Nutrient and suspended solid loads in the Laguna de Bay, Philippines

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Abstract The Laguna de Bay is the largest lake in the Philippines and is situated 15 km southeast of the centre of Metropolitan Manila. The population of the capital region is growing out of proportion, especially in the watershed area of the lake. This development is endangering the resource Laguna de Bay due to the increasing discharge of nutrient and suspended solid loads from the drainage basin into the lake. During the EU-funded project "Laguna de Bay, Philippines: An Ecosystem Approach for Sustainable Management" a monitoring campaign on selected tributary rivers was conducted. Based on the results of this monitoring and an analysis of census data, the total annual loads were estimated at about 8000 t N, 2300 t P and 160,000 t TSS. The occurrence of the typhoon "Loleng" in the research area during the monitoring campaign made it possible to state that about 25% of the annual load is drained during such a weather situation.

Keywords Load; nitrogen; phosphorus; suspended solids; typhoon; watershed

Introduction
Demands and conflicts on the Laguna de Bay
The Laguna de Bay is the largest lake of the Philippines and the second largest in southeast Asia (see Figure 1). It is situated about 15 km southeast of the historical centre of Metropolitan Manila on the island of Luzon. The National Capital Region had a population of almost nine million people in 1995 and an average population density of about 14,000 inhabitants per km². The population of this particular region is increasing unproportionally to Luzon and the Philippines. As a result of this fact, the urban sprawl of Metropolitan Manila is beginning to surround the lake. The lake's basin is used intensively by industry and agriculture. Large areas have been deforested in the last decades.

The water quality of Laguna de Bay is strongly affected by the pollutants discharge by the tributary rivers into the lake. The main sources of pollution are domestic, agricultural, industrial, and municipal wastes, which are emitted to a large extent untreated into the rivers. However, at the same time the lake is an important resource for the region. It is used intensively for fishing and aquaculture, it is the source of water for irrigation and hydroelectric plants, and possibly in the future a source for drinking water for the growing number of inhabitants in the Laguna de Bay region (Focken and Becker, 1999). All these uses require a proper management of the lake and, last but not least, especially of the watershed area.

The research project Laguna de Bay, Philippines: An ecosystem approach for sustainable management funded by the European Union, aimed to establish ecological model of the major processes in Laguna de Bay. This model can serve as a tool in decision making for a rational management of the resource Laguna de Bay. As a part of this project, the University of Hamburg carried out studies regarding the interaction between the lake and its drainage basin. The main attention was directed to a one year monitoring campaign on the selected tributary rivers. With these results an estimate of the total nutrient and suspended solid loads was calculated in cooperation with the University of Padova.
The river system of Laguna de Bay

About 35 tributaries drain into Laguna de Bay. The drainage area of these streams covers an area of about 2800 km². The grand total length of the rivers in the drainage basin of Laguna de Bay amounts to about 3000 km. The main features of the Laguna de Bay drainage basin are given in Table 1.

![The tributary rivers of Laguna de Bay and their basins](image-url)
The hydraulic regime in the river system is driven by the climatic conditions, especially by the occurrence of periods with very high precipitation caused by a typhoon or tropical cyclone. The mean annual precipitation is 2069 mm (Flores and Balagot, 1969). However, it ranges between a minimum of 906 mm and a maximum of 3920 mm (Kolb, 1978). Most of the precipitation occurs in the period between June and October during the southwest monsoon (rainy season). In this period, the monthly mean precipitation rate is higher than 200 mm. During the rest of the year, much lower rates of precipitation are observed on average (dry season). Very important sources of rainfall are tropical cyclones and typhoons which can bring up to 220 mm of rainfall within 24 hours. The analysis of the daily precipitation data of the period 1995 to 1998 provided by the Climate Unit of the International Rice Research Institute shows that between 10% and 25% of the annual precipitation is contributed during days with rainfall equal to, or more than, 100 mm. Nearly all typhoons and tropical cyclones affect the Philippines during the period from June to December. The research area in particular is affected by two to four tropical cyclones per year on average (Flores and Balagot, 1969).

The largest sub-basin of the Laguna de Bay watershed area—the drainage area of the Marikina River—drains into the Laguna de Bay only during such periods of high precipitation. Usually, the Marikina River drains through the Pasig River into the Manila Bay. However, the occurrences of very high precipitation in the Sierra Madre, a mountainous area upstream of the Marikina River, have led to floods in the lower parts of Metropolitan Manila along the Marikina and Pasig Rivers. The Mangahan Floodway and the Rosario Weir (the Effective Flood Control Operation System [EFCOS]) were constructed in the beginning of the 1980s to achieve an effective control of these floods in the Marikina and Pasig Rivers. In cases of high water levels in the Marikina River, the Rosario Weir is opened to discharge parts of the flow through the Mangahan Floodway into Laguna Lake which serves as a temporal reservoir for the flood waters.

For most of the year the Laguna de Bay discharges its surplus water through the Pasig River into the Manila Bay. However, intrusions of saltwater occur when the water level of the lake drops below the level of Manila Bay. This happens usually at the end of the dry season and during high tide in the Manila Bay. The salty seawater of this backflow is heavily polluted with industrial effluents and domestic waste emitted in Metropolitan Manila along the Pasig River.
the Pasig River. The volume of the seawater backflow can be regulated by the Napindan Hydraulic Control Structure (NHCS), a weir which is located at the Pasig River between Manila Bay and the lake.

**Changing land use in the Laguna de Bay drainage basin**

The land use patterns of the catchment area of the Laguna de Bay are influenced by the enormous growth of Metropolitan Manila. The annual growth rate of the population in the National Capital Region (NCR) is out of proportion to the rest of the island of Luzon and to the rest of the Philippines. Since the late 1930s, the growth rate has been higher than 4% per annum in the NCR. After World War II, it even reached 5.2% per annum. However, the growth of population has slowed down since the early 1980s of this century and reached 3.5% per annum in 1995, which is still much more than the national average of 2.5% per annum. The catchment area of the lake has been affected by the urban sprawl especially over the last four decades. The annual growth rates of the catchment were much higher compared with the rates of the NCR and ranged from 4.4% to 6.4%, and today about three million people live in the watershed area (without the Marikina River sub-basin). These growth rates were caused mainly by migration from the rural areas of the Philippines. People are attracted by the hope of finding a job in industry, which is concentrated in the urbanised areas in and around the NCR. A great share of the industrial enterprises are located in the corridor between Manila and Calamba, in the southwestern part of the watershed area of the lake. The Laguna Lake Development Authority gives a number of about 1000 industries in the watershed (Delos Reyes, 1995).

The agricultural development had to keep pace with the growing needs of a rapidly increasing number of inhabitants. The cultivation of land has been expanded to a larger area and has been intensified over the last two decades. However, it has to be noticed that there is not only a demand for a larger quantity of food, but also a shift to more protein originated from livestock. Today, there are about eight million chickens and ducks, 300,000 pigs and 60,000 head of cattle kept in the watershed area with natural discharge into the lake (without the Marikina River sub-basin).

**Methods**

**Sampling and calculation of the loads of the monitored rivers**

In the period between November 1997 and October 1998, a monitoring campaign on four tributary rivers of Laguna de Bay was conducted. The rivers and their catchment areas were chosen with the intention to cover different types of land use patterns. Sta. Rosa River and San Cristobal River in the southwest of Laguna de Bay are located in heavily urbanised areas with a high population density and many industrial enterprises. The catchment area of the Balanac River in the southeast of Laguna de Bay is dominated by agricultural land use. The Tanay River north of the lake is rather unused in its upper part due to the steep slope in this particular area. Downstream it is more populated and many livestock breedings are located there. Because of the potentially rapid change in volumetric discharge, the sampling was conducted once a week. The frequency was reduced to one collection per month during the dry season, after it had been shown that there were no rapid changes in the flow rates in this particular period.

The monitoring campaign included the occurrence of the typhoon Loleng on 22 October 1998. The duration of higher volumetric discharge was estimated to be about 36 hours. This estimation was based on the analysis of the hourly gauging data of Marikina River during the tropical storms Mameng in October 1995, Lum ing in August 1997, and an unnamed storm in October 1996. The computation of the data, which were provided by the EFCOS, indicated that the discharge rates began to increase eight hours before the
peak of the volumetric discharge and normalised 24 hours after it. It must be assumed that
the duration of high water levels in the Marikina River is shorter than in the other rivers
because its catchment area is characterised by an impervious covered urban surface. Due to
this and to the fact that the water samples were collected shortly before, and shortly after,
the peak of the occurrence of the typhoon "Loleng," the estimation of the typhoon loads has
to be interpreted as a minimal one.

Determination of the rivers' self purification capacity (SPC)

It can be observed that the (estimated) nutrient emissions in river systems are in general
higher than the measured loads in the rivers' outlet. This discrepancy has to be put down to
the occurrence of retention and/or losses in the river. The losses of nitrogen in river systems
are caused mainly by denitrification processes. The knowledge about retention of phospho-
rus in river systems has been very limited until now; however, it has to be presumed that
sedimentation processes are the main reason for P-retention. Further the consumption of
nutrients by benthic organisms can contribute to the retention of nutrients to a large extent
in streams and rivers as well (Behrendt and Opitz, 1999). To compare different sub-basins,
it is necessary to eliminate the influence of their different sizes. The ratio of the measured
loads to the estimated emissions represents the share of finally by the rivers discharged
emissions in such a normalised way, without the influence of the size of the sub-basins. The
river's capability of self purification is given by the following equation:

$$SPC = 1 - \frac{L}{E}$$

where SPC is the self purification capacity (which is equal to the emission weighted
retention), $L$ is the measured load, and $E$ is the sum of the estimated emissions.

The main sources of nutrient loads in rivers are the human excreta and the emissions of
agriculture, like manure originating from livestock production. Brought out artificial fer-
tilisers and nutrient loads originated from soil erosion could not be included in this study
due to the lack of data. However, it can be assumed that the quantity of brought out artificial
fertilisers is rather small due to high costs and low income of the farmers in the research
area. Data about the spatial distribution of the main sources (human beings, livestock pro-
duction) are included in the censuses of the National Statistics Office of the Philippines
published in the Provincial Profiles (National Statistics Office, 1996). These data are based
on the areas within the administrative border of the municipalities and cities, so that it was
necessary to transform these data into data based on the areas of the sub-basins. This was
done by multiplying the census-data-vector by a transformation matrix; these elements
represent the percentage of coverage between each administrative and each watershed bor-
dered area. For this method it had to be assumed that the density of these parameters was
well balanced all over the surface of the particular administrative unit. However, in one
case it was necessary to adjust this method. The area of the Municipality of Tanay covers a
very large area and is much larger than the drainage basin of the Tanay River. However,
most of the population lives along the shoreline of the lake. The hilly hinterland is rather
unpopulated so that, in this case, the determination method of the particular matrix element
had to be adjusted.

The gross loads produced by human beings and livestock can be computed by multiply-
ing the number of individuals by the nutrient contribution of each individual. Rough
assumptions had to be made about these unit loads due to the lack of data regarding the diet
composition of the population, the livestock, and the poultry. The nitrogen and phosphorus
production had to be adjusted to the conditions of a developing country. A European human
being with an average weight of 75 kg produces about 12 g N per day. It can be assumed that
the nitrogen production of a Filipino, with an average weight of between 40 and 50 kg, is about 7.5 g N per day. Following this, the yearly production of nitrogen accounts for up to about 3 kg N per capita. The loss of nitrogen depends on the paths of transportation. In the case of the transportation of sewage in a water sealed sewer system, the loss can be assumed to be about 15%. In the case of using a kind of pit as a toilet facility, the loss is about 30%. The yearly contribution of cattle ranges between 20 and 100 kg N, whereas pigs produce from 30 to 40 kg N per year. For this particular case it was assumed that the annual nitrogen production of one cow is about 40 kg N and of a pig about 25 kg N. Due to poultry dry excreta, it was assumed that there is no reduction of nitrogen in the case of this species. Unlike the case of poultry, the decrease of nitrogen was assumed to be about 30% in the case of cattle and hog, due to the higher content of urea in the excreta. The phosphorus contribution was assumed to be about 1.5 kg P per year for a human being, about 6 kg P per year for cattle and pigs, and for poultry some 0.1 kg P per year.

A concise estimate of the nutrient production was done for all the sub-basins of the watershed area of Laguna de Bay. The ratio between the loads determined by the monitoring campaign of the four rivers and the concise estimate of the generated loads gives an impression about the capacity of self-purification of the particular sub-basin.

Extrapolation to total drainage basin

For a rough estimate of the total discharge it was necessary to extrapolate the information about the SPC of the monitored river basins to the unmonitored ones. Behrendt and Optiz (1999) showed in their research that there is a high significance of the dependency of the P-retention on the runoff depth. They assumed that it is related to the main process of P-retention, the sedimentation. For nitrogen, it seems to be more related to the hydraulic load, which may be caused by better conditions for the denitrification process due to a larger extent of the sediment surface. However, the available database is very limited for this particular region. One of the most powerful parameters, which characterises the main rivers in the particular sub-basins, is the slope of the riverbed. It can be assumed that there is a relationship between the rivers' slope and the SPC; low slope means long persistence and high retention and vice versa. Based on the analysis of the relationship between slope and the SPC of the monitored rivers, a set of functions was found which makes an assignment of SPC to the unmonitored sub-basins possible. The computation of the generated loads, based on the census data, and the assignment of SPC have rendered the calculation of the grand total loads discharged into the Laguna de Bay.

Results and discussion

The watershed area is characterised by different types of land use. These differences in the land use can be displayed in the generated unit loads (Table 2). Particularly in the heavily urbanised areas in the western part of the Laguna de Bay basin, the generated loads are the highest (Muntinlupa-Sucat-Bi-an watershed area: 2 4.3 t N km$^{-2}$ per annum and 10.8 t P km$^{-2}$ per annum). These areas are well equipped with water sealed toilet facilities (between 80% and 90% of the households), so that the nitrogen losses are rather small. The number of animals kept in livestock and poultry production farms are smaller than in the more rural areas in the eastern part. Despite the higher density of animals in most of the rural watershed areas, the generated loads are smaller than in the urbanised watersheds.

The samples were taken in four rivers, characterised by different types of dominant land uses. The Sta. Rosa and San Cristobal Rivers are located in the outer parts of the urban sprawl of Metropolitan Manila and are densely populated (1700 inhabitants km$^{-2}$). The residential areas in these two sub-basins areas are well equipped with water sealed toilet
facilities. About 80% of the households are provided with such toilet facilities. In the more rural areas like in the watersheds of the Balanac and Tanay Rivers, about half of the households have only an open or closed pit as a toilet facility or no toilet facility at all. It can be assumed that in these areas the loss of nitrogen on its way from the source to the water bodies is much higher than in the case of a water sealed system. The dense population in the San Cristobal basin combined with a great number of animals which are kept in the livestock and poultry production results in a very high generated unit load, both of nitrogen (11.1 t N km⁻² per annum) and phosphorus (4.4 t P km⁻² per annum). Despite the less-dense population, the unit loads of nutrients in the Tanay River basin are very large as well, due to the fact that in this particular basin the livestock and poultry production is operated to a great extent, especially the production of hogs.

The results of the monitoring campaign related to the results of the calculation of the generated loads were summed up in the river systems’ capacity of self purification as shown in Table 3. The measured loads of the Tanay River show that this particular river has a very low capacity of self purification. Nearly all the generated nitrogen load and nearly half of the generated phosphorus load are discharged into the lake. Compared to the other rivers, the Tanay River system is characterised by a steeper slope of the watershed’s surface and of the river itself (Table 2), which implies a higher flow velocity and a shorter persistence in the river. The Sta. Rosa and the San Cristobal, rivers characterised by a very flat
The same picture emerges when analysing the results of the occurrence of the typhoon "Loleng": As shown in Table 3 the shares of the total annual loads discharged during the typhoon differ a lot from each other. Just a very small share of the loads in the Tanay River was discharged during the typhoon "Loleng": Only 40% of the total nitrogen and 3% of the total phosphorus annual loads were drained into the lake during this period. In comparison, the Sta. Rosa and the San Cristobal Rivers discharged between 20% and 25% of their annual load during the typhoon.

For the calculation of the total loads it is necessary to extrapolate the findings of these SPCs to the whole watershed area of the lake. As mentioned before, a relationship can be assumed between the slope and the SPC. In Figure 2, it becomes obvious that there seems to be a negative linear relationship between the slope and the SPC in the central part of the spectrum of slopes. For very small slopes with less than 0.7%, it has to be assumed that nearly all nitrogen and phosphorus is removed along the way to the outlet of the rivers (SPC = 0.95). For a few cases with a very steep slope the SPC was set to 0. In all other cases a negative linear function describes the relationship. Following this assignment of SPCs the
total loads can be estimated for the rivers with natural discharge into the Laguna de Bay at about 6000 t of nitrogen and 2000 t of phosphorus per year.

Additional loads coming from the Marikina River strongly depend on the operation of the Rosario Weir. The volumetric discharge is changing from year to year due to the variation of the occurrence of heavy rains and to technical reasons like the removal of water lilies from the course of the Mangahan Floodway. It totalled $40 \times 10^6$ m$^3$ in 1995, $3 \times 10^6$ m$^3$ in 1996, and $100 \times 10^6$ m$^3$ in 1997. In 1998, the Rosario Weir was closed all year, and the volumetric discharge was therefore 0. Comparing the volumetric discharge of the Marikina with the natural runoff into the lake (about $2.9 \times 10^9$ m$^3$), it becomes obvious that the loads contributed by the Marikina River basin into the Laguna de Bay are very low. No more than 600 t of the nitrogen load and 60 t of the phosphorus load originated from the Marikina River sub-basin (including the contribution from both point and diffuse sources). The saltwater intrusion through the Pasig River and the Napindan Channel at the end of the dry season, whose mean volume is given by Santos-Borja (1993) as about $2 \times 10^8$ m$^3$, contributes about 1800 t N and 200 t P. However, the quantity of the loads coming from the Pasig River during saltwater intrusion heavily depends upon the operation of the NHCS and may be managed by closing it.

The typhoon ÓLolengÓ contributed about 20% to 25% of the total annual load. About 1200 t N and 400 t P are discharged during this short period of high precipitation. Usually a higher number of such weather events are observed in the Laguna de Bay region during this season. However, most of the typhoons and tropical storms occur during a rather short period of the year, with the effect that a second or third typhoon or tropical storm does not contribute a comparable load to the first one. The increased load discharged during a typhoon is a problem of minor importance due to the short residence time in the lake.

The monitoring campaign in 1997 and 1998 was affected by the El Niño Southern Oscillation Phenomenon. The precipitation in the region was lower than on average. It has to be taken in consideration that the nutrient load Óand partic ular during the rainy season when additional diffuse pollution is discharged Ómay be increased slightly in a year with mean precipitation.

During the last 50 years, the Laguna de Bay has changed from a clearwater lake to the present state of turbid water due to the deforestation in large parts of the drainage basin. The reduction of light penetration impairs the primary productivity of the lake and reduces the value of the ecosystem (Bendoricchio and Jørgensen, 2001). The extrapolation of the monitored data to the watershed area with natural discharge into the lake gives a value of about 160,000 t of TSS. More than half of this amount was discharged during the typhoon ÓLolengÓThe contribution by the sub-basin of the Marikina River and the saltwater intrusion through the Pasig River could not be included due to the lack of data.

Conclusion

The drainage basin of the Laguna de Bay is characterised by the effects of the urbanisation of the National Capital Region of the Philippines which is located close to the lake. The land-use in the watershed area has immensely changed in the last decades of the 20th century. Large areas of the basin were deforested for the utilisation for agriculture in order to supply the growing number of inhabitants in the region with food. High densities of population and a large number of industries can be found in the urbanised areas. These demands on the basin of the Laguna de Bay increase the load of sediments and pollutants discharged into the lake.

The nutrient loads which were calculated to be about 8000 t N and 2300 t P do not endanger the productivity of the lake ecosystem (Bendoricchio and Jørgensen, 2001). Nevertheless, pollution control is necessary due to the continuing trend of further migration.
from the provinces to the National Capital Region and its surrounding areas. The further substitution of the dry latrine system, which is still very common in large areas of the watershed area, for a water sealed sewer system could have a negative effect on the water quality. Sewers require the use of large quantities of fresh water and the sewage is drained directly towards the water bodies. Expensive treatment plants would be necessary to ensure the water quality of the lake. This is not feasible for the municipalities and cities around the lake due to the high investments that are needed for the construction and the high expenses on the operation and maintenance of these facilities. This is much more expensive than the present latrine system, which provides a reduction of loads by the treatment of the waste in the soil.

The loads, in particular the diffuse loads during the rainy season which drain in addition to the point source pollution into the lake, can be controlled by the construction of interceptors at the shoreline of the lake. This is already planned for the rehabilitation of the Pasig River. However, these interceptors require a treatment plant as well.

The sediment load, estimated at about 160,000 t, also has to be managed. The lake productivity is limited most of the time by light, due to the present turbid state. Reforestation in the basins of the tributaries is necessary. First steps are being made in the basin of the Sta. Rosa River where a volunteer programme has been initiated to reforest the watershed.

The Laguna de Bay ecosystem is endangered by the growing demands on the resource which are directly related to the enormous growth of population in this region. Similar to other developing countries, the primacy of the Philippine capital has to be reduced. It has to be a main goal for the regional planning and the policymakers to create good conditions and provide a well-developed infrastructure in cities of subordinated hierarchy in order to allow a deconcentration of the urbanisation in the Philippines.

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