FIELD SURVEY ON HYDRODYNAMICS AND WATER QUALITY IN MANILA BAY AND LAGUNA LAKE

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Abstract: A series of field surveys was conducted in Manila Bay and Laguna Lake to clarify their physical and hydrodynamic environments and to provide basic information, which will be used to develop numerical models for the bay/lake system, including watershed hydrology. Data collected includes temperature, salinity, water level fluctuations, turbidity, Chl-a, TN, TP, SS, DO and others. The field surveys took into consideration the effects of season, wind conditions, tidal fluctuations, presence of fish pens and period of measurement. Initial analysis of the data collected indicates intrusion of saltwater into the lake in spring tide and lower TN/TP ratio in the lake and river during dry season. In dry season, SS, TN and TP in Laguna Lake were much higher than that for the rainy season. In Manila Bay, TN/TP ratio is greater than 16 except at the mouth of the Pasig River. The mixed layer is affected by wind speed. Positive correlation exists between σ, and turbidity.

Key Words: Hydrodynamics, water quality, Manila Bay, Laguna Lake, field survey

1. INTRODUCTION

Laguna Lake is one of the largest inland bodies in Southeast Asia, with an approximate total surface area of 900 km² and an average depth of 2.5 meters. Bounded by a number of
municipalities, around 100 streams drain into this lake. The watershed of the lake, covering an area of approximately 3820 km$^2$, has undergone significant changes resulting from population increase, urbanization, industrialization and land use conversion (Nauta et al., 2003). These changes resulted in increased siltation, eutrophication and pollution, thereby affecting the water quality and value in the lake. Laguna Lake is also subject to intensive and extensive aquaculture, as evidenced by the numerous fish cages and fish pens. Approximately 40% of the total fish production through aquaculture in the Philippines comes from this lake (UNEP, 1999).

Manila Bay is located in the western part of Luzon and has an area of about 1,700 km$^2$. The width of the bay varies from 22 km at its mouth to maximum of about 60 km. Average depth is 17 meters. Its watershed is approximately 17,000 km$^2$ and is composed of 26 catchment areas. Jacinto et al. (1998) noted that rough estimates of the discharge of inorganic nutrients into the bay is approximately 40 x 10$^6$ mol/yr of inorganic P and 600 x 10$^6$ mol/yr of inorganic N. With increasing population and still ineffective waste management, values of waste loading rates are higher today.

Manila Bay and Laguna Lake are both situated in the vicinity of Metro Manila, the most densely populated area in the Philippines. The increasing population, coupled with rapid developments in the nearby provinces, exerts pressure on the bay and the lake – higher water demand, disposal of wastewater, increased fishing activity, among others. Manila Bay and Laguna Lake are connected by the Pasig River, which discharges into the bay and is the only outlet of the lake. The water level in Laguna Lake may fall to a minimum of 10.5 meters (above mean sea level) during the dry season and during this time, intrusion of polluted seawater from Manila Bay occurs (Nauta et al., 2003).

This points to the need to adapt a comprehensive and integrative approach to modelling water quality and quantity, treating the bay and the lake not as exclusively separate but looking at it as a bay/lake system together with the surrounding watershed and tributaries. In connection with this, a hydrodynamic model that will incorporate the dynamic interaction between Manila Bay and Laguna Lake needs to be developed. This model is a very important component of an integrated study of the bay/lake system and surrounding watershed. The development of such model requires field measurements of various water characteristics for calibration and validation.

This paper reports on the field surveys conducted in Manila Bay, Laguna Lake and Pasig River over the period beginning October 2001 to February 2003. It also presents initial findings based on the result of these surveys. The figures are given at the end of the paper.

2. FIELD METHODOLOGY

Several field surveys were conducted from October 2001 to February 2003 to measure different variables. Measurements were taken in Manila Bay, Laguna Lake and Pasig River under different season and period of measurement. Long-term measurements (LP3) were carried out at stations (survey points) P3, L1, L4 and L8 (see Figure 1). Summary information about the surveys is given in Table 1.
Table 1: General Characteristics of the Field Surveys

<table>
<thead>
<tr>
<th>No.</th>
<th>Measured quantity</th>
<th>Date</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location: Laguna Lake and Pasig River</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LP1</td>
<td>Salinity, temperature, depth, turbidity,</td>
<td>October 2001</td>
<td>Rainy season, short-term measurement (3-4 days)</td>
</tr>
<tr>
<td></td>
<td>Chl-a, DO, 2D velocity, wind velocity, TP, TN, SS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LP2</td>
<td>Salinity, temperature, depth, turbidity,</td>
<td>February 2002</td>
<td>Dry season, short-term measurement</td>
</tr>
<tr>
<td></td>
<td>Chl-a, DO, 2D velocity, wind velocity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LP3</td>
<td>Salinity, temperature, depth, turbidity,</td>
<td>March-June 2002</td>
<td>Long-term measurement (continuous)</td>
</tr>
<tr>
<td></td>
<td>Chl-a, DO, 2D velocity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LP4</td>
<td>Salinity, temperature, depth, turbidity,</td>
<td>February-March 2003</td>
<td>Measurement in and around a fish pen</td>
</tr>
<tr>
<td></td>
<td>Chl-a, DO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location: Manila Bay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MB1</td>
<td>Salinity, temperature, depth, turbidity,</td>
<td>October 2001</td>
<td>Rainy season</td>
</tr>
<tr>
<td></td>
<td>Chl-a, DO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MB2</td>
<td>Salinity, temperature, depth, turbidity,</td>
<td>February 2003</td>
<td>Dry season</td>
</tr>
<tr>
<td></td>
<td>Chl-a, DO</td>
<td></td>
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</tr>
</tbody>
</table>

2.1 Sampling Distribution

The spatial distribution of survey points in Laguna Lake and Pasig River is shown in Figure 1. There are 10 points for Laguna Lake and 5 points for Pasig River. Two additional points were used, each around the intersections of Pasig River with San Juan River (S1) and with Marikina River (M1). Measurements were taken at all points for field survey LP1 and LP2. For LP3, only points P3, L1, L4 and L8 were used. For field survey LP4, a point inside a fish pen and four survey points along the perimeter were chosen as shown in the inset in Figure 1.

Figure 1 also shows the survey line transects, distribution of sensor deployment points (M1-M3) and location of wave gauges and anemometers for field survey MB1 and MB2, respectively. The A-Line transect was made parallel to the width of the mouth of the bay while the B-Line stretches across the bay in east-west direction starting near the mouth of Pasig River. An additional transect (C-Line) was supposed to be used for MB2 to investigate heat transport in relation to tidal fluctuations. However, due to some difficulties during MB2, only the B-Line was surveyed and no measurements were taken along the A and C-Line.

2.2 Methods and Instruments

The distribution of the survey points was designed such that sufficient data can be gathered to develop the bay/lake hydrodynamic and water quality model. The set of points in Laguna Lake has good coverage of the lake, particularly on those areas with relatively high hydrodynamic activity and water quality problem. The surveys (LP1 and LP2) were undertaken in different seasons (wet and dry) to determine the effects of seasonal variations. LP3 was undertaken to understand the long-term variations. There are several fish pens and fish cages in Laguna Lake. Field survey LP4 was conducted to determine the local effects of these structures on the hydrodynamic characteristics and water quality.

Field surveys LP1, LP2 and LP3 utilized the sensor deployment schemes illustrated in Figures 2a and 2c. The first scheme (Figure 2a) is designed for long-term measurement through the use of a data logger and fixed structure (fish pen). Wind velocity measurement
is also made possible. The second scheme (Figure 2c) is for areas where no structure is present. Wind velocity is not measured in this scheme. In both schemes, temperature is measured at various depths while salinity measurement is only taken at the surface and bottom. Water quality measurement is made using the water quality sensor, which measures salinity, temperature, depth, turbidity, Chl-a and DO at any depth (Figure 2b). Water is also sampled and later analyzed to determine the following: total nitrogen (TN), total phosphorus (TP), suspended sediments (SS), NO$_3$, NO$_2$, NH$_3$, PO$_4$ and SiO$_4$. The distribution of sampling points is shown in Figures 4 to 6. For the measurements in LP4, sensors attached to moored buoys were used to measure velocity, turbidity and Chl-a. A wave gauge was also used (Figure 2d).

Measurements were taken at five survey points along the stretch of Pasig River. This is aimed at studying the interaction between Manila Bay and Laguna Lake. Two additional points were utilized to investigate the influence of San Juan River and Marikina River on Pasig River. The scheme shown in Figure 2b was used.

Measurements in Manila Bay were carried out using the sensor deployment shown in Figure 2e for points M1, M2 and M3 (Figure 1). For the line transect surveys, the temperature, salinity, depth, turbidity and DO were measure using a water quality sensor. An acoustic Doppler current profiler (ADCP) was used to map the vertical profile of horizontal velocity along the A-Line. Water samples were also collected (Figure 2f).

3. DATA AND INITIAL ANALYSIS

A lot of data have been collected but only some will be presented with accompanying figures due to the limitation on the number of pages. Results of initial analysis and interpretation are provided in the following sections.

3.1 LP1 Results

The effect of the tidal fluctuation was negligible except for P1 near Manila Bay, and correspondingly the salinity was appreciable only at P1, indicating that in this period the brackish water did not intrude into Laguna Lake. This is due to the fact that field survey LP1 was done during the rainy season, in which the water table in Laguna Lake was higher than the annual average and therefore unidirectional flow toward Manila Bay prevailed. As shown in Figure 3, the winds at L3 and L10 in Laguna Lake are quite different from each other both in magnitude and direction. This is considered due to the effect of the surrounding terrain on the wind field.

The time series of water temperature measured at various points in the lake indicate a similar diurnal fluctuation of the near-surface temperature, showing its maximum around 10:00 AM until 3:00 PM. In the vertical distribution of the water temperature, however, appreciable difference was observed in the development of stratification; i.e., at L1 and L11 the temperature stratification was negligible, while at L2 – L6 the stratification was developed significantly but with different subsequent disappearance of the stratification. These features were caused by the difference in the development of water waves in the lake, which affect the vertical mixing of the water column, and hence by the difference in the fetch for the wind development in the lake.
The spatial distributions of TN, TP and SS for this field survey are shown in Figures 4, 5, and 6 respectively. The surface and bottom TN and TP in Laguna Lake are much lower than those computed for Pasig River. At a maximum, the difference can reach 0.5 mg/l in TP.

3.2 LP2 Results

In Pasig River the significant stratification of salinity was observed only at P1, indicating the saline water from Manila Bay did not reach Laguna Lake, although LP2 survey was done in February 2002, which is in the dry season.

Figures 7 and 8 show the vertical profiles of DO for various points in Laguna Lake and Pasig River at different time of the day. DO in the lake is nearly uniform with the value of around 6 mg/l. In Pasig River, on the other hand, significant decrease in DO with the depth especially at P1, P2, P3 and S1, which are located in and near the lower reaches of Pasig River. This means that in these locations anoxic water was developed below the surface layer.

Figures 9 to 11 show TN, TP and SS at the indicated locations in Laguna Lake and Pasig River. The appearance of the high values of TN, TP and SS at S1 and P2 located near the junction of Pasig River and San Juan River suggests the significant environmental loads from the Metro Manila area through the San Juan River.

Comparison with Figures 4 to 6 indicates that in Laguna Lake SS for the dry season was about ten times as large as that for the rainy season and TN, TP were nearly double in the dry season as compared with the rainy season. The TN/TP ratios for dry season in Laguna Lake and Pasig River are considerably lower than the corresponding ratios during rainy season (Figure 12). Note that all the ratios are below 16 (Redfield ratio required for algal growth).

3.3 LP3 Results

Field survey LP3 is a long-term continuous measurement in Laguna Lake and Pasig River conducted from March to June 2002. Figure 13 shows the time histories of the water depth variation at M1, P3 and L4. The fact that the water level fluctuation at P3 is similar to that at M1 indicates the tidal influence reached at least the mid of Pasig River during this period of observation. As shown in Figure 14, from late March, the seawater could intrude backward from Manila Bay into Pasig River in spring tide. Further significant increase in the salinity appeared at P3 from late April and it attained around 20 ‰ in May.

In Laguna Lake, the salinity at L1 and L4 increased in early and mid May, during which the water table in the lake was at its lowest, and then decreased in late May according to increase in the water table (Figure 15). The appearance of the brackish water in the lake is quite important both for hydrodynamic and bio-chemical processes.

3.4 MB1 Results

Profiles of orthogonal velocity, transverse velocity, temperature, salinity, density $\sigma_t$ and DO measured along A-Line were examined in relation to ebbing and flooding. However, there is not much difference observed except for stronger currents during ebb tide. DO is
greater than 5 mg/l from the surface to a depth of about 8 meters. At this region, distribution of DO from A1 to A5 is fairly uniform. As shown in Figure 16, the pycnocline (i.e. layer where density changes with depth most rapidly) occurs at a depth of around 5 to 10 meters. \( \sigma_t \) decreased from approximately 18 kg/m\(^3\) at A1 to around 15 kg/m\(^3\) at A5, particularly near the water surface.

Salinity and \( \sigma_t \) are generally lower along the B-Line. Regions of higher Chl-a concentration were observed, particularly near the surface. Comparing with DO distribution along A-Line, DO decreased from 8 mg/l at B4 to around 2 mg/l at B1 (Figure 17). This indicates possible effect of polluted water from Pasig River. A relatively higher turbidity was noticed near the bottom and also near the surface around B1. Profiles of TN, TP, TN/TP ratio and SS were also examined. A high TP is observed near B1 but SS is relatively low. TN/TP ratio is greater than 16 except at the mouth of Pasig River (Figure 18).

3.5 MB2 results

Figure 19 shows the wind speed during the survey runs along the B-Line. In dry season, pycnoclines can be observed around the bottom layer as can be seen in Figure 20. The thickness of the mixed layer increased due to high wind speed prevalent during the 2\(^{nd}\) run (16 m/s) until the 3\(^{rd}\) run (10 m/s), as evidenced by the pycnocline locations. Salinity and \( \sigma_t \) are higher compared to those in MB1. Temperature, however, is lower.

Near-surface turbidity is relatively higher at B1 and B2. The profiles of turbidity at these points are more erratic compared to those at the other points, which may be due to the effect of Pasig River. At B3, B4 and B5, turbidity is almost constant up to a depth of 20 meters and rapidly increases towards the bottom (Figure 21). Note that this corresponds to the pycnoclines in Figure 20. The profiles strongly indicate that turbidity is correlated with water density.

4. SUMMARY AND CONCLUSION

The previous sections presented the methodology, data and results of initial analysis for the field surveys conducted in Laguna Lake, Pasig River and Manila Bay. Summary of initial findings are given as follows:

- In rainy season, TN and TP in the lake are much lower than the river. TN/TP ratios in the lake and river are below 16 and are lower during dry season.
- In dry season, DO in the lake is almost constant with varying depth while in the river, higher DO near the surface is observed, decreasing gradually as the depth increases.
- The relatively high values of TP, TN and SS near the Pasig River-San Juan River junction indicate environmental loads from Metro Manila.
- In dry season, SS in Laguna Lake was about ten times as large as that for the rainy season and TN, TP were nearly doubled in the dry season as compared with the rainy season.
- Higher salinity fluctuations are observed in the lake and river during dry season, indicating saltwater intrusion especially during spring tide.
- Turbidity in the lake is generally higher during dry season.
- In rainy season, pycnoclines in Manila Bay occurred a few meters from the surface. However, in dry season, pycnoclines were observed around the bottom layer.
- Positive correlation exists between $\sigma_t$ and turbidity.

These observations result in a better understanding of the physical and hydrodynamic environments of Manila Bay and Laguna Lake and confirm results of previous studies. As stated earlier, these are just initial findings based on preliminary analysis of the data and a more detailed analysis may give additional results. Field survey MB1 was not completed as planned due to some difficulties encountered. Additional field surveys may be needed to look at other aspects that may be necessary for the development of a hydrodynamic and water quality model for the Manila Bay/Laguna Lake system.

REFERENCES


Appendix 1: Figures

Figure 2. Sensor Deployment Schemes
Figure 3. Surface Elevation and Wind Conditions in Laguna Lake

Figure 4. Spatial Distribution of TN in Rainy Season (2001)

Figure 5. Spatial Distribution of TP in Rainy Season (2001)

Figure 6. Spatial Distribution of SS in Rainy Season (2001)

Figure 7. Vertical Profiles of DO in Laguna Lake (26 Feb. 2002)
Figure 8. Vertical Profiles of DO in Pasig River (28 Feb. 2002)

Figure 9. Spatial Distribution of TN in Dry Season (2002)

Figure 10. Spatial Distribution of TP in Dry Season (2002)

Figure 11. Spatial Distribution of SS in Dry Season (2002)
Figure 12. TN/TP Ratio in Laguna Lake and Pasig River

Figure 13. Time Series of Water Depth

Figure 14. Salinity Fluctuation in Pasig River

Figure 15. Salinity Fluctuations in Laguna Lake
Figure 16. $\sigma_t$ Profiles Along A-Line

Figure 18. Profile of TN/TP Ratio Along B-Line in Manila Bay

Figure 17. DO Profiles Along B-Line in Manila Bay

Figure 19. Wind Speed in Manila Bay (Feb. 2003)
Figure 20. Profiles of Temperature, Salinity and $\sigma$ at B-Line

Figure 21. Profiles of Turbidity (in ppm) at B-Line