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FIELD SURVEY ON THE FLOW STRUCTURE AND WATER QUALITY OF PASIG RIVER IN METRO MANILA

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Field survey was conducted in Pasig River flowing through Metro Manila, the national capital region of the Philippines in order to get the basic information about flow and water quality for the future planning of river environmental management. Salinity, water temperature, DO, Turbidity, and Chl-a were measured with a water quality meter every 1km or 2km along the channel center line in the reach of 25km between Manila Bay and Laguna de Bay. The spatial structure of flow and water quality in the reach are estimated from these data. BOD was analyzed for water sampled at several stations. The rate of BOD load and the pollutant runoff coefficient are also roughly estimated.

Key Words *: Field measurements, Salt wedge, Dissolved oxygen, BOD load, Sediment Oxygen Demand*

1. INTRODUCTION

Water pollution load is rapidly increasing in Metro Manila, Philippines due to the population movement from the rural area, too rapid expansion of urban area and the growth of manufacturing industry. On the other hand, development of the waste water and materials treatment system lags behind these social changes. As a result, rivers and canals in Metro Manila are now highly polluted; almost anaerobic, black colored, generating bad-smelling gas, and containing a lot of solid waste.

This phenomenon is, to some extent, common in developing countries in Asia. It had also appeared in present developed countries in the past when they were about to take a course to industrialization and modernization of European style; as was seen in Thames River during the Industrial Revolution in the 18th century, and in rivers in Tokyo during the economic growth of Japan after World War II.

In almost all of developed countries, this problem has been solved by the construction of modern infrastructure for treating waste water and materials. However, it is not certain that the developing countries in Asia can take the same course in the future. Since ones appearing late into modernization are naturally bound by the restriction of distribution of energy resources and participation to the international markets, it may not be easy for them to yield an economic surplus to be invested toward the infrastructure for the improvement of water quality.

Therefore, the transfer of modern technology for water environment improvement from developed countries to developing countries might not be fully realistic. Rather, practical solutions not depending much on the expensive modern infrastructure must be considered as political alternatives. As a practical solution, the study of the phenomenon not in general, but in actual local field is essentially important.

Thus, in this study, field measurements were carried out in the Pasig River which flows through the center of Metro Manila, this part of the research project was supported by JSPS with aims to enlarge the possibilities of water environment improvement in Metro Manila.

Field survey was conducted at the end of May in 1999. Because Manila is located in the subtropical monsoon zone, rainy season and dry season are clearly separated, and the river flow rate is very small in May being the latter part of dry season. Accordingly, water quality becomes worse during this season while the flow structure is complicated because seawater intrudes from Manila Bay to its rivers.

Salinity, water temperature, DO, Turbidity, and Chl-a were measured with a water quality meter every 1km or 2km along the channel center line in the reach of 25km between Manila Bay and Laguna de Bay. The spatial structure of flow and water quality in the reach are estimated from these data. BOD was analyzed for water sampled at several stations. The rate of BOD load and the pollutant runoff coefficient are also roughly estimated.

2. STUDY AREA

(1) Flow system

Fig.1 shows a part of Pasig-Marikina River Basin which is located in the central part of Luzon Island. Marikina River originates in the western side of Sierra Mardre Mountain and flows into Manila Bay through Metro Manila. Its total catchment area is 634 km^2 and its length is 78 km. [1] The river unites with a stream named Napindan Channel flowing out of Laguna de Bay, the largest lake in Asia. The stretch of 19 km downstream from the confluence point is call Pasig River. The catchment area of this stretch is highly urbanized, while those of the upper Marikina River and Napindan Channel are comparatively rural area.

A large tributary named San Juan River joins at 9 km upstream from the river mouth, and in addition, a lot of drainage from the urban area runs into the river. Mangahan Floodway has been constructed to discharge flood water from Marikina River to Laguna de Bay, but the gates are opened only when flooding occurs. Hereafter, Laguna de Bay will be simply called as the lake and Manila

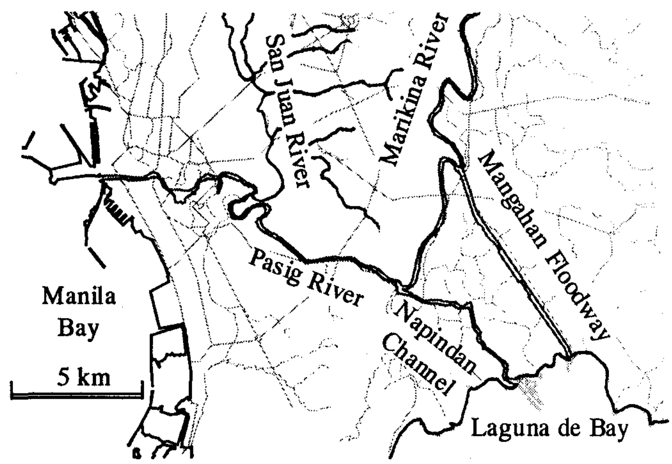

Fig. 1 Study area

Bay as the sea.

In dry season, the discharge from upper Marikina River is quite small, so that the flow of Pasig River is primarily controlled by the head difference between the lake and the sea. When the lake water level is extremely low because of rainfall shortage in its catchment, salt water sometimes flows up from the sea to the lake.

(2) Water quality

According to the results of monthly measurements done by DENR at some bridges across Pasig River, the annually averaged BOD of surface water is 10~30mg/l. However, its seasonal and annual variation is very large; BOD can reach 100 mg/l in dry season of a year when the lake water surface is extremely low. Even not in the extreme case, DO approaches to zero in almost all reach of Pasig River, and the river becomes biologically dead in dry season.

This inferior water quality is due to the considerable amount of pollutant load produced in the urban area. **Table 1** shows the production rate of water pollution load estimated by DENR in which the domestic wastewater is dominant.[2] In the estimation, 40gr/person/day is assumed as the basic production rate of domestic BOD. Although all of the load does not necessarily run into the river, its large fraction is considered to come out because of the following reasons:

Table 1 BOD load and production rate

Domestic Wastewater	200 ton BOD/day	60%
Industrial Wastewater	115	35%
Municipal Solid Waste	15	5%
Total	330 ton BOD/day	100%

There is no public sewage farm in Metro Manila. The treatment of domestic waste water depends on septic tanks, but its distribution is not

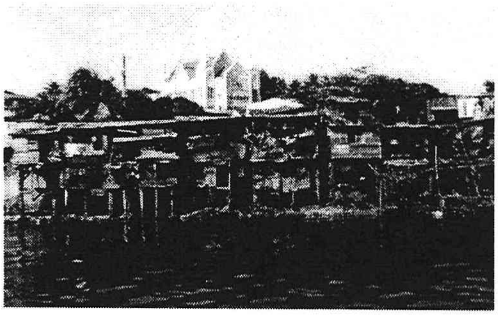

Photo 1 Squatters' house along the river bank

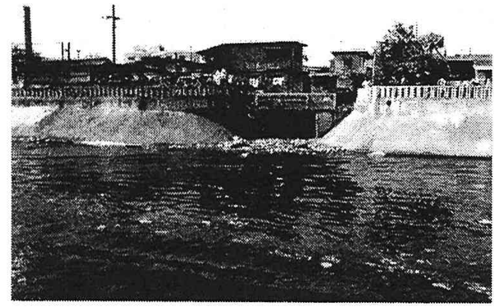

Photo 2 Drainage outlet along the Pasig River

large; besides BOD concentration of discharged water from septic tanks is estimated at 100~175 mg/l because of the problem of facility's quality and maintenance. Adding to this, squatters living at riverside dump organic materials including human waste directly into the water. According to a survey made by JICA in 1990,[3] the population of squatters in the catchment area was 1.6 million, more than 1/3 of total population, and 40% of them lived along the Pasig River. **Photo 1** shows their home.

Another component of pollutant load is solid waste. According to JICA's survey,[4] 21% of total solid waste generated in Metro Manila was illegally dumped in 1997. Since 45% of solid waste is kitchen garbage, it is an important factor of organic pollution. **Photo 2** shows a deposition of solid waste at an outlet of drainage, and **Photo 3** shows solid waste floating on the water which ran into the river just after a shower.

3 . FIELD MEASUREMENTS

(1) Configuration of measurements

Field measurements were carried out on May 26th and 27th in 1999. Coast Guard Office helped us to use a patrol boat for measurements. A multiple water quality meter (Alec Electro. Ltd., ACL1182-PDK) was used to measure the vertical profiles of salinity, water temperature, DO and Chl-a at every 1 km or 2 km in the reach between the sea and the lake as shown in **Fig.2.** But the measurement was not permitted at 6K because the point was just beside the President's residence in Marakanian Palace.

Water of 1 meter depth was sampled at the locations marked with ▼ in **Fig.2.** BOD concentration of the samples was analyzed in a hotel room by using a portable DO meter (Central Science Ltd., UC-12). Because the authors' stay in Manila after the field measurements was limited, only BOD_1 and BOD_2 were obtained from the DO reduction for 24 hours and 48 hours, respectively. Water samples were diluted five times with aerated distilled water and filled into plastic bottles of 500 ml without any chemicals added.[5] The bottles were set in water in a heat insulating container, which temperature was kept at around 28℃, nearly equal to the river water temperature at the time of sampling. The DO consumed at 24 hours is less than 15% and at 48 hours is less than 25% among the all samples.

Photo 3 The solid waste floating on the river mouth of the San Juan River

(2) Site condition during measurement

Fig.3 shows the water surface levels of the lake and the sea recorded by DPWH at stations marked with ▲ in **Fig.2.** The water level of Manila Bay, Pasig River and Laguna de Bay are measured from the common datum level. Based on this, mean sea level of Manila Bay is 10.462 m, the elevation of river mouth bottom is 7.5 m, the elevation of the lake bed near the Napindan channel is 5.2 m. The bed slope of Pasig River from upetream toward the bay is about 1/22,000. In dry season of 1999, the level of the lake was higher than the normal because of much rainfall in the previous rainy season. As a result, the flow rate of Pasig River was higher than that in an usual dry season, and water quality was comparatively better.

There was no any accurate measurement nor H-Q relation for estimating the flow rate of Pasig River. Therefore, at times when no wind blew during intervals of water quality measurements, we made the boat drift with current in Napindan Channel and measured the flow speed with a portable GPS. The averaged flow speed was 38 cm/sec. On the other hand, the standard cross

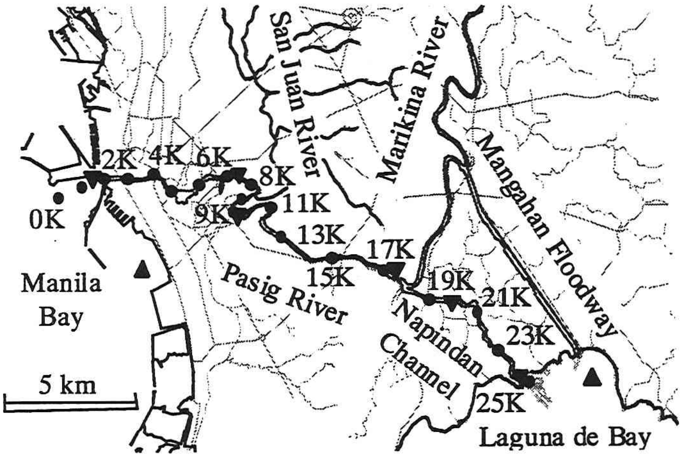

Fig.2 Measurement stations

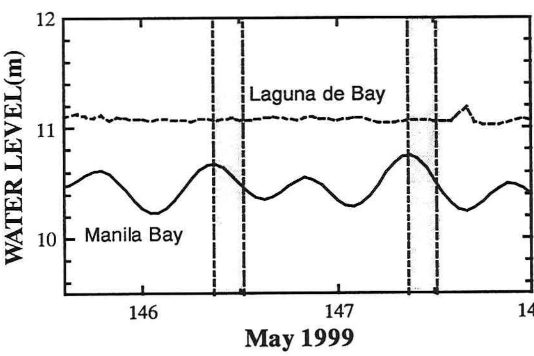

Fig.3 Water level and time period of measurements

section area of Napindan Channel is about 460 m^2 as shown in **Fig.4** according to the data provided by DPWH. Then, the flow rate was considered to be about 175 m^3/sec.

Since Napindan Channel is the only major outlet of Laguna de Bay, the flow rate could be roughly estimated from the variation of the lake water level in dry season. **Fig.5** shows the lake water level in dry season in 1999. It is noticed that there frequently appears a same slope of decreasing which is about 50cm/30 days. Assuming that this slope corresponds to non-rainfall days, the decreasing rate of water surface level corresponds to 174 m^3/sec in volume rate, as the surface area of the lake is about 900km^2. Of course, this estimation is quite rough: There must be some inflow to the lake; evaporation could not be neglected in water budget of dry season; and there are some small creeks flowing out of the lake. However, because it is close to the value estimated from the boat drifting experiment(175 m^3/sec), the previous estimation is considered to be fairly good.

4.DATA DESCRIPTION AND DISCUSSION

(1) Structure of flow and water quality

Fig.6 are the contour maps in a longitudinal-

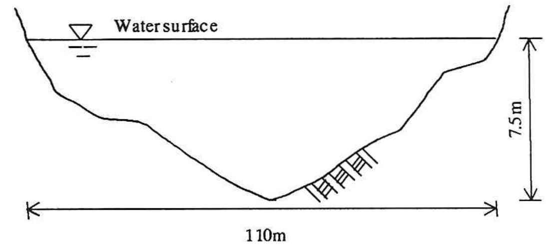

Fig.4 Cross section of Napindan Channel

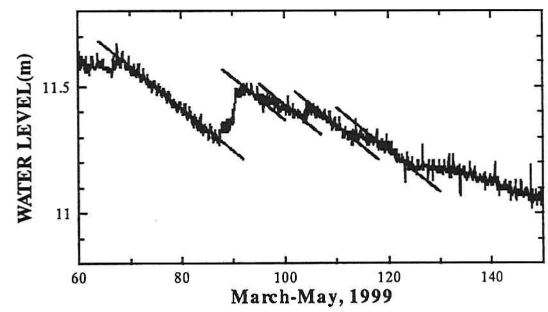

Fig.5 Wter level of Laguna de Bay in dry season in 1999

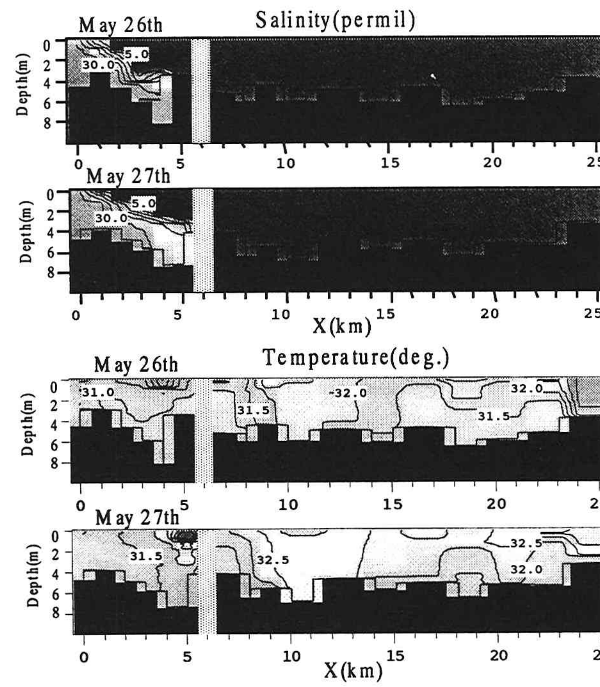

Fig. 6 Measurement results-salinity, and water temperature

vertical plane for salinity and water temperature obtained from the two series of measurements. In the figure water depth at each station, which are based on the water surface, was obtained from the data of water quality meter. The top of black pillars show the bottom at measurement stations. The column of 6K is filled with the black because the measurement was not permitted there, as mentioned earlier.

Since the measurements were carried out just after the high tide, a salt wedge was developed from the river mouth, and it blocks the flow of fresh water. The length of the salt wedge, however, stayed around 5 km which was probably much shorter than as usual in dry season. Water level of the lake in dry season varied in each year. In dry season of 1999, water level of the lake was high. But, it was reported that water level of the lake in dry season sometimes fell to what near the mean sea level, at that time salt water even entered the lake.

The water temperature is almost uniform in the whole reach of the channel. However, it can be noticed that the water was weakly stratified in the most upstream reach, probably because the lake water was heated by diurnal solar radiation. It is also found that the water temperature in the middle reach was comparatively high around the point of 9K where San Juan River joins.

Then, the flow structure of Pasig River in dry season may be characterized by the following three aspects: The first is the salt wedge in the downstream reach which blocks the fresh water flow though its length was rather short this time. The second is the thermal stratification in the upstream reach caused by the inflow of heated lake water. The third is the inflow from San Juan River in the middle stream reach.

Fig.7 are the contour maps of the same kind for DO, turbidity and Chl-a. The profile of DO at the downstream end is similar to that of salinity. This fact means that the sea water aerated by wind and waves transports oxygen into the river. But, it is exhausted before the head of the salt wedge. There is also found the stratification of DO at the upstream end which was caused by thermal stratification of lake water. Anaerobic condition developed gradually toward the conjunction point (19K). Then, in the most part of Pasig River, the water was almost completely anaerobic.

Turbidity and Chl-a were also stratified at the upstream end because the lake is eutrophicated. On the other hand, in the salt wedge at the downstream end, turbidity is low but Chl-a is high. The reason for this is not clear.

(2) BOD concentration and pollutant runoff coefficient

It is assumed that BOD_N (BOD for N days) is assumed to follow an equation,

$$BOD_N = BOD_\infty\{1-exp(-K_w \cdot N)\} \quad (1)$$

where K_w is the rate coefficient when 1st order chemical reaction is assumed, and BOD_∞ is a parameter which ideally corresponds to the total

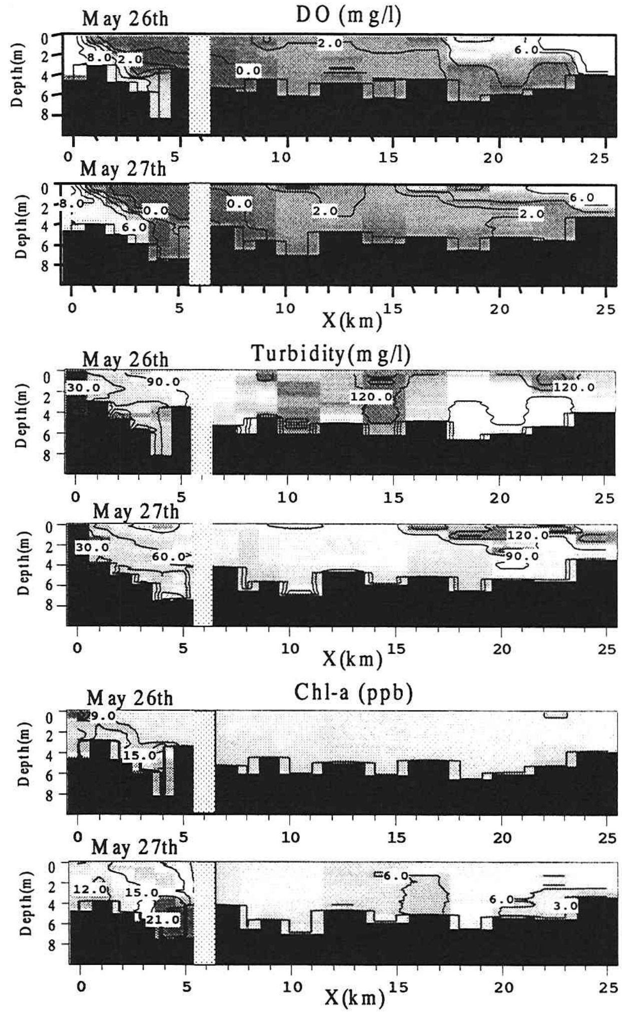

Fig. 7 Measurement results-DO, turbidity and Chl-a

BOD.

It is possible to determine the two parameters from the measured BOD_1 and BOD_2. However, the results are much affected by the error of measurements when the both parameters can move freely. Therefore, one value of K_w common to all water samples is determined so that the total residual squares becomes minimum with a set of BOD_∞ which is optimized for each water sample under the specified K_w. **Fig.8** shows the dependency of total residual squares on K_w. Then, the best value of K_w is around 0.3(/day) which is fairly reasonable in the order of magnitude in our experience.[5] **Fig.9** shows BOD_∞ obtained by optimization under K_w=0.3.

At the outlet of the lake (25K), BOD_∞ is very high because the lake is eutrophicated. Then, it drops before the conjunction of the upper Marikina River with 10mg/l. This fact corresponds to the decrease of DO in the reach as was shown in **Fig.7.** After the conjunction point, BOD concentration increased gradually with a rate of 0.3 mg/l/km due to the inflow of contaminated drainage water from

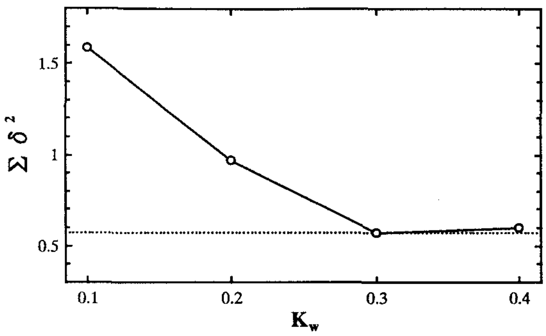

Fig.8 Summation of square of residual

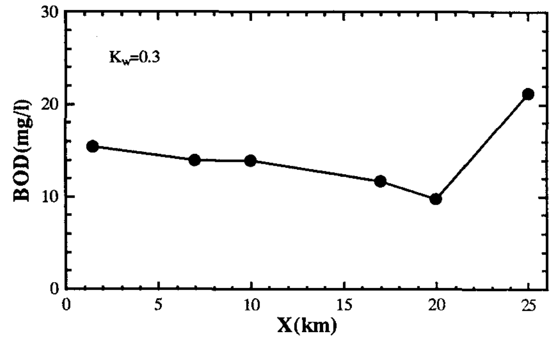

Fig. 9 BOD_∞ at each station

the urban area.

The total BOD load in a reach after the conjunction can be roughly estimated as follows: The increase of BOD concentration in the reach was about 6 mg/l while the decrease of DO concentration was about 3 mg/l. On the other hand, the flow rate during the measurements was estimated as 175 m^3/sec. Then, boldly ignoring the deposition of organic materials, the aeration at the surface and the oxygen consumption by bottom sediment, the BOD load can be calculated as [175m^3/sec $\times$(6+3)mg/l]. This results in about 140 ton/ day corresponding to 42 % of the BOD load being produced in the catchment area as was shown in **Table 1**. Therefore, the pollutant runoff coefficient is 42 %. It must be noted that this value is for non-rainfall days. In days of intense rainfall, more pollutant may runs off. Of course, this estimation is quite rough, and it must be renovated by more detailed survey in future. However, it is fairly nice that this rough estimation gives a reasonable result at least in the order of magnitude.

5. CONCLUSION

The field survey of this time was not fully satisfactory by many causes: The basic information of the river, such as the rainfall in the catchment area, the flow rate, and the location and size of drainage channels, were not available because the public sectors there have not invested much in river management system. The lack of access to and the insecurity at the region along the river were also a big problem so that we could not set any equipment for monitoring the flow conditions during the measurements. However, the following important characteristics of the river were found:

1) The flow structure of Pasig River in dry season is characterized by the following three aspects: The first is the salt wedge in the downstream reach which blocks the fresh water flow. The second is the thermal stratification in the upstream reach caused by the inflow of heated lake water. The third is the inflow from San Juan River in the middle stream reach. These factors control the structure of water quality such as BOD, DO, turbidity and Chl-a.

2) The BOD load discharged from the urban area along Pasig River is about 140 ton/day, and the pollutant runoff coefficient is about 42 % in non-rainfall days. Although this estimation must be renovated by more detailed survey in future, it is considered to be fairly reasonable at least in order of magnitude.

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