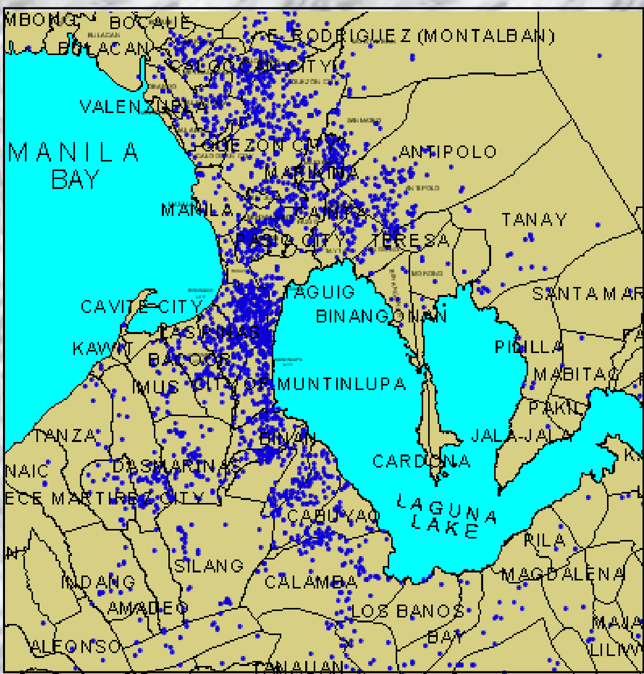
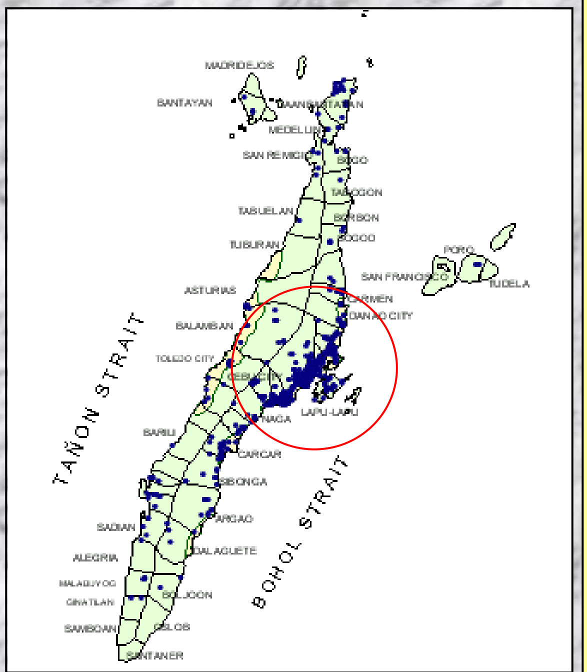
Republic of the Philippines
PAMBANSANG LUPON SA MGA YAMANG TUBIG
(National Water Resources Board)

WATER RESOURCES ASSESSMENT FOR PRIORITIZED CRITICAL AREAS (PHASE I)

FINAL REPORT
METRO MANILA



METRO MANILA



METRO CEBU

October 2004

CEST, Inc.

Executive Summary

1. Introduction

This assessment of water resources in Metro Manila and Metro Cebu will be applied as a tool for water use regulation. This will be replicated in other critical areas in subsequent studies.

The specific objectives of the Project are as follows:

- Inventory and updating of water related data and information;
- Mapping of updated water resources data and information;
- Evaluation of available water in prioritized critical areas of rapid growth expansion using modern techniques for evaluation; and
- Upgrading of capability of NWRB staff, through on-the-job training on water resources assessment, which include water balance computation and groundwater modeling, pumping test analysis, and earth electrical resistivity survey and interpretation.

The study was made following the sequence of activities below:

- Collection review and critiquing of available data and information;
- Field investigation and verification;
- Definition of aquifer geometry and characteristics;
- Groundwater modeling
- Calibration of groundwater model; and
- Training of NWRB staff on the use of the model, conduct of earth resistivity survey and interpretation of results, use of geographic information system in groundwater study, and conduct of pumping test and analysis of results.

2. Data Collection and Review

Prior to collection of data and information, coordinating meetings with concerned agencies were made. This is to inform and explain to these offices the necessary data and information needed in the study and to seek permission to enter into their properties, particularly well pumping stations. Other agencies were approached through writings. Among the government agencies coordinated were MWSS, MGB, LWUA, PAGASA and WELDAPHIL.

Secondary data and information obtained can be classified as reports, maps and drawings, well inventory data, water quality data, climatic data and hydrologic data.

Primary data were obtained through field investigations. A well inventory was conducted basically to acquire information on the current water level and water quality. For each well inventoried, the location (geographic coordinates), static water level and water quality were recorded. Among the water quality parameters examined on-site are electrical conductivity and total dissolved solids. Geo-resistivity surveys were conducted both in Metro Manila and MetroCebu.

3. The Study Area

The study area, from north to south, includes the following: the southern fringe of the Central Plain of Luzon that covers some towns of the Province of Bulacan; the cities and municipalities of Metro Manila; the western municipalities of the Province of Rizal; the northern towns of Laguna Province; northwestern portions of Laguna Lake; and portions of the Cavite Highlands

The delineated study area is bounded by the Meycauayan River in the north and extends towards the east through watershed dividing ridges leading to the western slopes of the South Sierra Madre Range. At the eastern side, only the catchment area (including Antipolo proper) that drains westward to the Marikina River Valley and to the western side of the Binangonan Peninsula form part of the study area. The Cañas River that starts from Tagaytay and terminates south of Cavite City into the Manila Bay bound the southwestern portion of the study area. The Santa Rosa River that originates from eastern Cavite Highlands and drains into Laguna de Bay bound the southeastern side of the study area.

All of the Pre-Quaternary age rocks form the hydrogeological basement of the study area. All members under this group have been described to have very low yielding water potential, except at localized fracture zones. Unconformably overlying the Pre-Quaternary basement rocks and underlying the Quaternary Alluvium is the Quaternary Volcanics, which has 3 members, the Guadalupe Formation, the Laguna Formation and the Taal Tuff, these three formations form the main host of the underlying aquifers of Metro Manila and the surrounding areas. These Quaternary Volcanic Sediments consist of intercalations of clay, silt, sand, and gravel lenses that have been described to dip gently toward the west in the central portion of the study area. The Quaternary Alluvium is generally consists of unconsolidated sediments of gravel, sand, silt, and clay. These deposits are also considered important aquifers in the study area.

A greater part of the study area falls under the Type I climate that is characterized by having two pronounced season, dry from November to April and wet during the rest of the year. High elevation areas on the east experience a shift from Type I to Type III that is characterized by seasons that are not very pronounced, relatively dry from November to April and wet during the rest of the year. Based on the available PAGASA climatological-normals (1971 to 2000), the mean annual rainfall over the study area is around 2,000 mm varying from 1,750 (NAIA, Pasay) on the west to 2,500 mm on the north and eastern highlands.

Total land area of the Study Area is estimated at 2,212 square kilometers that covers areas within the National Capital Region (Metro Manila), and portions of the Provinces of Rizal, Bulacan, Laguna, Cavite, and Laguna Lake. In Metro Manila, built-up areas occupy 47% of its total area. That of Cavite occupies about 21%; in Laguna 19%; in Rizal 11%; and in Bulacan 26% of the land area of the respective provinces. Uncontrolled increase of the population and influx of migrants from provinces in search of employment in these growth areas of industry and commerce has been seen as a factor in the spread of built-up areas.

4. Population and Water Demand

Based on the estimate of future population, domestic water demand was projected. Commercial, industrial and agricultural water demands were also estimated. The table below presents the projected future population.

Population Projection Metro Manila

City/Municipality		Projected Population (x 1000)				
		2005	2010	2015	2020	2025
Cities						
1)	Las Piñas	609	759	953	1,114	1,290
2)	Manila	1,473	1,345	1,286	1,146	1,011
3)	Makati	443	432	426	391	356
4)	Mandaluyong	281	277	280	264	246
5)	Marikina	436	472	530	556	576
6)	Muntinlupa	468	558	639	682	720
7)	Parañaque	507	554	637	683	725
8)	Pasig	555	595	658	679	694
9)	Valenzuela	560	624	719	773	823
10)	Caloocan	1,339	1,471	1,701	1,833	1,956
11)	Pasay	359	353	344	313	282
12)	Quezon	2,285	2,343	2,533	2,554	2,549
Municipalities						
1)	Malabon	369	390	414	411	404
2)	Navotas	244	253	267	264	258
3)	Pateros	57	56	57	55	52
4)	San Juan	109	98	93	82	71
5)	Taguig	588	711	897	1,055	1,227
Metro Manila Total		10,682	11,291	12,434	12,855	13,240

Source: The Study on Water Resources Development for Metro Manila in the Republic of the Philippines, JICA

Population Projection Outside Metro Manila

City/Municipality		Projected Population				
		2005	2010	2015	2020	2025
Bulacan						
1)	Bulacan	70,066	81,167	94,297	109,561	128,570
2)	Guiguinto	79,848	97,271	117,192	139,610	164,526
3)	Malolos	206,231	249,942	299,964	356,421	419,486
4)	Marilao	122,417	151,704	184,713	221,434	261,498
5)	Norzagaray	106,288	144,618	187,817	233,916	278,931
6)	Obando	58,697	68,283	79,163	91,995	107,868
7)	Pandi	55,524	66,351	78,386	92,919	108,957
8)	San Jose Del Monte	394,219	498,918	617,003	745,664	882,555
9)	Santa Maria	170,802	208,070	250,682	298,636	351,932
Cavite						
1)	Cavite City*	97,000	94,000	92,000	89,000	85,000
2)	Bacoor*	362,000	421,000	492,000	564,000	638,000
3)	Imus*	240,000	289,000	334,000	379,000	424,000
4)	Kawit*	67,000	71,000	75,000	79,000	80,000
5)	Noveleta*	35,000	37,000	41,000	44,000	47,000
6)	Rosario*	83,000	90,000	104,000	119,000	135,000
7)	Carmona	54,985	65,482	76,958	89,338	230,060
8)	Dasmariñas	472,321	595,793	727,799	863,616	102,544
9)	Gen. Mariano Alvarez	126,839	149,095	204,542	200,705	997,394
10)	General Trias	133,446	167,803	173,717	242,410	279,865
11)	Silang	173,148	200,668	231,360	265,610	303,900
12)	Tagaytay City	55,062	68,291	82,466	97,215	112,067

City/Municipality		Projected Population				
		2005	2010	2015	2020	2025
13)	Tanza	129,978	157,383	187,014	218,451	251,174
14)	Trece Martires	46,984	55,229	64,349	74,347	85,220
Laguna						
1)	Biñan	238,246	280,118	326,435	377,190	432,370
2)	San Pedro	279,114	332,792	391,626	455,080	522,491
3)	Santa Rosa	225,965	271,293	320,787	373,795	429,504
Rizal*						
1)	Antipolo	692,000	984,000	1,376,000	1,860,000	2,453,000
2)	Angono	90,000	104,000	124,000	142,000	160,000
3)	Binangonan	209,000	228,000	264,00	296,000	323,000
4)	Cainta	338,000	454,000	587,000	733,000	894,000
5)	Rodriguez(Montalban)	130,000	144,000	173,000	201,000	228,000
6)	San Mateo	33,000	36,000	218,000	225,000	290,000
7)	Taytay	226,000	255,000	303,000	349,000	392,000

Source: The Study on Water Resources Development for Metro Manila in the Republic of the Philippines, JICA, 2003

Considering the future population, the water demand was estimated. The total water demand is the sum of domestic, commercial, industrial and unaccounted-for-water. This also represents the average water demand for the study area. The tables below present the total water demand up to year 2035.

Total Water Demand Within MWSS Service Coverage

Cities/Municipality		Total Water Demand MLD				
		2005	**2010**	**2015**	**2020**	**2025**
West Zone						
NCR						
1)	Pasay	97,174	101,538	108,966	113,125	118,286
2)	Caloocan	270,435	306,923	402,069	494,688	598,571
3)	Las Piñas	98,913	190,577	245,000	298,438	366,000
4)	Malabon	127,391	137,308	147,759	153,594	160,857
5)	Valenzuela	160,000	180,769	212,759	239,531	271,000
6)	Muntinlupa	67,609	130,385	153,448	171,094	195,857
7)	Navotas	68,478	73,462	82,759	89,844	97,000
8)	Parañaque	125,217	172,692	198,448	218,594	240,429
Cavite						
1)	Cavite City	30,870	29,038	28,103	27,500	27,000
2)	Bacoor	59,783	100,577	115,000	129,219	145,429
3)	Imus	24,130	46,154	52,586	59,688	72,143
4)	Kawit	19,130	20,577	21,034	21,875	22,286
5)	Noveleta	5,217	5,769	7,414	9,531	11,429
6)	Rosario	17,609	19,423	22,414	25,781	29,714
East Zone						
NCR						
1)	Mandaluyong	169,783	175,962	189,483	202,500	221,000
2)	Marikina	154,522	162,692	182,069	195,938	212,286
3)	Pasig	197,826	209,808	232,069	247,344	265,143

4) Pateros	18,261	18,077	18,621	18,750	18,857
5) San Juan	69,348	69,808	73,448	77,813	84,571
6) Taguig	44,348	62,115	133,966	226,094	349,000
Rizal	-	-	-		
1) Antipolo	40,435	69,423	187,069	379,531	681,000
2) Cainta	35,000	62,115	88,103	138,125	206,571
3) Angono	-	-	11,379	25,625	42,143
4) Binangonan	-	-	21,207	46,250	74,000
5) Rodriguez	13,261	15,769	26,724	39,844	55,000
6) San Mateo	19,348	23,269	36,724	52,969	71,429
7) Taytay	22,391	27,308	46,724	70,000	96,286
Common Concession Area					
NCR					
1) Quezon City	898,913	931,346	1,014,310	1,072,656	1,148,571
2) Manila	661,304	640,192	654,655	662,656	689,571
3) Makati	270,000	278,654	296,724	314,219	341,143

Source: The Study on Water Resources Development for Metro Manila in the Republic of the Philippines, JICA, 2003

Total Water Demand Outside MWSS Water Service Coverage

Cities/Municipality	Total Water Demand (m^3/d)				
	2005	2010	2015	2020	2025
Bulacan					
1) Bulacan	10,772	13,037	16,199	19,866	24,055
2) Guiguinto	12,278	15,947	20,136	25,313	30,784
3) Malolos (Capital)	35,108	47,156	60,814	78,093	95,796
4) Marilao	23,586	31,958	42,397	53,594	66,309
5) Norzagaray	16,340	23,703	32,268	42,408	52,188
6) Obando	9,023	11,191	13,604	16,679	20,183
7) Pandi	8,535	10,877	13,466	16,841	20,383
8) San Jose Del Monte 1	75,965	105,101	141,636	180,463	223,784
9) Santa Maria	29,076	39,254	50,819	65,429	80,367
Cavite					
1) Carmona	7,809	10,542	13,121	16,707	20,741
2) Dasmariñas	71,433	102,075	132,530	173,729	215,951
3) General Trias	16,484	30,425	31,274	41,505	51,757
4 Silang	26,819	34,378	42,132	53,432	65,800

)					
5) Tagaytay City	9,038	12,761	16,446	21,440	26,657
6) Tanza	18,942	26,151	32,977	42,535	52,600
7) Trece Martires City	7,103	9,465	11,716	14,953	18,455
8) Gen. Mariano Alvarez	19,877	26,322	32,639	41,666	51,448
Laguna					
1) Biñan	28,697	37,143	68,778	106,294	129,084
2) San Pedro	38,460	50,930	79,131	104,657	137,187
3) Santa Rosa	28,293	38,122	68,628	105,337	128,229

Note: Project Estimate

5. Water Resources

Surface Water

The Angat River and Umiray River are the main sources of water supply of Metro Manila, contributing about 98% of the total water production. In addition to the above supply, MWSS abstracts water from Ipo, La Mesa and groundwater. At present, MWSS supplies a total of 4,000 MLD.

MWSS is embarking to augment its present supply capacity by optimizing the use of the existing water sources and developing new sources. These involve the following:

- Wawa River Supply;
- Angat Water Utilization Improvement, and
- Laguna Lake Bulk Water Supply.

Other alternative water sources for Metro Manila are identified as follows:

- Kaliwa River Basin (Laiban Dam);
- Kanan River Basin (Kanan No. 2 Dam);
- Pampanga River Basin;
- Marikina River Basin; and
- Taal Lake.

Groundwater Sources

The delineated surface water catchments contributing groundwater to Metro Manila aquifer constitute individual aquifer system where their groundwater discharges into Manila Bay and before reaching the sea, merge forming complex type of aquifer system. The extent of groundwater basin is delineated based on the surface water divides.

High transmissivity values, as high as 308 m^2/day, are observed to exist in the area at the proximity of Constitutional Hill in Quezon City and similarly in the adjacent town of San Mateo, Rizal with values of 307 m^2/day. The upgradient municipality of Montalban nearer to San Mateo has also high T-values, up to 240 m^2/day. In lower Marikina to Cainta, high values of transmissivities also exist to about 200 m^2/day. In the southern areas, high T-values are observed adjacent to Laguna Lake, particularly at Muntinlupa where the Marikina Valley Fault System is located. The existence of ancillary faults and fractures adjacent the main fault accounts for the development of secondary permeability of the aquifers.

Earth Resistivity

As part of this Project, georesistivity surveys were conducted in Metro Manila. In general, the georesistivity survey results confirmed the continuity and presence of the Guadalupe Formation underlying the subsurface that hosts the aquifers in Metro Manila.

Groundwater Levels

The 1955 piezometric map indicates that in the northern part near Novaliches reservoir and at +60 contour in the groundwater divide, two separating groundwater flow directions exist. One towards southeast direction to Marikina Valley and the other towards southwest direction to Pasig River near the sea. In the southern portion west of Muntinlupa, at +20 contour in the groundwater divide, two separating groundwater flows are also depicted by the groundwater level map. One direction of groundwater flow is towards the northeast to Laguna Lake and the other is towards the northwest to Manila Bay in Bacoor area. In the central portion at Laguna Lake shoreline, groundwater flow is towards the direction following the course of Pasig River to Manila Bay.

After 39 years since 1955, the groundwater flow pattern was significantly altered due to excessive withdrawal of groundwater in the aquifer. The adversely affected parts of the aquifer created cones of depression. Three (3) distinct cones of depressions are prominently seen within the groundwater abstraction areas, the Paranaque, Pasig and Valenzuela cones of depression.

The 2004 groundwater level map depicts the worsened situation as increased groundwater abstraction resulted in deeper cones of depressions reaching 235 meters below ground level at Pilar Subdivision in Paranaque City.

Water Quality

Groundwater in Metro Manila aquifer deteriorates progressively as a result of the landward movement of seawater from Manila Bay into areas of significantly decreased in aquifer pressures particularly at cones of depression to replace the dewatered freshwater. Upconing of brackish groundwater and connate groundwater also take place in several places.

The electrical conductivity (EC), which gives indication of groundwater quality on salinity is the most important parameter gathered during the fieldwork. The areas with EC values less than 2000 microsiemens/cm is categorized as groundwater with low salinity; the areas with EC values from 2000-5000 microsiemens/cm is categorized as brackish groundwater of various uses; the areas with EC values >5000 to <10000 microsiemens/cm is categorized as brackish groundwater of limited use and groundwater with EC values >10000 microsiemens/cm is categorized as saline and unusable groundwater.

pH range of 6.5 to 8.5 as specified in the National Standards for Drinking Water (NSDW) predominates in the study area, except in some parts of Bulacan with higher pH of about 9, particularly in the municipalities of Marilao, Pandi, Guiguinto, Malolos and Bulacan. Lower pH of <6 exists in the area at Pasig, Taytay and Marikina and in San Mateo, Rizal.

Areas closer to the sea are the first to be affected by the landward movement of seawater flowing into areas of reduced aquifer pressures due to excessive groundwater withdrawals. Excessive pumping of groundwater results in upcoming of brackish or connate groundwater from underneath. It was suspected that the lowering of groundwater levels down to more than 60 meters below sea level in Cainta, Taytay, Pasig, and Taguig is due to over-extraction of groundwater.

During periods when seawater is high particularly during high tides, seawater moves inland at the surface through rivers/streams like Pasig River. The Napindan structure built for purposes of blocking tidal inflow of seawater is believed to be not functioning effectively. Tidal inflow of seawater contributes to the existence of high salinity groundwater in Pasig and vicinity with electrical conductivity (EC) of groundwater reaching more than 3,000 uS/cm**.**

Industries discharging eflfluent on the ground surface, in rivers and lakes contaminate groundwater of the underlying aquifer. The Laguna Lake Development Authority (LLDA) has inventoried 336 industries and classified each according to their pollution potential. Large number of these industries is found along Marikina River, Pasig River, Laguna Lake and tributary rivers making use of these surface waters as disposal of their objectionable effluents. Polluted river and lake waters leak into the aquifer for which the groundwater is utilized for drinking by majority of existing drilled wells.

<u>Groundwater Abstraction</u>

The groundwater abstraction of MWSS wells accounts 3% of the total water consumption supplied by MWSS for Metro Manila.

The present amount of groundwater withdrawal legally registered with the NWRB totals 12,823.53 liters/second. Unregistered wells drawing groundwater from the aquifer are considered as illegal wells. The amount of groundwater abstracted by illegal wells plus the amount drawn by permitees exceeding their granted amount is believed to be more than 60% of the total groundwater extraction of registered wells.

<u>Groundwater Availability</u>

The main confined aquifer of Metro Manila is replenished from several sources.

a) Groundwater leakage inflow from the overlying shallow unconfined aquifer via aquitard;

b) Subsurface inflow of groundwater from upgradient (Tagaytay area and vicinity) unconfined aquifer;

c) Induced inflow of Laguna Lake; and

d) Subsurface inflow from upper portion of Marikina River catchment.

6. Groundwater Resource Management

Resource Allocation

Safe yield is the extraction rate in the aquifer so that groundwater contained in it could be used continuously ($t = \infty$) without drawing groundwater from its reserve/storage. *Mining Yield* is the extraction rate in the aquifer exceeding the Safe Yield limit. The amount of drawn groundwater in excess of the Safe Yield is mined from its reserve/storage annually until groundwater in the aquifer is totally exhausted.

Currently, issuance of groundwater permits for Sub-area 1 is temporarily stopped pending the result of this assessment study. The estimated Safe Yield of 2000 liters per second (NWRC & NHRC, 1983) is already exceeded. The present extraction rate for said sub-area totals 3324.4 liters/second for which 15% of the estimated Mining Yield was already granted.

Resources Monitoring

Water Quality

There is no regular activity of continuous measurement of water quality parameters for Metro Manila aquifers to record time series data by NWRB or other entities. Measurement is done only when a certain project is undertaken and during the time when an individual/company applies for a water permit at NWRB to comply with the requirements of the application.

Water Levels

The government does not require permitees to monitor water levels. Such undertaking should be incorporated as part of the activities in the maintenance of their waterworks systems is good engineering practice and should not only be encouraged but required to monitor water levels when possible. Water level sounding pipes should be integrated into well standard designs to enable water level monitoring.

Withdrawals

Abstraction rate by permit grantees is monitored by NWRB through its Monitoring and Enforcement Division only when verification of the granted amount is done. There is no activity of continuous measurement of well discharge to record historical data of pumpage. Permitees should be required to submit a historical record of production and technical specification of pump installed.

7. Groundwater Modeling/Water Balance

Models or simulations may be used to estimate the hydraulic response of an aquifer, at complied conditions at some future point in time. The predictive simulations must be viewed as *estimates*, not certainties, to aid the decision-making process.

The MODFLOW groundwater modeling software originally developed by McDonald and Harbaugh (1988) of the U.S. Geological Survey is used. The MODFLOW model is based on finite-difference method and designed for three-dimensional (3D) saturated groundwater flow.

One major task in groundwater modeling especially, 3-dimentional models, is the creation of the groundwater grid system based on the hydrogeological concept model. The grid file was prepared using Surfer graphic software over the study area. Having the same grid coordinate limits, this grid was then overlaid on the digitized geologic maps to be able to assign geologic codes at the surface. This particular grid system consists of 4743 block-centered nodes (51 columns from west to east; 93 rows from south to north) with a square size of 1 km by 1 km. There are 2,350 active nodes in which 2,182 nodes are land boundaries, 65 nodes represents Manila Bay boundary conditions and 103 nodes represent Laguna Lake boundary conditions. The remaining 2,393 nodes are inactive nodes, which are outside the physical boundary.

For the development of the aquifer geometry, the same grid was used and geologic codes were assigned to the grid cells based projections made from the surface geology and available subsurface geology. Geologically coded grid level maps, having the same grid limits, were prepared for zero (0) elevation (mean low, low sea level) and every 30 meters above masl up to the highest known elevation and projected every 30 below sea level to elevation of –210 m.

The model finite-difference grid consists of 18 layers with thickness of 30 meters with 6 layers below mean low, low water (MLLW) sea level and 11 layers above MLLW. It may be noted that for the code maps of layers above MLLW, the blank areas are inactive nodes representing the above ground surface grids.

In the coded maps for each layer, the finite-difference grid system has been classified into 10 types of soil/geologic characteristics. Each type of soil has a unique hydraulic conductivity, porosity and storage coefficient. The specific groundwater properties used in this study are discussed next.

Considering the given geology of the study area, the main sedimentary components are clay, silt, sand gravel, basaltic igneous rock (in varying degrees of fracturing) and minor limestone deposits. Based on the examined well logs of the Philippine Groundwater Database of NWRB, the components of sedimentary formations in the main aquifer present themselves as well sorted and mixed textures. To facilitate simplicity in the description of the formations, terminologies pertaining to origin such as “tuff”, “tuffaceous,” “adobe” were treated as an equivalent of silt, based on the consultant’s experience in checking drillers log on-site and local description of adobe. Only textural terminologies pertaining to grain size using the Wentworth scale of sedimentary grain-size were adopted.

There are several boundary (including interior boundary) conditions that must be in the model. It is important to properly define these boundary conditions since they govern the groundwater flows. These are the rainfall boundary condition including evapotranspitation. Another major recharge to the groundwater system are the river leakages. There are 328 nodes with river boundary conditions. Another major discharge boundary conditions in the model are the pumping wells. There are a total of 2,206 registered pumping wells in the NWRB database Two major head boundary conditions are specified in the model. These are Laguna Lake water levels and Manila Bay water levels. Another head boundary that being considered is the Novaliches Reservoir (lake leakage).

Model Calibration and Testing

Model calibration consists of changing values of model input parameters in an attempt to match field conditions within some acceptable criteria. This requires that field conditions at a site be properly characterized. Lack of proper site characterization may result in a model that is calibrated to a set of conditions, which are not representative of actual field conditions. The calibration process typically involves calibrating to steady-state and transient conditions. With steady-state simulations, there are no observed changes in hydraulic head with time for the field conditions being modeled. Models may be calibrated without simulating steady-state flow conditions, but not without some difficulty. At a minimum, model calibration should include comparisons between model-simulated (computed) conditions and field (measured) conditions for the following data:

- Hydraulic head data;
- Groundwater-flow direction;
- Hydraulic-head gradient; and
- Water mass balance.

A calibrated model uses selected values of hydrogeologic parameters, sources and sinks and boundary conditions to match field conditions for selected calibration time periods (either steady-state or transient). However, the choice of the parameter values and boundary conditions used in the calibrated model is not unique, and other combinations of parameter values and boundary conditions may give very similar model results. History matching uses the calibrated model to reproduce a set of historic field conditions.

.

In the case of the Metro Manila model, there is only one area with observation wells, in Las Piñas, that have a hydrograph available. It would have been ideal to have had a period of monitoring, say three years prior to the start of this project, with many observation wells distributed around the study area for water table measurements as historical basis for the model verification.

Notwithstanding the situation were the model would need some degree of calibration for its verity, the Metro Manila model could be calibrated using the transient method. Transient simulations involve the change in hydraulic head with time (e.g. aquifer test, an aquifer stressed by a well-field, or a migrating contaminant plume). These simulations are needed to narrow the range of variability in model input data since there are numerous choices of model input data values which may result in similar steady-state simulations. Future measurements to made from selected monitoring wells could be calibrated against the hydrographs of projected piezometric heads created using the Modflow that are presented in the later part of this chapter.

However, since the duration of this project is only 6 months, it cannot be done within the contract period. Thus, some recommendations are presented in the next Chapter 8 regarding the sustainability of the project, and only then can the calibration of the model be made.

Water Balance Study and Groundwater Simulation Scenarios

Four (4) simulation scenarios were performed for Metro Manila. Under the four scenarios, all conditions indicate groundwater mining. Projections for 10-year and 20-year periods were made for the 4 scenarios as follows:

Scenario 1: Current (2004) levels of groundwater pumping rates (taken from water permits) including unregistered wells, which is assumed to be 60% of the existing registered wells. The **Table 7-2** below is an accounting of the water balance of the study area under the first scenario.

Table 7-2: **Water Budget for Scenario 1**

SIMULATION SCENARIO 1 - EXISTING CASE (END 2004 PUMPING RATE)

PARAMETER	END OF 2004		END OF 2015		END OF 2025	
	CUMULATIVE VOLUMES (m^3)	RATES FOR THIS TIME STEP (m^3/day)	CUMULATIVE VOLUMES (m^3)	RATES FOR THIS TIME STEP (m^3/day)	CUMULATIVE VOLUMES (m^3)	RATES FOR THIS TIME STEP (m^3/day)
IN:						
STORAGE	2,249,900,000	2,125,400	5,346,300,000	590,640	7,165,000,000	441,930
CONSTANT HEAD	2,157,300,000	2,251,800	8,991,400,000	1,897,500	16,136,000,000	2,003,100
WELLS	0	0	0	0	0	0
RECHARGE	76,285,000	104,500	457,710,000	104,500	839,140,000	104,500
RIVER LEAKAGE	30,526	40	167,550	36	299,250	36
TOTAL IN	**4,483,500,000**	**4,481,700**	**14,796,000,000**	**2,592,700**	**24,140,000,000**	**2,549,500**
OUT:						
STORAGE	2,009,500,000	1,357,900	2,664,500,000	31,492	2,718,600,000	9,588
CONSTANT HEAD	549,030,000	446,010	676,210,000	3,171	681,110,000	422
WELLS	1,860,900,000	2,548,700	11,156,000,000	2,545,700	20,446,000,000	2,544,800
RECHARGE	0	0	0	0	0	0
RIVER LEAKAGE	21,801	60	433,010	124	891,850	126
TOTAL OUT	**4,419,500,000**	**4,352,700**	**14,498,000,000**	**2,580,400**	**23,847,000,000**	**2,554,900**
IN - OUT	***64,000,000***	***129,000***	***298,000,000***	***12,300***	***293,000,000***	***-5,400***

At the present withdrawal rate, the Metro Manila aquifer would be depleted having a negative water balance estimated at –5,400 cu.m. per day. This could happen in less than 20 years, since, when the real mining rates started, cannot be determined. It should be noted that there are no records for illegal or unregistered wells.

Scenario 2: Pumping rates of Scenario 1, plus 230 new wells applicants, still pending for approval.

Under the second scenario, the Metro Manila aquifer would be depleted having a negative water balance estimated at –6,500 cu.m. per day. This could happen in less than 20 years, since, when the real mining rates started, cannot be determined.

Table 7-3: Water Budget for Scenario 2

SIMULATION SCENARIO 2 - EXISTING CASE PLUS 230 WELLS

PARAMETER	END OF 2004		END OF 2015		END OF 2025	
	CUMULATIVE VOLUMES (m^3)	RATES FOR THIS TIME STEP (m^3/day)	CUMULATIVE VOLUMES (m^3)	RATES FOR THIS TIME STEP (m^3/day)	CUMULATIVE VOLUMES (m^3)	RATES FOR THIS TIME STEP (m^3/day)
IN:						
STORAGE	2,283,100,000	2,169,300	5,518,000,000	627,950	7,471,200,000	477,510
CONSTANT HEAD	2,178,800,000	2,287,500	9,222,000,000	1,964,600	16,629,000,000	2,078,200
WELLS	0	0	0	0	0	0
RECHARGE	76,285,000	104,500	457,710,000	104,500	839,140,000	104,500
RIVER LEAKAGE	30,505	40	167,780	37	299,830	36
TOTAL IN	**4,538,300,000**	**4,561,300**	**15,198,000,000**	**2,697,100**	**24,940,000,000**	**2,660,300**
OUT:						
STORAGE	1,982,600,000	1,325,200	2,584,000,000	25,441	2,630,800,000	8,948
CONSTANT HEAD	548,570,000	445,560	675,350,000	3,056	680,080,000	418
WELLS	1,943,000,000	2,661,200	11,649,000,000	2,658,200	21,350,000,000	2,657,300
RECHARGE	0	0	0	0	0	0
RIVER LEAKAGE	21,732	60	428,670	122	877,180	123
TOTAL OUT	**4,474,200,000**	**4,432,000**	**14,909,000,000**	**2,686,800**	**24,662,000,000**	**2,666,800**
IN - OUT	***64,100,000***	***129,300***	***289,000,000***	***10,300***	***278,000,000***	***-6,500***

Scenario 3: Pumping rates of Scenario 1, plus 461 new wells applicants, still pending for approval.

Table 7-4: Water Budget for Scenario 3

SIMULATION SCENARIO 3 - EXISTING CASE PLUS 461 WELLS

PARAMETER	END OF 2004		END OF 2015		END OF 2025	
	CUMULATIVE VOLUMES (m^3)	RATES FOR THIS TIME STEP (m^3/day)	CUMULATIVE VOLUMES (m^3)	RATES FOR THIS TIME STEP (m^3/day)	CUMULATIVE VOLUMES (m^3)	RATES FOR THIS TIME STEP (m^3/day)
IN:						
STORAGE	2,310,800,000	2,206,800	5,657,900,000	655,440	7,709,800,000	502,830
CONSTANT HEAD	2,198,000,000	2,319,300	9,415,100,000	2,019,100	17,036,000,000	2,139,300
WELLS	0`		0	0	0	0
RECHARGE	76,285,000	104,500	457,710,000	104,500	839,140,000	104,500
RIVER LEAKAGE	30,505	40	168,130	37	301,160	36
TOTAL IN	**4,585,100,000**	**4,630,500**	**15,531,000,000**	**2,779,100**	**25,585,000,000**	**2,746,600**
OUT:						
STORAGE	1,965,800,000	1,307,100	2,534,500,000	22,158	2,577,200,000	8,436
CONSTANT HEAD	547,880,000	444,910	674,430,000	2,994	679,090,000	417
WELLS	2,007,700,000	2,749,900	12,037,000,000	2,745,500	22,057,000,000	2,744,700
RECHARGE	0	0	0	0	0	0
RIVER LEAKAGE	21,528	59	423,520	120	863,840	121
TOTAL OUT	**4,521,400,000**	**4,502,000**	**15,246,000,000**	**2,770,800**	**25,314,000,000**	**2,753,600**
IN - OUT	***63,700,000***	***128,500***	***285,000,000***	***8,300***	***271,000,000***	***-7,000***

Under the third scenario, the Metro Manila aquifer would be depleted having a negative water balance estimated at –7,000 cu.m. per day. This could happen in less than 20 years, since, when the real mining rates started, cannot be determined.

Scenario 4: Based on the projected withdrawal for the years 2015 and 2025 that was based on the historical increase in the number of wells. The projected increase in the number of wells permittees was based on the historical data of NWRB records.

Table 7-5: Water Budget for Scenario 4

SIMULATION SCENARIO 4 - PROJECTED DEMAND FROM WELLS

PARAMETER	END OF 2004		END OF 2015		END OF 2025	
	CUMULATIVE VOLUMES (m^3)	RATES FOR THIS TIME STEP (m^3/day)	CUMULATIVE VOLUMES (m^3)	RATES FOR THIS TIME STEP (m^3/day)	CUMULATIVE VOLUMES (m^3)	RATES FOR THIS TIME STEP (m^3/day)
IN:						
STORAGE	2,342,400,000	2,238,800	6,238,400,000	915,590	11,016,000,000	1,290,600
CONSTANT HEAD	2,244,900,000	2,422,000	10,450,000,000	2,484,400	21,491,000,000	3,365,200
WELLS	0	0	0	0	0	0
RECHARGE	76,285,000	104,500	457,710,000	104,500	839,140,000	104,500
RIVER LEAKAGE	30,472	40	167,780	37	301,830	34
TOTAL IN	**4,663,600,000**	**4,765,400**	**17,147,000,000**	**3,504,500**	**33,347,000,000**	**4,760,300**
OUT:						
STORAGE	1,981,100,000	1,328,000	2,515,100,000	8,306	2,544,400,000	8,237
CONSTANT HEAD	513,430,000	424,640	629,590,000	1,870	631,410,000	250
WELLS	2,104,700,000	2,882,700	13,744,000,000	3,495,700	30,028,000,000	4,775,400
RECHARGE	0	0	0	0	0	0
RIVER LEAKAGE	21,906	60	424,090	118	844,700	112
TOTAL OUT	**4,599,300,000**	**4,635,400**	**16,889,000,000**	**3,506,000**	**33,205,000,000**	**4,784,000**
IN - OUT	***64,300,000***	***130,000***	***258,000,000***	***-1,500***	***142,000,000***	***-23,700***

Under the fourth scenario, the Metro Manila aquifer would be depleted having a negative water balance estimated at –1,500 cu.m. per day by 2015. This could happen in less than 10 years, since, when the real mining rates started, cannot be determined.

A comparative water budget summary of IN (minus) OUT flow through the Metro Manila Aquifer System under the different scenarios and periods are presented in **Table 7-6** Water Balance Summary Table at the end of Section 7.

<u>Results of Simulations Runs and Simulated Hydrographs</u>

Results of simulation runs using Modflow were produced to create data and binary files that was used to create a map image of the predicted water level surface and plotted using Surfer to show depth and lateral changes of the groundwater piezometric head under all scenarios described above, these are shown in Figures 7-7 to 7-12 and are presented in the last part of this section.

The simulated hydrographs of selected areas of Metro Manila were also developed from the data files of the generated heads under each scenario. The simulated hydrographs are presented in the last part of this chapter in **Annex E**.

In general the hydrographs shows a slight increase in water levels that should be considered as a warm up period for the program. However, the later part of the graph towards the years 2015 and 2025 shows a general decline in predicted water levels.

Final Remarks

The generated groundwater model is an initial step to having a quantified evaluation of the available groundwater in the Metro Manila Aquifer. However, like any model, it should be updated to reflect changes that are in process in a dynamic aquifer system.

The 1955 groundwater piezometric map of Metro Manila depicted water levels at 0.53 meters above sea level. Ideally, in any well field, extraction rates should not exceed the recharge capacity of the aquifer. A common adverse condition when the withdrawal rates exceed the groundwater potential is the lowering of the piezometric head to levels below zero or sea level. The actual measured and simulated cones of depressions in the Metro Manila Aquifer suggest a worsening situation that only confirms conclusion of earlier studies (such as the 1991 JICA Study, 1994 UNDP-MWSS Study and the 1993 IDRC/NHRC).

Already, measured and simulated piezometric levels are critical in the range of –40 to –60 below sea level. The Model still has to establish what would be the maximum allowable level for the piezometric heads in the study area to which the decision makers in NWRB can use to decide as what permissible is. Such a question arises, since the alternative water sources (to replace well sources) to supply the needs of the metropolis still has to be developed and constructed. Should permitting for wells in the metropolis continue, how deep should we allow the piezometric head to lower?

Aside from the physical manifestations of the abused aquifer, we could expect changes in water quality to change or even deteriorate. There is no question as to whether it should become policy to allow water to deteriorate or up what permissible levels contamination could be allowed. In any case it should not be allowed. This is another parameter of groundwater that the present model cannot address.

Hence, further studies and updating of the model should continue to establish what the physical and chemical manifestations are in the groundwater resource of the study area and how can the model be used as a tool to assist policymaking.

8. CONCLUSIONS AND RECOMMENDATIONS

Based on the findings indicated above, the following are the conclusions and recommendations of the project.

IDENTIFIED CRITICAL AREAS

Eight (8) sites within the study area are considered in need of urgent attention. These include the cones of depression *(dewatered portion of the aquifer due to over-extraction of groundwater that would induce saltwater intrusion due to landward advancement of seawater into cones of depression)* shown in the 2004 piezometric level contour map of the study area and are shown in **Figure 5-8** as the cones of depression in: 1) Guiguinto, 2) Bocaue – Marilao, 3) Meycauyan –

North Caloocan, 4) Navotas – Caloocan – West Quezon City, 5) Makati – Mandaluyong – Pasig – Pateros, 6) Parañaque-Pasay, and 7) Las Piñas – Muntinlupa. Considered also as critical area is the area of Dasmariñas in the Province of Cavite, where heavy groundwater abstraction is currently taking place.

Recommendations

In response to the adverse conditions manifested by the seven (7) major cones of depression, and the Dasmariñas area, which is considered a major abstraction zone, it is strongly recommended that drilling of monitoring wells *(if abandoned wells suited for use as monitoring well is not available)* for installation of data loggers to measure groundwater levels and electrical conductivities (EC) be implemented in these areas. This would allow time series recording of groundwater level declines and recording of water quality deterioration. NWRB staff shall monitor and maintain the observation wells and the installed data loggers.

The limits of the eight (8) sites for monitoring are as follows: Guiguinto

Area 1:	Guiguinto	Latitudes: 14° 50' to 14° 51' Longitudes: 120° 53' to 120° 53' 30"
Area 2:	Bocaue – Marilao	Latitudes: 14° 44' 30" to 14° 47' Longitudes: 120° 56' 30" to 120° 58'
Area 3:	Meycauyan – North Caloocan	Latitudes: 14° 44' to 14° 46' Longitudes: 120° 59' 30" to 121° 01'
Area 4:	Navotas – Caloocan – West Quezon City	Latitudes: 14° 39' 30" to 14° 41' Longitudes: 120° 59' to 121° 00' 30"
Area 5:	Makati – Mandaluyong – Pasig – Pateros	Latitudes: 14° 33' 30" to 14° 34' 30" Longitudes: 121° 02' to 121° 03'
Area 6:	Parañaque-Pasay	Latitudes: 14° 29' 30" to 14° 31' Longitudes: 121° 01' to 121° 02' 30"
Area 7:	Las Piñas – Muntinlupa	Latitudes: 14° 24' 30" to 14° 26' Longitudes: 121° 00' to 121° 01'
Area 8:	Dasmariñas	Latitudes: 14° 19' to 120° 20' Longitudes: 120° 57' to 120° 59'

Criteria for the Selection of Monitoring Wells

- Deepwells should have known coordinates and were plotted on a scaled topographic map
- Existing non-operational with known well design, having minimum depth of 200m
- The deepwells should be within the cone of depressions identified
- The well should have lithologic/electric log records and aquifer test data
- There should be access (open holes or sounding pipes) for the water level monitoring probe

- The wells should be granted access to NWRB staff by the owners

Frequency of Monitoring

- Monitoring shall be made at least twice a month

Parameters to be monitored

- EC, electrical conductivity
- Water Levels
- Nitrate

Instrumentation for Monitoring

- Automatic data logger, capable of recording the three above mentioned parameters.
- Data loggers 2002 price estimates were in the range of US$700 (each) and up, for a SOLINST Model 101 that could measure only water level and EC. Additional parameters to be measured would mean costlier equipment; laptop computer to download data is not yet included.

New Observation Wells

For new observation wells, the same frequency of sampling and parameters to be monitored could be as stipulated in the said report.

The estimated cost for drilling and construction of each new well for 200 meters depth is P1,611,741 or about P 8,060/meter of a completed well. Therefore, for the proposed 8 monitoring deepwells a total of about P12,900,000 should be allocated for drilling and construction of wells

GROUNDWATER MINING

The groundwater model having the worse scenario depicts that within 10 years, the decline of piezometric heads would accelerate to levels that would have irreversible adverse effects, such as:

1. Higher pumping cost due to lowered water levels, thus requiring higher energy.
2. Changes in water quality, through increased salinity by saltwater intrusion, or contaminants from near surface formations.
3. Reduction of porosity and permeability that result to ground subsidence
4. Overall, irreversible damage of the aquifer

It is now urgent that alternative sources of water be developed and constructed to serve the growing demand, thus, allowing water users to divert sources from wells to surface water provided by the MWSS concessionaires.

It is apparent from the above observations that Metro Manila aquifer is now on its course to being depleted to meet the present water demand of the metropolis. If landward advancement of seawater becomes extensive, it will become extremely difficult to flush the intruding saline water back to the sea. It will take many years if sufficient quantities of freshwater (at a head that would be difficult to artificially induce) to force back to the sea the saline water that is intruded in the aquifer.

Recommendations

1. It is strongly recommended that alternative sources of water be developed (such as the Kaliwa or Kanan River water sources) and constructed within the next 10 years that would allow waterwell users to shift from groundwater to using surface water from the MWSS and its concessionaires.

2. New permits applicants should be given temporary short-term (10 year) permits to operate new well sources. While, existing water rights grantees should be given notice that all existing permits shall be revoked within 20 years from 2004. This should prevent the accelerated decline of the piezometric levels of the Metro Manila Aquifer expected to occur in 10 years, and at the same time encourage waterwell users to plan ahead for their eventual shift from groundwater source to surface water through MWSS concessionaires.

3. These should be supplemented by an information campaign that would educate the general public and all groundwater users of the gravity of the situation and that measures are being undertaken to address the impending problem.

To save the aquifer from total depletion and degradation, a pre-feasibility study should be conducted for other mitigating measures such as artificially recharging the Metro Manila aquifer. Two potential sources of water for artificial recharge considered for further study are:

1. One suggested focus of the pre-feasibility study is the construction of long horizontal infiltration galleries 30 to 50 meters from the lake shoreline *(to allow filtering the objectionable constituents present in Laguna Lake water)* and parallel to Laguna Lake *(Sta. Rosa to Los Baños, Laguna)*, which would tap the groundwater from aquifer beneath the silty/clayey lakebed. Pumped groundwater from sump wells constructed at the ends and at intervals along the gallery could supply recharge wells *(abandoned wells or newly drilled recharge wells)* particularly at the cone of depression in Parañaque City/vicinity. Initially, short infiltration galleries could be tested to determine the yield per unit length and the quality of abstracted groundwater if it would meet the quality for recharge water.

2. Another suggested focus of the pre-feasibility study is to utilize untreated excess surface water overflows in dams, which are cleaner and fresher water coming from the mountains to artificially recharge the aquifer particularly at the cones of depressions shown by piezometric level maps *(water table or piezometric surface)* for depleted aquifers in highly urbanized cities adjacent to existing or future dams. Angat Dam, for example had a recorded total spillage of excess surface water of 234 million cubic meters in 1995 alone. This excess water was just spilled and wasted into the sea. This shows that we have surplus water during rainy seasons that can be tapped as a source for recharging the Metro Manila Aquifer.

GROUNDWATER RESOURCES MANAGEMENT

Groundwater Management Areas

Whereas the previous groundwater management areas in Metro Manila are subdivided into 8 separate sub-areas (divided by sub-river basins) having arbitrarily estimated safe yield and allowable mining yield, the present study treats the entire Metro Manila Aquifer as one aquifer having different properties at different areas, as reflected by its underlying geology, but reacting to pumping stress contiguously. Hence, instead of having arbitrarily (since these have never been calibrated) assigned numbers to guide the NWRB as to what safe yield or allowable mining yield is, the Modflow model treats the aquifer as a dynamic system. The mass water balance already shows that the underlying aquifer is being mined and conforms previous groundwater potential studies of Metro Manila.

Recommendation

As to how much an aquifer can produce to its optimum capacity should be measured from physical and chemical manifestations (changes) that should be used to determine the allowable or permissible limits of a natural system. Determining these limits remains to be done, a separate study is recommended.

Assessment of New Groundwater Permit Applications

With the prevailing groundwater mining conditions in Metro Manila as manifested in the 2004 Piezometric Map and the Groundwater Model developed in this study, it has become necessary to impose restrictions in groundwater withdrawal. Along with the recommended selective moratorium mentioned in Section 8.2, the allocation of new water permits outside of the selective moratorium areas could be granted after assessment using the groundwater model.

Recommendations

1. Well location of new applicants for well permits should not be within the identified cones of depressions, whose boundaries are mentioned in the above Section 8.1

2. Should the well location be outside the cones of depression, the new groundwater applicant's well should be evaluated using the model on the basis of its immediate effects on the nearest well. At any given time, should there be any interference, the effect withdrawal of the new well on other pre-existing wells should not exceed 2 meters of drawdown. These simulated effects must be confirmed on the field using actual measurements. Should there be any discrepancy in the simulated and actual, the actual measurements shall always prevail.

Enforcing Design Standards for New Wells and Requiring Submission of Monitoring Data

Many wells in Metro Manila have no provisions for measuring groundwater levels. Groundwater level measurement is essential in the proper monitoring of groundwater level changes over time.

Recommendations

1) In order for the NWRB to acquire more data on the historical record of groundwater levels and water quality, well permit applicants should be required to install sounding tubes in the wellheads of their respective wells. The water level sounding tube should be required as standard in well design. This would permit staff of the NWRB or the well owners to measure periodically the groundwater levels and water quality in the wells.

2) Water permit applicants for deep wells (60m or more) having at least 8-inches diameter casings could also be required to submit a water level and water quality monitoring program as part of the requirements for new applicants and re-issuance.

Identifying Illegal Wells

Along with the present amnesty program of NWRB to encourage well owners to register illegal wells, the study recommends more rigid steps in identifying illegal wells in order to regulate groundwater withdrawal and have an accurate approximation of groundwater abstraction in the study areas and nationwide.

Recommendations

In view of the numerous illegal or unregistered wells in Metro Manila the following suggestions are presented:

1) Pump manufacturers, suppliers, service centers and importers could be required to submit to the NWRB a list of all the pumps they sell and the end-user client's name and NWRB permit number of the well and the completed address where the pump was installed. This could assist the NWRB in identifying illegal or unregistered wells.

2) To minimize extraction of groundwater exceeding the granted discharge, the water applicant should be required to submit to NWRB the pump technical specifications, including pump curves, for newly installed pumps and replacement pumps. This will provide NWRB a good basis in estimating well discharges, particularly for monitoring purposes. This could also provide NWRB a good basis in selecting and specifying horse power (HP) of pump to be installed to correspond to the amount of groundwater granted.

3) NWRB could tap LGUs as partners to determine illegal withdrawal of water through wells. Identification of water sources of each business establishment can be made during the annual renewal of business permits. The scheme calls for business establishments to declare and subject their water sources to inspection by the members of the NWRB Enforcement and Monitoring Task Force as a pre-requisite to the renewal of their business permits issued by their respective LGUs. The NWRB together with LGUs could formulate a mechanism and guidelines on the procedure for identification of unregistered/illegal well sources in residences or business establishments. Details of this suggested scheme cannot be elaborated in this study due to the legal aspects involved that is not within the realm of the study team. Further study is recommended.

4) The issuance of official permanent plates (similar to vehicle registration plates) could be another way of regulating groundwater abstraction. Each registered well shall be issued one (1) tamper-proof plate and shall bear the official sign of the NWRB and the following data:

1. Well Permit No.
2. Owner' s Name
3. Granted Discharge
4. Depth
5. Geographical Coordinates
6. Date Completed

The issued plate should be installed on the wellhead of each well or on the pump pedestal. A corresponding fee shall be charged to cover the cost of the official identification plate.

Protection of Groundwater Quality

To prevent further deterioration of water quality of groundwater as well as surface waters, there should be provisions for or improvement of wastewater treatment, sewage treatment for highly utilized areas and septic treatment for less urbanized districts. Public awareness of sanitation practices should be a relentless campaign particularly in the less urbanized areas.

The MWSS is presently constructing Metro Manila Second Sewerage Project (MSSP) and preparing the Feasibility Study for the Manila Third Sewerage (MTSP), both of which are sewage treatment and sewerage facilities projects within their service areas in Metro Manila. Preparations are already underway for the Metro Manila Sewerage Master Plan. Municipalities outside the service area of MWSS, should also develop sewage system, septage treatment or improve and legislate the use of septic tank in the absence of a sewerage system.

Major fault systems in Metro Manila, particularly the Marikina Valley Fault System (MVFS), extend down to the groundwater aquifer system (See **Figure 2-5** Metro Manila Geological Cross Section). **Figures 8-5** and **8-6 shows the MVFS as modified from PHIVOLCS Map.** These geologic structures serve as conduit of recharge water directly into the aquifer system and are considered vulnerable to pollutants, and should therefore be protected from the dumping of garbage, animal/human wastes, effluent from industrial wastes and other pollutants. The major faults also have numerous tributary fractures extending several distances from the footwall or hanging wall of the fault. If contamination through this structures remains unchecked, the quality of the groundwater resource in the aquifer system could be greatly affected.

Recommendations

1) Most of the areas over the Marikina Valley Fault Zone are already occupied with human dwellings and buildings. Thus, reclassification of land use or the creation of buffer zones would be incredibly difficult along the zone. It is recommended that further studies on water quality be made on wells found along the fault zone with the intention of determining the effects of effluent on the aquifer through the Marikina Valley Fault then formulate strategies to approach the problem appropriately.

2) Efforts must be made to finance the construction or rehabilitation of sewage facilities in the rural areas found along the groundwater

recharge-fault zone, if possible through a grant. Alternatively, loan facilities are also available from government banks (such as Land Bank) that extend such service for drainage projects. These banks should be encouraged to provide special low interest, long term-payment loans for projects that would address this special case of protecting the Metro Manila aquifer. Likewise, the LGUs or MMDA should be made aware of the problem.

ENHANCEMENT OF THE GROUNDWATER DATA COLLECTION

The study team was faced with the difficulty of processing well data submitted by well drilling contractors/well owners due to lack of uniformity and completeness of data (such as using English units instead of SI units for pumping test data and wrong geographic location; no ground evaluation data and lack of standard system for naming sediments, lithologic description, etc.). In other countries, sample cuttings obtained from drilling are even analyzed through sieves for proper descriptions of permeability. This is still not practiced in this 21st century in the Philippines.

Well drilling companies and their respective field staff are in the forefront of gathering well data that is fed into the Philippine Groundwater Data Bank of NWRB. Most commonly, the insufficient or fragmented data submitted by the well drilling companies to the NWRB is due to the lack of trained or well-informed field personnel on how to accurately acquire the desired field data. Along with this, it is common that qualified field personnel in the drilling companies would be changed or transferred, thereby leaving a vacuum of able personnel that can obtain and report the desired field data.

Recommendations

1) In line with the upgrading the quality of the groundwater database of NWRB, it is recommended that there should be an effort to provide continuing education program for well drillers through an initiative by both NWRB and WELDAPHIL.

   The suggested continuing education should focus on the training of well drilling company staff on the accurate acquisition and correct completion of well and field information as those reflected in the Philippine Groundwater Database Forms (Screens 1 to 3) of NWRB. This could take place in the form of workshops that could be regularly held at least once a year. This should be made mandatory to all well drillers. The 1994 report of UNDP-LWUA entitled The Application of the Philippine Groundwater Data Bank – Geographical Information System for Evaluation of Groundwater Potential is referred to as one technical reference that should be used for such an educational program. In as much as NWRB has successfully created a databank that is very useful, the quality of data being submitted by well drillers needs much improvement. This measure should enhance the quality of groundwater database by assuring reliable data at the point of sampling/collection.

2) Alternatively, well drillers could be required to hire a qualified and licensed geologist or engineer who is familiar the proper description and preparation of all technical data that shall be submitted to NWRB.

3) As observed from the records of NWRB, a considerable number of pumping test data are insufficient or inaccurate. To have better assessment of the aquifer and the well, it is recommended to specify the type of tests required and duration of each test. For constant discharge test, required duration is 72 hours or until the water level stabilizes for several hours. The testing rate should be more than the design discharge. For well performance test, a minimum of three steps, each conducted for a minimum period of 1 hour. A qualified engineer or geologist should certify the conduct and analysis. **Tables 8-1** to **8-5** are suggested constant discharge, step-drawdown and recovery test forms for pumping tests and guide tables for discharge measurements.

   The proper conduct of pumping test could also be included in the continuing educational program for well drillers. The training module prepared and submitted to NWRB under this project is an excellent reference for the purpose of educating the well drillers.

SUSTAINABILITY OF GROUNDWATER MODELING STUDIES

This Water Balance and Groundwater Modeling is a continuing study and thus require a thorough understanding of its principles. There also remains the task of having a long-term (3-year period) monitoring wells and calibration of the model.

Whereas, the previous 2002 study of the Improvement of National Water Data Collection Network for Groundwater Monitoring proposes the MGB as the government agency that should conduct monitoring activities, it is asserted here that the MGB does not implement water policy. The groundwater model should be an ever-changing simulation reflecting the actual conditions with the updating of its database as more wells are drilled, for it to be an effective tool for the policy makers. Groundwater modeling is a management tool, therefore, NWRB as the lead magistrate over water resources should have mandate over the modeling of all groundwater resources for the agency to respond to the rapid changes in water demand and usage. The MGB, could instead participate in the collection of data since they have the resources and personnel in all regions of the Philippines. Collection and updating of water data from all regions and participating agencies should be able to perform the tasks through the NWIN.

Consequentially, a new purpose arises from the existence of this model – it being a starting point for site-specific groundwater flow models or contaminant flow models that could be devised through modification and addition of local detail. Such site-specific studies may arise from the scoping requirements prior to the issuance of ECCs that may be required by the EMB/DENR. The regional groundwater model covering the Metro Manila aquifer is ready for use to anyone interested and knowledgeable in groundwater modeling. The Metro Manila groundwater model provides a platform from which expansion or development of other sub-regional models may be created. Collecting and reviewing the incremental changes made to the Metro Manila groundwater model could contribute to updating and refinement when shared with all possible users of the model.

Recommendations

1) This project should not end with this report but the NWRB staff should carry out a continuous updating and refinement of the model for issuance of water permit.

2) The NWRB should compliment its manpower by having at least one (1) Hydrogeologist and one (1) Groundwater Modeler as members of its permanent staff to ensure the sustainability of the study and duplication in other groundwater areas.

3) The study and all data could be made available to other possible users of the model on the condition that the user will provide all the additional data back to the NWRB, including the user's generated model report as the updated model. The EMB/DENR should for its part, ensure that the updated model prepared by the proponent shall be provided to NWRB before issuing the ECC. Whether, the data will be accessible to the public for free or for-a-fee is for the NWRB to decide. Further studies should be conducted in the development of guidelines for the accessibility of the groundwater model data to other users.