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POLLUTION SOURCES AND WATER QUALITY ASSESSMENT IN METRO MANILA AND LAGUNA LAKE BASINS

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ABSTRACT

As one of the major tasks in the IDRC-funded project "Water Resources Management Model for Metro Manila," the water quality of both surface and groundwater resources in the Metro Manila and Laguna Lake Basins was assessed based on available data and information. Refuse dumpsites, industries, and underground storage tanks as possible pollution sources were identified and map-located. Groundwater quality data provided by the Metropolitan Waterworks and Sewerage System (MWSS) and the Department of Health (DOH) was evaluated and compared with the National Standards for Drinking Water. Groundwater quality maps for Metro Manila were generated for the following parameters: pH, chloride, turbidity, total dissolved solids, iron, and hardness. A groundwater vulnerability map was developed for Metro Manila based on mappable hydrogeological parameters. Report findings on the water quality status of the Laguna Lake and Metro Manila Rivers is also presented.

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INTRODUCTION

In order to provide adequate water supply to the fast-growing population of Metro Manila and the surrounding regions (see Figure 1), there is a pressing need to study the water supply problems in the region. Taking on a rational and integrated approach in water resources

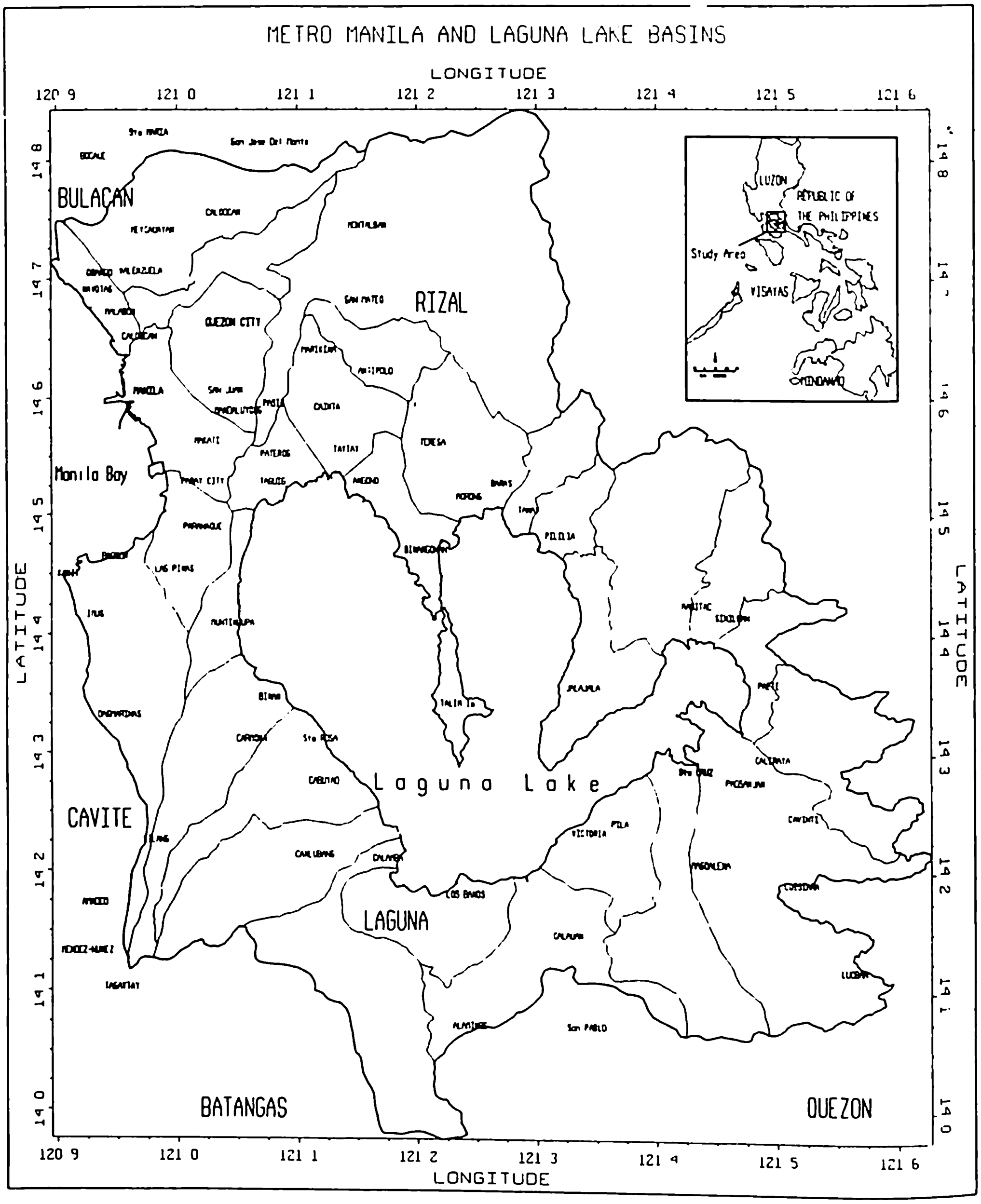


Figure 1. Location map of Metro Manila and Laguna Lake Basin

development by considering both surface water and groundwater availability in the entire Laguna Lake Basin, the National Hydraulic Research Center (NHRC) initiated in 1990 a project through a grant from the International Development Research Centre (IDRC) of Canada. Entitled "Water Resources Management Model for Metro Manila", the research project aims to provide a planning and management tool to assist the Metropolitan Waterworks and Sewerage System (MWSS) and other agencies in evaluating the various alternatives in the development and utilization of water supply sources to meet the demands of the increasing population. It may also be used in evaluating the need for regulatory measures to protect and conserve the water resources in the region.

Although the main supply for Metro Manila comes from surface sources, groundwater has been the alternative source for areas unserved by MWSS as well as for municipalities around Laguna Lake. An understanding of the groundwater dynamics, therefore,is a major concern of the modeling task. However, such conjunctive use study should not only address the dynamics and the water quantity aspects but also water quality. The study would be grossly incomplete without an assessment of the water quality of the existing water resources, particularly groundwater in the Metro Manila aquifer system. This paper aims to present the results for undertaking such task which includes the identification of possible pollution sources, the evaluation of the water quality of both surface and groundwater sources in the study area and an assessment of the groundwater pollution potential for Metro Manila.

POTENTIAL SOURCES OF GROUNDWATER CONTAMINATION

Refuse dumpsites, industries and underground storage tanks were identified as possible major sources of groundwater contamination in the area. Using available reports, cartographic data and field survey, these potential sources were located and subsequently plotted. Population data giving indications of the spatial distribution of human settlement sites are also discussed.

▪ Existing Refuse Dumpsites in Metro Manila

Open dumpsites, i.e. without appropriate liners and soil cover, predominate as the method of refuse disposal in Metro Manila. Their potential as sources of groundwater pollution is extremely high mainly due to leachate and storm runoff. To date, there are nine (9) dumpsites located in the study area (Figure 2) which are listed as follows:

Location	Area (has.)	Start-up Year	River Subbasin
Balut	14	1954	Obando-Malabon-Navotas Est.
Payatas	15	1973	Marikina
Valenzuela	9	1977	Tullajan
Taguig	2	1977	Taguig-Napindan
Pasig-1	6	1979	Taguig-Napindan
Pasig-2	4	1979	Taguig-Napindan
San Pedro	7	1983	San Pedro-Binan
Malabon	4	1986	Obando-Malabon-Navotas Est.
Ft. Bonifacio	6	1989	Taguig-Napindan

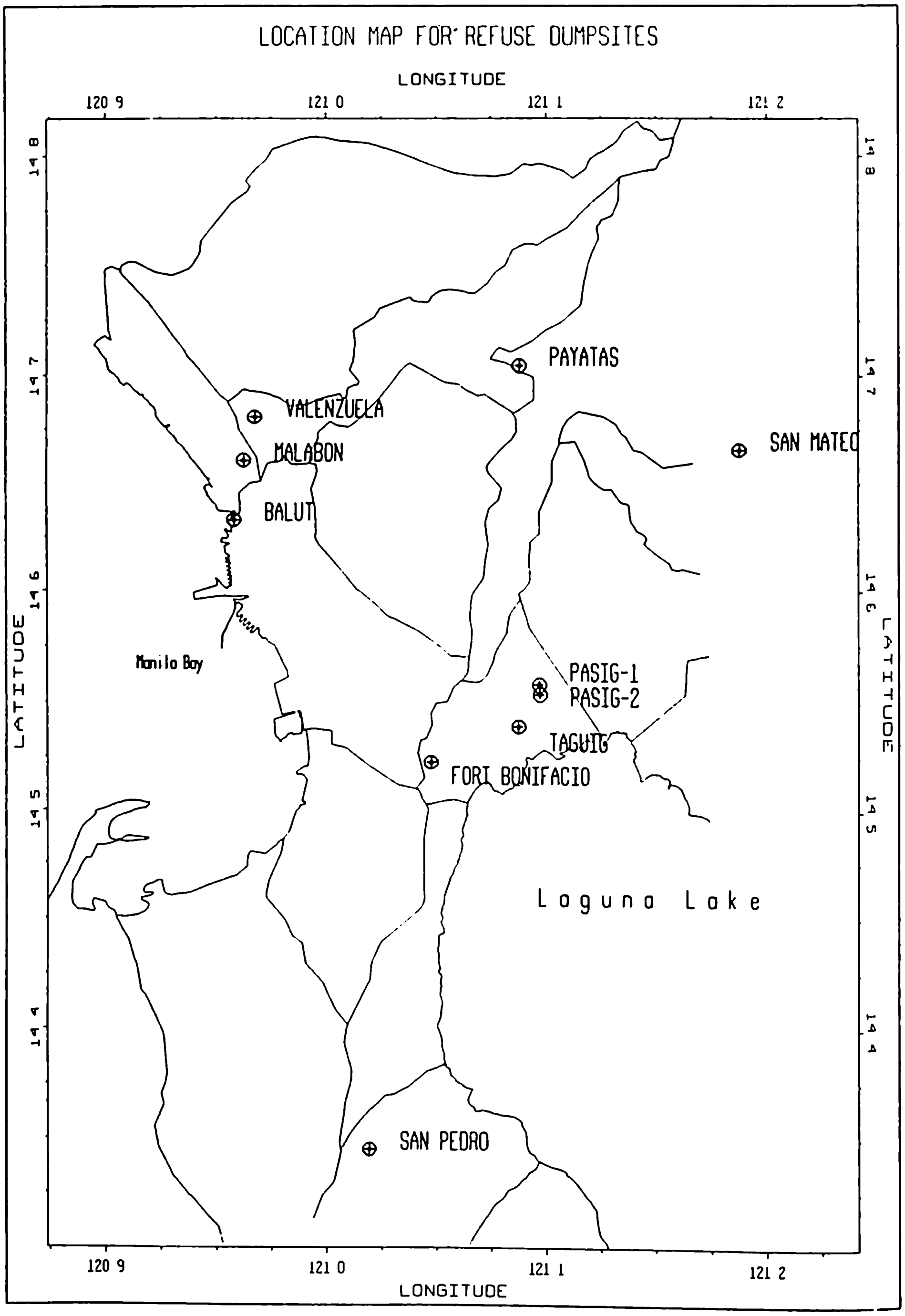


Figure 2. Refuse dumpsites in Metro Manila

▪ Polluting Industries in Metro Manila

Most of the industries plotted in Figure 3 were taken from the inventory of the Laguna Lake Development Authority (LLDA) classified according to their pollution potential. There are 336 industries identified as possible contributors to groundwater contamination. Majority of the industries are found in Pasig, Caloocan and Valenzuela.

▪ Underground Storage Tanks

The underground storage tanks or USTs are mostly associated with gasoline stations and bus terminals. USTs that are more than 16 years old are suspected to be leaking and therefore contribute to groundwater contamination as point sources. There are 405 USTs identified and plotted as shown in Figure 4. Majority of the UST's are located in the Pasig and San Juan River Basins, and relatively few in the adjacent basins. Around one-third of these UST's are more than 10 years old.

▪ Human Settlements

For more than four centuries, Manila has remained as the center of commerce and industry as well as the seat of the national government. This natural attraction for population migration coupled with the relatively high birth rate has resulted in a large concentration of population in Manila and in the adjoining towns and cities, the regional area currently known as Metro Manila which consists of 4 cities and 13 municipalities.

The most recent survey places the population of Metro Manila at eight million which comprises 13% of the total population (60 million) of the Philippines. It is interesting to note, however, that the land area of Metro Manila is only 636 square kilometers or merely 0.2% of the whole country.

The area with the highest population density (60,000 persons per square kilometer) for the entire country is Navotas, a town north of Manila. This is about 300 times the national average of 193. The City of Manila is not far behind with 50,000. Other areas in Metro Manila have population densities ranging from 3,718 in Muntinlupa to 26,258 in Pasay City.

By the year 2000, Metro Manila's population is estimated to swell to about 11.4 million. Similar population growth patterns are expected in the adjacent towns within the Laguna Lake Basin.

Pollution of Metro Manila's river system comes mainly from domestic sources (70%), with industrial sources (30%) coming in second (EMB, 1990). Since only 13% of Metro Manila's population is served by a sewerage system (MWSS, 1988) domestic wastes are simply allowed to flow into the rivers. The rest mostly depend on improperly maintained septic tanks, which could also pollute the groundwater underneath.

Spatial distribution of high density built-up areas where urban development is greatest as a result of industrialization and human settlements could be seen in enhanced and reclassified land cover images digitized from remotely-sensed data as shown by Figure 5.

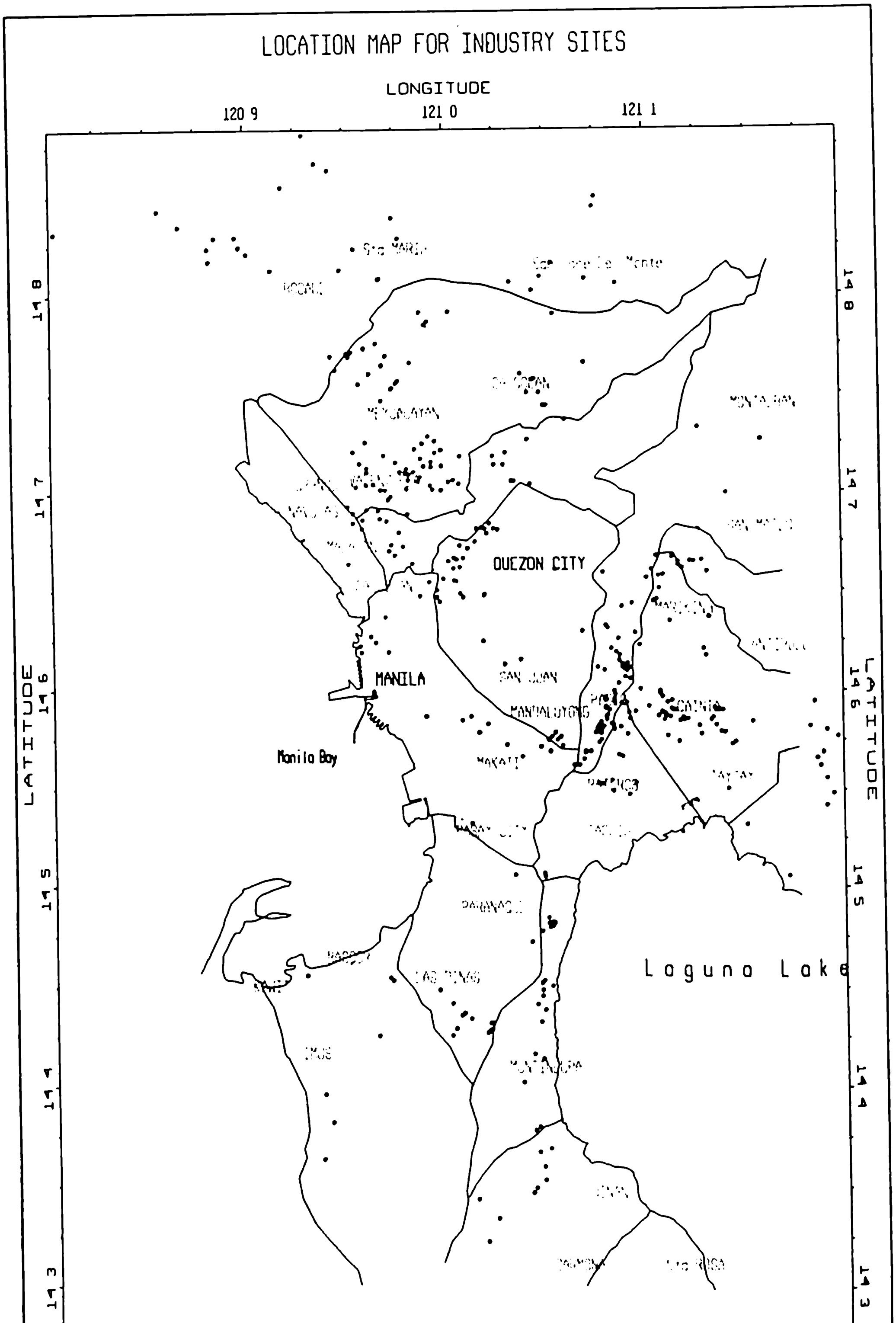


Figure 3. Polluting industry sites in Metro Manila

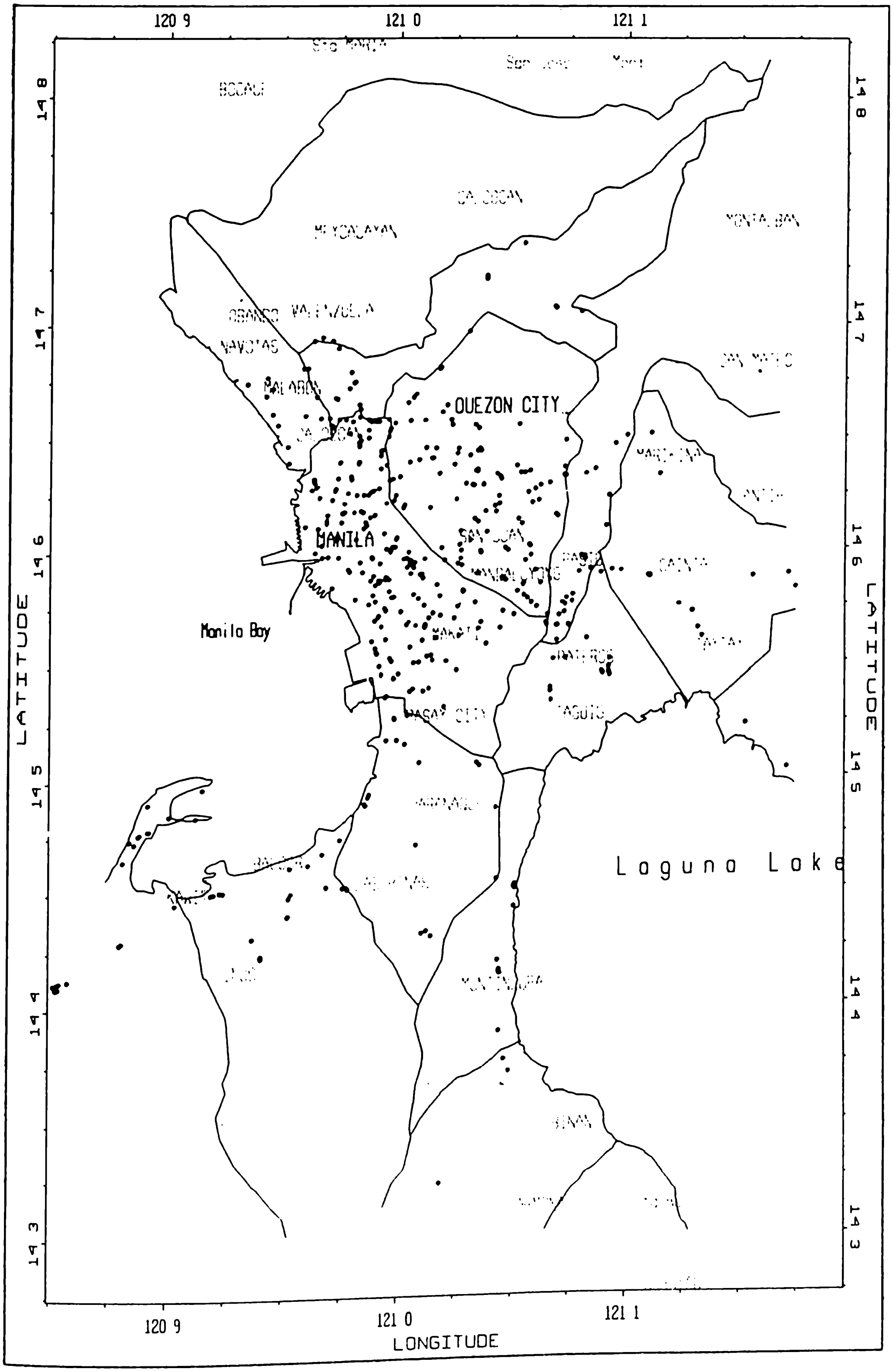


Figure 4. Location of underground storage tanks in Metro Manila

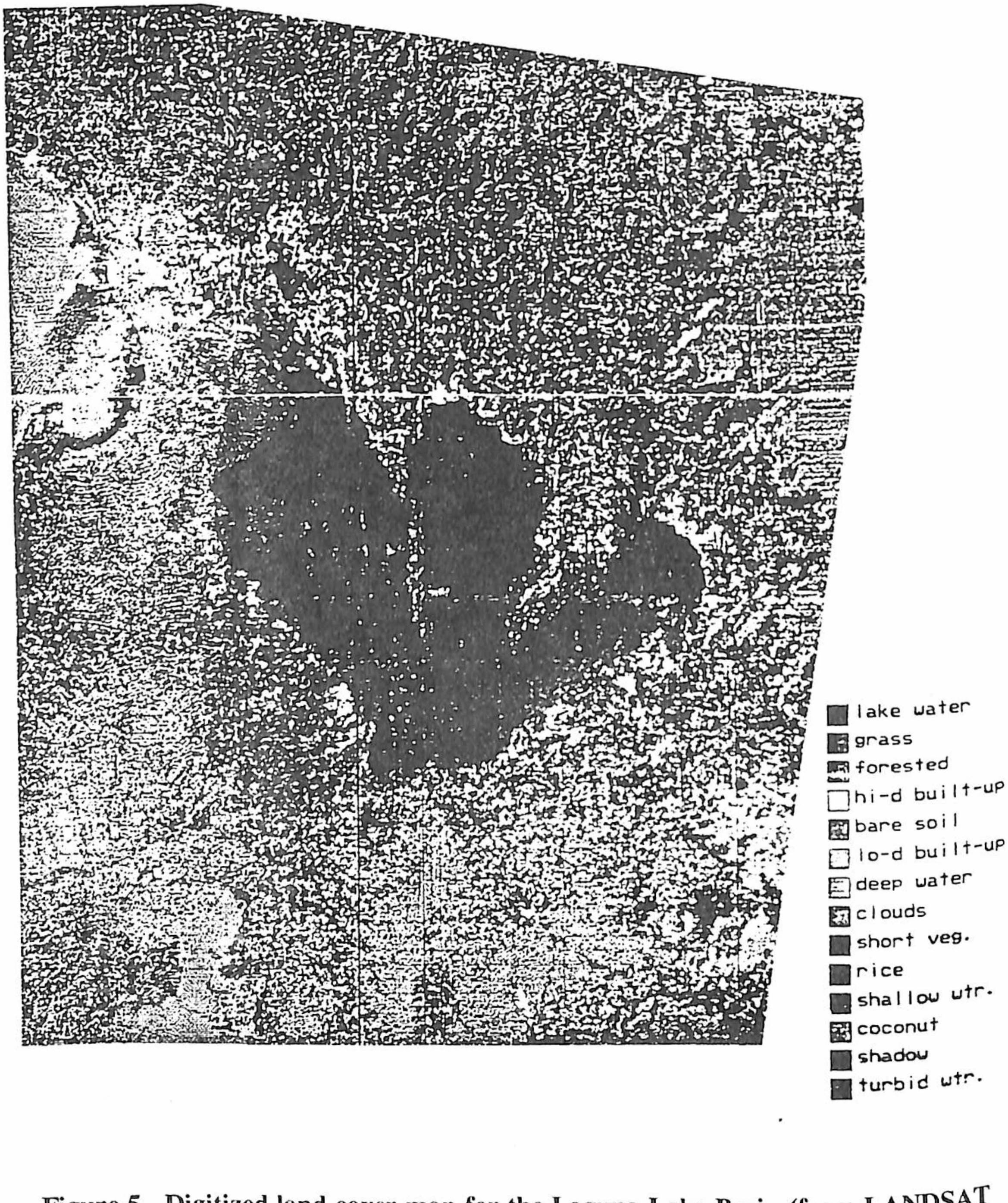


Figure 5. Digitized land cover map for the Laguna Lake Basin (from LANDSAT image taken February 1992)

SURFACE WATER QUALITY

Monitoring of the surface water quality in the Laguna Lake Basin are being undertaken by the following agencies:

EMB (Environmental Management Bureau) of the Department of Environment and Natural Resources -- collects water samples from the major rivers nationwide including those found in Metro Manila.

LLDA (Laguna Lake Development Authority) -- monitors the water quality of the Laguna Lake and its tributary rivers.

Metro Manila Rivers

For the past three decades, the unabated pollution of Metro Manila's four major rivers -- - Pasig, Tullajan-Tenejeros, San Juan and Paranaque-Zapote --- have rendered these rivers fit for nothing else but navigation . The dissolved oxygen in these rivers are well below the DENR criteria for Class C rivers while their biochemical oxygen demand (BOD) have become quite high, aside from being contaminated with heavy metals and pesticides (EMB, 1990).

The sources of pollution in these rivers could be attributed to a variety of sources which include domestic sewage and garbage, municipal wastes from public markets and slaughter houses, untreated or partially treated wastewater from industries and oil spills from gasoline stations, oil depots and barges, tankers and boats.

Laguna Lake Water Quality

A review of the monitoring results of LLDA from 1980 to 1988 indicates that levels of phosphate have risen, pH remained relatively constant, dissolved oxygen has been reduced gradually, turbidity has increased, total dissolved solids has decreased, coliform bacteria count has been erratic, and the temperature has remained at the same level (USAID, 1991). The rise in phosphates, lowering of DO, and increasing turbidity are all indications of increasing contamination around the drainage area from human and industrial development, agriculture, and airborne.

Non-point sources of pollution to the lake such as urban road sediments should be considered in the assessment of lake pollution. Gasoline laden with lead that is emitted by motor vehicles is adsorbed on dust particles that eventually reach the lake by airborne settlement or rainfall runoff. Surface runoff containing pesticides and fertilizers from agricultural sites also contribute continually to the contamination of the lake.

MWSS in agreement with LLDA is planning to tap the Laguna Lake as a source of drinking water supply. At present, Laguna Lake already has multiple uses which include irrigation, fishery, and industrial processes. DENR has also upgraded the water classification from Class C to Class A water in preparation for this shift in water use. However, at its present state, the western portion of the lake is obviously affected by pollution with lesser degrees on the eastern portions. For the lake water to be fit for drinking, tertiary water treatment will be required to eliminate the toxic heavy metals and organic compounds that have been discharged to the lake for almost two decades.

GROUNDWATER QUALITY DATA

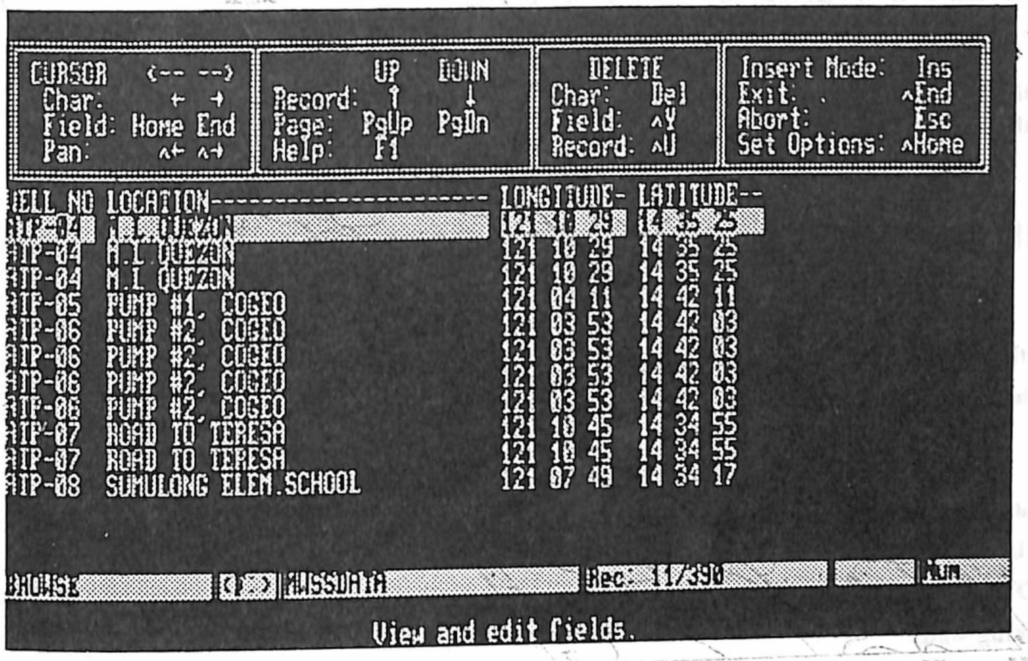
Water quality data have been collected to meet diverse objectives, ranging from monitoring for compliance with drinking water standards and criteria to conducting research on specific groundwater issues. Ideally, these data could be readily combined into one database for use in a regional groundwater quality assessment. However, certain characteristics of existing data limit their usefulness for a regional assessment of groundwater.

Database structure and format, as well as differences in procedures among agencies for collecting and analyzing the data preclude the combination of data from different sources to form a meaningful regional assessment. **Common limitations** of the data include:

- lack of information on quality control,
- inconsistent sampling, preservation, and analytical techniques among and within agencies,
- the clustering of sampling wells around known or suspected areas of contamination, which can impose a bias on water quality assessments,
- improper construction of wells, and
- lack of information on sampling locations, well depths, well construction, and aquifer characteristics.

The groundwater data for this study were collected from MWSS and the Department of Health (DOH). MWSS conducts monitoring of groundwater to determine its physical and chemical characteristics as well as to detect the extent of seawater intrusion. DOH, on the other hand, performs sampling and analysis with less regularity usually on a request-basis. The two agencies monitor different parameters at different locations. The monitoring activities of these two agencies provided several samples from wells or groundwater sources, and some from spring or tap water. There are **976 samples from DOH** during the period 1982-1991 **and 390 records from MWSS** taken during the period 1986-1991. They have been encoded and properly indexed for subsequent text and graphic processing.

The MWSS sampling points with the groundwater quality analyses were encoded in a database file which lists the well number, location, town, province, coordinates and the water quality data (date of sampling, odor, color, taste, pH, turbidity, alkalinity, acidity, total chloride, total hardness, total iron, residual chlorine, bicarbonate and free carbon dioxide). Figure 6 shows samples of the database screen display.



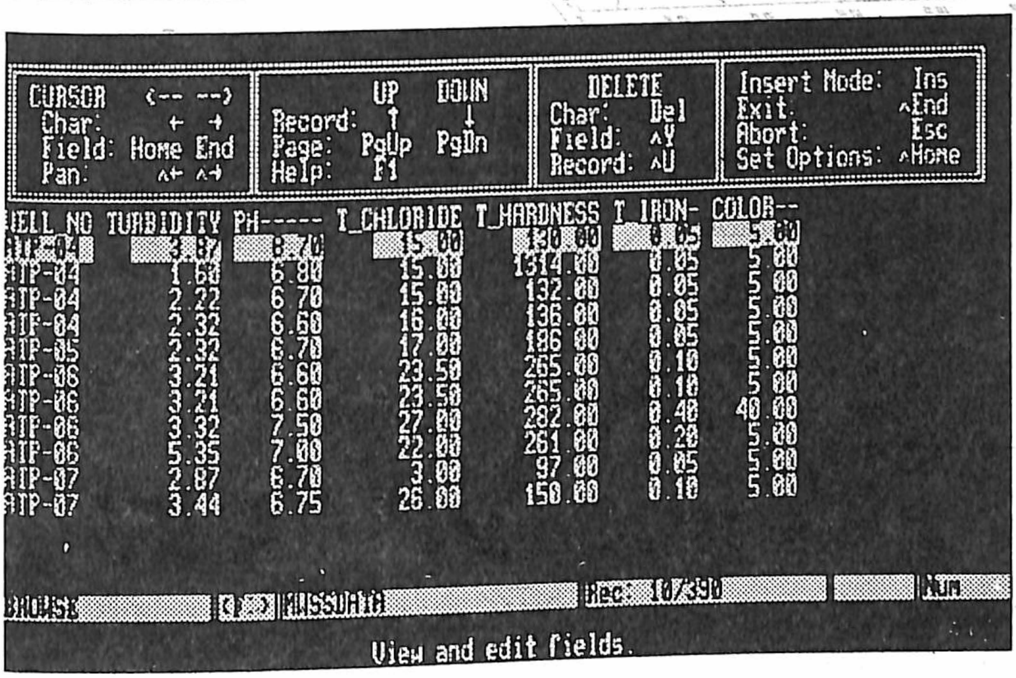


Figure 6. Sample database screen displays

A separate database file contains the DOH water quality data which includes odor, color, turbidity, alkalinity, acidity, total chloride, total hardness, total iron, total residue, pH, flouride, nitrite, and residual parameters (chlorine, calcium, magnesium, manganese, sulfate, silicate). It is worthwhile to note that the DOH files include both surface and groundwater sources.

A location map for the MWSS and DOH groundwater quality sampling points, at least for those with coordinates, was generated and is shown in Figure 7. The clustering of sampling points can be seen from the map especially in areas where most of the pumping wells are located.

DRINKING WATER QUALITY STANDARDS

Drinking water standards have been established for some constituents to protect human health and drinking water criteria have been set out for other constituents to provide acceptable aesthetic and taste characteristics.

Specific conclusions from the analysis of available water quality data were focused on constituents specified by the Philippine National Standards for Drinking Water (NSDW), which are based on World Health Organization (WHO) Standards. Both MWSS and DOH use the NSDW for comparing their monitoring data. Table 1 lists the NSDW/WHO standards for drinking water.

Table 1. NSDW/WHO Standards for Drinking Water

Parameter	NSDW/WHO Standards	Units
Calcium	100.00	mg/l
Chloride	200.00	mg/l
Color	5	units
Flouride	1.0-2.5	mg/l
Hardness	100	mg/l
Iron	1.0	mg/l
Magnesium	30.00	mg/l
Nitrates	10.00	mg/l
pH	6.5-8.5	
Potassium	300.00	mg/l
Sodium	100-200	mg/l
Sulfate	200-400	mg/l
Total dissolved solids (TDS)	300-600	mg/l
Turbidity	5.0	units
Fecal Coliforms	0	no./100ml
Coliform Organism	0	no./100ml

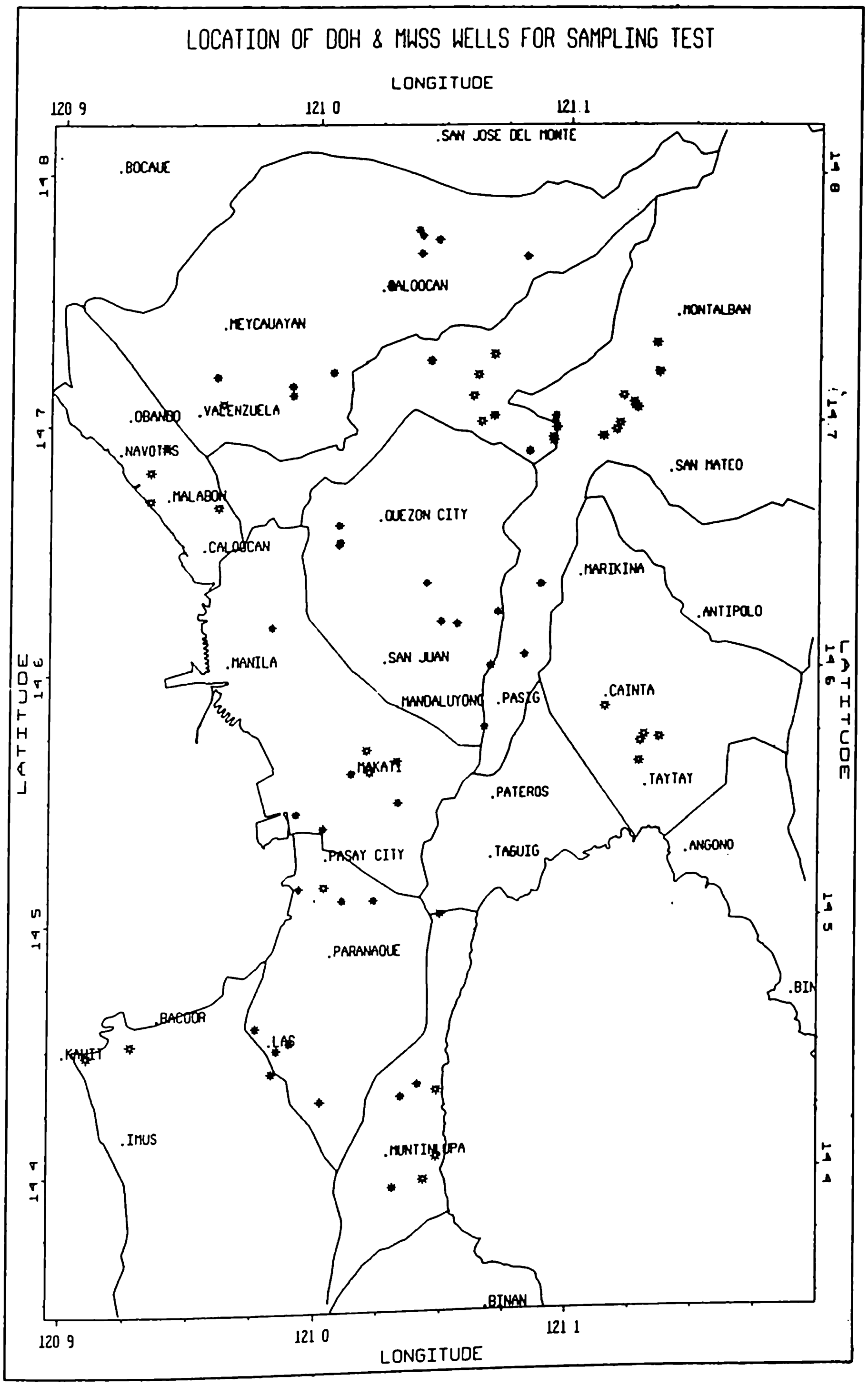


Figure 7. Location map of MWSS and DOH groundwater quality sampling points

ASSESSMENT OF GROUNDWATER QUALITY CONDITIONS

Groundwater quality data from both MWSS and DOH were compared with the WHO, NSDW and MWSS standards. Computer programs for the groundwater quality database were developed to display/print the well records and to compare data with WHO, NSDW and MWSS standards.

Data for pH and major inorganic constituents (such as hardness, chloride, sulfate and total dissolved solids) are relatively abundant. Only in 91 MWSS wells (23%) and in 87 DOH wells (9%) that low **pH** (acidic) was encountered. Data for **color** reveal that 102 MWSS wells (26%) and 218 DOH wells (22%) exceeded the standard of 5 units. Closely linked with color is **turbidity** which showed that 62 MWSS wells (16%) and 234 DOH wells (24%) are above the 5 turbidity units. Data for **hardness** of water from 162 MWSS wells (42%) and 664 DOH wells (68%) indicate that elevated concentrations are common; the concentrations exceed 100 milligrams per liter as calcium carbonate --- a concentration considered objectionable for ordinary domestic purposes. Hardness can become a nuisance by reducing lather formation and the effectiveness of soap as a cleanser as well as by creating scale deposits. Data for **total dissolved solids(TDS)** concentrations in water from all MWSS wells indicate that the concentrations are within acceptable limits, but 206 DOH wells (21%) indicate concentrations higher than 500 milligrams per liter. Data for **total iron** concentrations indicate that 12 MWSS wells (3%) and 130 DOH wells (13%) have concentrations higher than 1.0 mg/l. Data for **chloride** concentrations in water from 30 MWSS wells (8%) and 92 DOH wells (9%) indicate that concentrations exceed 200 milligrams per liter. Table 2 shows the percentage of wells where water does not meet the drinking water standards for each constituent.

Table 2. Percentage of wells which failed the Standards

Parameter	NSDW Standards	MWSS No.	MWSS %	DOH No.	DOH %
Chloride	200 mg/l	30	8%	92	9%
Color	5.0 units	102	26%	218	22%
Hardness	100 mg/l	162	42%	664	68 %
Iron	1.0 mg/l	12	3%	130	13%
pH	6.5-8.5	91	23%	87	9%
TDS	500 mg/l			205	21%
Turbidity	5.0 units	62	16%	234	24%

Based on the 1990 data from the MWSS and DOH wells, contour maps for the various water quality parameters were plotted to indicate areas where the standards have been exceeded. However, these contour maps should be interpreted with caution as the contour lines are affected by the location and spatial distribution of the sampling points, hence the formation of mounds and depressions around sampling points with abnormally high or low values. It should also be worthwhile to note the lack of information regarding the depth of sampling in the monitored wells.

- ***Chloride***

Elevated concentrations of chloride reflect local water quality problems influenced by human related activities such as domestic effluents, the application of fertilizer e.g. potassium chloride in agricultural areas and possibly saltwater intrusion induced by pumping. Figure 8 shows a contour map of chloride concentration for Metro Manila. Local incidences of high chloride concentrations especially in Marikina Valley may be due to the trapped seawater of a previous connection to the sea hence this salinity anomaly. There is a peak found along Pasay and Paranaque of concentrations above 200 mg/L indicative of saltwater intrusion that has been reported previously (NEPC, 1986).

- ***Hardness***

Elevated concentrations of hardness with peak values of 300 mg/L are also found in wells along Marikina Valley, Pasay City and Paranaque (see Figure 9). Around 50 % of the DOH and MWSS wells are above the recommended category for moderately hard water. However, there appears to be no firm evidence that water hardness causes ill effects in man. Hard water can be a nuisance by reducing lather formation and the effectiveness of soap as cleanser. Hardness also reflects the presence of calcium which may precipitate to form coatings and scales on pumps and pipes.

- ***Iron***

Iron is a natural constituent in groundwater. However in the study area peak concentrations above 1.0 mg/L are found in Caloocan, Pasay, and Muntinlupa (see Figure 10). Elevated concentrations may come from iron-rich sediments in reducing environments such as poorly drained and impermeable soils caused by oxidation of organic carbon.

These areas most likely are under reducing and low pH conditions in which ferric ion is reduced to soluble ferrous iron. High iron concentrations may cause brownish discolorations on plumbing fixtures, cooking utensils, and laundered goods, and may impart a bitter or astringent taste to water.

- ***pH***

The predominant groundwater pH is neutral throughout the study area except in isolated cases in Bulacan especially Obando and Bocaue and Cavite towards Bacoor and Kawit where the pH is a little above 8.5 (see Figure 11). Most of the pH values compiled are within the range specified in the NSDW standard which is 6.5 to 8.5. It should be noted that low pH or acidic water may pose water quality problems with regard to disinfection, water softening, and corrosion control, and it could increase treatment costs.

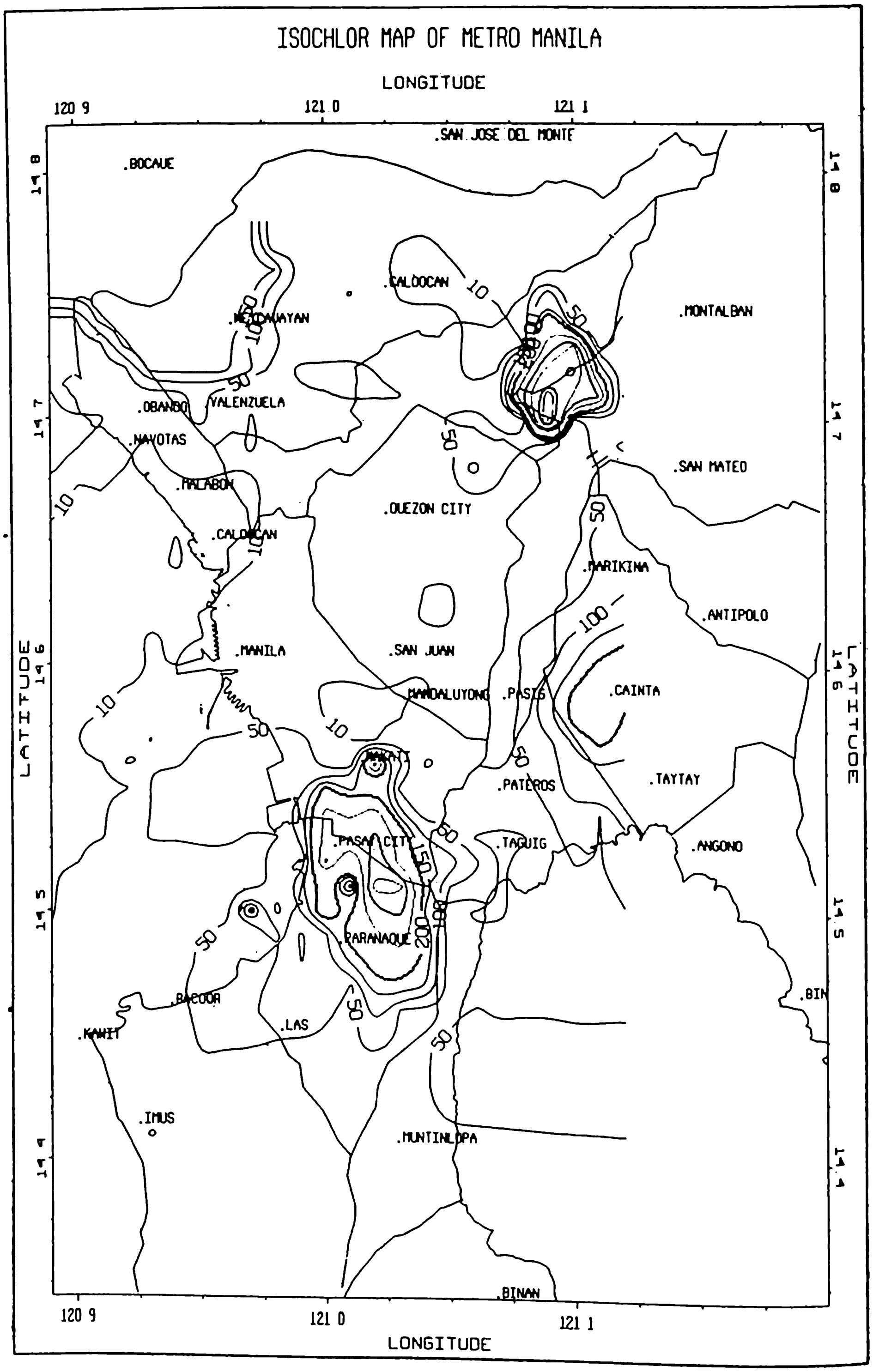


Figure 8. Groundwater chloride concentration map (mg/l)

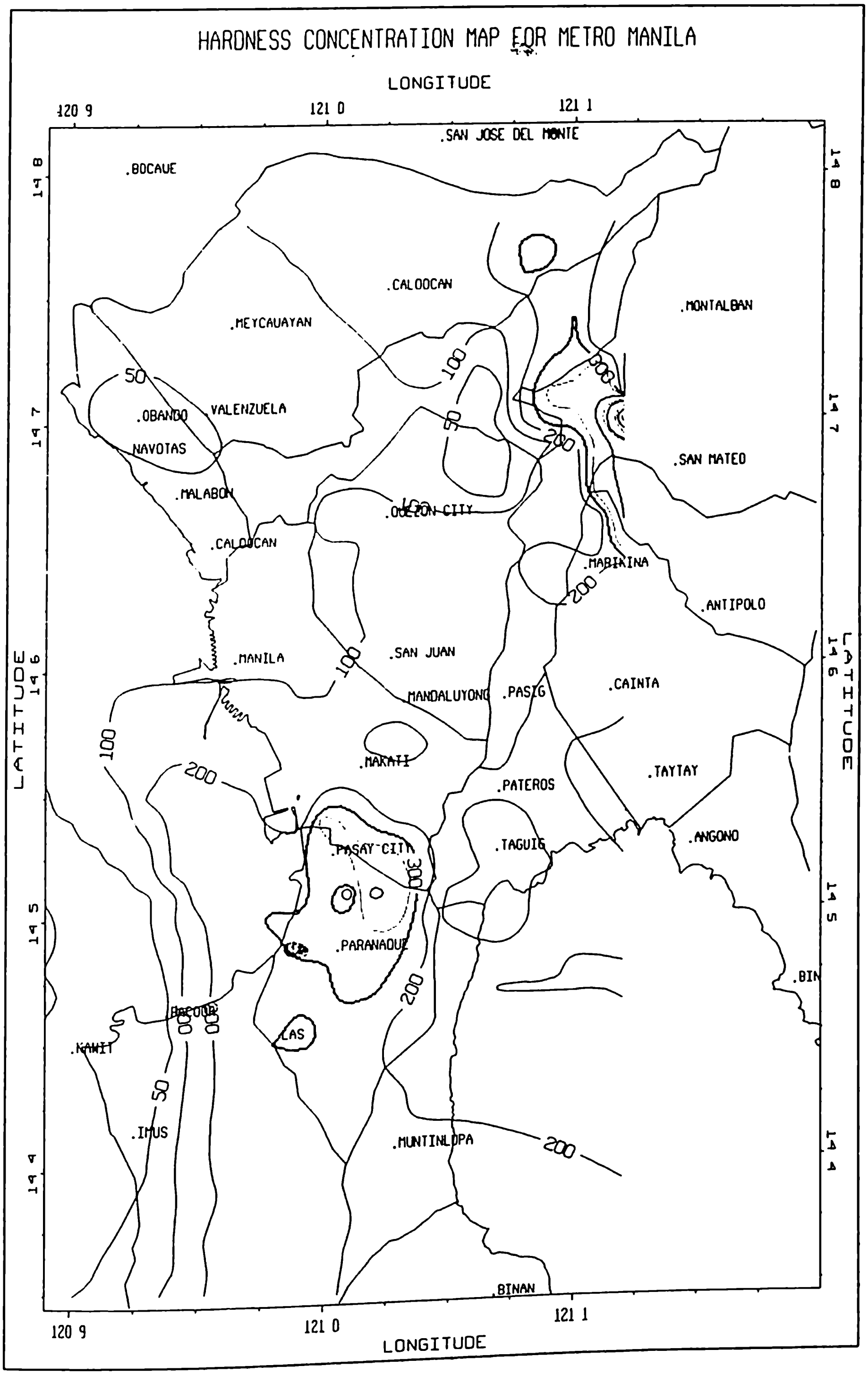


Figure 9. Groundwater hardness map (mg/l)

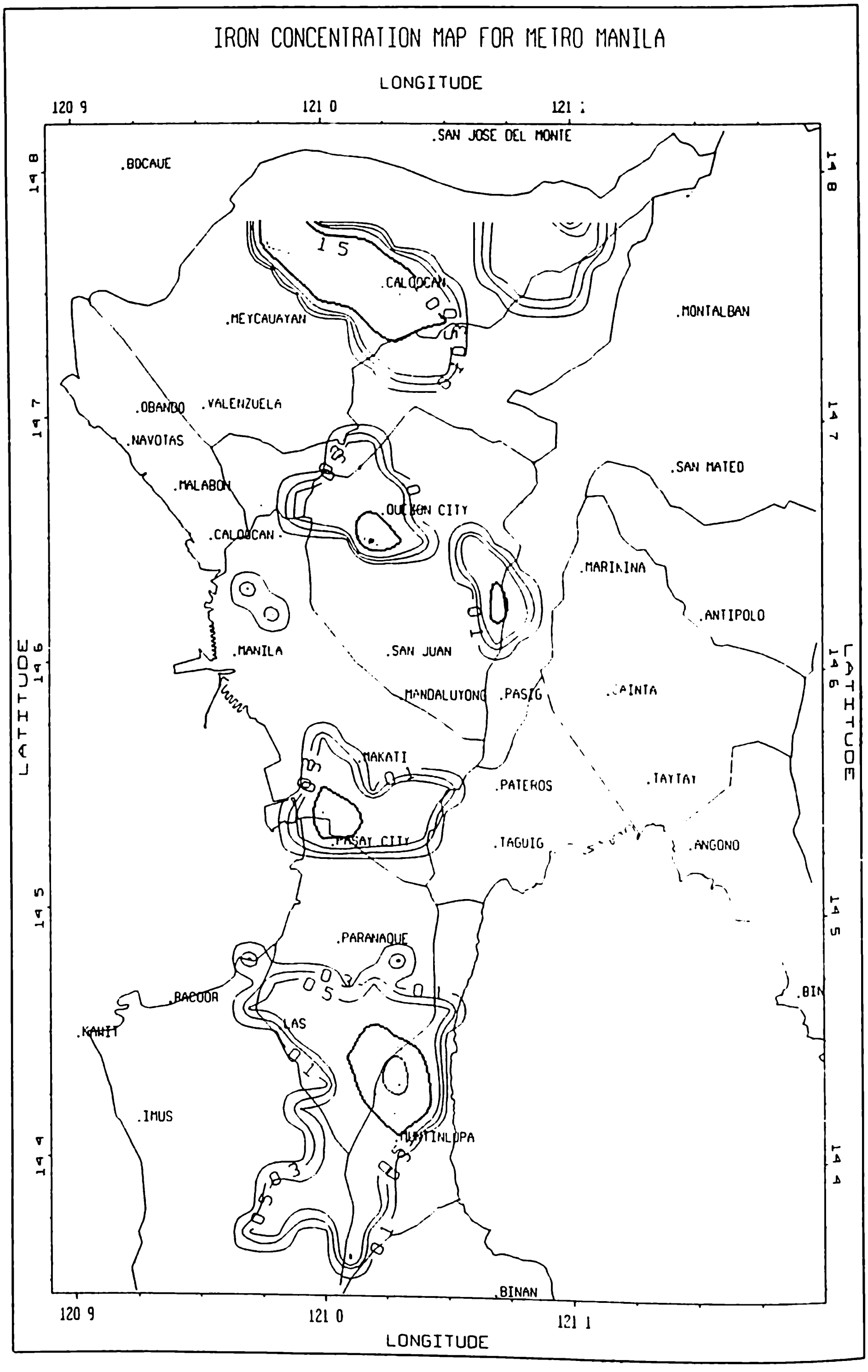


Figure 10. Groundwater iron concentration map (mg/l)

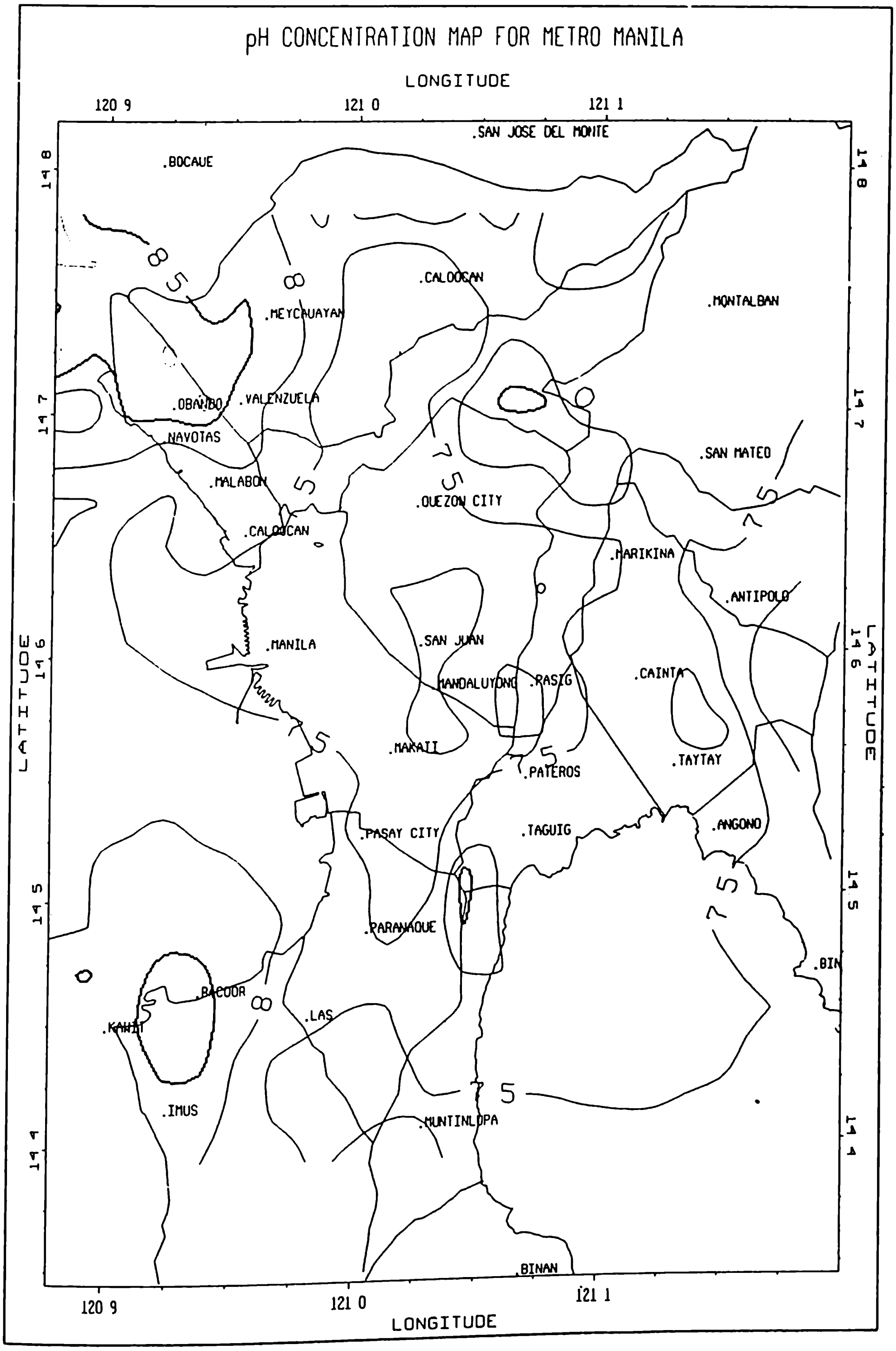


Figure 11. Groundwater pH map

■ *Total dissolved solids*

Elevated concentrations of more than 300 mg/L of total dissolved solids are present in 21% of DOH wells mostly in the northern (Marikina Valley) and western section (Pasay and Paranaque) of the study area as shown in Table 2 and Figure 12. The probable causes of elevated TDS concentrations are dissolution of minerals and the presence of saline water. High TDS concentrations could be a nuisance by imparting unpalatable mineral taste to the water and could raise drinking water costs because of scale deposits.

■ *Turbidity*

As stated in Table 2, 62 MWSS wells (16%) and 234 DOH wells (24%) have elevated concentrations of turbidity above 5 units. Figure 13 shows that these areas are mostly found in the northern section (Bulacan and Kalookan), portions of Pasig and Mandaluyong, and Pasay. Areas beside Laguna Lake such as in Muntinlupa and Las Pinas were found to yield slightly turbid waters. Possible contaminants may include sewage, industrial wastes and leachates from dumpsites.

■ *Organic Compounds*

Data for organic compound concentrations in groundwater are scarce. Potential sources of contamination of groundwater by organic compounds could be traced to landfills, spills, underground storage tanks, and industrial processes. More widespread are nonpoint sources such as fertilizer and pesticide which pose a considerable threat in the degradation of water quality. Unfortunately, there is no sufficient data to evaluate the existence or extent of contamination from organic compounds in the study area.

■ *Trace Elements*

Indications of saline water intrusions were previously reported in Malabon, Navotas, Parañaque, Las Piñas, Bacoor, Imus, Kawit, Pasig, Antipolo, San Mateo, Taguig, Cainta, Taytay, Alabang and Muntinlupa by Santos *et.al.*(1989) through the analysis of the uranium content of water samples from MWSS deepwells. The same report also indicated the exceedance of NSDW limits for mercury (six wells), manganese (four wells) and iron (two wells) in Metro Manila. Other trace elements such as Cr, Pb, Zn, Co and Ni were either not exceeded or not included in the NSDW list.

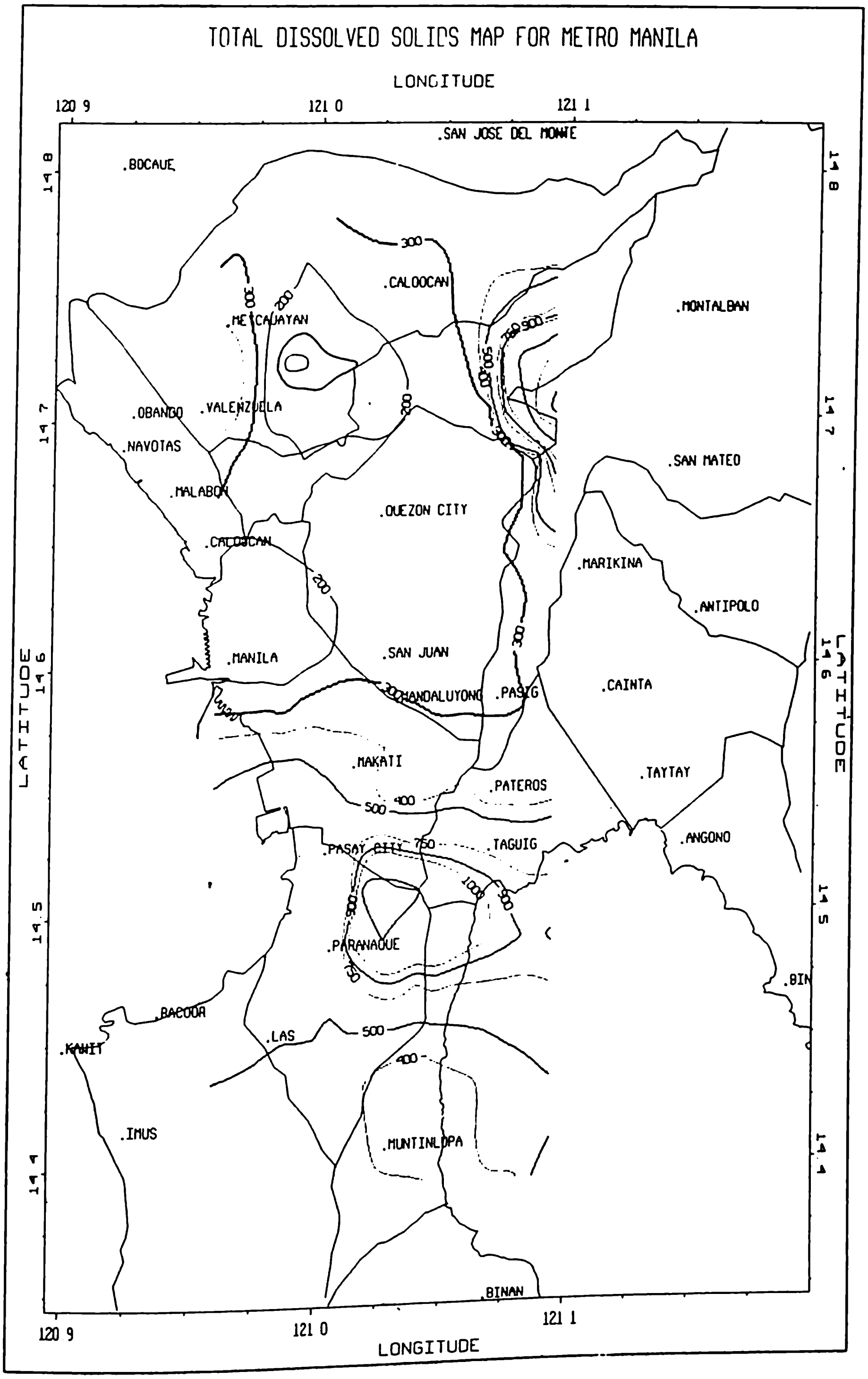


Figure 12. Groundwater total dissolved solids concentration (mg/l)

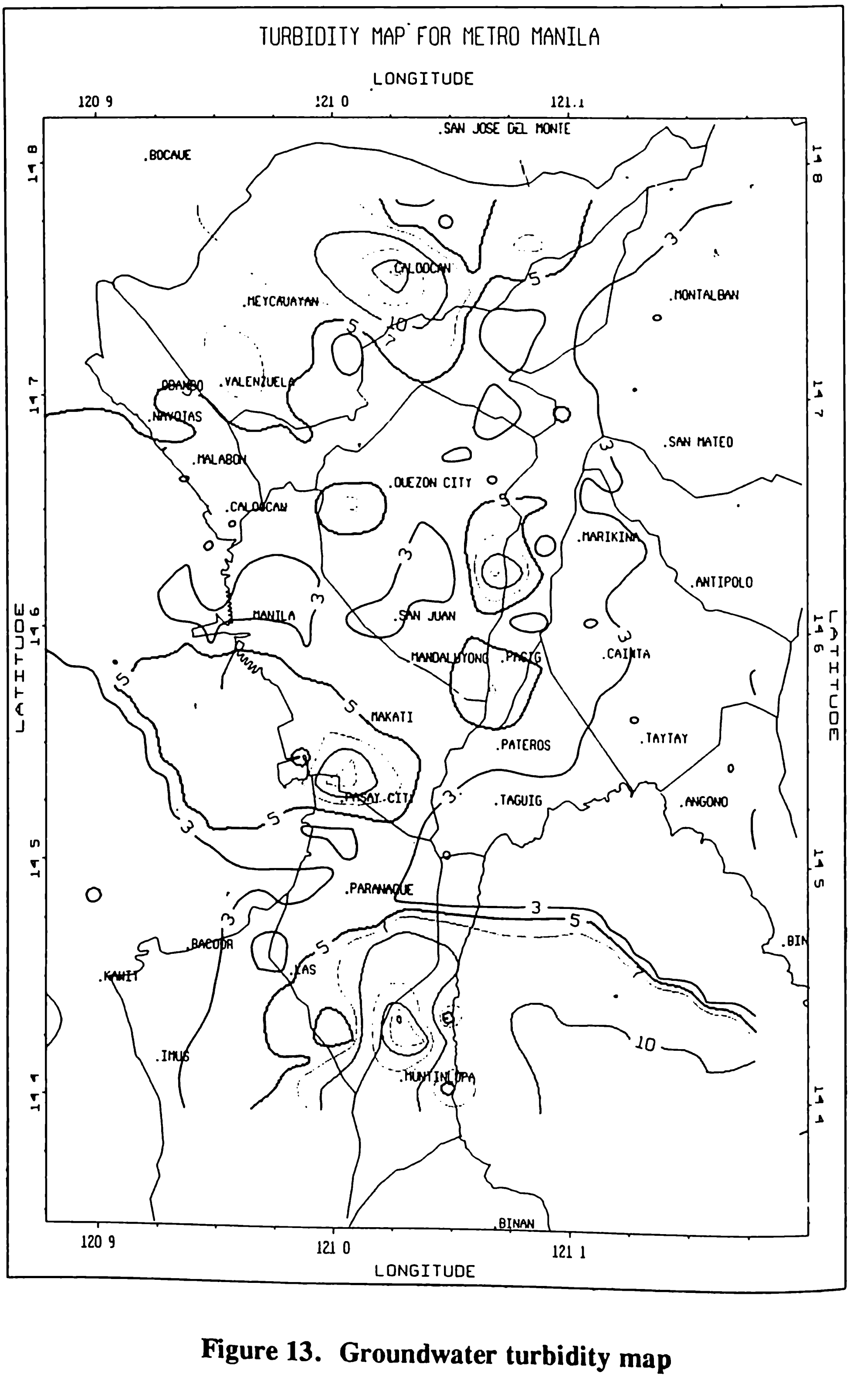


Figure 13. Groundwater turbidity map

VULNERABLE AREAS FOR GROUNDWATER CONTAMINATION

A preliminary assessment of groundwater pollution potential was studied by NHRC (Pascual,1992) by adopting the DRASTIC (Aller et al.,1987) approach, a standardized system using hydrogeological settings and the application of a scheme for relative ranking of hydrogeological parameters. This method determines regional variations in groundwater pollution potential by evaluating the following set of mappable hydrogeological parameters:

(1) Depth to water (unsaturated zone)
(2) net Recharge
(3) Aquifer media
(4) Soil media
(5) Topography
(6) Impact to vadoze zone media and
(7) hydraulic Conductivity.

Figure 14 shows the groundwater pollution vulnerability map for Metro Manila based on the DRASTIC approach. From the figure, it could be seen that most parts of Metro Manila have low vulnerability potential, which could be mainly due to the predominantly thick clay aquitard layer and deep groundwater levels in these areas. On the other hand, some portions near Marikina in the northeast can be classified as having high potential due to very shallow water table and relatively porous aquifer (sandstone) and soil (clay loam) media.

CONCLUDING REMARKS

As earlier presented, several problems regarding water quality data collection and monitoring were encountered. Such limitations still exist and apparently there seems to be no concerted effort on the part of the agencies concerned to address the issue. It is therefore recommended at this point that a standard inter-agency data monitoring, analysis, processing and reporting scheme be adopted in order to come up with a reliable and meaningful water quality monitoring and assessment program within the context of sustainable utilization and management of water resources.

The vulnerability map is a first attempt to evaluate pollution potential. By itself and at its present state it could only indicate probable areas of groundwater contamination. Before it could be used for policy formulation, it should be validated through the collection of groundwater samples on specific sites with a desired frequency. Results of the preliminary assessment could aid in the identification of specific studies which could be focused on areas with high vulnerability potential.

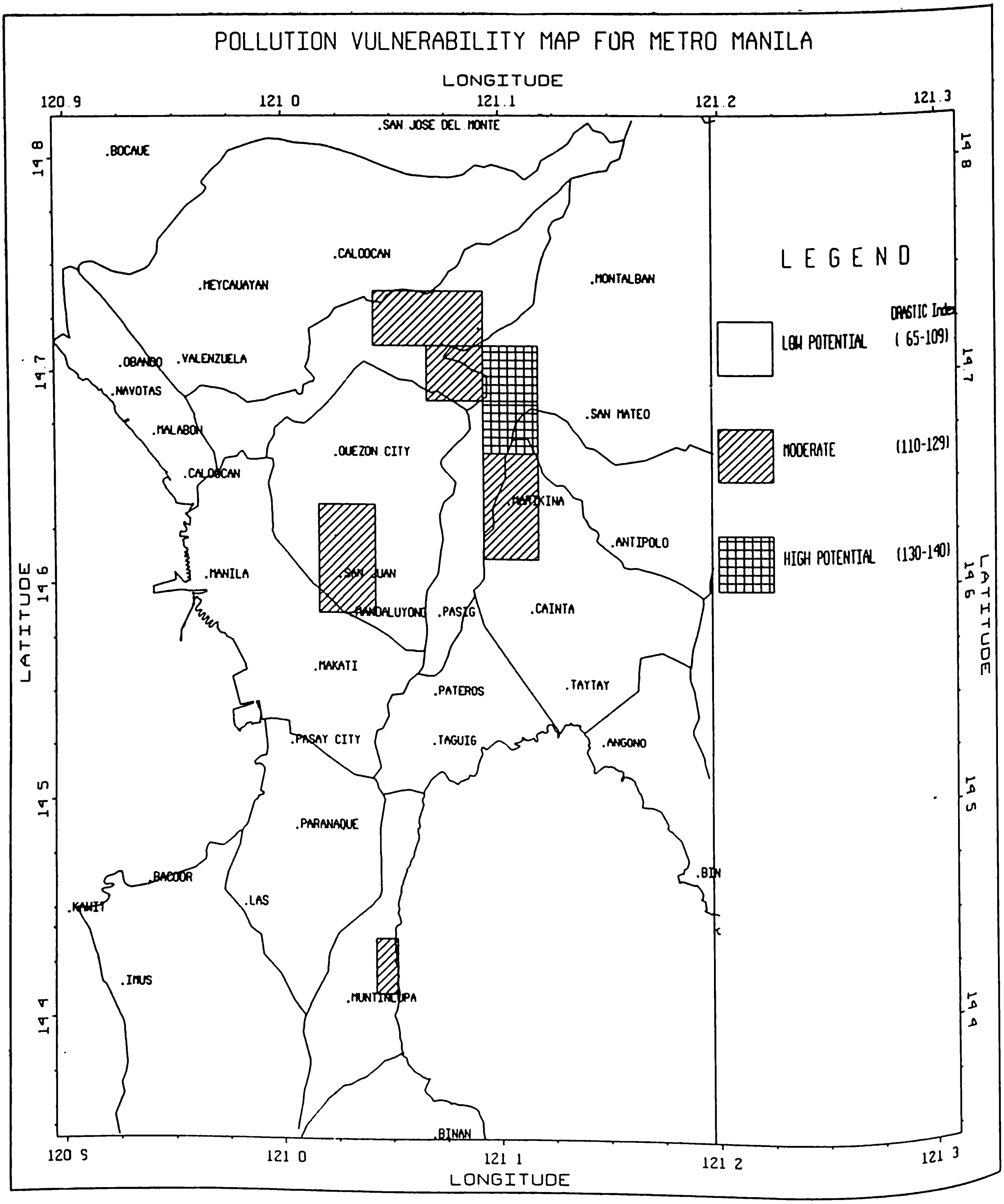


Figure 14. Groundwater vulnerability to pollution

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