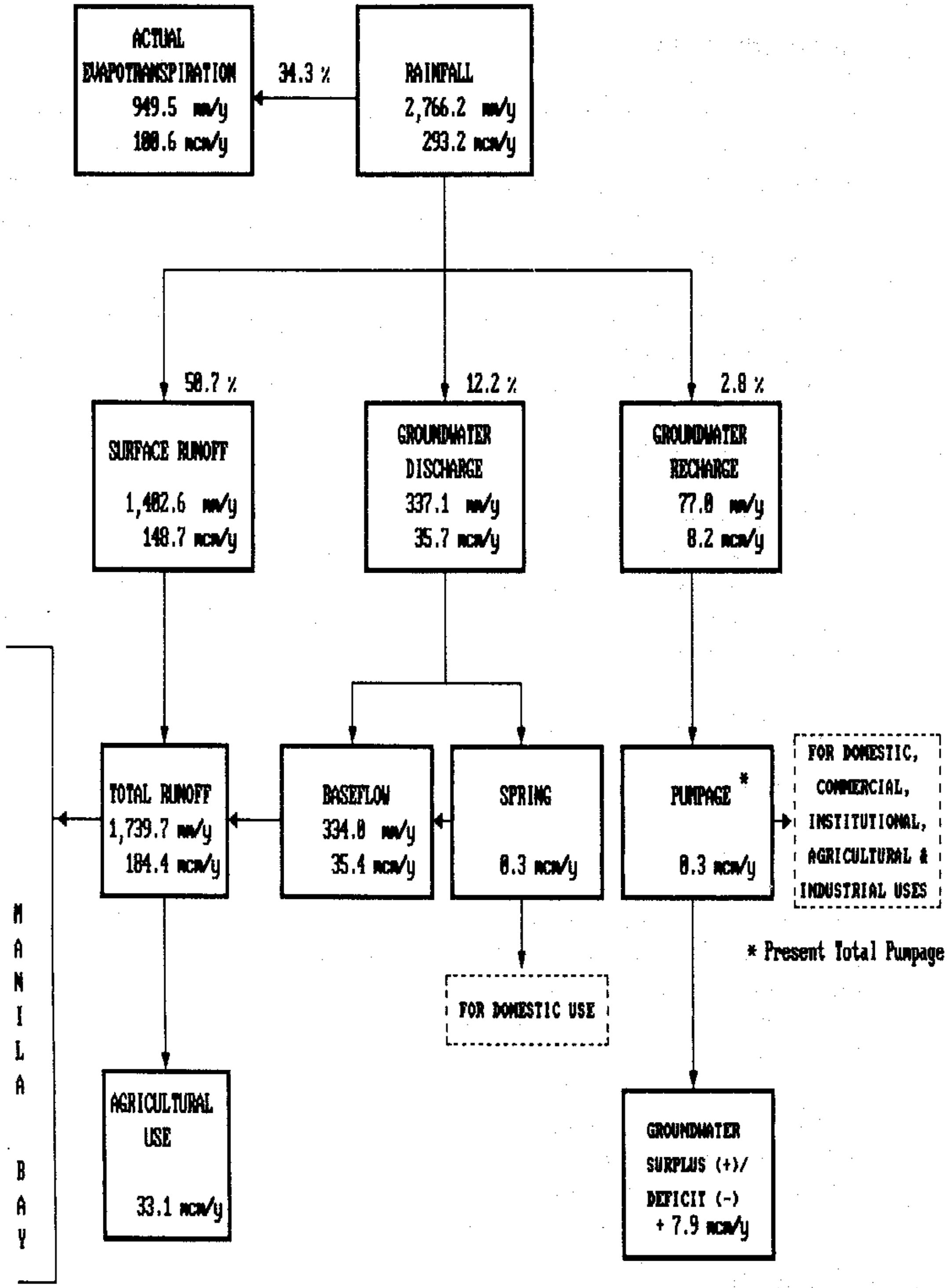
(4) SAN JUAN RIVER BASIN

This basin with an area of about 172 $km^2$ is represented by Ilang-Ilang River (60 $km^2$). As presented schematically in Fig. **4.3-4(e)** the annual rainfall depth over the basin is 2,602.6 mm; annual surface runoff depth is 1,155.9 mm; the actual evapotranspiration is 938.7 mm; and the groundwater discharge is 360.5 mm. Hence, the annual recharge is estimated at 147.4 mm or 5.7% of the annual rainfall.

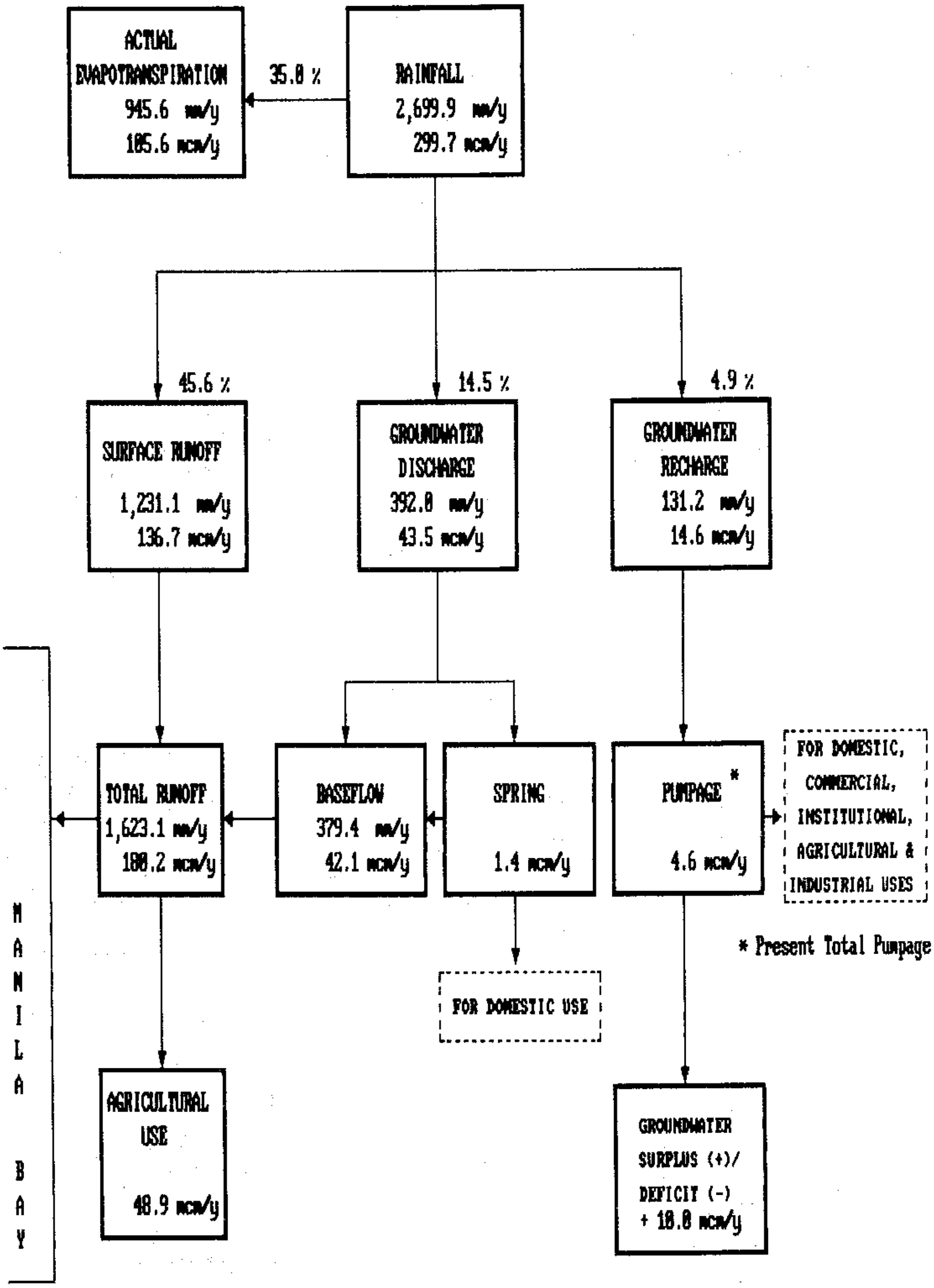
Comparing the present annual groundwater use of 20.2 x $10^6$ cum as presented in **Table 4.2-8** with the estimated groundwater recharge of 18.9 x $10^6$ cum, the tentative estimate of the groundwater deficit of the basin is placed at 1.3 x $10^6$ cum. This deficit confirms the annual decline of groundwater levels in the basin.

(5) IMUS RIVER BASIN

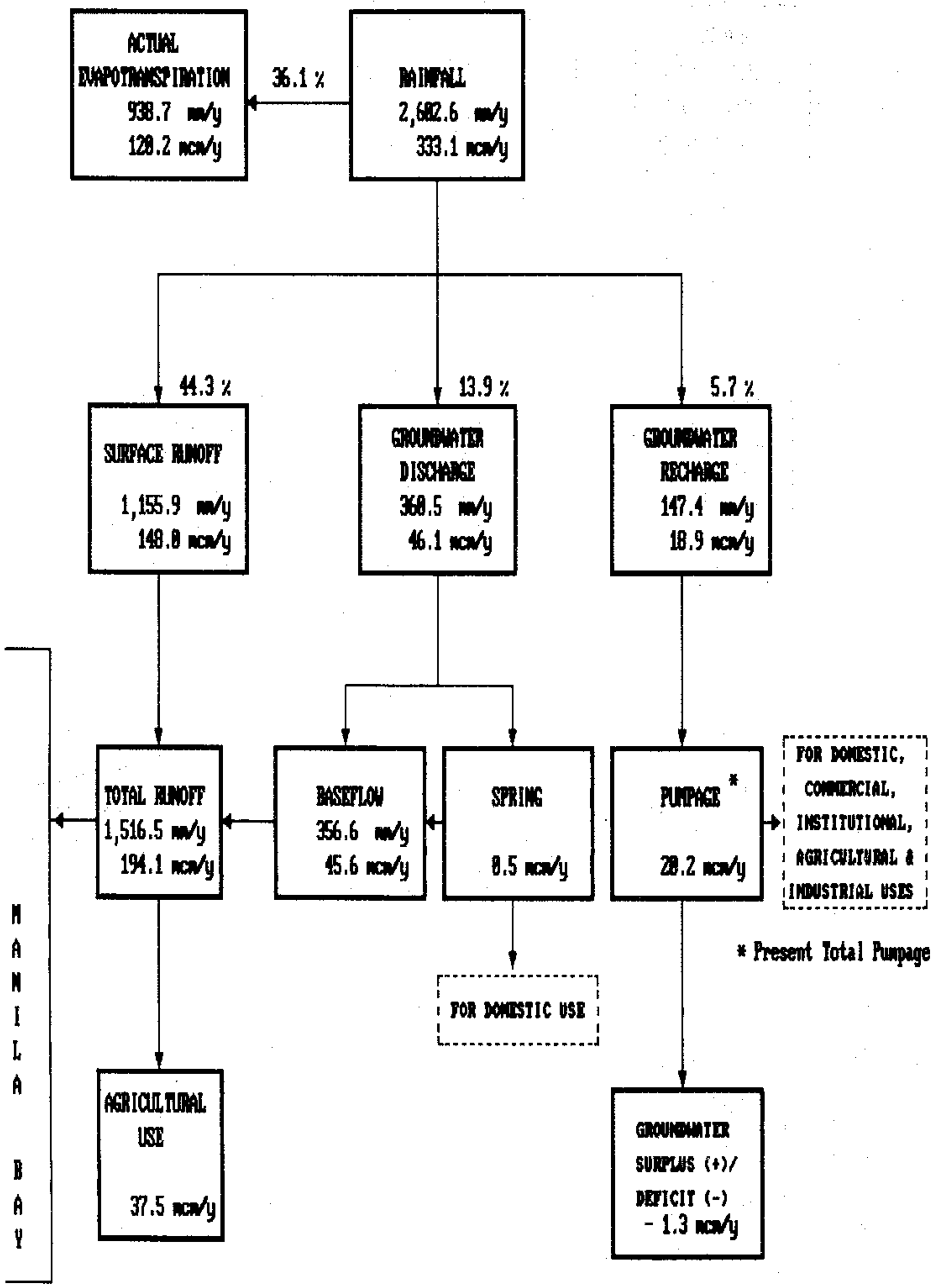
This basin has an area of about 128 $km^2$. As presented schematically in **Fig.4.3-4(f)**, the annual rainfall depth over the basin is estimated at 2,355.6 mm; the annual surface runoff depth is 983.1



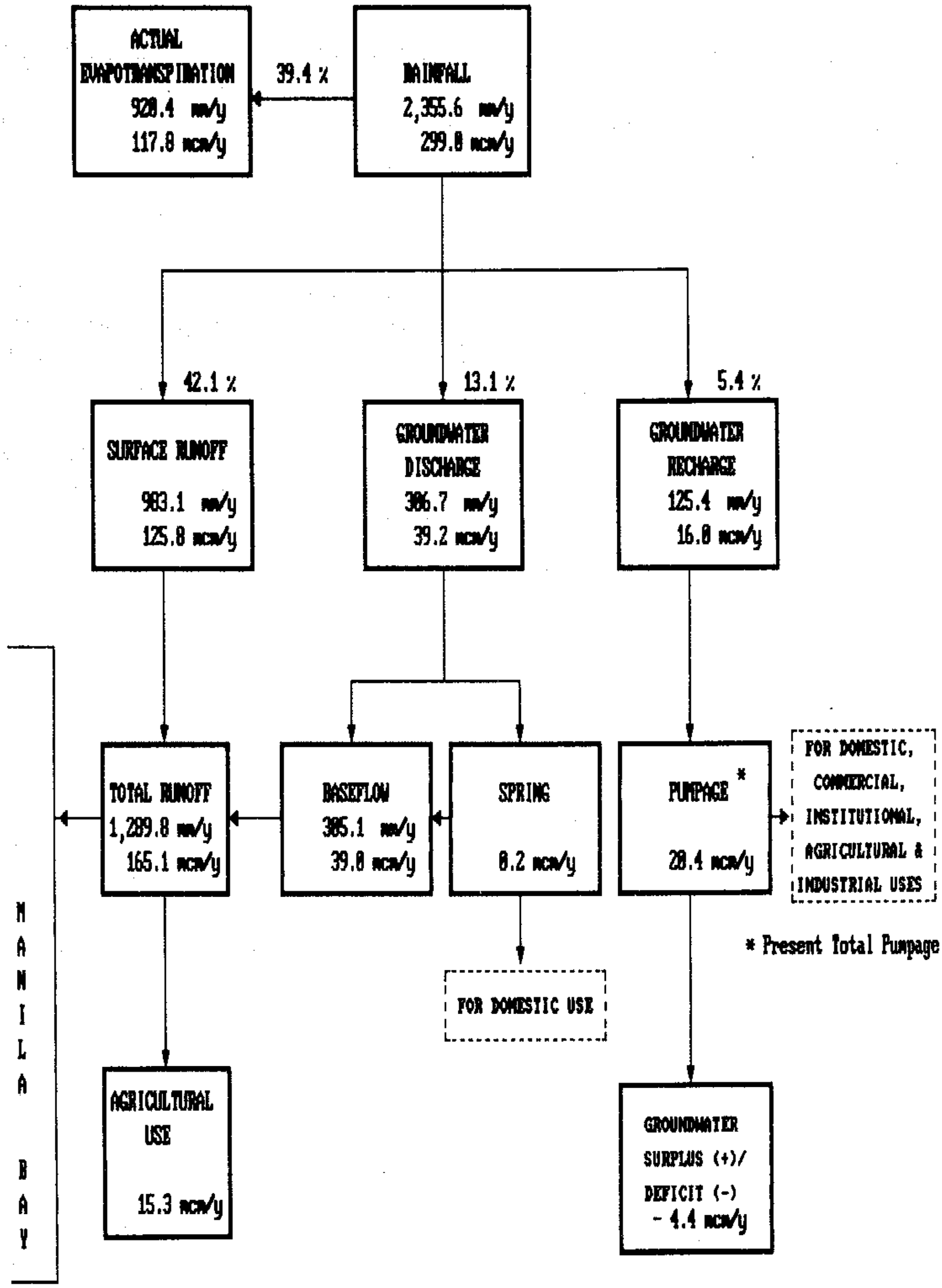

| CAVITE WATER SUPPLY DEVELOPMENT STUDY | Fig. 4.3-4(C) |
|---|---|
| JAPAN INTERNATIONAL COOPERATION AGENCY | ANNUAL AVERAGE WATER BALANCE FOR LABAC RIVER BASIN (D.A.=106 KM$^2$) |




| CAVITE WATER SUPPLY DEVELOPMENT STUDY | Fig. 4.3- 4(D) |
|---|---|
| JAPAN INTERNATIONAL COOPERATION AGENCY | ANNUAL AVERAGE WATER BALANCE FOR CAÑAS RIVER BASIN (D.A.=111 KM²) |




| CAVITE WATER SUPPLY DEVELOPMENT STUDY | Fig. 4.3- 4(E) |
|---|---|
| JAPAN INTERNATIONAL COOPERATION AGENCY | ANNUAL AVERAGE WATER BALANCE FOR SAN JUAN RIVER BASIN (D.A.=127 KM$^2$) |




| CAVITE WATER SUPPLY DEVELOPMENT STUDY | Fig. 4.3-4(F) |
|---|---|
| JAPAN INTERNATIONAL COOPERATION AGENCY | ANNUAL AVERAGE WATER BALANCE FOR IMUS RIVER BASIN (D.A.=128 KM²) |

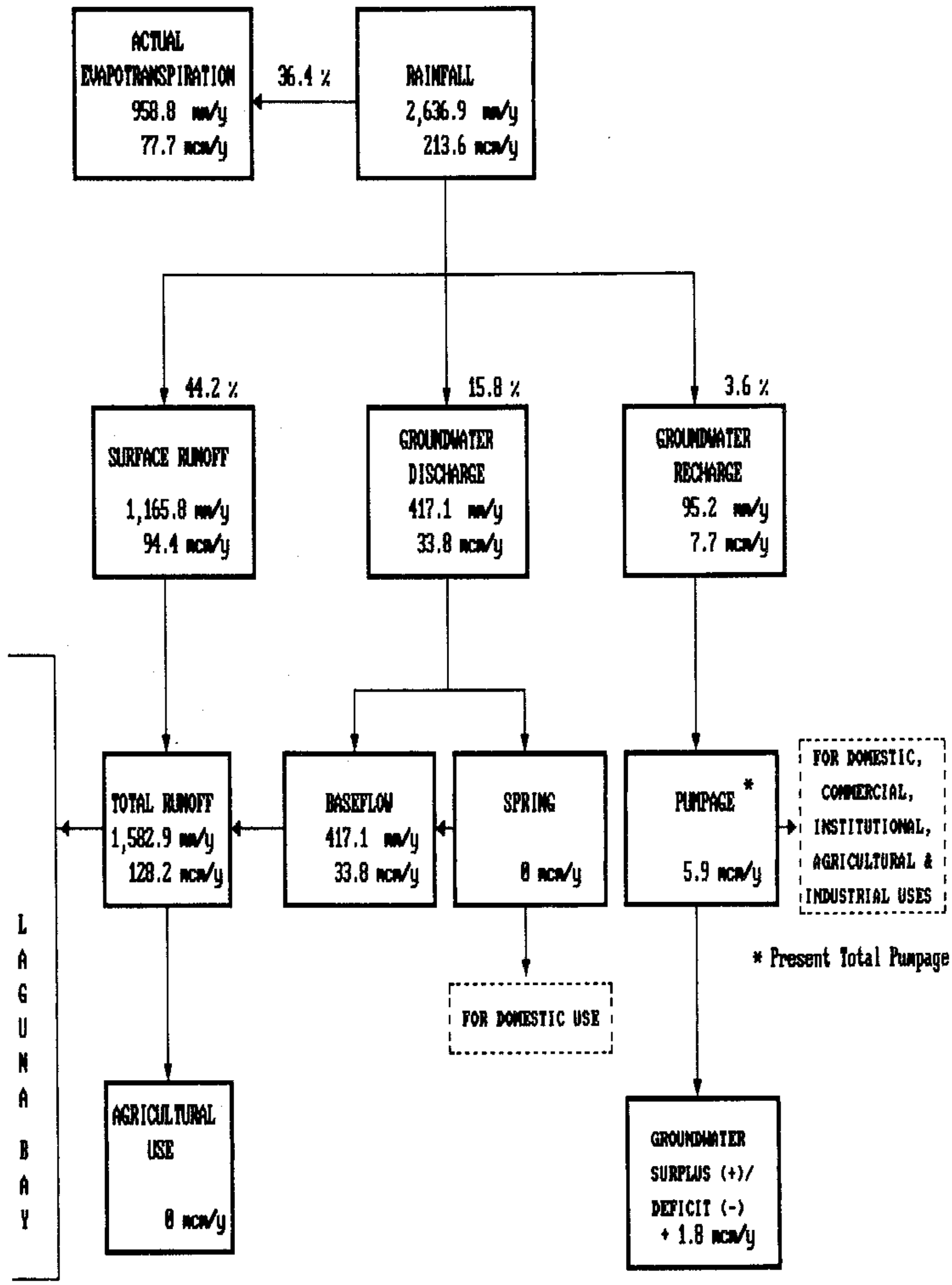
mm; actual evapotranspiration is 920.4 mm; and the groundwater discharge is 306.7 mm. Hence, the annual recharge is estimated at 125.4 mm or 5.4% of the annual rainfall.

Comparing the present annual groundwater use of 20.4 x $10^6$ cum as presented in **Table 4.2-8** with the estimated groundwater recharge of 16.0 x $10^6$ cum, the tentative estimate of the groundwater deficit of the basin is placed at 4.4 x $10^6$ cum. This deficit confirms the annual decline of groundwater levels in the basin.

(6) BINAN RIVER BASIN

This basin has an area of about 81 $km^2$. As presented schematically in **Fig.4.3-4(g)**, the annual rainfall depth over the basin is estimated at 2,636.9 mm; the annual surface runoff depth is 1,165.8 mm; actual evapotranspiration is 958.8 mm; and the groundwater discharge is 417.1 mm. Hence, the annual recharge is estimated at 95.2 mm or 3.6% of the annual rainfall.

Comparing the present annual groundwater use of 5.9 x $10^6$ cum as presented in **Table 4.2-8** with the estimated groundwater recharge of 7.7 x $10^6$ cum, the tentative estimate of the groundwater surplus of the basin is placed at 1.8 x $10^6$ cum.




| CAVITE WATER SUPPLY DEVELOPMENT STUDY | Fig. 4.3-4(G) |
|---|---|
| JAPAN INTERNATIONAL COOPERATION AGENCY | ANNUAL AVERAGE WATER BALANCE FOR BIÑAN RIVER BASIN (D.A.=81 KM$^2$) |

# CHAPTER 5

# RELATIONSHIP BETWEEN GROUNDWATER USE AND GROUNDWATER LEVEL FLUCTUATION

# CHAPTER 5

# RELATIONSHIP BETWEEN GROUNDWATER USE AND GROUNDWATER LEVEL FLUCTUATION


The groundwater simulation was conducted to examine the relationship between groundwater use and groundwater level fluctuation in the Study Area. The San Juan River Basin was selected as the objective area for groundwater simulation based on criteria set by the Study Team.

The groundwater simulation was conducted using MODFLOW. A 3-layer 3-D groundwater flow model was constructed based on the results of hydrogeological studies. Boundary conditions, initial conditions and parameter values were assigned to the model. Steady-state and historical calibrations were conducted, comparing the computed and observed piezometric levels.

The calibrated model was then used to predict future groundwater flow and piezometric heads based on three (3) future pumping schemes. The model response showed a maximum decline of 50 meters in the simulation area in ten years (1995 to 2005).

The accuracy and reliability of groundwater model installed at LWUA must be improved in the future by a more accurate and updated pumpage and aquifer parameter estimates and by a continuous monitoring of groundwater levels.


## 5.1 OBJECTIVE OF GROUNDWATER SIMULATION

Since groundwater utilization will continue as the Study Area develops, particularly no surface water supply system is feasible in the area at present, the problem of continual decline of piezometric levels will only get more serious in the future. This problem is basically due to unplanned groundwater resources development and management, far beyond the sustained capacity of the complex aquifer system underlying the Cavite area. Due to the complexity and seriousness of the problem, there is an urgent need for identifying rational solutions through systematic planning studies.

Computer models are essential for analyzing complex problems of groundwater flow because they provide a quantitative framework for synthesizing a large set of parameters that describe spatial variability within the subsurface environment, as well as spatial and temporal trends in hydrologic parameters and stresses, and historical trends in water levels. While some decisions can be made using best engineering or best geologic judgment, human reasoning alone is inadequate to synthesize the many factors involved in most complex problems.

A groundwater simulation was undertaken to predict spatial and temporal response of the aquifer system in terms of piezometric levels for the future pumping schemes based on the projected water demand in the Study Area from year-1995 to year-2005. The development and management strategy is ultimately aimed at regulating the groundwater pumpage to control the piezometric levels at allowable limits.

## 5.2 OBJECTIVE AREA FOR GROUNDWATER SIMULATION

### 5.2.1 Criteria for the selection of objective area

The San Juan River Basin, consisting of Ilang-Ilang River Basin and Malabon River Basin, was recommended by the Study Team as the objective area for groundwater simulation based on the following criteria.

(1) The objective area must be a unit hydrological basin in which the actual groundwater system can be easily conceptualized and the boundary conditions and system parameters for numerical simulation can be properly set.

(2) The objective area must have municipalities where groundwater levels have continually declined over the years due to overpumping of groundwater. This condition shall make the calibration of the mathematical model possible.

(3) The water balance calculations for the objective area must be performed with high accuracy.

As per criterion (1), the San Juan River Basin is a unit hydrological basin defined by the hydrological watershed divides in the topographic map. **Fig. 5.2-1** shows the objective area for groundwater simulation.

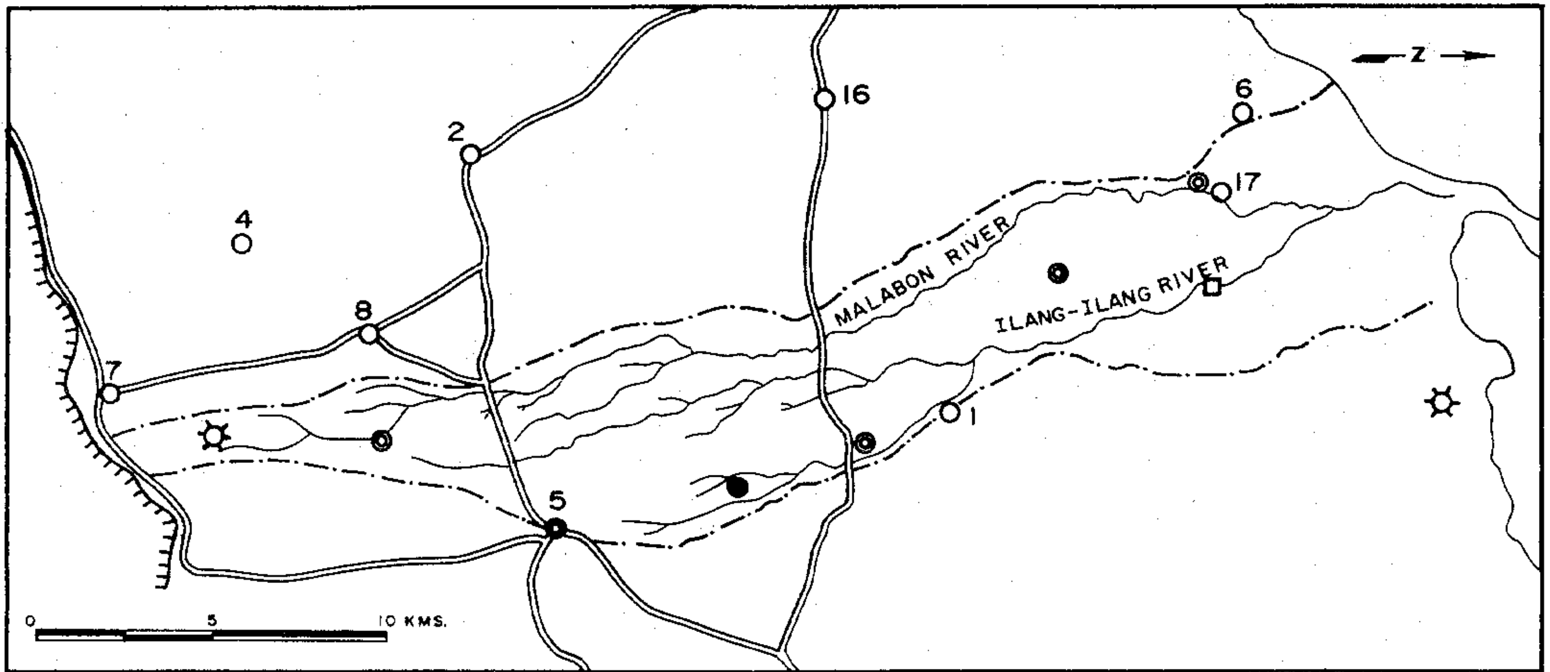
As per criterion (2), groundwater levels in Gen. Trias, Dasmarinas and Silang (portions of these municipalities are included in the San Juan River Basin) have declined significantly in recent years due to the rapid subdivision and industrial developments.

As per criterion (3), water balance analysis can be performed accurately for the San Juan River Basin based on the discussion in Chapter 4 regarding the monitoring of rainfall and groundwater levels, the dry and rainy seasons' survey of spring and river discharges, the availability of rainfall and runoff data, and the inventory survey of wells and groundwater use in the basin.

### 5.2.2 General Condition of the San Juan River Basin

The San Juan River Basin is bounded by Tagaytay Ridge to the south, Aguinaldo Highway to the east, municipalities of Noveleta, Kawit and Imus to the north, and Tagaytay-Gen. Trias Road to the west. It has a total land area of 155 $km^2$, which represents 12.5% of the total land area of the Study Area, and comprises portions of Tagaytay City, Amadeo, Silang, Dasmarinas, and General Trias. Portions of Imus, Noveleta, and Kawit, which are outside the Study Area, also form part of this basin.

The downstream portion of the basin is a small plain covered by Quaternary alluvium and Guadalupe formation, lying flat at slopes of 0 to 3%, facing Manila Bay, and below 100-meter elevation. The soil is typically sandy river deposits. The land use in these portions of Imus and Gen. Trias is largely prime agricultural lands while in Noveleta and Kawit at the southern end are built up areas, salt beds and marine ponds.




TAGAYTAY RIDGE
MAIN ROAD
WATERSHED
RIVER

PAGASA STATION
JICA GWL MONITORING STAION
JICA RAINFALL MONITORING STAION
BRS STREAMFLOW GAGING STAION

CAVITE WATER SUPPLY DEVELOPMENT STUDY

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. 5.2-1
OBJECTIVE AREA FOR GROUNDWATER SIMULATION

The central area is characterized by rolling and undulating terrain, sloping from 3% to 8% between elevations of 100m and 300m above MSL, and comprises portions of Dasmarinas and Silang. The middle reach of Malabon River and the upper section of Ilang-Ilang River are located in this area. The principal soil is made of loam, which includes tuff and pyroclastics as its base. Currently the land is used mainly to cultivate tree crops such as sugarcane and mango. Industrial and residential areas are expanding along main roads, especially Carmona-Trece Martirez-Naic Road, and water for these areas are supplied by deep wells. Although there have been no serious problems up to now, further urban and industrial developments in the future will correspondingly increase the dependency on groundwater which will result in uncontrolled decline of piezometric head.

The upland, with elevations higher than 300m above sea level, is hilly and mountainous, having slopes of 8% to 15%. The upland is geologically dominated by pyroclastics and tuff breccia. The upstream section of the Malabon River and several springs are located here. Portions of Silang, Amadeo and Tagaytay City are included in this southern part of the basin. The highest elevation of the basin, which forms part of the Tagaytay Ridge, is 610 meters above sea level. Tree crops such as coconut, coffee, mango, etc. are widely grown.

The San Juan River Basin is long and narrow, rolling and undulating with numerous moderately deep, narrow ravines and gullies. The direction of flow in the San Juan River System is generally dictated by the direction of slope in the upland areas. The Ilang-Ilang River which originates from the hills at Lucsuhin Spring more than one kilometer southwest of Silang flows north-northeast. Towards Dasmarinas, several creeks merge and contribute to its flow. Opposite this municipality, the river is joined by Dasmarinas River and meanders northwest to discharge finally into Manila Bay near Noveleta.

The Bureau of Public Works (BPW) constructed a gaging station in Alapan 2nd, Imus to monitor the flow of the Ilang-Ilang River. Details of this station is discussed in Chapter 4. This river is currently utilized by NIA for irrigation purposes. Several small dams, together with irrigation canals, were reportedly constructed by NIA across the river.

The Dasmarinas River originates from the highlands of Dasmarinas about 7.5 km southeast of the poblacion. It flows in a northwesterly direction rushing close to the poblacion. It then joins Ilang-Ilang River two kilometers northwest.

The Malabon River originates as Rio Grande River in Barangays Maitim and Matagbak, Amadeo about 10 km southwest of Poblacion, Silang, near Tagaytay Ridge. The Rio Grande River flows in a northwesterly direction and is joined by many tributaries towards Poblacion, Gen. Trias. The Pasong Camachile River joins this river to form the Malabon River which then flows in the north direction and drains into Manila Bay. The NIA dam across Rio Grande River diverts about 1,000 lps to irrigate the ricefields in the area.

The mean annual rainfall in the basin varies from 2,000 mm in the lowland to 3,800 mm in the upland.

## 5.3 METHOD OF GROUNDWATER SIMULATION

The groundwater simulation was conducted using the Modular Three-Dimensional Finite Difference Groundwater Flow Model (MODFLOW) developed by the U.S. Geological Survey (McDonald and Harbaugh, 1984). MODFLOW is a very popular, correctly formulated and versatile model with many options for hydrological computations and modular structure for efficient programming and modification purposes.

**Fig. 5.3-1** shows the general flowchart of the groundwater simulation. After defining the objective of the groundwater simulation, the 3-D groundwater flow model was constructed based on the results of the hydrogeological investigations and analyses. Appropriate boundary conditions and hydrogeological parameters were assigned to the model. To understand the model behavior, a steady-state calibration was carried out with neither recharge nor pumpage for a period of 10 years. The assigned boundary conditions and the input parameters were checked and/or modified by evaluating the computed piezometric heads.

After preparing the historical pumpage data, historical calibration of the model was performed. In the process, some earlier assumed parameters and boundary conditions were finally fixed. It was carried out using the input historical annual and monthly pumpage and recharge data. The calibration was conducted several times until the computed piezometric heads agreed satisfactorily with the observed data.

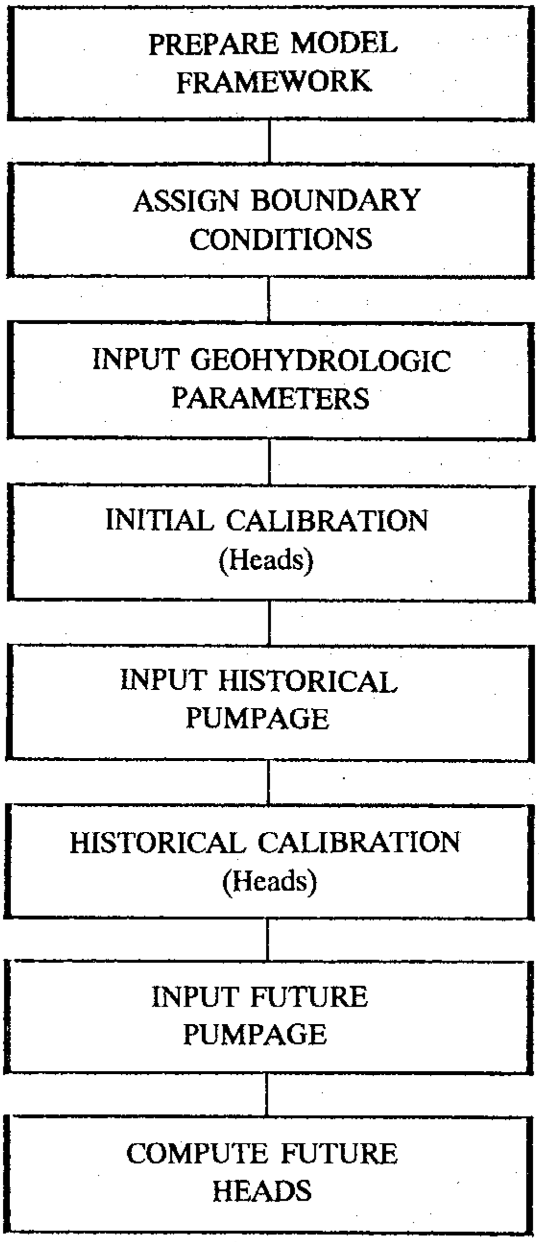
The calibrated model was then used to predict future groundwater flow and piezometric heads, based on the future groundwater pumpage plans. Three (3) future pumping schemes were generated from 1995 to 2005.

## 5.4 MODEL CONSTRUCTION AND BOUNDARY CONDITIONS

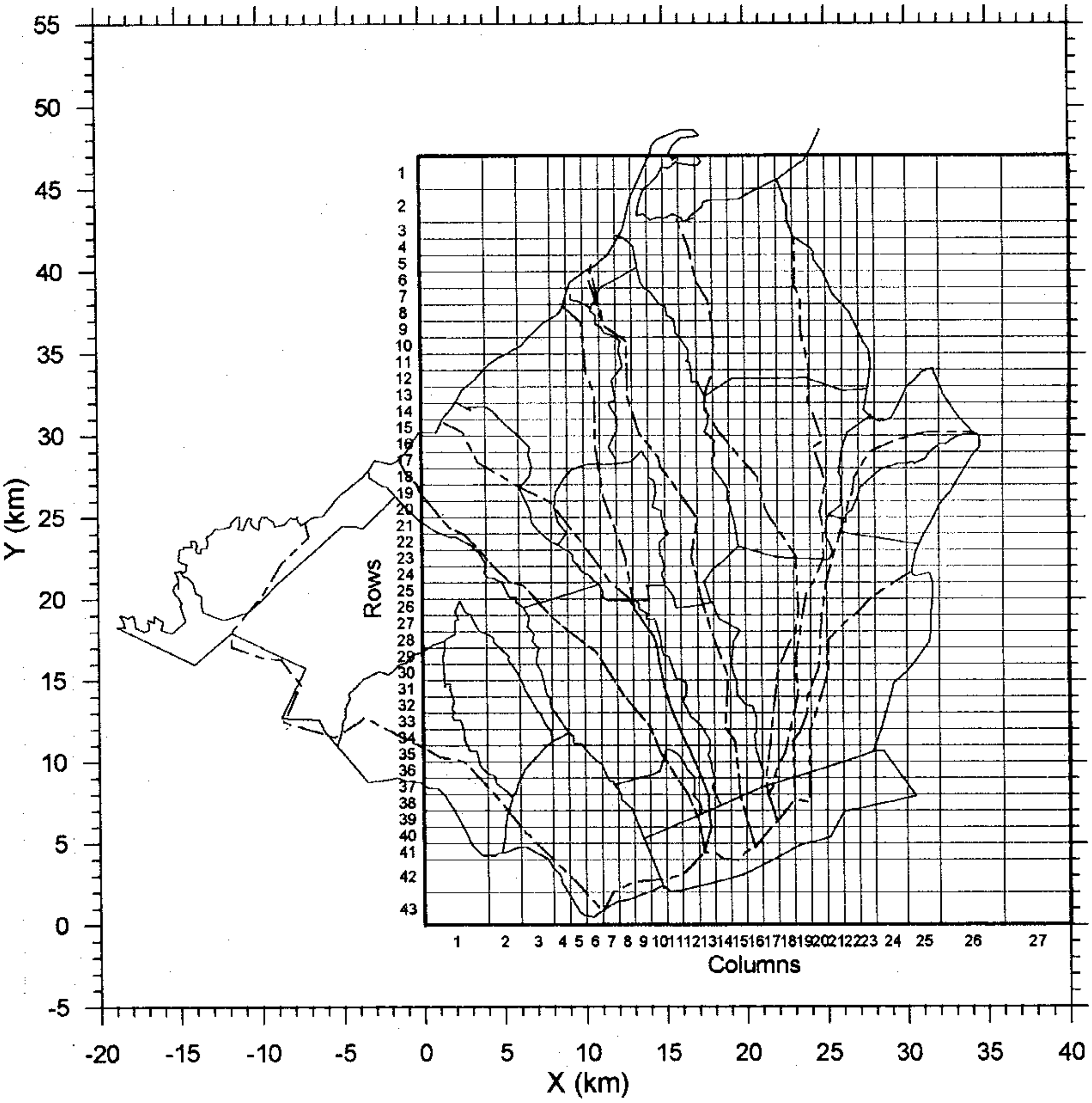
### 5.4.1 Model Grid

The simulation area covered the whole San Juan River Basin (SJRB). However, it was necessary to expand the model domain up to Maragondon River Basin on the west and beyond Binan River Basin on the east in order to reflect the structure of the groundwater basin itself in the model and to increase reliability of simulation at the marginal areas of the SJRB. For instance, it would be difficult to assign proper boundary conditions at the marginal areas if only the simulation area was taken into account as the model domain, because the aquifers continue outside the limits of the simulation area. Furthermore, the groundwater flow outside affects the groundwater flow inside the basin. Therefore, the model grid was located and established as shown in **Fig. 5.4.-1**.

**Fig. 5.4-2** illustrates the grid system of the 3-D groundwater flow model. The SJRB is located between columns 6 and 19 and rows 3 and 40. The grid size in the SJRB was fixed at 1 km × 1 km. However, it varied outside SJRB from 1 km × 2 km to 2 km × 4 km as the grid becomes farther from the simulation area.



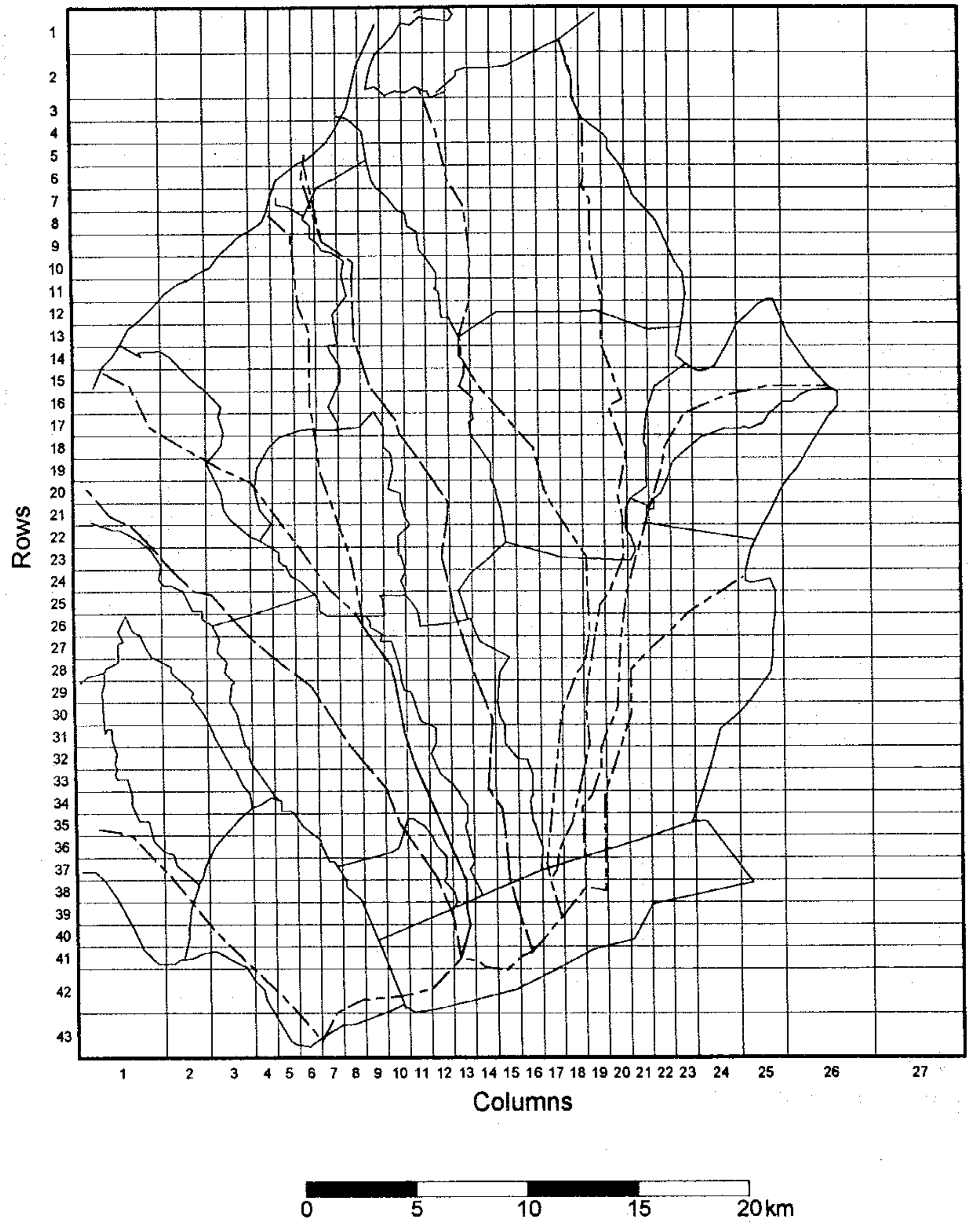

| | |
|---|---|
| CAVITE WATER SUPPLY DEVELOPMENT STUDY | Fig. 5.3-1<br>WORK FLOW OF GROUNDWATER SIMULATION |
| JAPAN INTERNATIONAL COOPERATION AGENCY | |




| Fig. 5.4-1 | LOCATION OF SIMULATION MODEL GRID |
|---|---|

**CAVITE WATER SUPPLY DEVELOPMENT STUDY**

| JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | KOKUSAI KOGYO CO., LTD. |
|---|---|




| Fig. 5.4-2 | GRID OF CAVITE 3-D GROUNDWATER FLOW MODEL |
|---|---|
| **CAVITE WATER SUPPLY DEVELOPMENT STUDY** | |
| JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | KOKUSAI KOGYO CO., LTD. |

The model was divided into three (3) independent layers based on the number of aquifer units as shown in the hydrogeological map and sections prepared by the Study Team. The total number of modeled grids in one (1) layer is 1,161 (43 rows × 27 columns), and the total number of 3-D cells is 3,483 (43 rows × 47 columns × 3 layers).

The modeled area was divided into three zones to define the structure of the 3-D model as presented in **Fig. 5.4-3**. The upper layer is composed of zones 1 and 2 and represents the unconfined aquifers, Kaybubutong Upper and Kaybubutong Middle; the middle layer is made up of zones 2 and 3, representing the confined aquifer, Kaybubutong Lower; and the lower layer consists of zones 1, 2, and 3 and represents the confined aquifer, Talisay Formation. The border between zones 1 and 2 indicates the upstream edge of the middle aquifer, while the boundary between zones 2 and 3 represents the downstream edge of the upper aquifer.

### 5.4.2 Boundary Conditions

Appropriate boundary conditions were specified for numerical calculation based on the hydrogeological information.

**Fig. 5.4-4** shows the boundary conditions of the upper aquifer. The cells located outside the boundaries were treated as inactive cells in the model. Also constant heads, which are equal to the initial heads, were assigned from columns 10 to 23 of the southern boundary. The no flow boundary condition was assigned to the active cells at the northern border.

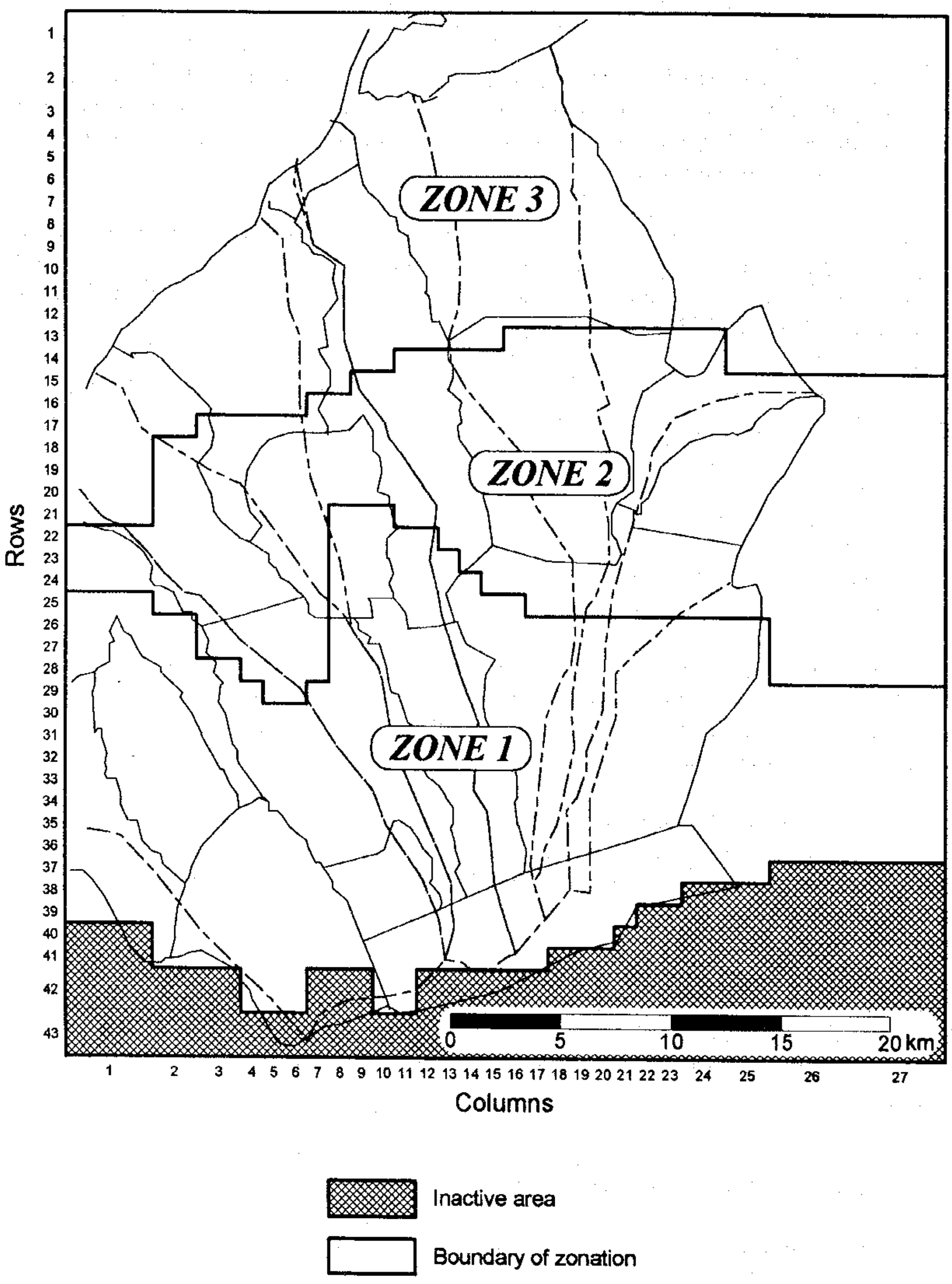
**Fig. 5.4-5** shows the boundary conditions of the middle aquifer. The cells located outside the boundaries were treated as inactive cells in the model. Also constant heads, which are equal to 0 meter, were assigned as shown in this figure. The no flow boundary condition was assigned to the active cells at the southern border.

**Fig. 5.4-6** shows the boundary conditions of the lower aquifer. The cells located outside the boundaries were treated as inactive cells in the model. Also constant heads, which range from -40 meters in Cavite City to -70 meters in Las Pinas (JICA, 1992), were assigned as shown in this figure. The no flow boundary condition was assigned to the active cells at the southern border of the lower aquifer.

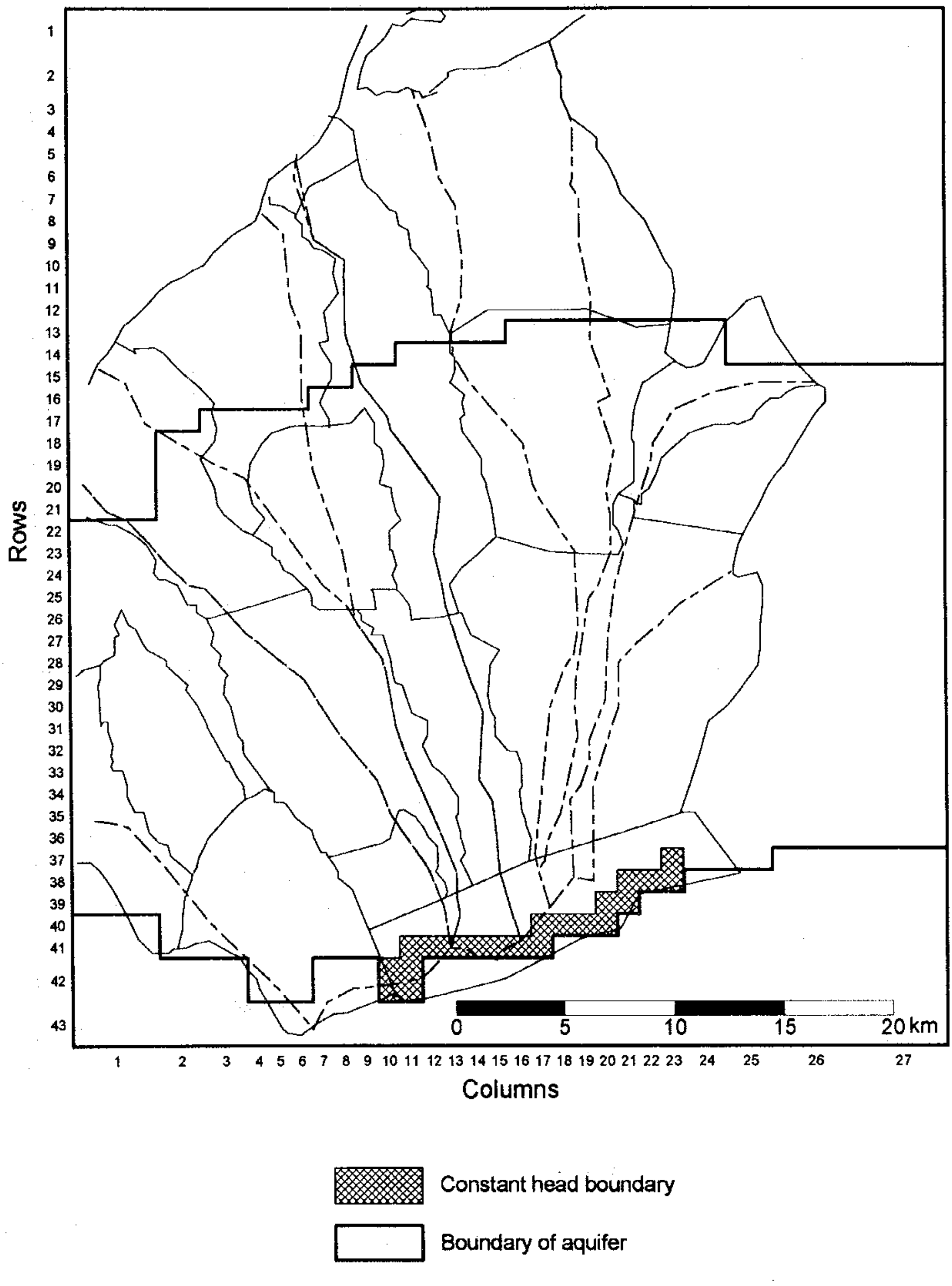
## 5.5 HYDROGEOLOGICAL PARAMETERS

The MODFLOW program requires the following hydrogeological parameters:

- Top and bottom elevations of each layer
- Type of each layer
- Porosity
- Specific storage
- Hydraulic conductivity



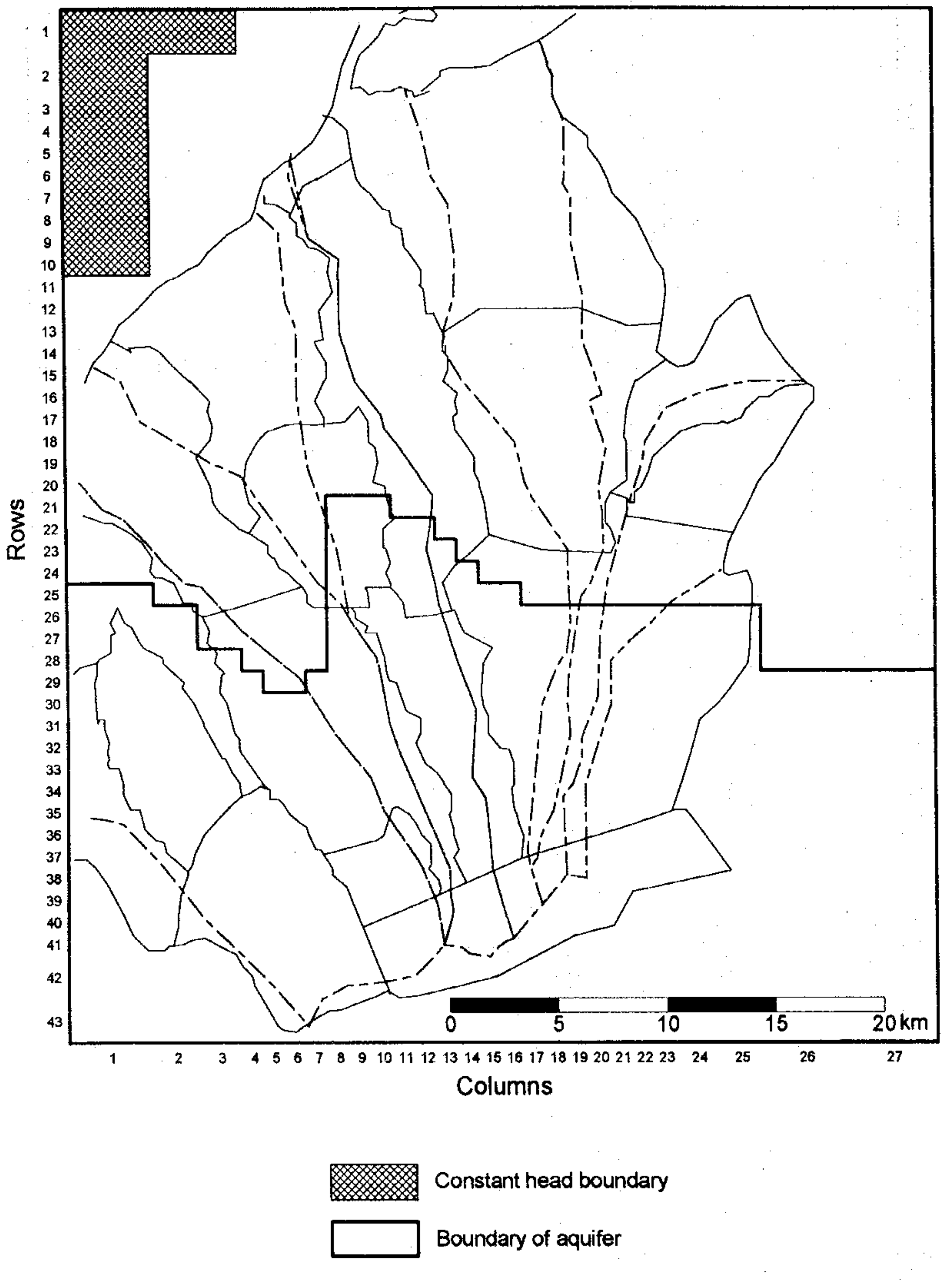

| Fig. 5.4-3 | ZONING MAP OF MODELED AREA |
|---|---|
| CAVITE WATER SUPPLY DEVELOPMENT STUDY | |
| JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | KOKUSAI KOGYO CO., LTD. |



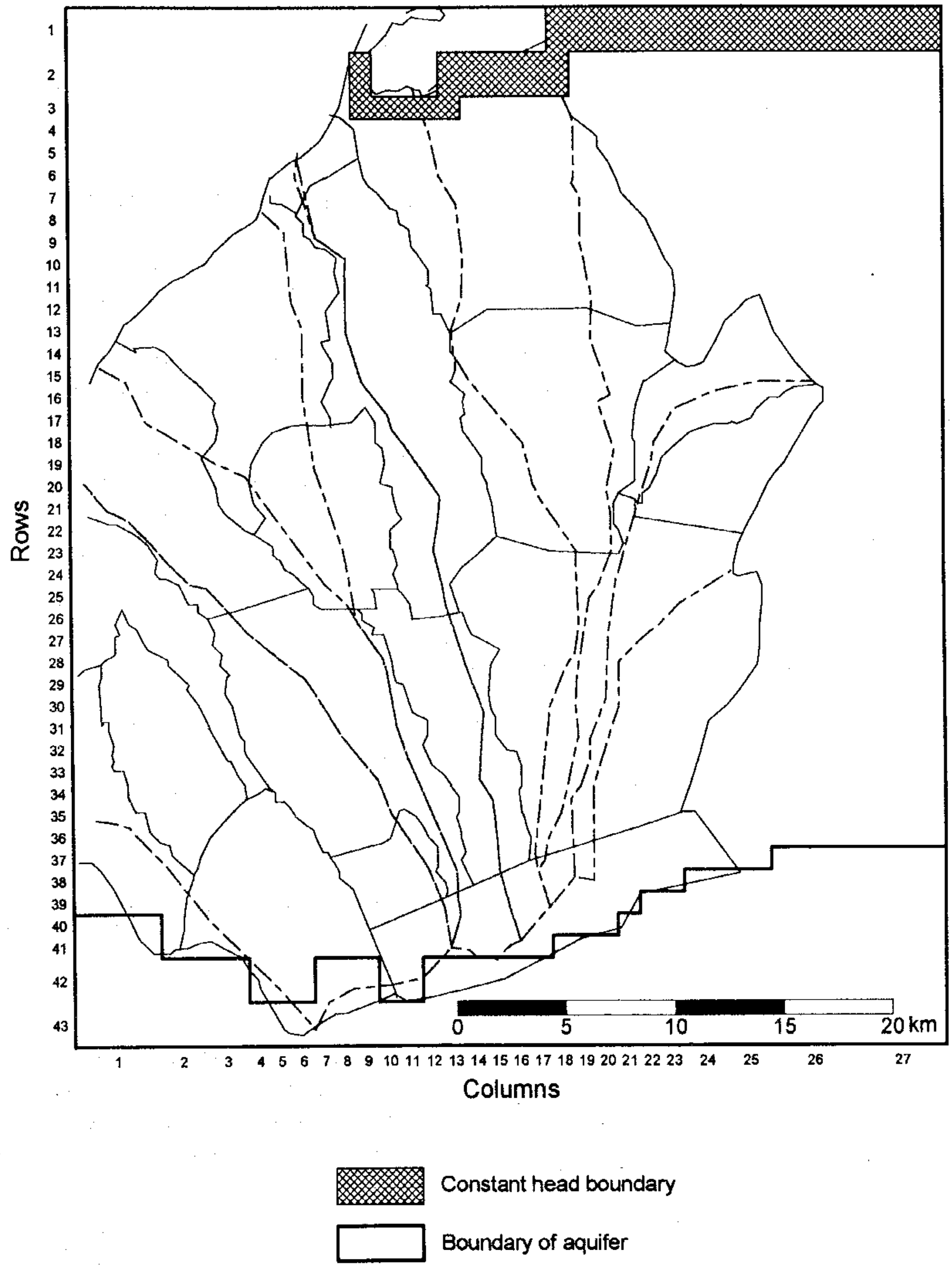

| Fig. 5.4-4 | BOUNDARY CONDITION OF UPPER AQUIFER |
|---|---|

**CAVITE WATER SUPPLY DEVELOPMENT STUDY**

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | KOKUSAI KOGYO CO., LTD.




| Fig. 5.4-5 | BOUNDARY CONDITION OF MIDDLE AQUIFER |
|---|---|
| CAVITE WATER SUPPLY DEVELOPMENT STUDY | |
| JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | KOKUSAI KOGYO CO., LTD. |




| Fig. 5.4-6 | BOUNDARY CONDITION OF LOWER AQUIFER |
|---|---|
| CAVITE WATER SUPPLY DEVELOPMENT STUDY | |
| JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | KOKUSAI KOGYO CO., LTD. |

- Vertical hydraulic conductivity
- Initial piezometric heads
- Recharge rate

These parameters were prepared from the hydrogeological studies and the updated PGDB for Cavite.

*Top and bottom elevations*

Top and bottom elevations of each layer were determined from the ground elevation map (1:50,000 topo map of NAMRIA) and the hydrogeological map and sections prepared by the Study Team.

The top elevation of the upper unconfined aquifer (zones 1 and 2) is the same as the ground elevation, its bottom elevation is equal to the top elevation of the lower aquifer in zone 1 and the middle aquifer in zone 2.

The top elevation of the middle confined aquifer (zones 2 and 3) is the same as the bottom elevation of the upper aquifer in zone 2 and the ground elevation in zone 3, its bottom elevation is equal to the top elevation of the lower aquifer in zones 2 and 3.

The top elevation of the lower confined aquifer (zones 1, 2 and 3) is the same as the bottom elevations of the upper aquifer in zone 1 and the middle aquifer in zones 2 and 3, its bottom elevation is assumed equal to its top elevation minus 300 meters.

*Type of each layer*

Upper layer was specified as unconfined aquifer, while middle and lower layers were designated as confined aquifers.

*Porosity*

For the simulation of steady state flow, porosity is not required by MODFLOW. However, porosity is required by MODPATH program, which is a subprogram of MODFLOW for the calculation of the flow velocities. Therefore, this parameter is required by MODFLOW input program, PREMOD. The porosity value of 0.2 was uniformly given to the model (upper, middle and lower aquifers).

*Specific storage*

The Block-Centered Flow (BCF) Package of MODFLOW program requires dimensionless storage coefficient values in each layer of the model. PREMOD converts the specific storage value of the cell material into dimensionless storage coefficient by multiplying it by the layer thickness of the cell.

The values of storage coefficient obtained from pumping tests usually have a wide range of variation. However, Walton (1970) suggested that the range of storage coefficient values in confined aquifers should vary between $1.0\times10^{-5}$ and $1.0\times10^{-3}$ for all soils and between $5.0\times10^{-5}$ and $1.0\times10^{-2}$ in productive aquifers. Therefore, the initial storage coefficient of the upper layer was assumed at $1.0\times10^{-1}$, while that of middle and lower aquifers was set at $1.0\times10^{-3}$. These values were then converted into specific storage by dividing them by the thickness of the cell.

*Hydraulic conductivity*

Transmissivity is the most important parameter for the model. The PREMOD computes transmissivity from horizontal hydraulic conductivity (or permeability) by multiplying it by the layer thickness. An anisotropy factor ($Tyy/Txx$) was specified in the model.

Generally, transmissivity values were obtained from pumping tests. The Study Team collected some pumping test data as a result of the well inventory survey and carried out pumping tests at the newly constructed test wells. However, the numbers of collected pumping test data and aquifer parameter information were insufficient to evaluate the regional aquifer characteristics. Therefore, the transmissivity values were obtained from the hydrogeological information and specific capacity data of the production wells stored in the PGDB database. The specific capacity map, showing the locations of the production wells with yield and drawdown data from pumping test, is presented in **Fig. 5.5-1.**

If the well has only the value of specific capacity, transmissivity can be estimated based on the following equation presented by Logan (1964):

$$T = 1.22\ Sc$$

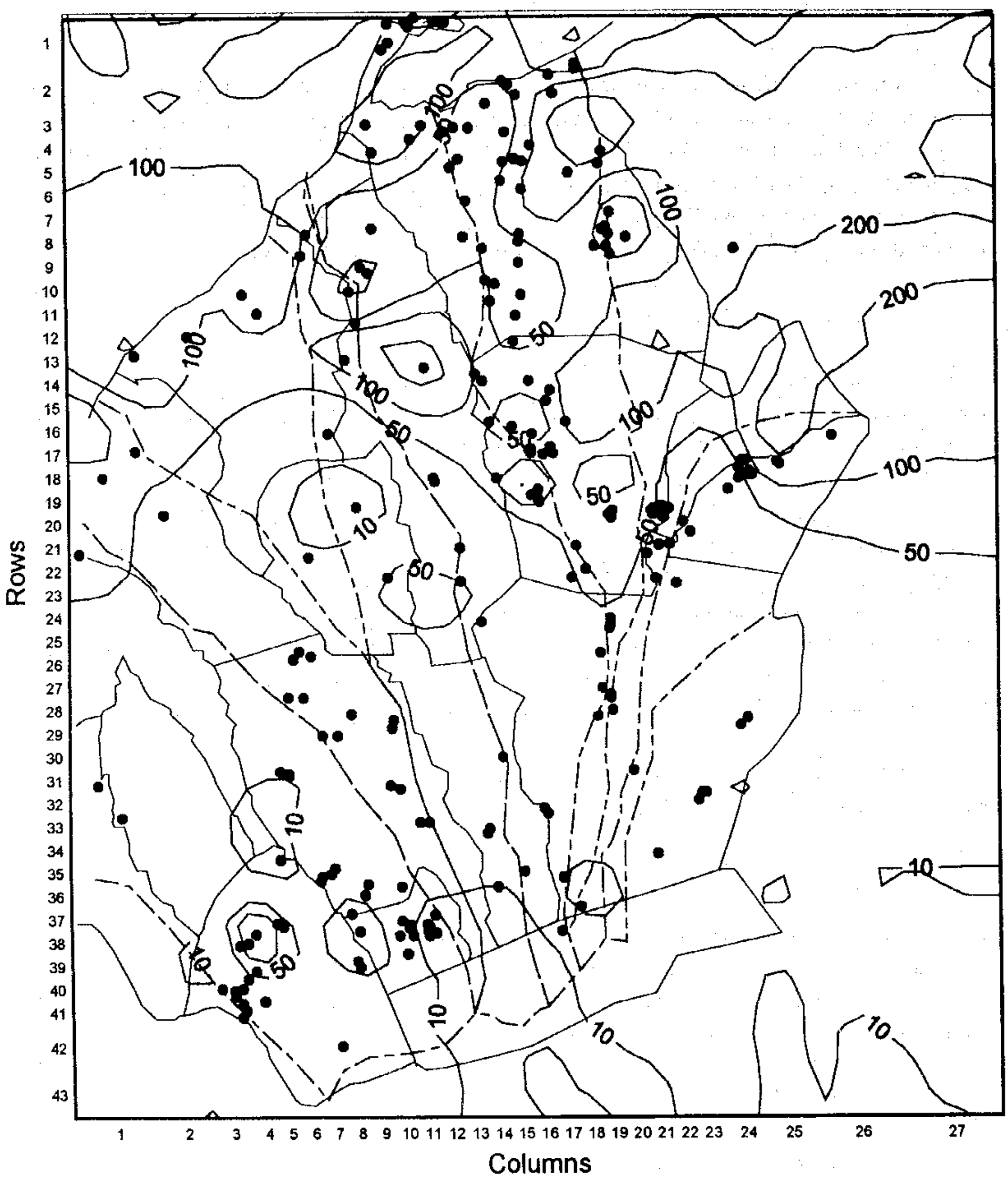
The estimated transmissivity can be called as "apparent transmissivity", because the estimated transmissivity describes the ability of the perforated portion of the aquifer to transmit water. After obtaining the apparent transmissivity of the well by the said methods, the permeability $k$ value was computed based on the definition of transmissivity given by:

$$k = T/b$$

where, $b$ is the thickness of the layer.

*Vertical hydraulic conductivity*

The MODFLOW needs an input data set of vertical hydraulic conductivity $k'$ to calculate the vertical groundwater flow terms. Here, the vertical hydraulic conductivity of each layer was assumed equal to 10% of the permeability $k$.




——— Line of equal specific capacity ($m^2/d$)

● Production well having specific capacity value

| Fig. 5.5-1 | DISTRIBUTION OF SPECIFIC CAPACITY |
|---|---|
| CAVITE WATER SUPPLY DEVELOPMENT STUDY | |
| JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | KOKUSAI KOGYO CO., LTD. |

*Initial piezometric heads*

The initial piezometric heads of the three (3) layers for the steady-state calibration were given as the assumed average static water levels in the Study Area in 1985. For the historical calibration period (1994), the computed heads by the steady-state calibration were input as the initial heads.

*Recharge rate*

The recharge rate expressed as a percentage of annual rainfall varies from basin to basin as shown in Chapter 4. Recharge rate was applied to the upper layer (zones 1 and 2) and the exposed downstream portion of the middle layer (zone 3).

## 5.6 MODEL CALIBRATION

### 5.6.1 Preparation of pumpage data

The estimated water use in the Study Area by municipality in 1993 (Table 4.2-7) was assumed equal to the groundwater pumpage for that year. Considering the type of use, the estimated amount for a certain municipality was distributed to the total number of wells in that municipality as registered in the updated PGDB for Cavite. The historical pumpage data were used for the model calibration. Each production well was located in the 1 km ×1 km grid system using its latitude and longitude coordinates (if the coordinates are not available, the barangay and road map information were used instead). The pumpage of each model grid was computed by summing up the pumpage of each well located in each model grid. The pumpage data covers not only the simulation area but also the Study Area.

For the 3-D groundwater flow model, the vertical distribution of the pumpage was assumed as follows:

Zone 1: 100% for upper aquifer
Zone 2: 1/3 for upper aquifer; 1/3 for middle aquifer; and 1/3 for lower aquifer
Zone 3: 50% for middle aquifer and 50% for lower aquifer.

### 5.6.2 Steady-state calibration

The steady-state calibration was carried out prior to the historical calibration. The purposes of the steady-state calibration are to understand model behavior, to check boundary conditions, to estimate approximate values of assumed hydrogeological parameters, and to generate initial piezometric heads at the beginning of the historical calibration for each aquifer unit.

Neither recharge nor pumpage were used for the steady-state calibration. A duration of 10 years was taken for the steady-state simulation at a time-step of one (1) year. The initial piezometric heads for the upper, middle and lower aquifers were given as the average measured static water levels in the Study Area.

For the JICA monitoring stations shown in **Fig. 5.6-1**, the computed heads of the three aquifers were almost balance within the ten time-steps of the steady state calibration. The computed heads were then used as the initial heads for the historical calibration.

### 5.6.3 Historical calibration

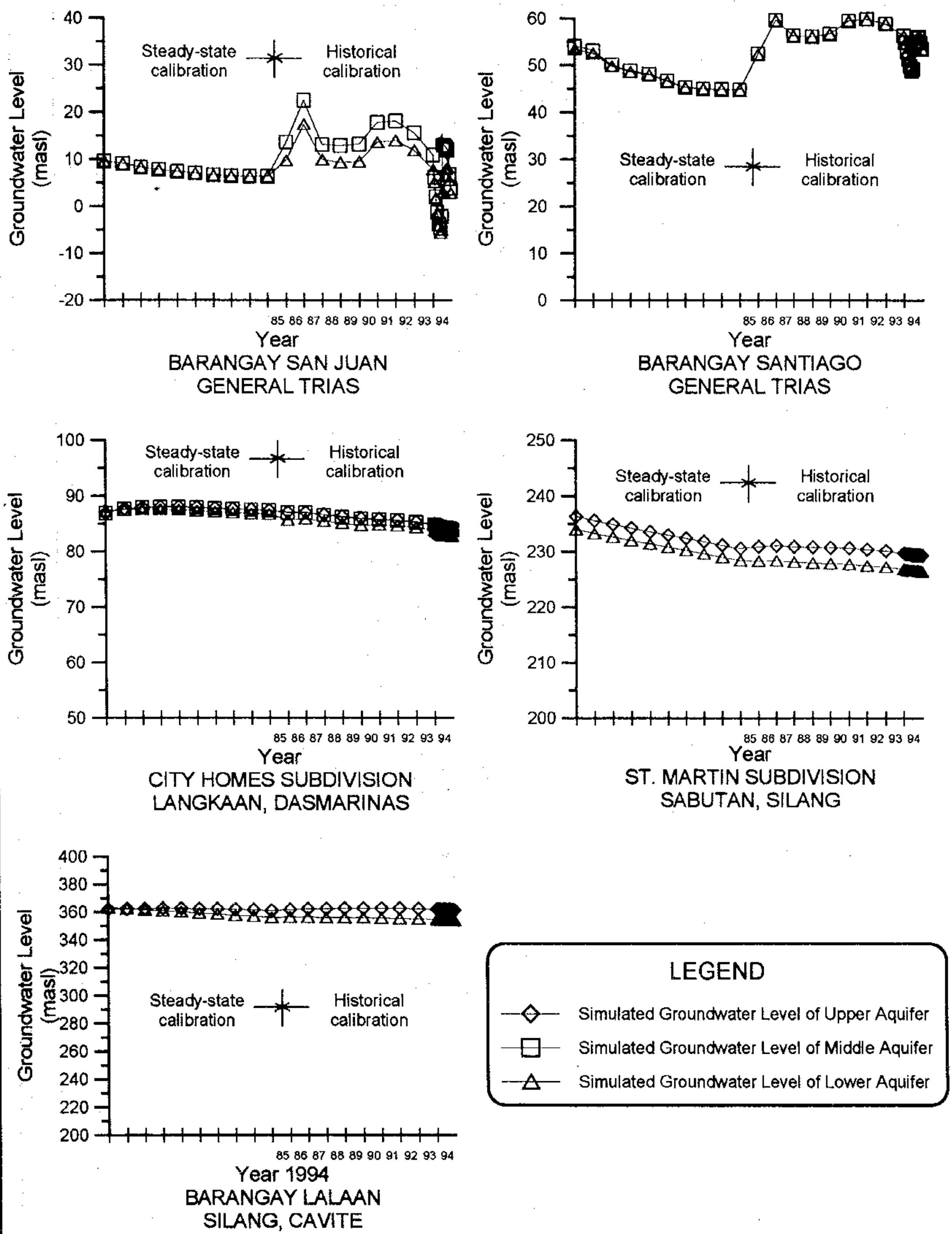
The historical calibration was performed in two stages for a total of 21 time-steps. The first stage was from 1985 to 1993 at one-year time-step (nine (9) time-steps in all) using annual recharge and a constant pumpage rate equal to the 1993 pumpage level, and the second stage consisted of 12 monthly time-steps from January to December, 1994 using monthly recharge and pumpage. The monthly historical pumpage data from January to December, 1994, which was assumed equal to 1994 pumpage amount divided by 12 months, were input to the model. **Fig. 5.6-2** shows the distribution of the 1994 groundwater pumpage in the Study Area. The recharge data were computed from observed rainfall data from PAGASA. During the historical calibration, computed piezometric heads were compared with the observed heads.

From the steady-state calibration to the historical calibration, the hydrogeological parameter values such as hydraulic conductivity, specific storage, etc. were not modified, only the boundary conditions were varied.

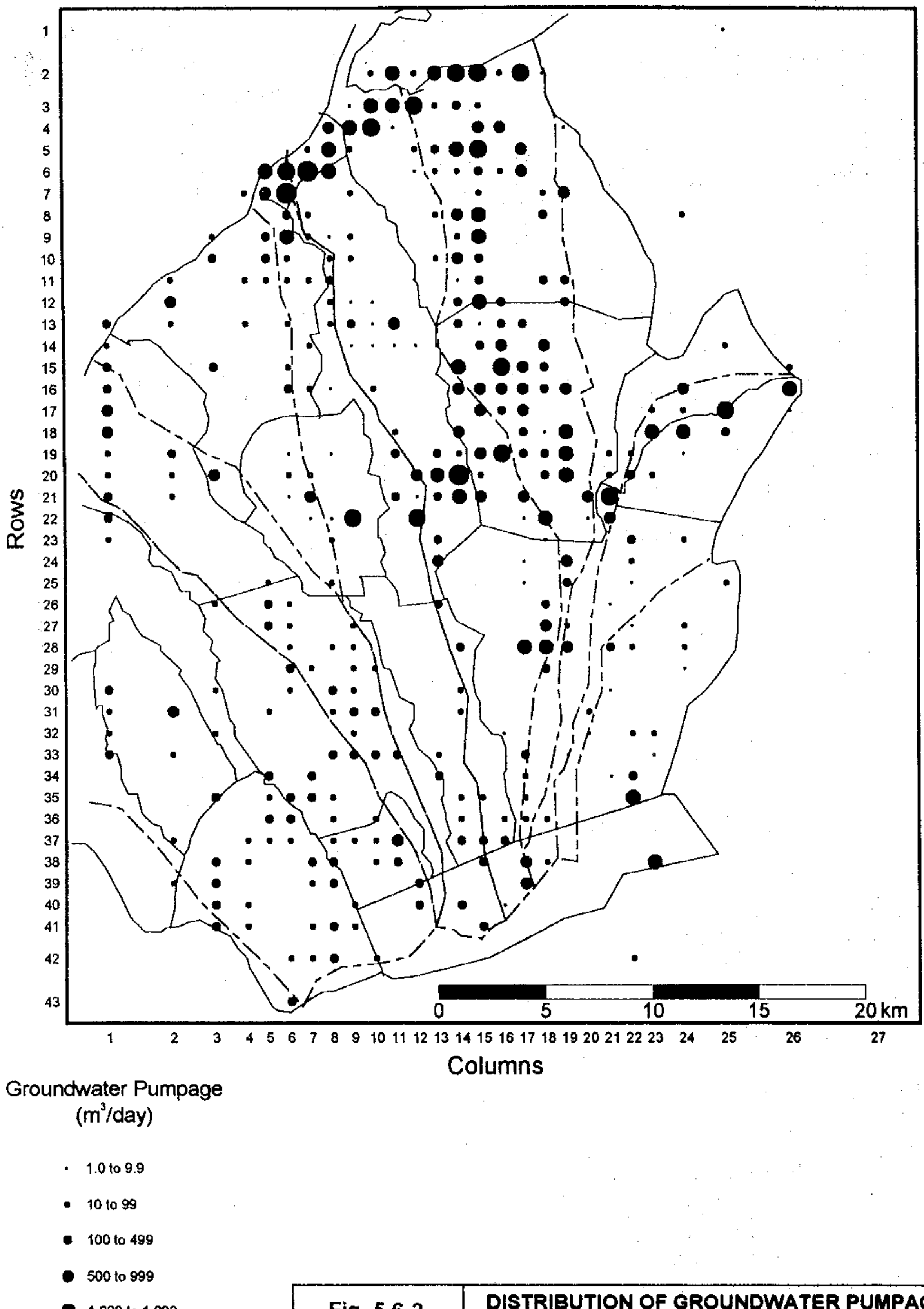
After modifying the boundary conditions, the historical simulation was re-run together with the steady-state simulation because the change affected the initial piezometric heads for the historical simulation. Therefore, the simulation of 31 time-steps, which consists of 10 time steps of steady-state simulation (1 time-step = 1 year) and 21 time-steps of historical simulation (9 time-steps at 1 time-step = 1 year and 12 time-steps at 1 time-step = 1 month), was carried out. **Fig. 5.6-1** also shows the results of the 21 time-steps historical calibration at the JICA monitoring stations.

**Figs. 5.6-3 to 5.6-5** show the comparison between the simulated groundwater levels and the 1994 groundwater levels as surveyed in the simultaneous groundwater leveling in dry and wet seasons. Within the SJRB, the simulated groundwater levels of the upper, middle, and lower aquifers satisfactorily matched the 1994 observed groundwater levels.

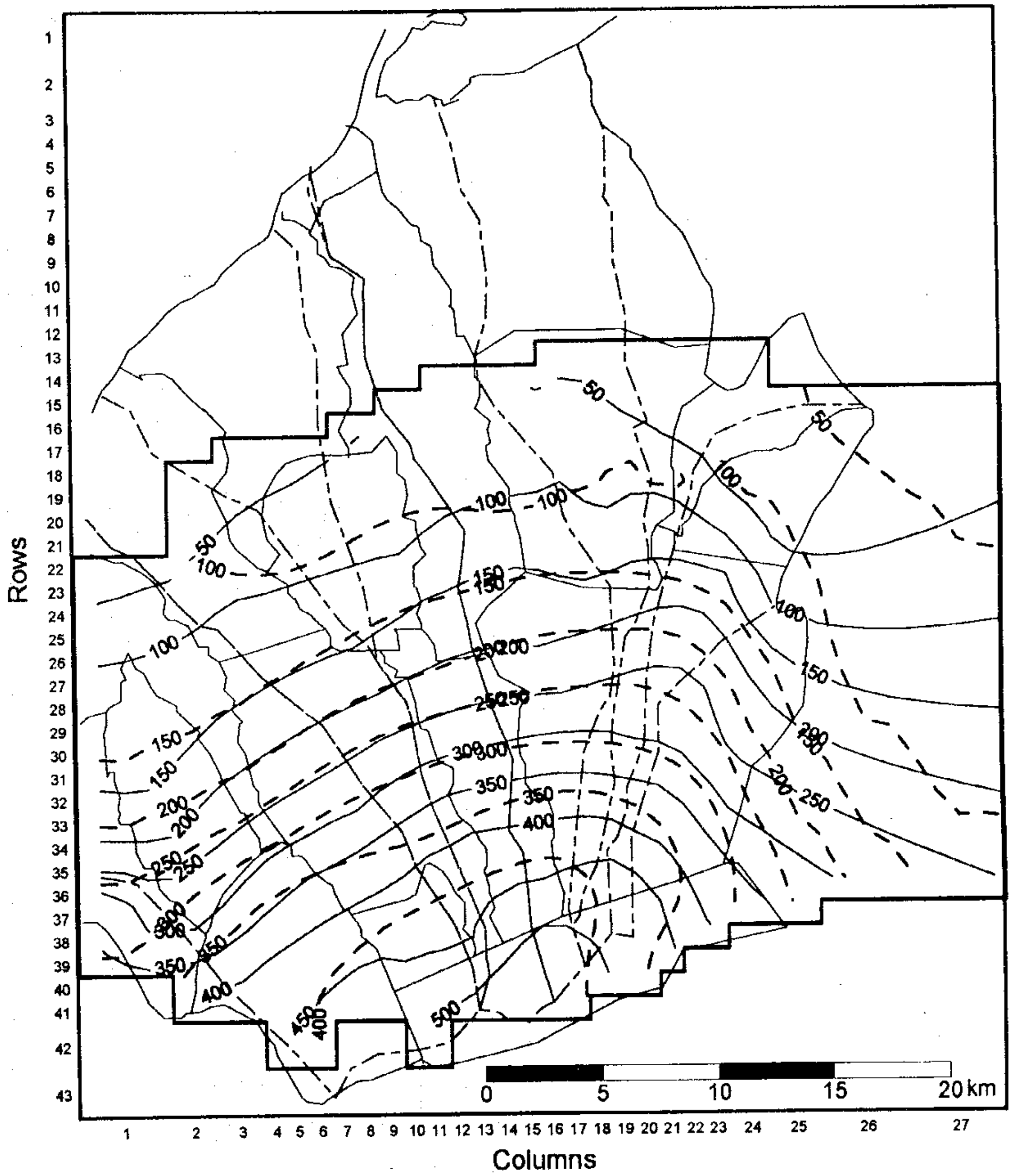
**Fig. 5.6-6** shows the comparisons between the simulated and observed piezometric heads at the JICA monitoring stations. The observed piezometric heads were reasonably simulated at the stations in Brgys. San Juan and Santiago, Gen. Trias and Bry. Sabutan, Silang. The significant difference between observed and simulated groundwater levels in the rest of the stations could be attributed to the assumed upstream boundary conditions.




| Fig. 5.6-1 | RESULTS OF STEADY-STATE AND HISTORICAL CALIBRATION |
|---|---|
| CAVITE WATER SUPPLY DEVELOPMENT STUDY | |
| JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | KOKUSAI KOGYO CO., LTD. |




| Fig. 5.6-2 | DISTRIBUTION OF GROUNDWATER PUMPAGE IN 1994 |
|---|---|
| CAVITE WATER SUPPLY DEVELOPMENT STUDY | |
| JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | KOKUSAI KOGYO CO., LTD. |

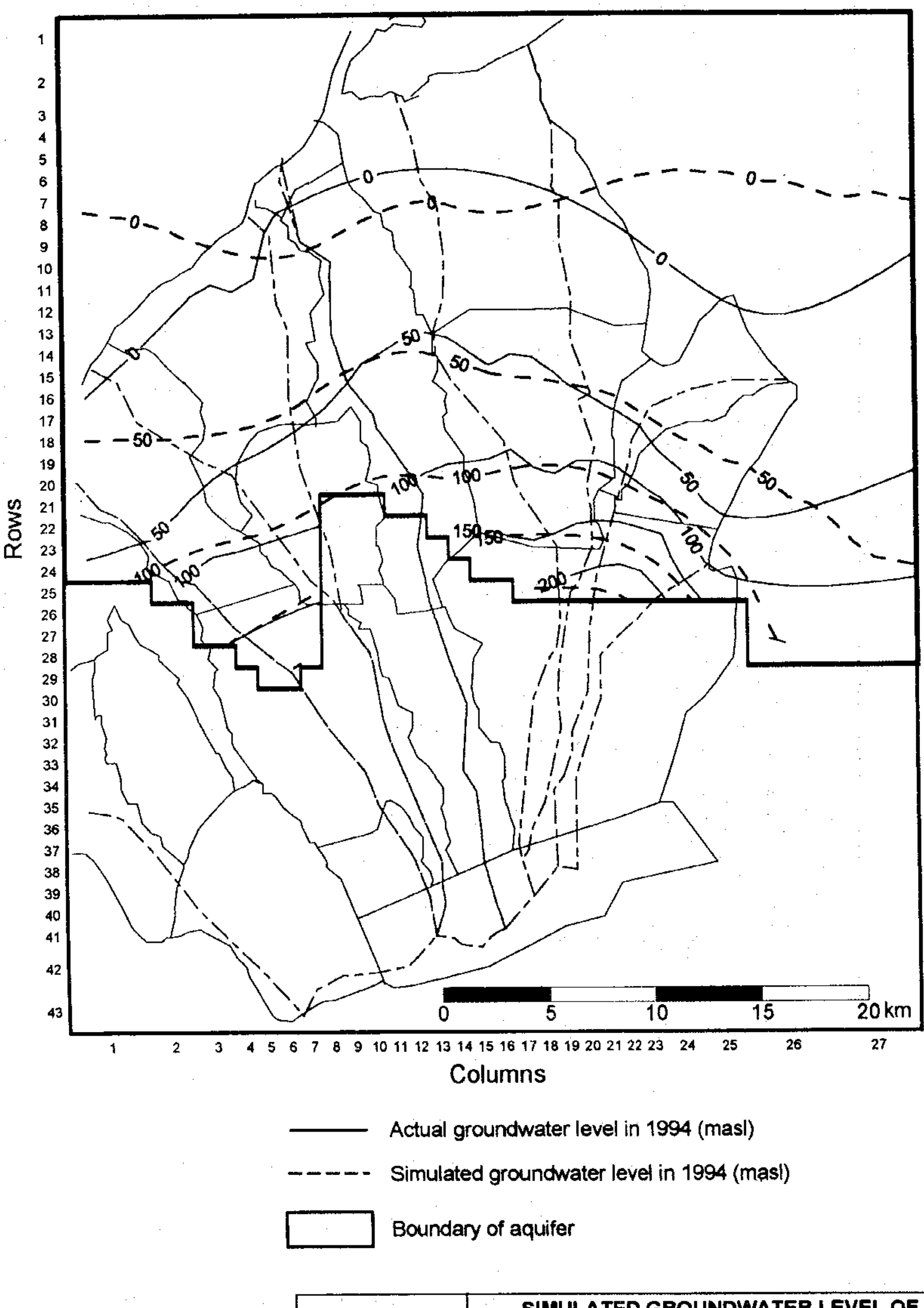



——— Actual groundwater level in 1994 (masl)

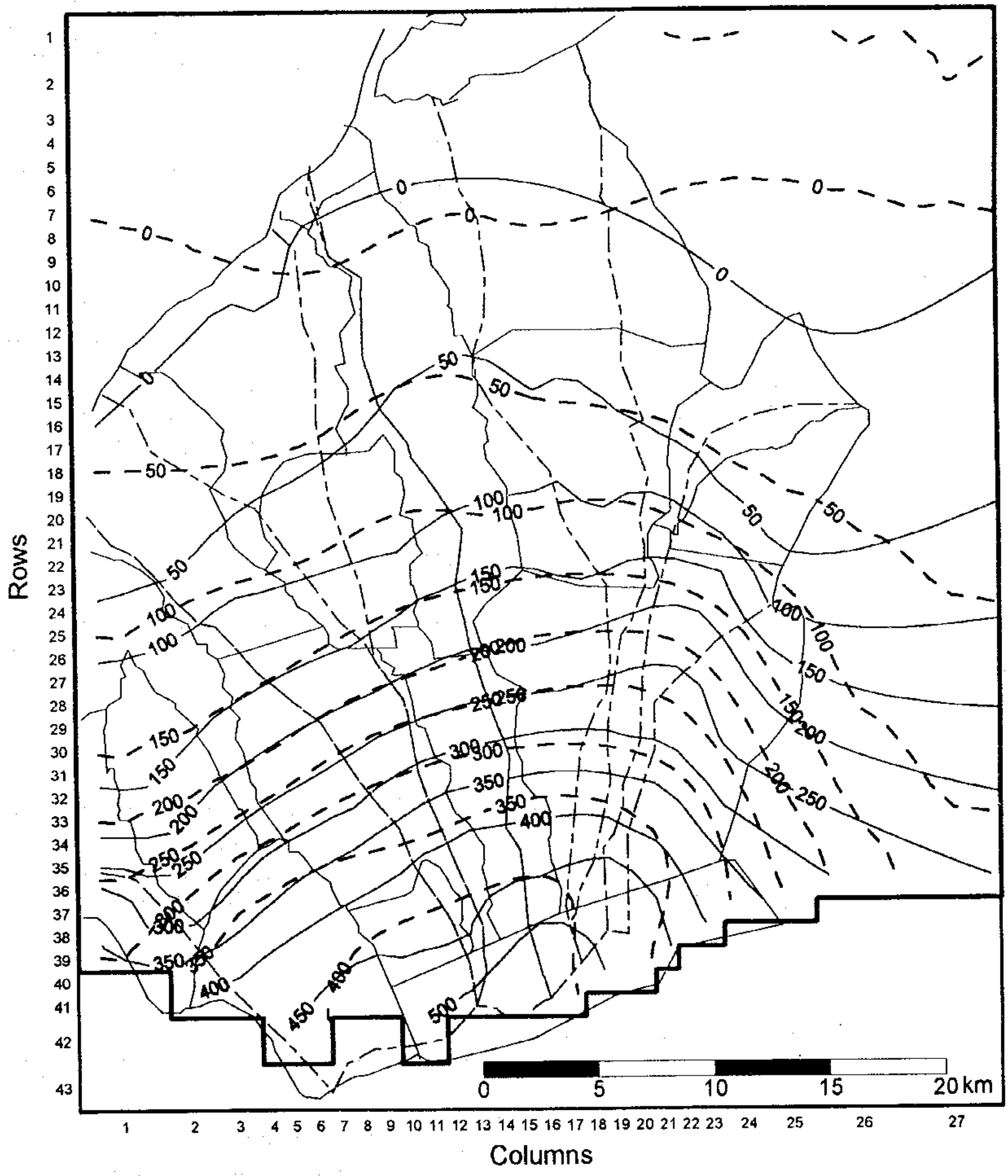
- - - - Simulated groundwater level in 1994 (masl)

▭ Boundary of aquifer

| Fig. 5.6-3 | SIMULATED GROUNDWATER LEVEL OF UPPER AQUIFER |
|---|---|
| **CAVITE WATER SUPPLY DEVELOPMENT STUDY** | |
| JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | KOKUSAI KOGYO CO., LTD. |




| Fig. 5.6-4 | SIMULATED GROUNDWATER LEVEL OF MIDDLE AQUIFER |
|---|---|
| CAVITE WATER SUPPLY DEVELOPMENT STUDY | |
| JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | KOKUSAI KOGYO CO., LTD. |

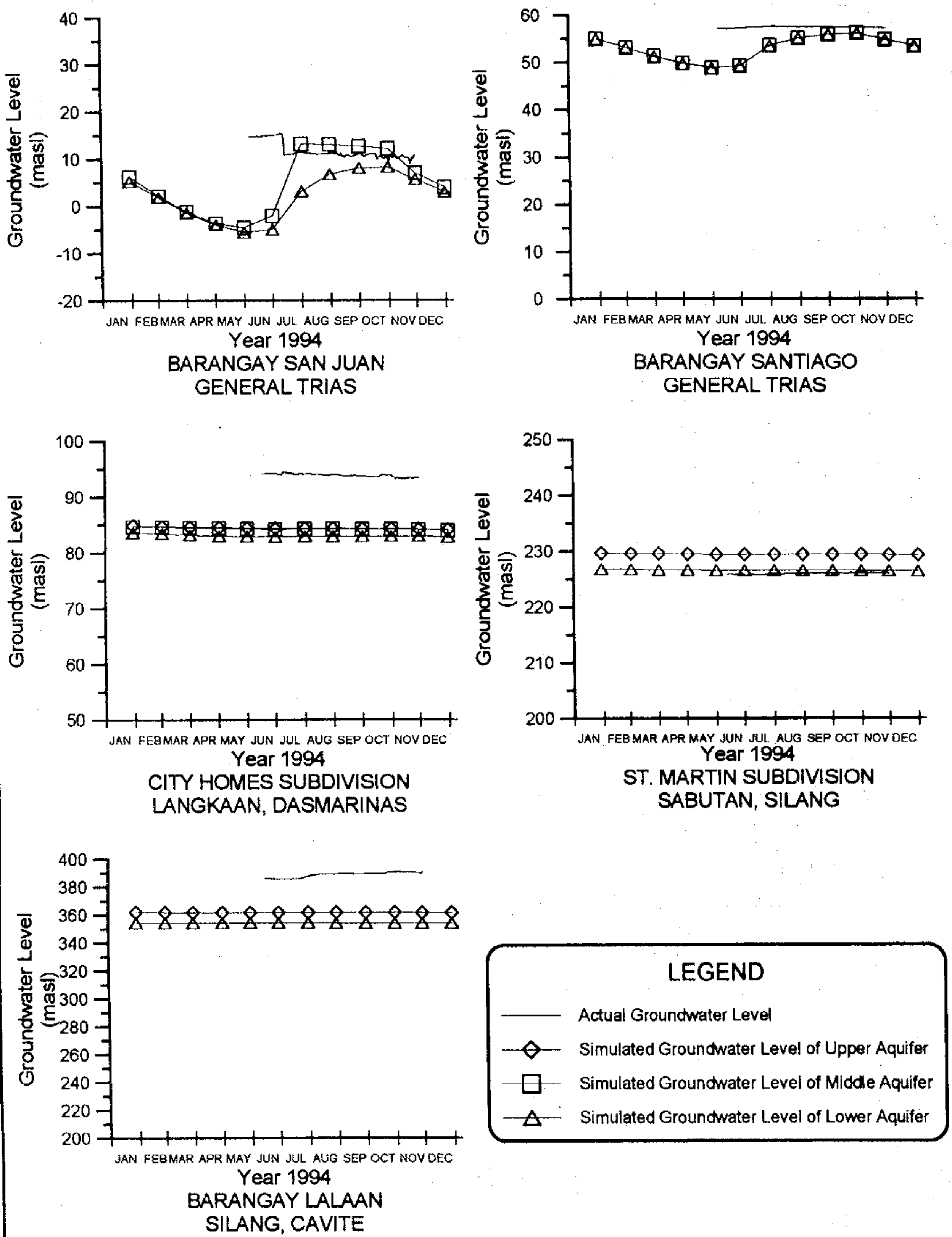



Actual groundwater level in 1994 (masl)

Simulated groundwater level in 1994 (masl)

Boundary of aquifer

| Fig. 5.6-5 | SIMULATED GROUNDWATER LEVEL OF LOWER AQUIFER |
|---|---|
| CAVITE WATER SUPPLY DEVELOPMENT STUDY | |
| JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | KOKUSAI KOGYO CO., LTD. |




| Fig. 5.6-6 | SIMULATED AND ACTUAL GROUNDWATER LEVELS AT JICA MONITORING STATIONS |
|---|---|
| CAVITE WATER SUPPLY DEVELOPMENT STUDY | |
| JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | KOKUSAI KOGYO CO., LTD. |