4. State of Lake Eutrophication and its Control in Developing Nations

Lakes in developing nations are various. Located in almost every climatic zone, including the tropical, the subtropical, the temperate, and the frigid, those lakes differ considerably in their climatic conditions as well as in their economic location. Their detention days (how closed they are), the depth, the water temperature, the pollution loads from the catchment area, and other conditions are all dissimilar, which determine their respective conditions of eutrophication and its control strategy. Giving consideration to such conditions, this chapter will cover the state of lake eutrophication in some developing countries and perspectives for its control.

4-1 Lake Taihu

4-1-1 Characteristics of the Lake and its Watershed

Lake Taihu is located in Jiangsu Province of the People's Republic of China (see Fig. 4-1-1). The lake is in the downstream part of the Changiiang River near the estuary delta, and its altitude is 3.1 m above sea level. Situated at N 30º55'40" to 31º32'58" and E 119º53'32" to 120º36'10", the lake is known as the third largest freshwater lake in China, with a lake area of 2,427,800,000 m^2 and a capacity of 4,300,000,000 m^3. The Taihu is a typical shallow lake, with the mean and the maximum depths of 2 m and 4 m, respectively. Within the lake are 51 islands of varying sizes, which cover 89.7 km^2 in total. The largest of all is the 79-km^2 Mount West Dongting Island. Embracing some densely populated cities such as Wuxi City (population of 4.26 million) and Suzhou City (population of 5.72 million), the Taihu watershed has a population of approximately 30 million and a density of 900/km^2. Farmlands account to 39.6 % of the catchment area. The Lake is connected with 70 influent rivers and 224 effluent rivers. Taihu offers an annual fish catch of around 13,700 t. The inflow rate is 195 m^3/s and the hydraulic detention time in the lake is 0.79 year.

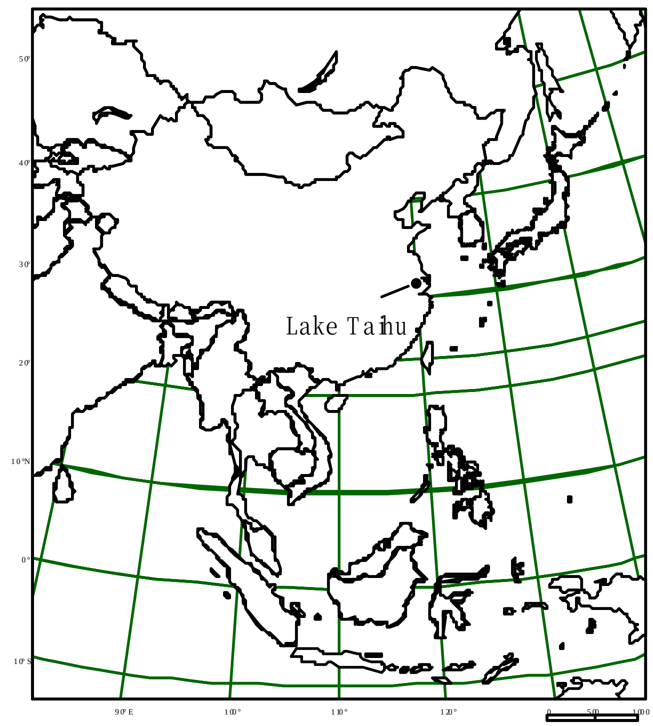

Fig.4-1-1 Situation of Lake Taihu

4-1-2 State of the Lake

Taihu Lake suffers from a surging pollution load from its catchment area, which imposes a serious environmental health problem. The major contamination sources are untreated household and industrial wastewater. The government of China designated the Taihu as the lake most prioritized for water environment remedy. The eutrophic state of the lake is not uniform, as seen in Fig. 4-1-2; the west of the lake called Xi Taihu and the northernmost area on the southeast of Wuxi City called Meilianghu, are particularly over-fertilized. The mesotrophic (relatively less eutrophic) areas in the lake are Huahu and Xuhu to the north of Mount West Dongting Island, which are sanctuarized as the spawning ground for daoyu with the breeding net cages installed in the area. Photo 4-1-1 illustrates the algae bloom layer on the surface of the lake, where a streaky ripple pattern of algae can be observed just as in the photograph when blown by the wind.

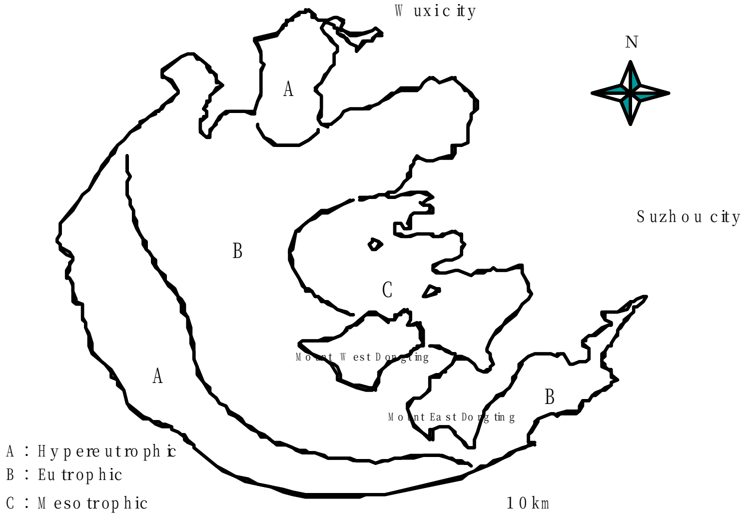

Fig.4-1-2 Trophic level of Lake Taihu

The average water quality figures of Taihu Lake are as follows: transparency 0.15-1.00 m (July to August); pH 8.0 (surface layer); suspended solid (SS) 50 mg/*l*; dissolved oxygen (DO) 9.56 mg/*l*; COD 1.04-5.21 mg/*l*; and NH_4-N 0.108 mg/*l*. All over the lake, cyanobacteria (*Microcystis aeruginosa aeruginosa*) bloom densely, whose concentration reaches 4.52 million colonies per liter in an accumulated area. Moreover, the toxic microcystin produced by this alga has exerted a serious deleterious effect on both human and livestock health, raising a grave social issue for many places in the world. The microcystins detected and reported in Lake Taihu are mainly microcystin-RR, microcystin-YR, and microcystin-LR. The total microcystin biomass was recorded as 0.57 μg/*l* inMeilianghu in the northernmost part of Taihu. Another report provided the estimated microcystin quantities in the algae-accumulated area as 219 μg/*l* for microcystin-RR, 120 μg/*l* for microcystin-YR, and 105 μg/*l* for microcystin-LR. Since the WHO guideline value of microcystin-LR in drinking water is set as 1 μg/*l*, the standing crop of microcystin derived from cyanobacteria in Lake Taihu is a matter of grave health concern.

Photo 4-1-1 Scenery of Lake Taifu with algae

4-1-3 State of Control Measures and their Future Direction

Studies and observations have already revealed that Lake Taihu undergoes an abnormal cyanobacterial proliferation every year, and suffers from a consequentially high concentration of dissolved microcystin toxicity derived from the algae. For this reason, it is of an urgent necessity to implement toxin control measures, such as the biofilm method at water purification plants to decompose and eliminate the algae, and the activated carbon method to adsorb and remove the toxic substances.


Photo 4-1-2 Carriage of collected water hyacinth

It is needless to say that fundamental and drastic steps, including sewerage service development and widespread use of the advanced private sewage treatment system in the basin area, are most effective to reduce the pollution load flowing into the ailing Lake. At the same time, however, execution of these measures for every pollution source in its wide catchment area will require a phenomenal cost and time. At present, a tight regulation is imposed on the industrial effluent from large-scale business, a substantial pollutant source in the basin, in order to reduce the pollution load by combating the untreated wastewater. This remedy targeting larger businesses is working with effect. On the other hand, the household wastewater and the industrial wastewater from small businesses are drained without treatment, and the prompt installation of purification devices, such as an advanced private sewerage system, is unlikely to happen due to the lack of finance for the initial capital investment and the management/maintenance expenditure. As a control scheme for these contaminant sources, the spotlight now focuses on purification methods using eco-engineering techniques, which require only a low budget for capital investment and management/maintenance, and can still exert a substantial effect in reducing the pollution load. These methods, including the soil trench treatment and the hydrophyte planting purification method, are characterized by their effective use of ecology in the treatment process. Although they have the drawback of requiring a vast operation area, the most striking characteristic of these methods is their low initial investment and running costs. Effective budget use and sustainable techniques, such as these, have been receiving great attention as a practical scheme for ecosystem remediation.


Photo4-1-3 Carriage of collected submerged plants

A lake-wide project for collecting suspending plants like *Eichhonia crassipes* (water hyacinth) and submerged plants such as *Potamogeton malaianus* and *Vallisneria asiatica* (eelgrass) to utilize as livestock feed is also conducted. The photos 4-1-2 and 4-1-3 show the scenes of collecting and carrying the water hyacinth (the first) and the submerged plants such as *Potamogeton malaianus* and *Vallisneria asiatica* (the second). On one hand, water hyacinth collection is relatively carefree, because its resource is plentiful without any possible exhaustion due to overexploitation. On the other hand, the submerged plants such as *Potamogeton malaianus* and *Vallisneria asiatica* essentially require controlled collection in terms of resource management, due to their vital role as a habitat for juvenile fish and small crustaceans, including the water flea, and a spawning bed for adult fish.

4-2 Lake Dianchi

4-2-1 Characteristics of the Lake and its Watershed

Lake Dianchi lies in Yunnan Province of the People's Republic of China (see Fig. 4-2-1). Located on the Yunnan-Guizhou Plateau, the lake is 1,887 m above sea level. Covering 2,920 km^2 at N 24º29' to 25º28' and E 102º29' to 103º01', Dianchi is known as the sixth largest freshwater lake in China, with a length of 114 km, an average width of 25.6 km, and a maximum capacity of 1,593,100,000 m^3.The mean and maximum depths of China's sixth largest lake are 5.1 m and 11.3 m, respectively. This slim-shaped lake lies in a north-south direction reaching Kunming City (population of 3.47 million), the capital of Yunnan Province, on its north end. The catchment area covers 2,920 km^2, with a population density of around 690 per square kilometer. Over 14 big rivers, such as the Xinhe River (basin of 112.5 km^2), the Daqing River (basin of 205.2 km^2), the Chaihe River (basin of 256.4 km^2), and the Dongda River (basin of 180.4 km^2), flow into Lake Dianchi with their annual rate of inflow reaching 696,000,000m^3 in total.

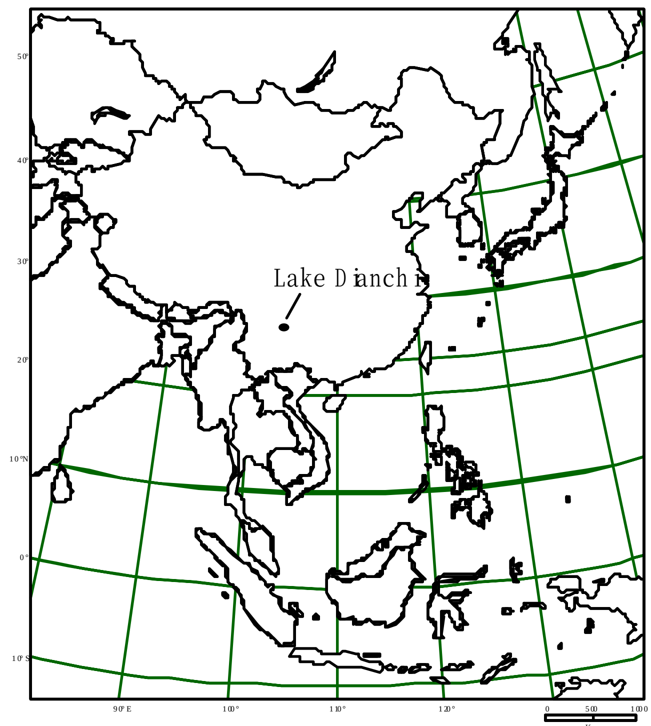

Fig. 4-2-1 Situation of Lake Dianchi

4-2-2 State of the Lake

Being slim in the north-south direction, Dianchi can be divided into Caohai (Inner Lake) of a constricted shape in the north and wide-shaped Outer Lake in the south. The effluent from the Kunming's urban area, which dominates the influent contamination load, first flows into the Inner Lake via the Daguan River, and then down to the Outer Lake. Because of such a flow route, the Inner Lake is more eutrophic than the Outer Lake; in fact, Caohai is a hypertrophic lake. The algae bloom is observed all across Lake Dianchi and, in particular, the surface of the Inner Lake is covered by dense cyanobacterial mats (shown in Photo 4-2-1). The water quality figures of Inner Lake and Outer Lake are, respectively, as follows: COD 15.7 mg/*l* and 6.5 mg/*l*; BOD 12 mg/*l* and 3.4 mg/*l*; TOC 12.4 mg/*l* and 8.3 mg/*l*; T-N 8.7 mg/*l* and 1.2 mg/*l*; and T-P 0.79 mg/*l* and 0.09 mg/*l*. These rates also manifest the severity of eutrophication in the

Inner Lake area. Across the Inner Lake, cyanobacteria (*Microcystis aeruginosa aeruginosa*) propagate densely, whose concentration reaches 3.95 million colonies per liter in an accumulated area. Phytoplankton of 87 genera in 39 families have been identified in the Inner and Outer Lakes in total, and the dominant species in both water areas are blue-green algae such as *Microcystis*, *Oscillatoria*, and *Anabaena*. The phytoplankton biomasses dominated by these cyanobacteria are 64,670,000 per liter in the Inner Lake and 13,649,000 per liter in the Outer Lake, the former reaching 4.7 times larger than that of the latter.The effluent from Kunming City accounts for a large portion of the pollution load into Lake Dianchi. Its basic units per capita per day are calculated as follows: CODcr 41.5 g; BOD 20.7 g; T-N 8.06 g; T-P 0.765 g; and SS of 19 g. Based on these figures, the annual pollution loads from Kunming in 1995 are estimated as 18,800 t for COD, 9,400 t for BOD, 3,700 t for T-N, 350 t for T-P, and 7,400 t for SS, which should have increased by the year 2000 up to 20,900 t for COD, 10,400 t for BOD, 4,100 t for T-N, 390 t for T-P, and 8,200 t for SS.

Photo 4-2-1 Lake Dianchi covered with cyanobacterial mats (Caohai)

4-2-3 State of Control Measures and their Future Direction

The eutrophication control measures in Lake Dianchi can be classified into on-site measures and administrative measures, and the former can be further divided into watershed management, point source management, non-point source management, and lake zone management. Some typical administrative measures are legislating effluent regulations, keeping accurate track of the state of pollution through monitoring, and publicizing the current state of contamination through PR campaigns. The specific approaches in the four on-site measures are as follows. The watershed management includes water conveyance from outside of the basin area. The point source management includes developing wastewater treatment facilities, recycling the effluent as a resource, and regulating the use of phosphate-containing detergents. The non-point source management includes expanding the recharging forests for the headwaters, reforestation to combat topsoil

Photo 4-2-2 Water hyacinth collection

erosion, and ensuring the observation of systematic and reasonable fertilization. The lake zone management includes promoting fishery, systematically expanding the hydrophyte biomass, and conducting direct aeration. These measures are characterized by an emphasis on household effluent in the point source management, and the stressed introduction of the eco-engineering approach that utilizes the abundant aquatic vegetation in the lake. Attention is being given to the hydrophyte utilization, which is currently under discussion for regional widespread application, as a low-cost and relatively maintenance-free treatment method. Water hyacinth, with its floating and exceedingly proliferative nature, often blocks the canals to such an extent that it hinders boat transportation. Such a nuisance of no value, when effectively used, can be converted into a reusable resource, which is offering an exciting prospective.

Photo 4-2-2 shows the scene of the water hyacinths that propagated so much to block the boat routes of the canals connected to the Inner Lake, and the collection of these using rafts. The recovered water plants are desiccated to serve as pulverized fertilizers as shown in Photo 4-2-3. Discussion is now proceeding over the pros and cons of this new method, including the costs, and hopes run high for rendering these otherwise worthless water hyacinth into a reusable resource.

Photo4-2-3 Fertilizer made by drying water hyacinth

Photo 4-2-4 shows the livestock feed made of the pelletized algae: the proliferated cyanobacteria were removed and collected from the lake by suction to make them into dehydrated cakes, which then were compressed and desiccated into solid pallets. Current research extends to the content rate of cyanobacteria by experiments with pigs, which evaluates the effective use of the propagated algae as a protein source for domestic animals in the future. In addition to the said water hyacinth project, discussion is also proceeding over the pros and cons of the cyanobacterial utilization method including the cost for commercializing the pellet feed, and hopes run high for this new

Photo 4-2-4 Livestock feed made of pelletized algae

method to recover a reusable resource.

4-3 Lake Erhai

4-3-1 Characteristics of the Lake and its Watershed

Lake Erhai lies in Yunnan Province of the People's Republic of China (see Fig. 4-3-1). Located on the Yunnan-Guizhou Plateau, the lake is 1,974 m above sea level. Covering 250 km^2 at N 25º25' to 26º16' and E 99º32' to 100º27', the Erhai is a freshwater lake with a north-south length of 42.5 km, an average width of 6.3 km, and the maximum capacity of 802,000,000 m^3.The Erhai basin, lying in the alpine region, embraces many forest zones. On the west coast of the lake is the Diancang Mountain range, a chain of 19 mountains with altitudes ranging from 3, 074 m to 4,122 m above sea level, which provide headsprings for 18 influent streams.The mean and maximum depths of Lake Erhai are 10.5 m and 21 m, respectively. This slim-shaped lake in a north-south direction, as shown in Fig. 4-3-2, neighbors some extensive urban areas, such as Xiaguan on its south and Dali on on its west.The Erhai is characterized by the counterclockwise surface current due to concurrent winds blown from different directions. The attenuation coefficient of the lake current ascribable to these winds was registered as 2.25×10^{-5} per second at the depth of 2 m.

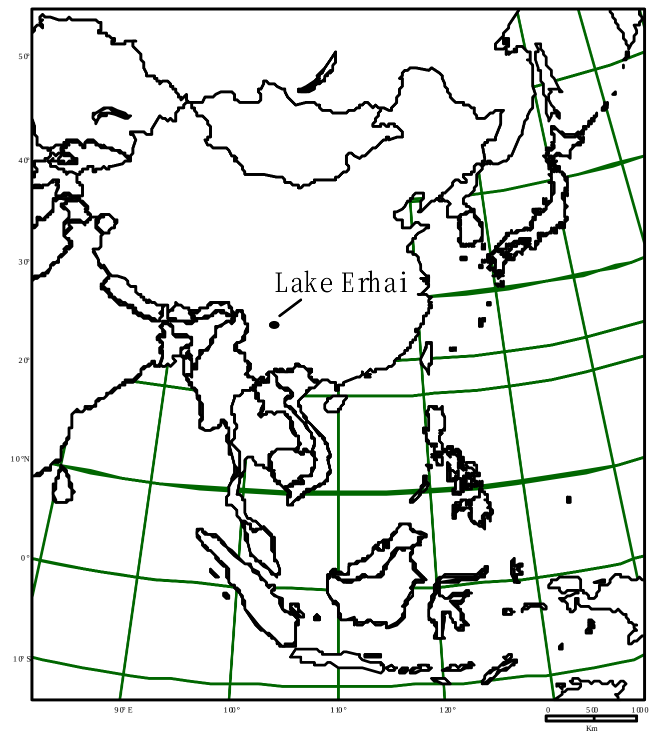

Fig.4-3-1 Situation of Lake Erhai

Fig.4-3-2 Drainage of Lake Erhai

4-3-2 State of the Lake

Encompassed by the mountain range, the catchment area of Lake Erhai can be classified into a forest zone (between 2,200 m and 3,000 m above sea level) and an alpine zone beyond the timberline (higher than 3,000 m). The major pollution sources for the lake are urban districts and farmlands developed like belts in the area between 1,974 m (lake surface altitude) and 2,200 m of altitude above sea level. Breakdown of the major land use patterns and their share in the basin is 19.8 % by forest, 24.8 % by shrubbery, 2.5 % by grassland, 9.5 % by paddy field, 9.5 % by watershed wetland, and 2.6 % by urban areas.

Photo 4-3-1 Algae bloom belts in Lake Erhai

The water quality figures of Lake Erhai are as follows: COD 2.8 mg/*l*; BOD 1.3 mg/*l*; T-N 0.31 mg/*l*; and T-P 0.018 mg/*l*. Judging from these average rates of water quality, the lake is clearer than other eutrophic lakes. Nevertheless, observation confirmed algae bloom belts in some parts of Lake Erhai due to the influx of household wastewater (see Photo 4-3-1). The most serious environmental issue surrounding Erhai at present is not eutrophication but depletion of the water resources incurred by its declining water level. Analysis during the period 1952 and 1988 showed that, for the 25 years prior to 1977, the average figures for the water level, the lake surface area, and the pondage were 1,974 m, over 255 km^2, and approximately 2.9 billion m^3, respectively. After 1977, however, the water level continued to fall to an average level of 1,972.3 m for the 12 years between 1977 and 1988, a decrease of 1.7 m from the former figure. As a consequence, the pondage decreased by 430 million m^3 to 2.49 billion m^3.

Depleting water resources has been posing a great damage to the waterfront vegetation zone, problematically reducing the once abundant hydrophyte biomass. Such considerable deterioration of the hydrophyte standing crop triggered various consequential problems, such as the loss of the spawning grounds for resource-providing fish and the extinction of numerous aquatic organisms that once inhabited the waterfront vegetation zone, hence developing into a serious social issue. The hydrophyte zone of Lake Erhai is renowned as the habitat of precious water plants, including *Potamogeton dentatus* which is endangered globally, which means that the threat of emergence and dry-out to these hydrophyte zones will directly unleash the extinction of these plants on the red data book from the earth.

Positioned in the alpine region, Lake Erhai is characterized by numerous forest zones in its basin. Deforestation in these areas, however, is apprehended to deteriorate the water retaining capacity. Although 11.4 % of the Diancang Mountain region on the west of the lake is still covered by forest, the forest area on the east coast has been developed into farmland and other forms of land use. The total average of the forest coverage accounts for 11.9 %, which is, in fact, mostly shared by sparse groves and coniferous forests. As a result, the issue here is the immensely receded share of the mature, deciduous broad-leaved forestry, a major contributor to recharging the springhead.

4-3-3 State of Control Measures and their Future Direction

The anti-eutrophication strategy focuses on implementing the regulative water quality standard. The effluent concentration criteria cap the T-N and T-P to 0.5 mg/*l* and 0.025 mg/*l*, respectively. At the same time, the western-Erhai water areas including Wanhua, Zhong He, Dali, and Xizhou, and the water area in the vicinity of Wase are designated as the specified areas for focused regulation, by enforcing the area-wide total pollutant control of annual nitrogen and phosphorus discharge as 1,254.48 t and 62.72 t, respectively.


Photo 4-3-2 Submerged plants harvested in Lake Erhai

As for arresting the diminishing water retaining capacity in the catchment area, a reforestation project is actively implemented to foster the regeneration of the forest vegetation. In addition, various degrees and types of management/control measures, including food input for fish farming and tourism and freight boats specifications, are undertaken in order to support the environmental conservation of Erhai Lake from multiple directions. The distinctive and most important measure among them is the protection and nurture of water plants. A diverse variety of submerged plants, such as *Potamogeton malaianus*, *P. dentatus*, *P. maackianus*, *P. crispu*s, and *Ottelia alismoides*, flourish on the lake shore, and these in combination with emerging plants, such as reeds and water oats, and floating-leaved plants, such as water chestnuts, enormously contribute to the natural decontamination of the watershed. In Lake Erhai, the aquatic plants are actively protected and nurtured for not only the purpose of water purification, but also making use of them as a nursery of juvenile fish for the fishery and fish farming. As shown in Photo 4-3-2, the submerged plants are currently harvested to feed livestock without particular care. Such actions will need to be regulated to prioritize the conservation and nourishment of the hydrophyte resource. The future direction of Lake Erhai conservation lies in maximizing the use of the ecosystem to bring out its natural purification capacity, such as through the aforementioned hydrophyte protection and nourishment.

4-4 Lake Nong Han

4-4-1 Characteristics of the Lake and its Watershed

Lake Nong Han is located in Sakon Nakhon Province of the Kingdom of Thailand; more specifically, it is at N 17º12' and E 104º11', in Isan Region in the northeast of Thailand, and approximately 650 km to the northeast of Bangkok (see Fig. 4-4-1). Nong Han is an artificial lake created in 1946, with a surface area of 135.2 km^2, a mean depth of 2.0 m, a maximum depth of 3.0 m, and a maximum pondage of 267.7 × 10^6 m^3. Its catchment area covers about 1,653 km^2. The altitude of the filled lake surface is 156 m above sea level, and the lakeshore length extends to 115.6 m. As shown in Fig. 4-4-2, four major rivers flow in from the north and south of the lake, whereas the effluent river exits from the east. The lake provides irrigation water for farmlands, as well as a fishing ground that extensively contributes to the local fishery.

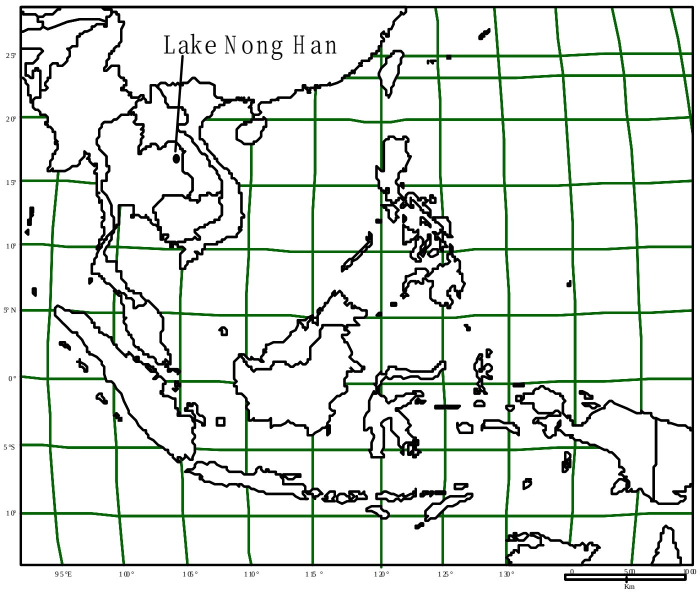

Fig.4-4-1 Situation of Lake Nong Han

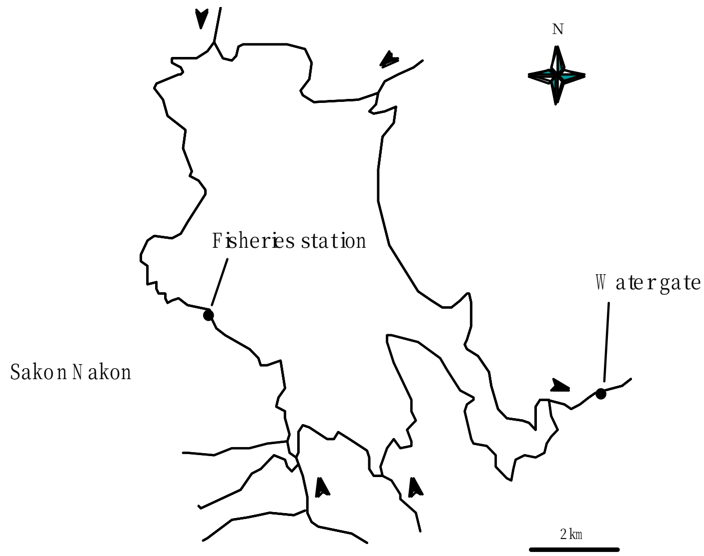

Fig.4-4-2 Drainage of Lake Nong Han

4-4-2 State of the Lake

Lake Nong Han suffers from advanced eutrophication due to household wastewater from the provincial capital Sakon Nakhon City (population of 27,000 as of 1991). The total pollution loads from the capital are estimated as 87.4 t/year for nitrogen and 24.6 t/year for phosphorus. Approximately 70 % of these loads allegedly flow into the lake without any treatment. Its basin population exclusive of Sakon Nakhon City is around 20,000 (as of 1991), and 10 % of the estimated total pollution loads (64.9 t/year for nitrogen and 18.3 t/year for phosphorus) are assumed to flow into the lake from that source. In addition, livestock wastewater, on a total pollution load basis, was estimated to be responsible for 613-t/year nitrogen and 456-t/year phosphorus. 10% of the effluent from the livestock industry is also untreated and flows directly into the lake. The influx pollution loads in total are calculated as 129 t/year for nitrogen and 64.8 t/year for phosphorus.

The water quality figures for July are as follows: chlorophyll concentration 2.92 μg/*l*; pH 7.3; transparency 74 cm; DO 6.9 mg/*l* on the surface and 5.7 mg/*l* on the bottom; NO_3-N 0.62 mg/*l*; PO_4-P 0.11 mg/*l*; water temperature of 30.9 ºC; alkalinity of 31.5 mg/*l*; and hardness of 39.3 mg/*l*. On the other hand, the water quality figures for October are as follows: chlorophyll concentration 5.57 μg/*l*; pH 5.9; transparency 93 cm; DO 6.7 mg/*l* on the surface and 5.2 mg/*l* on the bottom; NH_3-N 0.23 mg/*l*; NO_2-N 0.056 mg/*l*; NO_3-N of 1.5 mg/*l*; PO_4-P 0.43 mg/*l*; water temperature 28.7 ºC; alkalinity 25 mg/*l*; and hardness 17 mg/*l*.

Nong Han is a shallow lake on the whole, and the northern part is particularly so. Due to this, numerous submerged and emerging plants exuberate mainly on the bottom of the northern part. The lake also registers a large biomass of floating plants dominated by water hyacinths. The annual productions of these aquatic plants are estimated as 785,600 t of submerged plants and 714,950 t of floating plants. Observation has found that the advanced eutrophication triggered the algae bloom (*Microcystis aeruginosa aeruginosa*) on the lake surface. Photo 4-4-1 shows the landscape of Lake Nong Han with flourishing submerged plants.

As for the fishing resources, the fish biomass was calculated as 32.3 kg/ha. The dominant species are *Tetraodon leiurus* (Eyespot Puffer), *Ambasis siamensis*, and *Notopterus notopterus* (Asian Knifefish), which account for 31.5 %, 18.4 %, and 15.0 %, respectively, of the total fish biomass. Analysis of the ichthyofauna in Nong Han by the food habit reveals that carnivorous fish share the largest of the total fish biomass, amounting to 37.8 %.

Photo 4-4-1 Landscape of Lake Nong Han with submerged plants

4-4-3 State of Control Measures and their Future Direction

Lake Nong Han has been undergoing the algae bloom ascribable to eutrophication. The dominant species of such algae is *Microcystis aeruginosa aeruginosa*, a Cyanophyceae notorious for producing a toxic substance called microcystin. While no report has been made yet concerning the microcystin volume determined at Nong Han, various microcystin isomers, i.e., microcystin-RR, microcystin-LR, and microcystin-YR, have been detected at Bang Pra Reservoir (capacity: 1.17×10^6 m) in Chonburi Province in Thailand. The total microcystin concentration at the center of the reservoir was reported as 0.014 μg/*l* (as of November 1999). Since the water temperature goes above 30 ºC at Lake Nong Han with plenty nutritive salts under its eutrophic condition, it is expected that the advancing algae propagation will manifestly bring out the issue of microcystin of cyanobacterial origin.

Lake Nong Han is characterized by its ichthyofauna dominated by carnivorous fish; these fish, such as Eyespot Puffer, account for 38 % of the total fish biomass. In parallel, the planktotrophic fish eaten by the carnivorous fish share around 19 % of the total fish biomass, which indicates that the planktotrophic fish has a secure habitat. The field research at the lake confirmed that a wide range of hydrophyte vegetation was actually secured, which revealed that the lake-wide production of such water plants reached to 1,588,120 t/year. The habitat for these hydrophytes serves not only as the nursery for juvenile planktotrophic fish, but also as an enormous contributor to maintaining the biomass of large crustaceans such as water fleas that are reported to substantially help improve water transparency.

It is needless to say that the most efficient way to address the ever-expanding influx load is a drastic measure, namely the development of influent wastewater purification plants, although they require phenomenal construction and maintenance/operation costs. At the same time, facilitation of the lake's self-purification function by using its ecosystem has been offering great hope. Lake Nong Han, in particular, embraces large communities of submerged plants, such as *Potamogeton malaianus, Potamogeton crispus,* and *Vallisneria asiatica,* all across the lake including their normal habitat lakeshore, and hopes run high for the utilization of these communities as an arena for water purification. Conservation and nourishment of the existing aquatic vegetation for boosting the hydrophyte biomass will share an important aspect of the Lake Nong Han purification strategy as a method to bring out a high decontamination effect with low running costs.

4-5 Lake Kwan Phayao

4-5-1 Characteristics of the Lake and its Watershed

Lake Kwan Phayao is located in Phayao Province of the Kingdom of Thailand; more specifically, it is at N 19º10' and E 99º53', and approximately 730 km to the north of the capital Bangkok (see Fig. 4-5-1). The Kwan Phayao is an artificial lake created in 1938 on a 2-km^2 pond around which a weir was built. Its dimensional properties are: a surface area of 23.46 km^2, a mean depth of 2.03 m, a maximum depth of 4.5 m, and a maximum pondage of 47.68 × 10^6 m^3. The altitude of the filled lake surface is 391.5 m above sea level, and the lakeshore length extends to 25.3 m. As shown in Fig. 4-5-2, the shape of Lake Kwan Phayao is quite simple due to its origin as a dammed river that runs near downtown Phayao City. The lake provides irrigation water for farmlands, as well as a fishing ground that extensively contributes to the local fishery.

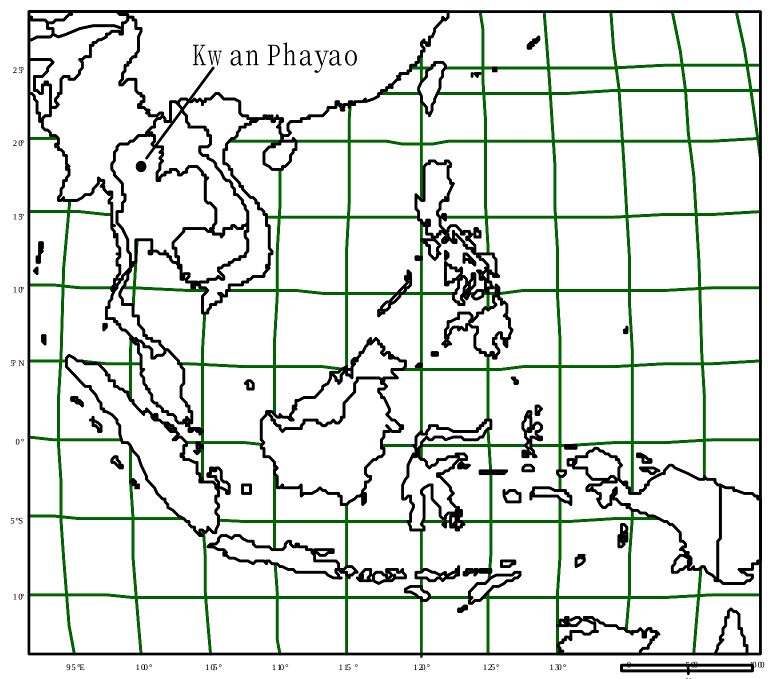

Fig.4-5-1 Situation of Kwan Phayao

4-5-2 State of the Lake

Lake Kwan Phayao suffers from advanced eutrophication due to the untreated wastewater flowing in from its catchment area. The major pollution sources are livestock effluent from the basin and household wastewater from Phayao City (population of 26,000 as of 1991). The total pollution loads from the city are estimated as 82.6 t/year of nitrogen and 23.2 t/year of phosphorus. Due to the lack of the wastewater treatment facilities within the catchment area, which includes Phayao City, approximately 10 % of the total loads flow into the lake without any purification processes. In addition, the livestock wastewater, on a total pollution load basis, was estimated to be responsible for 171-t/year nitrogen and 129-t/year phosphorus. 10% of the effluent from the livestock industry is also untreated and directly flows into the lake. The influx pollution loads in total are calculated as 77.4 t/year for nitrogen and 29.9 t/year for phosphorus.

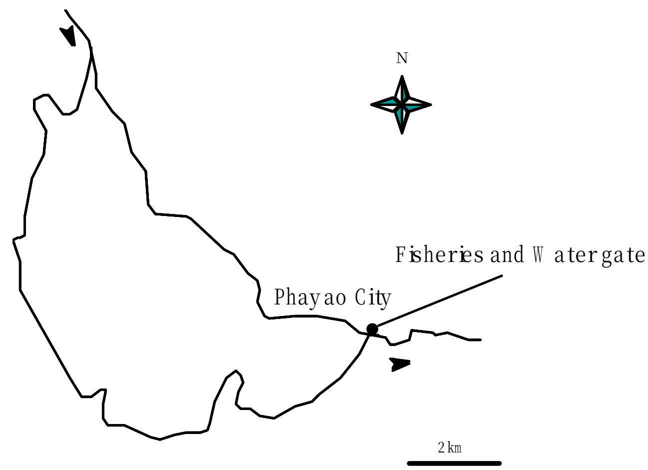

Fig.4-5-2 Drainage of Kwan Phayao

The water quality figures in July are as follows: chlorophyll concentration of 5.24 μg/*l*; pH 7.4; transparency 73 cm; DO 6.1 mg/*l* on the surface and 5.3 mg/*l* on the bottom; NO_3-N 0.19 mg/*l*; PO_4-P 0.035 mg/*l*; water temperature 30.2 ºC; alkalinity 34.3 mg/*l*; and hardness 34.7 mg/*l*. On the other hand, the water quality figures in October are as follows: chlorophyll concentration 3.74 μg/*l*; pH 6.0; transparency 140 cm; DO 6.0 mg/*l* on the surface and 3.5 mg/*l* on the bottom; NH_3-N 0.27 mg/*l*; NO_2-N 0.020 mg/*l*; NO_3-N 1.7 mg/*l*; PO_4-P 0.020 mg/*l*; water temperature 27.7 ºC; alkalinity 41 mg/*l*; and hardness 35 mg/*l*.

The Kwan Phayao is a shallow lake with a maximum depth of 4.5 m and its bottom conical from an easy grade. Due to this shape, numerous submerged and emerging plants exuberate on the bottom gently sloping from the lakeshore to the center. The lake also registers a large biomass of floating plants dominated by water hyacinths, which accumulate near the sluice drifted by the gentle current. The annual productions of these aquatic plants are estimated as 67,670 t of submerged plants and 34,000 t of floating plants.

As for the fishing resources, the fish biomass was calculated as 166 kg/ha. The dominant species are *Tilapia nilotica* (tilapia), *Pristolepsis fasciata*, and *Notopterus notopterus* (Asian Knifefish), which account for 53.6 %, 19.7 %, and 9.4 %, respectively, in the total fish biomass. Analysis of the ichthyofauna in Lake Kwan Phayao by the food habit reveals that the herbivorous fish share the largest of the total fish biomass, amounting to 55.7 %.

4-5-3 State of Control Measures and their Future Direction

Among the pollution load into Lake Kwan Phayao, application of aerated lagoon purification to the household wastewater from Phayao City is now under discussion. Phayao City is the only place with a relatively large urban area within the Kwan Phayao basin. No sewerage systems or wastewater treatment facilities have yet been developed in the city, and consequently, the untreated household effluent flows straight into the lake. For these reasons, the aerated lagoon should be able to significantly reduce the pollution loads from the household effluent. The lagoon, when developed, is expected to remove 35-85 % of the influent ammonia nitrogen. In spite of its drawback of requiring a vast site and a long retention time, decontamination with an oxidation pond can work effectively as a low construction and maintenance cost method in an area such as that of Lake Kwan Phayao basin where a relatively ample amount of land remains available.

For the non-point sources such as the livestock effluent, enhanced natural self-purification is considered most effective, either on the influent process or after having flown into the lake. Specifically, water plants are to be planted in the lake and canals in its basin, which raises expectations that they will exert a substantial effect. Planting high-market-value vegetables such as *phak bung* (swamp cabbage) can encourage the residents to regularly harvest the plants, which eliminates the danger of re-elution of nutritive salts from the dead plants. Consensus with the community members plays an important role in promoting and implementing this method, which also lets the community know the significant contribution of the water plants to the lake purification.

4-6 Lake Bung Boraped

4-6-1 Characteristics of the Lake and its Watershed

Lake Bung Boraped is located in Nakhon Sawan Province of the Kingdom of Thailand; more specifically, it is at N 15º42' and E 100º15', and approximately 250 km to the northeast of Bangkok (see Fig. 4-6-1). Lake Bung Boraped is an artificial lake created in 1926, with a surface area of 204.5 km^2, a mean depth of 1.4 m, a maximum depth of 5.0 m, and a maximum pondage of 218.2×10^6 m^3. The altitude of the filled lake surface is 23 m above sea level, and the lakeshore length extends to 62.5 m. As shown in Fig. 4-6-2, it is a slim lake in an east-west direction, due to its origin as a dammed river. The lake provides irrigation water for farmlands, as well as a fishing ground that extensively contributes to the local fishery.

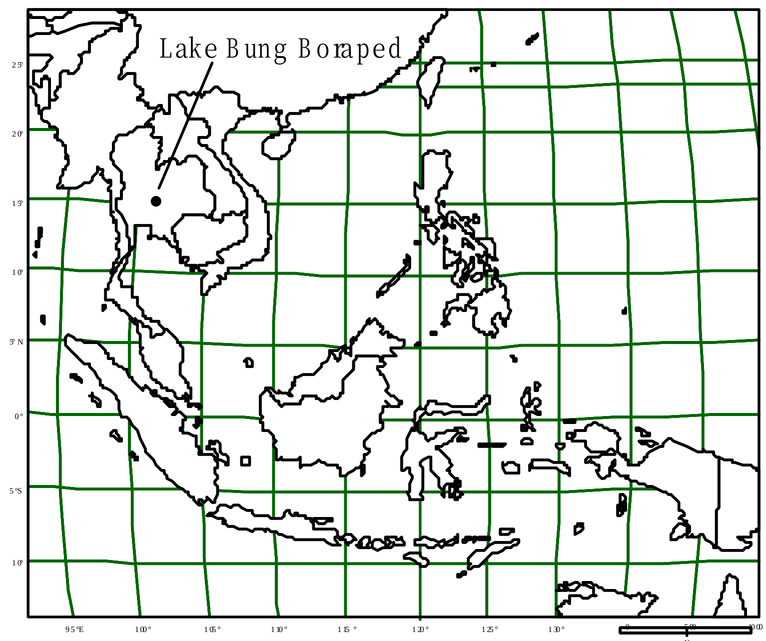

Fig.4-6-1 Situation of Lake Bung Boraped

4-6-2 State of the Lake

Much of the Lake Bung Boraped basin is used for lotus farms. The lotus farming needs massive spraying of pesticide, influx of which adversely affects the water quality and kills fishing resources. The provincial capital, Nakhon Sawan City is far away from the lake, making it free from influent urban pollution loads. The population around the lake is only about 6,800, with a population density in its catchment area as low as 92.2 /km^2. The total household pollution loads from the catchment area are estimated as 21.8 t/year of nitrogen and 6.1 t/year of phosphorus. Approximately 10 % of these total loads flow into the lake without any purification processes. In addition, the livestock wastewater, on a total pollution load basis, was estimated to be responsible for 149-t/year nitrogen and 107-t/year phosphorus. Approximately 10 % of these total loads also flow into the lake without any purification processes. The influx pollution loads in total are calculated as 14.9 t /year for nitrogen and 10.7 t /year for phosphorus. The water quality figures in July are as follows: chlorophyll concentration 4.12 μg/*l*; pH 6.6; transparency 109 cm; DO 5.4 mg/*l* on the surface and 4.0 mg/*l* on the bottom; NO_3-N of 0.55 mg/*l*; PO_4-P of 0.051 mg/*l*; water temperature 28.6 ºC; alkalinity 101.6 mg/*l*; and hardness 81.8 mg/*l*. On the other hand, the water quality figures in October are as follows: chlorophyll concentration 4.54 μg/*l*; pH 5.8; transparency 157 cm; DO 5.7 mg/*l* on the surface and 4.7 mg/*l* on the bottom; NH_3-N 0.43 mg/*l*; NO_2-N of 0.075 mg/*l*; NO_3-N of 1.4 mg/*l*; PO_4-P 0.51 mg/*l*; water temperature 30.1 ºC; alkalinity 61 mg/*l*; and hardness 48 mg/*l*.

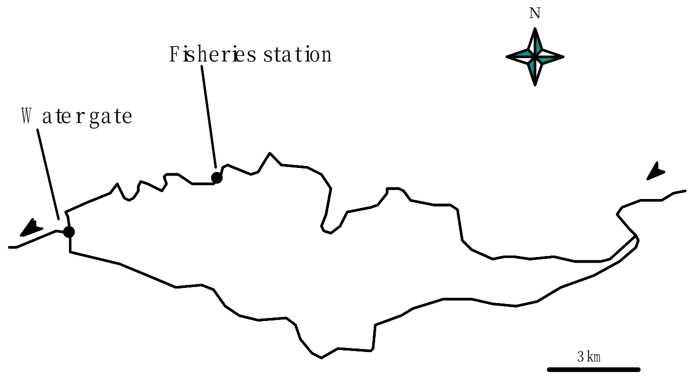

Fig.4-6-2 Drainage of Lake Bung Boraped

Lake Bung Boraped can be divided into three parts in general: the shallow and narrow eastern part that is the influent area with the lake bottom gently sloping toward the west; the water mass area in the center; and the western part near the sluice gate with a large community of submerged plants. The influent eastern area is characterized by the large biomass of waterfront emerging plants, whereas the central part and the western part near the sluice enjoy flourishing submerged and floating-leaved plants. The lake also registers a massive biomass of floating plants, mainly water hyacinths, scattered all across the lake. The annual productions of these aquatic plants are estimated as 529,000 t of submerged plants, 325,620 t of floating plants, and 200,800 t of emerging plants. The annual production of all the water plants totals 1,190,420 t.

As for the fishing resources, the fish biomass was calculated as 84.2 kg/ha. The dominant species are *Pristolepsis fasciata*, *Notopterus notopterus* (Asian Knifefish), and *Osteochei hasselti*, which account for 35.6 %, 22.4 %, and 12.8 %, respectively, in the total fish biomass. Analysis of the ichthyofauna in Lake Bung Boraped by the food habit reveals that the insectivorous fish share the largest of the total fish biomass, amounting to 58.0 %.

4-6-3 State of Control Measures and their Future Direction

Lake Bung Boraped is characterized by its catchment area free from a large urban area, which prioritizes non-point source control over point source management. As for the pesticides for lotus farming, it is unrealistic to request self-restraint in the use of chemicals; the stress is laid on rightsizing the use of agrochemicals to stop the influx of the surplus.The lake's distinctive characteristic, the ichthyofauna dominated by entomophagous fish, suggests that the elimination of nutritive salts via fishing work significantly well. To be more specific, the fish catch out of the lake can effectively remove the nutritive salts and organic matters in the fish accumulated and concentrated through the food chain process whereby the fish eats the aquatic insects that eat animalcules, algae, and small fish, while such fishing practice itself can be incorporated into the life of human beings as a viable vocation sharing a part of an industry. Since fishery has already been conducted at the lake, boosting the catch volume is the most efficient way for nutrient reduction. In practicing this control method, the lake's entomophagous-fish-dominated ichthyofauna should be taken into account: the biomass of aquatic insects that feed these fish needs increasing by reserving a large habitat for water insects. Reservation of a larger habitat for these insects vitally requires abundant water plants, which suggests a direction of water decontamination at Lake Bung Boraped toward an enhanced hydrophyte biomass.

4-7 Laguna de Bay

4-7-1 Characteristics of the Lake and its Watershed

Laguna de Bay is located between Rizal Province and Laguna Province on the central part of Luzon Island in the Republic of the Philippines; more specifically, it is at N 14º02-05' and E 121º00-05', east of Manila Bay, and approximately 40 km to the southeast of the capital Manila (see Fig. 4-7-1). Also known as Lake Bay, Laguna de Bay is the largest lake in the country. The lake, which used to be part of Manila Bay, is a creation of volcanic activities at the lake-south area, where the deposited lava separated the lake from the bay. It is now a brackish lake, mixed with seawater. 21 rivers of different sizes, such as Pasig River through the Metropolitan Manila, flow into Laguna de Bay. As shown in Fig. 4-7-2, the lake has a complex shape with the north-south-long Talim Island lying on the center and two large peninsulas protruded from the northern shore into the lake. With a considerably high volume of volcanic sediments deposited on its bottom, the lake is maximum 7.3 m deep, 2.8 m deep in average, and holds maximum $3{,}200 \times 10^6$ m^3. The altitude of the lake surface is 1.8 m above sea level, and the lakeshore length extends to 220 km. The catchment area of 3,820 km^2 is shared 41 % by natural vegetation as forests, 52 % by farmlands, and 6.5 % by others. The area embraces the population of 2.381 million, with a population density of approximately 713 /km^2. The lake provides irrigation water for farmlands, as well as a fishing ground that extensively contributes to the local fishery.

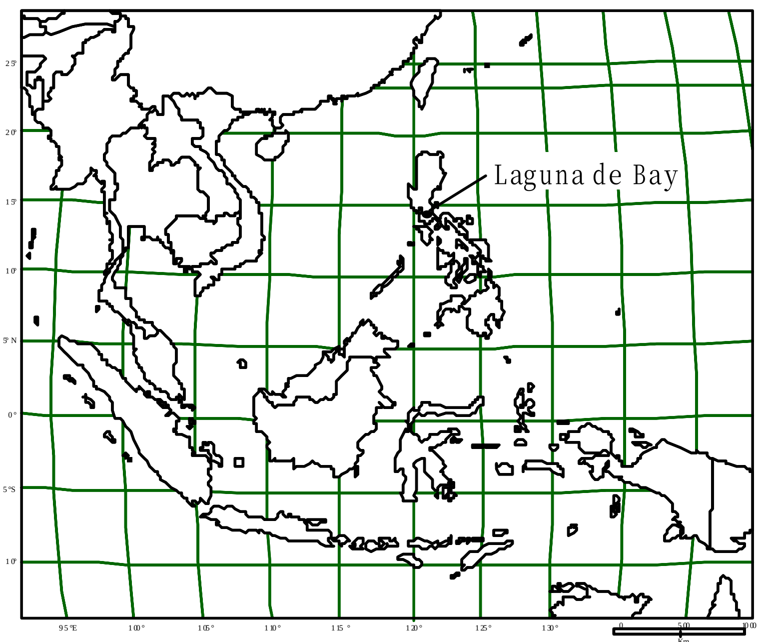

Fig.4-7-1 Situation of Laguna de Bay

4-7-2 State of the Lake

The contaminant load into Laguna de Bay can be divided by their origin: 40 % from agriculture, 30 % from factories and other businesses, and 30 % from households. In addition to the household effluent from Metro Manila flowing in through Pasig River, the influent load from other urban areas around the lake, such as Pasig on the north and Santa Cruz on the southeast, is increasing year by year. The industrial pollutant loads are mostly ascribable to effluents from food processing firms, pig farms, slaughterhouses, dyeing and textile factories, and paper and pulp mills. Fish farming, such as of tilapia, is raising a concern over the contamination through its feeding processes. The annual pollution load in 2000 is estimated as 61,200 t of household origin and 92,200 t of industrial origin. Within the Laguna de Bay basin, there are 1,481 offices/factories registered as industrial point sources; 695 of them are equipped with wastewater treatment facilities, the rest discharge the effluent untreated. Among the influx pollutants into the lake, the annual total nitrogen and phosphorus are calculated as 3,942 t and 942 t, respectively.

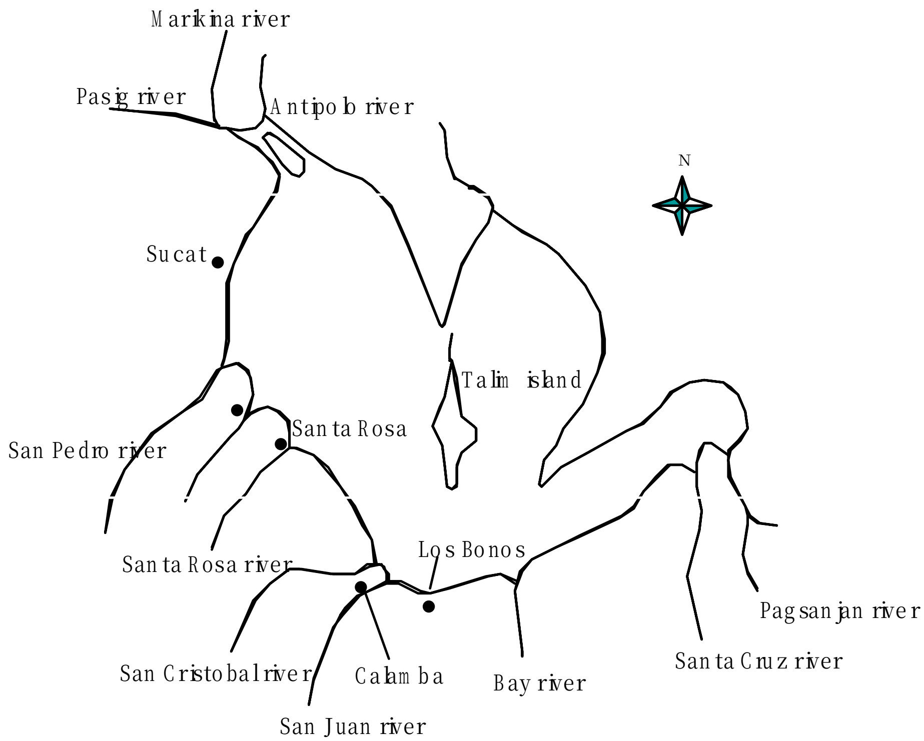

Fig.4-7-2 Drainage of Laguna de Bay

The water quality figures in Laguna de Bay are as follows: CODcr 5.3-32.7 mg/*l*; nitrate nitrogen concentration 0.02-0.4 mg/*l*; dissolved PO_4-P concentration 0.1-1.0 mg/*l*; and transparency 11-23 cm. May to October, a rainy season in the Laguna de Bay basin, sees the monthly precipitation reaching 300-500 mm, which exceeds the decupling of that in the dry season. For this reason, the water quality in the rainy season tends to improve somewhat. Wild weather, including typhoons, severely stirs the lake water, which is observed to discolor the water brown every year by rolling up the sediment deposits. Observation has found that, under such conditions, the COD level rises all the way up to around 50 mg/*l*, thus significantly reducing the transparency down to 6 cm.

4-7-3 State of Control Measures and their Future Direction

The influent pollutants into Laguna de Bay are controlled by various regulations and systems instituted mainly by the Department of Environment and Natural Resources (DENR) and its subsidiary organization the Laguna Lake Development Authority (LLDA). The measures at this lake are characterized by the Environmental User Fee (EUF). Under this system, the polluters are required to pay the tax according to their discharge volume, and the tax rate depends on the biochemical oxygen demand (BOD) of the effluent. The taxation now extends to approximately 1,400 facilities, and 31 cases were reported between 1998 and 2000 where businesses were forced to suspend operations as a penalty for violating the regulations. The taxation is in two tiers: fixed and progressive. As for the fixed rate, 15,000 pesos is imposed on a business with a daily discharge of 150 m^3 and over, 10,000 pesos on a business with a daily discharge of between 31 and less than 150 m^3, and 5,000 pesos on a business with a daily discharge of less than 31 m^3. As for the progressive rate, effluent with a BOD level of less than 50 mg/*l* is charged 5 pesos per kg BOD, whereas effluent with a BOD level of 50 mg/*l* and higher is charged 30 pesos per kg BOD. The annual BOD total is calculated as average BOD concentration (mg/*l*) × average daily discharge (m^3/day) × 300 × 10-3, which provides the basis for this specific tax. The constant 300 in the equation represents the average operating days a year. Under this tax system, any business that discharges more than 50 mg/*l* faces a larger taxation rate, which cannot be reduced simply by diluting the wastewater due to the volume-based element in the system. Such a system of taxation urges businesses to strive for minimizing the BOD rate of the effluent as well as the total discharge volume. The effluent is monitored by the local offices of the DENR, whose analysis capacities at the lab fall short of the number of samples. Under this circumstance, several private institutes have launched a measuring service, although the measured values are not officially certified and remain merely as a non-binding reference. The EUF system, currently in its first phase, targets organic wastewater, which results in a lack of nitrogen and phosphorus control. Discussion now proceeding for a second phase of the system concerns imposing a tax on businesses that discharge toxic substances and other pollutants in their industrial effluent. The EUF system ultimately aims at its application on the particles and NOx in the air. In this climate, the future challenge lies in the early enactment of a regulative law targeting nitrogen and phosphorus, which is essential for facilitating the efforts toward control of eutrophication at Laguna de Bay. At the same time, it is important to upgrade the monitoring system for rigid application of the EUF, such as through opening up the official certificate issuance in regard to the effluent analysis of the private institutions.

The Laguna de Bay catchment area stretches over an area as vast as 3,820km^2, of which 41 % and 52 % are covered by the natural vegetation of forests and farmlands, respectively. For this reason, the lake has more influx of infiltration water, which originates from rainfall on the forests which penetrate into the soil. This is corroborated by data showing that the lead-lag correlation between precipitation and chlorine ion concentration of the lake is about three months. Such rechargeability is crucial in terms of conserving the water resource. As Laguna de Bay is expected to supply the water to Manila in the future, environmental education PR activities for catchment residents and industries will share an important role in disseminating knowledge about the importance of the water resource.

4-8 Lake Ypakarai

4-8-1 Characteristics of the Lake and its Watershed

Lake Ypakarai is located in the Republic of Paraguay in South America; more specifically, it is at S 25º14-22' and W 57º17-22', and approximately 30 km to the east of the center of the capital Asuncion (see Fig. 4-8-1). The geometric features of the lake are as follows: a surface area of 59.6×10^6 m^2; a maximum depth of 3 m; a mean depth of 2 m; a surface altitude of 64.1 m above sea level; a water capacity of 115×10^6 m^3; a shore length of 40 km; and a catchment area of 833 km^2. Of the area surrounding the lake, farmland, including the pastureland, accounts for approximately 65 %, and natural vegetation, such as grassland and wetland, shares approximately 19 %. Its catchment area embraces cities such as San Lorenzo, Luque, Capiata, and San Bernardino, whose household wastewater flows into the lake through 20 influent rivers. As shown in Fig. 4-8-2, the major influent rivers are Yuquery River from the north and Pirayu River from the south. The lake has only one effluent river, the Salado, which flows into Rio de la Plata via the Paraguay River to reach the South Atlantic. The area between the efflux of the Salado and influx of the Yuquery on the north of the lake is extensively covered by wetland: the influent from the Yuquery flows into the lake through numerous streams.

The Ypakarai catchment population is about 207,000 with a rather low density of approximately 250/km^2. Mainly used for the recreational purpose, the lake has beaches, hotels, and villas developed along its watershed, and the population density in San Bernardino on the east and other cities skyrockets during the weekends and holiday seasons. The lake supplies service water and irrigation water for farmlands and pasturelands, and also provides a fishing ground that extensively contributes to the local fishery.

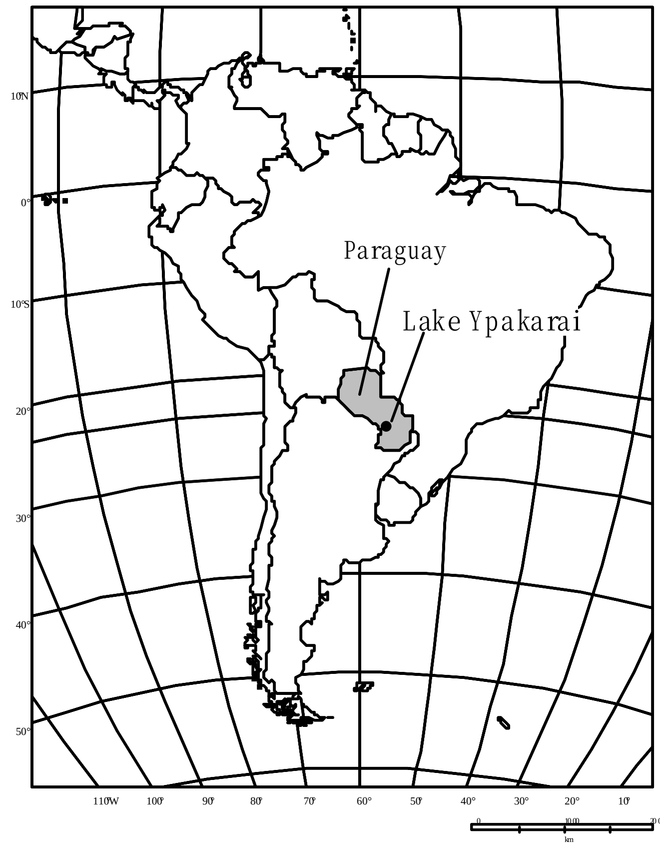

Fig.4-8-1 Situation of Lake Ypakarai

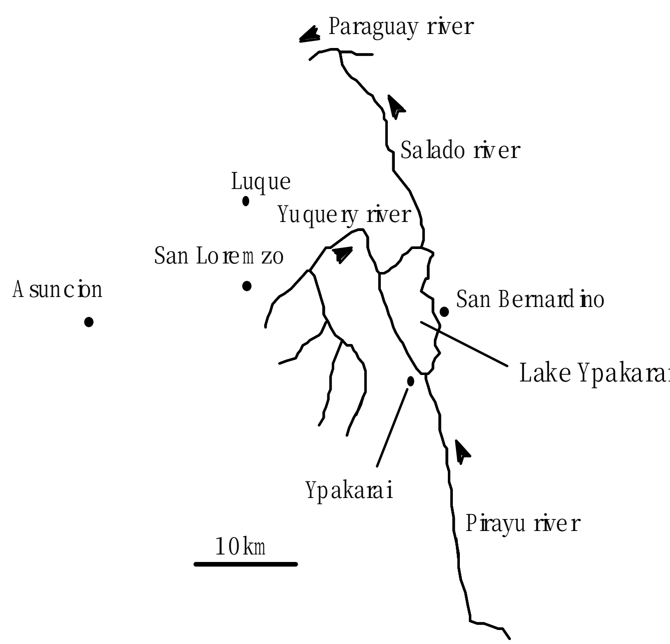

Fig. 4-8-2 Drainage of Lake Ypakarai

4-8-2 State of the Lake

Due to its shallowness (a mean depth of 2 m) and little headway in pollutant control in its catchment area, Lake Ypakarai has suffered from ever advancing eutrophication in recent years. The year 1999 saw precipitation decrease immensely, which triggered acute drought by reducing the water level by over 1 m. Consequently, the mean depth decreased to less than 1 m, sending the lake into a crisis with the extraordinary propagation of cyanobacteria. Photo 4-8-1 shows the blue-green algae bloom (*Microcystis aeruginosa aeruginosa*) blown toward the Ypakarai lakeshore. The drifted cyanobacteria, when decomposing, released a foul smell which plagued the lakeshore residents and industries. This obnoxious odor dealt a hard blow to the tourism industry: many lake beaches had practically no business despite being open. Relying on the lake for its water supply, San Bernardino on the east particularly faces considerable social problems when there is drought and the toxigenic cyanobacteria bloom. San Bernardino is a tourist city and summer retreat, which means that its water demand rises in summer when water is in short supply. Moreover, the city, without a sewerage system, drains its domestic wastewater untreated into its service water source Lake Ypakarai, which poses a fundamental problem to the city itself.

Photo 4-8-1 Algae bloom blown toward the Ypakarai

The lake water is colored brown from the influent soil particles due to soil erosion in the catchment area. For this reason, the lake is characterized by significantly low transparency (0.07-0.15 m) and a considerably high SS concentration (70-80 mg/*l*). Since the lake water constantly looks brown due to the suspended soil particles, it is hard to identify the green color of the cyanobacterial colony by the unaided eye. At the same time, however, a large mass of algae can be found accumulated by the sweeping waves, and the plankton sample collected from the lake water by plankton net always contains an extremely high concentration of blue-green algae. The algae concentrations at the lake center were 320,000 cells/m*l* of *Microcystis aeruginosa aeruginos*, and 96,000 cells/m*l* of *Anabaena spiroides* as of January 2000.

The water quality figures in Lake Ypakarai are as follows: CODcr 10.3-15.7 mg/*l*; T-N 0.58-0.89 mg/*l*; T-P 0.15-0.30 mg/*l*; DO 6.0-8.9 mg/*l*; and pH 6.0-8.7. The lake is distinctive for its relatively high phosphorus concentration compared to the nitrogen level, thus there is an excessively low ratio between nitrogen and phosphorus of 1.9-5.9.

Urban and domestic wastewater in the basin accounts for around 48 % of the loading pollutants flown into Lake Ypakarai. The industrial effluent from over 80 business establishments in the catchment area is estimated to share approximately 24 %, most of which are ascribable to meat packaging and leather processing. In Paraguay, deforestation swept most of its land, where virgin forests have fallen into a disastrous condition. The Ypakarai catchment area is no exception, where the forests are replaced by pastureland and wasteland. Consequently, such a land condition cannot prevent soil erosion, increasing the non-point loads of the catchment area to 9,800,000 kg/year of CODcr, 370,000 kg/year of T-N, and 94,000 kg/year of T-P. The influent soil particles raise the SS level to 20,000,000 kg/year. This situation clearly testifies that non-point source control is a critically urgent matter.

4-8-3 State of Control Measures and their Future Direction

In compiling the water quality improvement plan at Lake Ypakarai, there are some technological transfer projects provided by Japan to Paraguay: a development survey concerning the water quality improvement plan at Lake Ypakarai (recipient: Technical Secretariat of Planning, Presidency of the Republic) in 1988-1989; technological cooperation by individual specialists (recipient: National Environment and Health Service (SENASA)) in 1995-1998; and a specialist team sent in 1998-2001. Based on this technological cooperation series, deliberation is now proceeding regarding how to formulate and implement the water quality improvement plan. *Consejo de Municipalidades de la Cuenca del Lago Ypacarai* (CLYMA), composed of 21 municipalities in the Lake Ypacarai catchment area, and *Consejo de Gobernaciones Municipalidades de la Cuenca del Lago Ypacarai* (CLYGMA), composed of three departments (provinces) in addition to the said municipalities, were established in 1999 to concentrate efforts to improve the water quality in the Lake Ypacarai basin. These councils, through various activities, are expected to contribute to better water quality at the lake. The pilot projects for water quality improvement have just begun, and full-fledged project planning and project promotion are still on their way and eagerly awaited.

At present, Caacupe, though outside the Ypacarai basin, has been equipped with a sewerage system, and the same initiative was launched to develop a sewage treatment system in the Ypacarai basin cities such as Itagua, Capiata, and Ypacarai. Realization of this vision should contribute to drastic purification of the lake by reducing pollutants in the untreated effluent into the lake. Radical measures, such as the sewerage plan, are hard to implement, not to mention to complete early, in the Ypacarai catchment area. Furthermore, non-point sources share a large portion of the loading pollution, which clearly require more than the development of a sewer treatment system. Under these circumstances, an eco-engineering approach that makes best use of the vast wetland covering the north of the lake (shown in Photo 4-8-2) is considered to exert a substantial effect. Since the watercourse of the Yuquery River goes through this area, the pollutants from the Yuquery should be significantly abated with the effective use of aquatic plants. Ecological awareness and the ethics of the catchment community members have not yet reached an adequate level. Full-geared implementation of environmental education and edification will be able to greatly stimulate their interest in the lake pollution, thus slashing the pollutant loads such as through illegal waste dumping.

Photo 4-8-2 The vast wetland covering the north of the lake