CHAPTER 6

WELL INVENTORY AND GROUNDWATER USE SURVEY

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CHAPTER 6 WELL INVENTORY AND GROUNDWATER USE SURVEY

6.1 WELL INVENTORY

6.1.1 Introduction

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

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

6.1.2 Previous Well Inventory

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

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

6.1.3 Collection of Well Inventory Data

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

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

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

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

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

6.2 GROUNDWATER USE SURVEY

6.2.1 Objectives and Area Coverage

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

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

6.2.2 Survey Methods

<u>Data Gathering</u>

Wells were identified either as MWSS or private wells.

MWSS Wells

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

Private Wells

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

Private wells were sub-classified as follows:

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

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

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

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

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

(2) By type of user

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

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

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

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

a) Small - < 0.5 lps/m

b) Medium - 0.5 - 1.0 lps/m

c) Large - > 1.0 lps/m

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

Sample Selection

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

o Substitution

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

o Grounds for substitution

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

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

Questionnaire

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

Field Work

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

o Orientation of interviewers

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

<u>Estimation of the Average Annual Pumpage of Well</u>

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

(1) Use of Groundwater

P(ijkw) = Q(ijkw) x Y(ijkw) x 0.000001
where, P(ijkw) = pumpage of well w for sub-classification ijk,

in MCM

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

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

w = sampled well

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

Sub-classification:

i = depth of depression

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

j = specific capacity

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

k = type of user

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

(2) Well production/Operation Data

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

where, P(ijkw) = as previously defined

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

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

(3) Pump and Motor Data

$$P(ijkw) = RC(ijkw) \times H(ijkw) \times D(ijkw) \times 0.0001872$$

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

<u>Estimation of the Average Annual Pumpage of Wells by Sub-classification</u>

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

$$P(ijk) = P(ijkw) \times W(ijk)$$

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

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

$$P(i) = \sum_{jkw}\sum\sum P(ijkw) \times n(ijk)$$

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

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

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

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

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

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

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

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

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

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

Estimation of Groundwater Use for the Study Area

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

where, GWU = groundwater use in MCM

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

Estimation of the Year-1990 Groundwater Pumpage by Groundwater Simulations

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

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

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

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

4. Compare simulated piezometric heads and actual piezometric heads.

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

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

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

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

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

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

11. Modify pumpage data and input to the model.

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

13. Compute final pumpage modification coefficient at each element.

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

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

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

2. Pumpage of MWSS wells remains constant.

3. Year-1981 pumpage is not modified.

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

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

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

6.2.3 Survey Results

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

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

AVERAGE YIELD PER WELL (in lps)

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

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

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

TABLE 6.2.1 DISTRIBUTION OF SAMPLES

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1. By Type of User and Area of Depression

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

TABLE 6.2.1 (CONTINUATION)

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

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

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

TABLE 6.2.1 (CONTINUATION)

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

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

(in MCM)

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

TABLE 6.2.2 (CONTINUATION)

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

Source: Study Team's Survey Data

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

(in LPS)

Type of User/ Specific Capacity	Depth of Depression			
	+10m to +0m	+0m to -40m	-40m to -80m	-80m to -120m
PUBLIC - DOMESTIC				
Specific Capacity				
Small	7.7478	5.7018	4.0321	2.0400
Medium	6.4470	9.7560	6.0767	2.0400
Large	10.5500	11.5176	8.3100	2.1900
PUBLIC - INSTITUTION				
Specific Capacity				
Small	8.0600	5.2220	3.2425	4.7300
Medium	6.0640	3.8262	2.9940	4.7300
Large	6.0859	6.8570	2.9940	4.7300
COMMERCIAL				
Specific Capacity				
Small	4.6500	14.8460	3.4825	3.4825
Medium	4.6500	12.3200	8.2100	8.2100
Large	4.6500	9.5314	8.2100	8.2100
INDUSTRIAL - FOOD & BEVERAGES				
Specific Capacity				
Small	7.3600	12.0760	8.2357	8.1167
Medium	5.7575	9.5400	8.4512	8.4512
Large	5.7575	11.1942	8.4512	8.4512
INDUSTRIAL - CHEMICALS				
Specific Capacity				
Small	11.0400	2.6350	6.1714	4.5925
Medium	9.8200	2.6390	6.1540	4.5925
Large	9.8200	3.0733	6.1540	5.9233
INDUSTRIAL - LEATHER				
Specific Capacity				
Small	12.5000	12.5000	12.5000	12.5000
Medium	12.5000	12.5000	12.5000	12.5000
Large	12.5000	12.5000	12.5000	12.5000

TABLE 6.2.3 (CONTINUATION)

Type of User/ Specific Capacity	Depth of Depression			
	+40m to +0m	+0m to -40m	-40m to -80m	-80m to -120m
INDUSTRIAL - TEXTILE, PAPER & PULP				
Specific Capacity				
Small	11.2882	8.7667	12.8543	7.4686
Medium	13.0486	20.1300	9.3633	7.8900
Large	13.7982	16.7162	13.5344	7.4656
INDUSTRIAL - OTHERS				
Specific Capacity				
Small	0.2350	4.5624	5.1125	1.1700
Medium	12.1360	10.7821	2.8400	3.9333
Large	9.1243	13.7975	6.2225	10.2600

Source: Study Team's Survey Data

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

Type of User/ Specific Capacity	Depth of Depression			
	+40m to +0m	+0m to -40m	-40m to -80m	-80m to -120m
PUBLIC - DOMESTIC				
Specific Capacity				
Small	11.3125	17.9773	17.5172	15.0000
Medium	14.1000	16.0333	12.6667	15.0000
Large	13.5000	16.6957	14.1667	24.0000
PUBLIC - INSTITUTION				
Specific Capacity				
Small	7.6667	16.2000	12.0000	24.0000
Medium	16.6000	14.9231	12.8000	24.0000
Large	12.0000	15.5926	12.8000	24.0000
COMMERCIAL				
Specific Capacity				
Small	17.6429	4.6000	17.5000	17.5000
Medium	17.6429	9.1538	15.0000	15.0000
Large	17.6429	10.2857	15.0000	15.0000
INDUSTRIAL - FOOD & BEVERAGES				
Specific Capacity				
Small	18.6667	10.8000	13.4286	11.3333
Medium	19.0000	20.6667	13.0000	13.0000
Large	19.0000	16.8333	13.0000	13.0000
INDUSTRIAL - CHEMICALS				
Specific Capacity				
Small	18.0000	13.0000	14.2857	16.5000
Medium	18.0000	13.0000	13.6000	16.5000
Large	18.0000	15.6667	13.6000	19.6667
INDUSTRIAL - LEATHER				
Specific Capacity				
Small	24.0000	24.0000	24.0000	24.0000
Medium	24.0000	24.0000	24.0000	21.0000
Large	24.0000	24.0000	24.0000	24.0000

TABLE 6.2.4 (CONTINUATION)

Type of User/ Specific Capacity	Depth of Depression			
	+40m to +0m	+0m to -40m	-40m to -80m	-80m to -120m
INDUSTRIAL - TEXTILE, PAPER & PULP				
Specific Capacity				
Small	19.4545	18.6667	19.7143	22.8571
Medium	22.0909	24.0000	17.6667	23.3333
Large	18.1818	22.7692	16.8889	22.8571
INDUSTRIAL - OTHERS				
Specific Capacity				
Small	24.0000	16.0345	16.8125	12.0000
Medium	8.4000	13.4286	16.5000	19.0000
Large	16.2857	17.9643	14.1250	10.8571

Source: Study Team's Survey Data

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

Type of User/ Specific Capacity	Depth of Depression			
	+40m to +0m	+0m to -40m	-40m to -80m	-80m to -120m
PUBLIC - DOMESTIC				
Specific Capacity				
Small	6.9688	6.7273	6.6897	7.0000
Medium	6.8500	6.9697	6.6667	7.0000
Large	7.0000	6.7609	6.3333	7.0000
PUBLIC - INSTITUTION				
Specific Capacity				
Small	7.0000	7.0000	6.7500	7.0000
Medium	6.8000	7.0000	6.5000	7.0000
Large	6.3889	6.8519	6.8000	7.0000
COMMERCIAL				
Specific Capacity				
Small	7.0000	6.6000	6.7500	6.7500
Medium	7.0000	6.8462	6.6667	6.6667
Large	7.0000	7.0000	6.6667	6.6667
INDUSTRIAL - FOOD & BEVERAGES				
Specific Capacity				
Small	6.0000	5.6000	6.7143	5.6667
Medium	5.7500	5.6667	6.7500	6.7500
Large	5.7500	5.7500	6.7500	6.7500
INDUSTRIAL - CHEMICALS				
Specific Capacity				
Small	7.0000	6.6000	6.5714	6.2500
Medium	7.0000	6.6000	6.7000	6.2500
Large	7.0000	6.3333	6.7000	7.0000
INDUSTRIAL - LEATHER				
Specific Capacity				
Small	6.0000	6.0000	6.0000	6.0000
Medium	6.0000	6.0000	6.0000	6.0000
Large	6.0000	6.0000	6.0000	6.0000

TABLE 6.2.5 (CONTINUATION)

Type of User/ Specific Capacity	Depth of Depression			
	+40m to +0m	+0m to -40m	-40m to -80m	-80m to -120m
INDUSTRIAL - TEXTILE, PAPER & PULP				
Specific Capacity				
Small	6.3636	7.0000	6.1429	6.2857
Medium	6.5000	6.3750	6.6667	6.3333
Large	6.1518	6.5385	6.1111	6.2857
INDUSTRIAL - OTHERS				
Specific Capacity				
Small	7.0000	6.8621	6.3750	6.0000
Medium	4.4000	6.2857	6.5000	6.6667
Large	6.8571	6.4286	6.8750	6.8571

Source: Study Team's Survey Data

Annex 6-A Groundwater Use Survey Questionnaire

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

GROUNDWATER USE SURVEY

JICA STUDY FOR GROUNDWATER DEVELOPMENT IN METRO MANILA

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

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

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PUMP AND MOTOR DATA
Type of Pump : ______________ Brand : ______________
Pump HP Rating : ________ Rated Pump Capacity : ______ LPS
Total Dynamic Head (TDH) : ______ M Pump Setting : ______ M
Brand of Motor : ______________ Motor HP Rating : ________

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LOCATION MAP

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

(PLEASE ANSWER NEXT PAGE AT THE BACK)

USE OF GROUNDWATER (CHECK THE TYPE OF USER)

_____ 1 - PUBLIC: DOMESTIC (Subdivisions, Condominiums)

Number of Households : ____________

Number of Persons in the Above Households: ____________

Quantity of Water Used for

a) Sewage Treatment : ________ M3/day

b) Boiler and Cooling System : ________ M3/day

c) Others : ________ M3/day

TOTAL (a+b+c) : ________ M3/day

_____ 2 - PUBLIC: INSTITUTION (Schools, Public Administration Bldgs, Hospitals, Military Camps)

Number of Employees : ____________

Number of Enrollees/In-patients : ____________

Quantity of Water Used for

a) Drinking and Sanitation : ________ M3/day

b) Sewage Treatment : ________ M3/day

c) Boiler and Cooling System : ________ M3/day

d) Others : ________ M3/day

TOTAL (a+b+c+d) : ________ M3/day

_____ 3 - COMMERCIAL (Office Bldgs, Malls, Department Stores, Restaurants, Clubs, Hotels, Parks)

Number of Employees : ____________

Number of Guests/Customers per Day : ____________

Quantity of Water Used for

a) Drinking and Sanitation : ________ M3/day

b) Boiler and Cooling System : ________ M3/day

c) Irrigation : ________ M3/day

d) Others : ________ M3/day

TOTAL (a+b+c+d) : ________ M3/day

_____ 4 - INDUSTRIAL: FOOD and BEVERAGES

_____ 5 - INDUSTRIAL: CHEMICALS, DISTILLERIES, DRUGS

_____ 6 - INDUSTRIAL: LEATHER AND FOOTWEAR

_____ 7 - INDUSTRIAL: TEXTILE, PAPER and PULP

_____ 8 - INDUSTRIAL: OTHERS (Specify: ________________________)

COMMON TO TYPES 4 -> 8 (INDUSTRIAL)

Output per Day in Tons : ______ tons/day

(One Ton= 1000Kgs= One M3 of Water)

Quantity of Water Used per Ton of Output : ________ M3/ton

Total Quantity of Water Used : ________ M3/day

Number of Employees/Workers : ____________

Quantity of Water Used for

a) Drinking and Sanitation : ________ M3/day

b) Wastewater Treatment : ________ M3/day

c) Boiler and Cooling System : ________ M3/day

d) Irrigation : ________ M3/day

e) Others : ________ M3/day

TOTAL (a+b+c+d+e) : ________ M3/day

CHAPTER 7

WELL REHABILITATION SURVEY

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7.1 SURVEY AT WELL SITES

7.1.1 Survey Methodology

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

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

7.1.2 Present Condition of MWSS Wells

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

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

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

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

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

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

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

7.2 DETAILED SURVEY OF SELECTED WELLS

7.2.1 Scope and Specifications

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

A. TWO WELLS

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

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

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

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

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

B. TWELVE WELLS

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

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

- Measurement of static water level

7.2.2 Results of the Survey

(1) Cogeo No.1, Antipolo

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

The well and pumping unit have these following characteristics:

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

Insulation resistivity 1.5 megaohms
(Low)

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

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

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

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

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

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

(2) Cogeo No. 6, Antipolo

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

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

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

(3) Lagro No.5, Quezon City

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

Present condition of the well is as follows:

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

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

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

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

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

The condition of the well is as follows:

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

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

(5) Alabang Junction, Muntinlupa

The condition of the well is as follows:

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

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

(6) Malanday, San Mateo

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

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

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

(7) Dulong Bayan, San Mateo

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

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

No sandy materials were observed in the groundwater during pumping.

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

(8) Sumulong, Taytay

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

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

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

(9) Bangiad, Taytay

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

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

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

(10) Zapote, Las Piñas

The pumping test results are as follows:

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

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

(11) Naga Road No.2, Las Piñas

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

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

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

(12) Topacio Elementary School, Imus

The results are as follows:

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

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

(13) **Dalahican, Cavite City**

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

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

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

(14) **Forbes Park No.12, Makati**

The well characteristics are:

Well depth	304.80m
Static water level	48.50m

The pump unit was installed in September 1990.

(15) **Forbes Park No.11, Makati**

The well characteristics are:

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

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

(16) **Maricaban III, Pasay City**

Results of pumping test show:

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

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

7.2.3 Summary of the Survey

(1) Recommended for well rehabilitation

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

(2) Well in good condition

Bangiad, Taytay

(3) Improvement in water quality could not be expected

Zapote, Las Piñas

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

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

(5) Check and follow up the well condition

Lagro No.5, Quezon City

7.3 EXPERIMENTAL REHABILITATION WORK

7.3.1 Work Outline

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

The experimental work for rehabilitation involves the following activities:

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

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

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

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

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

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

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

First Pumping Test

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

(1) Step-drawdown Test

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

(2) Constant Discharge Test

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

(3) Recovery Test

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

(4) Flow Measurement

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

Surging and Bailing

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

Airlifting

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

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

Second Pumping Test

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

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

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

7.3.2 Effect of Rehabilitation

The results of experimental works are summarized in Table 5.3.2.

(1) Sumulong, Taytay Deepwell

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

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

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

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

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

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

(2) Cogeo Antipolo No. 1, Antipolo

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

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

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

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

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

The specific capacity was noted to have improved from 17.0 m2/day. Aquifer loss coefficient and well loss coefficient have also improved. This may indicate that the clogging of the well screen and aquifer were removed by rehabilitation work.

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

(3) Cogeo No. 6, Antipolo

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

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

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

The continuous pumping test was conducted at a discharge rate of 150 l/min. Duration of pumping for the first pumping test was 22 hours. Although it was planned for forty eight (48) hours, pumping was aborted due to power failure (brown out). Duration of the second pumping test was 48 hours. The discharge rate was small because the pumping water level declined rapidly and reached the pump setting position.

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

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

(4) IBP (Congress) No.3

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

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

(5) Naga Road No.2

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

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

For the first pumping test, the values of well loss parameters B and C obtained from Q-s/Q graphs were 3.20x10^{-2} day/m^{2} and 6.20x10^{-6} day^{-2}/m^{5}, respectively; for the second, 2.95x10^{-2} day/m^{-2} and 6.20x10^{-6} day^{-2}/m^{5}, respectively. Well efficiencies were calculated at 92.3% at the first pumping test and at 90.2% at the second. Discharge rate was 300 l/min (432 m^{3}/day).

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

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

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

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

7.3.3 Recommendations

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

(1) Sumulong, Taytay

The control panel of the submersible electric motor and all columns of riser pipes should be replaced. The submersible pump should have a smaller diameter and capacity than the existing one has. Pump should be set deeper because the diameter of the well casing pipes was reduced from 8" to 6" at a depth of 80.77m, and the pumping water level is below this depth when the well was pumped at a discharge rate of 240 l/min. Submersible cable should be replaced because its insulation resistance reading is only 10 megaohms.

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

(2) Cogeo No.1, Antipolo

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

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

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

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

(3) Cogeo No.6, Antipolo

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

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

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

(4) IBP (Congress) No.3

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

(5) Naga Road No.2

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

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

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

TABLE 7.1.1A (CONTINUATION)

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

TABLE 7.1.1A (CONTINUATION)

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

TABLE 7.1.1A (CONTINUATION)

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

Notes: Blank of actual condition is good condition.

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

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

TABLE 7.1.1B (CONTINUATION)

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

TABLE 7.1.1B (CONTINUATION)

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

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

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

TABLE 7.1.1C (CONTINUATION)

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

TABLE 7.1.1C (CONTINUATION)

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

TABLE 7.1.2 WELL CONDITIONS OF MWSS DEEP WELLS

(NUMBER OF WELLS)

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

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

UNIT: NUMBERS OF WELLS

MUNICIPALITY	Pumping Rate (l.p.s.)	ACTIVE WELLS			Inactive Wells	Abandoned Wells	EXISTING WELLS		
		Good	Damaged	Total			Good	No Good	Total
ANTIPOLO	153.29	11	4	15	0	1	11	5	16
BACOOR	74.00	8	0	8	0	2	8	2	10
CALOOCAN	0.00	0	0	0	2	1	0	3	3
CAINTA	56.36	3	2	5	2	2	3	6	9
CAVITE	92.59	12	3	15	0	7	12	10	22
IMUS	24.33	2	0	2	0	3	2	3	5
KAWIT	51.62	4	0	4	2	1	4	3	7
LAS PIÑAS	18.08	0	2	2	3	3	0	8	8
MANDALUYONG	0.00	0	0	0	0	3	0	3	3
MAKATI	95.77	6	5	11	23	1	6	29	35
MALABON	8.67	1	2	3	3	3	1	8	9
MANILA	0.00	0	0	0	0	3	0	3	3
MARIKINA	0.00	0	0	0	13	2	0	15	15
MONTALBAN	48.75	3	0	3	0	2	3	2	5
MUNTINLUPA	72.84	5	2	7	0	0	5	2	7
NAVOTAS	5.05	1	1	2	7	0	1	8	9
NOVELETA	88.38	9	0	9	0	0	9	0	9
PARAÑAQUE	33.09	5	0	5	2	5	5	7	12
PASAY	39.75	1	2	3	1	1	1	4	5
PASIG	3.25	1	1	2	1	2	1	4	5
PATEROS	0.00	0	0	0	0	2	0	2	2
QUEZON	191.24	14	2	16	9	0	14	11	25
ROSARIO	12.67	1	0	1	2	0	1	2	3
SAN JUAN	0.00	0	0	0	0	0	0	0	0
SAN MATEO	54.33	3	2	5	0	3	3	5	8
TAGUIG	10.00	1	2	3	1	3	1	6	7
TAYTAY	65.19	6	1	7	0	1	6	2	8
VALENZUELA	11.59	2	1	3	4	1	2	6	8
TOTAL	1210.84	99	32	131	75	52	99	159	258

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

TABLE 7.1.4 NUMBER OF WELLS UNDER UNSATISFACTORY CONDITIONS, BY MUNICIPALITY

UNIT: NUMBER OF WELLS

MUNICIPALITY	TYPE OF CAUSE OF DAMAGE															ANOTHER REASON				OTHERS			TOTAL			
	D PUMP			SALTY			CAVED-IN			DIRTY			DRY			STAND	REHAB	ADEQUATE		OTHERS			TOTAL			GT
	A	I	Ab	A	I	Ab	A	I	Ab	A	I	Ab	A	I	Ab	I	I	I	Ab	A	I	Ab	A	I	Ab	
ANTIPOLO	4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	1	5
BACOOR	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	2
CALOOCAN	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	1	3
CAINTA	1	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	1	0	0	2	2	2	6
CAVITE	0	0	0	1	0	1	0	0	5	0	0	0	0	0	1	0	0	0	0	2	0	0	3	0	7	10
IMUS	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	3
KAWIT	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	1	3
LAS PINAS	1	1	0	1	0	3	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	3	3	8
MANDALUYONG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	3	3
MAKATI	3	5	0	0	0	0	0	0	0	0	0	1	0	0	0	0	18	0	0	2	0	0	5	23	1	29
MALABON	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	1	0	2	0	2	2	3	3	8
MANILA	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3
MARIKINA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	3	2	2	0	0	0	0	13	2	15
MONTALBAN	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
MUNTINLUPA	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2
NAVOTAS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	1	0	0	1	7	0	8
NOVELETA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PARANAQUE	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	5	7
PASAY	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	2	1	1	4
PASIG	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	2	4
PATEROS	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
QUEZON	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	5	0	1	1	0	2	9	0	11
ROSARIO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	2
SAN JUAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SAN MATEO	0	0	0	0	0	0	1	0	0	1	0	2	0	0	0	0	0	0	0	0	0	1	2	0	3	5
TAGUIG	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	2	1	3	6
TAYTAY	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2
VALENZUELA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	1	0	1	1	4	1	6
TOTAL	13	9	3	2	0	17	1	0	14	3	0	5	0	0	3	16	25	23	6	13	2	4	32	75	52	159
G.T.	25			19			15			8			3			16	25	29		19			159			159

Notes:

- D PUMP - Defective pump/ motor unit
- SALTY - Salty water yields
- CAVED-IN - Well caved-in
- DIRTY - Dirty Water yields
- DRY - Well is almost dry
- STAND - Stand-by
- REHAB - Recommended for rehabilitation
- ADEQUATE - Adequate water supply

- A - Active wells
- I - Inactive wells
- Ab- Abandoned wells

TABLE 7.3.1 WELL LIST OF THE EXPERIMENTAL WORK ON REHABILITATION

Well Name	Municipality	Status	Total Depth	Casing Pipe Position Size	Well Screen Position	Exist. Pump		Test Pump		Pump After Rehab.	
						Set.	Cap.	Set.	Spec.	Set.	Spec.
Cogeo Antipolo No.1	Antipolo	In-active	91.44m	0m-9.75m 8" 9.75-91.44 6"	64m-87.78m	66m	7.5 Hp	78m	SP8-21 7.5HP OD 133	3" 78m	Existing Pump Installed
Sumulong	Taytay	In-active	202.69	0-80.77 8" 80.77-202.7 6"	Unknown	75	30	78m 120m	30 HP 10 HP OD 133mm	NO	No Pump Installed
Naga Road No.2	Las Pinas	Active	243.84	0-243.84 10"	103.63-121.91 128.01-158.49 164.59-170.68 182.88-213.36 219.45-237.74	78	30	120m 102m	SP45-12 30HP OD 150	3" 102m	Existing Pump Installed
IBP (Congress) No.3	Quezon City	In-Active	202.69	0-80 10" 80-202.69 8"	87-99 103-122 129-144 151-166 173-197	120	20	108	20 HP 9 stage OD 140	NO	No Pump Installed
Cogeo Antipolo No.6	Antipolo	In-Active	117.35	0-91.44 8"	91.44-177.35 bore hole	99	20	90	20 HP 9 stage OD 140	NO	No Pump installed

TABLE 7.3.2 EXPERIMENTAL REHABILITATION WORK RESULTS

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

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

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

TABLE 7.3.4 STATUS OF EXISTING PUMPING FACILITIES

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

Sumulong Taytay

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

IBM #3

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

Cogeo Antipolo #1

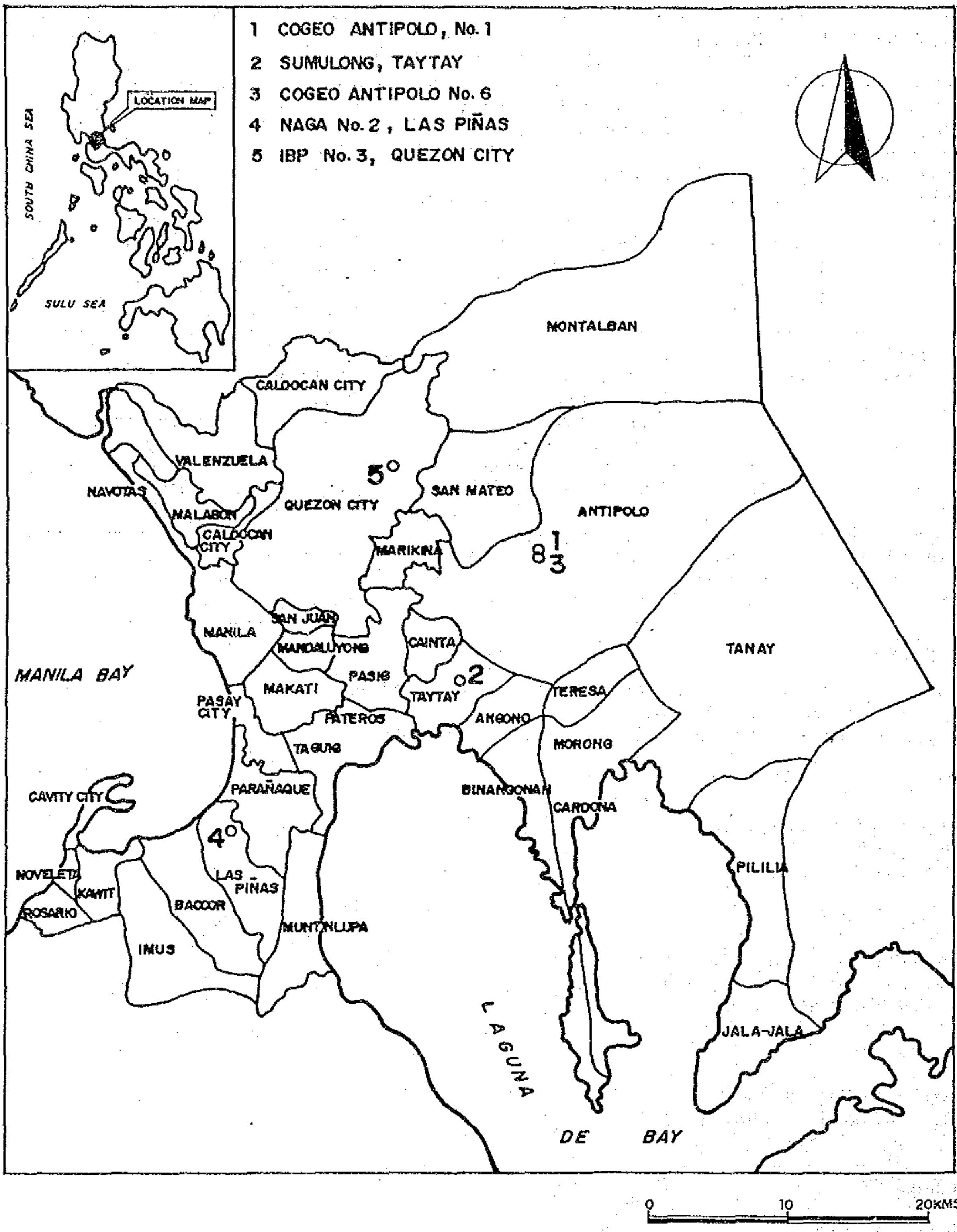
Grundfos pump model - sp 16-10
Franklin Electric motor 7.5 Hp
11 pcs 3"Ø riser pipes

Cogeo Antipolo #6

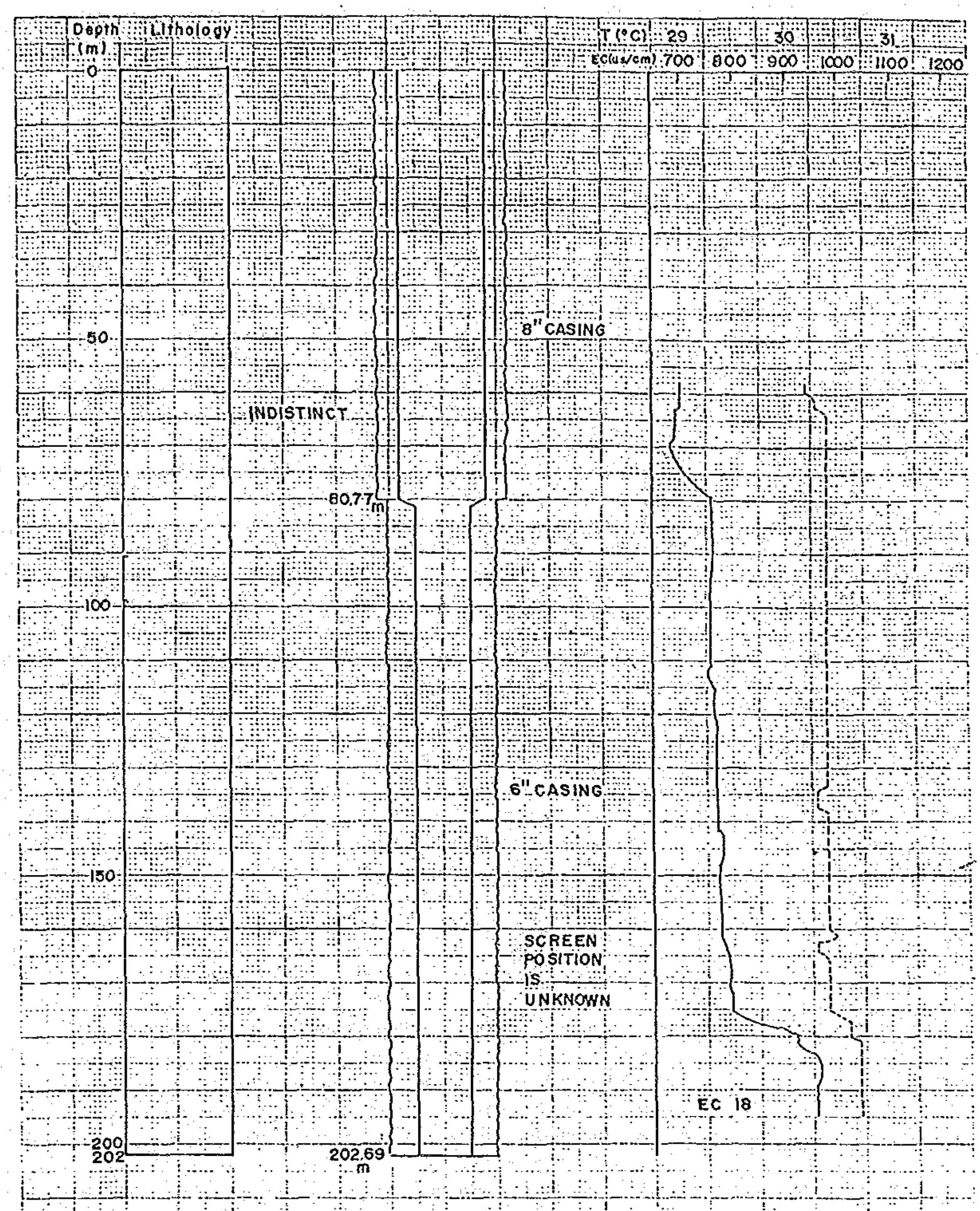
Fairbanks Morses Pumps
Colt Industries motor 20 Hp
16.5 pcs 3"Ø riser pipes

Naga Road #2

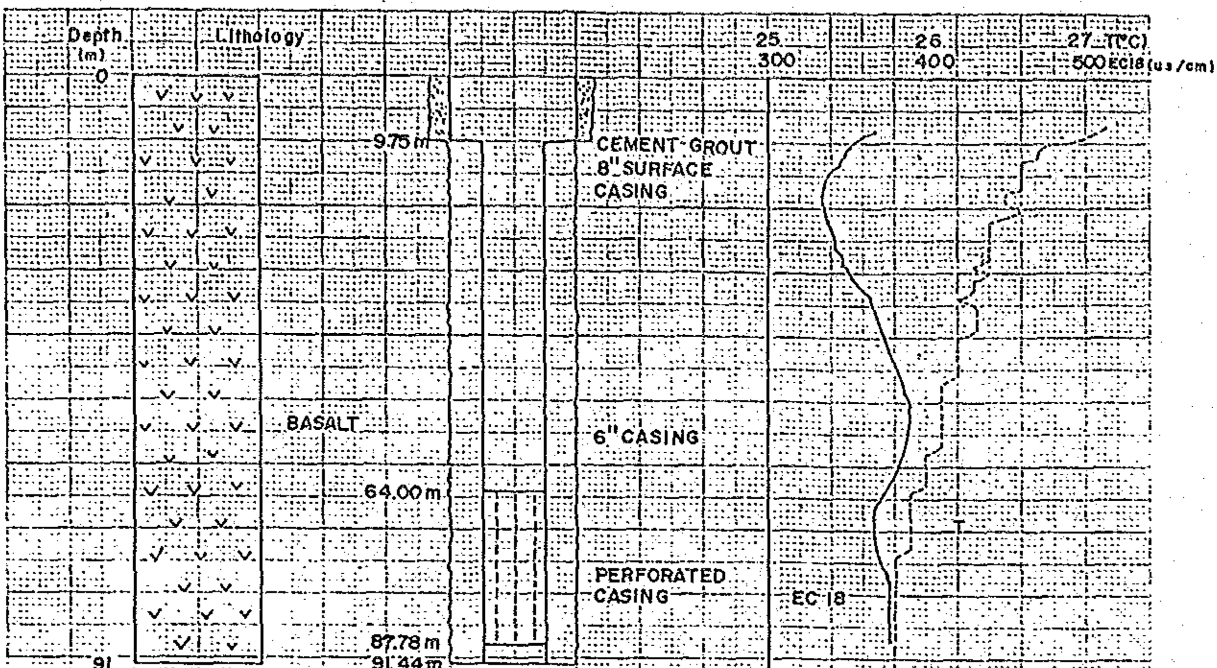
Grundfos pump
Franklin Electric motro 30 Hp
13 pcs 4"Ø riser pipes



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



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA	FIGURE 7.3.2
JAPAN INTERNATIONAL COOPERATION AGENCY	DETAILS OF MWSS WELLS FOR REHABILITATION (SUMULONG TAYTAY)

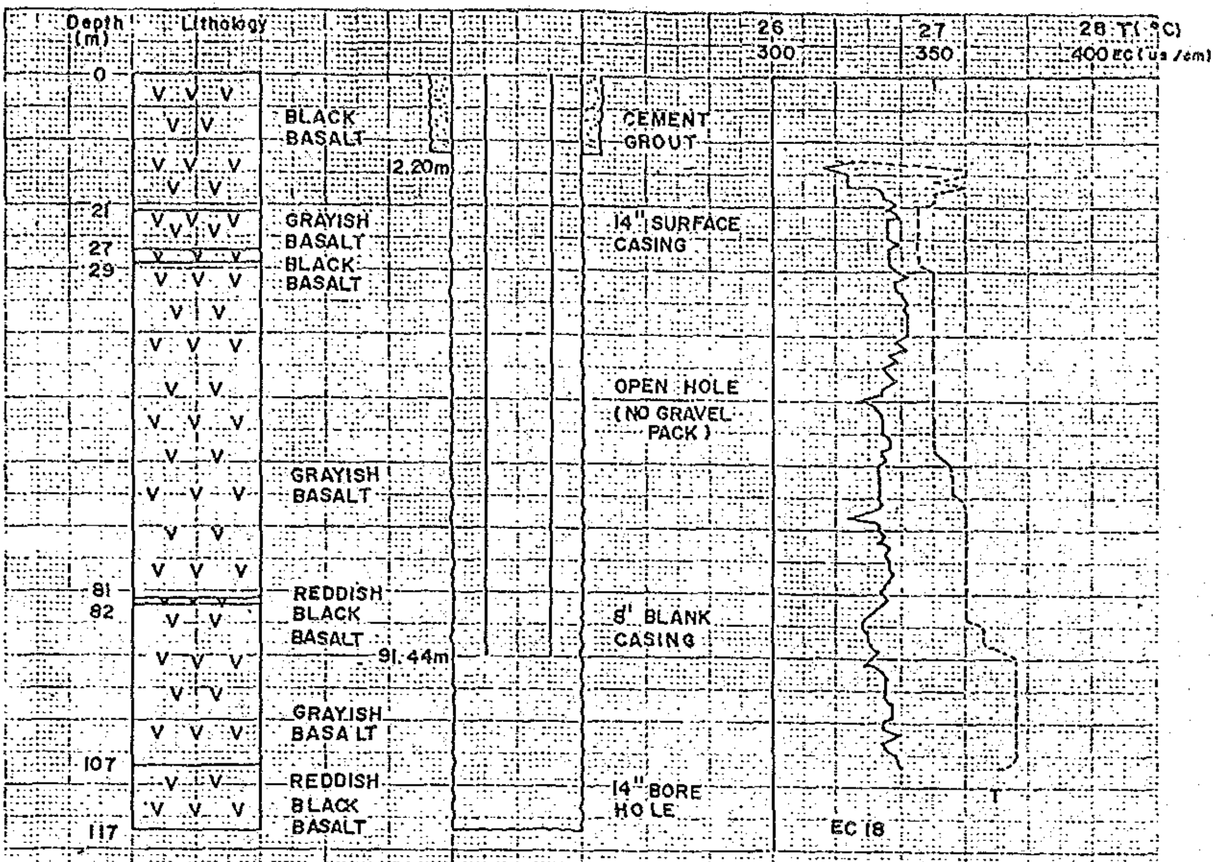


STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

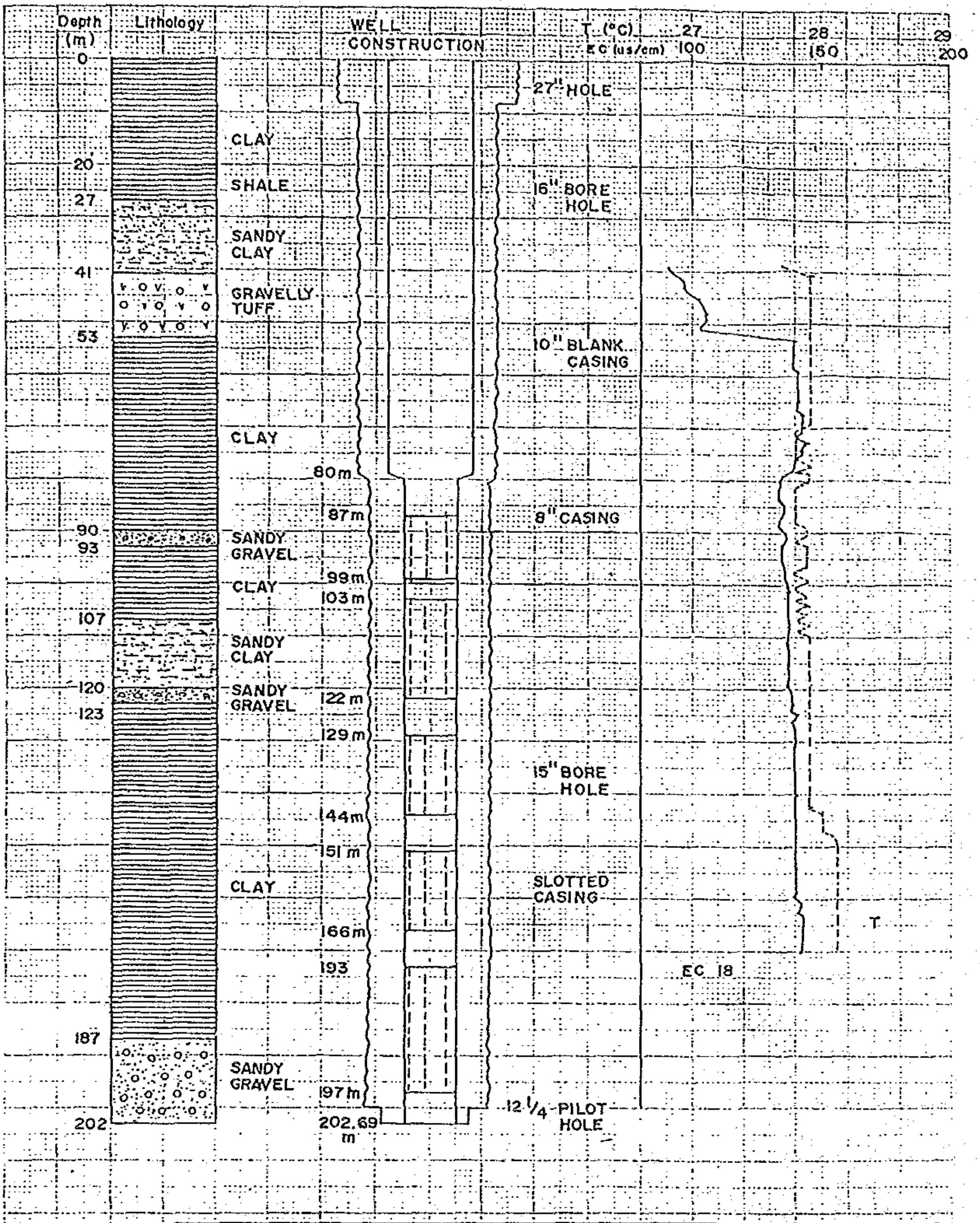
JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 7.3.3

DETAILS OF MWSS WELLS FOR REHABILITATION (COGEO ANTIPOLO NO. 1)



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



STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

FIGURE 7.3.5

DETAILS OF MWSS WELLS FOR REHABILITATION (IBP NO. 3)

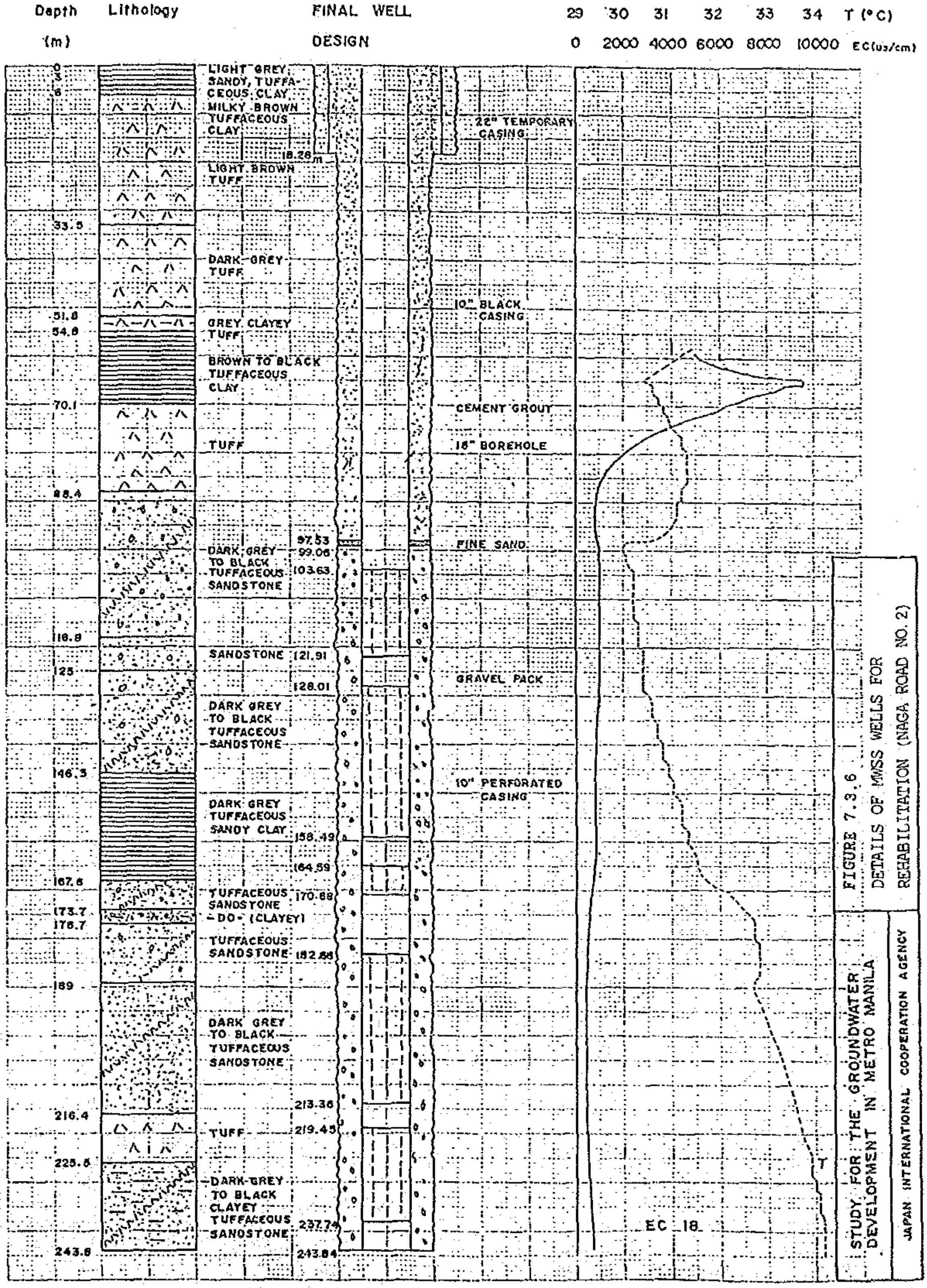


FIGURE 7.3.6 DETAILS OF MWSS WELLS FOR REHABILITATION (NAGA ROAD NO. 2)

STUDY FOR THE GROUNDWATER DEVELOPMENT IN METRO MANILA

JAPAN INTERNATIONAL COOPERATION AGENCY

CHAPTER 8

GROUNDWATER MODELING

CHAPTER 8 GROUNDWATER MODELING

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CHAPTER 8 GROUNDWATER MODELING

8.1 GENERAL

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

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

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

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

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

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

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

8.2 GROUNDWATER FLOW MODEL

8.2.1 Model Concept

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

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

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

8.2.2 Groundwater Flow Equation

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

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

where,

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

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

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

where,

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

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

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

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

8.2.3 Required Input Data and Output Data

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

for model framework

Element data
Node data
Boundary conditions
Model control card

for hydrogeological settings

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

for groundwater use

Discharge data

The output data from the model are:

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

8.2.4 Model Assumption

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

8.2.5 Model Calibration

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

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

8.3 SOLUTE TRANSPORT MODEL

8.3.1 Model Abstract

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

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

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

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

MOC couples the groundwater flow equation with the non-conservative solute-transport equation. The computer program uses the ADI or SIP procedure to solve the finite-difference approximation of the ground-water flow equation. The SIP procedure for solving the groundwater flow equation is most useful when areal discontinuities in transmissivity exist or when the ADI solution does not converge.

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

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

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

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

8.3.2 Theoretical Background

(1) Flow Equation

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

$$\frac{\partial}{\partial x_i}\left(T_{ij}\frac{\partial h}{\partial x_j}\right) = S\frac{\partial h}{\partial t} + W \qquad i,j=1,2 \qquad (8.3.1)$$

where,

- T_{ij} : the transmissivity tensor, L^2/T;
- h : the hydraulic head, L;
- S : the storage coefficient, (dimensionless);
- t : the time, T;
- $W(x,y,t)$: the volume flux per unit area, L/T; and
- x_i and x_j: the Cartesian coordinates, L.

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

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

where,

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

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

$$V_i = -\frac{K_{ij}}{\varepsilon}\frac{\partial h}{\partial x_j} \qquad (8.3.3)$$

where,

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

(2) Transport Equation

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

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

where,

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

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

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

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

where,

$\bar{C}$: the concentration of solute (absorbed or exchanged) in the porous medium, M/M;

b: the porous medium bulk density, M/L; and

: the decay rate constant, 1/T.

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

$$\frac{\partial C}{\partial t} + \frac{\rho b}{\varepsilon}\frac{d\bar{C}}{dt} = \frac{1}{b}\frac{\partial}{\partial xi}\left(bDij\frac{\partial C}{\partial xj}\right) - Vi\frac{\partial C}{\partial xi} + \frac{W(C-C')}{\varepsilon b} - \lambda C - \frac{\rho b}{\varepsilon}\lambda\bar{C}$$

(8.3.6)

(3) Dispersion Coefficient

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

Bear (1972) further states that the separation between the two processes is artificial. In this model, it is assumed that for flowing groundwater systems the definable contribution of molecular and ionic diffusion to hydrodynamic dispersion is negligible. The dispersion coefficient may be related to the velocity of groundwater flow and to the nature of the aquifer by using Scheidegger's (1961) equation:

$$D_{ij} = \alpha_{ijmn} \frac{V_m V_n}{|V|} \qquad (8.3.7)$$

where,

ijmn : the dispersivity of the aquifer, L;

V_m *and* V_n: components of velocity in the m and n direction, respectively, L/T; and

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

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

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

and

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

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

$$D_{xx} = D_L \frac{(V_x)^2}{|V|^2} + D_T \frac{(V_y)^2}{|V|^2} ; \qquad (8.3.10)$$

$$D_{yy} = D_T \frac{(V_x)^2}{|V|^2} + D_L \frac{(V_y)^2}{|V|^2} ; \qquad (8.3.11)$$

$$D_{xy} = D_{yx} = (D_L - D_T) \frac{V_x V_y}{|V|^2} , \qquad (8.3.12)$$

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

8.3.3 Numerical Methods

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

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

(1) Flow Equation

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

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

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

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

where,

- *i,j,k* : indices in the x, y, and time dimensions, respectively;
- *Wx, Wy, Wt*: increments in the x, y, and time dimensions, respectively; and
- *qw* : the volumetric rate of withdrawal or recharge at the (i,j) node, L^3/T.

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

(2) Transport Equation

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

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

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

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

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

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

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

where,

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

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

8.4 ANTIPOLO GROUNDWATER BASIN MODEL

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

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

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

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

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

8.4.1 Model Parameters and Boundary Conditions

(1) Boundary Conditions

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

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

(2) Model Parameters

Input parameters used in the model were collected/measured by the Study Team during study stages I to III. After data processing was completed, input data for the Q3P model were prepared. Those parameters were inputted to the model, and then modified and identified through model calibration. The period of model calibration is the ten (10) years from 1981 to 1990.

Model parameters used in the model are as follows:

(a) Transmissivity

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

(b) Storage coefficient

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

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

(c) Aquitard thickness and permeability

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

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

(d) Phreatic water level and initial heads

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

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

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

(e) Direct recharge

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

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

8.4.2 Verification of the Model

(1) Steady-state Simulation

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

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

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

(2) Nonsteady-state Simulation

The nonsteady-state simulation from 1981 to 1990 was carried out to simulate transient groundwater flow and decline of piezometric heads due to groundwater pumpage. The storage coefficient was also modified and identified throughout the simulation. The simulation period is divided into 10 time-steps, each time-step having 1 year (365 days).