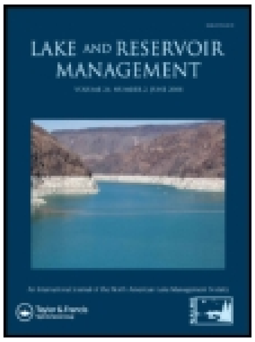

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The Control of Saltwater Intrusion into Laguna de Bay: Socioeconomic and Ecological Significance

Adelina C. Santos-Borja

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Adelina C. Santos-Borja
Laguna Lake Development Authority, Capitol Compound, Pasig MM 1601, Philippines.

ABSTRACT

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Laguna de Bay is the largest lake in Southeast Asia. At present it is being used for fishery, irrigation, power generation, and navigation and is considered to be a source of potable water in the year 2000. The only outlet of the lake is the 24 km Pasig River which drains into Manila Bay. When the lake level is lower than Manila Bay, the Pasig River enters the lake via the Napindan Channel. However, the water is not only saline, but also deoxygenated and polluted with industrial and domestic effluents. The backflow of the Pasig River further aggravates the pollution problem in the lake.

In 1983 a hydraulic control structure (HCS) was constructed at the confluence of the Pasig-Napindan River in order to prevent further pollution of the lake and to control the storage of lake water to firm up a dependable outflow for water supply and irrigation. However, operation of the HCS became a controversial issue among the different lake users. Fishermen and fishpen operators are against its operation because they claim it would reduce the natural food supply of fish especially the cultured milkfish. On the other hand, other sectors claim that the HCS is beneficial because it prepares the lake for its intended and future uses. Operation of the HCS continues to be a debatable issue and, due to pressures from different sectors, the HCS remains open from 1985 up to the present.

Key Words: Pasig River, saline water pollution, milkfish.

Laguna de Bay, an inland body of water located 15 km southeast of Manila, is the largest lake in the Philippines and ranks as one of the largest in Southeast Asia. It has a total surface area of 900 km^2 and an average depth of 3 m. Because of its high surface to volume ratio, the lake is generally turbid during most parts of the year.

There are about 21 tributary rivers that drain into the lake. Water is discharged through the Napindan River which diverges into the Pasig River and Marikina River forming a Y-shaped junction. The Pasig River serves as a link between Laguna de Bay and Manila Bay.

The hydraulic regime of the lake is extremely complex. Its mean water level is about 1 m above mean sea level in Manila Bay but at certain periods of high tides in Manila Bay and low water level in the lake, there is a reversal of flow in the Pasig River causing saline water intrusion into the lake (T. Ingledow and Associates 1970). The datum for Laguna de Bay is 10.5 m which is the mean sea level in Manila Bay and also the mean annual low lake level at which sea water backflow from Manila Bay into the lake occurs (WHO and LLDA 1978). Another contributory factor to the lake's unique hydraulic regime is the Marikina River, a tributary to the Pasig River, which in flood inundates the Manila area and backs up into Laguna de Bay (T. Ingledow and Associates 1970).

The Importance of a Salinity Barrier

The entire stretch of the Pasig River, including the 7 km Napindan River is 25 km in length. It is fed by three main tributaries which cut through the thickly populated and industrialized areas in Manila and suburbs. In the absence of proper and adequate wastewater treatment facilities in the different commercial, residential, and industrial areas in the 58 km^2 river basin, the river is not only saline but also deoxygenated and polluted with industrial and domestic effluents including the solid wastes that clog the creeks and canals draining into its tributaries. Based on the Laguna Lake Development Authority (WHO and LLDA 1978), the Pasig River is considered to be the largest

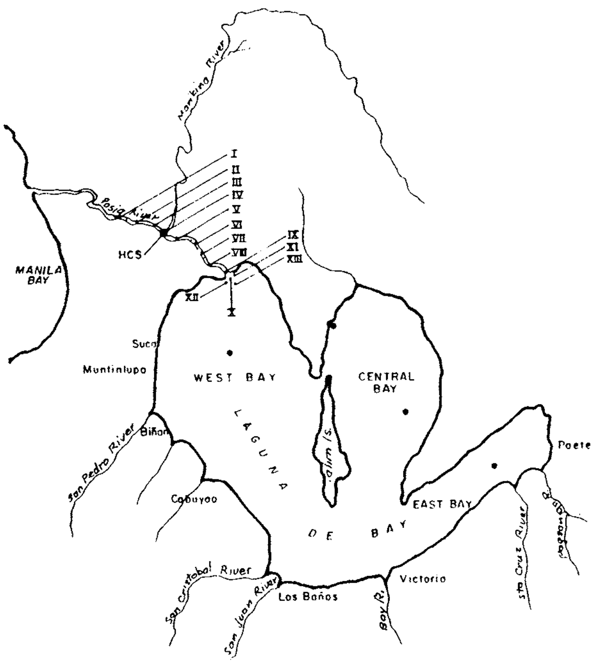

Figure 1.—Location of the hydraulic control structure (HCS) and sampling stations in the Pasig River and Laguna De Bay.

single contributor of pollutants and nutrients to the lake, contributing 930 tons of total nitrogen and 420 tons of total phosphorus for a backflow volume of 0.2 billion m^3. The Pasig River is known to be contaminated by synthetic detergents, heavy metals such as cadmium, mercury, iron, and zinc, pesticides, and unpleasant odor and color (DENR, NEDA, DANIDA 1990).

In line with the government's thrust of converting the lake into a multipurpose resource, major concern is given to pollution problems associated with the Pasig River backflow. The construction of a salinity barrier was recommended in the study conducted for the Philippine government by T. Ingledow and Associates in 1970. This was considered as the first step in reversing deterioration of Laguna de Bay in order to render the water available for irrigation and domestic water supply. Detailed studies conducted by SOGREAH (1973) also proved that development of the lake as a prime water resource was limited primarily due to lack of control of its hydraulic regime and the lack of an overall development plan that would assess effects of the lake's multiple uses. The appropriate site for construction of the HCS was identified, including the mode of operation and construction design.

In 1983 the HCS was constructed at the confluence of the Napindan-Pasig-Markina rivers (Fig. 1) to prevent further pollution of the lake and to control the storage of lake water to firm up a dependable outflow for water supply and irrigation.

Issues Concerning Construction and Operation of the HCS

Studies on water resource development of Laguna de Bay (T. Ingledow and Associates 1970, SOGREAH 1973) have always considered the lake as a multi-use water resource which was also the concept behind the construction of the HCS. Major emphasis was given on the economic benefits that would be derived from the HCS, especially on the lake fishery. From these studies, it was pointed out that nitrogen limits algal growth, so that elimination of nutrients entering the lake from the Pasig River may reduce concentrations of algae, which was then so prolific that they caused massive fishkills.

On the contrary the intrusion of saline water is viewed by fishermen and fishpen/fish cage operators as beneficial to the lake's fishery because of its effect on turbidity. Backflow of the Pasig River usually occurs from April to July which is also the period when water conditions are relatively calm. The high concentration of sodium cations in sea water reacts with the suspended colloidal particles in the water column which are negatively charged. Flocs are formed and due to the prevailing calm water condition, they easily sink to the lake bottom. As a result turbidity decreases and light penetration becomes deeper, thus enhancing the lake's primary productivity. This phenomenon is considered as a signal of good fish growth and high yield. These

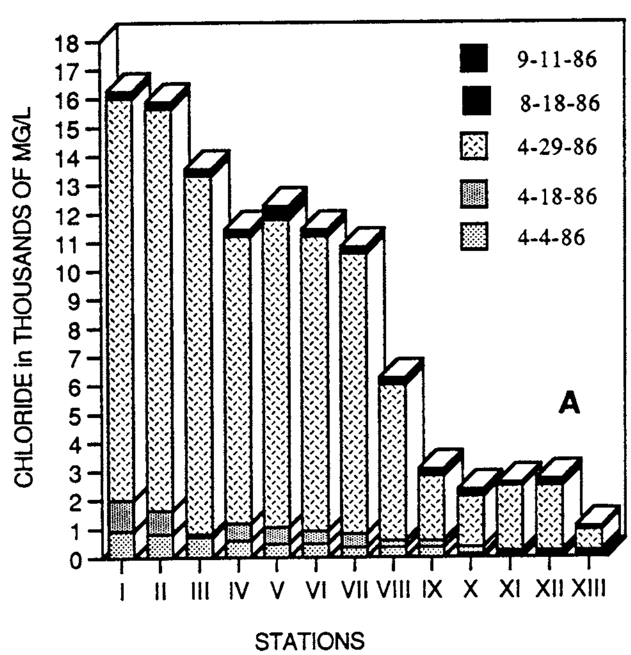

Figure 2. (A)—1986 Chloride concentrations along the Pasig River and the West Bay.

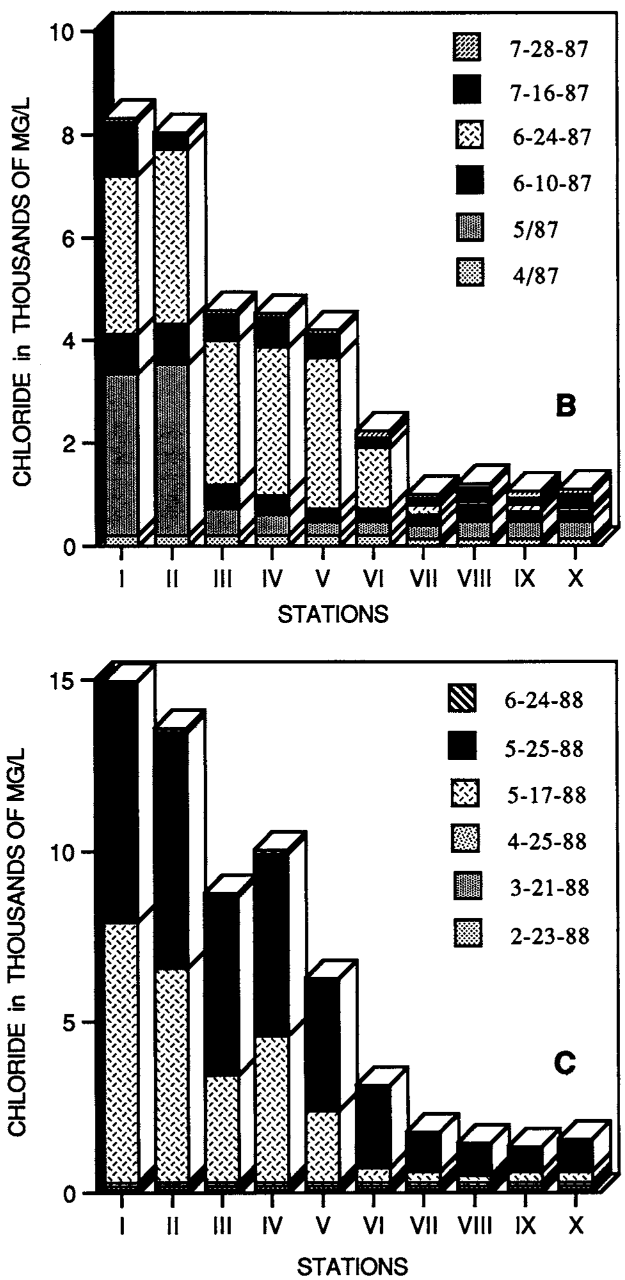

Figure 2. (B & C)—Chloride concentrations along the Pasig River and the West Bay. B) 1987, and C) 1988.

observations were further supported by Nielsen et al. (1981), who also argued that it is not nitrogen that limits algal growth, but instead the turbidity of the lake.

Because of the mounting pressures brought about by protest actions from fishpen operators, fishermen, and to some extent by farmers as well as the lack of a clear-cut government policy that would rationalize continuous operation of the HCS, the LLDA, in close coordination with the Department of Public Works and Highways, decided for the continuous opening of the structure (i.e. from 1985 to the present).

Recent Developments on Utilization of the Lake's Resource

In 1989, a policy decision was arrived at through a consensus formed among the different national and regional agencies and some private sector groups to utilize the lake as source of domestic water supply by 1992, a plan originally intended for the year 2000. This calls for upgrading the lake's water quality from the present classification of Class C (for fishery) to Class A (for domestic water supply).

If and when the government finally approves the plan, the argument on the operation of the HCS is perceived to be finally settled. According to Lopez (1989), the pursuit of this dominant use policy will resolve the conflicts in use of the lake. The issue on the possible negative effect of the HCS on the lake's productivity and fishery is a matter of great concern, not only because of its ecological significance, but also because of the economic and social problems attached to it. This paper therefore aims to address this specific issue with particular emphasis on primary productivity.

Methodology

Water quality monitoring of the Pasig River used to be a part of the regular monitoring activity of the LLDA. After completion of the Comprehensive Water Quality Management Programme in 1978, this activity followed an irregular schedule. From 1986 to 1988, monitoring was again resumed but only during backflow. Sampling stations were established along the stretch of the river from Guadalupe Bridge to the mouth of the Napindan Channel, which covers an approximate distance of 8 km. Aside from the LLDA representative station in West Bay, different stations were also established in areas immediately exposed to saltwater intrusion (Fig. 1). Several water quality parameters were analyzed, but only the chloride data were used in this study.

Primary productivity was measured in the lake from the surface to 2 m depth for 10-12 hours using the light and dark bottle technique. Water quality parameters such as dissolved oxygen, chloride, turbidity, nitrate, phosphate, algal biomass, and secchi disk transparency were also monitored. These activities were done weekly from 1986-1987 and were reduced to bimonthly in 1988.

Water samples were analyzed at the LLDA

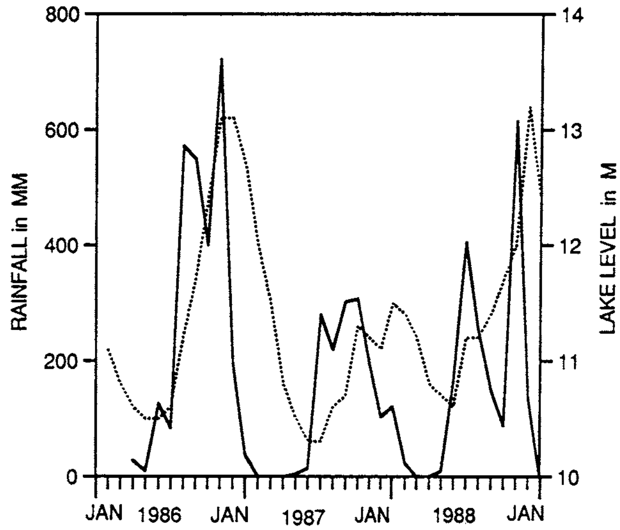

Figure 3.—Rainfall (solid line) and lake levels (dotted line) at West Bay.

laboratory using the American Standard Method of Analysis (APHA 1978) and the Philippine Standard Method (PSM 1978). Lake level data were measured by the LLDA, while data on rainfall were obtained from the Philippine Atmospheric Geophysical and Astronomical Services Administration.

Linear regression analyses on different data pairs were done, and served as one of the bases for determining effects of salinity on selected water quality parameters. The significance of the correlation coefficient (r) was evaluated based on the critical values of r at = 0.05 (Fisher and Yates, undated)

Results and Discussion

Pasig River Backflow and Lake Salinity

During the 3 years, the earliest backflow and highest concentration of chloride in the Pasig River occurred on April 29, 1986, at a salinity gradient of 14,000 mg L^{-1} (Standard I), 2325 mg L^{-1} (Standard IX), and 1646 mg L^{-1} (mean concentration in Standards X - X111) (Fig. 2A). The highest concentration at the middle of West Bay was observed in May at 906 mg L^{-1}. Such is the magnitude of saltwater intrusion that concentrations of chloride in the lake during August-December of 1986 were higher than in the same period in 1987 and 1988 (Figs. 2B and C, respectively).

Table 1.—Results of correlation analyses on several variables. Values of r greater than 0.42 are statistically significant at the 0.05 level.

Data Pairs	n	r
Chloride - Turbidity	36	0.5
Chloride - Secchi disk transparency	36	-0.8
Turbidity - Primary productivity	36	- 0.6
Nitrate - Algal biomass	36	- 0.3
Phosphate - Algal biomass	36	- 0.1

Combined effects of high tide in Manila Bay (DENR NAMRIA 1988) and higher amounts of rainfall (Fig. 3) on reversing the flow of the Pasig River were manifested in 1988. The lowest lake level was observed in May (specifically on the 11th and 24th) at 10.6 m, which is slightly above the critical level of 10.5 m (Fig. 5, but still there was significant increase in the chloride concentration in June at 338 mg L^{-1}.

The Effect of Chloride on the Lake's Turbidity

The immediate effect of an increase in chloride concentration in the lake is a decrease in turbidity (Fig. 4). Linear regression analysis of the two parameters gave a correlation coefficient (r) of -0.5 which is considered significant (Table 1). However, there are other factors controlling the lake's turbidity. The prevalence of calm water conditions generally experienced during the months of September-November also allowed for settling of the suspended particles in the water column. This is reflected in the decrease in turbidity from September to November, when the chloride concentration was relatively lower. However, settling of suspended particles was observed to be faster at higher salinity levels (BCEOM 1984), as shown in 1986 when the very high concentration of chloride at the onset of the Pasig River backflow caused an abrupt decrease in turbidity which was sustained up to the end of the year. Normally, turbidity is higher during the months of January-March and in December because of the prevailing northeasterly winds.

Improvement in Secchi disk transparency is also observed at higher chloride levels (Fig. 3). This is further supported by the strong correlation obtained between these two parameters (i.e., r = 0.8). Of the same degree is the inverse relationship between turbidity and Secchi disk transparency where r = -0.8. These analyses prove that chloride is an essential factor in improving the lake's turbidity and Secchi disk transparency because of the flocculating effect of saltwater on the suspended inorganic turbidity.

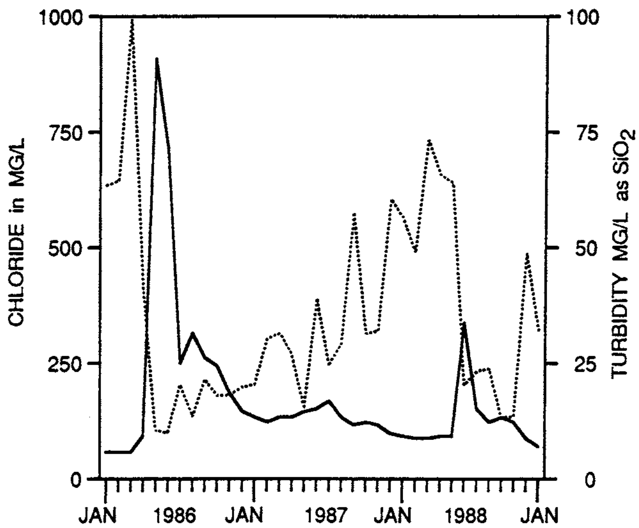

Figure 4.—Concentrations of chloride (solid line) and turbidity (dotted line) in West Bay.

The Effect of Turbidity on the Lake's Primary Productivity

A significant inverse correlation exists between turbidity and primary productivity at r= -0.6 which suggests that primary production in the lake is light-limited due to its turbid condition (Table 1, Figs. 4 and 5). The influence of other factors such as plant nutrients, nitrate, and phosphate on the primary producers (algae) was also investigated, but the relationship obtained was not significant (i.e., r = -0.3 and r = -0.1, respectively; Table 1, Fig. 6). Although it is a fact that nutrients are essential components of the photosynthetic process, the very low correlation coefficient could mean that there is sufficient supply of

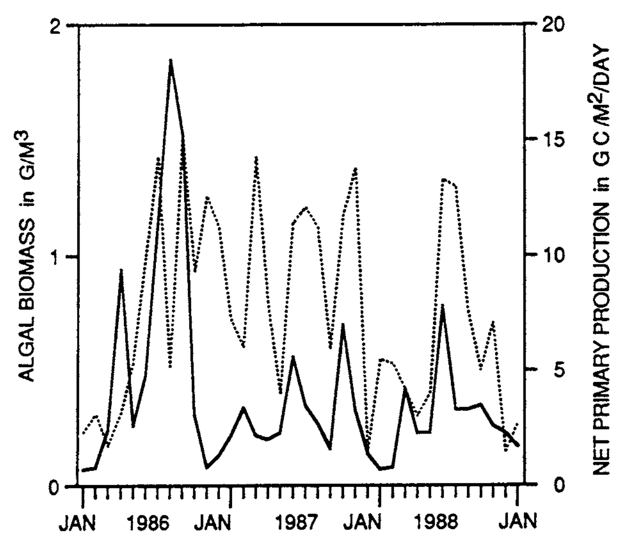

Figure 5.—Mean monthly algal biomass (solid line) and net primary production (dotted line) in West Bay.

these nutrients in the lake and as such, they are not limiting. Likewise, since the period of higher chloride concentration and higher primary production is generally observed during the wet season, the possible reduction in concentration of nutrients due to increased photosynthetic activity is compensated by the input coming from inflow of the tributary rivers.

Primary Productivity and Algal Biomass

Laguna de Bay is often classified as a eutrophic lake which can become hypereutrophic in summer (WHO and LLDA,1978). This was based on observations made in 1972, 1973, and 1977 where tremendous algal blooms followed after a significant concentration of chloride entered the lake. Serious fishkills occurred on a massive scale due to oxygen depletion that ensued

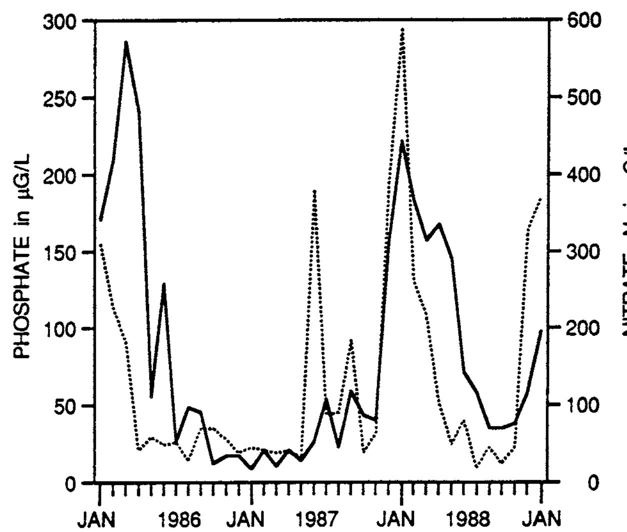

Figure 6.—Concentrations of phosphates (solid line) and nitrates (dotted line) in West Bay.

upon the collapse of bloom.

In the years covered by the present study, algal blooms were also observed (especially in 1986), but the concentration did not reach an alarming proportion (Fig. 5). The highest count recorded was 16,000 cells mL^{-1} compared to the early 1980's where counts during algal blooms ranged from 20,000 to 500,000 cells ml^{-1} (LLDA data, 1981-1988). Of significant influence is the dilution brought about by increased rainfall during and after the period of saltwater intrusion, which could have disrupted the buildup of biomass thus preventing the occurrence of serious algal bloom. Such dilution is also reflected on the abrupt decrease in chloride concentration in 1986 from 717 mg L^{-1} in June to 253 in July, due to higher amounts of rainfall(i.e, 575 mm.).

In spite of the stimulation of photosynthesis caused by increased lake salinity, the amount of production in the lake from 1986 to 1988 is still low with annual averages of 0.772, 0.896, and 0.603 g C m^{-2} day^{-1}, respectively. In the same order, these are equivalent to about 282, 327, and 220 g C m^{-2} day^{-1}. This was viewed by Nielsen et al. (1981) to be rather low for a tropical lake compared with similar lakes in the tropics or with fertilized fishponds. Based on their data, the production of Lake George in Uganda is 1980 g C m^{-2} day^{-1}, while that of fertilized fishponds with a temperature range of 25-30°C (similar to Laguna de Bay) fluctuates between 1460 and 2920 g C m^{-2} day^{-1}.

A decreasing trend in algal biomass was also observed that could be the effect of overgrazing by cultured fish in the lake. The amount of natural food seems insufficient because of the current practice of fishpen and fishcage operators of giving supplemental feeds to the fish. Thus, the observed decline in fish yield could be due to the following: proliferation and mismanagement of fishpens/fishcages, overutilization of the lake's resource, and lower productivity (Centeno et al. 1987) which actually is a linear sequence of cause and effect.

Conclusion and Recommendation

The stimulating effect of increased salinity on primary productivity results from a reduction of inorganic turbidity, when accompanied with favorable factors (e.g. calm weather). The immediate visible observation in the lake is the increase in Secchi disk transparency and the change in color from light brown to green. However, a higher chloride concentration does not necessarily result in higher primary production. It was observed in this study that chloride concentrations ranging from 150 to 300 mg L^{-1} could be effective in reducing the turbidity at a range of 20-40 mg L^{-1} as SiO_2, with a corresponding increase in primary productivity of 1-1.5 g C m^{-2} day^{-1} (Figs. 4 and 5, respectively). Coincidentally, according to the MWSS, the maximum amount of chloride that could be treated for water supply by conventional methods is 250 mg L^{-1}. However, the effect of this concentration on decreasing the lake's turbidity should be further investigated based on a detailed analysis of a more extensive data set on the subject.

There are a number of possibilities for explaining the increasing turbidity and decreasing productivity observed in the lake. Overutilization of the lake's resource in terms of intensive and extensive aquaculture practices, which started almost 20 years ago, is now taking its toll on the lake. Introduction of nonendemic fish species could have altered the food chain which leads to the imbalance being gradually observed in the lake. The population of endemic species like *Therapon plumbeus* and *Glossogobius giurus* is now decreasing, but this could also be due to illegal fishing practices such as the use of fine mesh nets that catch the juveniles which are then sold as duck feeds.

With regard to turbidity, uncontrolled developments in the watershed could be the main reason for its increase. Records show that from 1966 to 1977 alone, about 54,000 ha of land in the Laguna de Bay region were deforested, most of them transformed into unproductive open grass lands which now comprise 16% of the total land area (LLDA, undated). Housing projects have mushroomed in the watershed without the necessary facilities for trapping sediments in case of erosion. Such activities have caused serious floods and massive erosion resulting in siltation and sedimentation in the lake and its tributaries (Santos-Borja 1990).

Based on the report of Environmental Resources Limited to the Asian Development Bank (ERL 1986), the increased sediment input to the lake will shorten its life in the order of 700 years. However, based on LLDA estimates it would take 2,500 years to fill the lake (LLDA 1990). Regardless of these projections, the problem of massive erosion and siltation already exist at an alarming rate. Closer coordination among government agencies with jurisdiction on different developments in the watershed needs to be strengthened. Although one of the mandates of the LLDA is to monitor all development projects in the watershed, a number of agencies still have jurisdiction on certain concerns such as the Home Land Use and Regulatory Board which regulates land-use within the Laguna de Bay region.

Assessment of the pollution load of the Pasig River was not undertaken, which at present is currently being considered through the Feasibility Study on Pasig River Rehabilitation Project. The protection of the lake from further deterioration due to the backflow of the Pasig River could far outweigh the benefits derived from the stimulating effect of saline water on primary productivity. The success of the rehabilitation project will therefore have a direct bearing on the environmental problems behind the operation of the HCS.

This study also aims to reach the policy makers who may find the result as a necessary instrument for addressing the social, economic, and ecological problems associated with construction and operation of the HCS.

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